

### 5.4.3 Heat Pump Water Heaters

#### DESCRIPTION

The installation of a heat pump domestic hot water heater in place of a standard electric water heater in a home. Savings are presented dependent on the heating system installed in the home due to the impact of the heat pump water heater on the heating loads.

This measure was developed to be applicable to the following program types: TOS, NC, RF.  
If applied to other program types, the measure savings should be verified.

#### DEFINITION OF EFFICIENT EQUIPMENT

To qualify for this measure the installed equipment must be a Heat Pump domestic water heater.

#### DEFINITION OF BASELINE EQUIPMENT

The baseline condition is assumed to be a new electric water heater meeting federal minimum efficiency standards<sup>1</sup>:

For  $\leq 55$  gallons:  $0.96 - (0.0003 * \text{rated volume in gallons})$

For  $> 55$  gallons:  $2.057 - (0.00113 * \text{rated volume in gallons})$

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#### DEEMED LIFETIME OF EFFICIENT EQUIPMENT

The expected measure life is assumed to be 13 years.<sup>2</sup>

#### DEEMED MEASURE COST

The incremental capital cost for this measure is \$1,000, for a HPWH with an energy factor of 2.0. The full cost, applicable in a retrofit, is \$1,575. For a HPWH with an energy factor of 2.35, these costs are \$1,134 and \$1,703 respectively.<sup>3</sup>

#### LOADSHAPE

Loadshape R03 - Residential Electric DHW

#### COINCIDENCE FACTOR

The summer Peak Coincidence Factor is assumed to be 12%.<sup>4</sup>

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<sup>1</sup> Minimum Federal Standard as of 4/1/2015;

<http://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf>

<sup>2</sup> DOE, 2010 Residential Heating Products Final Rule Technical Support Document, Page 8-52

[http://www1.eere.energy.gov/buildings/appliance\\_standards/residential/pdfs/htgp\\_finalrule\\_ch8.pdf](http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_ch8.pdf)

<sup>3</sup> DOE, 2010 Residential Heating Products Final Rule Technical Support Document, Table 8.2.14

[http://www1.eere.energy.gov/buildings/appliance\\_standards/residential/pdfs/htgp\\_finalrule\\_ch8.pdf](http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_ch8.pdf)

<sup>4</sup> Calculated from Figure 8 "Combined six-unit summer weekday average electrical demand" in FEMP study; Field Testing of Pre-Production Prototype Residential Heat Pump Water Heaters

[http://www1.eere.energy.gov/femp/pdfs/tir\\_heatpump.pdf](http://www1.eere.energy.gov/femp/pdfs/tir_heatpump.pdf) as  $(\text{average kW usage during peak period} * \text{hours in peak period}) / [(\text{annual kWh savings} / \text{FLH}) * \text{hours in peak period}] = (0.1 \text{ kW} * 5 \text{ hours}) / [(2100 \text{ kWh (default assumptions)} / 2533 \text{ hours}) * 5 \text{ hours}] = 0.12$

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## Algorithm

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### CALCULATION OF SAVINGS

#### ELECTRIC ENERGY SAVINGS

$$\Delta \text{kWh} = (((1/\text{EF}_{\text{BASE}} - 1/\text{EF}_{\text{EFFICIENT}}) * \text{GPD} * \text{Household} * 365.25 * \gamma_{\text{Water}} * (T_{\text{OUT}} - T_{\text{IN}}) * 1.0) / 3412) + \text{kWh}_{\text{cooling}} - \text{kWh}_{\text{heating}}$$

Where:

$\text{EF}_{\text{BASE}}$  = Energy Factor (efficiency) of standard electric water heater according to federal standards<sup>5</sup>:

For  $\leq 55$  gallons:  $0.96 - (0.0003 * \text{rated volume in gallons})$

For  $> 55$  gallons:  $2.057 - (0.00113 * \text{rated volume in gallons})$

= 0.945 for a 50 gallon tank, the most common size for HPWH

$\text{EF}_{\text{EFFICIENT}}$  = Energy Factor (efficiency) of Heat Pump water heater

= Actual

GPD = Gallons Per Day of hot water use per person

= 45.5 gallons hot water per day per household / 2.59 people per household<sup>6</sup>

= 17.6

Household = Average number of people per household

Household Unit Type	Household
Single-Family - Deemed	2.56 <sup>7</sup>
Multi-Family - Deemed	2.1 <sup>8</sup>
Custom	Actual Occupancy or Number of Bedrooms <sup>9</sup>

365.25 = Days per year

$\gamma_{\text{Water}}$  = Specific weight of water

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<sup>5</sup> Minimum Federal Standard as of 1/1/2015;

<http://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf>

<sup>6</sup> Maureen Hodgins, email to SAG/TAC on August 26, 2014

<sup>7</sup> ComEd Energy Efficiency/ Demand Response Plan: Plan Year 2 (6/1/2009-5/31/2010) Evaluation Report: All Electric Single Family Home Energy Performance Tune-Up Program citing 2006-2008 American Community Survey data from the US Census Bureau for Illinois cited on p. 17 of the PY2 Evaluation report.  $2.75 * 93\%$  evaluation adjustment

<sup>8</sup> Navigant, ComEd PY3 Multi-Family Home Energy Savings Program Evaluation Report Final, May 16, 2012.

<sup>9</sup> Bedrooms are suitable proxies for household occupancy, and may be preferable to actual occupancy due to turnover rates in residency and non-adult population impacts.

= 8.33 pounds per gallon

$T_{OUT}$  = Tank temperature

= 125°F

$T_{IN}$  = Incoming water temperature from well or municipal system

= 54°F<sup>10</sup>

1.0 = Heat Capacity of water (1 Btu/lb\*°F)

3412 = Conversion from Btu to kWh

$kWh_{cooling}^{11}$  = Cooling savings from conversion of heat in home to water heat

$$= (((((GPD * Household * 365.25 * \gamma_{Water} * (T_{OUT} - T_{IN}) * 1.0) / 3412) - ((1 / EF_{NEW} * GPD * Household * 365.25 * \gamma_{Water} * (T_{OUT} - T_{IN}) * 1.0) / 3412)) * LF * 27\%) / COP_{COOL}) * LM$$

Where:

LF = Location Factor

= 1.0 for HPWH installation in a conditioned space

= 0.5 for HPWH installation in an unknown location

= 0.0 for installation in an unconditioned space

27% = Portion of reduced waste heat that results in cooling savings<sup>12</sup>

$COP_{COOL}$  = COP of central air conditioning

= Actual, if unknown, assume 3.08 (10.5 SEER / 3.412)

LM = Latent multiplier to account for latent cooling demand

= 1.33<sup>13</sup>

$kWh_{heating}$  = Heating cost from conversion of heat in home to water heat

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<sup>10</sup> US DOE Building America Program. Building America Analysis Spreadsheet. For Chicago, IL  
[http://www1.eere.energy.gov/buildings/building\\_america/analysis\\_spreadsheets.html](http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html)

<sup>11</sup> This algorithm calculates the heat removed from the air by subtracting the HPWH electric consumption from the total water heating energy delivered. This is then adjusted to account for location of the HP unit and the coincidence of the waste heat with cooling requirements, the efficiency of the central cooling and latent cooling demands.

<sup>12</sup> REMRate determined percentage (27%) of lighting savings that result in reduced cooling loads (lighting is used as a proxy for hot water heating since load shapes suggest their seasonal usage patterns are similar).

<sup>13</sup> A sensible heat ratio (SHR) of 0.75 corresponds to a latent multiplier of 4/3 or 1.33. SHR of 0.75 for typical split system from page 10 of "Controlling Indoor Humidity Using Variable-Speed Compressors and Blowers" by M. A. Andrade and C. W. Bullard, 1999:  
[www.ideals.illinois.edu/bitstream/handle/2142/11894/TR151.pdf](http://www.ideals.illinois.edu/bitstream/handle/2142/11894/TR151.pdf)

(dependent on heating fuel)

For Natural Gas heating, kWh\_heating = 0

For electric heating:

$$= (((GPD * Household * 365.25 * \rho * (T_{OUT} - T_{IN}) * 1.0) / 3412) - ((1 / EF_{NEW} * GPD * Household * 365.25 * \rho * (T_{OUT} - T_{IN}) * 1.0) / 3412)) * LF * 49\% / COP_{HEAT}$$

Where:

49% = Portion of reduced waste heat that results in increased heating load<sup>14</sup>

$COP_{HEAT}$  = COP of electric heating system  
= actual. If not available use<sup>15</sup>:

System Type	Age of Equipment	HSPF Estimate	$COP_{HEAT}$ (COP Estimate)
Heat Pump	Before 2006	6.8	2.00
	After 2006 - 2014	7.7	2.26
	2015 on	8.2	2.40
Resistance	N/A	N/A	1.00

For example, a 2.0 EF heat pump water heater, in a conditioned space in a single family home with gas space heat and central air conditioning (SEER 10.5) in Belleville:

$$\Delta kWh = [(1 / 0.945 - 1 / 2.0) * 17.6 * 2.56 * 365.25 * 8.33 * (125 - 54)] / 3412 + 185 - 0$$
$$= 1777 \text{ kWh}$$

#### SUMMER COINCIDENT PEAK DEMAND SAVINGS

$$\Delta kW = \Delta kWh / \text{Hours} * CF$$

Where:

<sup>14</sup> REMRate determined percentage (49%) of lighting savings that result in increased heating loads (lighting is used as a proxy for hot water heating since load shapes suggest their seasonal usage patterns are similar).

<sup>15</sup> These default system efficiencies are based on the applicable minimum Federal Standards. In 2006 the Federal Standard for Heat Pumps was adjusted. While one would expect the average system efficiency to be higher than this minimum, the likely degradation of efficiencies over time mean that using the minimum standard is appropriate.

Hours = Full load hours of water heater

$$= 2533^{16}$$

CF = Summer Peak Coincidence Factor for measure

$$= 0.12^{17}$$

For example, a 2.0 COP heat pump water heater, in a conditioned space in a single family home with gas space heat and central air conditioning in Belleville:

$$\text{kW} = 1777 / 2533 * 0.12$$

$$= 0.084 \text{ kW}$$

### NATURAL GAS SAVINGS

$$\Delta\text{Therms} = - \left( \left( \left( \text{GPD} * \text{Household} * 365.25 * \gamma_{\text{Water}} * (T_{\text{OUT}} - T_{\text{IN}}) * 1.0 \right) / 3412 \right) - \left( \left( \text{GPD} * \text{Household} * 365.25 * \gamma_{\text{Water}} * (T_{\text{OUT}} - T_{\text{IN}}) * 1.0 \right) / 3412 \right) / \text{EF}_{\text{EFFICIENT}} \right) * \text{LF} * 49\% * 0.03412 / (\eta_{\text{Heat}} * \% \text{ Natural Gas})$$

Where:

$\Delta\text{Therms}$  = Heating cost from conversion of heat in home to water heat for homes with Natural Gas heat.<sup>18</sup>

0.03412 = conversion factor (therms per kWh)

$\eta_{\text{Heat}}$  = Efficiency of heating system

= Actual.<sup>19</sup> If not available use 70%.<sup>20</sup>

<sup>16</sup> Full load hours assumption based on Efficiency Vermont analysis of Itron eShapes.

<sup>17</sup> Calculated from Figure 8 "Combined six-unit summer weekday average electrical demand" in FEMP study; Field Testing of Pre-Production Prototype Residential Heat Pump Water Heaters

[http://www1.eere.energy.gov/femp/pdfs/tir\\_heatpump.pdf](http://www1.eere.energy.gov/femp/pdfs/tir_heatpump.pdf) as (average kW usage during peak period \* hours in peak period) / [(annual kWh savings / FLH) \* hours in peak period] = (0.1 kW \* 5 hours) / [(2100 kWh / 2533 hours) \* 5 hours] = 0.12

<sup>18</sup> This is the additional energy consumption required to replace the heat removed from the home during the heating season by the heat pump water heater. kWh\_heating (electric resistance) is that additional heating energy for a home with electric resistance heat (COP 1.0). This formula converts the additional heating kWh for an electric resistance home to the MMBtu required in a Natural Gas heated home, applying the relative efficiencies.

<sup>19</sup> Ideally, the System Efficiency should be obtained either by recording the AFUE of the unit, or performing a steady state efficiency test. The Distribution Efficiency can be estimated via a visual inspection and by referring to a look up table such as that provided by the Building Performance Institute:

(<http://www.bpi.org/files/pdf/DistributionEfficiencyTable-BlueSheet.pdf> ) or by performing duct blaster testing.

<sup>20</sup> This has been estimated assuming that natural gas central furnace heating is typical for Illinois residences (66% of Illinois homes have a Natural Gas Furnace (based on Energy Information Administration, 2009 Residential Energy Consumption Survey:

<http://www.eia.gov/consumption/residential/data/2009/xls/H6.9%20Space%20Heating%20in%20Midwest%20Region.xls> ))

In 2000, 24% of furnaces purchased in Illinois were condensing (based on data from GAMA, provided to Department of Energy during the federal standard setting process for residential heating equipment - see Furnace Penetration.xls). Furnaces tend to last up to 20 years and so units purchased 10 years ago provide a reasonable proxy for the current mix of furnaces in the State. Assuming typical efficiencies for condensing and non-condensing furnaces and duct losses, the average heating system efficiency is estimated as follows:

% Natural Gas = Factor dependent on heating fuel:

Heating System	%Natural Gas
Electric resistance or heat pump	0%
Natural Gas	100%
Unknown heating fuel <sup>21</sup>	87%

Other factors as defined above

For example, a 2.0 COP heat pump water heater in conditioned space, in a single family home with gas space heat (70% system efficiency):

$$\Delta \text{Therms} = -(((25.1 * 2.56 * 365.25 * 8.33 * (125 - 54) * 1.0) / 3412) - (17.6 * 2.56 * 365.25 * 8.33 * (125 - 54) * 1.0 / 3412 / 2.0)) * 1 * 0.49 * 0.03412) / (0.7 * 1)$$

#### WATER IMPACT DESCRIPTIONS AND CALCULATION

N/A

#### DEEMED O&M COST ADJUSTMENT CALCULATION

N/A

**MEASURE CODE: RS-HWE-HPWH-V04-150601**

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$$(0.24 * 0.92) + (0.76 * 0.8) * (1 - 0.15) = 0.70$$

<sup>21</sup> 2010 American Community Survey.