Evaluating Domestic Water Heater Performance for NY Homes

NYSERDA Agreement 15606

Screen and Select DHW Systems and Distribution Architecture for Testing (Task 2 deliverable)

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Introduction and Overview

Water heating is the second largest energy expenditure in existing homes in the Northeast, after space heating (EIA, 2008b). Historically, efforts to improve residential efficiency have focused on space conditioning, often neglecting water heating improvements. Several new or recently-refined water heating technologies are now available on the market including: solar water heaters; gas-fired, tankless units; and heat pump water heaters. Tax credits are currently available for some of these systems that are expected to boost consumer interest.

Current DOE rating procedures to determine the Energy Factor (EF)[1], or efficiency, of these systems may be a poor indicator of actual energy use, in part because the amount and timing of water use greatly impacts the performance and relative efficiency ranking of these systems. Robust measured data is needed to help consumers, manufacturers, and installers understand the efficiency, costs, and environmental impacts of both new and conventional domestic hot water systems.

56% of households in the Northeast use natural gas fueled water heaters (EIA, 2008). A more specific breakdown of water heating fuels for New York State household is given in the table below from a NYSERDA Energy Profiles document based on 2005 data (2011). The average size of the heating load associated with each fuel is also given. Electricity accounts for 12% households and tended to be used in apartments where loads are smaller (38 gallons per day). Natural gas is by far the most popular fuel, accounting for 57% of households. The average load size (56 gallons per day) is more in line with expectations for a single family home. Nearly every home with natural gas available (and used for space heating) uses this fuel for water heating as well. Fuel oil is used in 2.1 million homes for space heating, however only a portion of these homes (1.7 million, or 25%) also use it for their water heating fuel (estimated loads are large at 107 gallons per day). Fuel oil is less prevalent for water heating due to the high cost of these appliances. When fuel oil is used, it is most likely with a boiler that has an additional heat exchanger or indirect tank for domestic water heating. Propane is not widely used (only 6%) for water heating, perhaps only in cases when it is also used for cooking fuel in rural applications.

[1] As defined in 10CFR430 Subpart B, Appendix E and ASHRAE Standard 118.2

Table 1. Breakdown of Water Heating Fuels in NY Homes

	No of NY Households for Water Heating	Avg Use / Cost	Implied[1] Hot Water Use (gal/day)	No of NY Households for Space Heating
Electricity	800,000 (12%)	2,526 kWh / $367	38	600,000 (9%)
Natural Gas	3,800,000 (57%)	200 therms / $260	56	3,800,000 (57%)
Fuel Oil	1,700,000 (25%)	232 gal / $481	107	2,100,000 (31%)
Propane	400,000 (9%)	286 gal / 607	75	200,000 (3%)
TOTAL	6,700,000			6,700,000

Notes: 1 – implied water use determined using fuel energy content, expected efficiency and 70F temp rise.

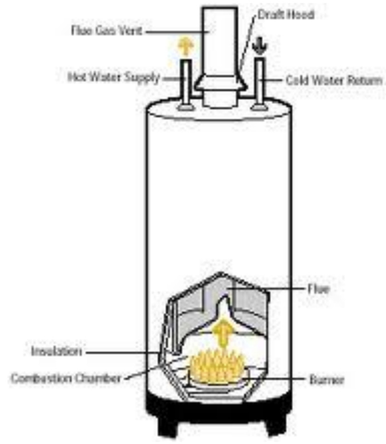
Domestic Hot Water (DHW) Technologies

Residential water heaters are classified by their input fuel and by the amount of storage capacity. The two primary fuels used for the US market are electric and natural gas. Most natural gas units can also be converted to propane. Oil-fired units are also available but are much less common (in New York State homes indirect heat exchangers are thought to be more common than direct-fired tanks).

The DOE rating procedure for Energy Factor (EF) applies to storage water heaters both gas and electric, as well as tankless units and heat pump water heaters. To be classified as tankless the burner input must be at least 50 MBtu/h and the storage capacity must be less than 2 gallons. EF is a measure of a water heater's overall daily efficiency based on the amount of hot water produced per unit of fuel consumed. The draw profile for the EF rating consists of six (6) consecutive draws of 10.7 gallons at the beginning of each hour, for a total of 64.3 gallons a day.

Standard Gas Storage

From Kenmore



From NRCan

Standard gas storage water heaters have an EF range of 0.56 to 0.62, an input rating of 30 to 75 MBtu/h, and a first hour rating between 48 and 114 gallons per hour (AHRI, 2011). A standard gas storage water heater burns fuel in bottom of the tank and exhaust gases pass through a flue passage in the center of the storage tank. The water in the tank extracts the heat from the combustion gases in combustion chamber and flue. Standard units have a standing pilot flame and controls that typically do not require electric power to operate.

The installed cost of a 40 gallon standard gas storage water heater with an EF below 0.60 is typically in the range of $350 to $600 according to ACEEE (2011).

High Efficiency (HE) Gas Storage: Non-Condensing

AO Smith GPVR-40

There are two types of high efficiency (HE) gas storage water heaters: non-condensing and condensing. According to the DOE (2010) a non-condensing HE gas storage unit can save as much as $246 a year with a simple payback in as little as 10 years. As of September 1, 2010 there were 60 models available that qualified for Energy Star certification (DOE, 2010).

HE non-condensing gas storage water heaters are similar to standard gas storage units. These HE units meet the Energy Star criteria with an EF rating of 0.67 or greater, which is typically 12-16% more efficient than a standard gas-fired unit. The increased efficiency is typically obtained through:

- Electronic ignition: eliminating the continuous pilot light,
- Improved flue baffling: increasing the surface area and turbulence to improve heat exchange,
- Flue dampers: dampers close while the water heater is in standby mode; restricting off-cycle airflow that loses heat up the flue.
- Additional insulation: increasing the tank R-value to reduce heat losses to the surrounding space.
- Heat traps: one-way valves installed on the hot/cold outlet/inlet pipes to prevent convective heat and mass flow.
- Forced air intake systems and power venting: improves combustion efficiencies and heat exchange.

The approximate installed cost of a HE non-condensing gas storage water heater is $1,300 (ACEEE, 2011). The four major manufacturers of HE non-condensing gas storage water heaters listed in the table below.

Table 2. High Efficiency Non-Condensing Gas Storage Units

Manufacturer / Brand	**Storage Size (gal)**	**Rating**
A.O. Smith Water Products	40, 50, and 75	EF = 0.67 to 0.70
American Water Heater Company	40 or 50	EF = 0.67 to 0.70
Bradford White Corporation	40 to 65	EF = 0.67 to 0.70
Rheem Manufacturing	29 to 50	EF = 0.67 to 0.70

High Efficiency (HE) Gas Storage: Condensing

From AO Smith

From Heat Transfer Products

Condensing gas storage water heaters incorporate technology that captures latent heat of water vapor released during combustion. A coil-like flue that spirals up through the tank increases surface area for better heat exchange. According to ACEEE (2011) this helps to improve the efficiency a further 10% over the non-condensing units. A list of Energy Star qualified condensing gas storage units (with EF ratings) is not yet available. These units are generally considered by DOE to be commercial water heaters; however, smaller "commercial" condensing water heaters are available for residential applications. The approximate installed cost of a condensing gas storage water heater is $2,500 (ACEEE, 2011). There are currently four companies that offer condensing gas storage water heaters that are listed in the table below.

Table 3. High Efficiency Condensing Gas Storage Units

Manufacturer / Brand	Storage Size	Rating
A.O. Smith (Vertex™)	50 gallons	90-96% thermal efficiency
American Water Heater (Polaris®)	34 to 50 gallons	95+% thermal efficiency
Bradford White (EFR)	60 gallons	95% thermal efficiency
Heat Transfer Products (Phoenix®)	55 gallons	93.7-95.1% thermal efficiency

Note: No EF rating is available for these units.

Tankless Gas Water Heater

Tankless water heaters are currently installed in 1.3 million homes in the Northeast region, with 400,000 estimated to be in New York (EIA, 2009). According to Energy Star yearly savings of up to $201 are possible with a simple payback of 7 to 19 years (DOE, 2010). Tankless gas water heaters have a large burner (and no storage) so that water is heated on demand. To be considered tankless by the Department of Energy the unit must have a storage capacity no greater than 2 gallons.

From Navien

From Rheem

Condensing Tankless Water Heater

Condensing tankless water heaters add additional heat exchanger surface to extract more heat from the combustion gases. These condensing units have EF ratings to 0.91, compared to 0.82 for non-condensing. The condensing tankless water heaters are approximately 37% more efficient than standard gas storage units. The approximate installed cost of a condensing tankless unit is $2,900 plus $85 for recommended annual tankless maintenance (ACEEE, 2011). Energy Star and AHRI directory list five manufacturers of condensing gas tankless water heaters.

Table 4. Tankless Condensing Water Heaters

Manufacturer / Brand	Input	Rating
A.O. Smith Water Products	180 MBtuh to 199 MBtuh	EF = 0.91
Bosch Water Heating	175 MBtuh to 225 MBtuh	EF = 0.92 to 0.98
Navien America Inc.	150 MBtuh to 199 MBtuh	EF = 0.95 to 0.97
Noritz America Corp.	157 MBtuh to 199 MBtuh	EF = 0.91 to 0.94
Rheem Manufacturing	157 MBtuh to 199 MBtuh	EF = 0.92 to 0.94

<u>**Hybrid Gas**</u>

From AO Smith

From Eternal Water Heater

Hybrid water heaters combine the large burner of a tankless heater with a small storage tank to overcome some of the performance short comings of tankless units. The large burner supplies a continuous supply of hot water reducing the standby losses of a storage water heater. The small storage helps to avoid the "cold water sandwich" problem commonly reported in tankless units and helps to eliminate the delay in hot water delivery as the system first activates and warms (ACEEE, 2011). Condensing hybrid units have higher thermal efficiency than non-condensing hybrid heaters. The estimated installed cost of a non-condensing hybrid water heater is $1,726 with an additional $85 a year for recommended tankless maintenance (ACEEE, 2011). The installed cost of a condensing hybrid unit is $2,300 (ACEEE, 2011). The current manufacturers are listed below.

Table 5. Hybrid (Small Storage) Water Heaters

Manufacturer / Brand	Model	Input	EF or Efficiency
A.O. Smith Water Products	NEXT Hybrid®	100 MBtuh	90%
Grand Hall USA	Eternal Hybrid™	100 MBtuh to 195 MBtuh	EF = 0.94 to 0.96

Standard Electric Storage

About 21% of households in the Northeast use electric storage tanks to meet their water heating needs (Table HC11.8, EIA, 2008). This fraction is 12% in New York State (NYSERDA 2009). Standard electric storage water heaters have an EF range of 0.81 to 0.95, power input of 1.5 kW to 5.5 kW, and a first hour rating of 17 to 120 gallons per hour (AHRI, 2011). Although electric storage water heaters are more efficient per unit of energy, the higher cost of electricity makes gas storage water heaters cheaper to own over the lifetime of the unit (assuming gas is available). An electric storage heater has a resistance element that directly heats the water in the tank. Electric water heaters are often used in apartments or other confined spaces where flue gas venting is difficult or impossible.

Heat Pump Water Heaters

From AO Smith

Fron Rheem

Heat pump water heaters (HPWH) "concentrate" heat from the ambient air to the water in the storage tank. The heat pump extracts heat from the surrounding air, providing sensible cooling and dehumidification. The AHRI directory shows that HPWHs have EFs in the range of 2.00 to 2.51, inputs of 2.5 to 5.0 kW, and a first hour ratings of 56 to 84 gallons per hour. According to the DOE (2010) a HPWH can save homeowners around $234 a year in some climates compared to standard electric storage units, with a simple payback of 3 years. HPWHs are available as integrated units that include storage tank as well as add-on units that can be added to an existing tank. To have an acceptable first hour rating a resistance heating element is required. There are currently eight manufacturers of HPWHs.

Table 6. Heat Pump Water Heaters

Manufacturer / Brand	Model	Input	Rating
A.O. Smith Water Products	Voltex®	4.5 kWh	EF = 2.33
Airgenerate LLC	AirTap™	4.0 kWh to 5.0 kWh	EF = 1.92 to 2.21
Bosch Water Heating	HP 200-1	4.5 kWh	EF = 2.20
General Electric	GeoSpring™	4.5 kWh	EF = 2.35 to 2.40
Heat Transfer Products	HTP Hybrid	4.0 kWh	EF = 2.20
Rheem Manufacturing	EcoSense	2.5 kWh to 4.0 kWh	EF = 2.00
Stiebel Eltron Inc.	Accelera® 300	2.2 kWh	EF = 2.51
USI Green Energy	Green Star	5 kWh	EF = 2.39 to 2.40

An Energy Star HPWH must have an EF of at least 2.0, a first hour rating of at least 50 gallons per hour, a warranty of at least 6 years, and meet the required UL safety standards (Energy Star, 2011). Energy Star rates both integrated or drop-in HPWH configurations. The expected installed price of an Energy Star HPWH is $1,600 with over $300 in base savings over a standard electric storage water heater[2]. There is also an additional annual savings of $20 (annual cost of operating a standalone dehumidifier) due to the dehumidification capacities of the HPWH (ACEEE, 2011).

Using a HPWH in a Northern climate often requires special considerations. Therefore, the Northwest Energy Efficiency Alliance (NEEA, 2011) has proposed a Northern HPWH specification that includes:

- HPWH is Energy Star qualified (EF $\geq$ 2)
- First Hour Rating comparable to equivalent resistance water heater (60 gallons per hour)
- Additional safety and service parameters for condensate management, air filters, diagnostics, and freeze protection.
- Additional exhaust ducting and noise control features for units to be installed in living spaces.

ACEEE estimates that the installed cost of this Northern HPWH is $1,700 (ACEEE, 2011). In our opinion some of these features (such as the existing ducting) may not be appropriate in a New York State application where units are likely to be mounted in a basement.

Add-on HPWH

An add-on HPWH is a standalone air source heat pump that is separately connected to a third party tank via a pumping circuit. Cold water enters the heat pump where it is heated and pumped back to the tank. Add-on heat pumps are not federally regulated. The Department of Energy does not consider them to be complete water heaters, because they rely on third party

[2] Assumed $0.1158/kWh, EF=0.90 and 4,878 kWh/yr for standard electric, EF=2.00 and 2,195 kWh/yr for HPWH.

tanks with unknown thermal properties. Therefore, a recognized rating method does not yet exist, and have been excluded from the Energy Star Water Heater program. These units have an estimated installed price of $800 with an additional annual savings of $20 for no longer needing a standalone dehumidifier (ACEEE, 2011).

Electric Tankless Water Heater

Electric tankless water heaters are smaller units that can be located at or near the end use location or point of use (POU), such as the sink or shower/tub. Electric POU water heaters can also be used to boost the hot water temperatures from a central storage system or solar storage. The increased efficiencies attributed to these units are primarily from the decrease in distribution losses of longer runs from a centralized heating system. Distribution losses are primarily a concern in commercial application but can also be an issue in larger residential applications. Standby losses from the tank are also eliminated. Eemax is the only manufacturer listed in the AHRI directory and a web search found Bosch Water Heating (Powerstar and Ariston), and Stiebel Eltron Inc. Rheem produces commercial models possibly suitable for residential applications. ACEEE estimated the installed cost of an electric tankless unit in a remote, but extensively used bathroom to be $1,700 (ACEEE, 2011).

Other DHW Approaches

Indirect Tank Systems

In New York State 3.2 million households use natural gas or fuel oil boilers for space heating (Table HC6.8, EIA, 2009b). The boiler can also provide water heating via an internal heat exchanger or an indirect tank. The internal heat exchanger approach is a tankless approach where the boiler must fire on demand to provide tankless water heating. Indirect tanks add another circuit or zone to boiler to heat water in an insulated tank. These tanks provide water heating at the efficiency of the space heating boiler (excluding piping losses) and typically have internal controls to turn off the boiler-side pumps or valves.

Ground Source Heat Pump Systems

Ground source heat pumps (GSHPs), also known as Geothermal or GeoExchange systems, provide space conditioning (heating and cooling). Many of these systems can also provide domestic hot water. There are two common configurations for GSHP-based water heating systems: one is a desuperheater heat exchanger that is integrated into the GSHP unit, or the second is a triple-function GSHP unit that uses its full heating capacity to meet DHW loads. The desuperheater uses the hot gases from the heat pump's compressor to assist in heating the water. During the cooling season the desuperheater provides "free" hot water, but during heating season water heating is provided at the space heating COP. A shortcoming of the desuperheater concept is that water heating is only provided as a consequence of space conditioning operation. The triple-function GSHP can use its full heating capacity to provide water heating. The unit includes different refrigerant valving and controls to enable compressor operation based on space heating, water heating, or cooling loads (thus the triple function). The estimated incremental cost of a triple-function heat pump is $900 more than the desuperheater unit, with little to no change to the installation costs; however other changes in the GSHP may increase the cost further (ACEEE, 2011).

Solar Water Heaters

The solar heater market was the only area that saw a decline in Energy Star qualified shipments from 2006 to 2009. This is thought to be the result of overestimation of qualified products and the lack of engagement from some solar manufacturers becoming active within Energy Star. Solar with electric backup has an annual savings around $259 and an approximate payback period of 10 years (DOE, 2010). Solar water heaters consist of three components; collector, circulation, and storage.

Collector Type

There are three types of collectors used in solar water heating systems.

1. ***Batch or Integral Collectors***
   A batch collector, also known as an integrated collector-storage system, typically stores water in a tank attached to the collector. Heat transfer between the tank and collector is normally achieved by passive heat transfer via a thermosyphon. This system is normally unsuitable for northern climates where temperatures are frequently below freezing.

2. ***Flat Plate Collectors***
   Flat plate collectors consist of tubes attached to absorber plates which are all contained within an insulated box.

3. ***Evacuated Tube Collectors***
   Evacuated tube collectors are glass tubes containing water or heat transfer liquid inside a larger glass tube. The space between the tubes is at a vacuum and helps to improve efficiency. Evacuated tube collectors have been shown to work at -40°F and individual tubes can be replaced.

Circulation Approach

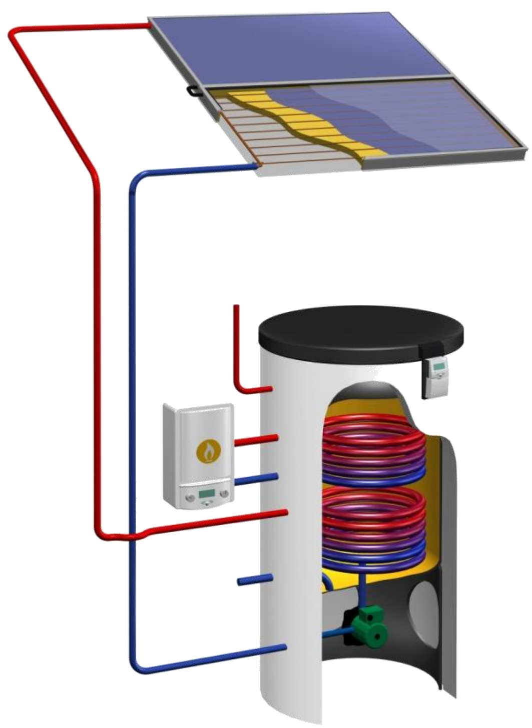
Solar systems can use two different water circulation approaches:

1. ***Direct / Drainback***
   Direct circulation approaches pump potable water directly through the collector where it is heated and sent back to the tank. Usually the water “drains-back” to the tank when solar heat is not available and when the risk of freezing is high. This is approach is preferable for warmer climates where it rarely freezes, since heat transfer is better without an intermediate fluid.

2. ***Closed Loop or In-Direct***

   In a closed-loop system a non-freezing liquid flows through the collector and returns to a heat exchanger in or near the storage tank. This approach is common for cold climates where the risk of freezing is high.

A new in-direct, drain-back system is now available for Northern climates from Wagner & Co (Secusol). The Secusol system has a drainback glycol loop in an in-direct heat exchanger inside the water heating tank. The internal glycol heat exchanger has large enough volume to store all the glycol needed to operate the system – and store it when the system is off. This system provides the freeze protection of a glycol system but eliminates the extra components and installation labor needed for closed loop, pressurized glycol system. It is also resistant to overheating and stagnation issues that can degrade the glycol fluid on a sealed system.



From Wagner and Compnay (SECUSOL, Glycol drain back system)

DHW Systems Identified for the Laboratory Test

Based on the technology review above we recommend the systems listed in Table 7 for laboratory testing in this project. The systems were chosen based on their applicability and potential in New York State homes. Table 7 lists the characteristics for the recommended systems.

Table 7. Recommended DHW Systems

Location	Technology Classification	Manufacturer and Model	EF or SEF	Input and Size
1	**GAS-STD** Standard Gas Storage	A.O. Smith GCVX-50	0.58	65MBtu/h 50 gal
2	**GAS-HE-PVNT** Non-condensing Power Vent Gas Storage	A.O. Smith GPVR-40	0.67	40MBtu/h 40 gal
3	**SOLAR-DRAIN** Drain-Back Solar Hot Water	Wagner & Co SECUSOL 350-2 144014 28	3.1	4.5 kW 92 gal
4	**ELECT-STD** Standard Electric Storage	A.O. Smith ECT-52	.91	4.5kW 52 gal
5	**SOLAR** Flat Plate, Glycol Solar Hot Water	Rheem SOLPAK 3.2 RS120-64BP	3.2	4.5 kW 120 gal
6	**TANKLESS-COD** Condensing Gas Tankless	Rheem RTGH-95DVLN	0.94	199MBtu/h
7	**GAS-HE-COND** HE Condensing Gas Storage	A.O. Smith Vertex™ GDHE-50	Not rated by EF (96% efficiency)	100MBtu/h 50 gal
8	**HYBRID** Hybrid HE Small Storage	A.O. Smith NEXT HYB-90N	not rated by EF (90% efficiency)	100MBtu/h
9	**HPWH** Heat Pump Water Heater	GE GEH50DNSRSA	2.35	0.55-4.5 kW 50 gal

Notes: Location corresponds to the position in the laboratory. Location 1 and 2 on 1st floor. Locations 3 to 9 on 4th floor from west to east.

We focused on gas and electric appliances even though oil-fired water systems are relatively prevalent in New York State. We believe that oil-fired systems are typically not stand-alone, direct-fired appliances but instead are more commonly part of the boiler system used for space heating.

The installed base of tankless units are mostly non-condensing units. However, we recommend that a modern condensing unit be laboratory tested to understand the characteristics and performance of these more advanced units.

While Heat Pump Water Heaters (HPWHs) are more widely used in southern climates they also have potential as an efficiency improvement in NYS homes with electric water heaters. Therefore this unit has been included in the test program.

Solar Hot Water Systems are not being directly funded by the NYSERDA portion of the project but are being separately funded by a separate DOE project at Syracuse University (DE-EE0002121). We have selected two types of systems that are appropriate for cold climates:

- A conventional glycol-filled system with an indirect heat exchanger in the storage tank (Rheem)

- An innovative glycol-fired drainback system that is simpler to install and has better performance (Wagner).

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