Natural Gas Internal Combustion Engine Heat Pump Field Trial Final Report

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1. Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) is a non-profit working to mobilize the Northwest to become increasingly energy-efficient for a sustainable future. One of NEEA's market transformation strategies is supporting emerging technologies through field-performance testing to demonstrate performance and identify potential adoption barriers. NEEA identified a natural gas internal combustion engine (ICE) heat pump water heater as a candidate for testing. This technology uses a natural gas engine to drive a heat pump cycle. Additionally, waste heat from the engine is captured and used to help heat the water.

The primary advantage of this technology is the ability to provide hot water for domestic hot water (DHW) and heating hot water (HHW) at significantly higher efficiencies than natural gas boilers. By using free heat from outside air through the heat pump cycle, efficiency can exceed 100%.

This report summarizes actions and performance results from the installation, operation and testing of this product in the field. This report includes analysis of two months of collected data from the baseline system and over eight months from the retrofitted system. Field data from the retrofitted system was collected from April through December of 2017.

1.1 Scope of Study

For this field test, the following actions were performed by Energy 350:

- Selected Capital Manor Retirement Community in Salem, OR as the test site.
- Installed monitoring equipment to quantify load profiles and baseline boiler efficiency.
- Installed the ICE heat pump and associated equipment to connect to Capital Manor's DHW and HHW systems.
- Installed long term monitoring equipment to monitor and quantify performance.
- Removed the monitoring equipment at the conclusion of this study in December 2017. Capital Manor has opted to keep and continue to use the ICE heat pump.

1.2 Summary of Results

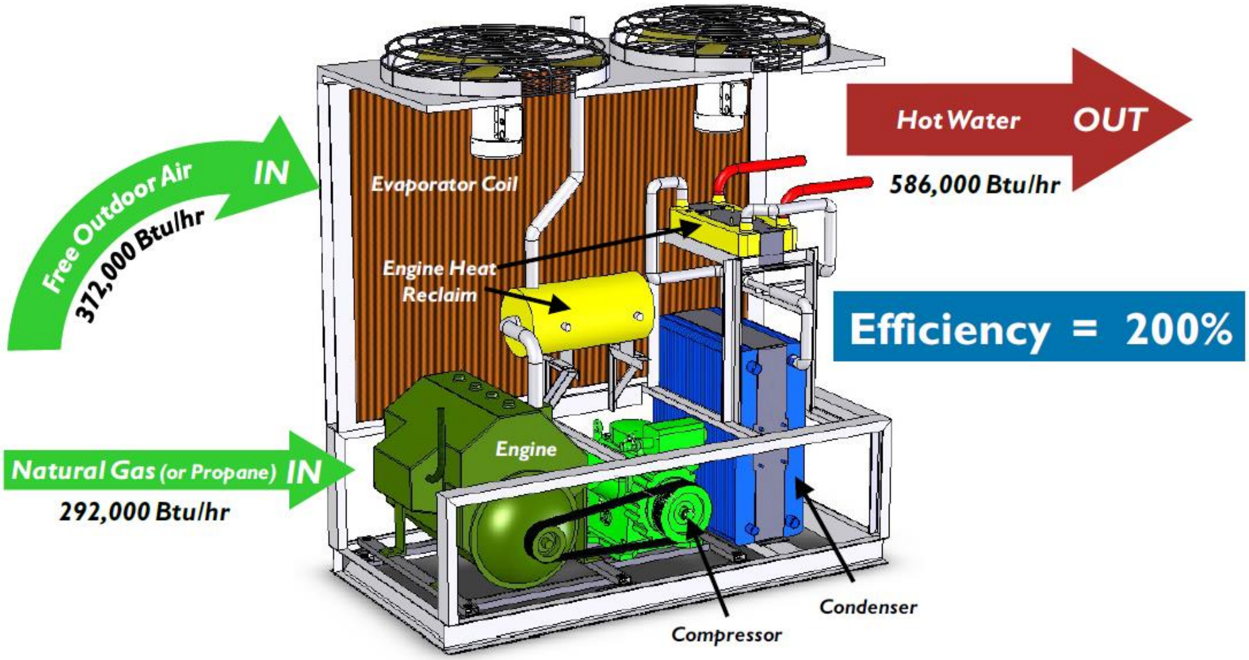
Table 1 summarizes some key performance indicators of the heat pump water heater.

TABLE 1 - SUMMARY OF KEY PERFORMANCE INDICATORS

Baseline DHW Boiler Efficiency	67.1%	
Baseline HHW Boiler Efficiency	73.1%	
ICE Heat Pump Overall COP	1.34	
ICE Heat Pump Capacity @ 40F Ambient	220,535	Btu/hr
ICE Heat Pump Capacity @ 75F Ambient	421,519	Btu/hr
Total Installed Cost	$138,927	
Annual Energy Savings	11,350	Therms
Annual Energy Cost Savings	$6,483	
% Energy Savings	39%	
Estimated Annual Maintenance Cost	$2,167	
Simple Payback (Current Gas Prices & Actual Installed Cost)	32.2	Years
Simple Payback (Projected Moderate Gas Price Escalation)	19.2	Years
Simple Payback (Reduced First Cost & High Gas Price Escalation)	9.8	Years

The product chosen for testing was the Ilios HEWH-500-AS, manufactured by Tecogen. Figure 1 shows an overview of the technology.

FIGURE 1 - HEAT PUMP OVERVIEW

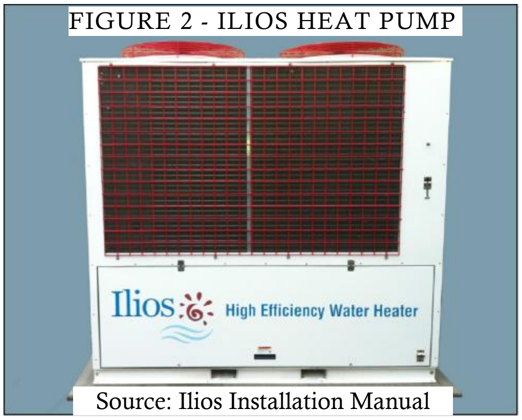


Source: Ilios Data Sheet, www.tecogen.com/water-heaters/air-source-water-heater

The heat pump has a rated capacity range of 400,000 – 600,000 Btu/hr, depending on outside temperature. It has a manufacturer rated Coefficient of Performance (COP) range of 1.2 to 2.2, also depending on outside temperature. The heat pump delivers 50 gpm of hot water between 100° to 160°F, which is user selectable. The packaged unit includes the following components:

- 50 hp, 4-cylinder natural gas or propane fueled engine, manufactured by Ford.
- Open-drive reciprocating compressor, belt-driven by the engine, utilizing refrigerant R-134a.
- Compact brazed-plate condenser.
- Air-cooled evaporator coils.
- 5 kW internal generator for parasitic load.
- Heat recovery system that recovers heat from the engine jacket and exhaust as well as the heat rejected from the condenser.
- 1.5 hp water pump for hot water delivery.
- Internal controllers, sensors, etc.

FIGURE 2 - ILIOS HEAT PUMP



Source: Ilios Installation Manual

2. Site Overview

An ideal site is one with a large DHW load, significant DHW storage capacity and reasonable installation logistics. Storage capacity is important because it smooths out peaks in usage, allowing for less heating capacity to be installed. This allows the heat pump to be sized closer to the base load rather than the peak, dramatically increasing loading and run hours. Additionally, by smoothing out peaks in DHW use, a larger portion of the heating loads can be met by the heat pump, relying less on the backup boilers (or other heating source) to cover peaks in load.

After evaluating several facilities, we selected the Capital Manor Retirement Community in Salem, OR as the location for the field testing. Capital Manor is comprised of the Manor Care building and Main Tower building, each of which have separate mechanical systems. For this demonstration, the tower was selected, which is a 10-story, 185,000 square foot building. The first floor contains a lobby, kitchen, dining hall, auditorium, and various other common areas. The basement contains storage space and maintenance offices. The remaining floors in the Main Tower are common areas and individual tenant spaces. An additional attractive attribute of Capital Manor is that there is a heating loop in close proximity to the DHW loop. This allows for the heat pump to be used for both DHW and HHW via a hydronic loop.

FIGURE 3 - CAPITAL MANOR MAIN TOWER

3. Baseline Equipment and Monitoring

3.1 Site Overview

Figure 4 and Figure 5 show an overview of the facility and the boiler building that houses the existing boilers and newly installed equipment. The heat pump is now installed just outside the boiler building. The hot water is delivered to the tower building via underground piping.

FIGURE 4 - BIRD'S EYE VIEW OF CAPITAL MANOR

FIGURE 5 - BOILER BUILDING

3.2 Baseline System

The baseline system consists of one 1,900 kBtu heating boiler that serves five common area air handlers and two 600 kBtu domestic hot water boilers. Two parallel pumps (one redundant) serve the DHW loop and a 5,000-gallon storage tank stores hot water at 120-125°F. Two parallel pumps (one redundant) also serve the HHW loop, which has a setpoint of 150°F. Table 2 summarizes the baseline equipment, Figure 6 and Figure 7 show the baseline DHW and HHW boilers respectively, and Figure 8 through Figure 10 show the remainder of the primary baseline equipment.

TABLE 2 - BASELINE EQUIPMENT SCHEDULE

Count	Equipment	Manufacturer	Model	Capacity (ea.)	Notes
1	HHW Boiler	Weil-McLain	Model 888	1,900 kBtu	160 °F Setpoint
2	HHW Pump	Bell & Gossett	DVA-56T17D	3-HP	72 GPM
2	DHW Boilers	A.O. Smith	DH-720-3100S	600 kBtu	Natural Draft
2	DHW Pump	Bell & Gossett	2A-AB-6.375	2-HP	50 GPM
1	DHW Tank	-	-	5,000 gal	120 °F HW Setpoint

FIGURE 6 - TWO 600 KBTU DHW BOILERS

FIGURE 7 - 1,900 KBTU HEATING BOILER

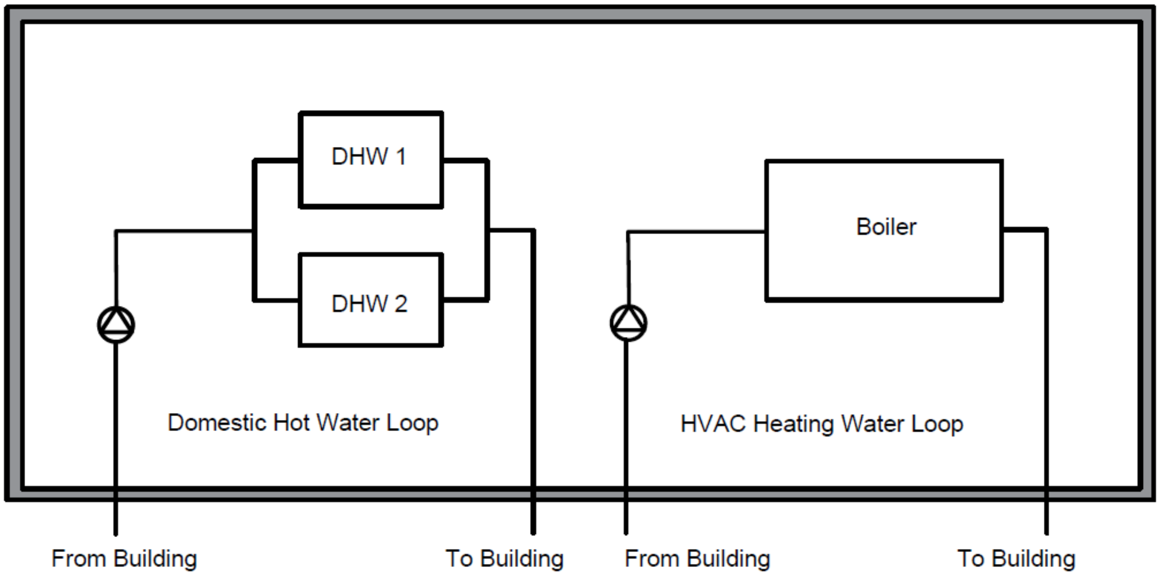
FIGURE 8 - TWO HHW PUMPS

FIGURE 9 - TWO DHW PUMPS

FIGURE 10 - PRE-INSTALLATION BOILER ROOM

Figure 11 shows a simplified baseline system configuration.

FIGURE 11 - BASELINE SYSTEM CONFIGURATION



4.3 Monitoring Equipment

We used ultrasonic flow meters to measure the DHW, HHW, and glycol loop water flows, and NW Natural was contracted to install gas flow meters with pulse outputs on all baseline boilers as well as the new heat pump. Table 3 lists the manufacturer and model number of the flow meters used in the study and Figure 12 through Figure 15 show photos of the monitoring equipment. We measured all data continuously and then averaged in 5-minute or less intervals. The data was sent via a wireless signal and uploaded every hour to Hobolink, a cloud-based data storage center, for easy access.

TABLE 3 - MONITORING EQUIPMENT SCHEDULE

Count	Equipment	Manufacturer	Model
2	DHW & HHW Water Flow Meter	M&A Instruments	TUF-2000M
1	Glycol Loop Water Flow Meter	Omega Engineering	FTB8020HW-PT
3	DHW, HHW, & Ilios Gas Meter	Elster	AL-425
1	Spot Check Ultrasonic Liquid Flow Meter	General Electric	TransPort PT-878

FIGURE 12 - ULTRASONIC FLOW METER ON DHW LOOP

FIGURE 13 - GAS FLOW METER (ONE ON EACH BOILER & ICE HEAT PUMP)

FIGURE 14 - GLYCOL LOOP TURBINE FLOW METER

FIGURE 15 - ILIOS GAS FLOW METER

4. Ilios Installation

We began installation of the heat pump and related equipment in early March and the startup and commissioning was completed April 6th, 2017. Prior to installation, there were many planning, design and permit related activities that were necessary. The installation did require engineering and construction expertise, though overall went smoothly. An installation with this complexity required design, four permits, equipment selection, crane coordination and multiple trade contractors. This complexity would typically require a General Contractor (GC), which would increase the installation cost for a typical end-user. Throughout the process, we found Tecogen to be knowledgeable and helpful, providing great factory support. The startup technician was very knowledgeable. Aside from a small issue with a control valve that was installed incorrectly by the controls contractor (unrelated to Tecogen), the startup & commissioning was straightforward.

4.1 Design and Equipment Selection

There are several ways to configure a system that integrates the heat pump with the existing DHW and HHW loops, while leaving the existing boilers in place for backup and to cover peaks in load. The capacity of the heat pump is smaller than their peak demand, and only a fraction of the capacity of the existing boilers, which necessitates that the existing boilers remain in place and active to supplement the heat pump during times of high load. Leaving the boilers in place is ideal in that it allows the heat pump to be sized closer to the base load, which maximizes the use and efficiency of the heat pump. Additionally, the heat pump performance is best when operating at or near full load.

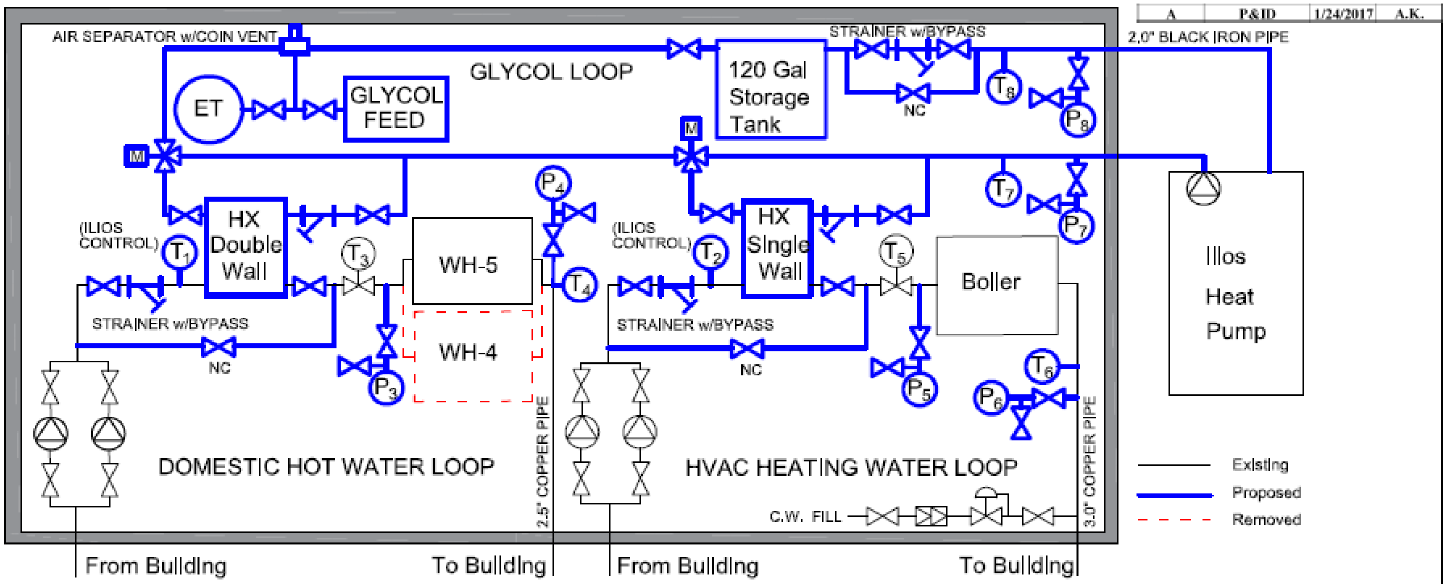
Since the DHW loop is significantly cooler than the HHW loop, a cascading loop control strategy was selected to integrate the two loops in series. This allows the hottest supply water from the heat pump to first heat the HHW loop. Then, the exiting water from the HHW loop is cooler, but still hot enough to heat the DHW loop.

Two plate and frame heat exchangers transfer heat from the heat pump loop to the DHW and HHW loops. To maximize heat transfer and minimize the heat pump supply temperature, low approach heat exchangers, with approximately a 5°F approach were selected. Approach is the difference between the heat pump loop supply temperature and the building loop supply temperature. For example, with a 5°F approach heat exchanger and 150°F heat pump supply temperature, 145°F HHW supply to the building is achievable. Since the heat pump loop requires glycol for freeze protection, a double walled heat exchanger was selected for the DHW loop. This is required by code and adds increased protection against potential contamination of potable water from the glycol.

Figure 16 and Figure 17 show the system design. The glycol loop from the heat pump heats the HHW and DHW loops in series via plate-and-frame heat exchangers. The series design takes advantage of the differential in temperature requirements of the two loops. The HHW loop requires approximately 145°F, while the DWH loop requires approximately 130°F. Based on these offset temperatures, the glycol loop still has a high enough temperature to heat the DHW loop even after heating the HHW loop. Both heat exchangers are controlled with a 3-way valve that either allows flow through the heat exchanger or bypasses it. Under this configuration, if one of the loops does not need heat, the heat exchanger is simply bypassed, preserving the flow and temperature for the loop that does need heating.

Additional equipment required includes temperature and pressure sensors throughout, strainers, a glycol feeder, pressure tank, air separator and a storage tank. The storage tank is required because the heat pump continues to run for two minutes after receiving a stop command. The storage tank simply provides additional thermal mass to store the additional two minutes worth of heating without causing overheating at the heat pump.

FIGURE 16 - DESIGN SCHEMATIC



Bill of Materials Capital Manor Ilios Heat Pump			
Loop	**No.**	**Part**	**Quantity**
Glycol	1	2" Y Type Strainer	3
	2	2" Isolation Valve	8
	3	Modulating 2" 3-Way Valve	2
	4	2" Thermo-well	2
	5	0.75" Isolation Valve	6
	6	0.75" Pressure Gauge	2
	7	Expansion Tank	1
	8	Compact Glycol Feed System CGL17	1
	9	120 Gallon Storage Tank	1
	10	2" Air Seperator with Coin Vent	1
	11	Single Wall Plate and Frame Heat Exchanger	1
	12	Double Wall Plate and Frame Heat Exhanger	1
Domestic Hot Water	13	2.5" Y Type Strainer	1
	14	2.5" Isolation Valve	3
	15	2.5" Thermo-well	2
	16	0.75" Isolation Valve	4
	17	0.75" Pressure Gauge	2
	18	Thermistor for Ilios Control	1
HVAC	19	3" Y Type Strainer	1
	20	3" Isolation Valve	3
	21	3" Thermo-well	2
	22	0.75" Isolation Valve	4
	23	0.75" Pressure Gauge	2
	24	Thermistor for Ilios Control	1

Notes:

1. Heat pump will be mounted on a poured concrete pad outside the existing structure.
2. The engine and compressor are mounted on vibration isolators and all of the piping connections to them are flexible. As such, piping connections to the unit will be rigid.
3. Heat pump will be bolted to concrete pad.
4. All additions to the Domestic Hot Water Loop and HVAC Heating Water Loop shall be compatible with the existing copper piping.
5. The heat pump is gas powered, but requires a small electrical service for controls. Installation to include a single phase service connection (120 VAC/60 Hz/15 A).
6. This project will include removal of existing WH-4. Terminations on existing piping will be copper. This gas service will be used to supply the new heat pump.
7. All glycol loop piping will be 2" insulated piping.
8. Piping size for pressure gauges, expansion tank, and glycol feed system can match the connection dimensions of that equipment.

	NAME	DATE	CAPITAL MANOR BUILDING D	
DRAWN	A.K.	1/24/2017		
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ENERGY 350. ANY REPRODUCTION IN PART OF AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ENERGY 350 IS PROHIBITED.			DWG. NO.	REV A
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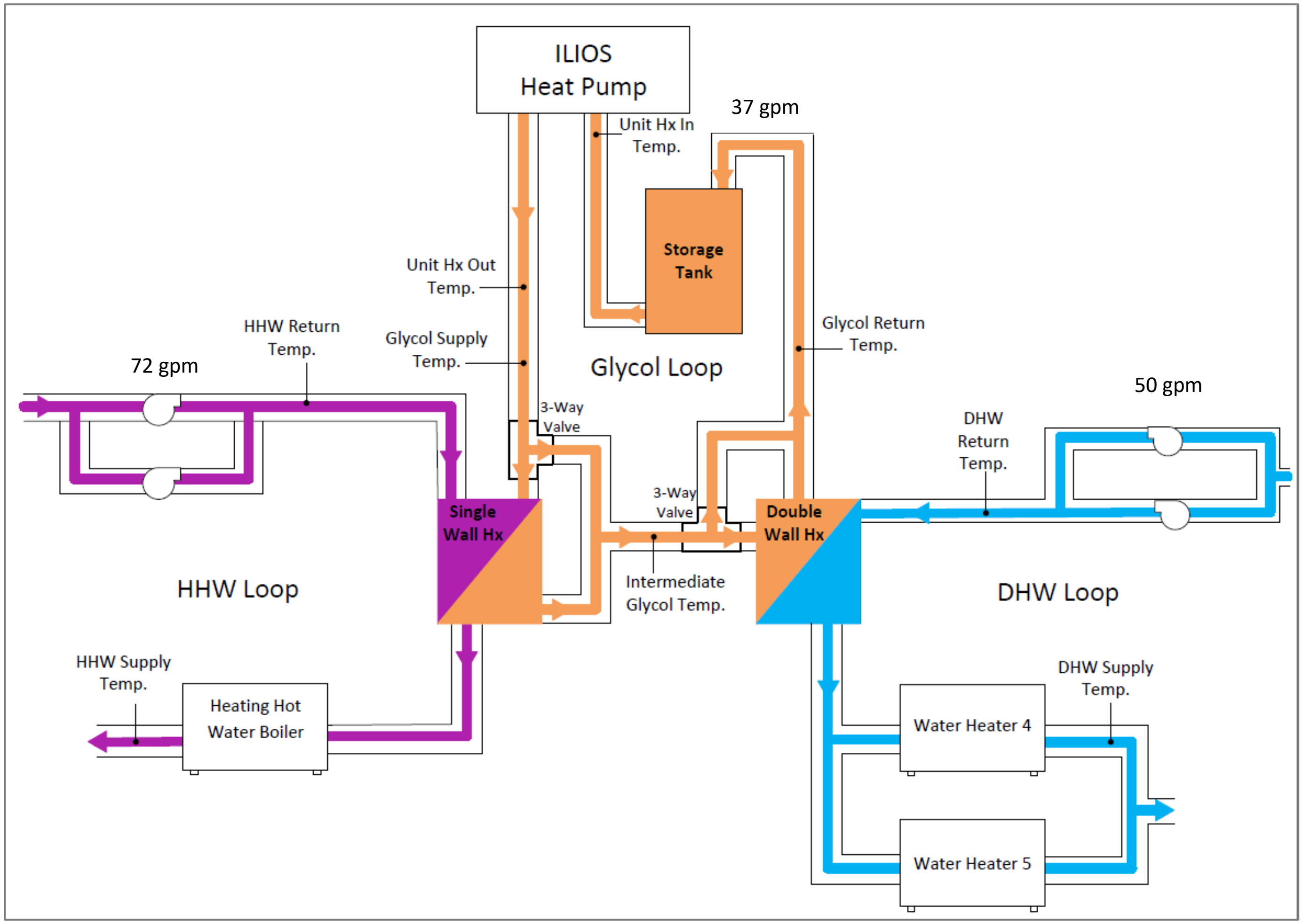
FIGURE 17 - AS-BUILT SYSTEM SCHEMATIC



4.2 Permitting

Before starting a construction project, all necessary permits must be obtained. This project required building, mechanical, plumbing and electrical permits from the City of Salem.

When installing equipment greater than 400 pounds, the building permit requires a PE stamped Seismic calculation and recommendations. For this, a structural engineer was hired to calculate required slab design and bolting for the storage tank, heat exchangers and heat pump. The existing slab in the outbuilding was sufficient for the storage tank and heat exchangers, and the new equipment was attached to the existing slab at recommended points with recommended seismic bolts. The heat pump required a specially designed pad with significant depth, rebar and specific mounting points, and the use of stainless steel seismic bolts.

The design documents, equipment specifications, stamped seismic calculations and design, permit applications, and fees for the four required permits were submitted to the city. Permits were reviewed and approved within a week. Upon completion of installation, final inspections were requested. The installation passed all inspections without the need for modifications and all permits have been closed out.

4.3 Crane

Due to the size of the equipment, a crane was required for removal from the delivery truck and placement on the structural slab. For this, Santana Crane was commissioned. Since the heat pump is pad mounted, not roof mounted, a smaller, less expensive crane was used. Cranes such as this typically charge a rate of $250-$600/hour and often also charge a mobilization fee or have a minimum rental cost.

As is typical, exact delivery time is tough to predict with precision. The crane was lined up for the anticipated delivery date, but the equipment arrived a day early. This created a scramble to find a crane available at the last minute. Unfortunately, the freight delivery was two hours late, and added slightly to the crane cost. Despite these challenges, the overall delivery and placement was smooth and inexpensive.

4.4 Electrical

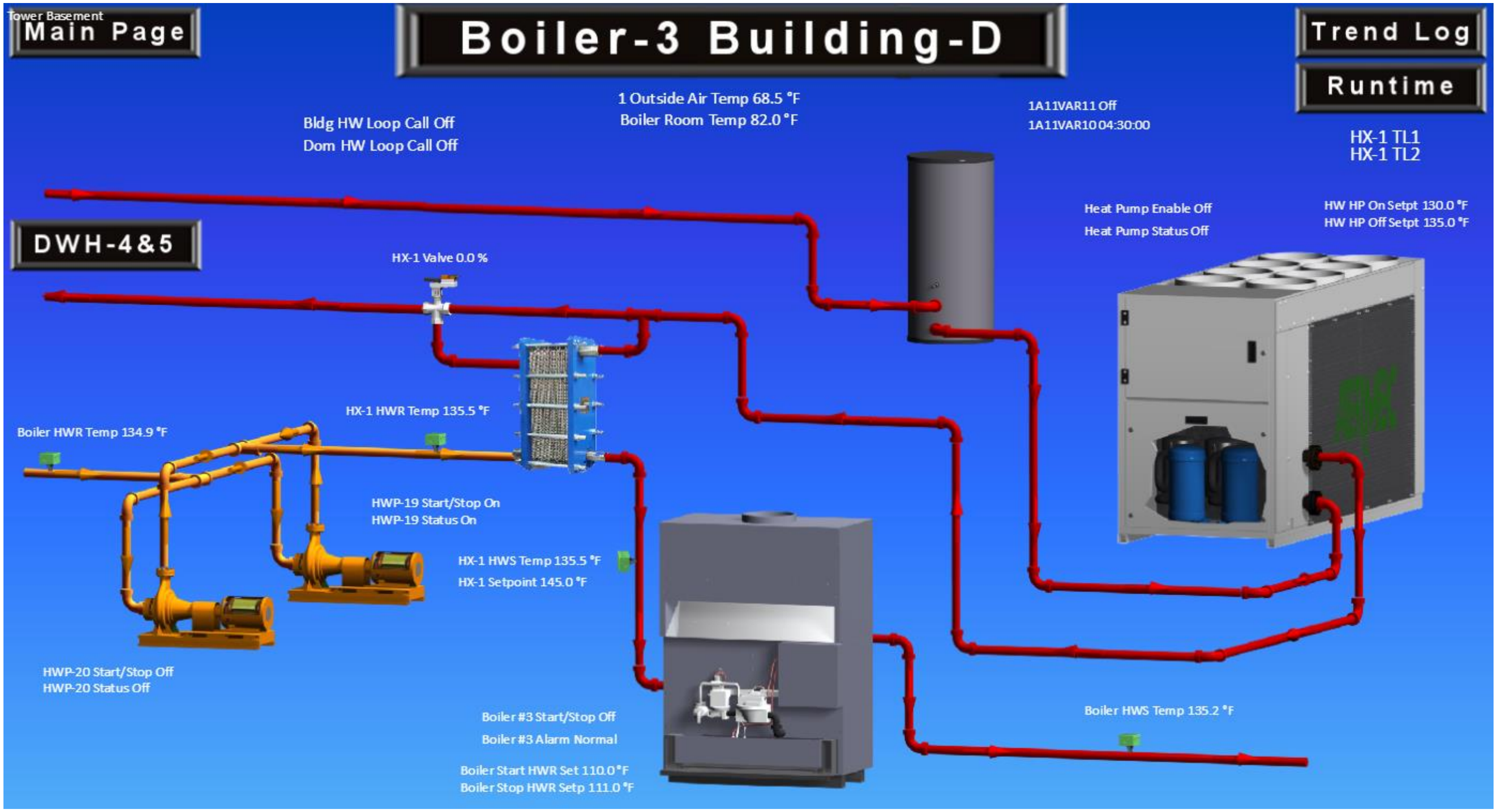
The heat pump generates its own electricity to power the parasitic loads such as evaporator fans and pump. However, it does require a small electrical service for controls and charging the battery. This requires a small, 15 Amp, 110 Volt electrical connection. An electrician was required to run wire & conduit, install an external disconnect, and connect power to the heat pump. This was simple, low-cost electrical work.

4.5 Controls

A simpler installation that only provides heat to a single source could be installed without the need for controls. However, two factors necessitated the need for controls as a part of this installation. First is the added complexity of heating two loops with different load profiles and temperatures. Proper control of the two-loop configuration requires controls. Additionally, like most sizable facilities, Capital Manor has a facility wide control system and requested integration of the new heat pump into this system.

An additional control panel, two actuating valves (one for each loop), temperature sensors at various points, heat pump status, heat pump start/stop command and graphics were added to the existing control system. This allows control of the supply temperature of each loop and a custom sequence of operations that allows fine tuning of the controls to maximize performance. An example of the performance optimization that controls allow is that the heat pump efficiency is greatest when the load is close to full capacity. Often either the HHW or DHW loop is calling for heating, but not both, which can create low load operation for the heat pump and reduce efficiency. Because of this, we programmed the heat pump to start when either loop calls for heating, but when running, the heat pump will heat both loops as long as neither is overheated. This allows the heat pump to run closer to full load and at increased efficiency. This control strategy has allowed the heat pump to operate 69% of its run-time at greater than 80% load. Figure 18 and Figure 19 show the control graphics.

FIGURE 18 - GRAPHICS FOR HEAT PUMP AND HHW LOOP



1 Outside Air Temp 68.5 °F
Boiler Room Temp 82.0 °F

Bldg HW Loop Call Off
Dom HW Loop Call Off

1A11VAR11 Off
1A11VAR10 04:30:00

Heat Pump Enable Off
Heat Pump Status Off

HW HP On Setpt 130.0 °F
HW HP Off Setpt 135.0 °F

HX-1 Valve 0.0 %

HX-1 HWR Temp 135.5 °F

Boiler HWR Temp 134.9 °F

HWP-19 Start/Stop On
HWP-19 Status On

HX-1 HWS Temp 135.5 °F
HX-1 Setpoint 145.0 °F

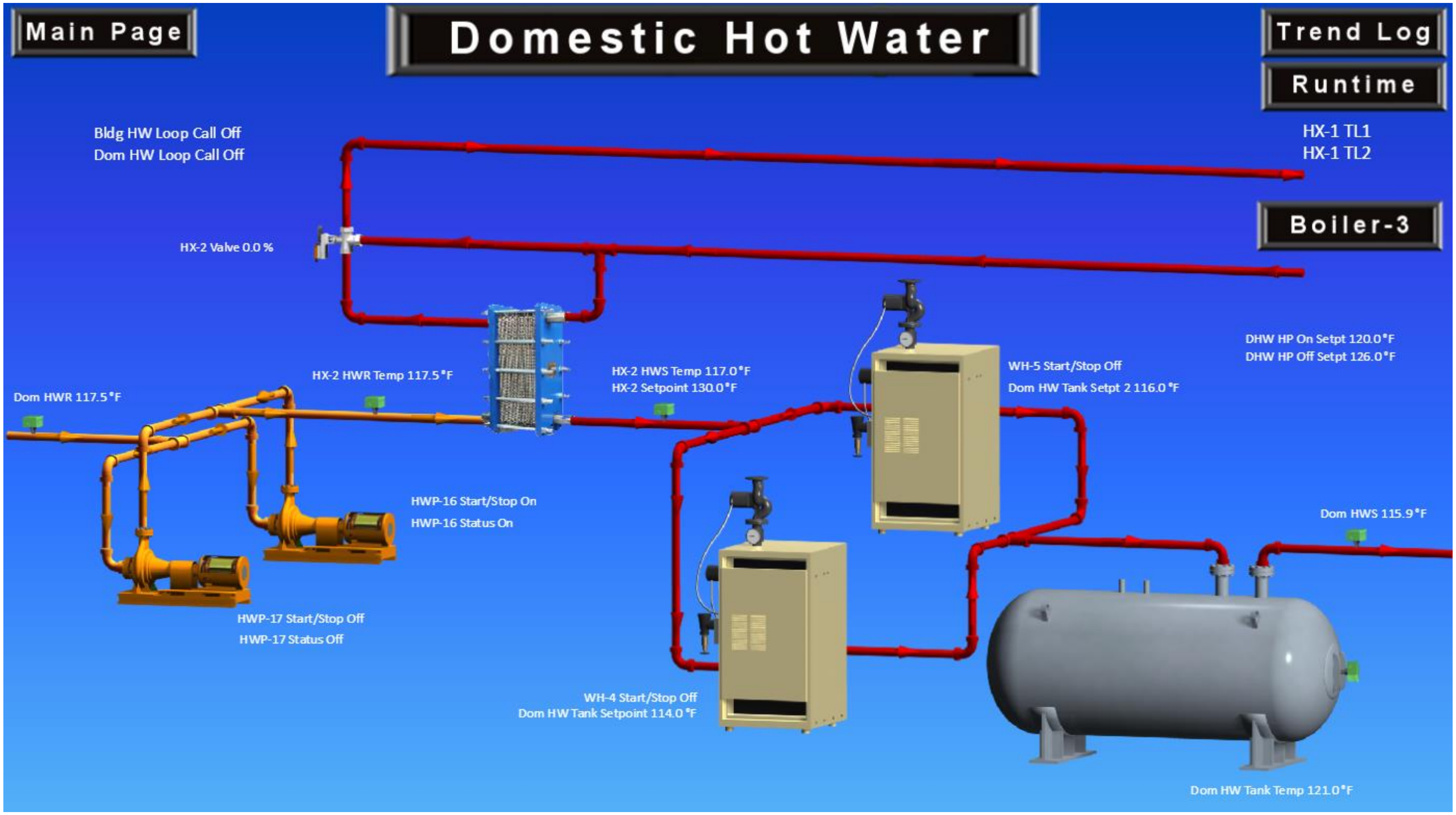
HWP-20 Start/Stop Off
HWP-20 Status Off

Boiler #3 Start/Stop Off
Boiler #3 Alarm Normal

Boiler Start HWR Set 110.0 °F
Boiler Stop HWR Setp 111.0 °F

Boiler HWS Temp 135.2 °F

FIGURE 19 - GRAPHICS FOR DHW LOOP



Bldg HW Loop Call Off
Dom HW Loop Call Off

HX-2 Valve 0.0 %

Dom HWR 117.5 °F

HX-2 HWR Temp 117.5 °F

HX-2 HWS Temp 117.0 °F
HX-2 Setpoint 130.0 °F

WH-5 Start/Stop Off
Dom HW Tank Setpt 2 116.0 °F

DHW HP On Setpt 120.0 °F
DHW HP Off Setpt 126.0 °F

HWP-16 Start/Stop On
HWP-16 Status On

HWP-17 Start/Stop Off
HWP-17 Status Off

Dom HWS 115.9 °F

WH-4 Start/Stop Off
Dom HW Tank Setpoint 114.0 °F

Dom HW Tank Temp 121.0 °F

4.6 Installation

While the heat pump was being shipped, we began the installation with the glycol loop plumbing, storage tank, expansion tank, air separator, heat exchangers, valves, strainers, temperature sensors, pressure sensors and controls. With the prep work done, the final portion of the installation was quite simple. Contractors used a crane to remove the heat pump from the truck and place it on a reinforced concrete pad. The heat pump was then bolted to the pad and connected to the plumbing, electrical hookups and controls. Tecogen was then commissioned to startup the system. The lead time for startup was approximately two weeks. Figure 20 through Figure 24 show during and after photos from the installation.

FIGURE 20 - ILIOS INSTALLATION

FIGURE 21 - ILIOS INTERNAL COMPONENTS

FIGURE 22 - DHW DOUBLE-WALL HEAT EXCHANGER

FIGURE 23 - HHW SINGLE-WALL HEAT EXCHANGER

FIGURE 24 - CAPITAL MANOR TOWER POST-INSTALLATION

Table 4 summarizes the primary equipment that were added to the baseline equipment as a part of this project, and Table 5 lists the balance of equipment.

TABLE 4 - PRIMARY EQUIPMENT SCHEDULE

Count	Equipment	Manufacturer	Model	Capacity	Notes
1	ICE Heat Pump	Ilios	HEW-500-AS	400-600 kBtu	160 °F Setpoint
1	DHW Heat Exchanger	Bell & Gossett	GPX P20 - DW	472 kBtu/hr	Double Wall
1	HHW Heat Exchanger	Bell & Gossett	GPX P20	472 kBtu/hr	Single Wall
1	Storage Tank	Lochinvar	RJA120	120 gal	Glass Lined

TABLE 5 - SECONDARY EQUIPMENT SCHEDULE

Loop	Part	Quantity
Glycol	2" Y Type Strainer	3
	2" Isolation Valve	8
	Modulating 2" 3-Way Valve	2
	2" Thermo-well	2
	0.75" Isolation Valve	6
	0.75" Pressure Gauge	2
	Expansion Tank	1
DHW	Compact Glycol Feed System CGL17	1
	2" Air Separator with Coin Vent	1
	2.5" Y Type Strainer	1
	2.5" Isolation Valve	3
	2.5" Thermo-well	2
	0.75" Isolation Valve	4
	0.75" Pressure Gauge	2
	Thermistor for Ilios Control	1
HVAC	3" Y Type Strainer	1
	3" Isolation Valve	3
	3" Thermo-Well	2
	0.75" Isolation Valve	4
	0.75" Pressure Gauge	2
	Thermistor for Ilios Control	1

4.7 Startup/Commissioning

Upon completion of installation, Tecogen was scheduled to start up the system two weeks out. A Tecogen technician flew from the Midwest for startup, and was there for a total of two days of startup work. The first half-day he inspected the installation and various aspects of the heat pump such as refrigerant pressures, oil levels, belt tension, etc. Early afternoon on day one, the technician started the heat pump. The heat pump started successfully and ran before shutting off due to high head pressure, caused by an overheating of the glycol supply temperature. The remainder of the day was spent troubleshooting. We suspected the problem was an air pocket in the new piping that prevented the pump from working, which is a common issue during startup of new plumbing.

The morning of day two, the troubleshooting process continued. At this point, we discovered that the controls contractor had installed the HHW control valve backwards. When the heat pump would turn on, the valve would be commanded open, but would actually close. After this discovery, we easily coreected the valve installation, and the system began working smoothly by late morning of day two. The system continued to be monitored throughout the afternoon, at which point the startup was complete.

Energy 350 continued to monitor the system and fine-tune the controls over the next two weeks. Continued monitoring has shown that the controls are well commissioned to maximize performance.

5. Performance Results Summary

The preliminary results of the performance period are summarized in Table 6. To quantify efficiency, we calculate Coefficient of Performance (COP), which is a ratio of the work done per unit energy input. The overall COP[1] for the period between April 6th and December 17th, 2017 was 1.34, which is in-line with the manufacturer-stated performance given the hot water setpoint and ambient conditions over the monitored performance period. Figure 25 shows the manufacturer's stated COP of the heat pump when operating at full capacity, and the data points indicate the actual field performance of the heat pump. The heat pump has operated with a setpoint of 150°F over the performance period and the measured COP lined up relatively well with the manufacturer-provided data above 40°F. However, as is typical with heat pump technologies, below 40°F the heat pump's COP falls below the manufacturer's curve as the unit entered defrost. Defrost cycles are necessary to prevent the coils from freezing over during cold temperature periods.

TABLE 6 - FIELD PERFORMANCE RESULTS[2]

Overall COP	Average Capacity (Btu/hr)	COP @ 40°F Ambient	COP @ 75°F Ambient	Capacity @ 40°F Ambient (Btu/hr)	Capacity @ 75°F Ambient (Btu/hr)
1.34	315,525	1.01	1.50	220,535	401,519

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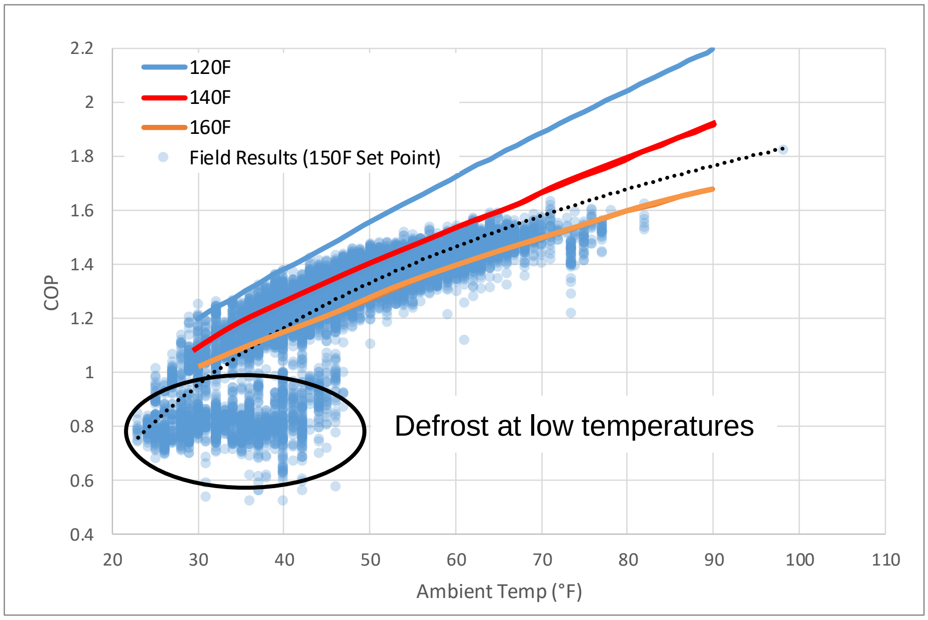
[1] Overall COP is defined as the sum of the total work done divided by the sum of the total energy input over the monitored period.

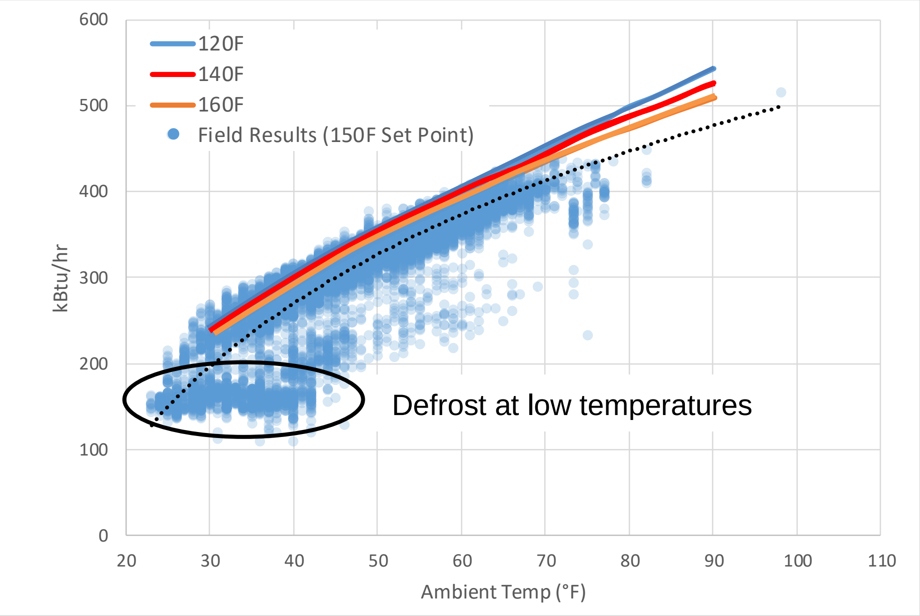
[2] The COP and Capacities listed are points on the line of best fit.

FIGURE 25 - FIELD PERFORMANCE VS. MANUFACTURER DATA



As seen in Figure 26, the field measured capacity lines up well with the manufacturer provided curves. However, similar to the COP performance at low temperatures, the capacity below 40°F is reduced due to the heat pump entering a defrost cycle.

FIGURE 26 - FIELD MEASURED CAPACITY VS. MANUFACTURER DATA



6. Economic Summary

Table 7 summarizes the preliminary energy savings and Table 8 lists a range of paybacks at different scenarios explained later in this section. The base scenario results in an annual gas savings of $6,483 and a simple payback of 32.2 years. If only the project costs and energy savings are considered, the resulting simple payback is 21.4 years. However, there is an increase in maintenance costs between the baseline (boilers only) and performance (ICE heat pump + boilers) systems. Tecogen sells a comprehensive factory service program for $1.25 per run-hour, or approximately $8,178 annually[3] in this case. The cost of an annual maintenance agreement exceeds the value of the energy savings. However, after speaking with Tecogen, for regions with low natural gas prices like the Northwest, a more practical economic decision would be to accept time and material (T&M) pricing for maintenance rather than purchasing a maintenance contract. Based on Tecogen's estimates of $500 per year of preventative maintenance (parts and labor) and a $10,000 engine rebuild (parts and labor) every 6 years, this averages out at $2,167 annually. Either way, the maintenance costs of the ICE heat pump technology are meaningful to the project economics, and depending on gas prices and maintenance contracting approach, could exceed the energy savings. In order for a project in the Northwest to be cost effective, the customer would need to assume the risk of a parts and labor service agreement.

TABLE 7 - PRELIMINARY ENERGY SAVINGS RESULTS

NWN Schedule:	32CSF
Energy Cost:	$0.5712 /therm

Baseline Annual Gas Consumption (Therms)	Performance Gas Consumption (Therms)	Annual Gas Savings (Therms)	Annual Gas Savings ($)	Annual Maintenance Costs ($)	Total Project Costs	Simple Payback (Years)
28,759	17,409	11,350	$6,483	$2,167	$138,927	32.2

TABLE 8 - PAYBACK SUMMARY

Simple Payback (Years)	Maintenance Excluded Payback (Years)	Low Gas Price Payback (Years)	Medium Gas Price Payback (Years)	High Gas Price Payback (Years)	Optimal Scenario Payback (Years)
32.2	21.4	26.5	19.2	15.4	9.8

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[3] See figure in appendix for annual run-hours calculation.

Table 9 summarizes the project costs which totaled $138,927 for this retrofit. The project costs do not include any sensors, equipment, or engineering time associated with monitoring the performance of the equipment. In a simple installation or new construction scenario we estimate the project costs could be as low as $100,000. A simple installation would include only one hot water load source, which would eliminate the need for controls as well as at least one heat exchanger.

TABLE 9 - PROJECT COSTS SUMMARY

Description	Equipment Costs	Labor Costs	Total Costs
ICE Heat Pump	$68,585	$2,500	$71,085
Heat Exchangers	$14,121		$14,121
Plumbing	$9,565	$31,080	$40,645
Controls	$1,609	$7,451	$9,060
Permits & Fees	$1,321		$1,321
Seismic Engineering		$2,200	$2,200
Crane		$495	$495
Total	**$95,201**	**$43,726**	**$138,927**

A major simplification of the simple payback cost effectiveness test is that it assumes constant gas prices. Natural gas prices are historically volatile and are expected to increase from their current near-historic lows. According to the Norwest Power and Conservation Council's 20-year Fuel Price Forecast from their Seventh Power Plan[4], the Northwest regional gas prices are expected to rise by almost 4% annually[5] (216% of 2015 prices by 2035) in their medium scenario and as high as 6.6% (355% by 2035) in their high scenario. To account for this uncertainty, we apply low, medium, and high gas price scenarios of the Council's regional forecast to a cash flow model based on preliminary savings results. Figure 27 shows the cumulative cash flows in 2017 dollars for the low, medium, and high scenarios[6]. The resulting break-even year (analogous to simple payback) is 19.2 years for the medium gas price scenario, 26.5 years in the low scenario, and 15.4 years for the high scenario.

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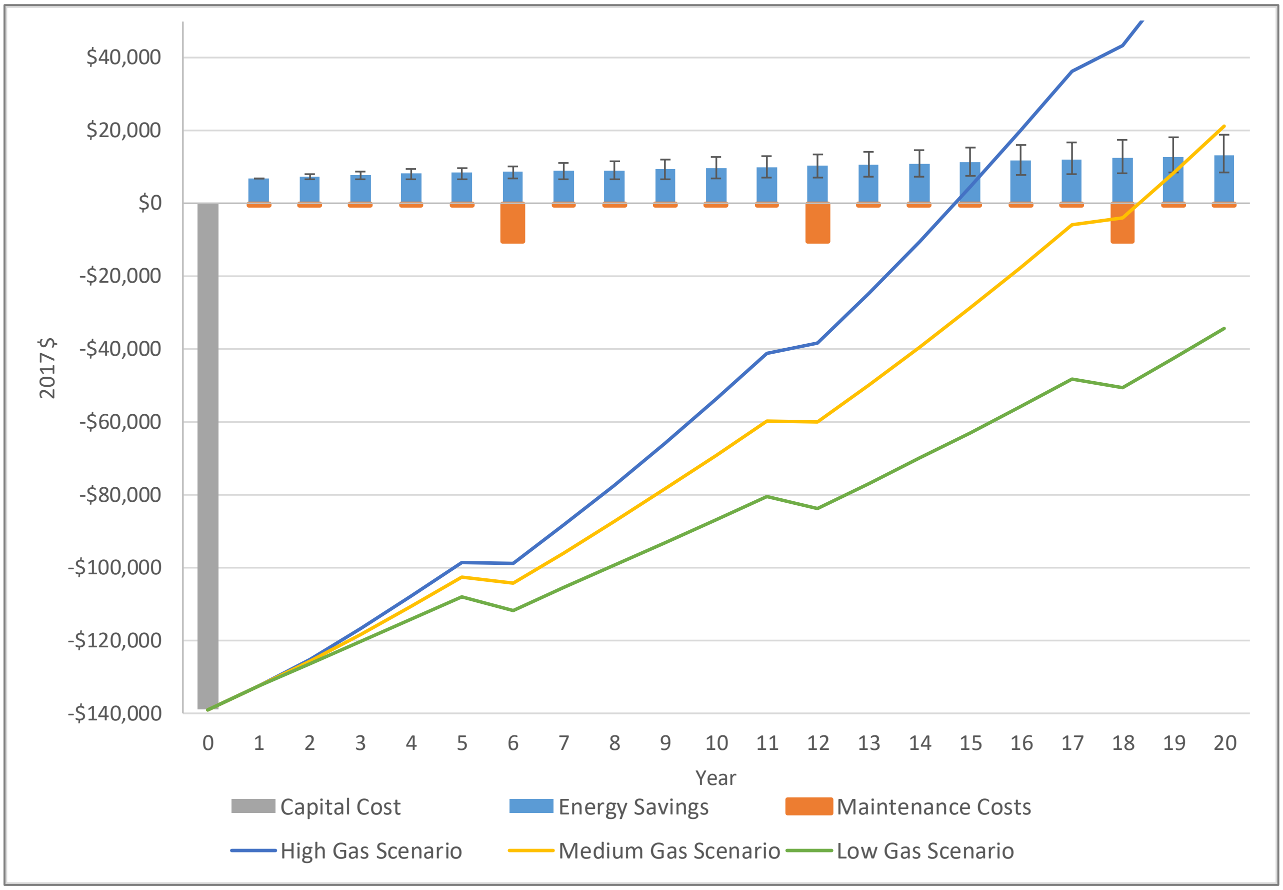
[4] Source: Natural Gas Price Forecast (XLSX), www.nwcouncil.org/energy/powerplan/7/technical accessed 5/17/2017.

[5] Inflation adjusted.

[6] See the Appendix for 20-year gas price forecast and gas rates used in the economic analysis.

FIGURE 27 - CUMULATIVE CASH FLOWS FOR LOW, MEDIUM AND HIGH GAS PRICE SCENARIOS



While the project economics are most sensitive to gas prices, other factors also impact the viability of a potential ICE heat pump project. Figure 28 shows the sensitivity of the project economics to gas prices, project costs, system performance, and maintenance costs. In an optimal scenario with future gas prices rising higher than expected, low project costs of $100,000, and a hot water setpoint of 120°F or below[7] we calculate the payback could be as low as 9.8 years.

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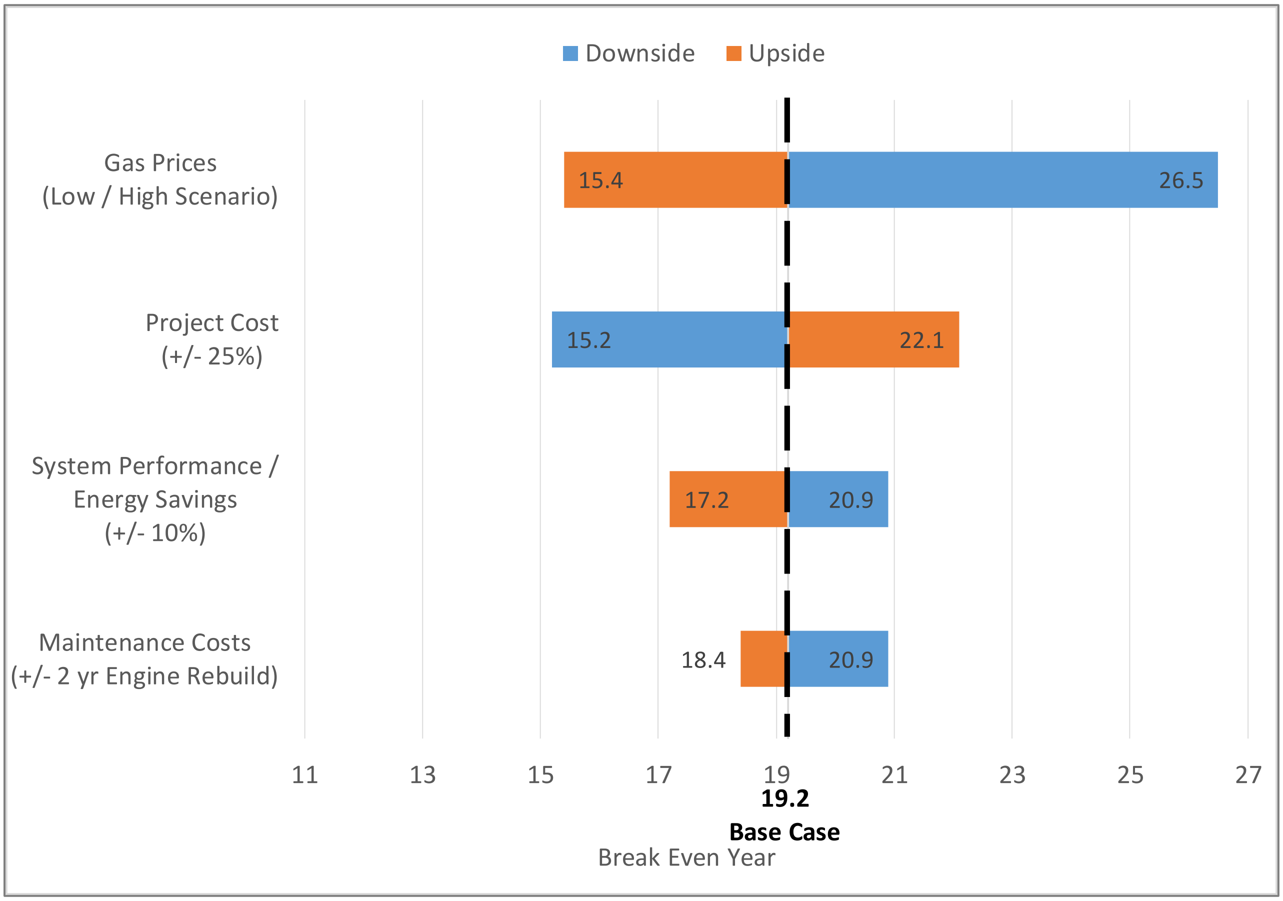
[7] A lower hot water setpoint application (DHW/pool only) would likely increase system performance by as much as 25%.

FIGURE 28 - SENSITIVITY OF MODEL INPUTS ON PROJECT ECONOMICS



7. Analysis

7.1 Baseline Analysis

The efficiencies of the DHW and HHW boiler are calculated by dividing the work done by the energy input. To calculate the work done by the boilers, we measured water flow and the inlet and outlet water temperatures over the baseline period from December 2016 through February 2017. To calculate the gas energy input, we measured the volumetric flow of gas and converted to energy using the monthly gas energy factors[8] from NW Natural[9], while correcting for the pressure at the respective gas flow meters[10]. The measured efficiencies of the DHW and HHW boilers were 67% and 73% respectively.

---

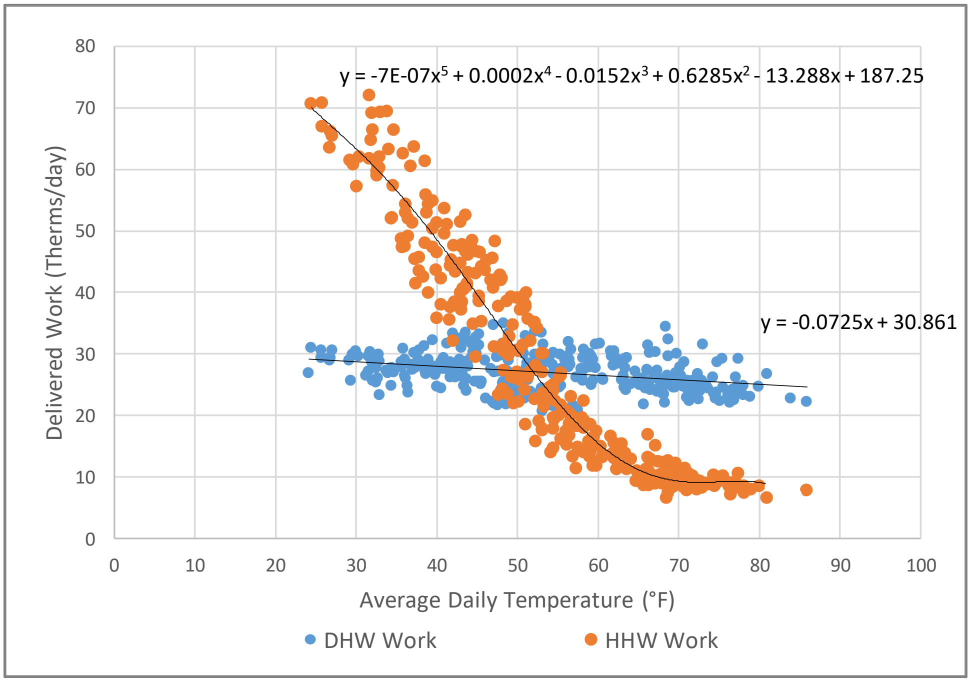
[8] The monthly gas energy factors include the average gross heating values of the fuel with corrections for temperature and pressure measured at the site.

[9] NW Natural billing factor ranged from 1.179 to 1.230 therms/ccf (1,179 to 1,230 btu/ft^3) from Dec-May at a pressure of 2.0 psig, and the corresponding gas energy content factors at the meters ranged from 1,060 to 1,117 btu/ft^3 at a meter pressure of 0.3248 psig (9" w.c.).

[10] See Section 6 for pressure calculation and gas energy content factors used.

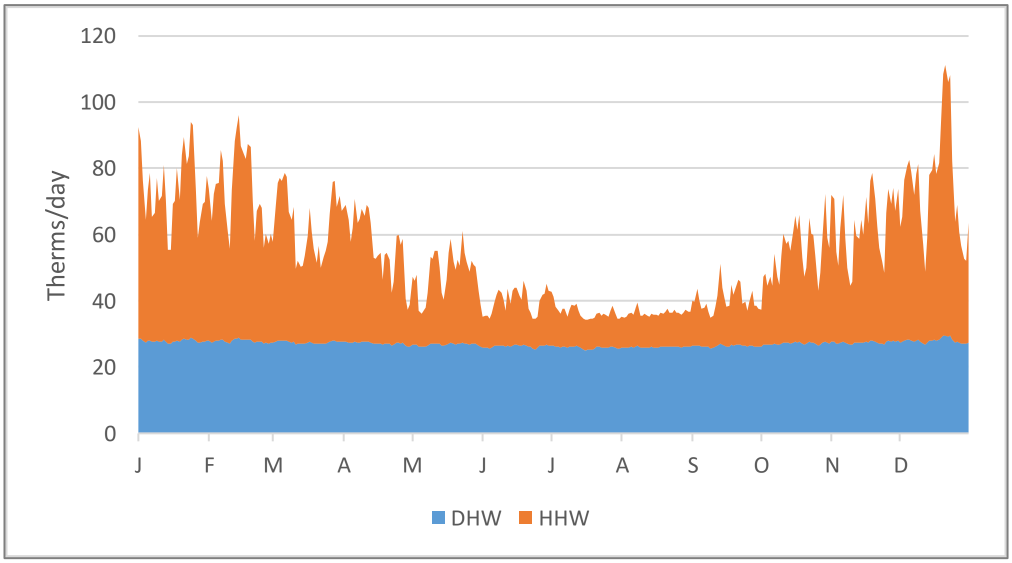
During the performance period (April through May 2017), we measured the glycol flow and heat pump supply and return temperatures to calculate total work done by the unit. Additionally, we measured an intermediate glycol temperature (after HHW heat exchanger and before DHW heat exchanger) to calculate the respective hot water load of the individual HHW and DHW loops. Figure 29 shows the delivered DHW and HHW load over the baseline and performance periods over a range of daily average ambient outside temperatures.

FIGURE 29 - DAILY DELIVERED HOT WATER LOADS



By applying the DHW and HHW regressions shown in Figure 29 to typical meteorological year (TMY3[11]) average daily temperatures, we calculate an annual hot water load profile for the site. Figure 30 below shows the daily load to the facility on a typical weather year.

FIGURE 30 - ANNUAL HOT WATER LOAD PROFILE[12]



Using the annual hot water load profile and the boiler efficiencies calculated during the baseline monitoring period, we calculate an annual gas consumption of 28,759 therms per year for the site. Table 10 summarizes the annual load and gas consumption for a typical year.

TABLE 10 - BASELINE ANNUAL HOT WATER LOAD AND GAS CONSUMPTION

DHW Load (kBtu/year)	HHW Load (kBtu/year)	Total Baseline Load (kBtu/year)	Baseline Gas Consumption (therms/year)	Baseline Energy Cost ($/year)
985,925	1,027,915	2,013,841	28,759	$16,427

---

[11] Typical Meteorological Year 3 (TMY3) is a weather data set of hourly values developed by the National Renewable Energy Laboratory (NREL). The TMY3 data set includes measured data from 1991-2005 and represents a “typical year” of weather data. The Salem McNary Field site was used for this analysis.

[12] The DHW and HHW loads shown in Figure 30 are stacked. The peak load of 111 therms/day shown in in December is the total hot water load (29 therms/day DHW and 82 therms/day HHW), not the HHW load alone.

7.2 Performance Period

We analyzed the baseline and performance periods by measuring energy in and work done by the three boilers and the heat pump. During the performance period the DHW boilers typically only ran on days with average temperatures below 48°F and the HHW boiler only ran during morning warmup on days with average daily temperatures below 50°F. On the colder days, the AHUs, which turn on at 5am, called for more heating HW than the heat pump could deliver alone. Figure 31 shows the operation on April 13th, 2017, a day in which the boiler came on shortly after the 5am AHU warm up period. The HHW supply temperature falls below 125°F at 5:15am and the boiler runs 10 minute cycles a few times before load drops enough to allow the heat pump to cover it in full. When sizing the heat pump closer to the base load, it is expected that the backup boilers will come on to cover peaks. The system was tuned to minimize boiler use, but by design, the boilers continue to operate during times of peak load.

FIGURE 31- HHW BOILER BACKUP ON APRIL 13TH, 2017

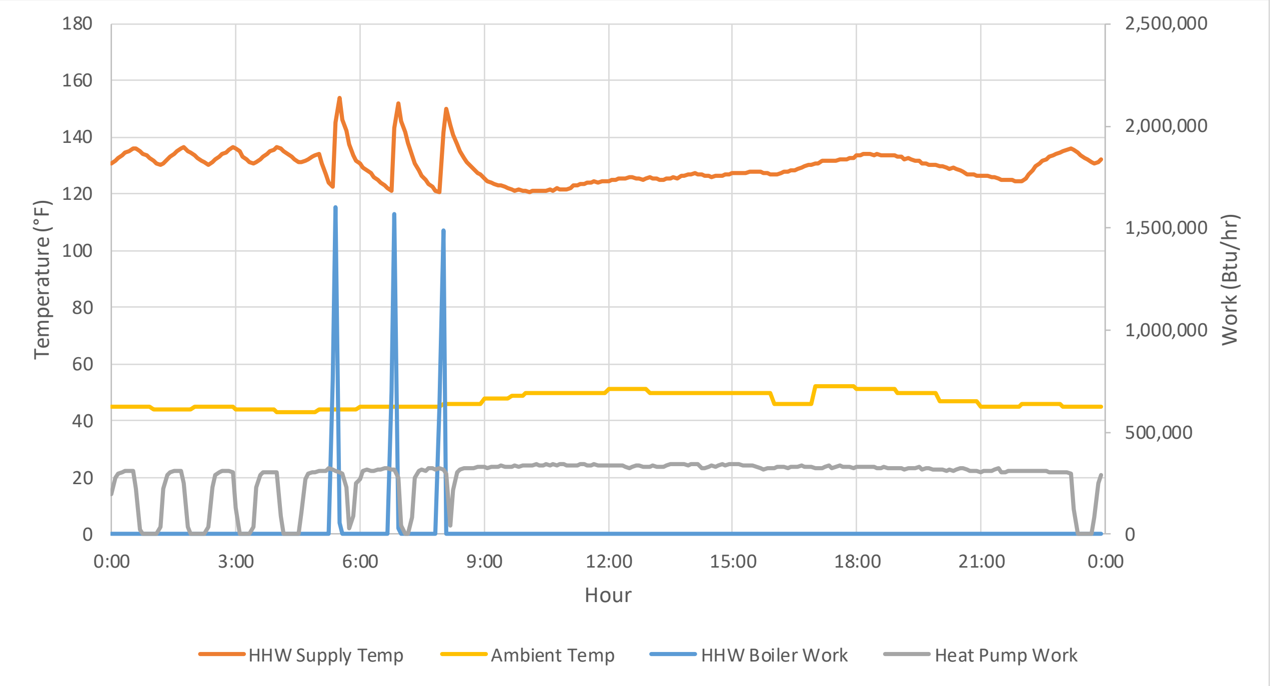
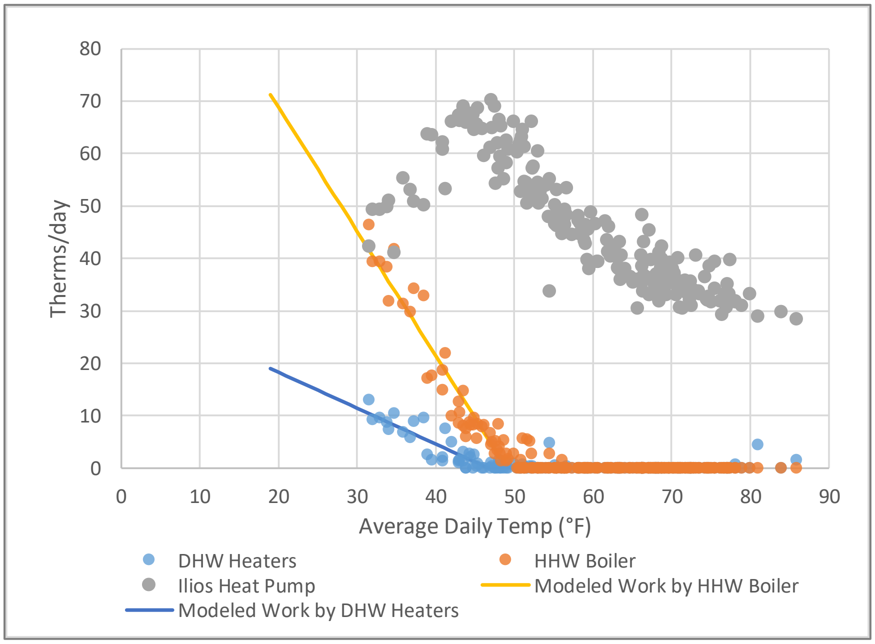


Figure 32 shows the measured and projected work done by each heating source. A linear line of best fit is applied to the HHW load delivered by the HHW boiler and the DHW load delivered by the DHW boilers during the performance period. These lines are used to calculate the proportion of the total loads delivered by the boilers. The remainder is delivered by the Ilios unit. Other than a few outliers, the Ilios handles all of the HHW load when the average ambient temperature is at or above 50°F and all of the DHW load at or above 48°F. At temperatures lower than these cut-in temperatures, the Ilios unit delivers less of the total load for two reasons. First, the instantaneous HHW demand required by the HVAC units increases with colder weather and the available capacity of the heat pump decreases due to a lower temperature heat source and the need for defrost cycles. At high peak demand the heat pump is unable to maintain the hot water temperature setpoint and the boilers must come on.

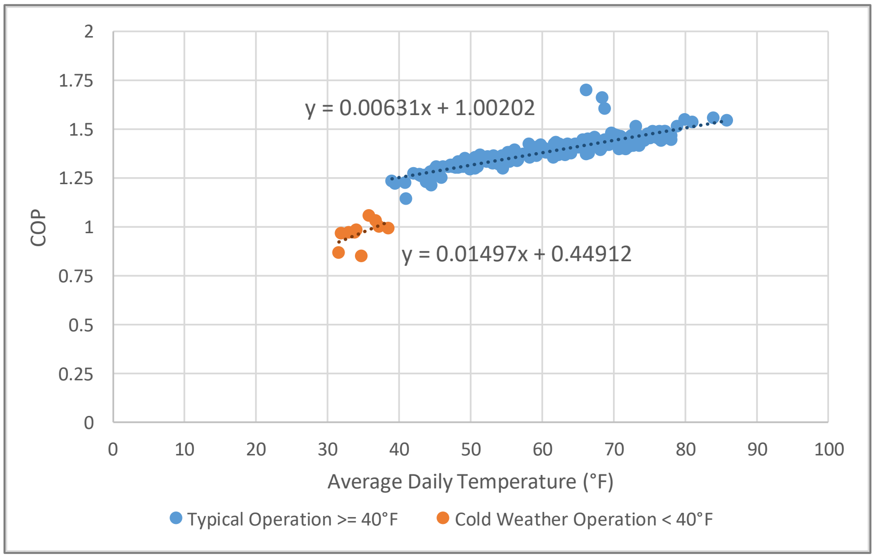
Secondly, at colder temperatures, the total 24 hour DHW and HHW increases and is higher than the heat pump could deliver even with a perfectly smooth load profile. As typical with heat pump technologies, cold weather presents a challenge for the ICE heat pump, but in moderate climates like the NW there are few days with average temperatures well below 40°F and overall the ICE heat pump handled 92% of the total load during the performance period. Figure 32 demonstrates the effective commissioning that allows the heat pump to carry all of the load in moderate to warm weather.

FIGURE 32 - HOT WATER LOAD BY SOURCE



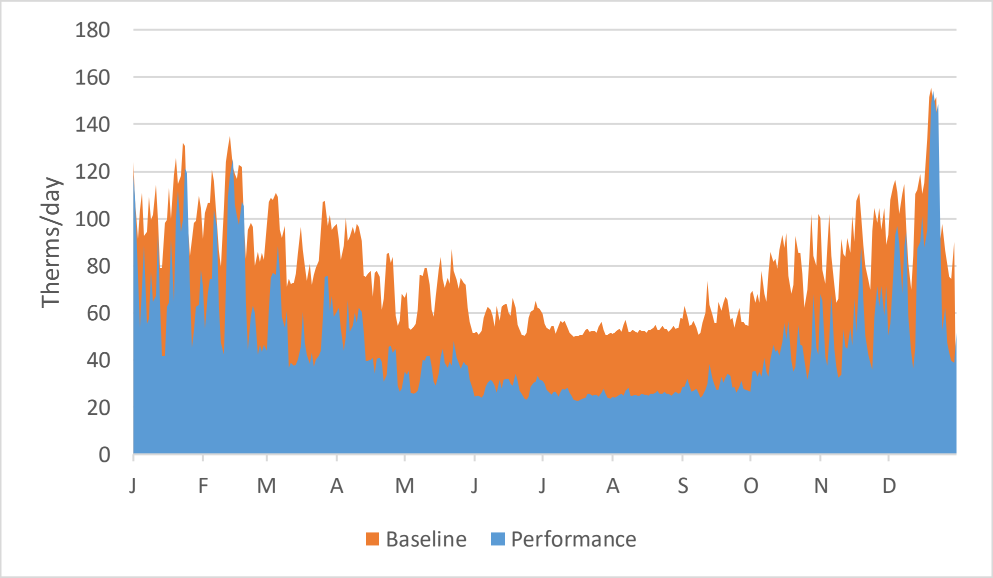
To calculate the annual gas consumption of the heat pump during a typical weather year, we derived two linear relationships between the average COP and daily average ambient temperature. During typical operation, the COP varies linearly with ambient temperature, increasing with warmer weather due to a warmer heat source to draw from. However, there is a sharp drop off below 40°F as the boiler runs more and the heat pump capacity is reduced due to colder air temperatures. Figure 33 shows these two relationships and the drop off in performance on days with an average ambient temperature below 40°F. However, the DHW and HHW boilers were found to have 67% and 73% effective efficiencies during the baseline period, so even in cold weather the ICE heat pump outperforms the baseline system in this case.

FIGURE 33 - DAILY AVERAGE HEAT PUMP PERFORMANCE



By applying the heat pump performance profile and calculated boiler efficiencies from the baseline period to the daily delivered hot water load profiles, we calculate an annual gas consumption of 17,409 therms per year in the performance case. This represents an annual savings of 11,350 therms (39% reduction) relative to the baseline case.

FIGURE 34 – ANNUAL GAS CONSUMPTION



8. Observations

8.1 Starter Failure

On April 3rd, 2017, the engine starter failed. Tecogen recently upgraded to an industrial-duty starter, but this unit shipped with their older style, automotive-grade starter. Upon diagnosis of the problem, Tecogen shipped a new starter that was installed on April 10th. This was a simple fix and is not considered to be a major product deficiency.

8.2 Temperature and Pump Failure

On October 2nd, 2017, the heat pump began displaying a "Hi Coolant Temp" alarm and ceased operation. Tecogen was notified on October 3rd about the issue, and later discovered that the coolant temperature sensor had failed as well as an internal coolant pump. While the repair was simple, scheduling and parts delivery took a month and the heat pump began operation again on November 3rd.

8.3 Maintenance Costs

Tecogen offers a full-service maintenance contract for $1.25 per run-hour, or approximately $8,125 annually according to the expected runtime at Capital Manor. In areas with higher energy prices the value of the annual energy savings significantly outweighs these maintenance costs. However, the Northwest has particularly low gas rates and because of this the ICE heat pump is currently a low volume product for Tecogen and their technicians are in the Midwest and Northeast, where they service significant volume of other products[13]. Due to these factors, the cost of the maintenance contract would exceed the value of the energy savings for a Northwest end-user.

However, Tecogen projects that time and materials (T&M) maintenance costs would be $500 annually, and $10,000 every six years. In order for the energy savings to exceed the maintenance costs a Northwest end-user would need to accept the T&M maintenance risk instead of the full-service maintenance contract.

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[13] Tecogen's large volume product is Combined Heat and Power (CHP) generators, which thrive in areas of high electric prices such as the Northeast. Due to the Northwest's low electric prices, they do very little volume in the region, not enough to cost justify local technicians.

9. Calculations

The following section summarizes the primary calculations used in the analysis.

9.1 Water Heating Load

The metered HHW and DHW data is in 1-minute intervals, and we calculate the water heating load using the following equation. An example calculation of a 1-minute DHW load delivered by the boilers in the baseline period is shown for reference.

$$Heating\ Load\ = HW\ flow\ \left(\frac{gal}{min}\right) \times\ [T_{outlet} - T_{inlet}]^{14}(°F)\ x\ interval\ (min) \times\ \bar{c}_{p,water}{}^{15}\ \times\ \rho_{water}{}^{16}$$

$$Heating\ Load\ = 50\ \frac{gal}{min} \times\ (125°F - 110°F)\ \ \times\ 1\ min\ x\ 0.997 \frac{Btu}{lbs - °F} \times\ 8.26875 \frac{lbs}{gal} = 6{,}183\ Btu$$

10.2 Coefficient of Performance

We collected the Ilios gas and delivered heat data continuously, and then averaged in 5-minute intervals. To calculate performance, we summed the total water heating load delivered and the total energy consumed by the unit over a given monitoring period. The following equation shows the calculation for COP over a 1-day interval:

$$\text{COP} = \frac{\Sigma\ \text{Heat Load Delivered (Btu)}}{\Sigma\ \text{Gas Energy In (Therm)}} \times \frac{\text{Therm}}{10^5\ \text{Btu}}$$

$$\text{COP} = \frac{9{,}240{,}000\ \text{Btu}}{70\ \text{Therms}} \times \frac{\text{Therm}}{10^5\ \text{Btu}} = \ 1.32$$

9.3 Baseline Boiler and Hot Water Heater Efficiencies

To calculate the HHW and DHW boiler efficiencies, we measured the gas flow, water flow, supply water temperature, and return water temperature continuously from December 6th, 2016 through February 19th, 2017. We then averaged the data and recorded it in 1-minute intervals. Using the water heating load calculation from section 6.1, we calculate boiler efficiencies using the following equation:

$$Eff_{Boiler} = \frac{\Sigma\ Work\ Delivered}{\Sigma\ Gas\ Input} = \frac{\Sigma\ Water\ Heating\ Load\ (Btu)}{\Sigma\ Gas\ Flow\ (Ccf)\ \times\ Gas\ Energy\ Content\ \left(\frac{Therms}{Ccf}\right)}$$

$$= \frac{356{,}500{,}000\ Btu\ \times\ \frac{Therm}{10^5 Btu}}{4{,}402.6\ Ccf\ \times\ 1.107\ \left(\frac{Therms}{Ccf}\right)} = 73\%$$

---

[14] $\boldsymbol{T_{outlet}}$ is the HW temperature measured at the outlet of the tank. $\boldsymbol{T_{inlet}}$ is the cold water temperature from the city or well measured at the inlet of the tank.

[15] $\boldsymbol{\bar{c}_{p,water}}$ is the average specific heat of water at 150°F for the glycol loop, 130°F for the HHW loop, and 110°F for the DHW loop.

[16] $\boldsymbol{\rho_{water}}$ is the density of water at 150°F for the glycol loop, 130°F for the HHW loop, and 110°F for the DHW loop.

9.4 Monthly Gas Energy Content

The gas energy content for the analysis is based on the reported NW Natural gas factors to correct for the monthly energy density of the gas as well as the delivered gas pressure (gas use is metered volumetrically, so Btu content per volume varies with pressure). We metered the natural gas flows into the heat pump, DHW boilers, and HHW boiler. The NW Natural meter operates at 2.0 psig gas pressure, while the Ilios, DHW, and HHW boilers operate at 0.32, 0.34, and 0.47 psig respectively. Hence, it was necessary to convert the NW Natural gas factors using the following equations and conversion factors:

$$Pressure\ Factor\ (PF) = \frac{\text{Metering Pressure (psig)} + Atmospheric\ Pressure\ (psia)}{14.73\ psia}$$

To convert from volumetric flow rate to energy input, we use the following gas factors in the analysis:

TABLE 11 - GAS ENERGY CONTENT FACTORS

Month	DHW Energy Content (Btu/cf)	HHW Energy Content (Btu/cf)	Ilios Energy Content (Btu/cf)	Source
December '16	1,068	1,077	--	NWN December Bill
January	1,061	1,070	--	NWN January Bill
February	1,078	1,087	--	NWN February Bill
March	1,106	1,116	--	NWN March Bill
April	1,107	1,117	1,106	NWN April Bill
May	1,103	1,112	1,101	NWN May Bill
June	1,109	1,118	1,108	NWN June Bill
July	1,116	1,126	1,115	NWN July Bill
August	1,097	1,106	1,096	NWN August Bill
September	1,076	1,085	1,075	NWN September Bill
October	1,083	1,092	1,082	NWN October Bill
November	1,083	1,092	1,081	NWN November Bill
December '17	1,068	1,077	1,066	NWN December '16 Bill (not billed yet)

TABLE 12 - NW NATURAL GAS ENERGY CONTENT FACTORS

Month	Energy Content (Therms/ccf)	Source
December '16	1.186	NWN December Bill
January	1.179	NWN January Bill
February	1.197	NWN February Bill
March	1.229	NWN March Bill
April	1.230	NWN April Bill
May	1.225	NWN May Bill
June	1.232	NWN June Bill
July	1.240	NWN July Bill
August	1.219	NWN August Bill
September	1.189	NWN September Bill
October	1.203	NWN October Bill
November	1.203	NWN November Bill
December '17	1.186	NWN December '16 Bill (not billed yet)

10. Conclusion

Field test results have shown significantly improved efficiency of the ICE heat pump above traditional boilers. However, they have also highlighted challenges such as the following:

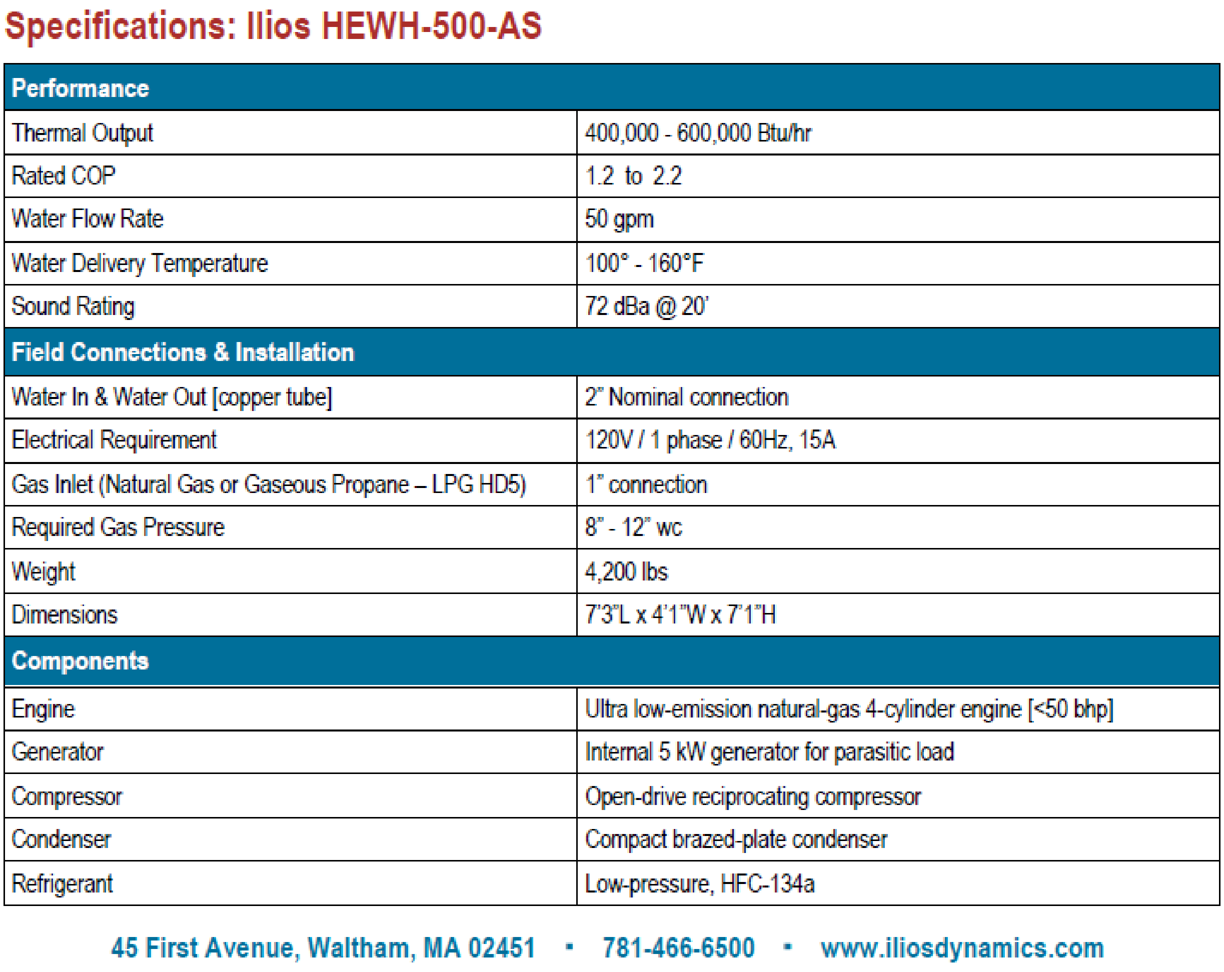
- Maintenance costs associated with an internal combustion engine are higher than that of a boiler. A typical boiler service contract may cost in the range of $400/year for a basic annual service, while the comprehensive service package offered by Tecogen costs $1.25 per run-hour or approximately $8,178 for this field trial.
- Purchase price, installation price, and complexity are significantly higher than that of a boiler.
- Performance (COP and capacity) is meaningfully degraded by higher hot water supply temperatures and lower ambient temperatures. These factors limit the practicality of using this technology for traditional space heating applications that have high loads in cold weather.
- Unit capacity limits DHW applications to facilities with large DHW use such as very large nursing homes and hospitals or hotels with on-site laundry facilities. This limited candidate pool caps the potential consumers of this product and thus, its resource potential. During the search for a candidate site, several large multifamily facilities were evaluated, and their DHW use was found to be too low to base load the heat pump, indicating that multifamily applicability would be limited in the NW region.

In addition to DHW, there are other strong candidates for this technology, including:

- Large public pools such as those found in community centers, based on the following attributes:
    - Fairly flat heating load profile
    - Lower water temperature requirements
    - Potentially reduced installation logistics
- Hotels with pools and on-site laundry facilities, due to their significant DHW use and pool heating requirements.

Overall, the performance and the heat pump's ability to exceed a COP of 1.0 (equivalent to 100% efficiency) are encouraging. However, without reductions in purchase, installation and/or maintenance costs, currently low gas prices and a small number of strong candidate facilities in the NW region may limit its market potential to niche applications such as those listed above.

11. Appendix



Specifications: Ilios HEWH-500-AS

Performance	
Thermal Output	400,000 - 600,000 Btu/hr
Rated COP	1.2 to 2.2
Water Flow Rate	50 gpm
Water Delivery Temperature	100° - 160°F
Sound Rating	72 dBa @ 20'
Field Connections & Installation	
Water In & Water Out [copper tube]	2" Nominal connection
Electrical Requirement	120V / 1 phase / 60Hz, 15A
Gas Inlet (Natural Gas or Gaseous Propane – LPG HD5)	1" connection
Required Gas Pressure	8" - 12" wc
Weight	4,200 lbs
Dimensions	7'3"L x 4'1"W x 7'1"H
Components	
Engine	Ultra low-emission natural-gas 4-cylinder engine [<50 bhp]
Generator	Internal 5 kW generator for parasitic load
Compressor	Open-drive reciprocating compressor
Condenser	Compact brazed-plate condenser
Refrigerant	Low-pressure, HFC-134a

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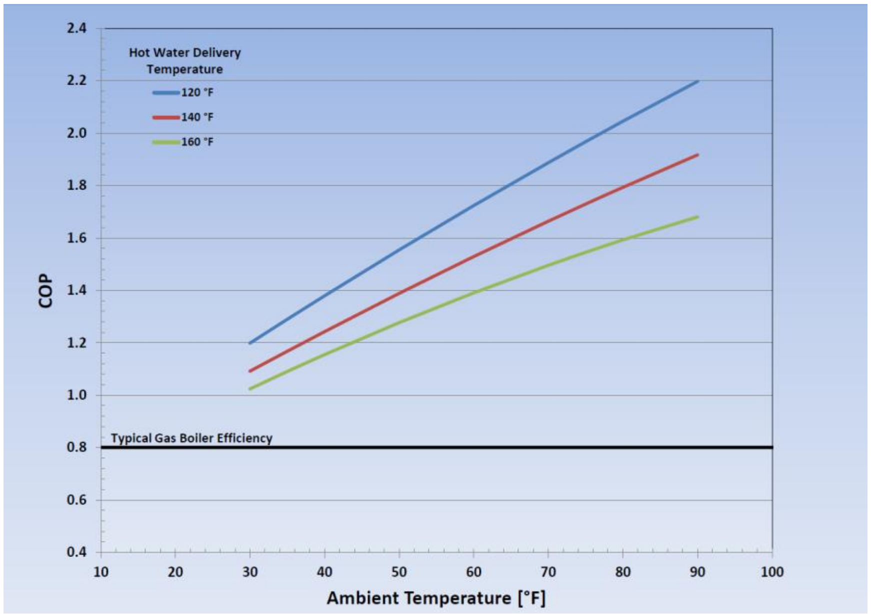
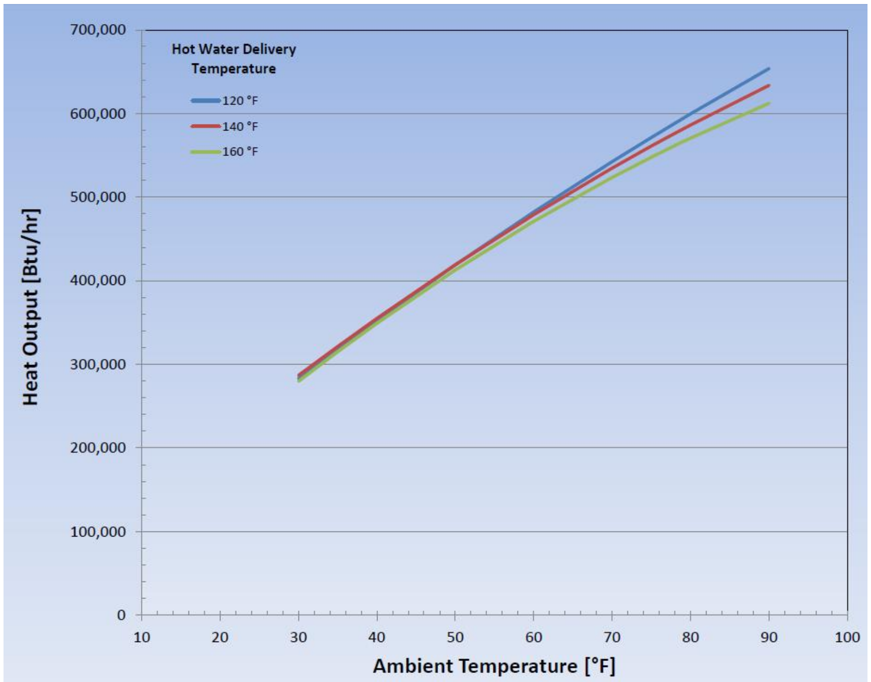
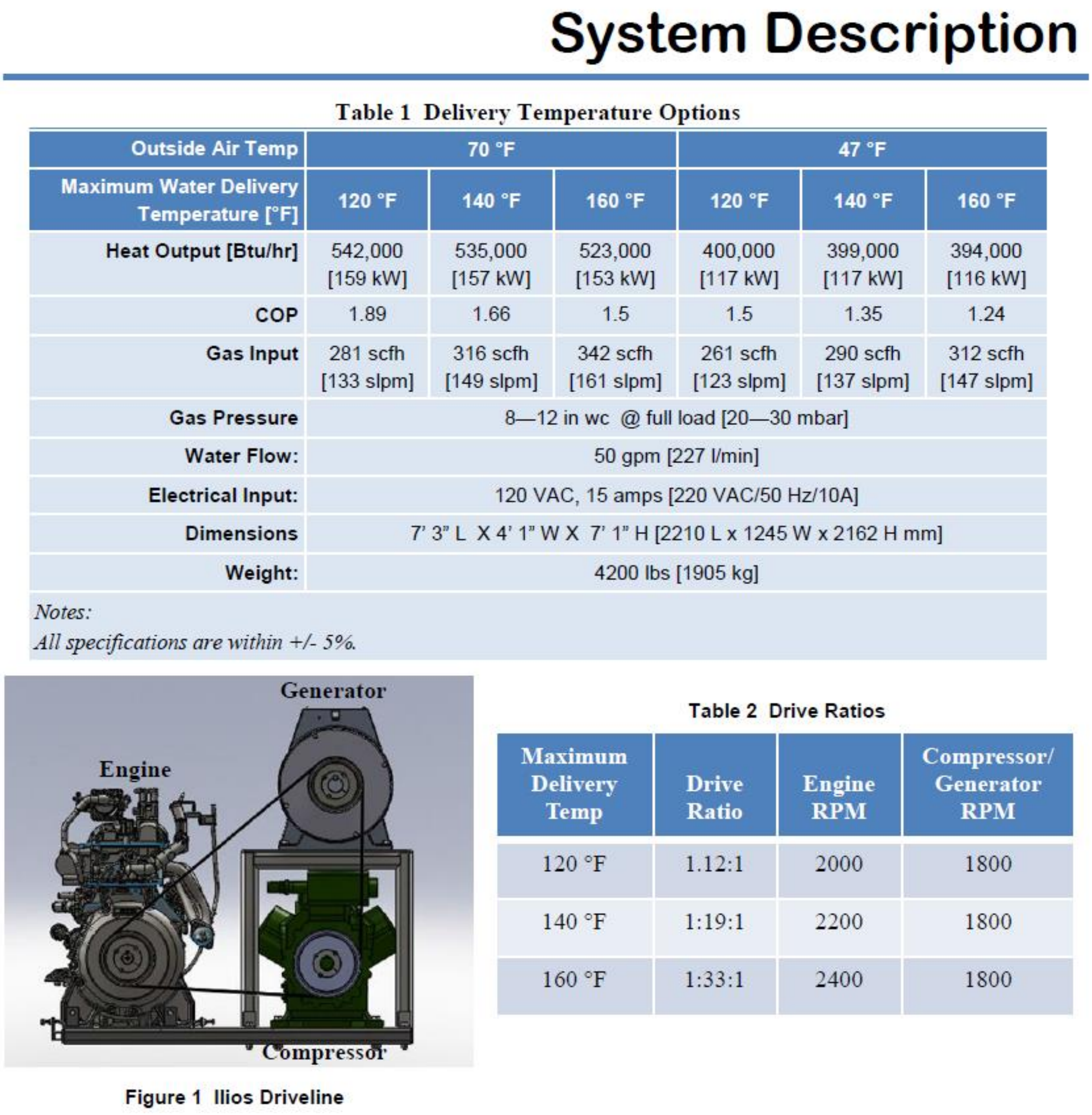
Manufacturer Reported Performance



Manufacturer Reported Heat Output



Note: The curves shown in Figure 26 of the report are adjusted by a factor of 0.83. The heat pump was tuned to run at 83% of full speed to maximize efficiency. This was done by adjusting the gear ratios between the engine and compressor, which results in increased efficiency but de-rated capacity.



System Description

Table 1 Delivery Temperature Options

Outside Air Temp	70 °F			47 °F		
Maximum Water Delivery Temperature [°F]	120 °F	140 °F	160 °F	120 °F	140 °F	160 °F
Heat Output [Btu/hr]	542,000 [159 kW]	535,000 [157 kW]	523,000 [153 kW]	400,000 [117 kW]	399,000 [117 kW]	394,000 [116 kW]
COP	1.89	1.66	1.5	1.5	1.35	1.24
Gas Input	281 scfh [133 slpm]	316 scfh [149 slpm]	342 scfh [161 slpm]	261 scfh [123 slpm]	290 scfh [137 slpm]	312 scfh [147 slpm]
Gas Pressure	8—12 in wc @ full load [20—30 mbar]					
Water Flow:	50 gpm [227 l/min]					
Electrical Input:	120 VAC, 15 amps [220 VAC/50 Hz/10A]					
Dimensions	7' 3" L X 4' 1" W X 7' 1" H [2210 L x 1245 W x 2162 H mm]					
Weight:	4200 lbs [1905 kg]					

Notes:

All specifications are within +/- 5%.

Figure 1 Ilios Driveline

Table 2 Drive Ratios

Maximum Delivery Temp	Drive Ratio	Engine RPM	Compressor/ Generator RPM
120 °F	1.12:1	2000	1800
140 °F	1:19:1	2200	1800
160 °F	1:33:1	2400	1800

Engine Specifications

Model	**2.3 L**	**2.5 L**
Type	Spark Ignition, Gaseous Fueled	
Manufacturer	Ford Power Products	
Fuel	Natural Gas or LPG	
Nominal Rated RPM	2500	2300
BHP at Rated RPM	50	
Aspiration	Natural	
Configuration	Inline 4	
Displacement	2.3 litre (140 CID)	2.5 litre (152.5 CID)
Bore and Stroke (Inches)	3.44" x 3.7"	3.5" x 3.93"
Compression Ratio	9.7 to 1	
Weight	290 lbs	351 lbs
Ignition System	Electronic	
Firing Order	1-3-4-2	
Air/Fuel Mixture (Std)	0.5% Oxygen	
Lubrication System		
- Oil Type	5W-20 Synthetic Blend	
- Oil Tank Capacity	9 gallons (21 gallons w/Extended Service Interval option)	
Cooling System		
- Type	Direct Jacket Cooling, Closed Loop	
- Pressure	Pressure Cap, 15 psi	
- Cooling Fluid	50% Ford Premium Gold Engine Coolant (VC7B), 50% Deionized Water	
- Coolant Capacity	3 gallons	
Starting System		
- Type	12 Volts DC	
- Battery	750 CCA /140 RC	
- Battery Charger		
* Type	Electronic - Constant Voltage Supply	
* Rating	16 Amp DC	

Compressor Specifications

Type	Open Drive, Reciprocating
Weight (lb.)	337
Full Load Drive RPM	1750
Theor. Displacement @ Full Rated RPM (cfh)	4711
# of Cylinders	6
Bore and Stroke (mm)	70 x 55
Crankcase Heater	140 Watts
Refrigerant	HFC-134a
Operating Limits	
- Suction (PSI)	275
- Discharge (PSI)	363
Lubrication System	
- Oil Type	BSE55
- Oil Capacity	5.5 quarts
- Oil Pump Type	Positive displacement, internal
- Oil Cooling	None
- Net Oil Pressure	30—35 psi
Capacity Control	
- Speed Modulation[1]	1500-Max speed
- Cylinder unloading	2 steps, 2 cylinders per step
- Approximate Minimum Capacity	25%

[1] *Maximum Speed is based upon drive ratio. See Table 2.*

Generator Specifications

Type	4-pole, AC, brushless
Weight (lb.)	160
Full Load Drive RPM	1800
Power at Rated RPM	5 kW
Voltage/Frequency at Rated RPM	208 VAC/60 Hz

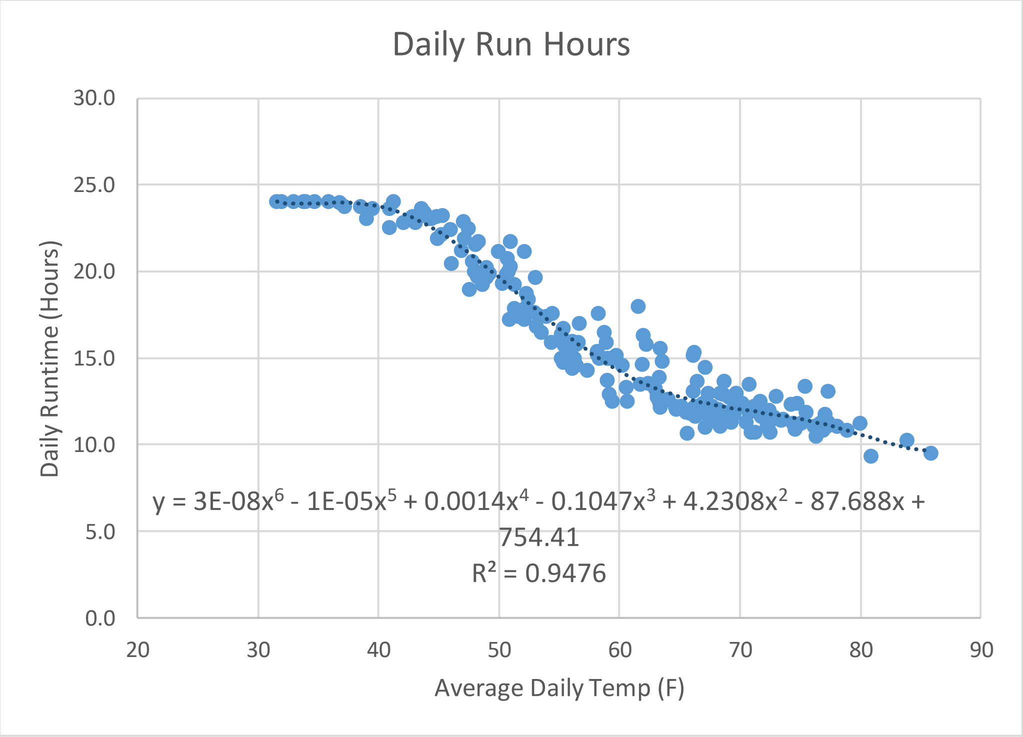
Condenser Specifications

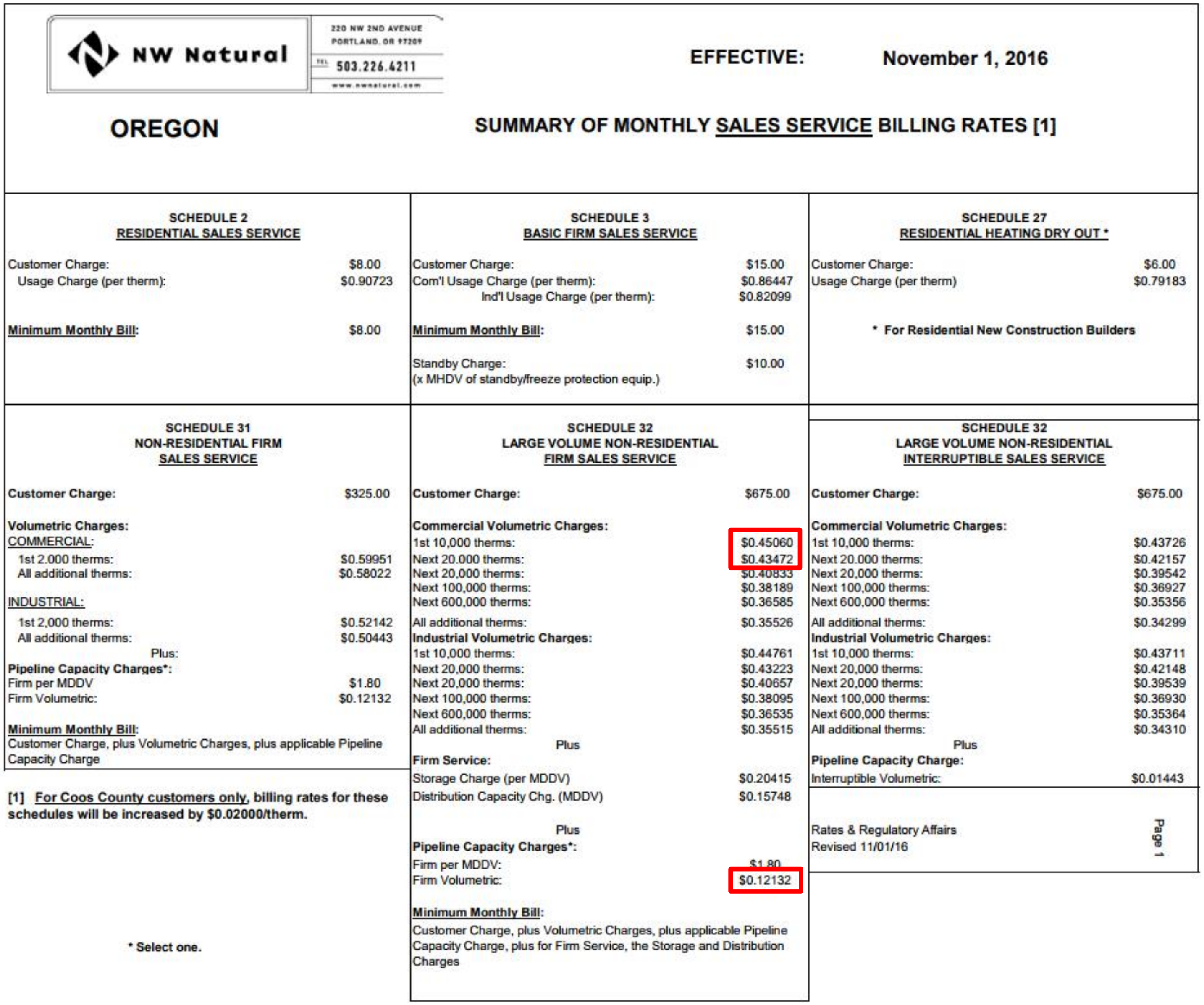
Type	Brazed Plate
Weight (lb.)	219
Refrigerant	HFC-134a
Maximum Pressure (psi)	392
Plate Material	316L
Plate Thickness (in.)	0.0138
No. of Circuits	1

Evaporator Coil Specifications

Type	Air-Cooled, Vertical
Refrigerant	HFC-134a
Maximum Pressure (psi)	380
Tube Material	Copper
Fin Material	Aluminum

Annual run hours were calculated to estimate the comprehensive maintenance package cost which is based on run-hours. The relationship between daily run hours and average daily temperature during the performance period was developed. By applying the equation shown in figure below to average daily temperatures of TMY3 data, the Ilios heat pump is calculated to typically run on average 6,543 hours per year.





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EFFECTIVE: November 1, 2016

OREGON

SUMMARY OF MONTHLY SALES SERVICE BILLING RATES [1]

SCHEDULE 2
RESIDENTIAL SALES SERVICE

Customer Charge:	$8.00
Usage Charge (per therm):	$0.90723
Minimum Monthly Bill:	$8.00

SCHEDULE 3
BASIC FIRM SALES SERVICE

Customer Charge:	$15.00
Com'l Usage Charge (per therm):	$0.86447
Ind'l Usage Charge (per therm):	$0.82099
Minimum Monthly Bill:	$15.00
Standby Charge: (x MHDV of standby/freeze protection equip.)	$10.00

SCHEDULE 27
RESIDENTIAL HEATING DRY OUT *

Customer Charge:	$6.00
Usage Charge (per therm)	$0.79183

* For Residential New Construction Builders

SCHEDULE 31
NON-RESIDENTIAL FIRM SALES SERVICE

Customer Charge:	$325.00
Volumetric Charges:	
COMMERCIAL:	
1st 2.000 therms:	$0.59951
All additional therms:	$0.58022
INDUSTRIAL:	
1st 2,000 therms:	$0.52142
All additional therms:	$0.50443
Plus:	
Pipeline Capacity Charges*:	
Firm per MDDV	$1.80
Firm Volumetric:	$0.12132

Minimum Monthly Bill:
Customer Charge, plus Volumetric Charges, plus applicable Pipeline Capacity Charge

SCHEDULE 32
LARGE VOLUME NON-RESIDENTIAL FIRM SALES SERVICE

Customer Charge:	$675.00
Commercial Volumetric Charges:	
1st 10,000 therms:	$0.45060
Next 20.000 therms:	$0.43472
Next 20,000 therms:	$0.40833
Next 100,000 therms:	$0.38189
Next 600,000 therms:	$0.36585
All additional therms:	$0.35526
Industrial Volumetric Charges:	
1st 10,000 therms:	$0.44761
Next 20,000 therms:	$0.43223
Next 20,000 therms:	$0.40657
Next 100,000 therms:	$0.38095
Next 600,000 therms:	$0.36535
All additional therms:	$0.35515
Plus	
Firm Service:	
Storage Charge (per MDDV)	$0.20415
Distribution Capacity Chg. (MDDV)	$0.15748
Plus	
Pipeline Capacity Charges*:	
Firm per MDDV:	$1.80
Firm Volumetric:	$0.12132

Minimum Monthly Bill:
Customer Charge, plus Volumetric Charges, plus applicable Pipeline Capacity Charge, plus for Firm Service, the Storage and Distribution Charges

SCHEDULE 32
LARGE VOLUME NON-RESIDENTIAL INTERRUPTIBLE SALES SERVICE

Customer Charge:	$675.00
Commercial Volumetric Charges:	
1st 10,000 therms:	$0.43726
Next 20.000 therms:	$0.42157
Next 20,000 therms:	$0.39542
Next 100,000 therms:	$0.36927
Next 600,000 therms:	$0.35356
All additional therms:	$0.34299
Industrial Volumetric Charges:	
1st 10,000 therms:	$0.43711
Next 20,000 therms:	$0.42148
Next 20,000 therms:	$0.39539
Next 100,000 therms:	$0.36930
Next 600,000 therms:	$0.35364
All additional therms:	$0.34310
Plus	
Pipeline Capacity Charge:	
Interruptible Volumetric:	$0.01443

[1] **For Coos County customers only, billing rates for these schedules will be increased by $0.02000/therm.**

* Select one.

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The customer's gas bill have historically been over 10,000 therms per month in winter months and under 10,000 therms per month during summer month. Based on the preliminary findings the customer will see approximately 75% of the annual savings during the winter months. By weighting the winter gas savings by 75% and the summer savings by 25%, the incremental gas savings rate is calculated as follows:

$$\boldsymbol{Incremental\ Gas\ Rate} = (\$\mathbf{0.12132} + \mathbf{25\%} \times \$\mathbf{0.4506} + \mathbf{75\%} \times \$\mathbf{0.43472}) \times \mathbf{2\%}\ \boldsymbol{Salem\ Tax}$$

$$= \$\mathbf{0.5712}\ \boldsymbol{per\ therm}$$

Charge	Rate	Unit	Weight
< 10,000 Block	$0.45060	/therm	25%
>10,000 Block	$0.43472	/therm	75%
Volumetric	$0.12132	/therm	
Salem Tax	2%		
Total	**$0.5712**	**/therm**	

NW Power Council's 20-Year Gas Price Forecast for the Norwest (west) Region

Year	Medium ($/mmBtu)	Low ($/mmBtu)	High ($/mmBtu)
2015	2.83	2.83	2.83
2016	3.05	2.62	3.48
2017	3.28	2.67	3.81
2018	3.50	2.59	4.39
2019	3.73	2.55	4.85
2020	3.95	2.55	5.21
2021	4.04	2.54	5.37
2022	4.13	2.67	5.66
2023	4.22	2.60	6.07
2024	4.31	2.56	6.36
2025	4.45	2.57	6.61
2026	4.60	2.63	7.00
2027	4.74	2.72	7.11
2028	4.88	2.77	7.43
2029	5.03	2.82	7.76
2030	5.17	2.87	8.10
2031	5.36	2.92	8.47
2032	5.55	3.01	8.87
2033	5.73	3.09	9.27
2034	5.92	3.18	9.62
2035	6.10	3.26	10.04

Retail Gas Price adjusted to Annual Forecast for Cash Flow Summary

Base Scenario ($/Therm)	Low Scenario ($/Therm)	High Scenario ($/Therm)
-	-	-
-	-	-
$0.553	$0.553	$0.553
$0.591	$0.537	$0.638
$0.629	$0.529	$0.705
$0.667	$0.529	$0.758
$0.682	$0.527	$0.780
$0.697	$0.553	$0.822
$0.712	$0.538	$0.881
$0.727	$0.530	$0.924
$0.751	$0.532	$0.961
$0.776	$0.544	$1.017
$0.800	$0.563	$1.034
$0.825	$0.574	$1.080
$0.849	$0.585	$1.128
$0.873	$0.595	$1.177
$0.905	$0.605	$1.230
$0.936	$0.623	$1.288
$0.967	$0.640	$1.348
$0.999	$0.658	$1.398
$1.030	$0.676	$1.459

Source: Natural Gas Price Forecast (XLSX), www.nwcouncil.org/energy/powerplan/7/technical , accessed 5/17/2017.