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Robur Heat Pump Field Trial

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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 testing to demonstrate performance and identify potential barriers to market adoption. NEEA has identified natural gas absorption heat pump (GAHP) water heaters as a candidate for testing in the field. This technology uses natural gas combustion to drive an absorption heat pump cycle.

The primary advantage of this technology is its ability to service loads for both domestic hot water (DHW) and heating hot water (HHW) at higher efficiencies than conventional gas boilers. By using free heat from outside air through the heat pump cycle, the Coefficient of Performance (COP_{gas}) of GAPHs can exceed 1.0.

While GAHPs are typically less efficient than electric air-to-water heat pumps, which often have an annual COP above 2.0 in Northwest climates, GAHPs provide several unique advantages over their electric counterparts:

- GAHPs can deliver hot water at a lower cost, depending on the local gas and electric utility rates[1].
- Being that much of the Northwest grid relies on gas power plants to meet peak loads, use of GAHPs instead of air-to-water electric heat pumps could also result in lower source emissions.
- GAHPs typically use an ammonia-water solution as the refrigerant, which has a global warming potential (GWP) of zero[2]. By contrast, electric heat pumps commonly use HFC refrigerants with GWPs greater than 1,000.

This report summarizes key learnings and performance results from the installation, operation and testing of a GAHP product in the field. Data was collected over two months from the existing system and over ten months (between February and November 2019) from the GAHP system.

FIGURE 1 - GAHP-A

Source: Roburcorp.com

Heat Pump Technical Overview

The installed system featured two Robur model GAHP-A air-source gas absorption heat pumps (GAHP-A), pictured in Figure 1. The GAHP-As are modular, meaning additional GAHP-A units can be connected until the desired capacity is achieved. Each unit has a rated capacity of 123,500 Btu/hr, thus a total system capacity of 247,000 Btu/hr was installed. When multiple GAHP-A units are used, the units operate in parallel, and a Robur DDC package that controls and sequences

[1] Assuming a GAHP COP_{gas} of 1.06, gas rate of $0.57/therm, air-to-water heat pump COP of 2.25 and an electricity rate of $.08/kWh, the GAHP would deliver 100,000 Btu of hot water energy at $0.59 while the electric heat pump would deliver 100,000 Btu for $1.04.

[2] Lithium bromide absorption chillers are also common which use water as the refrigerant and lithium bromide as the absorber. Like ammonia, lithium bromide also has a GWP of zero.

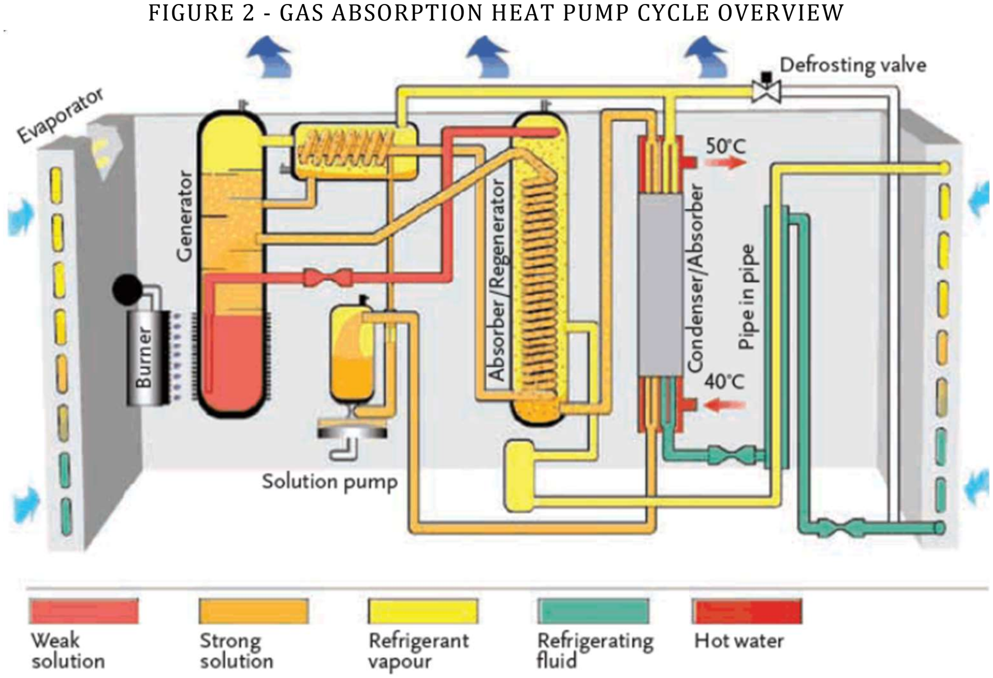
multiple GAHP-A units was implemented in this study. Table 1 outlines the manufacturer ratings, and all ratings are per unit.

TABLE 1 - MANUFACTURER RATINGS

Heating Capacity	123,500	Btu/hr
Gas Input	95,500	Btu/hr
Minimum Operating Temperature	-20	°F
Maximum Operating Temperature	113	°F
Maximum Outlet Temperature	140	°F
Maximum Inlet Temperature	122	°F
Weight	770	lbs

The GAHP-A units utilize a non-reversible gas absorption heat pump cycle, illustrated in Figure 2[3]. The GAHP-A gas absorption cycle is driven by gas combustion that uses an ammonia-water solution as the refrigerant. Similar to electric air-source heat pump water heater technology, GAHP-A units extract heat from the ambient air through an evaporator and deliver heat to provide hot water with a condenser. The primary difference between the gas absorption cycle and the vapor compression cycle used by electric heat pumps is that instead of an electrically driven compressor, GAHPs use a burner with a generator and absorber/regenerator to drive the flow of refrigerant. The Robur GAHP-A units have no turndown capability (they are either on or off) but can be staged when multiple units are installed to provide some variable heating output capability.

FIGURE 2 - GAS ABSORPTION HEAT PUMP CYCLE OVERVIEW



Source: Robur; roburcorp.com/technical_dossiers/heat_pumps_absorption_technology

[3] GAHP-AR

Summary of Results

Table 2 summarizes some key results from the testing of two GAHP-A water heaters in this field study.

TABLE 2 - SUMMARY OF RESULTS

Robur GAHP-A Annual COP_{gas} (2-unit configuration)	1.06	
Robur GAHP-A @ 30°F Ambient (2-unit configuration)	245,080	Btu/hr
Robur GAHP-A Capacity @ 60°F Ambient (2-unit configuration)	281,820	Btu/hr
Total Installed Cost	$46,710	
Annual Natural Gas Savings	5,134	Therms
Annual Avoided cost of Natural Gas	$2,933	$/year
Percent Reduction in Natural Gas Consumption	18	%

1. Introduction

1.1 Site Overview

Capital Manor Retirement Community in Salem, OR was selected as the location for the field testing of the GAHP-A units for several reasons. The site's management was open to improvements and had participated in a previous field study, where a different emerging heat pump unit was no longer functional. This provided in interesting opportunity for research as a secondary water/glycol loop with two heat exchangers made it straightforward to test the GAHP-A units in a combination DHW-HHW application.

Capital Manor is comprised of the Manor Care building and Main Tower building, each of which has separate mechanical systems. For this demonstration, the Main Tower building was selected, which is a 10-story, 185,000 square foot building (see Figure 3). 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 a combination of small common areas and over 200 individual tenant apartments.

FIGURE 3 - CAPITAL MANOR MAIN TOWER

1.2 Existing System

Prior to installation of the GAHP-A units, the existing system consisted of one 1,900 kBtu/hr HHW boiler and two 600 kBtu/hr DHW water heaters. The larger boiler served five air handling units (AHUs) that provided space heating to the common spaces of the Main Tower. The two DHW water heaters provided hot water to the 200 apartment units, as well as to the common bathrooms. Two parallel pumps (one redundant) served the DHW loop and a 5,000-gallon storage tank, which was located in the basement of the facility and stored hot water at 135-140°F. Two parallel pumps (one redundant) also served the HHW loop, which had a setpoint of 160°F.

Table 3 summarizes the equipment for the existing system, Figure 4 and Figure 5 show the DHW water heaters and HHW boilers, respectively, and Figure 6 through Figure 8 show the remainder of the system equipment.

TABLE 3 - EXISTING EQUIPMENT SCHEDULE

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

FIGURE 4 - TWO 600 KBTU/HR DHW HEATERS

FIGURE 5 - 1,900 KBTU/HR HHW BOILER

FIGURE 6 - TWO HHW PUMPS

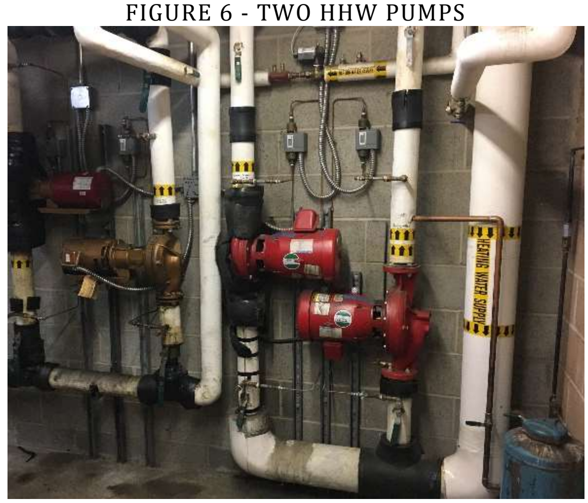


FIGURE 7 - TWO DHW PUMPS

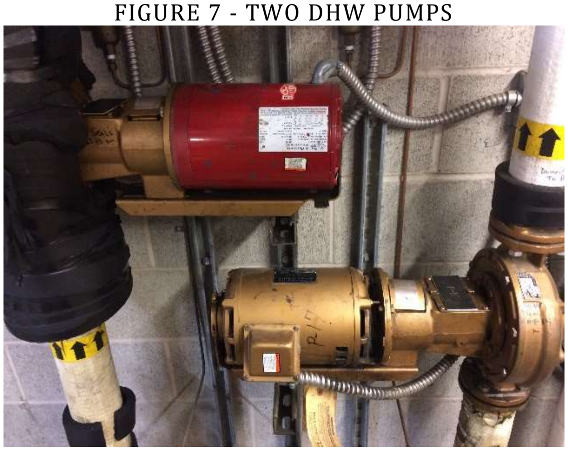
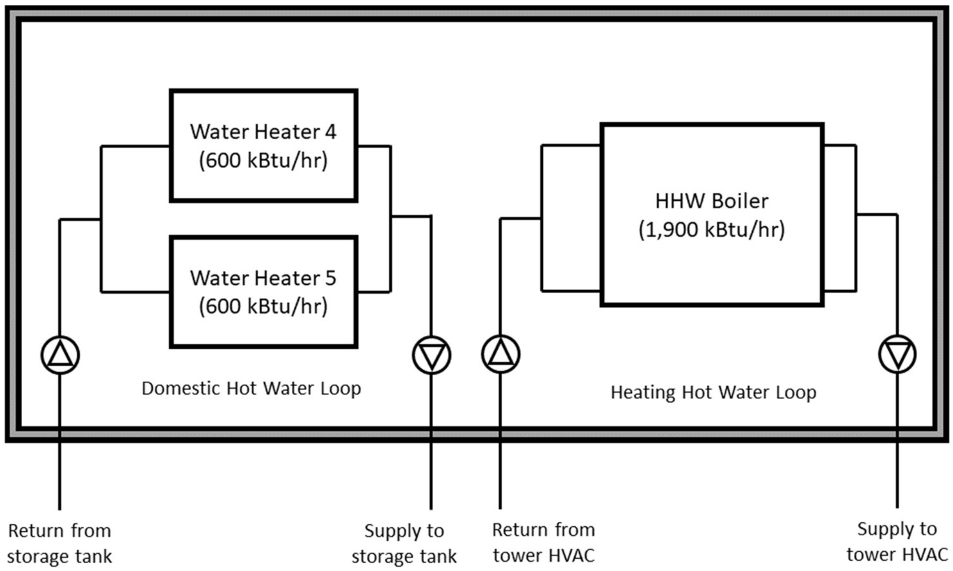


FIGURE 8 - PRE-INSTALLATION BOILER ROOM

Figure 9 shows a simplified configuration of the existing system, excluding the secondary loop and heat exchangers that remained in place after the conclusion of the previous field study. Refer to Figure 23 to see the layout of the secondary loop in relation to the DHW and HHW loops.

FIGURE 9 - EXISTING SYSTEM CONFIGURATION



1.3 Secondary Loop and Heat Exchangers

While reusing the ancillary water/glycol loop from the previous field trial added some complexity to the installation and controls integration, it ensured the GAHP-A units would be able to offset more of the DHW load from the water heaters throughout the year and thus increase the annual utilization of the GAHP-A units. One of the primary challenges the heat exchangers presented was an approach temperature (difference between water/glycol temperature output of GAHP-A units and the DHW and HHW loop temperatures). The approach temperatures of these heat exchangers in practice are about 10°F at the typical operating conditions. Given the design constraints of the system, this is a very low temperature range in which to operate. Figure 10 and Figure 11 show the two heat exchangers that were in place from the previous field study.

FIGURE 10 - DHW DOUBLE-WALL HX

FIGURE 11 - HHW SINGLE-WALL HX

2. Phase 1 – Lowering Return Temperatures

The GAHP-A units have temperature requirements that required careful consideration when balancing those needs with site needs. Before installing the GAHP-A units, it was important to ensure that their design constraints did not curtail the delivery of heating and domestic hot water to the building. This section describes the challenges and steps taken to modify the existing system so that the GAHP-A units could be installed. The pre-installation preparation is referred to as Phase 1.

2.1 GAHP-A units Provide a Limited Maximum Supply Temperature

The maximum water/glycol temperature at the outlet of the Robur GAHP-A units is 140˚F. Due to the lack of modulation control, in practice this outlet temperature varies between 130˚F and 140˚F. Given the heat exchanger characteristics, this range of GAHP-A outlet temperatures results in a maximum DHW and HHW delivery temperature from the heat exchangers of only 120˚F to 130˚F.

Capital Manor's existing system maintains a DHW tank temperature of 140˚F to prevent Legionnaires' disease and used a 160˚F set point for the HHW loop. It was determined that the 160˚F set point was excessive and could be reduced to 105˚F and still meet delivery temperature needs, however the DHW had to be maintained at 140˚F.

With the existing DHW and HHW system capacity being roughly three times that of two GAHP-A units, the new system was never intended to fully displace the boilers. Rather, it was estimated that the two new units could provide the baseload heating requirement of the two loops, and the existing boiler and water heaters would satisfy the peak loads. However, if the DHW and HHW temperature setpoints were above the maximum output of the GAHP-A units, the higher efficiency heat pumps would offset significantly less load from the low efficiency boiler and water heaters.

2.2 GAHP-A units Require Inlet Temperature Control

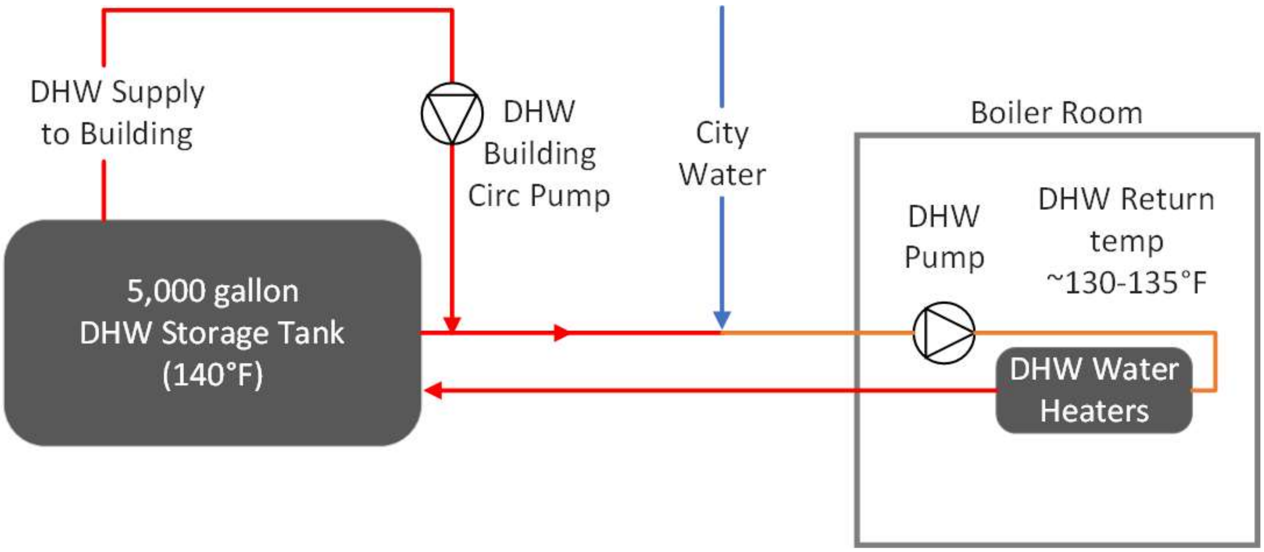
The water/glycol temperature at the inlet of the Robur GAHP-A units must not exceed 122˚F, or else the units will cycle off to prevent high pressure in the refrigerant cycle. Given the approach temperature of the heat exchangers, the return temperature of DHW and HHW from the building must therefore not exceed 110˚F, if the GAHP-A units are to provide heat to the loops. The existing system, however, had return temperatures from both DHW and HHW loops that were significantly above 120˚F most of the time. To reduce and control the inlet temperatures to the GAHP-A units the following mitigation strategy was employed.

2.3 Water Temperature Mitigation

2.3.1 DHW Return Temperature Reduction

Figure 12 shows the existing DHW distribution configuration before modifications. There are two loops, one is the circulation loop through the building, and the other pulls a mixture of tank water, DHW return and city make-up water through the water heaters and back to the tank.

FIGURE 12 - SIMPLIFIED EXISTING DHW SYSTEM CONFIGURATION



As is typical in circulation loops, both pumps were constant speed and over-circulated water. The volume of city water is independent of pumping and is equal to the volume of hot water used within the building. Therefore, the ratio of cold city water to heated return water, and therefore, the resulting water inlet temperature to the water heaters, is dependent on pumping flows. As circulation pumps are slowed, and the volume of city water remains fixed, the ratio of the volume of heated water to that of cold water reduces. This results in a reduced water inlet temperature to the water heaters.

To control the circulation of the return water the following equipment was installed:

- Variable Frequency Drives (VFDs) added to DHW Pump – This allowed flow control of the DHW return loop and helped reduce the water inlet temperature to the water heaters during most hours. However, at night there was almost no DHW use, thus almost no cold city make-up water. So, at night, the inlet temperature to the water heaters tended to increase above the limit of the GAHP-A units. During this time of night, the GAHP-A units would simply be turned off on a schedule, and the existing water heaters would manage the load.

- Variable Speed Pump replaced DHW Building Circulation Pump – To minimize excess circulation of the building loop, the oversized and constant speed pump was replaced with a variable speed pump. The variable speed pump came packaged with an electronically commutated (EC) motor, integrated sensors and control options, and is shown in Figure 13. EC motors are more efficient than AC motors, particularly at fractional HP sizes. Additionally, the smart sensors and controls allowed the implementation of a control strategy without the need for an external control system. This strategy was successful in contributing to reduced water heater inlet temperature, by significantly reducing flow through the building loop, while maintaining instant availability of hot water at delivery points.

FIGURE 13 - EC "SMART PUMP"

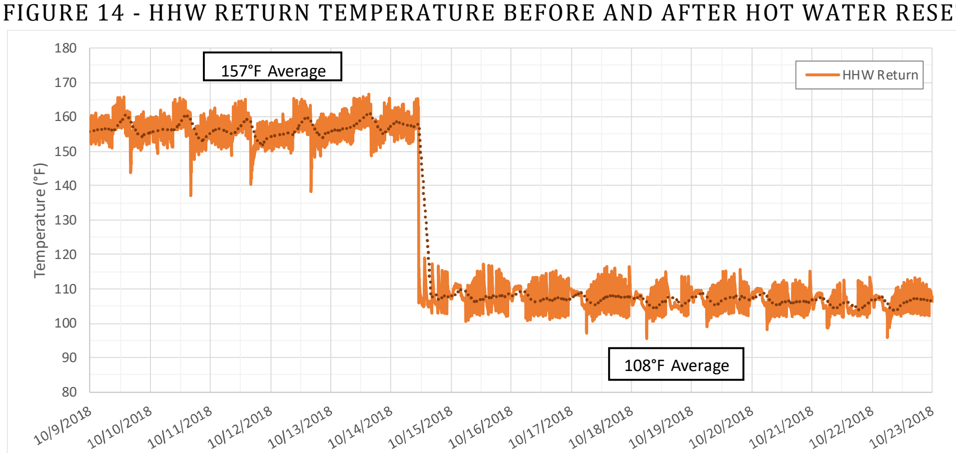
2.3.2 HHW Supply and Return Temperature Reductions

The existing HHW boiler control setpoint (160°F) exceeded the supply capability of the GAHP-A units and worked against the reduction of circulation return temperatures to the boiler. Without correction it would be impossible to use the GAHP-A units for the HHW loop. This issue was solved by implementing a hot water temperature reset on the HHW temperature setpoint. Through this reset, it was possible to keep the HHW in the range of allowable supply and return temperature for all hours of the day throughout the year.

2.4 Results of Water Temperature Mitigation Modifications

Figure 14 and Figure 15 show the results of the DHW and HHW return temperature reduction strategies that were implemented as a part of Phase 1 in the Fall of 2018 before the GAHP-A units could be installed.

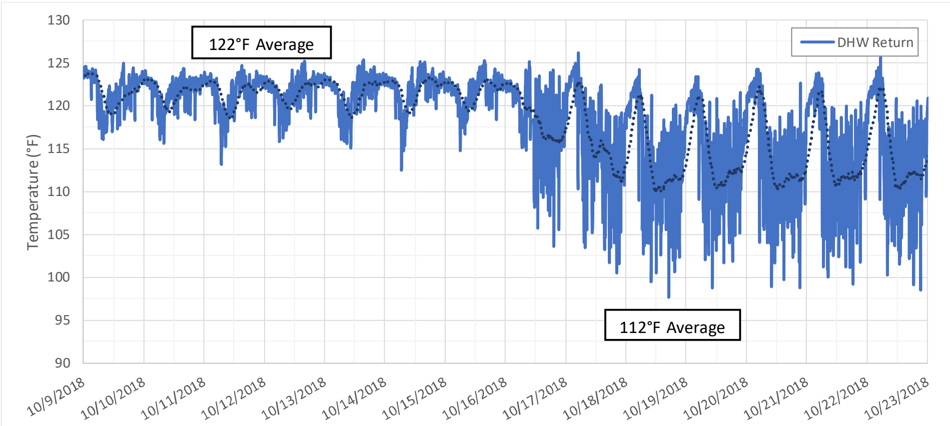
FIGURE 14 - HHW RETURN TEMPERATURE BEFORE AND AFTER HOT WATER RESET



The addition of VFDs on the DHW water heater pumps and an EC smart pump on the building circulation loop resulted in a 10°F reduction in average DHW return temperature, and the average HHW loop temperature was reduced by nearly 50°F. The DHW and HHW return temperature reductions in Phase 1 enabled the GAHP-A units with supply temperatures between 120-140°F to transfer heat to both loops most of the time.

However, at night when there was minimal DHW load, the proportion of return water volume that was recirculated from the storage tank was nearly 100%, thus the return loop temperature would rise, and the GAHP-A units would cycle off. The shift in temperatures is clear in Figure 15, where the peaks remain near 125°F, but the average dropped from 122°F to 112°F. Additionally, during the night time hours, the HHW load is typically low due to night temperature setbacks, thus the GAHP-A units are not be able to effectively transfer heat when these conditions exist and are cycled off.

FIGURE 15 - DHW RETURN TEMPERATURE BEFORE AND AFTER PUMP SPEED CONTROL ADJUSTMENTS



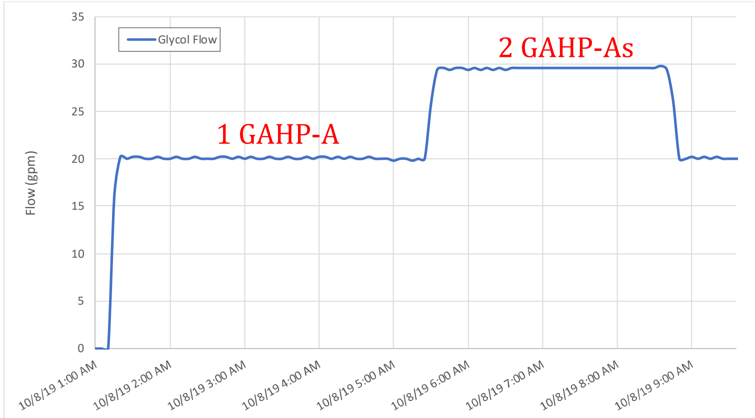
3. Phase 2 - Robur Installation

After system modifications of Phase 1 were put in place and functional, two Robur GAHP-A heat pumps were installed on December 26, 2018. Additional plumbing and controls work was completed over the last two weeks in January 2019, and the system was commissioned on February 15, 2019. This new "Performance System" consisted of the Phase 1 modifications, the new Robur GAHP-A units with DDC control, the existing boiler/water heaters used for peak loads, and the DHW storage tank.

The GAHP-A units are largely self-contained, making for a straightforward installation. They require an external pump to circulate water/glycol to the heat exchangers and have a defined acceptable flow range. It was possible to install a single pump for the two units. To accommodate the variable flow requirements, which was dependent on whether one or both units were operating, a variable speed "smart pump" was installed.

Actuating isolation valves were also installed at each GAHP-A unit. When a unit shuts off, flow is continued for a cool down period, after which time the isolation valve closes. The smart pump has an on-board differential pressure sensor. When an isolation valve closes, the differential pressure at the pump increases. The pump responds by gradually slowing down, which allows appropriate flow to be supplied with a single pump, regardless of how many units are running. Figure 16 shows the water/glycol flow changing, as the smart pump increases speed, as one and then two GAHP-A units come online.

FIGURE 16 - SMART PUMP VARIABLE FLOW



There was one minor logistical challenge in the installation. In the northwest region of the United States, building codes typically require that larger equipment receive a structural engineering stamp of approval and is seismically secured. Typically, this means that the equipment would have to be bolted in place with seismic bolts. The GAHP-A units come on rails that do not allow enough room for an easy installation of seismic bolts (see Figure 17). There were two primary challenges in bolting the modules. The first was that the rail height is 3.75 inches, which is less than a typical 4-inch seismic bolt. The second was that typically to seismically secure equipment, the equipment would be set on the pad, while the installer drills into the pad and then installs the bolts through the drilled holes. In this case, there was no access from above to allow for drilling holes for the bolts.

Both challenges were overcome by pre-drilling the holes in the pad, installing the seismic bolts, then setting the modules on the bolts using a crane. This required a high level of precision and added risk and complexity to the installation. For ease of seismic installations in the future, it is recommended to include anchor points on the sides of the modules with access from above to allow installers to first set the modules, and then drill and bolt them with free access from above. Figure 18 shows one of the two plate and frame heat exchangers installed that allowed free access from above to drill and mount seismic anchors. Figure 19 through Figure 22 show other installation photos from Phase 2.

FIGURE 17 - ROBUR SEISMIC BOLTING

FIGURE 18 - HEAT EXCHANGER SEISMIC BOLTS

FIGURE 19 - HEAT PUMP CRANE LIFT

FIGURE 20 - STORAGE TANK & EC CIRC PUMP

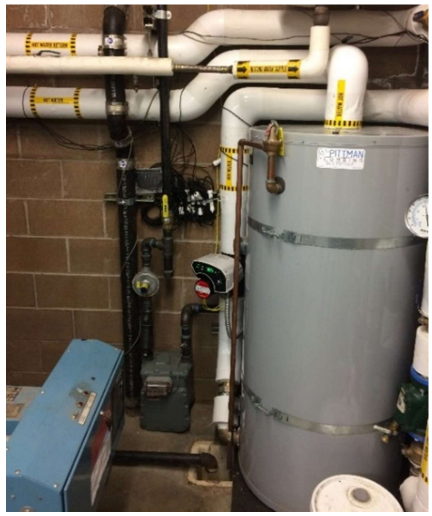


FIGURE 21 - INTERNAL COMPONENTS

FIGURE 22 - INSTALLED HEAT PUMPS

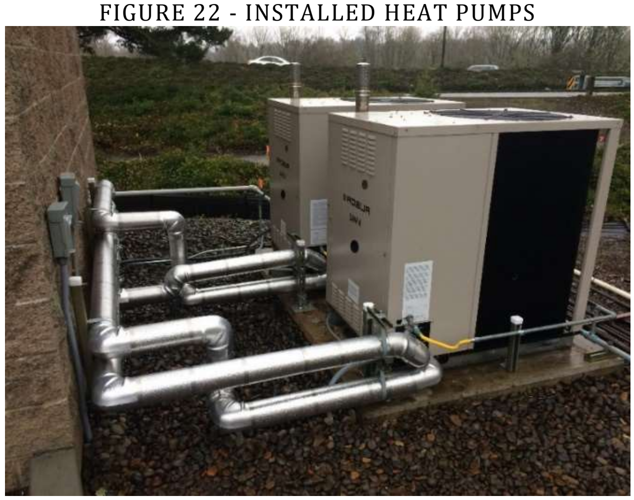


Figure 23 shows a schematic of the Performance System, including three hot water loops (DHW, HHW and Heat Pump glycol loops) and the locations of the primary temperature sensors and flow and energy meters that were monitored over the year.

FIGURE 23 - DHW, HHW AND GAHP-A HEAT PUMP SYSTEM SCHEMATIC

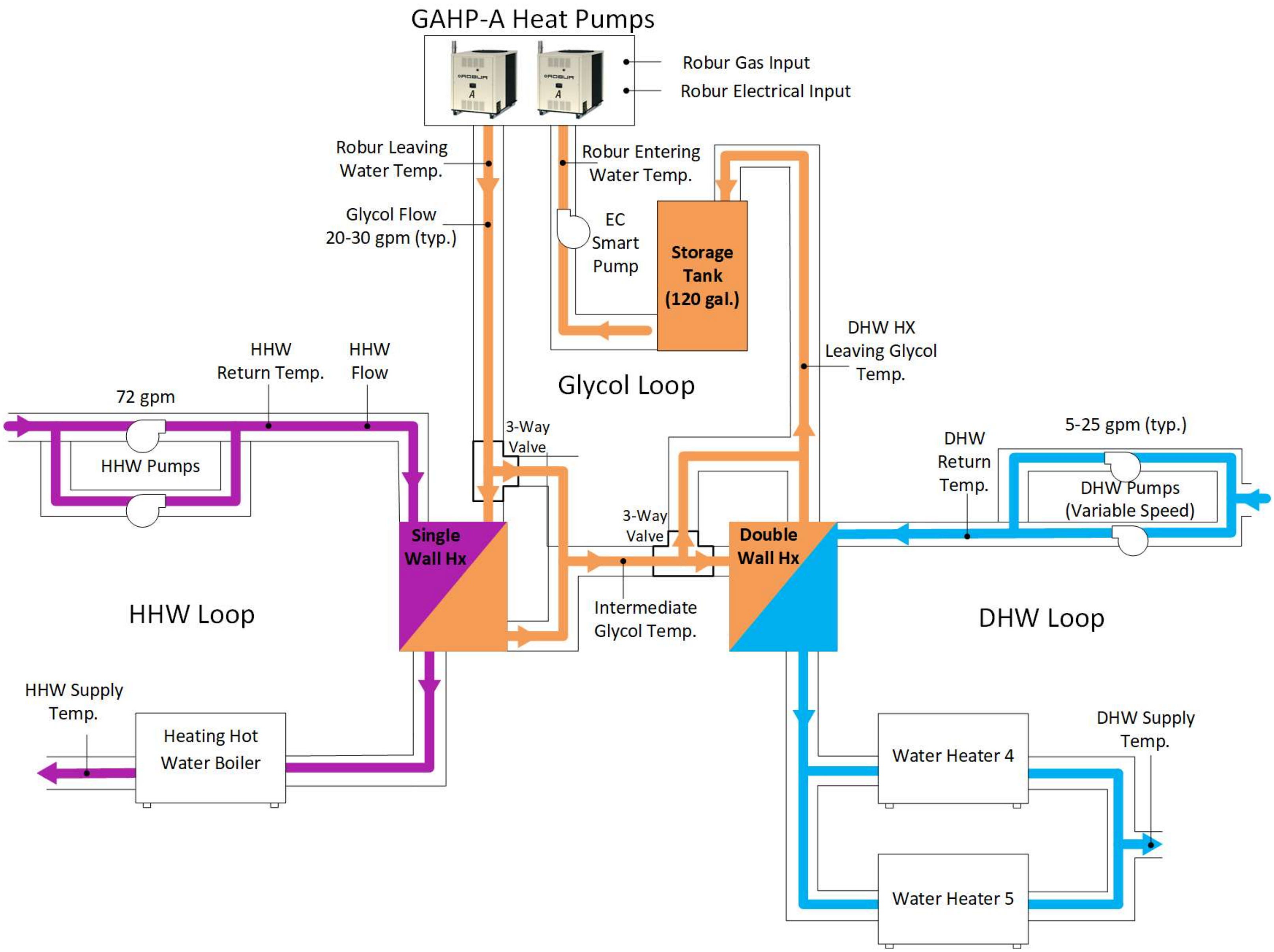


Table 4 summarizes the primary equipment that was installed to comprise the Performance System.

TABLE 4 - PERFORMANCE SYSTEM PRIMARY EQUIPMENT SCHEDULE

Count	Equipment	Manufacturer	Model	Capacity	Notes
2	Gas Absorption Heat Pump	Robur	GAHP-A	123 kBtu/hr (ea.)	140 °F max outlet water
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

4. Methodology and Analysis

This section describes the methodology used to calculate the annual energy savings and simple payback of the gas absorption heat pumps relative to the existing boiler and hot water heater system.

4.1 Metering Equipment and Data Acquisition

We measured all data continuously in 1-minute intervals, which was uploaded every four hours to a secure, cloud-based data storage center for easy access. Table 5 lists the metering equipment used in the study.

TABLE 5 - INSTALLED METERING EQUIPMENT

Monitoring Point	Unit	Sensor/Meter Manufacturer	Model	Adapter/Module	Accuracy
DHW Supply/Return HHW Supply/Return GAHP-A Supply/Return Intermediate HX Temperatures	°F	Onset	S-TMP-M002 12-Bit Temp Sensor	N/A	±0.36°F
DHW/HHW/GAHP-A Water Flow	Gal.	Omega Engineering	FTB8020HW-PT	Onset S-UCD-M006	1.5% of reading
Gross Fuel Input	Cubic Feet	Elster	AL-425 Natural Gas Flow Meter	Onset S-UCD-M006	N/A
Heat Pump Energy (x2)	kWh	Veris Industries	Onset T-VER-E50B2 Real Power Meter	Dent CT-HSC-020-U Split Core CTs Onset S-UCC-M006	Meter: ±0.5% CTs: <0.5% from 0.25 to 40A
Circulator Pump Current	Amps	Continental Control Systems	CTML-0350-05 Split Core CT	Onset S-FS-TRMSA-D Module	±1% from 10 to 100% Rated Current

Figure 24 through Figure 27 show example sensor and meters installed in the field.

FIGURE 24 - HEAT PUMP GAS FLOW METER

FIGURE 25 - HEAT PUMP HW FLOW METER

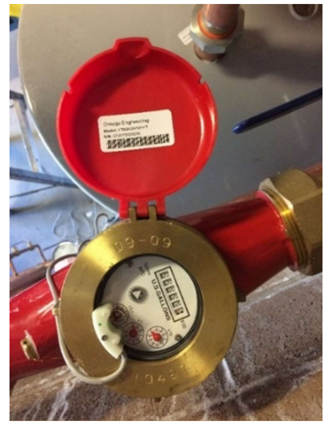
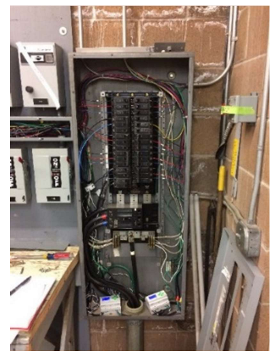


FIGURE 26 - THERMAL WELL USED FOR HW RETURN TEMP

FIGURE 27 - HEAT PUMP POWER METERS



4.2 Existing System

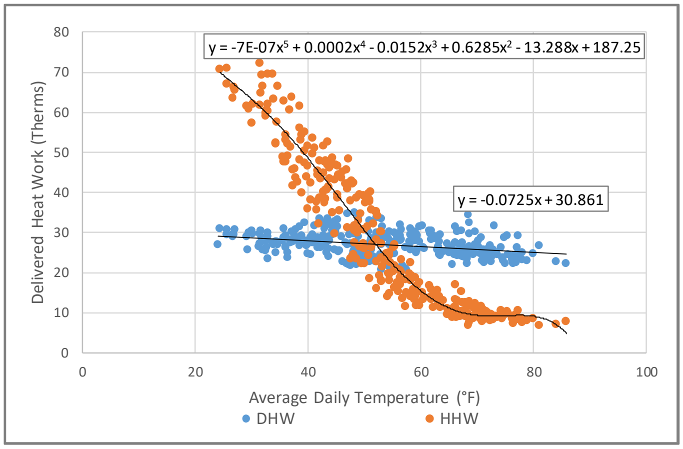
For each of the existing HHW boiler and DHW heaters heat output and energy input were measured over a three-month period before the heat pump system was installed to calculate the effective system efficiencies[4]. The heat output was calculated using the measured values of the water flow and inlet and outlet water temperatures of both the HHW and DHW hot water loops. The volumetric natural gas flow was measured using temperature corrected utility-grade gas meters with electronic pulse outputs. NW Natural provided daily gas energy factors for the site over the monitoring period. The gas energy content factors were corrected to account for the differences in gas pressure at the individual meters[5]. The measured efficiencies of the HHW boiler and DHW water heaters were 73% and 67%, respectively.

Throughout the existing and performance periods, the measured values for glycol flow and heat pump supply and return temperatures were used to calculate total work done by the unit. Additionally, an intermediate glycol temperature (after HHW heat exchanger and before DHW heat exchanger) was measured and used to calculate the respective hot water load of the individual HHW and DHW loops. Figure 28 shows the total system delivered DHW and HHW load (output) over the

[4] The system efficiencies were measured and calculated before the DHW VFDs were installed and the HHW temperature reset was implemented.
[5] The site utility meter pressure is regulated to 2.0 psig, and the individual HHW, DHW and heat pump gas meters are regulated to a pressure of 0.4692 psig (13" w.c.), 0.3429 psig (9.5" w.c.) and 0.3248 psig (9" w.c.), respectively.

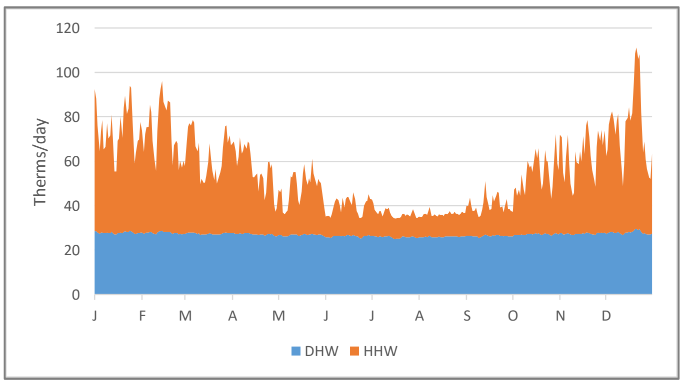
existing and performance periods over a range of daily average ambient outside temperatures, which include both heat pump and boiler/water heater outputs.

FIGURE 28 - DAILY SYSTEM HOT WATER LOADS



By applying the DHW and HHW regressions shown in Figure 28 to typical meteorological year (TMY3[6]) average daily dry-bulb temperatures, an annual hot water load profile was generated for the site. Figure 29 shows the daily load to the facility over a typical weather year.

FIGURE 29 - ANNUAL HOT WATER LOAD PROFILE



Using the annual hot water load profile and the boiler/water heater efficiencies calculated during the existing system monitoring period, an annual gas consumption of 28,759 therms (output) per year was calcuated for the site. Table 6 summarizes the annual load and gas consumption of the total hot water system for a typical year.

TABLE 6 - EXISTING SYSTEM ANNUAL HOT WATER LOAD AND GAS CONSUMPTION

DHW Output (therms/year)	HHW Output (therms/year)	Existing System Output (therms/year)	Existing System Input Gas (therms/year)	Existing System Gas Cost ($/year)
9,859	10,279	20,138	28,759	$16,427

[6] Typical Meteorological Year (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. Data from the Salem/McNary weather station (SLE) was used for this analysis for its proximity to Capital Manor.

4.3 Heat Pump Analysis

The annual GAHP-A performance is reported in terms of two metrics: gas only Coefficient of Performance (COP_{gas}) and Coefficient of Performance including electric loads (COP_{g-e}). COP_{gas} corresponds to the ratio of heat energy output to natural gas energy input only, while COP_{g-e} is the net performance which also includes the electrical energy consumed by the heat pump units (condenser fans, solution pump, controls, etc.). Unless otherwise noted, the annual COP is reported based on the measured performance of the heat pump system over 2019, which is then modeled over a typical weather year.

$$[Eq\ 4.1]\quad COP_{gas} = \frac{Annual\ Heat\ Output}{Annual\ Natural\ Gas\ Input}$$

$$[Eq\ 4.2]\quad COP_{g-e} = \frac{Annual\ Heat\ Output}{Annual\ Natural\ Gas\ Input + Annual\ Electricity\ Input}$$

The annual modeled COP_{gas} and COP_{g-e} are calculated using the following methodology:

1. Calculate total heat pump heat output at 5-minute intervals, based on average water flow, supply temperature and return temperature.
2. Calculate heat pump gas input energy, based on temperature-corrected natural gas flow meter and utility-provided gas heat contents (higher heating values provided daily by NW Natural).
3. Sum heat output and gas input energy to daily totals.
4. Calculate daily COP_{gas} using the ratio of heat output to gas input.
5. Calculate relationships of daily heating load, COP_{gas} and electricity consumed, compared to average daily dry-bulb temperature reported by nearest weather station[7].
6. Apply heat output and electricity consumption relationships to the average daily temperature for each of the 365 days in a typical weather year (TMY3, Wilcox 2008) to calculate daily heat output and electric energy input.
7. Apply COP_{gas} relationship to average daily temperature for each of the 365 days in a typical weather year to calculate daily heat pump performance.
8. Divide daily heating load by daily efficiency to calculate daily input gas energy of the heat pumps.
9. Sum the 365 days of heating output and gas energy input; calculate ratio of output to input to obtain COP_{gas}. (See Eq. 4.1)
10. Convert annual electric input to the same units as heating load and gas input; calculate ratio of annual output heat to the sum of annual gas and electric inputs to obtain COP_{par}. (See Eq. 4.2)

Because the heat pumps only displace a portion of the system's total DHW and HHW loads, the annual energy savings were calculated by measuring the portion of heat output delivered to the respective

[7] Daily average dry-bulb temperatures are reported by the nearest weather station (SLE) reported by NOAA to be consistent with the TMY3 data used for the annual energy model.

hot water loops at different daily weather conditions. The avoided gas energy input was then calculated using the average efficiency measured during the existing period.

4.3.1 Heat Output

The heat output rate of the GAHP-A units was calculated on a five-minute time interval, by using the difference in the heat pump supply and return water/glycol solution temperatures and flow rate[8]. The water/glycol volumetric flow rate was measured, taking into accoutn the density and specific heat of a 20% (by volume) glycol/water solution at 120°F, as shown in Equation 4.3.

$$[Eq\ 4.3]\quad \dot{Q}_{output} = \dot{V}_{glycol} \times \rho_{glycol} \times \bar{c}_{p,glycol} \times (T_{supply} - T_{return})$$

where:

$\dot{Q}_{output}$ = heating output rate $\left(\frac{btu}{hr}\right)$

$\dot{V}_{glycol}$ = volumetric flow of glycol water solution $\left(\frac{gal}{min}\right)$

ρ_{glycol} = density of glycol solution $\left(\frac{lb}{gal}\right)$; 8.505 $\left(\frac{lb}{gal}\right)$ for 20% (by volume) glycol @ 120°F

$\bar{c}_{p,glycol}$ = specific heat of glycol solution $\left(\frac{Btu}{lbs-°F}\right)$; 0.928 $\left(\frac{Btu}{lbs-°F}\right)$ for 20% (by volume) glycol @ 120°F

T_{supply} = glycol supply temperature $(°F)$

T_{return} = glycol return temperature $(°F)$ [9]

4.3.2 Gas Energy Input

Diaphragm gas meters were installed to monitor the volumetric gas flow (cubic foot pulses) into the heat pumps. All meters are temperature-compensated and equipped with electronic pulse output. The daily gas energy content values, in higher heating values (HHV), were provided by the site's natural gas utility and adjusted for line pressure to account for the pressure of our gas meters (0.3248 psig, 9" w.c.). Table 7 lists the average monthly gas energy factors as provided by the utility, as well as the adjusted values used to convert the volumetric gas flow through the meter to an energy input rate.

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[8] As the heat output calculations are based on the supply and return temperatures near the heat pump, this ignores both pipe and heat exchanger skin losses. The mechanical room temperature ranges from 70°F to 110°F throughout the year. Heat loss calculations based on an average working fluid temperature of 130°F and the piping insulation thicknesses indicate these losses are less than 0.5% of total heat pump delivered heat. Thus, we chose to ignore these minor losses.

[9] The density and specific heat values used in Eq 4.3 are from published values from Table 10 and Table 22 in the *Engineering and Operating Guide for DOWTHERM* (Dow Chemical)

TABLE 7 - AVERAGE MONTHLY GAS ENERGY CONTENT FACTORS

Month	Gas Utility Energy Factors (Btu/ft^3)	Adjusted for Meter Pressure (Btu/ft^3)
January	1,048	1,068
February	1,059	1,078
March	1,045	1,065
April	1,042	1,061
May	1,077	1,097
June	1,081	1,101
July	1,052	1,072
August	1,046	1,065
September	1,048	1,068
October	1,052	1,072
November	1,041	1,061
Average:	**1,054**	**1,074**

4.3.3 Heating Load and Performance

Figure 30 shows the total daily work delivered by the heat pumps at a range of outside air temperatures. On colder days, there was more HVAC heating load required and a colder HHW return temperature, which allowed the heat pumps to operate longer. On the coldest days (<40°F), both heat pumps are able to deliver useful heat for over 20 hours. However, on warmer days (>45°F), the HVAC system requires less heat and both the DHW and HHW loop return temperatures often exceed 120°F due to low loads. Without lower temperature water loops to deliver heat to, the heat pumps remain off for most of the day and deliver far less useful heat.

FIGURE 30 - TOTAL DAILY HEAT PUMP WORK

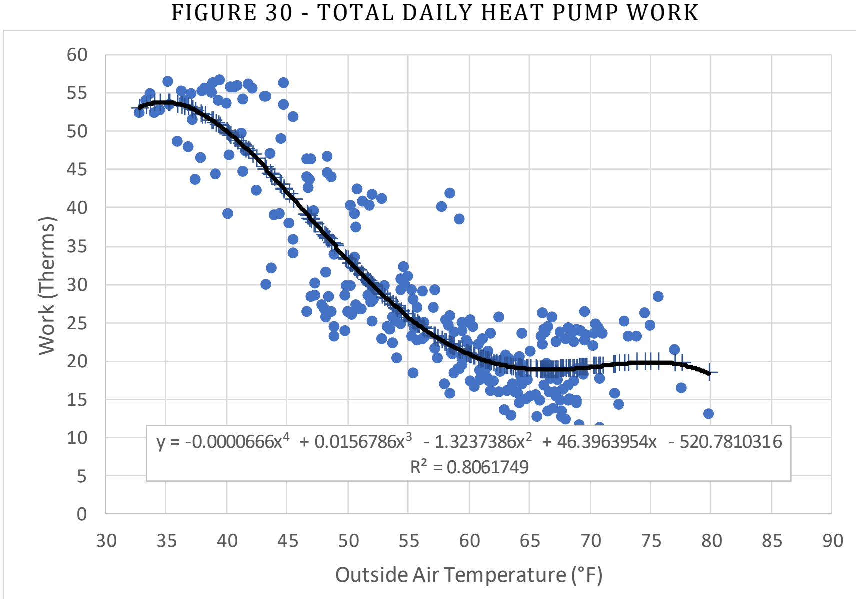
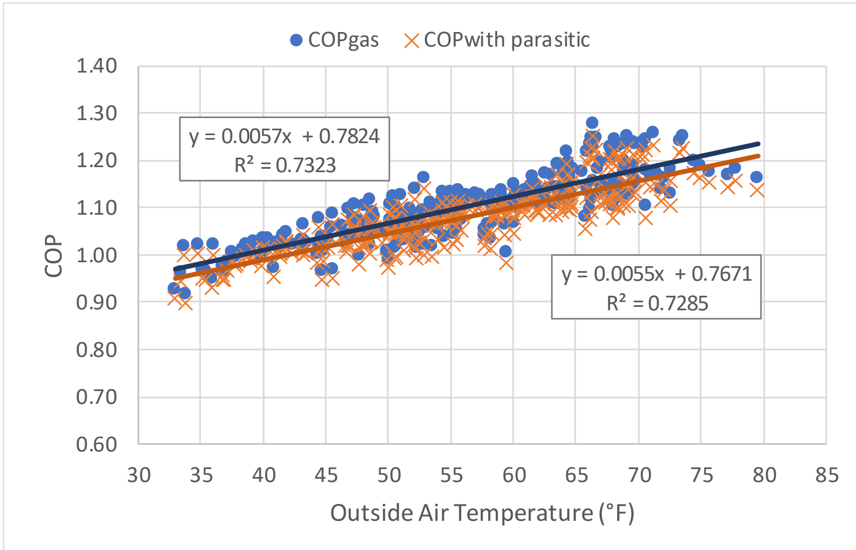


Figure 31 shows the relationship between heat pump performance and the daily average outside air temperature (ambient to the GAHP-A units).

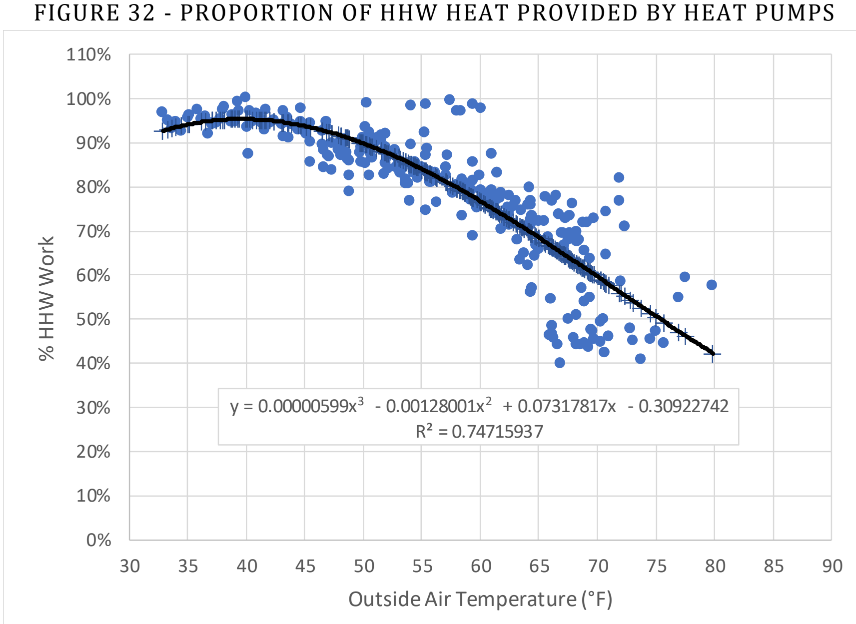
FIGURE 31 - HEAT PUMP PERFORMANCE



4.3.4 Annual Energy Savings

Because the existing HHW boiler and DHW water heaters have different efficiencies, the amount of HHW and DHW heat load offset by the heat pumps was modeled separately throughout the year. Figure 32 shows the proportion of HHW to DHW load offset during the monitoring period which was measured using an intermediate temperature sensor located in the glycol loop between the HHW and DHW heat exchangers.

FIGURE 32 - PROPORTION OF HHW HEAT PROVIDED BY HEAT PUMPS



Using the building DHW and HHW load profiles described in Section 4.2 and the weather relationships described in Section 4.3, the expected annual gas consumption of the performance system (heat pumps, DHW heaters and HHW boiler) was modeled and compared with the existing system (DHW heaters and HHW boiler). Table 8 shows the annual gas consumption of each system by component and Figure 33 and Figure 34 show the annual gas consumption and monthly gas savings. In total, the Robur heat pumps are expected to reduce the hot water system's annual gas consumption by 5,134 therms per year.

TABLE 8 - PERFORMANCE SYSTEM ANNUAL GAS CONSUMPTION

	HHW Boiler (Therms)	DHW Heaters (Therms)	Heat Pumps (Therms)	Total System (Therms)
Existing	14,056	14,704	0	28,759
Performance	560	12,070	10,995	23,625
Savings	**13,495**	**2,634**	**-10,995**	**5,134**

FIGURE 33 - ANNUAL GAS CONSUMPTION

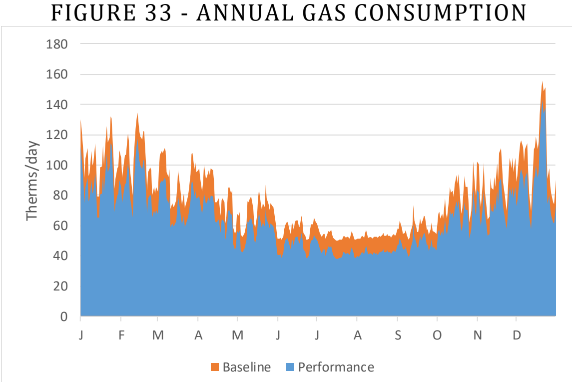


FIGURE 34 - MONTHLY GAS SAVINGS

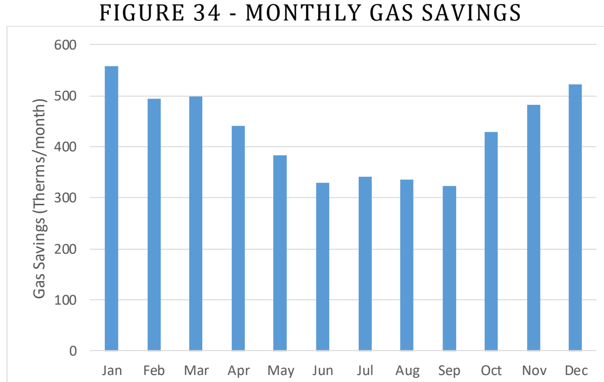
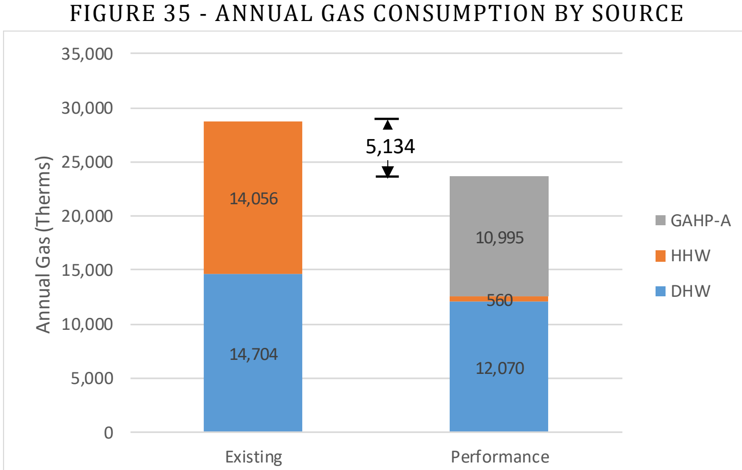


Figure 35 shows the annual gas consumption broken down by equipment in the existing and performance systems. With the installation of the GAHP-A, the HHW boiler consumption is nearly eliminated on all but the coldest days. The result is a 96% reduction in annual HHW boiler gas consumption. However, this result does not imply that the boiler capacity is unneeded, as the GAHP-As are sized closer to the baseload of the facility, not the peak. The HHW boiler's rated capacity of nearly 2 million Btu/hr is mostly needed on the coldest days of the year. Given the limited hours of extreme cold weather, the GAHP-A units are able to carry a majority of the HHW load over the remained of the year.

FIGURE 35 - ANNUAL GAS CONSUMPTION BY SOURCE



5. Economic Summary

Table 9 itemizes the total installed project costs for the GAHP-A system including installation, contractor markup and permitting.

TABLE 9 - PROJECT COSTS

Description	Cost
(2) Robur GAHP-A Gas Heat Pumps (Including DDC & Freight)	$15,845
35% Contractor Markup	$5,546
Mechanical/Plumbing Installation	$16,800
Circulator Pump	$2,125
Controls (building controls integration)	$3,749
Crane	$500
Electrical	$750
Structural Analysis & Drawings	$896
Building Permits	$500
Total	**$46,710**

Table 10 shows the value of the gas savings and electric penalty based on site's average marginal utility rates. The expected annual gas savings total 5,134 therms ($2,933 with a gas rate of $0.5712/therm).[10]

TABLE 10 - ENERGY SAVINGS SUMMARY

Total Project Costs	Annual Gas Savings (Therms)	Annual Gas Savings ($)	Annual Electric Penalty (kWh)	Annual Electric Penalty ($)
$46,710	5,134	$2,933	5,916	$473

6. Performance Results

The GAHP-A system performed well over the monitoring period with a measured COP_{gas} of 1.08 and $COP_{g\text{-}e}$ of 1.06 between February 2019 through November 2019. Once adjusting for operation in a typical weather year, including the colder December and January months, an annual COP_{gas} of 1.06 and $COP_{g\text{-}e}$ of 1.04 was calculated.

COP_{gas} | 1.06

The performance of the heat pumps is dependent on outside air temperature. Similar to an electric air-source heat pump, gas absorption heat pumps extract heat from the ambient air. As seen in Figure 36, the warmer the outside air temperature, the higher daily COP_{gas}. On days where the average outside air temperature falls below about 35°F, the average COP_{gas} falls below 1.0 and begins to

[10] Actual gas savings and project economics will vary based on the project site's gas rate. The average commercial gas rate in Oregon during the performance period was $0.7029/therm (DOE-EIA).

approach the performance of a condensing boiler. On days where the average outside air temperatures are above 70°F, the COP_{gas} of the heat pumps rises above 1.2 and as high as 1.29. These values are in line with, although slightly below, the stated performance curves provided by the manufacturer for a supply water temperature of 140°F.

FIGURE 36 - DAILY HEAT PUMP PERFORMANCE

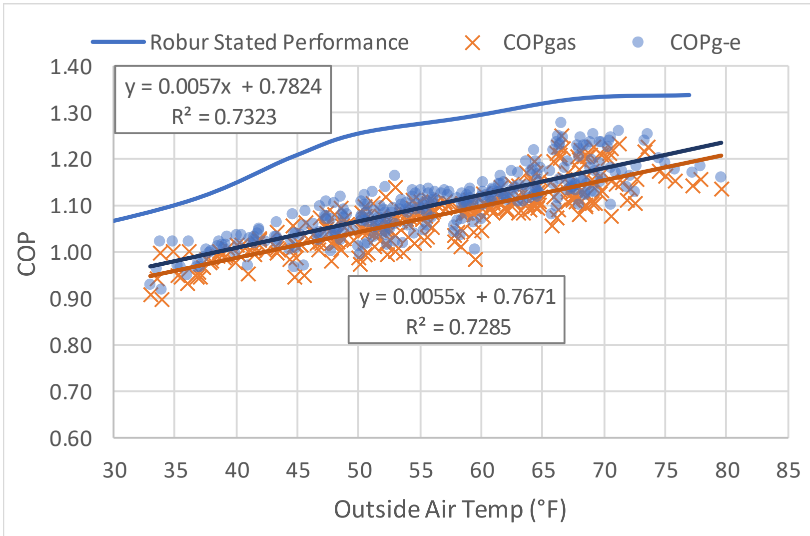
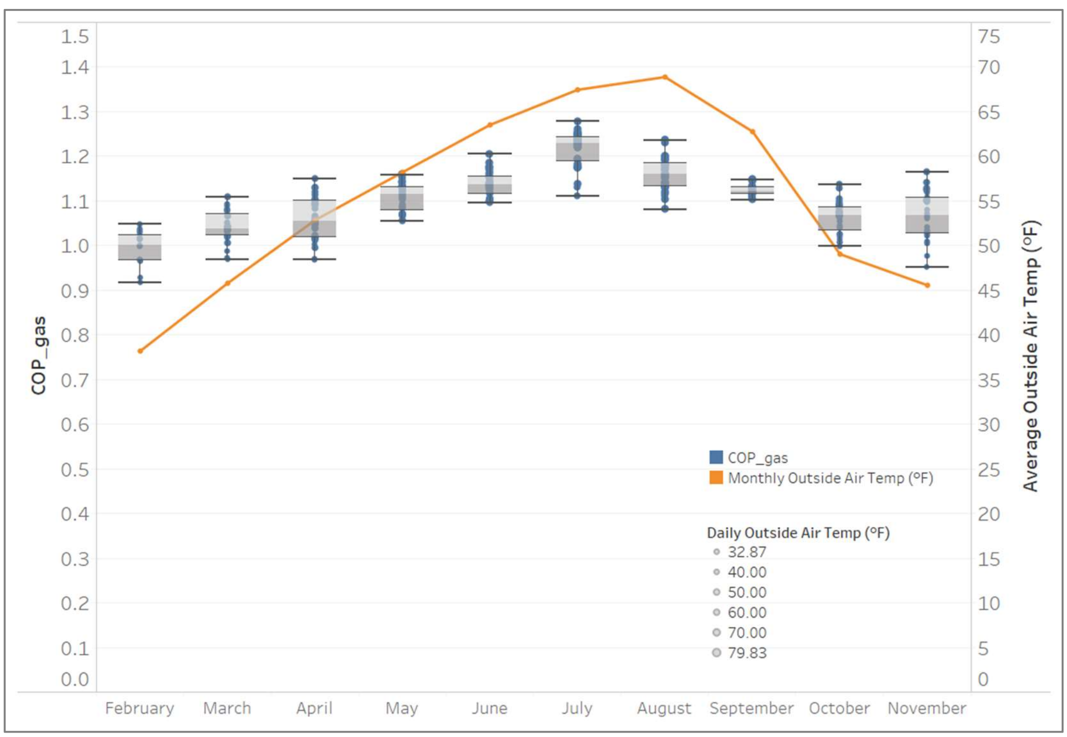


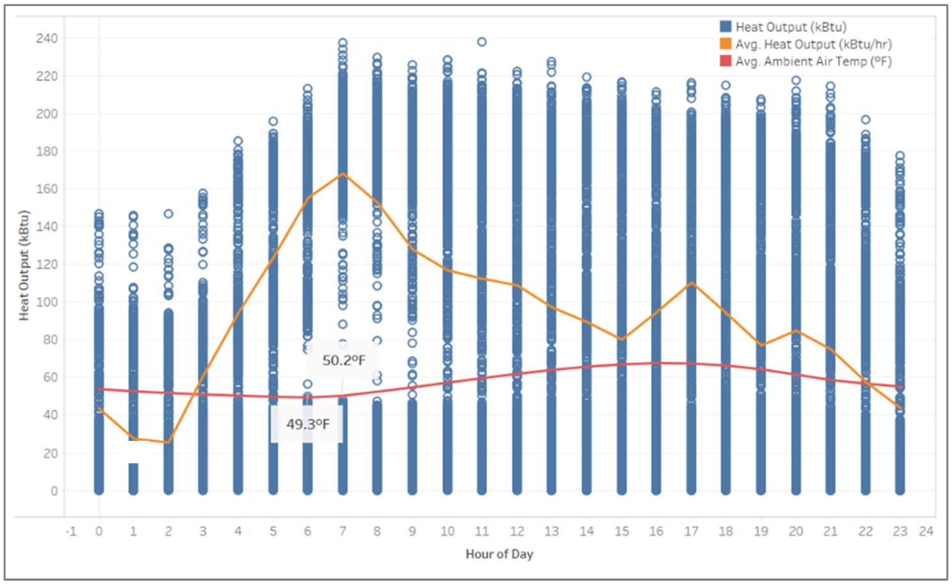
Figure 37 shows the daily spread of COP_{gas} by month and the corresponding average outside air temperature during that month.

FIGURE 37 - MONTHLY HEAT PUMP PERFORMANCE



As shown in Figure 38, the hourly heat pump output shows two peaks: a morning peak at 7am and an evening peak at 5pm. These two peaks align with the highest DHW demand, when the return water temperature from the building is low, due to a high percentage of cold city makeup water. Also shown in the figure below is the average ambient air temperature, which is the coldest on average at 5am through 7am. These cold morning hours correspond to the highest heat pump outputs when performance is the lowest. This coincidence of high output during cold hours helps explain why the daily COP_{gas} falls below the reported manufacturer performance curve.

FIGURE 38 - HOURLY HEAT PUMP SYSTEM OUTPUT



As seen in Figure 39, the daily COP_{gas} of the GAHP-A system remains above 1.1 over the warmer summer months and performs near or above 1.0 during the colder days in February and November.

FIGURE 39 - DAILY COP AND OUTSIDE AIR TEMPERATURE

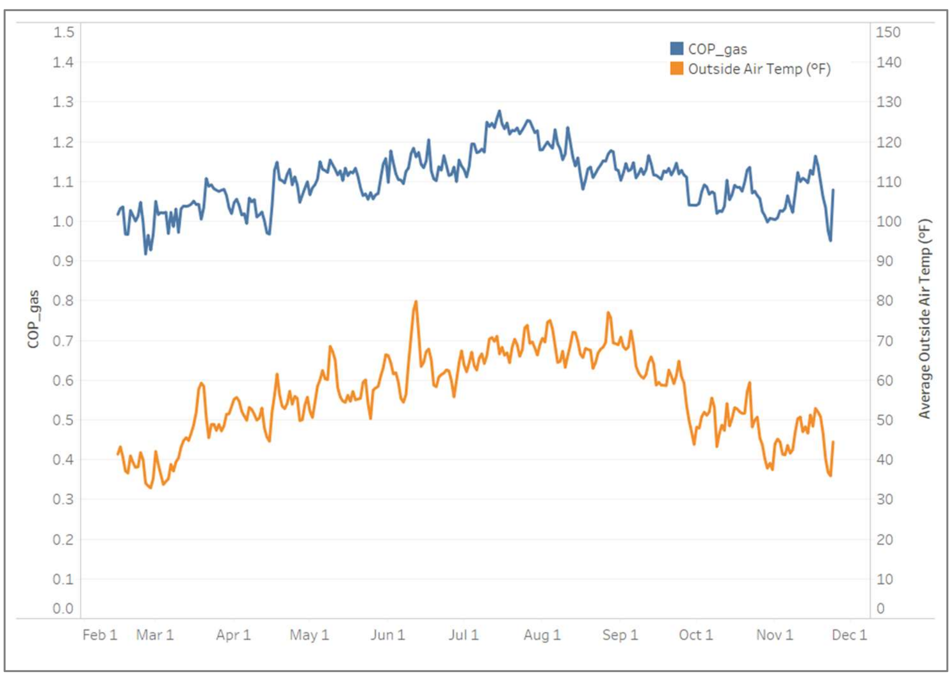


Table 11 shows the performance results from the performance period, which was between 2/14/2019 and 11/24/2019. On average the GAHP-A system delivered 98,178 Btu/hr which represents a system utilization of 39.7% based on the nominal capacity of 123,500 Btu/hr for each of the two units. On the coldest days of the performance period (<40°F), the units consistently delivered 190,000 Btu/hr, indicating both units operated over 18 hours in a 24-hour period (76.9% utilization).

TABLE 11 - PERFORMANCE PERIOD RESULTS

Totals (2/14/19 - 11/24/19)							
Average OAT (°F)	**Input Gas (Therms)**	**Output Heat (Therms)**	**Input Electric (kWh)**	**COP_{gas}**	**COP_{g-e}**	**Average Output (Btu/hr)**	**Utilization**
56.2	6,171	6,692	3,854	1.08	1.06	98,178	39.7%

Table 12 provides a summary of the primary claims by the manufacturer, and how those claims held up in the field testing. Some conditions, such as extreme ambient temperatures, were not validated due to the lack of extreme conditions in western Oregon. For those conditions that were able to be tested in the field all claims by the manufacturer were met or exceeded except for the heating efficiency.

TABLE 12 - VALIDATION OF MANUFACTURER CLAIMS

Manufacturer Claim	**Value**	**Conditions**	**Meets or Exceeds?**	**Note**
Nominal heating output	123,500 Btu/hr	44.6°F ambient 122°F HW temp	Yes	Max 124,100 Btu/hr @ 60.5°F
Heating efficiency	129%	44.6°F ambient 122°F HW temp	Sometimes	COP_{gas} between 1.0 and 1.45 (1.1 average) @ 44-46°F ambient and 120-129°F HW temp
Max outlet water temp	140°F	ΔT = 27 °F	Yes	Some hours @ 139-140°F
Max ambient air temp	113°F	Stable operation	Not tested	Max 99°F tested
Min ambient air temp	-20°F	Stable operation	Not tested	Min 25°F tested
Electric input	0.9 kW	@ 123,500 Btu/hr	Yes	0.6-0.9 kW @ 123 MBH
High reliability	--	Few moving parts	Yes	Minimal downtime in 1st year of operation
Flexibility and modularity	--	--	Yes	2 modular units worked seamlessly
Outdoor installation rated	--	--	Yes	Equipment appears to be weathering well after 1+ year

7. Practical Learnings

Overall, the GAHP-A heat pumps performed reliably over the ten-month monitoring period with minimal downtime or issues. The unit start-up was straightforward, and the manufacturer technical support was excellent. The technical support team is extremely knowledgeable, responsive and quick to provide answers to any questions throughout the field trial. The following section describes some of the minor issues that needed to be diagnosed and resolved.

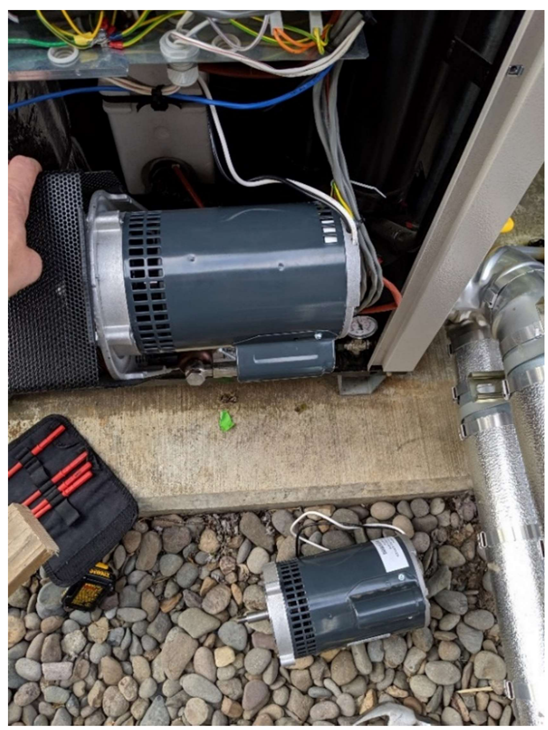
7.1 Blocked Flow Switch

During the monitoring period atypical operation of the units was discovered (significantly different flows through the two units and abnormal cycling between the two units), which was originally diagnosed with support from Robur as a failed flow switch. Robur immediately sent out a replacement flow switch. While replacing the flow switch, a rubber gasket was discovered to be lodged in the flow switch which was causing the issues. The gasket was foreign to the heat pump system and likely entered the water loop from an external component (valve, flow meter or other fitting). This issue did not cause any downtime, other than the two hours spent replacing the flow switch.

7.2 Failed Solution Pump Motor

We noticed that one of the two Robur units had not cycled on for a couple days in late July 2019. The site was visited and the unit and its primary components were inspected. The DDC showed an alarm code for "insufficient rotation of hydraulic pump" which is generated when the sensor on the pully of the ½ hp pump that moves an oil/water is not sensing enough revolutions in an allotted time. After clearing the alarm, the unit started up and ran for a 24-hour period before shutting down again. The hydraulic pump motor, while functioning, was noticed to be making an atypical grinding sound. Robur quickly sent out a replacement motor which resolved the issue. The pump motor is a common piece of equipment and this was likely a typical, although uncommon component failure. Figure 40 shows a photo of the solution pump motor being replaced.

FIGURE 40 - PUMP MOTOR REPLACEMENT



Because this issue took place during the summer, there was minimal impact on the system performance or savings. For one, the other heat pump ran more consistently instead of alternating in the lead/lag positions. During the summer, the two heat pumps rarely ran at the same time, so there was almost no impact on the system's energy savings. Additionally, these units run in parallel with the DHW heaters and HHW boiler so there was no impact on occupant comfort in the building tower.

8. Conclusion

In summary, the Robur gas absorption heat pumps have a positive outlook. Its reasonable first cost, ease of installation, efficient operation, reliability, and low maintenance operation result in a viable solution for achieving natural gas savings.

- **Efficiency improvement:** The GAHP-A water heaters provide a significant improvement in performance above conventional gas-fired technologies. At the field trial site, the existing DHW heaters and HHW boiler operate at 67% and 73% efficiencies, respectively. With an annual COP_{gas} of 1.06, the GAHP-A performance represents a 58% improvement above the DHW heaters and a 45% improvement above the HHW boiler. The end result is a total system fuel consumption reduction of 18%, even though the nominal capacity of the GAHP-A is a fraction of the capacity of the existing DHW/HHW system.
- **System reliability and minimal maintenance:** The Robur GAHP-A water heaters operate reliably and with minimal maintenance. There are few moving parts and the maintenance requirements are minimal. The manufacturer recommends a qualified HVAC or boiler technician knowledgeable with the GAHP-A technology to perform a number of system component checks and clean the finned coils on an annual basis. Overall, the maintenance is expected to require about an hour per unit per year by a skilled technician.
- **Excellent technical support:** The manufacturer provided excellent technical support throughout the design, installation and commissioning phases of the project and was extremely helpful in diagnosing and resolving the few issues that came up during the field study. This support is critical with emerging technologies that are often unfamiliar to maintenance and service professionals.
- **Return temperature limitation:** One of the largest challenges with finding a suitable application for this technology is finding a site that requires a consistent and significant hot water load and sufficiently low temperature heat sink. The Robur heat pumps require a maximum return temperature of 122°F. As discussed in the Phase 1 section, many heating hot water and domestic hot water applications have return temperatures that consistently exceed 122°F. Without a lower temperature heat sink, the heat pumps lack a means to add useful heat to the system, thus their utilization and resulting energy savings will be low.
- **Lack of modulation:** The Robur heat pumps operate either on or off and do not have modulation capability. The manufacturer does provide a direct digital controller (DDC) which can control multiple heat pumps as a hot water plant. This method can allow for multiple stages of heating, similar to a modulating burner, but only in larger applications. However, for smaller applications the lack of modulation return temperature limitation makes it difficult to maintain a consistently high hot water supply temperature.
- **Other ideal applications:** The Capital Manor retirement community was selected as the location of this field trial for its large year-round domestic hot water load and because of the opportunity to test the unit as a combination DHW and HHW system. However, other applications such as commercial pools, laundry facilities and potentially food processing sites

could be excellent locations for GAHP-A units. Commercial pools in particular may have great applicability with their lower water temperature requirements and built-in thermal storage. Multifamily buildings may also be good applications, but careful consideration must be taken to ensure a low enough DHW return temperature provides a sufficient heat sink for the GAHP-A units to provide consistent water heating.

- **Installation simplification:** Due to the site infrastructure in place before this field demonstration (separate glycol loop with HHW and DHW heat exchangers), the GAHP-A utilization was maximized by serving both the HHW and DHW loops. However, this decision added some complexity and cost to the installation, and only increased savings by an estimated 20% above an HHW only application. If the DHW load was forgone and only the HHW was served, annual run hours and gas savings would be reduced, but the reduction in installation and total project costs would likely improve the project economics. Future research should target a lean and simple installation, focusing on heating only.

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Appendix A – Robur GAHP-A Submittal

The submittal data sheet provided by the manufacture is included below for reference.

ROBUR

caring for the environment

Submittal Data

GAHP Line A Series

Gas Fired Absorption Heat Pump

Heating

GAHP is the acronym for Gas Absorption Heat Pump. The GAHP-A is a high efficiency air source heat pump boiler, utilizing a water-ammonia absorption cycle that is designed for outdoor use. The GAHP-A is able to heat water up to 140 °F, with external ambient temperatures from -20 °F up to 113 °F. The cycle of the GAHP-A is driven by thermal energy provided by a gas burner. Therefore, the required electric energy is limited to driving the fan and pump motors. The GAHP-A is fed by natural gas or LPG, and supplied with 208-230 V - 60 Hz SINGLE PHASE electrical power. The evacuation of combustion products takes place through an appropriate exhaust terminal, located on the side of the appliance, with the outlet in a vertical position.

Operating mode

The appliance uses an absorption cycle to recover heat from the outside environment via the finned coil, which when combined with the heat produced by the combustion of natural/LPG gas, is transferred into the exchanger and then into the medium to be heated, ensuring efficiency of 129% (under nominal conditions). The GAHP-A is equipped with the following devices:

- steel sealed circuit, externally coated with epoxy paint;
- premixed multigas burner with ignition and flame sensing device managed by the electronic control box;
- steel tube air heat exchanger with single-row coil and aluminum fins;
- titanium stainless steel tube bundle water heat exchanger, with external insulation;
- two-way automatic defrosting valve, controlled by the microprocessor, allows for fin coil defrosting.

Control and safety devices

The GAHP-A is controlled and monitored by the S60 control board through the peripheral W10 card. These cards and other components compose the control and safeties of the GAHP-A, as listed below:

- S60 Electronic Control Board with integrated microprocessor, LCD display and encoder located inside the electric box; it is programmable and it controls and monitors the operation of the heat pump;
- hot water flow switch; located on the return water line; monitors the hot water flow and helps prevent the overheating of the condenser-absorber;
- sealed circuit high temperature limit; located on the external wall of the generator; helps prevent overheating of the generator;
- hot water high temperature limit switch; located on the outlet water line; prevents water circuit from overheating;

1

• differential air pressure switch; located inside the electric box; it helps manage the combustion system by monitoring the air flowing into the air-gas mixing chamber and stopping the burner if the air flow is too low;
• flue gas temperature limit switch; located inside the rear portion of the combustion chamber; helps prevent overheating of the generator;
• sealed circuit safety relief valve;
• safety by-pass valve; located inside the sealed system; prevents over pressurizing of the sealed system;
• ignition control box; located inside the electric box; it manages the combustion system controlling the burner ignition, the gas valve, the air pressure switch, the air blower and the flame sensor;
• dual gas valve;
• temperature probes; located both on the sealed system and on the water lines; they monitor functional parameters of the unit.

The GAHP-A is especially suited for gas heating plants wanting to achieve higher overall operating performance. Total plant efficiency rises when one or more GAHP-A units are used in combination with standard boilers. When operating in a moderately cool climate, a plant with 25-30% of thermal load supplied by GAHP-A units (and the residual supplied by ordinary boilers) can reach a total efficiency up to 120-130%, with proportionally lower combustible consumption.

PERFORMANCE RATINGS (1)			GAHP-A
Heating capacity (2)		BTU/h	123,500
Gas input		BTU/h	95,500
Ambient operating temperature	maximum	°F	113
	minimum	°F	-20
Hot water temperature	maximum outlet (to hydronic system)	°F	140
	maximum inlet (to unit)	°F	122
Water flow	nominal	GPM	13.6
	maximum	GPM	22
	minimum	GPM	6.2
Internal pressure drop at nominal hot water flow		Feet of Head	10.1
		psi_g	4.3

ELECTRICAL RATINGS (1)		
Required voltage, 60 Hz, single phase (3)	V	208 - 230
Operating consumption (4)	kW	0.9
MCA (Minimum Circuit Ampacity)	A	8.0
MOP (Maximum Overcurrent Protection)	A	10.9

PHYSICAL DATA (1)			
Operating weight		pounds	770
Gas inlet connections		FPT	1/2"
Dimensions	width	inches	33 1/2
	length	inches	48 1/2
	height	inches	50 3/4

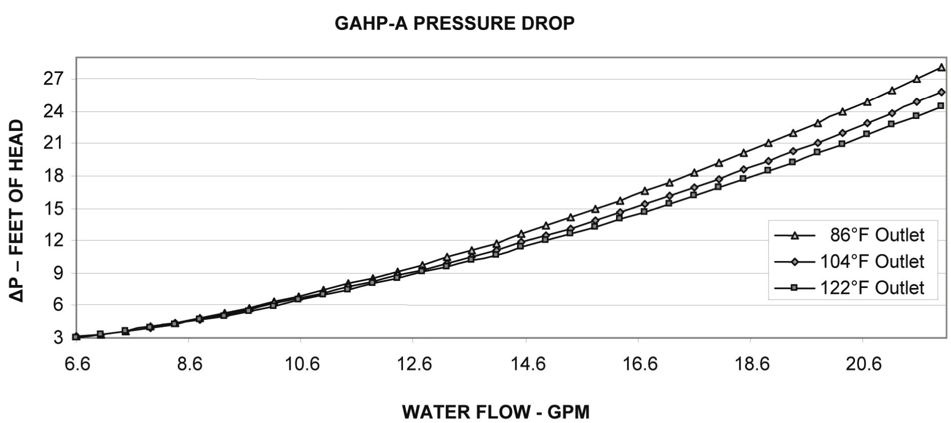
(1) All illustrations and specifications contained herein are based on the latest information available at the time of publication.
(2) Heating capacity at standard conditions of 44.6 °F ambient temperature. Hot water outlet temperature 122 °F, hot water inlet temperature 104 °F.
(3) Units are factory-wired for 208-230 volts operation.
(4) May vary by ± 10% as function of both power supply and electrical motor input tolerance.

Due to continuous product innovation and development, Robur reserves the right to change product specifications without prior notice.

HEATING MODE CAPACITY (BTU/h)

External ambient operating temperature (dry bulb)	Outlet (to plant) hot water temperature			
	86 °F	113 °F	122 °F	140 °F
	ΔΔT = 18 °F			ΔΔT = 27 °F
-20.0 °F	97,600	88,700	85,000	83,600
-13.0 °F	98,600	89,700	86,000	84,600
-4.0 °F	99,600	90,800	87,000	85,600
5.0 °F	102,000	93,500	90,100	88,400
14.0 °F	111,600	102,400	95,900	92,800
19.4 °F	117,000	108,200	100,000	96,200
35.6 °F	126,900	122,200	114,000	105,800
44.6 °F	132,400	130,700	123,500	115,300
50.0 °F	134,800	134,400	128,000	120,100
59.0 °F	136,500	136,500	132,000	123,500
68.0 °F	138,200	138,200	133,800	127,300
77.0 °F	139,200	139,200	134,800	128,000

Nominal value in bold type.
ΔT is the difference between outlet and inlet temperature.



PRESSURE DROP - Heating mode (ΔP condenser / absorber)

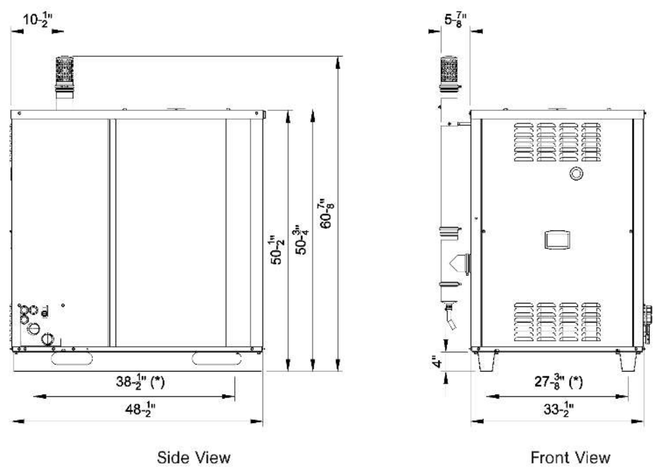
Hot water flow	Outlet water temperature		
	122.0 °F	104.0 °F	86.0 °F
GPM	ΔΔP (Feet of Head)		
6.60	3.05	3.08	3.15
7.04	3.30	3.32	3.35
7.48	3.58	3.62	3.65
7.93	3.89	3.98	4.05
8.37	4.25	4.35	4.42
8.81	4.64	4.76	4.86
9.25	5.05	5.19	5.28
9.69	5.50	5.66	5.77
10.13	5.96	6.18	6.29
10.57	6.45	6.66	6.83
11.01	6.95	7.16	7.39
11.45	7.47	7.68	7.97
11.89	7.99	8.21	8.57
12.33	8.52	8.76	9.18
12.77	9.06	9.32	9.80
13.21	9.59	9.90	10.43
13.65	10.12	10.50	11.07
14.09	10.64	11.11	11.72
14.53	11.36	11.81	12.60
14.97	11.98	12.48	13.35
15.41	12.63	13.17	14.12
15.85	13.29	13.87	14.91
16.29	13.97	14.60	15.72
16.73	14.67	15.35	16.55
17.17	15.39	16.11	17.40
17.61	16.13	16.90	18.27
18.05	16.88	17.70	19.16
18.49	17.65	18.53	20.07
18.93	18.44	19.37	21.00
19.37	19.25	20.23	21.94
19.81	20.08	21.11	22.91
20.25	20.92	22.01	23.90
20.69	21.78	22.93	24.90
21.13	22.66	23.87	25.93
21.57	23.56	24.82	26.97
22.01	24.48	25.80	28.03

APPROXIMATE WATER FREEZING POINT TEMPERATURE

Percentage of monoethylene glycol	10	15	20	25	30	35	40
Water freezing point temperature (°F)	26.6	23.0	17.6	10.4	5.0	-4.0	-13.0
Percentage of increase in pressure drop	--	6	8	10	12	14	16
Loss of efficiency of unit	--	0.5	1	2	2.5	3	4

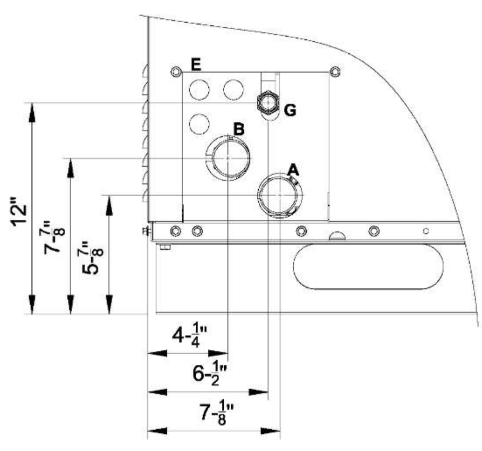
The numbers provided in this table are approximate and you must refer to the glycol manufacturer's instructions for additional instructions and amount of glycol required based on expected ambient conditions.

GAHP-A DIMENSIONS



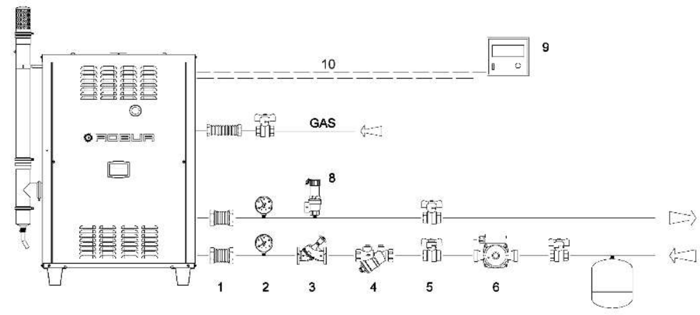
Side View　　Front View

GAHP-A SERVICE PLATE DIMENSIONS



A Water outlet (to water loop) ø 1" FPT
B Water inlet (to unit) ø 1" FPT
E Electrical knockouts ø 7/8" FPT
G Gas connection ø 1/2" FPT

GAHP-A HYDRONIC SYSTEM: Typical Installation Arrangement (External Components not included with Robur Unit)

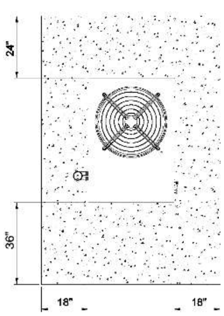


1 Antivibration flexible hoses
2 Pressure gauge
3 Flow regulating valve
4 Water filter
5 Shut-off valve
6 Circulating water pump
7 Expansion tank
8 Safety valve
9 DDC (optional from Robur)
10 Can Bus cable (optional from Robur)

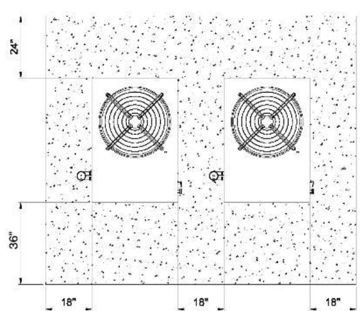
Clearances

Position the appliance so that minimum clearances from combustible surfaces and constructions (walls and other equipment) are maintained, as shown in the figure below.
The appliance may be installed directly on wood flooring.
Minimum clearances are necessary for operating performance, and in order to be able to carry out maintenance operations and to ensure the correct airflow required for proper heat exchange with the finned coil. There must not be any obstructions or structural overhangs (roof edges, balconies) over the top of the unit. The re-circulation of the air discharged from the condenser results in poor unit performance.
When the unit is installed in close proximity to buildings, keep the unit away from the roof edge drip line.
In no case should the unit be placed within 6 feet of any external air intakes of the building. For installations on balconies or roofs, the unit must not be located within 8 feet from chimney flues, outlets and other such vents.
It is important that the unit is located so that hot or contaminated air is not drawn into the air intakes of the unit.

Observe all local and State codes.



Single unit



Multiple units

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827 E. Franklin Street Evansville Indiana 47711 USA Ph. (812) 424-1800 Fax (812) 422-5117

Appendix B – Maintenance Schedule

Regulation of plant operating parameters

Regulation of operating parameters of the plant occurs via the electronic board (see Paragraph 3.8 on page 43) or via the DDC (if connected).

If the appliance is connected to a Direct Digital Controller (DDC), for operations regarding the regulation of plant operating parameters according to the user's requirements, refer to the DDC manual (final user manual – book 2) supplied with it.

5.2 MAINTENANCE

Correct maintenance prevents problems, guarantees maximum operating efficiency of the appliance and allows running costs to be reduced.

Before carrying out any operation on the appliance, switch it off via the appropriate on/off command (or via the DDC, if connected and in controller mode) and wait for the shutdown cycle to terminate.
When the appliance is off, disconnect it from the gas and electricity mains via the external disconnecting switch (GS) and the gas valve.

Caution: Label all wires prior to disconnection when servicing controls. Wiring errors can cause improper and dangerous operation.
Verify proper operation after servicing.

Any operation that regards internal components of units of the appliance must be carried out by an authorized Robur Technical Assistance Centre (TAC), according to the instructions supplied by the manufacturer.

Ordinary scheduled maintenance

Perform the operations described below **at least once a year**. If the unit is subjected to particularly heavy use (for example in processing plants or in other conditions of continuous operation), these maintenance operations must be performed more often.

Maintenance operations that may be performed by the user:

- Cleaning the finned coil.
  If the installation environment is particularly dusty, it is advisable to fit a filter for the finned coil – see the "Optionals and Spare Parts" section, on page 77.

You will need: the appliance disconnected from gas and electricity supply

- with a brush, remove any dust and dirt that has accumulated on the outside of the finned coil, taking care not to damage the fins;
- check that all dirt has been removed;
- restore the supply of gas and electricity to the appliance: open the gas supply valve and put the external disconnecting switch (GS) in the "ON" position;
- start the appliance by means of the on/off operation commands (or via DDC, if connected and in controller mode).

Maintenance operations that the user may NOT carry out
(operations to be performed by a Robur TAC).

- Checking that the combustion circuit is fully functional:
- inspect and clean flue gas passage (see after);
- cleaning of the burner (see after)
- checking the ignition and flame detector system.
- Checking that the oleodynamic pump is operating correctly:
- checking the oil level;
- checking the transmission belts (replacement every 5 years or 10,000 hours of operation).
- Checking cleanliness of the water filters and efficiency of internal water flow meter.

Inspection and cleaning of the flue gas passage:

You will need: the unit shut off

1. Turn off gas and electric supply to the unit.
2. Remove front panel.
3. Clean the base pan around the generator housing of any debris.
4. Look at the flue opening at the right of the generator housing and clear any debris that may be obstructing the opening (see Figure 23).
5. Look at the air intake chute for combustion air and clear any debris that may be obstructing the opening.
6. Reinstall front door.
7. Turn on gas and electric supply to the unit.
8. Start unit to check for correct operation.

Inspection and cleaning of the burner:

You will need: the unit shut off

Tools Needed:

- Fiber Bristle Brush
- Dust Mask (3M #8710 or equal)
- Safety Goggles
- Hand Tools

1. Shut off gas and electric supply to unit.
2. Remove front panel.
3. Remove bolts and nuts securing pre-mixer blower housing to burner tube flange.
4. Remove screws holding burner and insulation retaining straps.

Note: Wear a dust mask (3M #8710 or equal NOISH/MSHA TC-21C mask) during burner removal, cleaning, and assembly operations.

5. Pry bottom of burner tube out to clear bottom of generator housing. Pull burner down and out to remove from generator housing.

Note: Be careful not to distort or damage the burner tube or the igniter and sensor assemblies in the generator housing.

6. Position burner tube with open end down.
7. Clean burner tube ports with fiber bristle brush and shake any debris out of the tube.
8. Inspect burner tube gasket that seals the burner tube to the generator housing and the burner flange gasket that seals burner to pre-mixer blower housing. Replace either gasket if damaged during burner removal process (See “Optionals and Spare Parts” on page 77).
9. Replace burner tube in reverse order of removal.

Note: Make sure the two gaskets are positioned correctly and that generator housing is properly sealed.

10. Turn on gas and electric supply to unit.
11. Start unit and check for correct operation.

Extraordinary maintenance

The operations described in this paragraph must be carried out as and when necessary.

- Adding water and antifreeze to the hydraulic plant

If it should be necessary to add water to the plant, add a suitable quantity, making sure that it contains the minimum quantity (see Paragraph 3.5 on page 37).

If necessary (see Paragraph 3.5 on page 37), add to the water in the plant (free from impurities) glycol antifreeze of the inhibited monoethylene type in a quantity in proportion to the MINIMUM winter temperature in the area of installation.

For the filling operation, proceed as described in Paragraph 3.5.

Bring the plant to the correct pressure, making sure that the water pressure is never less than 14.5 PSIg and does not exceed 29 PSIg.

Appendix C – Capacity and Performance Curves

Figure 41 shows the manufacturer stated gas utilization efficiency (output heat/input gas) and Figure 42 shows the output capacity curves at four outlet hot water temperatures. The performance curves were generated from the output capacity tables reported in the product submittal data (see Appendix A) and assume a constant gas input rate of 95,500 Btu/hr as advised by the manufacturer.

FIGURE 41 - GAHP-A PERFORMANCE CURVES

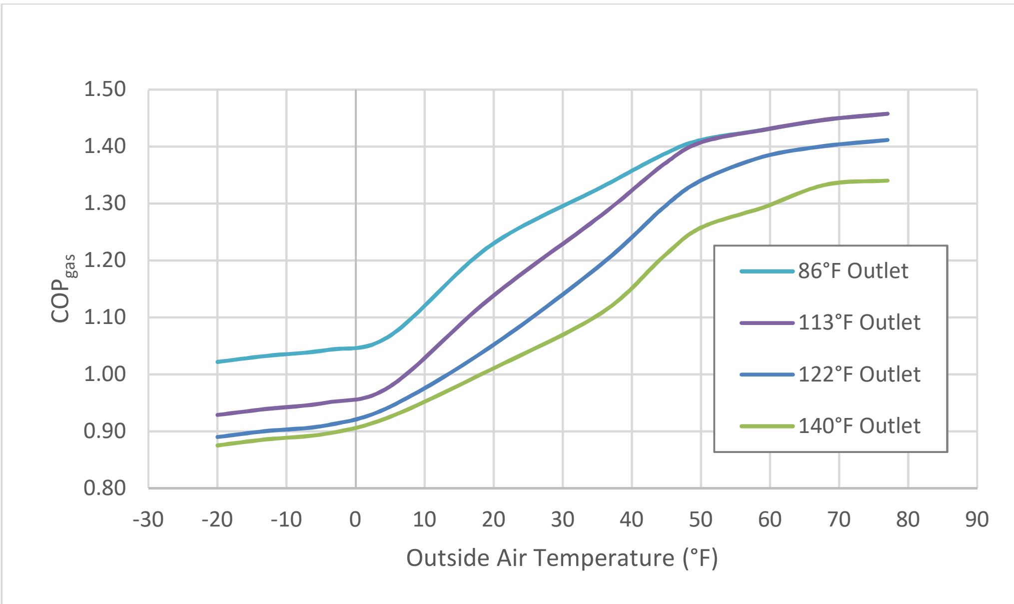

FIGURE 42 - GAHP-A OUTPUT CAPACITY CURVES