Gas Absorption Heat Pump (GAHP) #1 Performance Mapping

Project Number ET23SWG0015

GAS EMERGING TECHOLOGIES (GET) PROGRAM
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Abbreviations and Acronyms

Term	Abbreviations and Acronym
British Thermal Unit	BTU
California Long Term EE Strategic Plan	CLTEESP
Coefficient of Performance	COP
Carbon Dioxide	CO_2
Cubic Foot	CF
Energy Efficiency	EE
Gallon	GAL
Gallons per Minute	GPM
Gas Absorption Heat Pump	GAHP
Gas Emerging Technologies	GET
Greenhouse Gas	GHG
Gas Technology Institute	GTI
Higher Heating Value	HHV
Hour	H
Kilo British Thermal Unit	KBTU
Kilogram	KG
Kilowatt	KW
Measurement & Verification	M&V
Outside Air Temperature	OAT
Part Load Percentage	PLR
Pound-Mass	LBM
Pounds per Square Inch	PSI
Pounds per Square Inch Absolute	PSIA
Relative Humidity	RH
Return Temperature	RT
Supply Water Temperature	SWT
Thermal Heat Pump	THP

Executive Summary

The GET Program conducted a laboratory study to evaluate the performance of a commercially available gas absorption heat pump (GAHP) unit. In collaboration with GTI Energy who provided laboratory services and technical assistance, a thorough test plan was developed to include equipment commissioning, a steady state evaluation, a defrost evaluation, and a load-based evaluation of the Robur GAHP-A unit.

During the steady state testing, the system limitations were discovered where short cycling occurred. This was ultimately due to test conditions, which resulted in the supply water temperature (SWT) exceeding the rating of the equipment at 140°F. Note that short cycling data points were excluded from the steady state analysis. The results proved to be consistent with the manufacturer's published data, therefore, providing sufficient steady state capacity measurements to be implemented in the load-based analysis.

Although the defrost testing proved to have minimal impact with an average derate of 2.6% relative to electric-driven heat pumps of up to 15%, it is recommended that additional defrost testing be conducted to properly characterize defrost derate across multiple operating conditions.

The load-based testing was conducted using the steady state testing operating conditions where various cycle ON and OFF times were tested. Note that test conditions where short cycling occurred were omitted in the load-based testing. Based on the steady state capacity experimental data, the load-based curves were developed where the coefficient of performance (COP) as a function of part load percentage was modeled using a logarithmic trendline.

EnergyPlus modeling performance curves were developed, which resulted in a ±6% accuracy to all operating conditions evaluated according to the test plan developed. These performance curves will then be integrated with EnergyPlus to develop the GAHP modeling portfolio as part of a separate collaborative GET Project (ET22SWG0009) with the National Renewable Energy Laboratory (NREL).

Introduction

This study aims to characterize the performance of the Robur GAHP-A unit to sufficiently populate model inputs in EnergyPlus. Gas heat pump water technology is a new technology where evidence-based lab testing has confirmed that the technology functions well and can save approximately 50% over the incumbent technology. Some key advantages of a GAHP unit over the incumbent equipment include the following [1, 2]:

- Reduction in energy usage – Heat pumps have the capability to operate over 100% efficiency (COP basis).
- Maintain optimal efficiency levels – The thermal compressor integrated in GAHP units is more efficient and has lower operation costs relative to traditional gas-fired appliances.
- Lower emissions – The reduction in full reliability on fossil fuels ultimately lowers emissions relative to traditional heating/cooling systems.
- Decentralized heating/cooling – GAHPs are suitable for decentralized heating and cooling applications, which reduces the need for extensive energy transportation infrastructure.

With water heating being the largest non-industrial end-use of natural gas in California, a significant impact can be made where reductions in natural gas consumption are implemented. The targeted sector for this study is specific to commercial or multifamily, low-rise (i.e., three stories or less) buildings.

With the recent passing of California legislation including SB 1477 (building decarbonization/space heating/water heating), California Long Term EE Strategic Plan (CLTEESP), and AB 758 (comprehensive energy efficiency (EE) in existing buildings law), there is a collective push for energy efficiency solutions specifically in the commercial sector.

The testing to be used for EnergyPlus modeling consists of both static performance mapping and transient performance mapping.

Assessment Objectives

The main objective of this laboratory study is to conduct a comprehensive analysis on a market-ready GAHP unit to integrate performance mapping curves in EnergyPlus. This is part of an ongoing study to test various market-ready heat pump units to contribute to the EnergyPlus heat pump modeling portfolio and increase its overall accuracy and versatility. Within the EnergyPlus modeling space, the primary objectives include forecasting of energy consumption, utility bills, and greenhouse gas (GHG) emissions. The targeted audience includes California policymakers, program designers, software developers, and manufacturers.

Test Plan

This test plan was designed to split the laboratory testing into three phases – commissioning, steady state evaluation, and load-based (transient) evaluation. The commissioning phase of the system is based on the manufacturer's published performance data per the test point outlined in Table 1. Corresponding testing tolerances for the commissioning phase are outlined in Table 2.

Table 1: Target conditions for commissioning test.

Test Point	Dry Bulb Outdoor Air Temperature (OAT), °F	Return Temperature (RT), °F	Flow Rate, GPM
1	44.7	104	13.6

Table 2: Commissioning test tolerances.

Variable	Tolerance
Return and Supply Heating Loop Temperatures	±1.0°F
Heating Loop Flow	±2.0%
Simulated Outdoor Air Dry-bulb Temperature	±1.0°F
Firing Rate	±2.0%
GAHP-A Electrical Power	±1%
% CO_2 in Exhaust (Initial Commissioning Only)	±0.4%

The steady state evaluation was performed over a range of operating conditions outlined in

Table 3. In addition to a steady state evaluation, Table 4 outlines the test points for the defrost evaluation. Corresponding testing tolerances for the steady state phase are outlined in Table 5.

Table 3: Target conditions for steady state evaluation.

<table>
<tr><th>Test Point</th><th>Dry Bulb Outdoor Air Temperature (OAT), °F</th><th>Return Temperature (RT), °F</th><th>Flow Rate, GPM</th></tr>
<tr><td>1-6</td><td>110</td><td rowspan="4">1) 120
2) 110
3) 95</td><td rowspan="4">1) 13.6
2) 7.0</td></tr>
<tr><td>7-12</td><td>90</td></tr>
<tr><td>13-18</td><td>75</td></tr>
<tr><td>19-24</td><td>60</td></tr>
</table>

Test Point	Dry Bulb Outdoor Air Temperature (OAT), °F	Return Temperature (RT), °F	Flow Rate, GPM
25-30	47		
31-36	35		
37-42	17		
43-48	15		
49-54	7		
55-60	0		

Table 4: Target conditions for defrost evaluation.

Test Point	Dry Bulb Outdoor Air Temperature (OAT), °F	Return Temperature (RT), °F	Flow Rate, GPM
1	35	120	13.6
2		110	
3		120	7.0
4		110	

Table 5: Steady state and defrost evaluation tolerances.

Variable	Tolerance
Return and Supply Heating Loop Temperatures	±2.0°F
Heating Loop Flow	±2.0%
Simulated Outdoor Air Dry-bulb Temperature	±2.0°F
Glycol Concentration	±3.0%

The load-based evaluation was performed over a range of operating conditions outlined in Table 6. Corresponding testing tolerances for the load-based phase are outlined in Table 7.

Table 6: Target conditions for load-based evaluation.

Test Point	Dry Bulb Outdoor Air Temperature (OAT), °F	Return Temperature (RT)/Flow Rate (GPM)	Cycle ON-time, hr.	Cycle OFF-Time, hr.
1-36	110	1) 120°F / 13.6 2) 95°F / 7.0	1) 0.9 2) 0.7	1) 1.0 2) 0.5
37-72	90			

Test Point	Dry Bulb Outdoor Air Temperature (OAT), °F	Return Temperature (RT)/Flow Rate (GPM)	Cycle ON-time, hr.	Cycle OFF-Time, hr.
73-108	75		3) 0.5 4) 0.3 5) 0.2 6) 0.1	3) 0.2
109-162	60	1) 120°F / 13.6 2) 110°F / 7.0	1) 0.9 2) 0.7 3) 0.5 4) 0.3 5) 0.2 6) 0.1	1) 1.0 2) 0.5 3) 0.2
163-216	47			
217-270	35			
271-324	17			
325-378	15			
379-432	7			
433-450	0	1) 95°F / 7.0	1) 0.9 2) 0.7 3) 0.5 4) 0.3 5) 0.2 6) 0.1	1) 1.0 2) 0.5 3) 0.2

Table 7: Load-based tolerances.

Variable	Tolerance
Return and Supply Heating Loop Temperatures	±5.0°F
Heating Loop Flow	±2.0%
Simulated Outdoor Air Dry-bulb Temperature	±5.0°F
Glycol Concentration	±3.0%

Equipment Commissioning

The GAHP-A was installed in GTI Energy's thermal heat pump (THP) testbed. Figure 1 shows the installation of the unit from multiple angles.

Figure 1: GAHP-A installation pictures [3].

Figure 2 shows the measuring and verification (M&V) instrumentation used for this evaluation, including the THP testbed environmental chamber equipment. Simplified details and tags of the M&V instrumentation are described in Table 8.

Figure 2: Diagram of the M&V instrumentation [3].

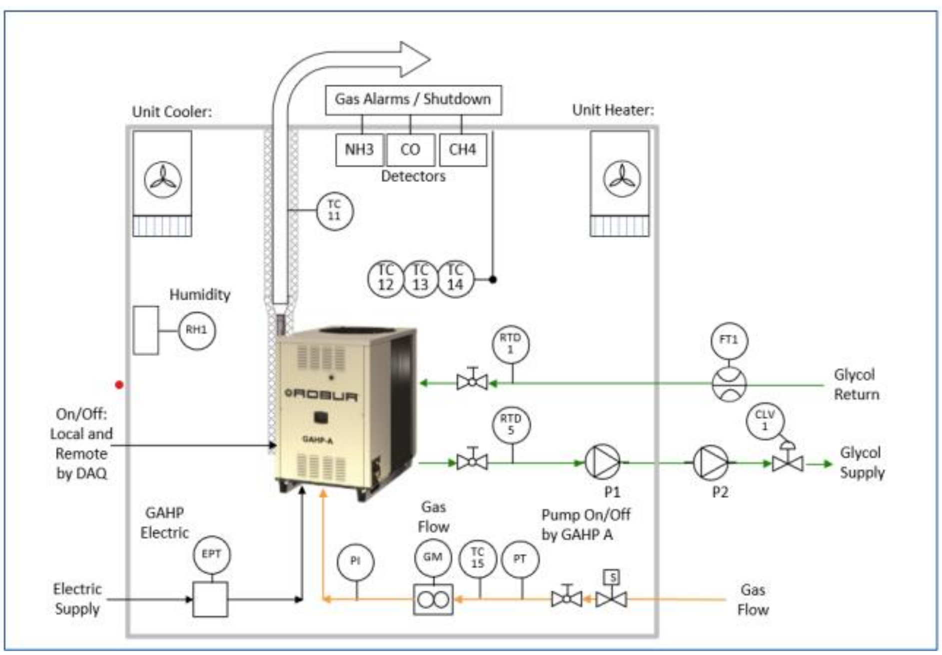


Table 8: Instrumentation tags and details.

Tag	Measurement
RTD1	GAHP-A return temperature
RTD5	GAHP-A supply temperature
TC15	Natural gas temperature
TC12, 13, 14	Environmental chamber temperatures
TC11	Exhaust gas temperatures
NG PT	Natural gas inline pressure
FT1	GAHP-A flow rate
GM	Natural gas flow rate
EPT	GAHP power
RH1	Environmental chamber humidity

Additional details on the testbed hydronic test rig and gas valve set-up which preceded the commissioning test can be found in Appendix 1.0.

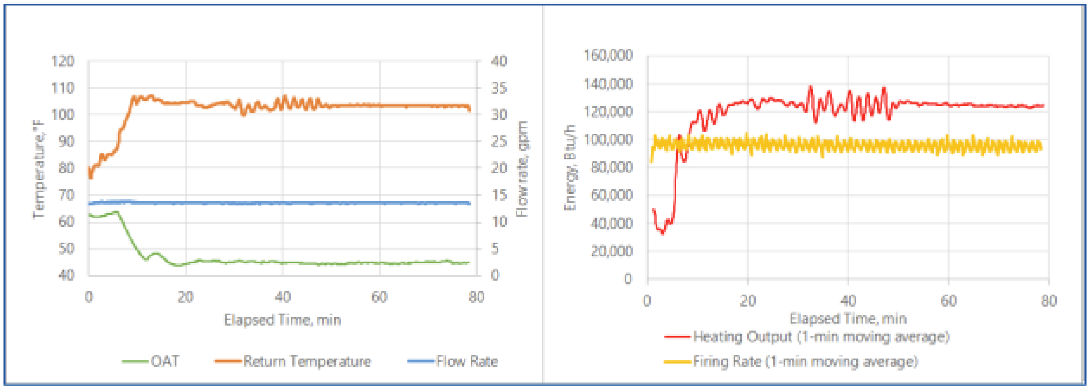
The GAHP-A system was operated at the predefined steady state rating conditions per the conditions and tolerances outlined in Table 1 and Table 2. The commissioning was performed by first running the GAHP-A after calibrating the gas valve manifold pressure. The THP testbed equipment controlled the target simulated OAT and RT and the evaluation took approximately 80 minutes to achieve the target operating conditions. Energy rates were calculated and compared with the manufacturer's specification per the 15-minute average test results and published values outlined in Table 9. Additionally, the time series of the key variables outlined in Table 9 are shown in Figure 3 [3].

Table 9: Test results compared to published values.

Variables	Test Results	Published Values [4]
Flow Rate	13.5 GPM	13.6 GPM
Outdoor Air Temperature	44.9°F	44.6°F
Return Temperature	103.3°F	104°F
Supply Temperature	121.7°F	122°F
Firing Rate	95,562 Btu/h	95,500 Btu/h
Energy Output	123,743 Btu/h	123,500 Btu/h
Gas COP	1.29	1.29

Variables	Test Results	Published Values [4]
Fumes Flow Rate	1,220 CFH @ 1,040 Btu/cF (HHV calculated based on EPA Method 19 [5])	1,750 CFH @ 1,014 Btu/cF HHV

Figure 3: Time series of commissioning condition.



Calculations

Steady State and Load-Based Evaluation

The performance results include the energy input, power, heating output, and the COP. The energy input will be calculated using Equation 1.

Equation 1: Energy input.

$$Q_{in} = \sum V_g \cdot \frac{P_a}{P_s} \cdot \frac{T_s}{T_a} \cdot HHV$$

where

Q_{in} = accumulated natural gas energy input, British thermal unit (Btu).
V_g = natural gas volume, cubic foot (CF).
P_a = actual line pressure and barometric pressure, pounds per square inch absolute (psia) (referencing weather data).
P_s = standard pressure of 14.969 pounds per square inch (psi).
T_a = actual line temperature, °R.
T_s = standard temperature of 520°R.
HHV = natural gas higher heating value (HHV), Btu/cF (values to be measured daily).

Following these calculations in Equation 1, the energy input will be converted to a firing rate as a rolling average over each test point period.

The electricity consumption ($Q_{Elec,GAHP}$) of the GAHP-A unit will be directly measured using a watt node. Each test point will be evaluated and converted to power and energy demand for the given test periods.

The GAHP-A hydronic energy output will be calculated using Equation 2.

Equation 2: Energy output.

$$Q_{out_f} = \sum \dot{V}_f \cdot C_{p_f} \cdot \rho_f \cdot (T_S - T_R) \cdot \Delta t$$

where

Q_{out_f} = GAHP-A accumulated energy output, Btu.

$\dot{V}_f$ = heating loop flow rate, gallons per minute (gpm).

c_{p_f} = heating loop specific heat as a function of average process temperature and volume base glycol water mix %, Btu/pound-mass (lbm)-°F

ρ_f = heating loop density at the average process temperature and volume base glycol water mix %, lbm/gallon (gal).

T_S = water glycol loop supply temperature, °F.

T_R = water glycol loop return temperature, °F.

Δt = data logger time-step of 5 seconds, min.

With Equation 1 and Equation 2 defined, the gas only COP and the overall system COP (includes electric power consumption) can be calculated according to Equation 3 and Equation 4, respectively:

Equation 3: Gas only COP.

$$COP_g = \frac{\dot{Q}_{out_f}}{\dot{Q}_{in}}$$

Equation 4: Overall system COP (including electric power consumption).

$$COP_{GAHP} = \frac{\dot{Q}_{out_f}}{\dot{Q}_{in} + \dot{Q}_{Elec,GAHP}}$$

The COP ratio can be calculated by incorporating both the steady state and load-based results according to Equation 5 and Equation 6, respectively.

Equation 5: Gas only COP ratio.

$$COP_g\ Ratio = \frac{COP_{g,load-based}}{COP_{g,SS}}$$

Equation 6: Overall system COP raio.

$$COP_{GAHP}\ Ratio = \frac{COP_{GAHP,load-based}}{COP_{GAHP,SS}}$$

where

$COP_{g,SS}$ = gas only COP at relative steady state testing parameter.

$COP_{GAHP,SS}$ = overall system COP at relative steady state testing parameter.

$COP_{g,load-based}$ = gas only COP at load-based testing parameter.

$COP_{GAHP,load-based}$ = overall system COP at load-based testing parameter.

The part load percentage (PLR) is represented by Equation 7.

Equation 7: PLR.

$$PLR = \frac{\dot{Q}_{out_f,load-based}}{\dot{Q}_{out_f,SS}} \cdot 100\%$$

where

$\dot{Q}_{out_f,SS}$ = GAHP-A accumulated energy output at relative steady state testing parameter, Btu/hour (h).

$\dot{Q}_{out_f,load-based}$ = GAHP-A accumulated energy output at load-based testing parameter, Btu/h.

EnergyPlus Performance Curve Development

Heating Output Rate

The following outlines the equations used to develop the EnergyPlus performance curves based on the lab data and analysis. The GAHP-A heating capacity outlined in Equation 8 is used to calculate the part-load performance in EnergyPlus. The capacity is also used to estimate the gas input and power utilization of the GAHP which are both outlined in Equation 10 and Equation 14, respectively.

Equation 8: Heating output rate.

$$GAHP\ Heating\ Capacity = RatedCapacity \cdot CAPFT$$

where

$GAHP\ Heating\ Capacity$ = heating capacity output rate, kilo British thermal unit (kBtu)/h.

$RatedCapacity$ = 123.5, kBtu/h.

$CAPFT$ = heating capacity correction factor as a function of ambient and return temperature (Equation 9).

The heating capacity correction factor (CAPFT) is calculated using Equation 9.

Equation 9: CAPFT.

$$CAPFT = a1 + b1 \cdot Tret + c1 \cdot Tamb + d1 \cdot Tret^2 + e1 \cdot Tret \cdot Tamb + f1 \cdot Tamb^2 + g1 \cdot Tret^3 + h1 \cdot Tret^2 \cdot Tamb + i1 \cdot Tret \cdot Tamb^2 + j1 \cdot Tamb^3$$

where

$Tamb$ = heating capacity output rate, kBtu/h.

$Tret$ = 123.5, kBtu/h.

i_1 = coefficients listed in

Appendix 5.0 (Table 16).

Gas Input Utilization

The GAHP-A gas input utilization is calculated according to Equation 10.

Equation 10: Gas input utilization.

$$GAHP\ Gas\ Use = \frac{Load \cdot EIRFT \cdot EIRFPLR \cdot EIRDEFROST}{CRF}$$

where

$GAHP\ Gas\ Use$ = gas utilization, kBtu.

$Load$ = EnergyPlus heating load as a function of time, kBtu.

$EIRFT$ = gas utilization operating conditions correction factor (Equation 11).

$EIRFPLR$ = gas utilization cycling correction factor (Table 18).

$EIRDEFROST$ = defrost factor (Equation 12).

CRF = gas input utilization correction factor as a function of cycling operation for modulating equipment (Equation 13).

The gas input utilization operating conditions correction factor (EIRFT) is calculated using Equation 11.

Equation 11: EIRFT.

$$EIRFT = a2 + b2 \cdot Tamb + c2 \cdot Tamb^2 + d2 \cdot Tret + e2 \cdot Tamb \cdot Tret + f2 \cdot Tamb^2 \cdot Tret$$

where

i_2 = coefficients listed in

Appendix 5.0 (Table 17).

The gas input utilization correction factor (EIRFPLR) is calculated using an interpolation method as a function of PLR. PLR is calculated according to Equation 7. The resultant table can be found in

Appendix 5.0 (Table 18).

The defrost factor (EIRDEFROST) is calculated using Equation 12 [8]. Note that GTI Energy recommends implementation of this equation as it is referenced in the "Pathways to Decarbonization of Residential Heating" source.

Equation 12: Defrost factor.

$$EIRDEFROST = -0.0011 \cdot Tamb^2 - 0.006 \cdot Tamb + 1.0317 \; for -8.89°C \leq Tamb \leq 3.333°C$$

The gas input utilization cycling correction factor (CRF) is calculated using Equation 13.

Equation 13: Gas input cycling correction factor.

$$CRF = 0.4167 \cdot CR + 0.5833$$

where

CR = the cycling modulating derate factor that needs to be set to 1 for the GAHP-A.

Power Input Utilization

The GAHP-A power input utilization is calculated using Equation 14.

Equation 14: Power utilization.

$$Electric\ Power\ Consumption = RatedPower \cdot Aux_{Elec,EIRFT} \cdot Aux_{Elec,EIRFPLR}$$

where

$Electric\ Power\ Consumption$ = power input utilization, kWh.

$RatedPower$ = 0.90, kWh.

$Aux_{Elec,EIRFT}$ = power input utilization correction as a function of return and ambient temperatures.

$Aux_{Elec,EIRFPLR}$ = power input utilization correction factor as a function of part-load.

The power input utilization operating conditions correction factor ($Aux_{Elec,EIRFT}$) is calculated using Equation 15.

Equation 15: Power utilization operating conditions correction factor.

$$Aux_{Elec,EIRFT} = a4 + b4 \cdot Tamb + c4 \cdot Tamb^2 + d4 \cdot Tamb^3 + e4 \cdot Tret + f4 \cdot Tamb \cdot Tret$$

where

i_4 = coefficients listed in

Appendix 5.0 (Table 19).

The power input utilization cycling correction factor ($Aux_{Elec,EIRFPLR}$) is calculated using Equation 16.

Equation 16: Power utilization cycling correction factor.

$$Aux_{Elec,EIRFPLR} = a5 \cdot PLR + b5$$

where

i_5 = coefficients listed in

Appendix 5.0 (Table 20).

Steady State Evaluation

All resultant test parameters were measured except for the propylene glycol volume % as this was measured and controlled prior to conducting the experiment. A comprehensive snapshot of the target conditions, the test results summarized at a 15-min average, and the performance results can be found in Appendix 2.0.

It is important to note that for the test results indicated by the '†' symbol, the GAHP unit experienced cycle oscillations or short cycling at the corresponding test conditions; therefore, this data is excluded from the overall performance map.

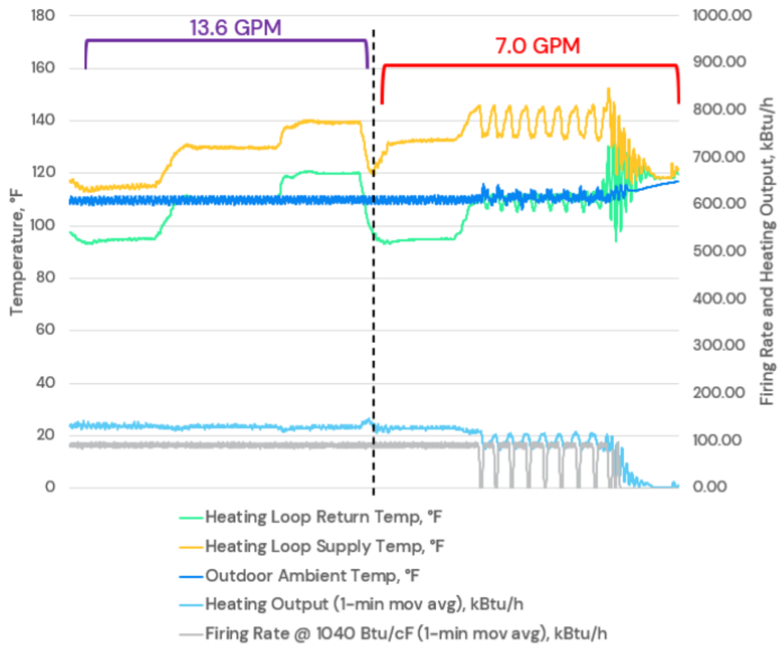
During the initial low OAT tests, the chamber was not cooling effectively, and the chamber temperature drifted up, which resulted in a marginally higher capacity; this led to an increased SWT. Therefore, after the initial low temperature steady state tests, a buffer tank was added to provide a more stable RT while preventing the unit from short cycling during minor temperature deviations. The following results reflect this corrective action.

Of the test points that were outlined in the steady state test matrix in

Table 3, insufficient heating cycles, otherwise known as short cycling, occur at the maximum OAT of 110°F and continues down the testing matrix through an OAT of 35°F. The 110°F OAT cycle is represented in a ~6-hour time series in Figure 4 to illustrate the short cycling behavior.

Figure 4: Timeseries for a cycle at an OAT of 110°F.

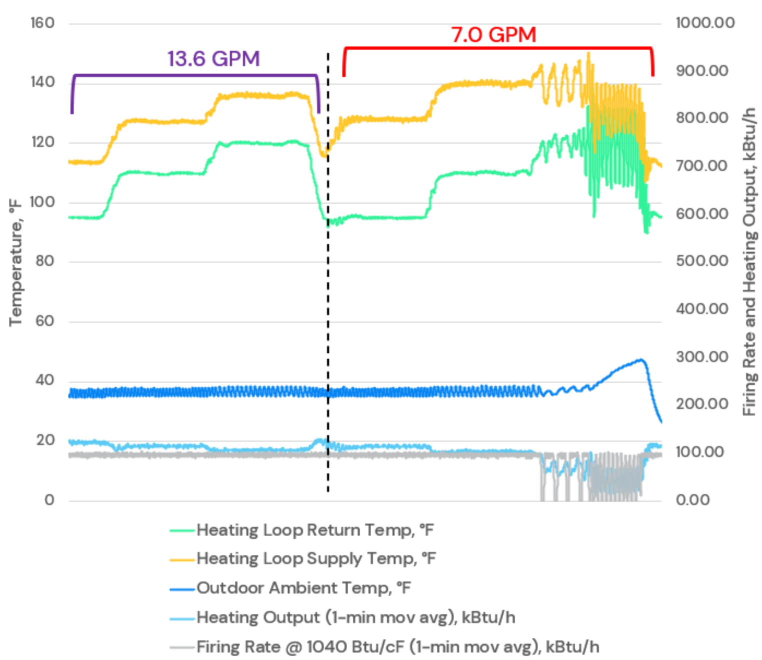
Target Conditions		
Outside Air Temperature (OAT), °F	Glycol Flow Rate, GPM	Return Temperature (RT), °F
110	13.6	95
		110
		120
	7.0	95
		110
		120



Similarly, Figure 5 illustrates the 35°F OAT cycle to offer a comprehensive understanding of both the upper and lower OAT boundaries where short cycling occurs in the GAHP unit.

Figure 5: Timeseries for a cycle at an OAT of 35°F.

Target Conditions		
Outside Air Temperature (OAT), °F	Glycol Flow Rate, GPM	Return Temperature (RT), °F
35	13.6	95
		110
		120
	7.0	95
		110
		120



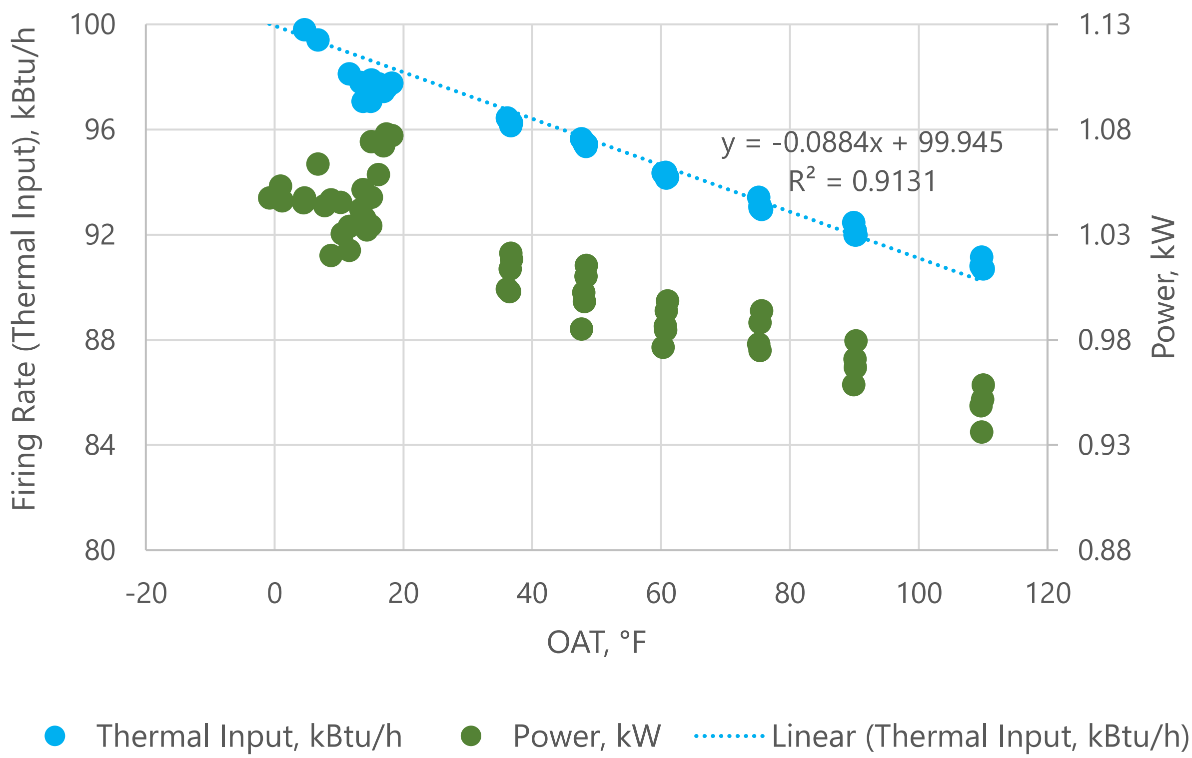
The short cycling behavior that is represented in Figure 4 and Figure 5 occurs at a water-propylene glycol flowrate of 7.0 GPM. Therefore, this suggests that the main driver is the reduction in heat capacity at lower flowrates relative to higher flowrates. Additionally, this suggests that there is insufficient heat exchange between these conditions to keep the unit from reaching its high limit.

Once the OAT falls below 35°F, the GAHP unit does not experience any short cycling at the corresponding glycol flow rate and RT conditions. However, for the testing conditions where short cycling does occur, in addition to the insufficient heat exchange, this behavior can also be attributed to the limitations of the heat pump capacity and the SWT limits. Figure 4 and Figure 5 begin to show oscillatory behaviors at a RT of 110°F and 120°F, respectively, while operating at the 7.0 GPM flowrate. Since the capacity of the heat pump is greater at an OAT of 35°F, the oscillations are lessened relative to the OAT of 110°F. However, an OAT between 35°F and 110°F at a flowrate of 7.0 GPM is not recommended for optimal GAHP performance. If the GAHP is operating under short cycling conditions, there is a greater risk of poor temperature control, high energy usage, more frequent repairs, and additional system wear and tear. Additionally, based on the SWT output which occurs under the short cycling testing conditions, the unit is not able to sufficiently operate at SWTs greater than the rating of the equipment at 140°C.

The operating issues that come with operating the GAHP where short cycling occurs further justifies its exclusion from the overall data output, curve fitting, and overall system performance analysis. Therefore, all subsequent data trends and outputs do not include data where a steady state output could not be reached due to cycling oscillations.

For the performance of the system where short cycling does not occur, Figure 6 is used to represent the overall trend of the firing rate and power as a function of the OAT.

Figure 6: Firing rate [left y-axis] and power [right y-axis] as a function of OAT.



Power consumption decreases at a linear rate as the OAT increases. Therefore, less power is required as the OAT approaches its maximum temperature. However, note that the range at which power decreases is relatively small with a differential of only approximately 0.15 kilowatt (kW).

The relatively small influence that the power has on the overall COP is shown below in Figure 7 and

Figure 8 using the blue and green data points, respectively. In both Figure 7 and

Figure 8, COP is plotted as a function of the temperature differential between RT and OAT to reflect a normalized metric. The blue data points in Figure 7 represent the COP with respect to gas consumption alone and the green data points in

Figure 8 represent the COP with respect to gas and power (electric) consumption. Electric consumption is primarily attributed to the circulating pump and fan components of the GAHP system. Note that the solid blue/green dots and hollow blue/green dots are for operating conditions at a 13.6 GPM and 7.0 GPM flowrate, respectively. Not only is there a minimal difference in COP at the two flowrate conditions, but the same is true for a COP with and without electrical component consumption included.

Additionally, it is important to point out that the COP falls below 1.0 at OATs that fall between 0°F and 17°F. Note the area outlined by the bottom right hand box indicated by the solid black lines in both Figure 7 and

Figure 8. Therefore, it is implied that the incumbent equipment, in this case a condensing boiler, may be more cost efficient than a GAHP retrofit where the OAT falls below 17°F. However, this is not a conclusive finding as there are several unknown factors that would warrant a definitive conclusion.

Figure 7: COP (Gas-Only) as a function of the RT and OAT differential.

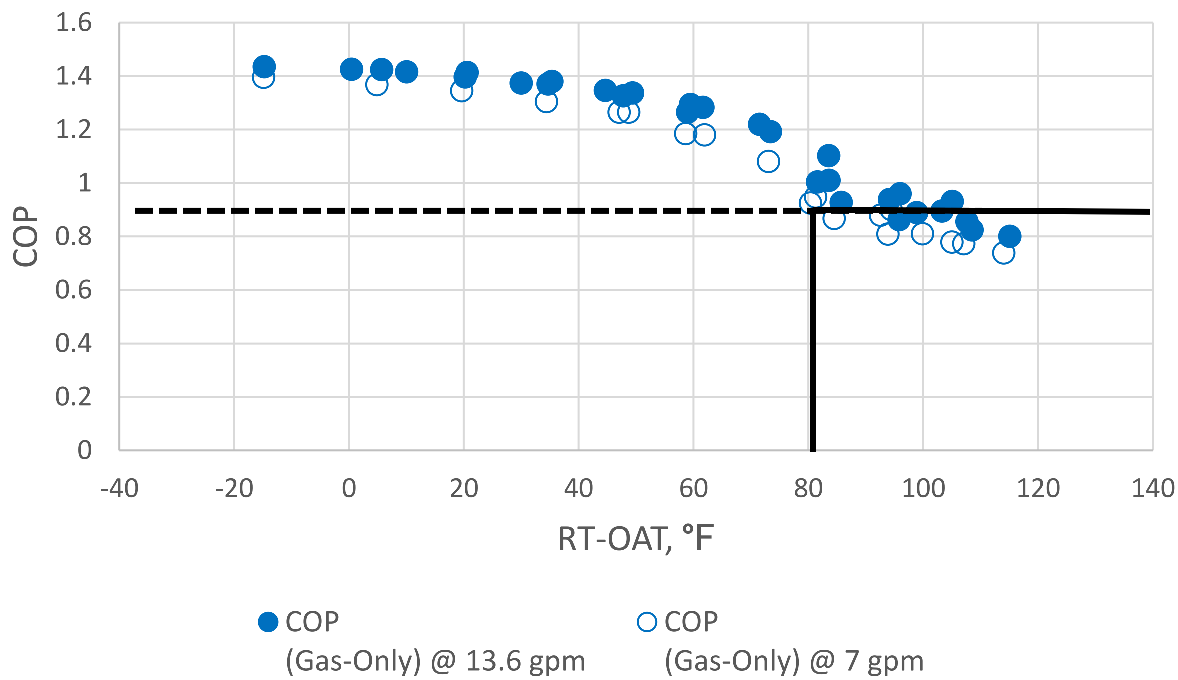
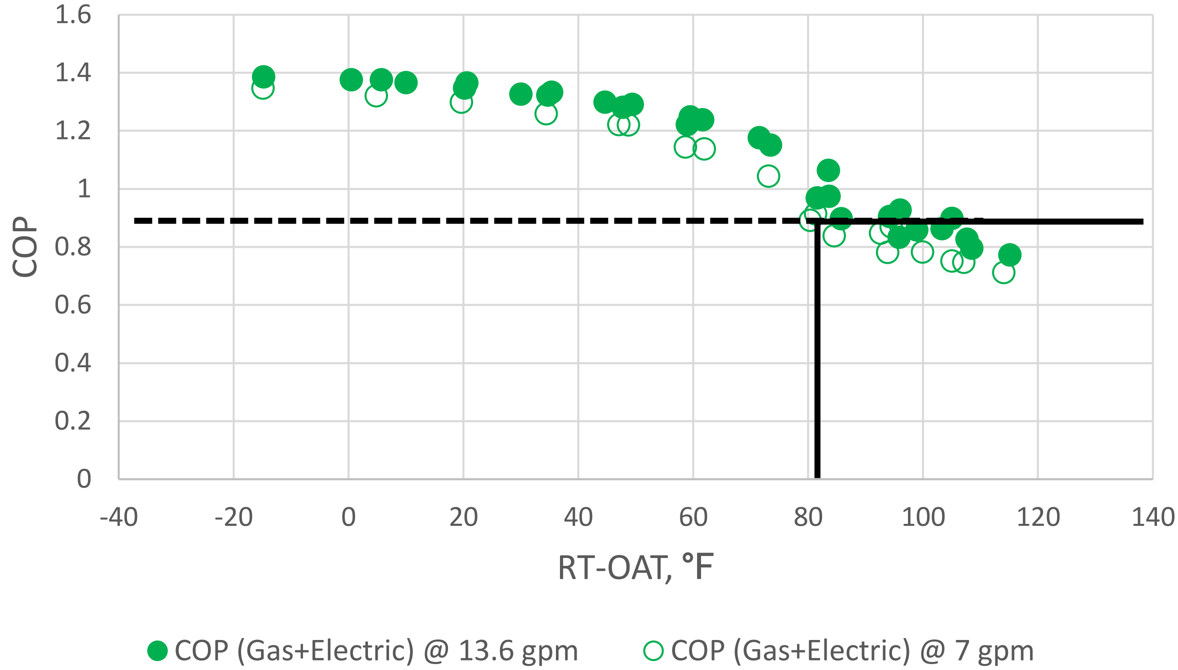
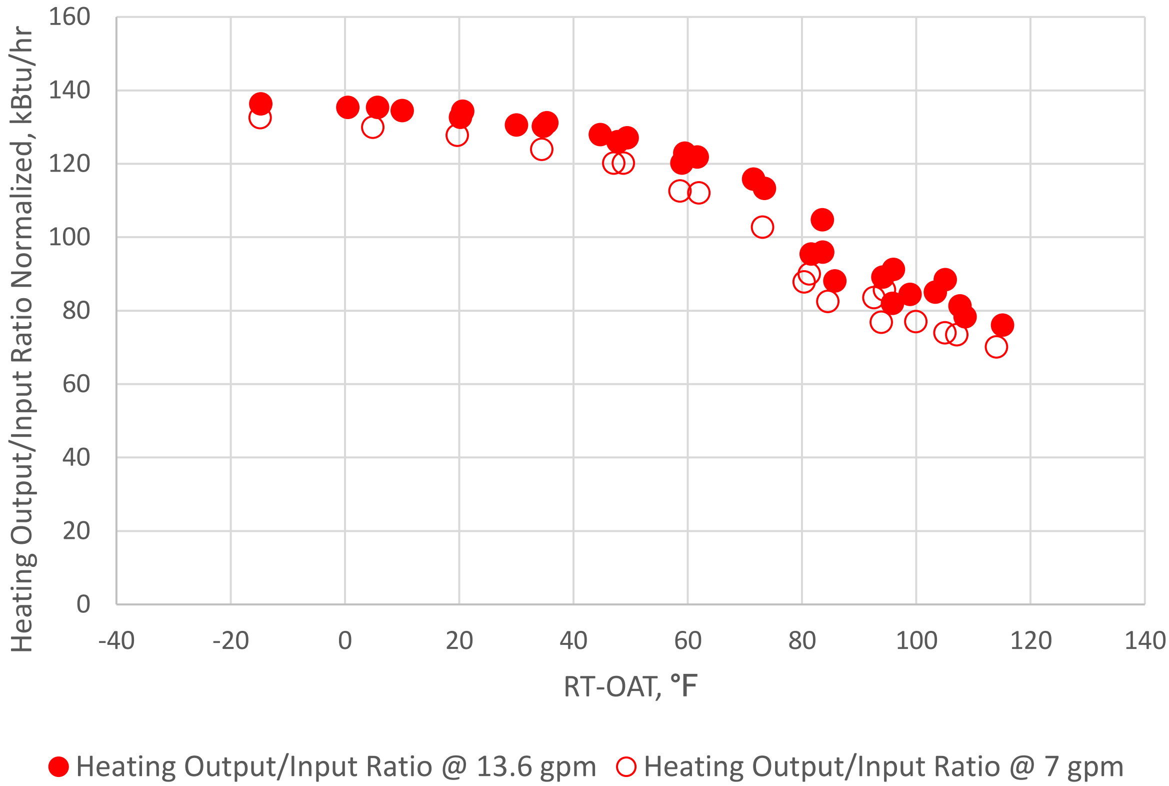


Figure 8: COP (Gas+Electric) as a function of the RT and OAT differential.



Additionally, the normalized heating output, illustrated by the red dots in Figure 9, follows a similar trend to the COP curves. The solid red dots and hollow red dots represent operating conditions at a 13.6 GPM and 7.0 GPM flowrate, respectively. The decreasing COP as the RT and OAT differential increases can be attributed to the higher temperature differential that exists between the target RT and OAT. It is important to note that the COP behavior is contingent on ambient site conditions; therefore, a lower OAT will negatively impact the COP of the system.

Figure 9: Normalized heating output as a function of the RT and OAT differential.



A primary goal of the overall study is to determine how closely the experimental results from this study match the manufacturer's published results.

To establish a one-to-one comparison between the experimental data and manufacturer's data, the information gathered from Figure 6 was revisited. Where the power behavior as a function of the OAT was previously explored, the firing rate as a function of the OAT (the blue line) is of more relevance to compare the experimental and manufacturer data. A linear curve fit is established to approximate the relationship between the firing rate and the OAT. Then, this equation can be used to accurately predict the heating output under the experimental conditions in this study which is illustrated by the red solid dots in Figure 10 and compared to the manufacturer published data.

In Figure 10, the heating output to input ratio is normalized relative to the temperature differential between the RT and the OAT for the experimental data (red solid dots) gathered at a water-propylene glycol mixture flowrate of 13.6 GPM. The yellow, green, and blue solid dots represent the manufacturer's published data at 86°F/13.5 GPM, 113°F/13.0 GPM, and 122°F/12.4 GPM SWT, respectively, with an 18°F temperature differential, and a 35 volume % propylene glycol solution. The overlap amongst all 4 curve trends suggests that close alignment exists between the collected experimental data and the manufacturer's published data.

Figure 10: Alignment of experimental data and the manufacturer's results (13.6 GPM).

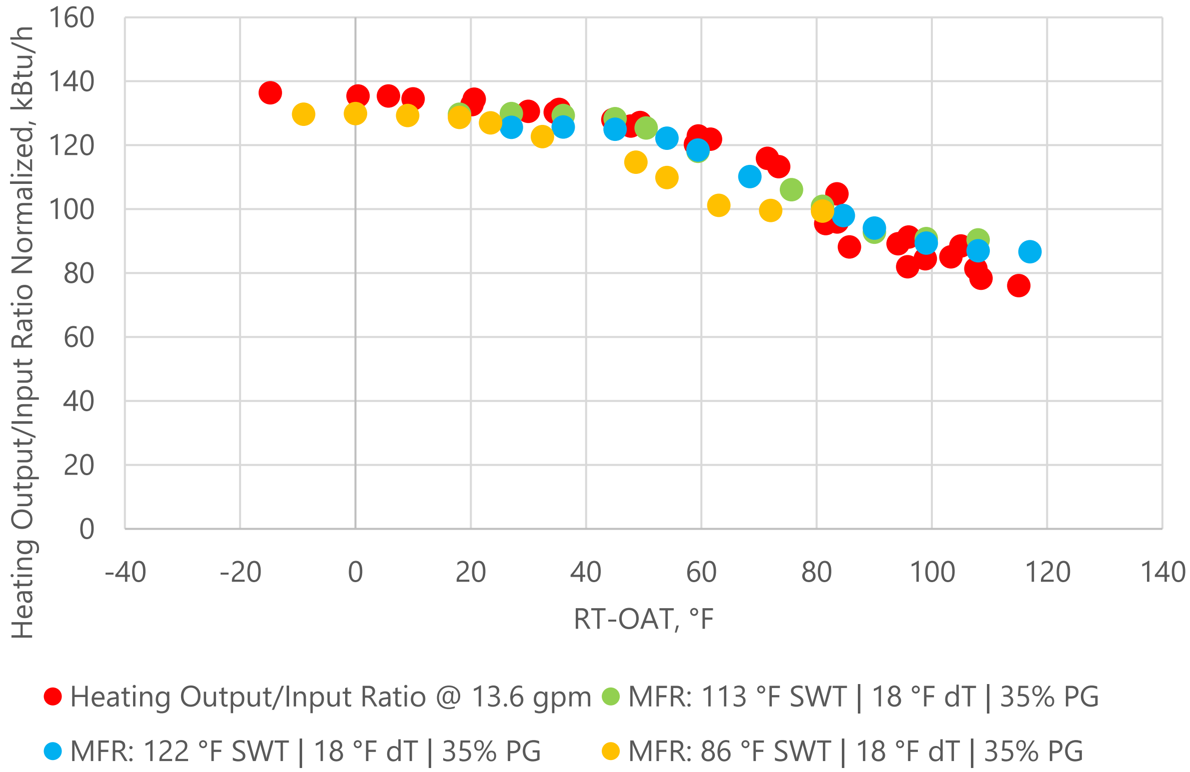
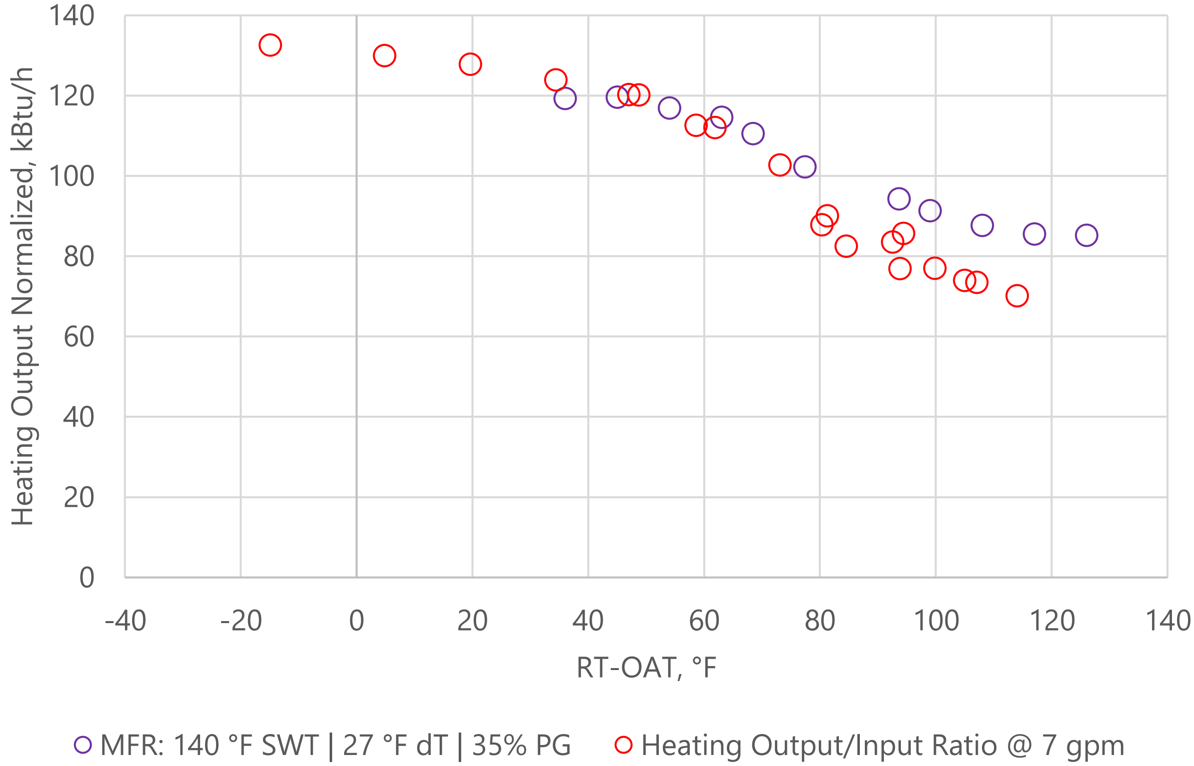


Figure 11 illustrates the normalized experimental heating output to input ratio in the red hollow dots for the water-propylene glycol solution at a flowrate of 7.0 GPM. The purple hollow dots represent the manufacturer's published data at 140°F/7.9 GPM SWT with a 27°F temperature differential, and a 35 volume % propylene glycol solution. There exists some alignment between the manufacturer's data and the experimental test sequence when comparing flowrates at 7.9 GPM and 7.0 GPM, respectively. Similar to the behavior illustrated in Figure 7,

Figure 8, and Figure 9, the decreasing heating output as the RT and OAT differential increases for Figure 9 and Figure 10 can be attributed to the higher temperature differential that exists between the target RT and OAT.

Figure 11: Alignment of experimental data and the manufacturer's results (7.0 GPM).

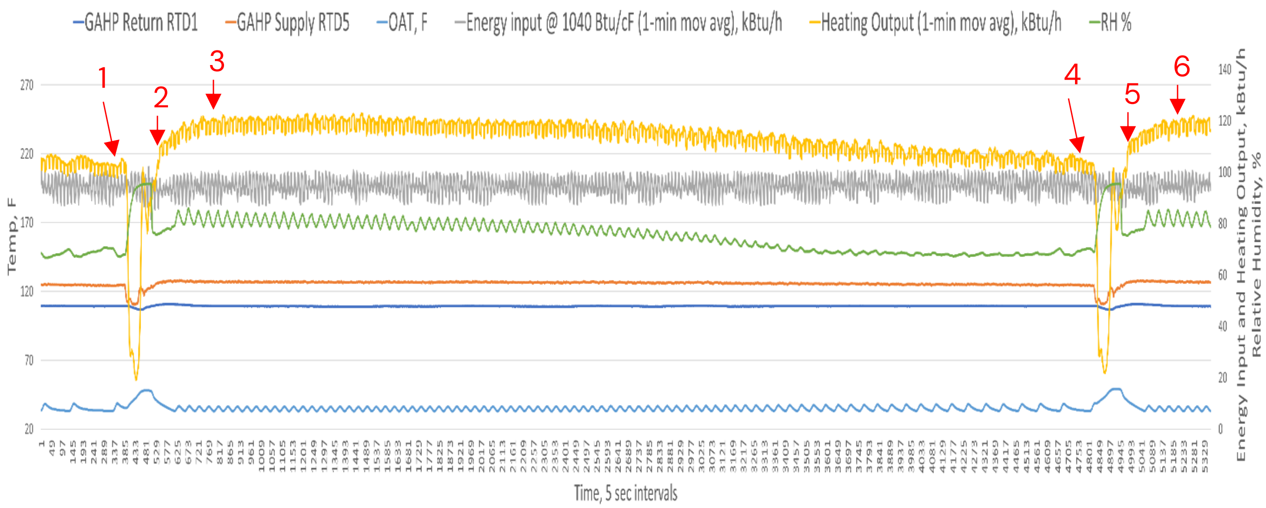


Defrost Characterization

Defrost characterization was also performed per the conditions outlined in Table 4. Defrost conditions can occur in GAHPs near freezing temperatures, particularly when relative humidity (RH) levels are high. While the environmental chamber unit experienced cooler defrost cycles at this condition, there were no clear defrost cycles of the GAHP-A. The project team at GTI Energy determined that the humidity levels in the environmental chamber were insufficient for this test. Therefore, a General Filters 5500 model steam humidifier was installed and operated to increase the environmental chamber humidity at frosting temperatures. The steam humidifier injected steam into the environmental chamber, with a rated capability of 1.6 to 4.5 kilogram (kg)/h of steam. It was operated to maintain 80% to 100% RH in the chamber during the conditions outlined in Table 4 [3].

An example curve of two defrost cycles is shown below in Figure 12 which illustrates a time series of the RT, SWT, OAT, energy input, heating output, and RH percentage.

Figure 12: Timeseries @ 5 second intervals of two defrost cycles.



The key metrics to focus on here are the yellow curve and gray curve which illustrate the heating output and energy input, respectively; these metrics define the COP or heat pump efficiency. The uptake in RH, illustrated by the green curve, and rapid decline of heating output occurring at the far left and right points on the graph reflect the onset of a defrost cycle; this occurs between points 1-2 and 4-5. Just before the onset of the defrost cycle, at point 1, the heating output is stabilized at approximately 103 kBtu/h and the energy input is stabilized at approximately 94 kBtu/h. The heat pump remains in the defrost cycle for approximately 10 minutes before returning to the previous heating output recorded at point 1. It takes approximately 20 minutes before the heating output reaches its highest stabilized condition at point 3. Note that upon fully exiting the defrost cycle and returning to normal operating conditions at point 3, the heat pump stabilizes at a heating output of approximately 120 kBtu/h. This is 17 kBtu/h greater than the stabilized heating output recorded prior to the defrost cycle at point 1. Prior to the second defrost cycle at point 4, the heating output returns to its steady state of approximately 103 kBtu/h. This initial jump in heating output occurs as the system is restarting its normal operations and eventually returns to its steady state. A similar pattern occurs for the second defrost cycle as was described for the first defrost cycle.

A summary of the defrost characterization results per the conditions outlined in Table 4 is shown in Appendix 3.0.

Note that the defrost derate percentage refers to the reduction in capacity or performance of the GAHP system during the defrost cycle. Test point 4, which corresponds to an RT and flow rate of 95°F and 7.0 GPM, resulted in the highest defrost derate at 5.7%, whereas test point 3 resulted in the lowest defrost derate of 0.5% which corresponded to a RT and flow rate of 110°F and 7.0 GPM. Since the combustion air is pulled from the outside environment, the outside humidity and temperature conditions may have contributed to variances in the data during the simulated defrost testing conditions.

Test results suggest additional evaluation is needed to properly characterize defrost derate across multiple operating conditions, e.g. 0°F to 40°F OAT and 40% to 100% RH levels. That said, the overall impact of the average 2.6% derate is minimal relative to electric-driven heat pumps of up to 15%. Examples of capacity reduction in cold climate air source heat pump shows 9% to 15% drop as a result of defrost [3, 6-7].

Load-Based Evaluation

All resultant test parameters were measured except for the propylene glycol volume % as that was measured and controlled prior to conducting this part of the experiment. A comprehensive snapshot of the target conditions, the test results summarized at a 15-min average, and the performance results for the load-based testing can be found in Appendix 4.0. Figure 13 and

Figure 14 illustrate the relationship of the COP_g and COP_{GAHP} ratios as a function of the PLR, respectively.

Figure 13: COP_g Ratio as a function of the PLR.

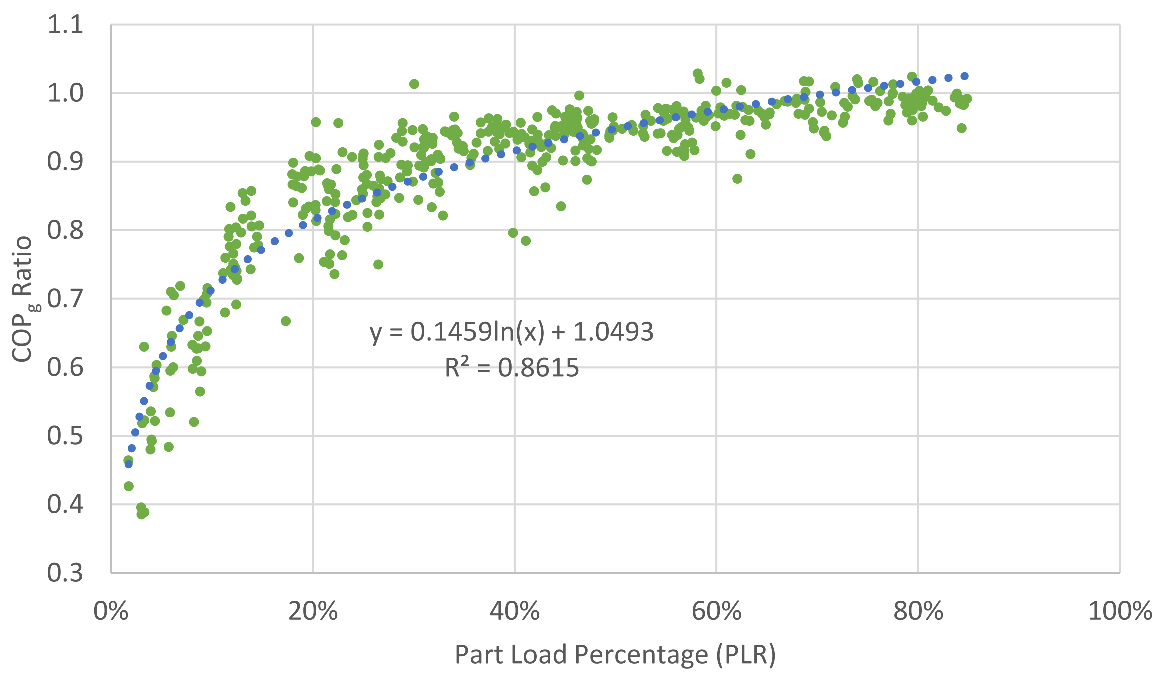
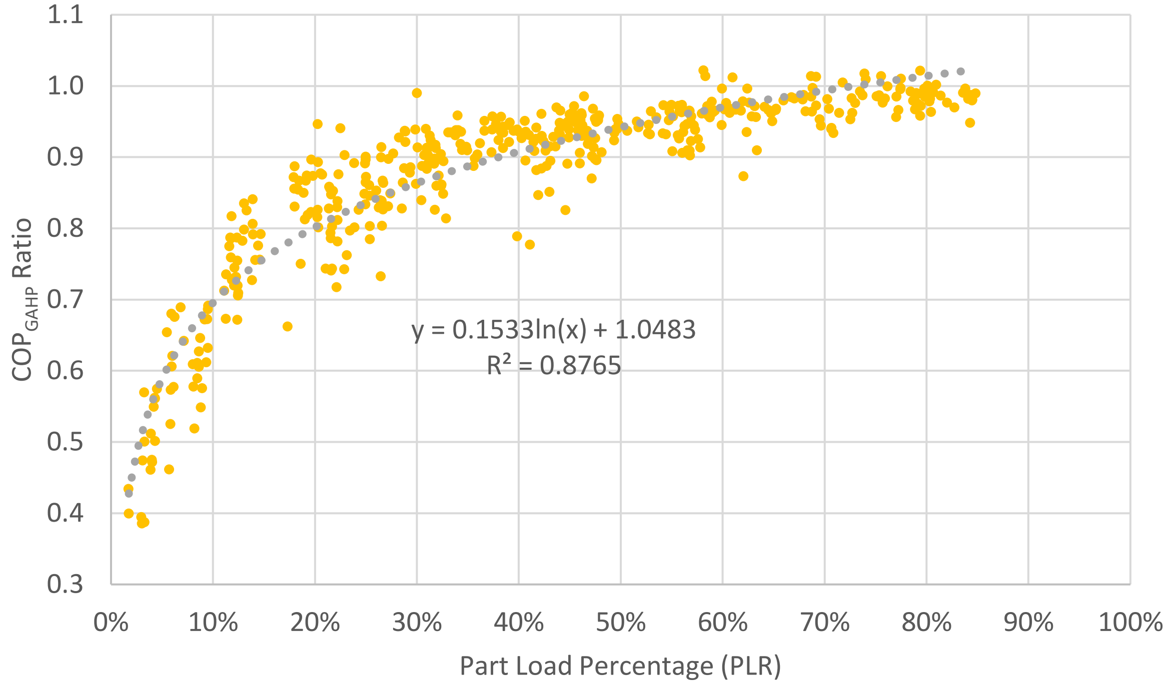


Figure 14: COP_{GAHP} Ratio as a function of the PLR.



The relative steady state data is the maximum capacity achievable at the respective testing conditions relative to the load-based data. Therefore, the COP ratio is used to show the efficiency of the GAHP unit with respect to the load. Based on the plotted data points, a logarithmic trendline is sufficient to model the experimental data across various loads as the R^2 value is large at 0.8615 and 0.8765 for Figure 13 and

Figure 14, respectively. Based on the raw data, the larger part load percentages correspond to a longer cycle runtime and shorter cycle off time. This allows sufficient time for the GAHP to reach its steady state, which ultimately limits COP degradation. Note that there is minimal difference between the COP_g and COP_{GAHP} ratios, therefore, implying that the electrical components have minimal effect on the overall GAHP efficiency. Electric consumption is primarily attributed to the circulating pump and fan components of the GAHP system.

Draft Field Test Comparison

As part of the GET program, a separate field test (ET23SWG0002) is also being conducted with the GAHP-A unit. Following a thorough M&V instrument installation, the unit was set to run at variations conditions. Averages were taken of the field operating conditions and are populated in Table 10. Note that there are several OAT and RT lab test combinations to choose from, however, the ones listed were selected to draw sufficient comparisons between the draft field and lab data.

Table 10: Sample Field and Lab Test Points.

Variable	Field Test	Lab Test
Outdoor Air Temperature (OAT)	122°F	120°F
Return Temperature (RT)	68°F	75°F
Flow Rate	16 GPM	13.6 GPM

Figure 15 shows the lab test conditions at various cycle ON run times; this is illustrated to outline the effects of longer cycle on run times with respect to GAHP's ability to achieve steady state. Figure 16 shows the field test condition and minute frequencies with respect to the minute at which the GAHP was running during any given cycle. In both cases, the COP reaches its steady state in approximately 20-30 minutes. However, note that the steady state COP in Figure 15 and Figure 16 are about 1.38 for the lab tests and 1.10 for the draft field tests, respectively. The difference may be attributed to the controlled aspect of the lab test where temperature fluctuations are more infrequent, and load variations are controlled relative to conditions in the field.

Figure 15: Lab test COP – Gas Only for various cycle on times as a function of runtime.

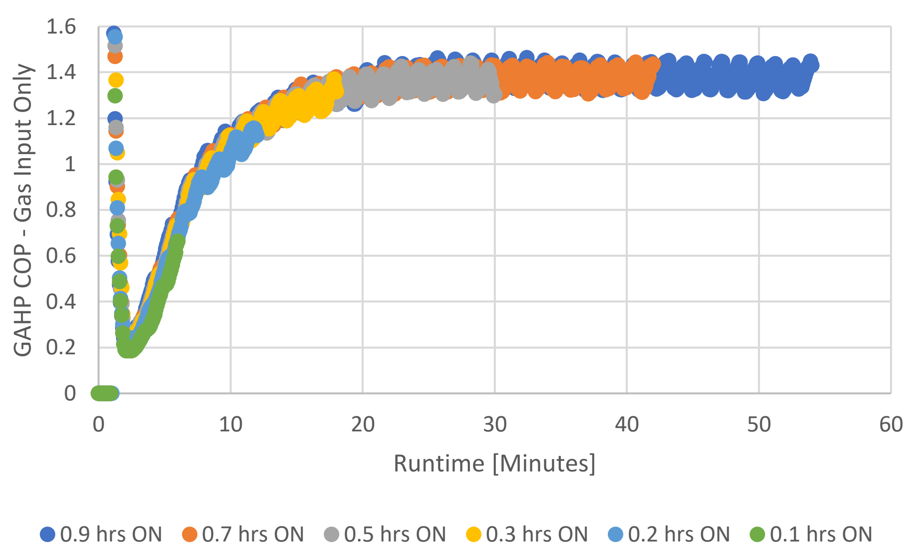
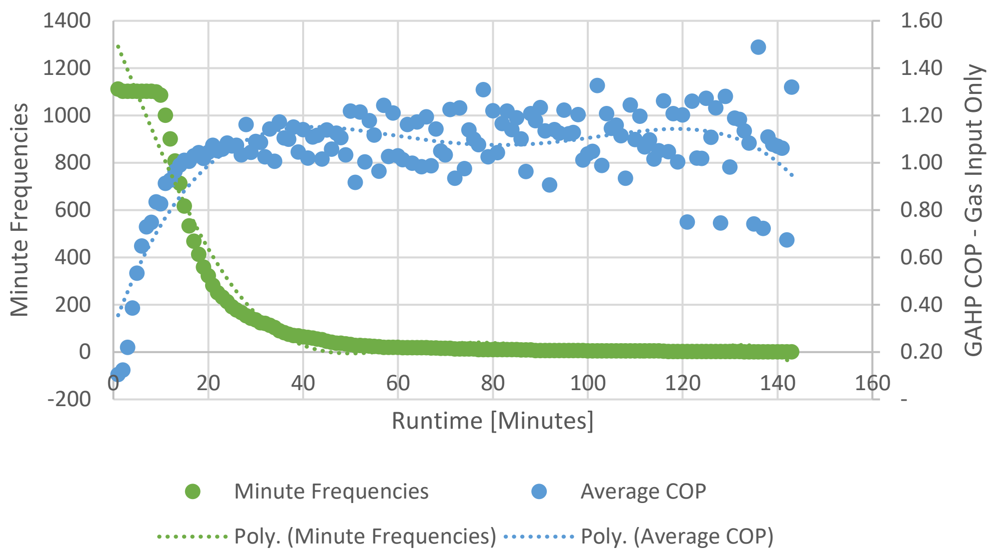


Figure 16: Field test COP – Gas Only as a function of runtime.



EnergyPlus Modeling Performance Curves

Results from the steady state and load-based laboratory testing have been used to develop performance characterizations for EnergyPlus modeling. GTI Energy developed these curves using the "Pathways to Decarbonization of Residential Heating" [8]. Calculations used to develop these curves are outlined above and the corresponding constants derived can be found in

Appendix 5.0. Based on the designed test plan, limitations in the modeling equations include:

- Heat transfer fluid properties are based on a water-propylene glycol mix with a concentration of 35% flowing between 7.0 and 13.6 GPM.
- Ambient temperature ranges between 0°F and 110°F.

The EnergyPlus module has two independent input variables: ambient dry bulb temperature (T_{amb}) and hydronic return temperature (T_{ret}). Within the range of test results, a function (CAPFT) of these two variables outputs the maximum capacity of the GAHP-A when multiplied by the manufacturer's rated capacity at 123.5 kBTU/h. Each time steps in an EnergyPlus simulation, the load demand is given and used with the maximum capacity to set a PLR. Several functions are provided to determine the overall gas usage as a function of the two input variables, T_{amb} and T_{ret} (EIRFT), as a function of the PLR (EIRFPLR), and defrost cycle derate (EIRDEFROST) when ambient temperatures are between -8.89°C and 3.33°C (16°F and 38°F). The COP_g can be determined from the gas usage and heat delivered at any given operating conditions of the input variables and PLR. Similar to gas usage, electric consumption is determined as a function of the two input variables, T_{amb} and T_{ret}, ($AUX_{ELEC,EIRFT}$) and a function of the PLR ($AUX_{ELEC,EIRFPLR}$). The COP_{GAHP} with combined gas and electric consumption equals the rate of heat delivered (kBTU/h) divided by the sum of the energy consumed (gas and electricity converted to kBTU/h) [3].

Figure 17 illustrates various modeling parameters relative to measured (experimental) data. Based on the error measurements shown in Figure 18, these parameters can be predicted within ±5%.

Figure 17: Comparison between model prediction data and measured data [3].

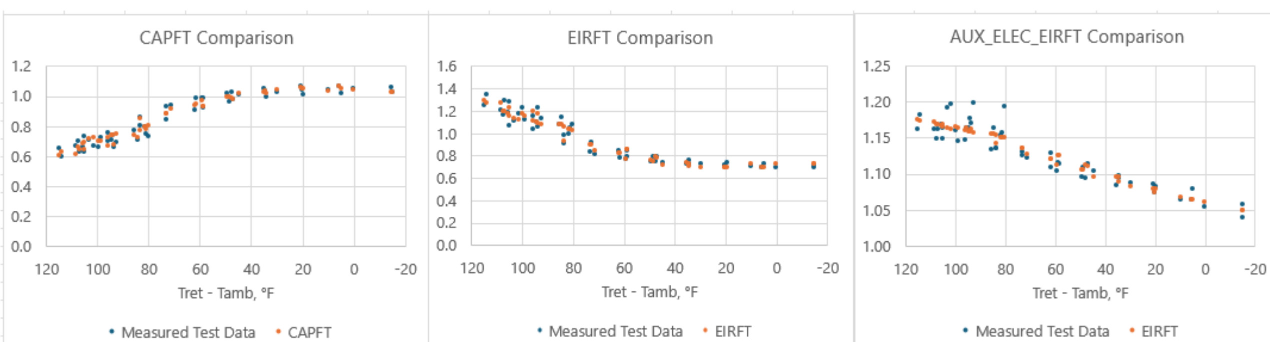
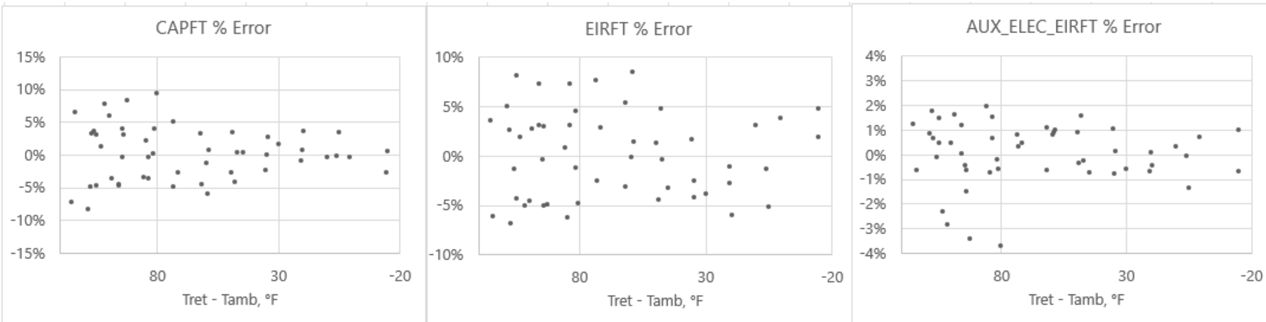


Figure 18: Error between model prediction data and measured data [3].



For COP_g, the overall modeling accuracy is about ±6% across the part-load spectrum and operating temperatures as shown in Figure 19.

Figure 19: COP_g comparison and error between model prediction data and measured data [3].

Note that the EnergyPlus model includes a factor to account for the defrost performance penalty (up to 4% near 27°F). Testing performed for the GAHP-A unit showed an average performance impact with a temperature of 35°F which is within the same range. However, more extensive testing would be required to revise the modeling tool's default defrost performance curve. Until further testing is performed, the current recommendation is to use the default defrost performance curve currently in EnergyPlus [3].

Conclusions

A comprehensive test matrix was established to gain a thorough understanding of how the GAHP-A unit operates under various steady state and load-based conditions. The key independent variables across both tests were the propylene glycol flowrate, OAT, RT, cycle on runtimes, and cycle off times.

For the steady state testing conditions:

1) At a flowrate of 7.0 GPM, the unit tends to cycle at higher temperatures due to low heat transfer and SWT rating limitations. Therefore, the system should be designed to avoid operating below optimal conditions where oscillatory behavior occurs, which is indicative of poor cycle performance. The conditions most likely to cause short cycling are at the lower flow rate @ 7.0 GPM, highest RT @ 120°F, and highest OAT @ 110°F. Under these conditions, the SWT is around 140°F and increases as the heat pump capacity increases. When the heat pump temperature exceeds 140°F, then the unit will begin to short cycle.
2) The system trends show close alignment of the experimental testing of the GAHP-A unit and the manufacturer's published data at higher flows (13.6 GPM). There was less agreement at higher RTs and lower flows (7.0 GPM) though. Other related findings include:
    - There was a minimal difference found between the gas only COP and the overall system COP.
    - There was a minimal difference found between the higher and lower flow rates.
3) During the defrost test points, the heating output reached a higher heating output immediately following the defrost cycle relative to the heating output just before the onset of the defrost cycle. The heating output gradually decreases to its steady state prior to the next defrost cycle.
4) The GAHP system experiences minimal defrost derating.

For load-based testing conditions:

1) The COP_g and COP_{GAHP} ratio as a function of the part load percentage have minimal differences in curve behavior. This implies that the electrical components in the GAHP unit have minimal impact on the overall efficiency.
2) The COP_g and COP_{GAHP} ratio as a function of the part load percentage can be modeled using a logarithmic trendline.

Close alignment of the model prediction data to the measured data of about ±6% accuracy provides sufficient confirmation for integration of the GAHP-A laboratory data into EnergyPlus. In collaboration with NREL, these modeling performance curves will then be integrated with the GAHP EnergyPlus modeling packages where additional analysis will be conducted. This includes tool enhancement as well as Residential Stock Analysis (ResStock) to develop the EnergyPlus GAHP modeling portfolio.

Recommendations

This study provided the following recommendations based on the laboratory study and EnergyPlus performance curve development:

1. Based on the short cycling which occurred at the lower flowrate (7.0 GPM) due to rating limits, it is recommended that the unit be configured according to the application. In this case, a lower flowrate (7.0 GPM) is recommended for lower temperature pool heating or space heating applications, whereas a higher flowrate (13.6 GPM) is recommended for higher commercial water heating applications.
2. Additional experimental defrost testing with the GAHP-A unit should be conducted to provide additional input on the default defrost performance curve currently in EnergyPlus.
3. To gain additional insights into the GAHP-A operability and resultant emissions, it is recommended to conduct hydrogen blend testing up to 30%.
4. To further contribute to the EnergyPlus GAHP modeling portfolio, additional prototype and commercially available GAHP units should be tested. It is recommended that a similar test plan as the GAHP-A unit be developed to draw comparison conclusions related to the parameters analyzed in this study.

Appendices

Appendix 1.0

Testbed Hydronic Test Rig

The GAHP-A was plumbed to the THP testbed hydronic test rig and filled with water at 20 psi. Given that this rig has been previously utilized with propylene glycol, several flushes were performed until the propylene glycol percentage was low enough, and the resulting heat recovery fluid was mainly water. The resulting propylene glycol percentage in the heat recovery fluid was 3%, which results in less than ±1% in density and specific heat deviation from water, as shown in Table 11. These 3% propylene glycol water mix properties were used in the resulting energy input and output calculations as shown in Table 9 of the commissioning test.

Table 11: Fluid properties [3].

Temperature	Density, lbm/cF			Specific Heat, Btu/lbm-°F		
	Water	PG @ 3%	% Diff.	Water	PG @ 3%	% Diff.
40	8.34	8.39	0.52%	1.000	0.992	-0.84%
60	8.33	8.37	0.47%	0.998	0.991	-0.66%
80	8.31	8.35	0.43%	0.998	0.993	-0.51%
100	8.29	8.32	0.39%	0.998	0.994	-0.39%
120	8.25	8.28	0.37%	0.999	0.996	-0.30%
140	8.21	8.24	0.37%	1.001	0.999	-0.24%
PG = propylene glycol Diff = difference						

Gas Valve Set-up

Before testing, the gas valve was adjusted to account for site-specific conditions, following guidelines in the GAHP-A Installation Manual shown in

Figure 20 [4].

Figure 20: GAHP-A exhaust gas specifications and gas manifold pressure settings [4].

Table 3.3 *Flue gas exhaust characteristics*

Natural gas	Fumes flow rate	SCF	1750
	Flue temperature	°F	293
	CO_2 percentage in fumes	%	9.2

Table 5.1 *Manifold pressure [inch WC] based on gas input (HHV) of 95.500 Btu/hr using a 0.21" nozzle*

MJ/m³	Btu/CU.FT.	Specific gravity of natural gas			
		0.55	0.60	0.65	0.70
35.40	950	3.15	3.43	3.72	4.01
36.33	975	2.99	3.26	3.53	3.80
37.26	1000	2.84	3.10	3.36	3.61
38.19	1025	2.70	2.95	3.20	3.44
39.12	1050	2.58	2.81	3.04	3.28
40.05	1075	2.46	2.68	2.90	3.13
40.98	1100	2.35	2.56	2.77	2.99
41.92	1125	2.24	2.45	2.65	2.86

Our reference:

MJ/m³	Btu/CU.FT.	Specific gravity of natural gas
		0.555
37.78	1014	2.77

A series of gas manifold pressure tests were performed to achieve a firing rate of 95,500 Btu/h while maintaining the simulated OAT in the environmental chamber at 44.6°F. The manifold pressure was adjusted, and the response in gas firing rate was observed for at least 15 minutes. The manifold pressure to achieve the rated input was 2.58 in WC. Table 12 shows the resulting carbon dioxide (CO_2), gas flow, and firing rate at each manifold pressure. Figure 21 shows the measurement of manifold pressure and exhaust gas constituents during the gas manifold pressure tests. It should be noted that the GAHP-A manufacturer's instructions assume the technician performing the installation will know the gas input HHV and specific gravity. Both are variables, and it is likely that the technician will not know these particular values at the time of installation, so the firing rate in actual practice could vary significantly.

Table 12: Gas manifold pressure tests [3].

Manifold Pressure, inWC	Exhaust Gas CO_2,%	Gas Flow, cfh	Firing Rate, Btu/h
2.99	9.2	100.9	103,200
2.77	8.8	97.2	99,400
2.58	8.2	93.1	95,300
2.50	8.0	91.1	93,200

Figure 21: Exhaust gas constituents [left] and manifold pressure [right] [3].

Appendix 2.0

Table 13: Steady state test matrix, the test results with a 15-min average, and the performance results [3].

Target Conditions			Test Results, 15-min average			Cycling Rates and Performance				
Outside Air Temp, °F	Flow Rate, gpm	Return Temp., °F	Outside Air Temp., °F	Flow Rate, gpm	Return Temp., °F	Heating Output, kBtu/h†	Thermal Input, kBtu/h†	Power, kW†	COP (Gas-Only)	COP (Gas + Electric)
110	13.6	95	109.8	13.5	94.9	130.9	91.2	0.94	1.44	1.39
		110	109.7	13.5	110.1	129.5	90.8	0.95	1.43	1.38
		120	110.0	13.6	120.0	128.5	90.7	0.96	1.42	1.37
	7.0	95	109.9	6.9	95.0	126.7	90.7	0.95	1.40	1.35
		110	†							
		120	†							
90	13.6	95	89.9	13.5	95.6	131.8	92.5	0.96	1.43	1.38
		110	90.1	13.6	110.3	128.8	92.2	0.97	1.40	1.35
		120	90.3	13.6	120.2	126.5	92.0	0.98	1.38	1.33
	7.0	95	90.1	7.1	94.9	126.0	92.0	0.97	1.37	1.32
		110	†							
		120	†							
75	13.6	95	75.1	13.5	95.7	132.2	93.4	0.98	1.41	1.37
		110	75.3	13.6	110.0	127.8	93.1	0.99	1.37	1.32
		120	75.6	13.6	120.2	125.3	93.0	0.99	1.35	1.30
	7.0	95	75.4	7.1	95.0	125.2	93.0	0.98	1.35	1.30
		110	†							
		120	†							
60	13.6	95	60.3	13.5	95.6	130.3	94.4	0.98	1.38	1.33
		110	60.7	13.6	110.0	126.1	94.3	0.99	1.34	1.29
		120	60.8	13.6	120.2	121.9	94.2	0.99	1.29	1.25
	7.0	95	60.7	7.2	95.1	123.2	94.4	0.98	1.31	1.26
		110	61.0	7.1	109.7	119.2	94.2	1.00	1.27	1.22
		120	†							
47	13.6	95	47.6	13.5	95.4	126.9	95.7	0.99	1.33	1.28
		110	48.1	13.6	109.7	122.5	95.5	1.00	1.28	1.24
		120	48.3	13.7	119.8	116.3	95.4	1.01	1.22	1.18
	7.0	95	48.0	7.1	95.0	121.0	95.5	1.00	1.27	1.22
		110	48.4	7.1	110.2	112.7	95.5	1.02	1.18	1.14
		120	†							
35	13.6	95	36.1	13.6	95.1	122.1	96.4	1.00	1.27	1.22

Target Conditions			Test Results, 15-min average				Cycling Rates and Performance			
Outside Air Temp, °F	Flow Rate, gpm	Return Temp., °F	Outside Air Temp., °F	Flow Rate, gpm	Return Temp., °F	Heating Output, kBtu/h†	Thermal Input, kBtu/h†	Power, kW†	COP (Gas-Only)	COP (Gas + Electric)
		110	36.5	13.6	109.9	114.8	96.3	1.01	1.19	1.15
		120	36.7	13.7	120.2	106.1	96.2	1.02	1.10	1.06
	7.0	95	36.4	7.1	95.0	114.2	96.3	1.00	1.19	1.15
		110	36.7	7.1	109.8	104.2	96.3	1.02	1.08	1.04
		120	†							
17	13.6	95	14.0	13.5	95.5	98.2	97.7	1.04	1.01	0.97
		110	16.1	13.6	110.2	91.9	97.8	1.06	0.94	0.91
		120	16.9	13.7	120.1	87.3	97.5	1.07	0.90	0.86
	7.0	95	15.0	7.0	95.3	90.6	97.9	1.07	0.93	0.89
		110	17.3	7.0	109.9	85.9	97.6	1.08	0.88	0.85
		120	18.2	7.0	119.7	82.9	97.8	1.08	0.85	0.82
15	13.6	95	11.5	13.5	95.1	99.2	98.1	1.02	1.01	0.98
		110	14.3	13.6	110.3	93.9	97.6	1.03	0.96	0.93
		120	14.9	13.7	119.9	90.5	97.1	1.03	0.93	0.90
	7.0	95	13.4	7.0	94.6	92.8	97.8	1.04	0.95	0.92
		110	15.0	7.0	109.4	87.9	97.4	1.05	0.90	0.87
		120	13.7	7.0	119.5	81.7	97.1	1.05	0.84	0.81
7	13.6	95	8.7	13.5	94.4	95.1	102.4	1.02	0.93	0.90
		110	10.5	13.6	109.3	90.1	101.3	1.03	0.89	0.86
		120	11.6	13.7	119.2	86.4	100.8	1.03	0.86	0.83
	7.0	95	8.7	7.0	93.2	87.5	100.7	1.05	0.87	0.84
		110	7.8	7.0	107.6	81.5	100.4	1.04	0.81	0.78
		120	10.2	7.0	117.3	77.57	100.17	1.05	0.77	0.75
0	13.6	95	-0.8	13.5	95.0	86.70	100.37	1.05	0.86	0.83
		110	1.1	13.6	109.6	83.07	100.68	1.05	0.83	0.80
		120	4.5	13.7	119.5	80.37	100.31	1.05	0.80	0.77
	7.0	95	0.9	6.9	94.7	81.52	100.62	1.05	0.81	0.78
		110	4.6	6.9	109.6	77.83	99.80	1.05	0.78	0.75
		120	6.7	6.9	120.7	73.47	99.41	1.06	0.74	0.71

† Under these conditions, the unit is cycling on high supply temperature and is not representative of steady-state

Appendix 3.0

Table 14: Defrost characterization results.

Defrost Tests	Target Operating Conditions	OAT, °F | Relative Humidity, %	Cycles	Time Between Defrost Cycles, hr	Avg. Time Between Defrost Cycles, hr	Avg. Defrost Cycle Duration, min	Avg. Heating Output Derate During Defrost Cycles, %	Avg. Heating Output Derate Prior to a Defrost Cycle, %	Avg. Defrost Derate Impact on Heating Cycle, %
1	13.6 gpm | 120 °F RT	36.3 | 82.1	4	6.5	8.1	20	72%	89%	1.0%
		35.4 | 81.6		8.4					
		35.3 | 81.2		9.6					
		34.7 | 80.4		7.9					
2	13.6 gpm | 110 °F RT	34.7 | 82.4	4	7.7	6.5	27	78%	87%	3.2%
		35.0 | 75.2		6.2					
		35.0 | 74.9		6.2					
		35.1 | 75.5		6.2					
3	7.0 gpm | 110 °F RT	34.9 | 79.6	4	7.0	7.3	19	74%	92%	0.5%
		34.9 | 81.9		7.3					
		35.1 | 81.4		7.3					
		34.9 | 81.5		7.5					
4	7.0 gpm | 95 °F RT	34.7 | 75.0	5	5.9	5.2	25	67%	86%	5.7%
		35.6 | 83.0		3.2					
		42.6 | 84.7		5.8					
		44.1 | 84.7		5.8					
		38.8 | 81.0		5.4					
Average of all tests					**6.7**	**23**	**73%**	**89%**	**2.6%**

Appendix 4.0

Table 15: Load-based test matrix, the test results with a 15-min average and the performance results for the load-based testing [3].

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
110 | 13.6 | 120	0.1	0.2	111.8	13.5	116.4	29.1	25.6	0.5	1.14	1.07
	0.1	0.5	112.1	13.5	115.6	11.6	11.4	0.3	1.01	0.94
	0.1	1.0	112.2	13.6	114.3	5.7	6.5	0.2	0.87	0.80
	0.2	0.2	111.1	13.5	116.8	53.8	41.3	0.6	1.30	1.24
	0.2	0.5	111.2	13.6	115.9	28.0	22.6	0.4	1.24	1.17
	0.2	1.0	110.2	13.5	114.8	15.6	13.4	0.2	1.17	1.10
	0.3	0.2	109.5	13.6	118.0	70.3	51.7	0.7	1.36	1.30
	0.3	0.5	109.7	13.5	117.4	41.2	31.4	0.4	1.31	1.25
	0.3	1.0	109.7	13.6	116.8	28.4	20.5	0.3	1.39	1.32
	0.5	0.2	110.0	13.6	118.8	88.3	63.6	0.8	1.39	1.33
	0.5	0.5	110.2	13.6	118.5	59.2	43.8	0.5	1.35	1.30
	0.5	1.0	110.1	13.6	118.1	38.9	29.5	0.4	1.32	1.26
	0.7	0.2	109.9	13.6	119.1	98.0	70.4	0.8	1.39	1.34
	0.7	0.5	110.0	13.6	118.8	71.3	52.4	0.6	1.36	1.31
	0.7	1.0	106.5	13.8	118.4	48.6	35.6	0.5	1.37	1.31
	0.9	0.2	106.5	13.8	119.3	101.1	71.2	0.8	1.42	1.37
	0.9	0.5	106.4	13.8	119.1	78.2	55.6	0.6	1.41	1.35
	0.9	1.0	106.5	13.8	118.8	57.0	41.3	0.5	1.38	1.33
110 | 7 | 95	0.1	0.2	110.1	7.0	93.4	32.7	26.5	0.5	1.23	1.16
	0.1	0.5	108.7	7.0	93.2	13.9	12.8	0.3	1.09	1.02
	0.1	1.0	108.5	7.0	92.9	6.7	6.8	0.2	0.98	0.91
	0.2	0.2	108.6	7.0	94.0	56.2	41.7	0.6	1.35	1.28
	0.2	0.5	108.1	7.0	93.8	29.8	22.9	0.4	1.30	1.23
	0.2	1.0	109.3	7.0	93.4	16.4	13.6	0.2	1.21	1.14
	0.3	0.2	108.6	7.0	94.4	70.5	50.5	0.7	1.40	1.34
	0.3	0.5	108.5	7.0	94.3	41.7	30.8	0.4	1.35	1.29
	0.3	1.0	107.9	7.0	94.5	24.9	19.1	0.3	1.30	1.24
	0.5	0.2	108.1	7.0	95.7	86.7	61.2	0.7	1.42	1.36
	0.5	0.5	108.0	7.0	95.6	58.4	42.2	0.5	1.38	1.33
	0.5	1.0	107.9	7.0	95.3	38.4	28.3	0.4	1.36	1.30
	0.7	0.2	107.7	7.0	95.7	95.4	67.1	0.8	1.42	1.37
	0.7	0.5	107.7	7.0	95.6	70.0	49.9	0.6	1.40	1.35

Targeted Conditions	Test Results					Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	107.6	7.0	95.4	49.4	35.8	0.4	1.38	1.33
	0.9	0.2	107.5	6.9	95.7	101.7	71.3	0.8	1.43	1.37
	0.9	0.5	107.5	6.9	95.6	78.1	55.6	0.6	1.40	1.35
	0.9	1.0	107.5	7.0	95.5	57.0	40.9	0.5	1.39	1.34
90 | 13.6 | 120	0.1	0.2	92.1	13.5	117.6	27.5	26.0	0.5	1.06	0.99
	0.1	0.5	91.5	13.6	116.4	10.2	11.7	0.3	0.87	0.81
	0.1	1.0	91.8	13.5	114.6	5.0	6.8	0.2	0.74	0.68
	0.2	0.2	90.9	13.6	118.2	52.9	42.9	0.6	1.23	1.18
	0.2	0.5	91.1	13.7	117.2	27.0	23.3	0.4	1.16	1.10
	0.2	1.0	91.1	13.6	115.9	14.9	13.9	0.2	1.07	1.01
	0.3	0.2	90.5	13.6	118.5	69.2	53.3	0.7	1.30	1.24
	0.3	0.5	90.7	13.6	117.8	40.2	32.3	0.4	1.24	1.19
	0.3	1.0	90.7	13.6	116.8	23.9	20.1	0.3	1.19	1.13
	0.5	0.2	90.2	13.6	118.9	86.7	64.8	0.8	1.34	1.29
	0.5	0.5	90.3	13.6	118.5	58.2	44.7	0.5	1.30	1.25
	0.5	1.0	90.2	13.6	117.9	38.1	30.0	0.4	1.27	1.22
	0.7	0.2	90.0	13.6	119.0	96.4	71.2	0.8	1.35	1.30
	0.7	0.5	90.1	13.6	118.7	70.0	52.7	0.6	1.33	1.28
	0.7	1.0	90.0	13.7	118.1	48.8	37.6	0.5	1.30	1.25
	0.9	0.2	89.9	13.6	119.1	102.2	75.5	0.8	1.35	1.30
	0.9	0.5	90.1	13.6	118.8	78.6	58.8	0.7	1.34	1.29
	0.9	1.0	90.1	13.6	118.4	57.6	43.7	0.5	1.32	1.27
90 | 7 | 95	0.1	0.2	91.7	6.9	93.0	34.3	28.7	0.5	1.20	1.13
	0.1	0.5	91.8	7.0	91.3	14.8	13.8	0.3	1.07	1.00
	0.1	1.0	91.9	7.0	90.4	7.2	7.4	0.2	0.97	0.90
	0.2	0.2	91.0	6.9	93.2	58.2	44.9	0.6	1.29	1.23
	0.2	0.5	91.1	7.0	93.0	31.3	25.1	0.4	1.25	1.19
	0.2	1.0	91.0	6.9	92.2	17.1	14.5	0.2	1.18	1.12
	0.3	0.2	90.6	6.9	94.0	72.8	54.4	0.7	1.34	1.28
	0.3	0.5	90.7	6.9	93.8	43.5	33.5	0.4	1.30	1.24
	0.3	1.0	91.0	6.9	93.3	25.6	20.6	0.3	1.24	1.19
	0.5	0.2	90.3	6.9	94.6	89.1	65.5	0.8	1.36	1.31
	0.5	0.5	90.3	6.9	94.3	60.9	45.5	0.6	1.34	1.28
	0.5	1.0	90.4	6.9	93.9	39.5	30.4	0.4	1.30	1.25
	0.7	0.2	90.1	6.9	94.8	98.0	72.0	0.8	1.36	1.31
	0.7	0.5	90.0	6.9	94.6	72.1	53.8	0.6	1.34	1.29

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	90.0	6.9	94.3	50.3	38.5	0.5	1.31	1.25
	0.9	0.2	89.9	6.9	94.9	104.5	77.0	0.8	1.36	1.31
	0.9	0.5	89.9	6.9	94.6	80.4	59.6	0.7	1.35	1.30
	0.9	1.0	89.9	6.9	94.4	58.5	44.0	0.5	1.33	1.28
75 | 13.6 | 120	0.1	0.2	76.8	13.5	116.8	27.5	27.2	0.5	1.01	0.95
	0.1	0.5	76.8	13.5	115.3	10.6	12.6	0.3	0.84	0.78
	0.1	1.0	76.9	13.6	113.5	4.9	7.4	0.2	0.66	0.61
	0.2	0.2	76.5	13.6	117.1	52.0	44.2	0.6	1.18	1.12
	0.2	0.5	76.6	13.5	116.1	26.7	24.1	0.4	1.11	1.05
	0.2	1.0	76.5	13.6	114.7	14.8	14.5	0.2	1.02	0.97
	0.3	0.2	76.0	13.6	117.8	68.3	54.3	0.7	1.26	1.20
	0.3	0.5	76.1	13.6	117.0	39.5	33.2	0.4	1.19	1.14
	0.3	1.0	75.8	13.6	116.0	23.5	20.8	0.3	1.13	1.08
	0.5	0.2	75.4	13.6	118.3	86.4	66.3	0.8	1.30	1.25
	0.5	0.5	75.8	13.6	117.9	58.0	45.7	0.6	1.27	1.22
	0.5	1.0	75.7	13.6	117.2	37.8	30.8	0.4	1.23	1.18
	0.7	0.2	75.3	13.6	118.6	95.9	72.0	0.8	1.33	1.28
	0.7	0.5	75.5	13.6	118.2	69.8	53.6	0.6	1.30	1.25
	0.7	1.0	75.5	13.6	117.7	48.4	38.0	0.5	1.27	1.22
	0.9	0.2	75.3	13.6	118.8	101.9	75.8	0.9	1.34	1.29
	0.9	0.5	75.3	13.6	118.4	78.0	59.1	0.7	1.32	1.27
	0.9	1.0	75.3	13.6	118.1	57.0	43.9	0.5	1.30	1.25
75 | 7 | 95	0.1	0.2	76.8	6.9	92.3	33.4	28.9	0.5	1.16	1.09
	0.1	0.5	76.9	6.9	90.5	14.3	14.2	0.3	1.01	0.94
	0.1	1.0	77.0	6.9	89.5	6.7	7.7	0.2	0.88	0.81
	0.2	0.2	76.1	6.9	92.7	57.1	45.9	0.6	1.24	1.19
	0.2	0.5	76.4	6.9	92.3	30.7	25.8	0.4	1.19	1.13
	0.2	1.0	76.2	6.9	91.3	16.6	14.9	0.2	1.11	1.06
	0.3	0.2	75.8	6.9	93.5	71.9	55.5	0.7	1.30	1.24
	0.3	0.5	75.9	6.9	93.1	43.0	34.2	0.5	1.26	1.20
	0.3	1.0	75.8	6.9	92.4	25.3	21.0	0.3	1.20	1.15
	0.5	0.2	75.4	6.9	94.1	88.4	66.8	0.8	1.32	1.27
	0.5	0.5	75.4	6.9	93.7	60.3	46.3	0.6	1.30	1.25
	0.5	1.0	75.5	6.9	93.2	39.3	30.9	0.4	1.27	1.22
	0.7	0.2	75.1	6.9	94.3	97.4	72.9	0.8	1.34	1.29
	0.7	0.5	75.2	6.9	94.0	71.6	54.4	0.6	1.32	1.27

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	75.3	6.9	93.6	49.6	38.3	0.5	1.29	1.24
	0.9	0.2	75.1	6.9	94.3	103.5	76.8	0.9	1.35	1.30
	0.9	0.5	75.0	6.9	94.1	80.0	60.2	0.7	1.33	1.28
	0.9	1.0	75.0	6.9	93.8	57.9	44.9	0.5	1.29	1.24
60 | 13.6 | 120	0.1	0.2	60.6	13.6	118.2	27.2	26.1	0.5	1.04	0.98
	0.1	0.5	60.9	13.5	116.8	10.2	11.9	0.3	0.86	0.80
	0.1	1.0	61.1	13.6	115.2	4.8	7.2	0.2	0.67	0.62
	0.2	0.2	60.0	13.6	118.7	51.0	43.3	0.6	1.18	1.12
	0.2	0.5	61.3	13.6	117.8	25.6	23.5	0.4	1.09	1.04
	0.2	1.0	60.2	13.7	116.4	14.3	14.2	0.2	1.00	0.95
	0.3	0.2	60.3	13.6	119.1	66.7	53.4	0.7	1.25	1.19
	0.3	0.5	60.7	13.6	118.2	38.4	32.4	0.4	1.19	1.13
	0.3	1.0	60.3	13.7	117.2	23.2	20.4	0.3	1.14	1.08
	0.5	0.2	59.9	13.6	119.5	85.1	64.4	0.8	1.32	1.27
	0.5	0.5	59.9	13.7	119.0	56.4	44.3	0.6	1.27	1.22
	0.5	1.0	60.0	13.7	118.3	36.8	30.1	0.4	1.22	1.17
	0.7	0.2	59.8	13.7	119.7	94.0	70.9	0.8	1.33	1.27
	0.7	0.5	59.8	13.7	119.3	68.0	52.4	0.6	1.30	1.24
	0.7	1.0	59.7	13.7	118.7	47.7	37.5	0.5	1.27	1.22
	0.9	0.2	59.4	13.6	119.8	100.2	74.5	0.9	1.34	1.29
	0.9	0.5	59.7	13.6	119.5	76.3	57.4	0.7	1.33	1.28
	0.9	1.0	59.6	13.6	119.2	55.5	43.2	0.5	1.28	1.23
60 | 7 | 110	0.1	0.2	60.7	7.0	106.2	30.4	28.2	0.5	1.08	1.01
	0.1	0.5	60.7	7.0	105.3	12.2	13.0	0.3	0.94	0.88
	0.1	1.0	60.2	7.0	103.4	5.6	7.2	0.2	0.77	0.71
	0.2	0.2	60.2	6.9	106.9	53.7	44.5	0.6	1.21	1.15
	0.2	0.5	60.4	6.9	105.7	27.8	24.4	0.4	1.14	1.08
	0.2	1.0	60.2	6.9	104.3	15.0	14.4	0.2	1.04	0.98
	0.3	0.2	59.7	6.9	107.5	67.8	54.9	0.7	1.23	1.18
	0.3	0.5	60.1	6.9	106.9	39.1	33.4	0.4	1.17	1.12
	0.3	1.0	60.3	7.0	105.8	23.0	20.8	0.3	1.10	1.05
	0.5	0.2	60.1	6.9	108.6	77.4	62.9	0.7	1.23	1.18
	0.5	0.5	60.2	6.9	108.1	51.9	43.3	0.5	1.20	1.15
	0.5	1.0	60.3	6.9	107.2	34.2	28.8	0.4	1.19	1.14
	0.7	0.2	60.0	6.9	108.8	85.2	67.1	0.8	1.27	1.22
	0.7	0.5	59.9	6.9	108.3	62.0	49.7	0.6	1.25	1.20

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	61.3	7.1	107.6	47.0	38.0	0.5	1.24	1.19
	0.9	0.2	59.7	7.0	108.3	99.2	76.6	0.9	1.29	1.25
	0.9	0.5	59.6	7.1	107.9	75.7	59.7	0.7	1.27	1.22
	0.9	1.0	59.7	7.1	107.4	55.2	44.2	0.5	1.25	1.20
60 | 7 | 95	0.1	0.2	61.0	7.1	93.4	32.7	28.8	0.5	1.14	1.07
	0.1	0.5	61.2	7.1	91.1	14.4	14.0	0.3	1.02	0.96
	0.1	1.0	60.1	7.1	90.1	6.6	7.6	0.2	0.87	0.81
	0.2	0.2	60.4	7.0	93.5	56.6	45.5	0.6	1.24	1.19
	0.2	0.5	60.4	7.1	93.0	30.2	25.5	0.4	1.19	1.13
	0.2	1.0	59.8	7.0	91.8	16.4	14.8	0.2	1.11	1.06
	0.3	0.2	60.2	7.0	94.5	71.7	54.9	0.7	1.31	1.25
	0.3	0.5	60.3	7.0	94.0	42.8	33.7	0.5	1.27	1.21
	0.3	1.0	60.3	7.0	93.0	25.2	20.6	0.3	1.23	1.17
	0.5	0.2	59.9	7.0	95.1	88.7	65.1	0.8	1.36	1.31
	0.5	0.5	59.9	7.0	94.6	59.9	45.3	0.6	1.32	1.27
	0.5	1.0	59.7	7.0	94.1	39.0	30.3	0.4	1.29	1.23
	0.7	0.2	59.6	7.0	95.3	97.5	71.4	0.8	1.37	1.31
	0.7	0.5	59.5	7.0	94.9	71.5	53.4	0.6	1.34	1.29
	0.7	1.0	59.4	7.0	94.7	49.5	38.1	0.5	1.30	1.25
	0.9	0.2	59.5	7.0	95.3	103.0	75.4	0.9	1.37	1.32
	0.9	0.5	59.5	7.0	95.0	79.5	59.0	0.7	1.35	1.30
	0.9	1.0	59.5	7.0	94.6	57.7	43.7	0.5	1.32	1.27
47 | 13.6 | 120	0.1	0.2	51.6	13.6	118.3	26.8	26.4	0.5	1.01	0.95
	0.1	0.5	50.8	13.6	117.2	9.2	12.4	0.3	0.74	0.69
	0.1	1.0	48.4	13.6	114.3	4.5	7.4	0.2	0.61	0.57
	0.2	0.2	48.0	13.6	118.9	48.4	43.1	0.6	1.12	1.07
	0.2	0.5	47.5	13.6	117.7	24.2	24.0	0.4	1.01	0.96
	0.2	1.0	46.1	13.6	115.5	13.6	14.7	0.2	0.92	0.87
	0.3	0.2	46.2	13.6	119.9	62.5	54.0	0.7	1.16	1.11
	0.3	0.5	46.9	13.6	119.1	35.9	32.8	0.5	1.09	1.04
	0.3	1.0	46.8	13.6	118.8	22.1	20.2	0.3	1.10	1.04
	0.5	0.2	46.4	13.6	120.5	79.4	65.9	0.8	1.20	1.16
	0.5	0.5	46.9	13.6	120.1	52.9	45.7	0.6	1.16	1.11
	0.5	1.0	46.1	13.6	119.0	34.7	31.1	0.4	1.11	1.07
	0.7	0.2	46.1	13.6	120.7	88.8	73.0	0.8	1.22	1.17
	0.7	0.5	46.2	13.7	120.4	63.6	54.0	0.6	1.18	1.13

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	46.2	13.7	120.0	44.8	38.4	0.5	1.17	1.12
	0.9	0.2	46.2	13.7	120.7	94.4	76.7	0.9	1.23	1.18
	0.9	0.5	46.5	13.7	120.6	71.5	60.1	0.7	1.19	1.14
	0.9	1.0	46.2	13.7	120.3	50.6	43.3	0.5	1.17	1.12
47 | 7 | 110	0.1	0.2	47.4	6.9	106.7	30.4	28.9	0.5	1.05	0.99
	0.1	0.5	47.9	6.9	105.1	11.6	13.7	0.3	0.84	0.79
	0.1	1.0	47.9	6.9	102.1	5.4	7.6	0.2	0.71	0.66
	0.2	0.2	48.0	6.9	106.8	52.9	45.9	0.6	1.15	1.10
	0.2	0.5	48.4	6.9	105.6	27.2	25.2	0.4	1.08	1.03
	0.2	1.0	47.4	6.9	104.4	14.5	14.9	0.2	0.97	0.92
	0.3	0.2	47.0	6.9	107.3	66.8	56.1	0.7	1.19	1.14
	0.3	0.5	47.2	6.9	106.5	38.2	34.0	0.5	1.12	1.07
	0.3	1.0	47.3	6.9	105.6	22.4	21.0	0.3	1.07	1.02
	0.5	0.2	47.1	6.9	108.1	81.4	66.9	0.8	1.22	1.17
	0.5	0.5	47.1	6.9	107.3	54.1	46.2	0.6	1.17	1.12
	0.5	1.0	47.3	6.9	106.4	31.9	28.5	0.4	1.12	1.07
	0.7	0.2	46.9	6.9	108.4	89.7	73.7	0.8	1.22	1.17
	0.7	0.5	47.3	6.9	108.0	64.8	54.8	0.6	1.18	1.14
	0.7	1.0	46.9	6.9	107.4	44.9	38.9	0.5	1.15	1.11
	0.9	0.2	46.9	6.9	108.6	94.5	78.3	0.9	1.21	1.16
	0.9	0.5	47.1	6.9	108.2	71.8	61.0	0.7	1.18	1.13
	0.9	1.0	47.0	6.9	107.7	49.5	43.1	0.5	1.15	1.10
47 | 7 | 95	0.1	0.2	47.5	6.9	92.3	32.7	29.3	0.5	1.12	1.05
	0.1	0.5	48.4	6.9	91.1	13.9	14.5	0.3	0.96	0.90
	0.1	1.0	47.5	6.9	89.8	6.2	7.9	0.2	0.78	0.73
	0.2	0.2	47.0	6.9	93.0	56.2	46.5	0.6	1.21	1.15
	0.2	0.5	47.0	6.9	92.2	29.7	26.1	0.4	1.14	1.09
	0.2	1.0	46.9	6.9	90.9	16.1	15.2	0.2	1.06	1.01
	0.3	0.2	46.9	6.9	93.7	70.8	56.4	0.7	1.25	1.20
	0.3	0.5	47.2	6.9	93.1	41.7	35.0	0.4	1.19	1.14
	0.3	1.0	46.9	6.9	92.2	24.5	21.5	0.3	1.14	1.09
	0.5	0.2	46.7	6.9	94.4	87.0	68.3	0.8	1.27	1.22
	0.5	0.5	46.7	6.9	94.0	58.6	47.4	0.6	1.24	1.19
	0.5	1.0	47.2	6.9	93.4	38.1	31.8	0.4	1.20	1.15
	0.7	0.2	46.8	6.9	94.5	95.2	74.1	0.8	1.29	1.24
	0.7	0.5	47.0	6.9	94.1	69.7	54.9	0.6	1.27	1.22

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	46.9	6.9	93.8	48.2	38.9	0.5	1.24	1.19
	0.9	0.2	46.6	6.9	94.6	101.1	77.9	0.9	1.30	1.25
	0.9	0.5	46.6	6.9	94.3	77.8	60.9	0.7	1.28	1.23
	0.9	1.0	46.6	6.9	94.0	56.8	44.8	0.5	1.27	1.22
37 | 13.6 | 120	0.1	0.2	34.2	13.5	117.8	26.0	27.1	0.5	0.96	0.90
	0.1	0.5	36.6	13.6	115.9	9.9	13.1	0.3	0.76	0.71
	0.1	1.0	34.7	13.6	113.1	4.6	7.5	0.2	0.61	0.56
	0.2	0.2	34.4	13.6	118.2	45.9	43.9	0.6	1.05	1.00
	0.2	0.5	35.8	13.6	117.1	23.0	24.1	0.4	0.96	0.91
	0.2	1.0	37.7	13.6	114.5	7.6	9.7	0.2	0.78	0.72
	0.3	0.2	34.0	13.6	118.9	58.3	54.8	0.7	1.06	1.02
	0.3	0.5	35.8	13.6	118.0	33.6	33.3	0.4	1.01	0.97
	0.3	1.0	35.5	13.7	115.5	14.7	16.3	0.3	0.90	0.85
	0.5	0.2	35.6	13.7	119.2	73.5	67.0	0.8	1.10	1.05
	0.5	0.5	36.0	13.6	118.7	49.3	46.2	0.6	1.07	1.02
	0.5	1.0	35.9	13.7	117.0	27.7	27.2	0.4	1.02	0.97
	0.7	0.2	35.7	13.6	119.4	82.5	71.7	0.8	1.15	1.11
	0.7	0.5	36.5	13.6	119.0	59.5	53.4	0.6	1.12	1.07
	0.7	1.0	35.9	13.7	117.9	37.5	34.8	0.5	1.08	1.03
	0.9	0.2	35.7	13.7	119.5	88.0	76.5	0.9	1.15	1.11
	0.9	0.5	35.9	13.7	119.1	67.2	59.7	0.7	1.13	1.08
	0.9	1.0	35.5	13.7	118.2	45.5	41.8	0.5	1.09	1.04
35 | 7 | 110	0.1	0.2	36.1	6.9	106.4	28.3	29.6	0.5	0.96	0.90
	0.1	0.5	37.2	6.9	104.7	11.0	13.9	0.3	0.79	0.74
	0.1	1.0	37.3	6.9	102.2	5.0	7.8	0.2	0.64	0.59
	0.2	0.2	36.1	6.9	106.4	49.1	46.7	0.6	1.05	1.00
	0.2	0.5	36.8	6.9	105.7	24.7	25.7	0.4	0.96	0.92
	0.2	1.0	37.7	6.9	103.7	8.0	10.0	0.2	0.81	0.75
	0.3	0.2	36.2	6.9	107.3	61.5	56.5	0.7	1.09	1.04
	0.3	0.5	37.4	6.9	106.2	35.5	34.3	0.5	1.03	0.99
	0.3	1.0	37.1	6.9	105.2	20.7	21.4	0.3	0.97	0.93
	0.5	0.2	35.7	6.9	107.9	75.4	68.3	0.8	1.10	1.06
	0.5	0.5	35.9	6.9	107.1	50.1	47.2	0.6	1.06	1.02
	0.5	1.0	35.9	6.9	106.0	28.4	27.8	0.4	1.02	0.97
	0.7	0.2	35.5	6.9	108.2	83.1	75.0	0.8	1.11	1.07
	0.7	0.5	36.0	6.9	107.7	59.7	55.5	0.6	1.08	1.03

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	36.0	6.9	107.0	38.1	35.9	0.5	1.06	1.01
	0.9	0.2	35.5	6.9	108.3	88.0	78.6	0.9	1.12	1.08
	0.9	0.5	36.0	6.9	107.9	67.0	61.6	0.7	1.09	1.05
	0.9	1.0	35.8	6.9	107.4	45.3	42.3	0.5	1.07	1.03
35 | 7 | 95	0.1	0.2	34.6	6.9	92.5	33.7	29.4	0.5	1.15	1.08
	0.1	0.5	36.0	7.0	90.9	13.0	14.4	0.3	0.90	0.85
	0.1	1.0	34.3	7.0	89.4	6.0	8.0	0.2	0.74	0.69
	0.2	0.2	34.5	6.9	92.6	53.6	46.3	0.6	1.16	1.11
	0.2	0.5	35.1	6.9	91.7	28.3	26.0	0.4	1.09	1.04
	0.2	1.0	34.3	7.0	90.9	14.9	15.2	0.2	0.98	0.93
	0.3	0.2	34.3	6.9	93.6	67.3	56.0	0.7	1.20	1.15
	0.3	0.5	35.0	6.9	92.7	39.3	34.7	0.5	1.13	1.08
	0.3	1.0	35.2	6.9	92.0	23.0	21.4	0.3	1.08	1.03
	0.5	0.2	35.1	6.9	94.2	82.2	67.6	0.8	1.22	1.17
	0.5	0.5	35.6	6.9	93.6	55.2	47.2	0.6	1.17	1.13
	0.5	1.0	35.7	6.9	93.0	34.2	30.0	0.4	1.14	1.09
	0.7	0.2	35.0	6.9	94.2	90.5	74.1	0.8	1.22	1.18
	0.7	0.5	35.5	6.9	93.8	65.9	55.4	0.6	1.19	1.15
	0.7	1.0	35.4	6.9	93.5	45.7	39.4	0.5	1.16	1.12
	0.9	0.2	35.0	6.9	94.4	95.9	77.9	0.9	1.23	1.19
	0.9	0.5	35.7	6.9	94.0	73.6	61.0	0.7	1.21	1.16
	0.9	1.0	35.1	6.9	93.6	53.1	44.8	0.5	1.19	1.14
17 | 13.6 | 120	0.1	0.2	17.4	13.6	117.6	22.2	28.3	0.5	0.78	0.74
	0.1	0.5	16.9	13.6	115.5	7.8	13.5	0.3	0.58	0.54
	0.1	1.0	16.0	13.6	107.0	1.7	4.1	0.1	0.42	0.38
	0.2	0.2	17.0	13.6	115.8	35.9	46.9	0.6	0.76	0.73
	0.2	0.5	17.7	13.6	116.3	18.5	25.2	0.4	0.73	0.70
	0.2	1.0	18.6	13.5	116.3	11.4	14.7	0.2	0.78	0.74
	0.3	0.2	17.7	13.6	118.6	49.8	55.7	0.7	0.89	0.86
	0.3	0.5	17.3	13.6	117.5	27.8	34.2	0.5	0.81	0.78
	0.3	1.0	26.9	13.6	117.4	19.5	20.9	0.3	0.93	0.89
	0.5	0.2	17.2	13.7	119.2	62.3	68.2	0.8	0.91	0.88
	0.5	0.5	17.0	13.7	118.2	41.4	47.1	0.6	0.88	0.84
	0.5	1.0	16.9	13.6	118.1	27.6	31.4	0.4	0.88	0.84
	0.7	0.2	17.4	13.6	119.4	70.0	74.8	0.9	0.94	0.90
	0.7	0.5	17.6	13.7	118.7	50.1	55.5	0.7	0.90	0.87

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	17.1	13.7	117.9	33.6	37.5	0.5	0.90	0.86
	0.9	0.2	17.2	13.7	119.4	74.4	77.6	0.9	0.96	0.92
	0.9	0.5	17.6	13.7	119.0	57.1	60.7	0.7	0.94	0.90
	0.9	1.0	17.2	13.7	118.3	40.4	43.7	0.5	0.93	0.89
17 | 7 | 110	0.1	0.2	16.9	6.8	106.8	24.2	29.1	0.5	0.83	0.78
	0.1	0.5	16.1	6.8	104.6	8.7	14.0	0.3	0.62	0.58
	0.1	1.0	15.4	6.8	96.3	3.0	8.2	0.1	0.37	0.35
	0.2	0.2	16.9	6.8	106.9	39.3	46.6	0.7	0.84	0.80
	0.2	0.5	16.2	6.8	105.9	19.7	25.5	0.4	0.77	0.73
	0.2	1.0	16.6	6.8	106.0	11.6	14.9	0.3	0.78	0.73
	0.3	0.2	16.0	6.8	108.2	49.6	56.6	0.7	0.88	0.84
	0.3	0.5	17.0	6.8	106.6	28.5	34.3	0.5	0.83	0.80
	0.3	1.0	17.8	6.8	106.6	17.7	21.1	0.3	0.84	0.80
	0.5	0.2	16.7	6.8	108.6	62.8	68.3	0.8	0.92	0.88
	0.5	0.5	16.9	6.8	108.3	42.7	47.5	0.6	0.90	0.86
	0.5	1.0	17.9	6.8	107.6	27.3	31.4	0.4	0.87	0.83
	0.7	0.2	17.0	6.8	108.9	69.2	74.7	0.9	0.93	0.89
	0.7	0.5	16.9	6.8	108.3	49.1	55.8	0.6	0.88	0.85
	0.7	1.0	16.3	6.8	108.2	34.6	39.5	0.5	0.88	0.84
	0.9	0.2	16.4	6.8	109.0	73.8	80.0	0.9	0.92	0.89
	0.9	0.5	16.9	6.8	108.5	55.8	62.1	0.7	0.90	0.86
	0.9	1.0	15.9	6.8	107.1	36.7	41.5	0.5	0.88	0.85
17 | 7 | 95	0.1	0.2	15.5	7.0	92.7	28.4	29.3	0.5	0.97	0.91
	0.1	0.5	16.7	6.9	90.6	10.8	14.7	0.3	0.73	0.69
	0.1	1.0	16.6	6.9	89.3	5.0	7.4	0.2	0.68	0.63
	0.2	0.2	14.6	6.9	93.3	44.2	46.4	0.7	0.95	0.91
	0.2	0.5	17.2	6.9	92.0	20.9	26.0	0.4	0.80	0.76
	0.2	1.0	15.6	6.9	90.6	11.5	14.1	0.2	0.82	0.77
	0.3	0.2	14.7	6.9	93.8	56.0	57.0	0.7	0.98	0.94
	0.3	0.5	16.1	6.9	92.9	31.9	35.4	0.5	0.90	0.86
	0.3	1.0	15.3	6.9	91.6	17.5	20.8	0.3	0.84	0.80
	0.5	0.2	15.1	6.9	94.5	67.3	69.2	0.8	0.97	0.93
	0.5	0.5	16.0	6.9	94.1	44.6	47.8	0.6	0.93	0.89
	0.5	1.0	15.3	6.9	93.5	27.8	30.8	0.4	0.90	0.86
	0.7	0.2	15.3	6.8	95.0	73.1	75.0	0.9	0.97	0.94
	0.7	0.5	15.0	6.9	94.4	51.8	56.0	0.7	0.92	0.89

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	14.9	6.9	93.7	35.3	38.6	0.5	0.91	0.88
	0.9	0.2	14.8	6.9	95.0	76.4	79.0	0.9	0.97	0.93
	0.9	0.5	14.9	6.8	94.8	57.4	61.7	0.7	0.93	0.89
	0.9	1.0	15.0	6.8	94.6	41.4	44.9	0.5	0.92	0.88
15 | 13.6 | 120	0.1	0.2	15.1	13.6	117.3	22.7	28.4	0.5	0.80	0.75
	0.1	0.5	15.0	13.6	114.8	8.0	13.5	0.3	0.60	0.56
	0.1	1.0	14.8	13.6	103.4	3.0	8.2	0.1	0.36	0.35
	0.2	0.2	15.5	13.6	112.3	35.2	46.8	0.6	0.75	0.72
	0.2	0.5	14.4	13.6	116.0	18.8	25.1	0.4	0.75	0.71
	0.2	1.0	14.8	13.6	108.6	2.9	5.8	0.2	0.49	0.43
	0.3	0.2	14.4	13.6	119.3	48.4	56.3	0.7	0.86	0.82
	0.3	0.5	15.0	13.7	117.2	27.7	34.2	0.4	0.81	0.77
	0.3	1.0	14.6	13.7	113.3	9.6	13.8	0.3	0.70	0.65
	0.5	0.2	14.5	13.7	119.0	61.7	68.2	0.8	0.90	0.87
	0.5	0.5	14.4	13.7	118.3	40.3	47.4	0.6	0.85	0.82
	0.5	1.0	14.2	13.7	115.7	22.3	27.8	0.4	0.80	0.77
	0.7	0.2	14.2	13.7	119.2	68.3	74.8	0.8	0.91	0.88
	0.7	0.5	14.5	13.7	118.7	48.9	55.7	0.6	0.88	0.84
	0.7	1.0	14.3	13.7	116.8	30.0	35.4	0.5	0.85	0.81
	0.9	0.2	15.1	13.7	119.3	72.6	78.1	0.9	0.93	0.90
	0.9	0.5	14.3	13.7	118.9	55.0	61.0	0.7	0.90	0.87
	0.9	1.0	14.2	13.7	117.2	35.9	41.1	0.5	0.87	0.84
15 | 7 | 110	0.1	0.2	14.3	6.9	105.7	23.3	29.9	0.5	0.78	0.74
	0.1	0.5	14.2	6.8	99.0	8.5	14.8	0.3	0.58	0.54
	0.1	1.0	14.2	6.9	99.2	3.3	6.9	0.2	0.48	0.45
	0.2	0.2	14.5	6.8	106.1	40.3	46.5	0.6	0.87	0.83
	0.2	0.5	14.7	6.9	104.3	19.8	25.7	0.4	0.77	0.74
	0.2	1.0	18.1	6.9	101.7	17.9	29.1	0.4	0.62	0.59
	0.3	0.2	14.3	6.9	106.8	49.7	56.6	0.7	0.88	0.84
	0.3	0.5	14.7	6.8	105.2	28.4	34.7	0.5	0.82	0.78
	0.3	1.0	14.9	6.9	105.2	17.4	21.4	0.3	0.81	0.78
	0.5	0.2	14.3	6.9	107.1	61.8	68.2	0.8	0.91	0.87
	0.5	0.5	14.7	6.9	106.5	40.3	47.1	0.6	0.86	0.82
	0.5	1.0	14.4	6.9	105.7	25.4	30.3	0.4	0.84	0.80
	0.7	0.2	14.2	6.8	107.6	67.6	74.4	0.9	0.91	0.87
	0.7	0.5	14.5	6.8	106.9	48.6	55.3	0.6	0.88	0.85

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	14.2	6.9	106.5	32.5	37.4	0.5	0.87	0.83
	0.9	0.2	14.2	6.9	107.8	71.9	77.9	0.9	0.92	0.89
	0.9	0.5	14.3	6.9	107.3	54.2	61.0	0.7	0.89	0.86
	0.9	1.0	14.2	6.9	106.6	37.6	43.2	0.5	0.87	0.84
15 | 7 | 95	0.1	0.2	14.1	7.1	93.0	27.2	29.6	0.5	0.92	0.87
	0.1	0.5	14.6	7.1	90.5	10.5	14.6	0.3	0.72	0.68
	0.1	1.0	14.2	7.1	87.6	2.4	4.0	0.2	0.61	0.53
	0.2	0.2	14.1	7.1	93.2	43.6	46.6	0.6	0.94	0.89
	0.2	0.5	14.5	7.1	91.9	22.8	26.2	0.4	0.87	0.83
	0.2	1.0	14.1	7.1	90.2	11.1	14.2	0.2	0.79	0.74
	0.3	0.2	14.0	7.1	94.0	56.0	57.1	0.7	0.98	0.94
	0.3	0.5	14.3	7.1	93.1	31.9	35.4	0.5	0.90	0.86
	0.3	1.0	14.6	7.1	91.9	17.6	20.7	0.3	0.85	0.81
	0.5	0.2	14.1	7.1	94.6	67.3	68.8	0.8	0.98	0.94
	0.5	0.5	14.2	7.1	94.0	44.4	47.9	0.6	0.93	0.89
	0.5	1.0	14.1	7.1	93.3	27.4	30.6	0.4	0.89	0.86
	0.7	0.2	14.0	7.1	94.8	73.6	75.3	0.9	0.98	0.94
	0.7	0.5	13.9	7.1	94.2	52.9	56.3	0.7	0.94	0.90
	0.7	1.0	14.0	7.1	93.7	35.8	38.6	0.5	0.93	0.89
	0.9	0.2	14.0	7.1	94.9	77.5	78.7	0.9	0.98	0.95
	0.9	0.5	18.4	7.1	95.1	74.0	68.3	0.8	1.08	1.04
	0.9	1.0	14.0	7.1	94.1	42.0	44.9	0.5	0.94	0.90
7 | 13.6 | 120	0.1	0.2	7.6	13.6	116.4	20.5	30.5	0.5	0.67	0.63
	0.1	0.5	10.7	13.6	113.1	7.3	14.5	0.3	0.50	0.47
	0.1	1.0	7.2	13.6	106.0	2.9	8.4	0.1	0.35	0.33
	0.2	0.2	9.9	13.6	116.2	35.6	47.8	0.7	0.75	0.71
	0.2	0.5	11.2	13.6	114.8	17.7	26.4	0.4	0.67	0.64
	0.2	1.0	7.4	13.6	109.6	4.9	10.2	0.2	0.48	0.45
	0.3	0.2	10.4	13.6	117.9	49.8	63.8	0.7	0.78	0.75
	0.3	0.5	9.4	13.7	115.7	26.1	35.6	0.5	0.73	0.70
	0.3	1.0	9.7	13.7	113.3	15.2	22.4	0.3	0.68	0.65
	0.5	0.2	11.9	13.7	117.8	57.9	68.8	0.8	0.84	0.81
	0.5	0.5	9.9	13.7	116.8	37.6	48.2	0.6	0.78	0.75
	0.5	1.0	9.9	13.7	115.0	24.5	32.5	0.4	0.75	0.72
	0.7	0.2	9.1	13.7	118.6	65.4	75.2	0.9	0.87	0.84
	0.7	0.5	9.6	13.7	117.2	45.9	56.1	0.6	0.82	0.79

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	9.4	13.7	116.2	33.5	42.3	0.5	0.79	0.76
	0.9	0.2	10.0	13.7	118.3	67.5	79.6	0.8	0.85	0.82
	0.9	0.5	9.8	13.7	117.5	50.5	62.0	0.7	0.81	0.78
	0.9	1.0	9.1	13.7	116.4	37.2	46.1	0.5	0.81	0.78
7 | 7 | 110	0.1	0.2	6.1	7.0	105.6	22.1	29.0	0.5	0.76	0.72
	0.1	0.5	6.2	7.0	103.1	7.8	14.0	0.3	0.56	0.52
	0.1	1.0	6.1	7.0	97.4	1.6	4.0	0.1	0.40	0.36
	0.2	0.2	5.7	6.9	106.1	37.1	46.3	0.7	0.80	0.76
	0.2	0.5	6.2	7.0	104.4	18.1	25.7	0.4	0.70	0.67
	0.2	1.0	6.3	6.9	104.4	10.4	15.0	0.2	0.69	0.66
	0.3	0.2	5.7	6.9	106.5	46.8	56.4	0.7	0.83	0.80
	0.3	0.5	5.7	6.9	105.1	26.2	34.8	0.5	0.75	0.72
	0.3	1.0	5.6	6.9	105.2	16.1	21.5	0.3	0.75	0.71
	0.5	0.2	7.4	6.9	107.3	58.7	68.4	0.8	0.86	0.83
	0.5	0.5	6.7	6.9	106.4	37.9	47.6	0.6	0.80	0.76
	0.5	1.0	7.7	6.9	105.7	24.6	31.2	0.4	0.79	0.76
	0.7	0.2	6.1	6.9	107.5	63.8	74.5	0.9	0.86	0.82
	0.7	0.5	6.1	6.9	106.9	45.2	55.8	0.7	0.81	0.78
	0.7	1.0	6.3	6.9	105.9	30.5	38.5	0.5	0.79	0.76
	0.9	0.2	6.5	6.9	107.8	67.9	78.7	0.9	0.86	0.83
	0.9	0.5	8.3	6.9	107.4	51.7	61.7	0.7	0.84	0.81
	0.9	1.0	6.2	6.9	106.6	35.6	44.5	0.5	0.80	0.77
7 | 7 | 95	0.1	0.2	8.3	7.0	90.1	25.4	30.3	0.5	0.84	0.79
	0.1	0.5	12.3	6.9	87.9	10.6	15.2	0.3	0.70	0.66
	0.1	1.0	6.8	6.9	84.7	3.9	8.4	0.1	0.47	0.45
	0.2	0.2	7.3	6.9	90.6	40.9	48.0	0.7	0.85	0.81
	0.2	0.5	7.9	6.9	89.1	21.5	27.3	0.4	0.79	0.75
	0.2	1.0	7.1	6.9	87.2	7.3	11.9	0.2	0.61	0.58
	0.3	0.2	8.1	6.9	91.3	52.3	57.9	0.7	0.90	0.86
	0.3	0.5	8.4	6.9	90.2	29.9	36.4	0.5	0.82	0.79
	0.3	1.0	9.2	6.9	90.0	18.4	22.4	0.3	0.82	0.78
	0.5	0.2	8.7	6.9	91.9	63.8	70.0	0.8	0.91	0.88
	0.5	0.5	9.0	6.9	91.1	41.7	49.2	0.6	0.85	0.82
	0.5	1.0	8.9	6.9	91.0	28.4	32.7	0.4	0.87	0.83
	0.7	0.2	8.7	6.8	92.1	69.5	77.1	0.9	0.90	0.87
	0.7	0.5	8.5	6.9	92.0	50.7	57.6	0.7	0.88	0.85

Targeted Conditions			Test Results			Performance Results				
OAT, °F | Flow Rate, gpm | RT, °F	On Time, hr	Off Time, hr	OAT, °F	Flow Rate, gpm	RT, °F	Heating Output, kBtu/h	Thermal Input, kBtu/h	Power, kW	COP (Gas-Only)	COP (Gas + Electric)
	0.7	1.0	8.0	6.9	90.8	34.2	40.9	0.5	0.84	0.80
	0.9	0.2	8.5	6.8	92.2	72.8	81.1	0.9	0.90	0.86
	0.9	0.5	8.0	6.8	91.9	55.3	63.9	0.7	0.87	0.83
	0.9	1.0	7.7	6.8	91.8	40.7	47.1	0.5	0.86	0.83
0 | 7 | 95	0.1	0.2	0.7	6.9	91.9	24.2	29.5	0.5	0.82	0.77
	0.1	0.5	1.6	7.0	89.7	8.8	14.5	0.3	0.61	0.57
	0.1	1.0	-0.6	7.0	86.4	3.0	7.1	0.2	0.43	0.39
	0.2	0.2	0.7	6.9	92.4	39.4	46.5	0.7	0.85	0.81
	0.2	0.5	0.1	6.9	91.0	19.6	26.5	0.4	0.74	0.70
	0.2	1.0	-0.1	6.9	89.4	9.5	14.5	0.2	0.65	0.62
	0.3	0.2	2.4	6.9	93.2	49.8	56.4	0.7	0.88	0.85
	0.3	0.5	3.4	6.9	92.3	28.5	35.1	0.5	0.81	0.78
	0.3	1.0	1.2	6.9	91.0	14.6	20.0	0.3	0.73	0.70
	0.5	0.2	2.5	6.9	93.9	60.7	68.4	0.8	0.89	0.85
	0.5	0.5	3.1	6.9	93.3	40.0	47.6	0.6	0.84	0.81
	0.5	1.0	0.7	6.9	91.9	22.5	28.5	0.4	0.79	0.75
	0.7	0.2	2.3	6.9	94.3	65.8	74.9	0.9	0.88	0.85
	0.7	0.5	2.8	6.9	93.9	47.5	55.9	0.6	0.85	0.82
	0.7	1.0	1.7	6.9	93.4	31.5	38.5	0.5	0.82	0.78
	0.9	0.2	3.3	6.9	94.6	70.1	79.3	0.9	0.88	0.85
	0.9	0.5	7.9	6.9	94.3	55.3	61.9	0.7	0.89	0.86
	0.9	1.0	2.9	6.9	93.7	37.6	44.9	0.5	0.84	0.80

† accumulated cycling measurement over the cycle duration and not energy rates.

Appendix 5.0

Table 16: CAPFT coefficients (Equation 9) [3].

Coefficients	Values
a1	-5.399E+01
b1	1.541E+00
c1	-6.523E-03
d1	-1.438E-02
e1	2.626E-04
f1	-6.042E-05
g1	4.440E-05
h1	-1.052E-06
i1	6.212E-08
j1	2.424E-08

Table 17: EIRFT coefficients (Equation 11) [3].

Coefficients	Values
a2	5.205E-01
b2	4.408E-05
c2	1.760E-05
d2	6.990E-03
e2	-1.215E-04
f2	5.196E-07

Table 18: EIRFPLR values [3].

PLR	Values
1%	2.250
5%	1.700
10%	1.450
15%	1.250
20%	1.150
30%	1.070
50%	1.035
75%	1.020
100%	1.000

Table 19: $Aux_{Elec,EIRFT}$ coefficients [3].

Coefficients	Values
a4	1.102E+00
b4	-8.714E-04
c4	-9.238E-06
d4	6.487E-08
e4	6.447E-04
f4	7.846E-07

Table 20: $Aux_{Elec,EIRFPLR}$ coefficients [3].

Coefficients	Values
a5	8.421E-01
b5	1.714E-01

References

1. Clearesult. "Gas Absorption Heat Pumps Best Practices Guide." (2023). https://www.cdn.fortisbc.com/libraries/docs/default-source/rebates-and-energy-savings-documents/rebates-for-business/gahp-best-practices-guide.pdf?sfvrsn=635e1441_1
2. "Residential Natural Gas Heat Pumps." *Enbridge*, https://www.enbridgegas.com/sustainability/clean-heating/gas-heat-pumps
3. Guada, Alejandro; Van Dixhorn, Lee; Fridlyand, Alex; Katz, Ari. "Robur GAHP A Performance Mapping." GTI Energy, 2023.
4. Robur. "Installation, use and maintenance manual" (2020). *Robur*, https://fs.hubspotusercontent00.net/hubfs/3937356/doc/D-LBR369_G_19MCLSVI006_GAHP-A_USA_CSA_60Hz_bici_EU.pdf
5. "Method 19 – Determinations of sulfur dioxide removal efficiency and particulate matter, sulfur dioxide, and nitrogen oxide emissions rates" (2023). https://www.epa.gov/sites/default/files/2017-08/documents/method_19.pdf
6. Martin, Cara; Oppenheim, Paul; Bush, John; and Stillman, Hal, "Alternative Defrost Strategies for Residential Heat Pumps" (2018). International Refrigeration and Air Conditioning Conference. Paper 1898. https://docs.lib.purdue.edu/iracc/1898
7. "Technical Data Book" (2017). *Mitsubishi Electric*, https://meus1.mylinkdrive.com/viewPdf?srcUrl=http://s3.amazonaws.com/enter.mehvac.com/DAMRoot/Original/10003%5C2017_P-Series_Engineering_Manual.pdf
8. Fridlyand, Alex; Glanville, Paul; and Garrabrant, Michael, "Pathways to Decarbonization of Residential Heating" (2021). International High Performance Buildings Conference. Paper 354. https://docs.lib.purdue.edu/ihpbc/354