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An Assessment of Gas Absorption Heat Pump Integration Strategies with Combination and Commercial Space Conditioning Systems

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Abstract

Gas absorption heat pumps (GHP) are an emerging class of high efficiency heating equipment that upgrade low-quality ambient heat via an ammonia-water absorption process. This technology can reduce fuel consumption of space heating systems served by furnaces or boilers by 35%-55%, with rated seasonal heating efficiencies of 140% AFUE or greater, based on the application and climate region. GHPs are commercially available, but the commercial space conditioning market adoption is low due to the upfront investments and a lack of installation and maintenance experience. Drawing from multiple case studies, the authors explored the implementation of heat pumps in cold climates for water heating and / or hydronic space conditioning applications. This paper summarizes important design considerations, installation best practices, controls, commissioning and lessons learned from successfully integrating GHPs into hot water plants, often with existing equipment to boost overall plant efficiencies.

Keywords: Gas Absorption Heat Pumps; Reversible Cycle; Space Heating; Space Cooling; Chilled Water; Service Hot Water; Ammonia Absorption Cycle; Combination Heating Systems;

1. Introduction

Commercial space conditioning (heating, cooling and ventilation) accounted for about 7.0 quads per year, or about 40% of total commercial energy use, in terms of primary energy consumption, in the United States [1]. Per a 2018 survey of commercial buildings [2], total number of buildings increased 6% from 2012 to 2018 or about 11% increase in floorspace. By 2050, commercial building floor space is estimated to reach 124 billion square feet, or a 33% increase from 2020 [3]. Natural gas or electricity was the primary fuel source for commercial space heating, while electricity was primarily used for cooling. Packaged heating units and furnaces were used to condition 50% of commercial floor space, boilers accounted for 30% and heat pumps accounted for 15%. For commercial space cooling, packaged A/C units conditioned 58% commercial floor space, central chillers accounted for 19% and heat pumps accounted for 12%.

EIA forecasts short term commercial electricity pricing to increase from 11.27 cents / kWh in 2021 to 12.23 cents in 2023. Natural gas spot pricing is expected to remain high into early 2023, due to lower than average natural gas inventories. Rapid electrification of buildings to achieve decarbonization and sustainability goals may increase grid reliance from 20% to 50% [4]. As systems decarbonize and shift towards pumped hydroelectric, wind, solar, battery storage, etc., there will be a renewed reliance on natural gas to provide peak load balancing to allow for this transition to be seamless. The above factors may contribute to higher prices for commercial space conditioning.

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Conventional fuel fired heating systems such as gas fired furnaces and boilers have approached their thermodynamic limit over the past few decades. Electric heat pumps are highly efficient and have been growing in popularity (where electrification for existing buildings is economically feasible), but their heating performance in cold climate retrofits is low [5]. Additional barriers include high capital and maintenance costs of equipment [7] and associated electric infrastructure upgrades, and challenges in maintaining SHW supply temperatures at peak winter conditions.

Gas absorption heat pumps (GHPs) are an emerging class of high efficiency Thermally Driven Heat Pump (TDHP) equipment that upgrade low-quality ambient heat via an ammonia-water absorption cycle process. This technology can reduce fuel consumption of space heating systems served by furnaces or boilers by 35%-55%, with rated seasonal heating efficiencies of 140% AFUE or greater, based on the application and climate region [8]. GHPs also employ internal heat recovery for coil defrost such that the Coefficient of Performance (COP) and output capacity reduction at low ambient temperatures is less significant when compared to other heat pump technologies. In a study of ammonia absorption cycle heat pump installs across multiple types of commercial buildings in the US Midwest and Canada, TDHPs have shown a consistent Coefficient of Performance for Gas Consumed (COPg) of >1 in cold climate installs. Despite the benefits outlined above, and the commercial availability of GHPs, integration and adoption of GHPs in the commercial space conditioning market is low.

2. A Summary of GHP Integration Strategies with Water Heating, Space Heating, Combination, and Space Cooling Systems

This section aims to assess and summarize key aspects of a hybrid GHP-Boiler integration into water heating and / or space conditioning systems. The term ‘Hybrid’ here refers to a combination of 2 heating sources. Information such as the site selection process, capacity sizing and storage design considerations, construction and commissioning, controls integration, and operational lessons learnt are also discussed.

2.1. Hybrid GHP-Boiler Integration in Combination SHW Systems

The Toronto Atmospheric Fund’s case study [9] in association with a local utility selected a social housing complex in Toronto, ON, Canada to demonstrate GHP integration into a gas-fired SHW and space heating system to maximize emissions reductions.

Existing Conditions: The existing oversized boilers provided both space and SHW heating at an average of 54% TE (thermal efficiency) baselined through a 12,133-liter SHW storage tank.

System Design and Sizing: Two (2) heating only GHPs with a heating capacity of 36.2 kW were selected through a SHW system modelling approach to provide 58% of the overall SHW capacity, while also being able to handle 100% of the baseload non-peak demand at a 54 ºC SHW setpoint. A brazed plate and frame double-walled heat exchanger (PFHX) separated the glycol and potable water systems, and supplemental SHW and space heating demand was met by a pair of high-efficiency condensing boilers. Since GHPs are installed in unconditioned or exterior spaces exposed to weather elements, a water-glycol mixture was used as a heat transfer medium to prevent freezing of pipes. The equipment manufacturer provided performance correction factors which were utilized during the design and selection process. Although, these correction factors were developed only under an ambient temperature of 35ºC and a supply water temperature of 6.6ºC. It would be helpful to explore capacity correction factors under a range of glycol operating temperatures in the future.

Modelled seasonal efficiency of the condensing boiler and GHP system providing SHW and space heating was expected to reach 110%. The study restricted the GHP sizing to two (2) units only due to space constraints in the mechanical room, and to reduce construction costs required to install equipment on the roof. In addition, utilization of the ‘N’th unit would be limited to peak SHW load conditions only. The installed system configuration and associated monitoring devices is shown in Figure 1**Error! Reference source not found.**.

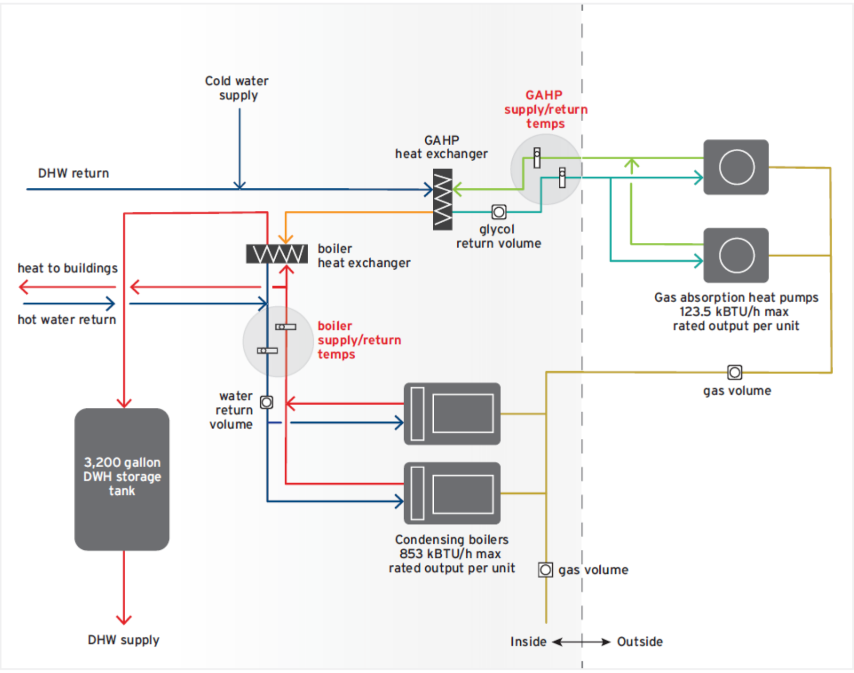

Figure 1. GHP Integration with a Combination Space and Water Heating System [9]

System Performance: GHP performance was represented using the COP measure as shown below.

$$COP = \frac{usable\ heat\ supplied\ by\ GAHP}{natural\ gas\ consumed + electricity\ consumed\ by\ GAHP} \tag{1}$$

The study achieved a mean (averaged during cooler weather operation) COP of 1.14 and at an average GHP Supply Water Temperature (SWT) of 46.6 ºC. When the Outside Air Temperature (OAT) fell below -12 ºC, COP fell below 1.0. It is important here to understand the GHP’s cold climate performance to contextualize its COP. This heating only GHP (36 kW, 6ºC ambient, 50ºC outlet temperature) is a commercially available product developed by Manufacturer A and works on a Generator-Absorber Heat Exchange (GAX) cycle and does not modulate in capacity. Figure 2 shows the performance impact of manufacturer A’s product due to OAT under laboratory test conditions. The mean COP achieved in this case study was realistic due to variabilities in the field such as glycol percentage, system flowrates, cyclic operation, etc, which may impact performance. Also shown is the laboratory tested performance of a product from Manufacturer B. This was a prototype operating on a single effect direct fired ammonia absorption cycle with capacity modulation, but was not commercially available at this time.

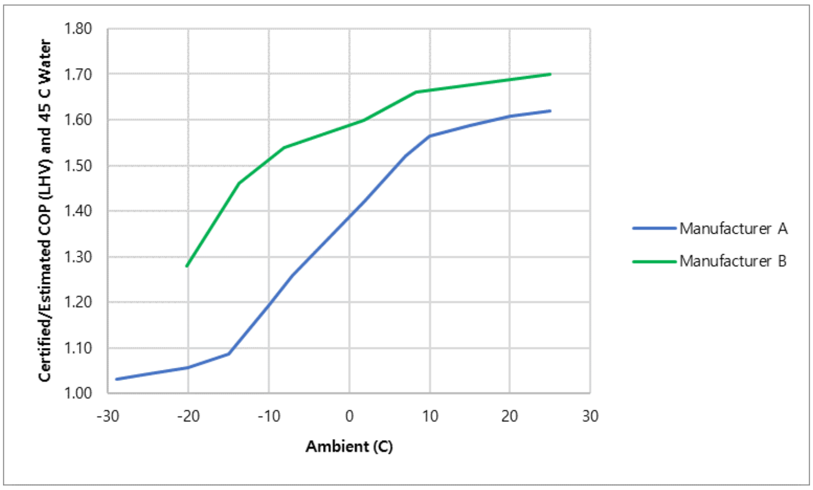

Figure 2. Comparison of Laboratory Performance of two GHPs at different Ambient Temperatures [10]

Operational Challenges and Lessons Learned:

1. Boilers were manually operated for two weeks which resulted in high Return Water Temperatures (RWT) that were close to or exceeded the GHP RWT limit of 50 ºC. This error in sequencing impaired the operation and performance of the GHPs.
2. During periods of no SHW demand, or when the RWT exceeded 50 ºC, the GHPs and their associated glycol circulation pumps were sequenced to shut down. Unfortunately, the GHP flow switches would trip due to premature stopping of the circulation pumps thereby transferring SHW heating load to the backup boilers. This issue was resolved by sequencing the pumps to shut down only after the GHPs stopped consuming electricity.
3. SHW use at the site resulted in fluctuating utilization of the GHP capacity with peak SHW use occurring between 8-10am, and a second peak occurring between 4-6pm. Hourly average capacity utilization was 40% and peaked to 61% at 9am. Capacity utilization of the GHP was lower than pre-installed modelling where it was expected to meet 100% of the daily-off peak loads. To address this underutilization, the GHP will be prioritized when there is an SHW demand instead of calling for heat from the GHPs and boilers simultaneously. This is expected to increase GHP utilization in summer, but not during the shoulder and winter seasons since the boilers will be operational at colder ambient temperatures.
4. When specifying equipment, it is important to determine the % glycol in the glycol-water mixture and apply performance correction factors. An optical refractometer is recommended for this purpose.

2.2. Hybrid GHP-Boiler Integration with a Re-designed Buffer Tank in Combination SHW Systems

GTI Energy's (GTI) study in association with NEEA [11] selected a multifamily residential site in Evanston, IL to demonstrate GHP integration into a gas fired SHW and space heating (or combination) system. The GHP was a prototype developed by manufacturer B (see Figure 2 above) and tested under laboratory conditions [8].

Existing Conditions: One (1) existing oversized non-condensing 80% TE boiler (123 kW) provided both space and SHW heating to six (6) housing units. Daily SHW load is approximately 757-946 liters/day.

System Design and Sizing: Analysis of past utility bills estimated the baseline boiler to have only 6-8 equivalent full load hours (EFLH) during peak winter conditions. During summer with SHW loads only, peak load was estimated as 879.3 kW/day. One (1) heating only GHP with a heating capacity of 23.4 kW, 4:1 modulation, a peak delivered temperature of 73.8 ºC and active defrost was selected. If the GHP was expected to meet 40% of SHW load assuming a COPg of 1.10 during peak winter conditions, it yielded 20 EFLH which indicates the GHP may be well sized for this application. A brazed plate double walled PFHX separated the glycol and potable water systems. A buffer tank was designed and installed as a 'volume' where the GHP loop and the main return loop mixed to preheat cold service makeup water through a coil, to avoid cyclic GHP operation. The existing oversized boiler was replaced with two (2) 84% AFUE and 58.6 kW boilers. One boiler was installed in series with an indirect storage tank to handle SHW loads, and both boilers can provide full redundancy to the GHP. A dedicated Plant Controller was installed and configured to stage the GHP and Boiler operation based on RWT, Space or SHW demand, and OAT reset. Details of the control strategy were published [8] and the installed system configuration is shown in Figure 3**Error! Reference source not found.**.

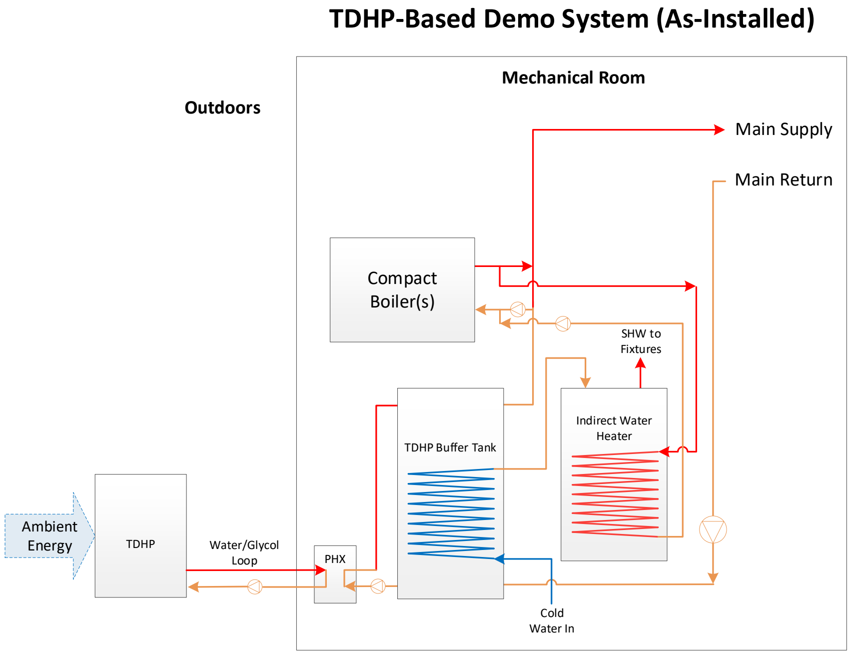

Figure 3. Final Integrated GHP-Boiler Combination Piping Layout (as-installed)

System Performance: At steady state operation under laboratory conditions (50% fire, ambient 0ºC, 49.4ºC RWT), COPg was measured at 1.20. This demonstration saw a COPg of 1.24 under steady state field conditions. During a 13-day continuous operating period between February and March 2020 of the GHP, where RWT is above 51.6 ºC and close to maximum operating capacity, the GHP's efficiency was close to the laboratory measured COPs of 1.12 at -10 ºC and 1.32 at 8 ºC [8]. The system efficiency formula is below:

$$System\ Efficiency = \frac{\Sigma(\mathrm{Q}\ Hydronic,THP + \mathrm{Q}\ Hydronic,Boiler1 + \mathrm{Q}\ Hydronic,Boiler2)}{\Sigma(\mathrm{Q}\ NG,Boilers + \mathrm{Q}\ NG,THP + \mathrm{Q}\ Elec,Pumps + \mathrm{Q}\ Elec,Boilers + \mathrm{Q}\ Elec,THP)} \tag{2}$$

$$COPgas = \frac{\Sigma(\mathrm{Q}\ Hydronic,THP)}{\Sigma(\mathrm{Q}\ NG,THP)} \tag{3}$$

Despite this room for optimization, the projected annual therm savings and GHG emissions reductions were estimated to be 43% for SHW mode and 41% for combined space heating and SHW mode for the GHP/boiler system over the original equipment, or 24% for the compact boiler only architecture. Using the rated 80% TE as the baseline, this corresponds to a hybrid GHP/boiler system delivered efficiency of 136%. On financial payback for the 2835 therms saved/year, at $0.76/therm this system as installed with two compact boilers would have a 4-year payback, or 1.3 years for an optimized system with a single boiler.

Operational Challenges and Lessons Learned:

1. This was a 1st of its kind demonstration of GHP-Boiler integration to multifamily hybrid combination systems with a new product developed by the manufacturer and GTI and tested through this field demonstration. The GHP underwent repairs and a full replacement due to unique failure modes caused by excess wear and tear of the prototype GHP leading to service interruptions. Subsequent design improvements were undertaken on key components (such as the solution pump). The project team recommissioned the system as of spring 2022 and will monitor performance for one (1) year.
2. A parallel study by GTI to utilize GHPs for SHW in full-service restaurants identified a sweet spot for sizing the GHP to carry 30%-60% of peak water heating demand.
3. Capacity and efficiency loss are often a strong function of higher RWTs. High RWTs also lead to high-limit shutdowns, thereby reducing utilization of the GHP. Use of variable speed circulation pumps and a reduced boiler reset temperature setting can help with lowering RWTs.
4. Design and sizing of buffer tanks is critical to manage the high thermal inertias associated with GHPs, variable SHW loads and to smooth out cyclic GHP operation. Depending on GHP size, technology and setpoints, GHPs can require between 5 – 15 minutes to reach steady state capacity and efficiency.

5. The original piping scenario was designed so that the backup boilers would be installed to serve the main space heating loop and the indirect water heating tanks. The GHP would still be installed outdoors and the glycol and service hot water loops would be separated by a PFHX. The first zone is the higher priority water heating tank, and the return is mixed with the main return line. The second zone is the buffer tank, which allows the GHP to preheat return water to the boilers. An alternate layout includes all the above but includes a second PFHX that allows the GHP to heat the SHW directly and is shown in Figure 4. The team identified pitfalls with both layouts:
    a. Combination operation could lead to warming up the RWT as the indirect SHW tank warms up, which would lead to premature shutdowns.
    b. In space heating only mode, as the circulation pumps cycle, adverse mixing on the hot and cold sides of the PFHX would hurt the GHP performance due to temperature swings in the buffer tank.
    c. For SHW only, since the feed water to the indirect water heater tank is a mix of cold water and building recirculation, RWTs to the GHP PFHX would be warm / hot

    These issues led the team towards the piping design described under "System Design and Sizing".

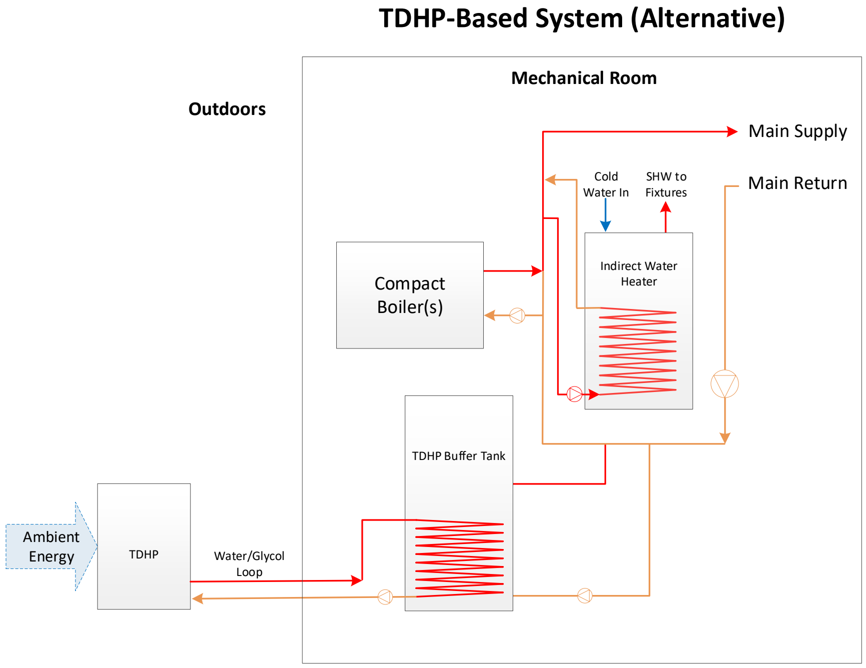

Figure 4. Preliminary Integrated GHP-Boiler Combination Piping Layouts

2.3. Hybrid GHP-Boiler Integration in SHW Systems, with future Space Heating Considerations

Building Energy Solutions Ltd. (BES) and Fortis BC collaborated on a measurement and verification study to investigate the performance of GHPs integrated into SHW systems at five (5) multi-unit residential buildings in Canada. This paper reviews the work performed at site #4 (site numbers designated by the study). The results of the study will be published by the authors at a later date.

Existing Conditions: The SHW system consists of one (1) existing standard efficiency (80%) boiler with a 296 kW capacity, a separate standard efficiency (80%) SHW boiler with a 116.9 kW capacity, and a 435-liter SHW storage tank. The project team estimated that the actual boiler operating efficiency of both boilers was between 65% - 79% based on a number of factors including submetering of boiler input and output parameters, independent flue gas analysis, age and condition of the boilers, and losses in efficiency due to cyclic operation.

System Design and Sizing: Historical gas utility data was weather normalized over a 10-year period (2008-2018) to determine baseline SHW consumption. Since natural gas is used for space and SHW heating, a baseline average of historical gas consumption during summer months was calculated for sizing considerations. The design team developed and built a prefabricated skid that housed the double wall heat exchanger, pumps and control valves, and the skid was installed within the mechanical room. Two (2) heating only GHPs from manufacturer A with a combined capacity of 76.2 kW were installed on the roof with reinforcement. One of the existing SHW storage tanks was replaced with a similarly sized preheat buffer tank with an internal heat exchanger. Per local building codes, SHW must be heated to 60 ºC prior to consumption to eliminate harmful bacteria. A 3-way control valve was installed to bypass the existing hot water boiler when the GHPs were operational to prevent internal corrosion of the standard efficiency boiler's tubes. The project team installed advanced controls to automatically sequence, schedule and change setpoints of the integrated systems to boost energy savings and efficiencies. The installed system configuration is shown in Figure 5**Error! Reference source not found.**.

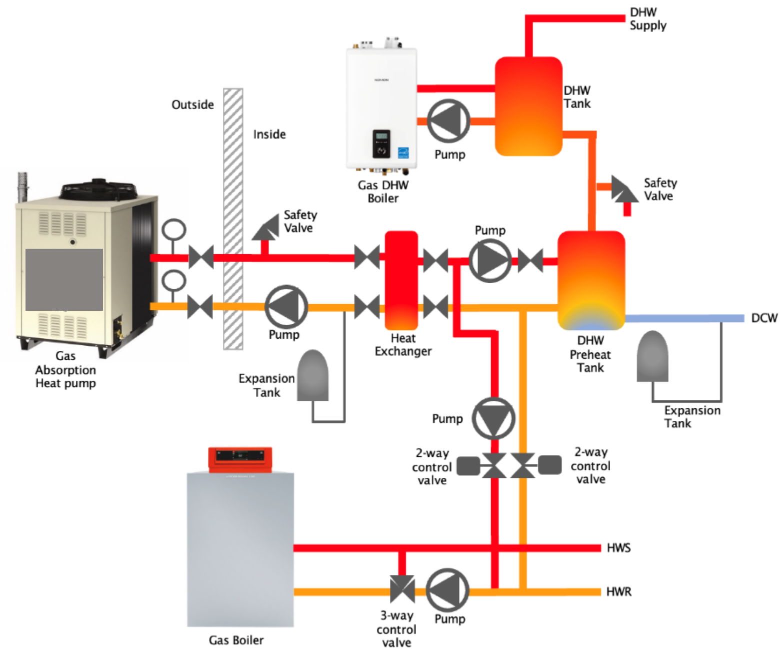

Figure 5. GHP Integration into an existing combination system

<u>*System Performance:*</u> The GHP was able to operate efficiently in heating mode between 15 ºC - 17 ºC ambient air temperatures due to the high heating load requirement of the building below these temperatures. i.e., the output of the GHPs was approximately 25% of the output of the existing SHW boiler. A 15.7% reduction in the site's SHW natural gas consumption and a 8.9% reduction in space heating natural gas consumption from baseline was achieved when test results were extrapolated over a full year. The project team attempted to right-size the GHP capacity by using one of the two installed GHPs to handle SHW demands. A 19.0% SHW gas consumption savings was achieved through this effort. In addition, with a differential temperature of greater than 2ºC across the GHP, the average COP was measured at 1.14. At differential temperatures greater than 8ºC, the GHP can achieve a COP of 1.2 to 1.4.

<u>*Operational Challenges and Lessons Learned:*</u>

1. The project team installed two (2) gas meters to measure consumption for the site versus the GHPs respectively. There were inconsistent readings between the site versus GHP gas flowrate measurements which pointed to data collection and instrumentation errors. In a similar vein, a few sites within the demonstration's portfolio of test sites had 0.1-meter diameter SHW flow meters installed, which was unable to record flowrates below 227 liters/min. Unfortunately, these factors limited calculation of the system efficiency. For critical parameters, it is important to use high accuracy sensors with the right measurement ranges and calibration certificates.
2. Standard efficiency boilers are on average 80% efficient per their nameplates. Based on the age and condition of the boilers, the baseline efficiency of the boilers at full fire was determined to be between 70% - 78%.
3. Efficiency of the GHP is strongly tied to the SHW load profile, which is typically intermittent. Maintaining a large and sustained temperature differential across the GHP (greater than 2 ºC) helps boost efficiencies. Right sizing of the GHP is also very important to improve response times and the temperature differentials.
4. The project estimated a 3.7% thermal efficiency loss occurs across the heat exchanger between the glycol loop and SHW loop. Other sources of efficiency loss included the use of glycol in the loop and

the inadvertent effect of short cycling of the existing boiler under reduced load (~>10%) due to introduction of the GHP for SHW heating. Short cycling significantly reduces efficiencies especially for boilers with limited turndown ratios.

5. The project determined that replacing the existing standard boiler with a minimum 5:1 modulating condensing boilers and improving system sequencing controls as detailed on point #6 could achieve an overall system COP of above 1.0. Introducing condensing boilers can eliminate corrosion concerns thereby modifying the system to a hybrid configuration where the GHP can meet stage 1 demands. In addition, integrating GHP operation with smaller and more consistent heating loads such as Make-Up air handling unit coils or swimming pool heating could allow the GHP to operate for longer periods, thereby improving the COP. This would require additional system design / controls considerations which BES and Fortis BC are exploring in the next phase of their pilot study.
6. Important control parameters for the GHP system are the heating temperature setpoint and the deadband. 'Deadband' is the difference between the supply water temperature when the system cycles off, and the return water temperature when the system cycles on and can vary between products and for a given product-based controls. The heating outlet temperature limit of a GHP is generally between 55 ºC – 58 ºC. The GHP would shutoff due to internal limits before it approaches 60 ºC supply water temperature.

2.4. Hybrid GHP-Water Heater Integration with a Space Cooling Application

GTI in association with the California Energy Commission [6] demonstrated a low-cost gas-fired heat pump integrated with existing commercial water heating and air-conditioning at two (2) restaurants in Los Angeles. The commercial restaurant sector consumes more natural gas per square foot than other commercial building types, with water heating being the largest thermal load. With condensing efficiencies being the ceiling for water heating technologies, the project looked towards deploying gas-fired GHPs. GHPs had the ability to operate at 140% or greater efficiencies and reduce gas consumption by 43% [12]. In addition, GHPs could displace up to 20% electricity demand for air conditioning providing greater operational savings. The project team assumed that an added 0.5 – 2.2 tons of cooling capacity could be useful in all instances with the range dependent on the GHP modulation. Los Angeles has only 1,200 heating degree days per year on average and the internal loads in the kitchen are expected to demand cooling year-round.

Existing Conditions: Depending on SHW loads and redundancy requirements, typical restaurants have one or two hot water heaters with integrated or external storage tank(s) and a recirculation loop to provide 60 ºC SHW for kitchen operation. HVAC equipment should be sized to handle high ventilation loads and internal heat gain totalling to 5-7 times greater energy consumption than other commercial building types. This paper reviews the work performed at site #1 (site numbers designated by the study). Site #1 has two identical storage type 82% TE gas-fired water heaters (79.1 kW input) with 378 liters of storage each. Site #1 consumed 10,290 liters on average of SHW per day, with a peak of 14,142 liters, and a peak flowrate of 45 lpm. The annualized gas input was 875.5 GJ at an average delivered efficiency of 70%. Space conditioning is provided by five heat pumps of 17.5 kW capacity each and one RTU of 44 kW capacity. Weather normalized power demand for the RTU was estimated to be 79 MWh.

System Design and Sizing: A 23.4 kW output GHP, a 427.7-liter indirect storage tank, associated piping and controls were assembled on a 1.2 m x 2.4 m skid to allow for ease of install and maintenance. The GHP skid was installed to act as a preheater for the existing gas fired water heaters. This system was sized and controlled to be SHW demand led, with the GHP carrying most of the SHW load and the gas fired water heaters handling peak loads. For space conditioning, an indoor fan coil unit was sized to deliver 9.3 kW/h and installed in the kitchen which typically experiences year-round cooling requirements. The installed system configuration is shown in Figure 6**Error! Reference source not found.**.

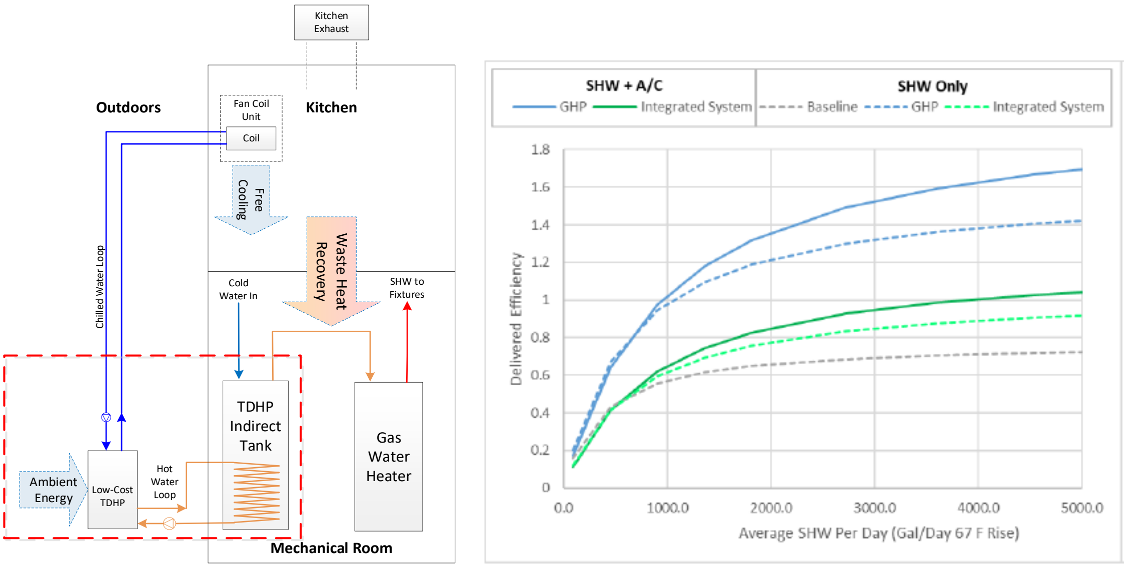

Figure 6. GHP Integration with SHW and Space Conditioning Equipment (Left); Delivered Efficiencies Projection (Right)

System Performance: The GHP system operated for 4,790 hours and 1,150 cycles through a 1-year monitoring period. The project recorded a heating only COPg range of 1.10 - 1.30, and a heating / cooling COPg range of 1.30 - 1.70. Figure 6**Error! Reference source not found.** shows the projected delivered efficiencies of the GHP system and the integrated system (GHP + Existing Gas Water Heaters). Ambient temperatures for the site varied between 1.6 ºC - 43.8 ºC. Use of the retrofit space conditioning system yielded a 14% electric savings (10,820 kWh/year). The GHP carried most of the SHW load through the day, which was approximately 30-60% of the total SHW load.

Operational Challenges and Lessons Learned:

1. Skid assembly and pre-shipment preparations included development of contractor training materials and instructions to ensure a smooth install and on-site commissioning.
2. The GHP skid was to be installed beside an exterior parking space or on the rooftop due to the lack of extra space within the mechanical room or the roof. To minimize hot water piping to the indirect storage tank and chilled water lines to the FCU, an alternate location closer to the water heaters was chosen. Although, the manufacturer required clearance / setback to install a portion of the evaporator coil was not achieved which limited the airflow thereby reducing performance of the GHP.
3. The GHP and FCU were integrated with glycol and chilled water lines respectively. The host site expressed concerns with the glycol mixture's proximity to the cooking areas due to potential leaks. Unfortunately, the final placement of the FCU was less useful in improving thermal comfort of restaurant employees as they were not directed at portions of the cookline and food preparation areas. Although, as discussed in the "system performance" section, there was a 14% reduction in AC kWh usage for a year-round cooling requirement. In addition, the chef and cooks provided positive feedback on the retrofit AC's functionality.
4. The length of and restrictions within the FCU Chilled Water loop prevented the installed system from reaching its designed chilled water flowrates as recommended by the manufacturer. Supplemental A/C effectiveness was further reduced due to a lack of effective air removal from the hydronic loops during routine service. Site #1 achieved only 55% of the target CHW flowrate.
5. Nuisance "blocked vent" errors caused early interruptions of GHPWH operation. Issue was resolved when vents were properly sloped for condensate disposal.
6. Due to prototype status of this product from manufacturer B, hardware / software issues were identified during operation and resolved. The first issue was with a faulty startup capacitor which stopped condenser fan motor operation. The fan motor was replaced, and the issue did not recur. Second, the solution pump showed signs of wear on the bearing which required a pump replacement. Third, over the course of the 12-month study, the evaporator coil had accumulated excessive dust /

lint due to site conditions. Exterior fouling was addressed by simply hosing down the coil. Each issue was identified and rectified with the manufacturer, and design improvements were recommended.

3. Conclusion

With the push towards electrification and decarbonization in a steadily growing commercial building market, it is important to integrate high efficiency heating technologies such as GHPs into water heating or space conditioning systems. Utilities are already using natural gas fired plants to meet increased electricity demand due to electrification of water and space heating systems. Extreme cold and hot weather events can also trigger unexpected spikes, grid instability, and power outages. Depending on the geographic fuel mix for electricity generation, the consumer may pay more for electricity consumption and demand. GHPs can help flatten peak electricity demand especially during the heating season and maintain efficiencies above conventional heating systems. GHPs can also serve as a drop-in replacement for conventional boilers / water heaters and require minimum updates to existing infrastructure. However, attention must be paid to critical design considerations and integration strategies for a successful deployment of GHPs.

This paper summarizes key design considerations and operational lessons learned from four (4) field demonstrations across North America, with a few aspects highlighted below:

- Existing SHW or Combination systems typically have an oversized 80% TE non-condensing boiler with redundant capacity. SHW systems also have large storage tanks and variable demand through the day which lead to the boilers cycling and hence reduce overall system efficiency.
- A retrofit GHP system can be sized to meet baseload non-peak demand with supplemental heating provided by existing boilers. Design and right-sizing can also consider analyses of past utility bills, sub metered / monitored data for a range of OATs and building loads, results from system modeling, capacity correction factors when using a glycol-water mixture and utilization of a heat exchanger internal or external to a buffer tank (review manufacturer published recommendations for buffer capacity). OAT reset controls for space conditioning systems must consider the GHP’s SWT limit of 60ºC and RWT limit of 50ºC. GHPs must be installed exterior to the building with adequate access and clearances provided.
- A majority of lessons learned are from implementation of control parameters / limits used to stage the hybrid heating plant. GHPs must be prioritized to handle baseload and to maximize runtime (reduce cycling). Controls for ancillary equipment such as 3-way control valves and circulation pumps must be commissioned on a system level to prevent premature shutdown of GHPs. Other mechanical and plumbing considerations are to maintain appropriate slope for condensate vents, clean condenser coils prone to fouling due to dust, and install air removal vents at high points of hydronic systems.

The authors hope to provide a roadmap to design, install and operate hybrid heating systems with heat pumps, which would ultimately increase adoption of this emerging technology.

4. Nomenclature

A/C	Air Conditioning
AFUE	Annual Fuel Utilization Efficiency
COP	Coefficient of Performance
EIA	Energy Information Administration
EFLH	Equivalent Full Load Hours
GAX	Generator-Absorber Heat Exchange Cycle
GHP	Gas Absorption Heat Pumps
NEEA	Northwest Energy Efficiency Alliance
OAT	Outside Air Temperature
PFHX	Plate and Frame HX
RWT	Return Water Temperature
SHW	Service Hot Water
SWT	Supply Water Temperature
$Q_{\text{Hydronic, THP}}$	GHP’s hot water output
$Q_{\text{Hydronic, Boiler}}$	Boiler’s hot water output
$Q_{\text{NG, THP}}$	Gas consumed by the GHP
$Q_{\text{NG, Boiler}}$	Gas consumed by the boiler
$Q_{\text{Elec, Pumps}}$	Electricity consumed by pumps
$Q_{\text{Elec, Boilers}}$	Electricity consumed by the boilers

$Q_{Elec, THP}$	Electricity consumed by the GHP during operation
TDHP	Thermally Driven Heat Pump
%TE	% Thermal Efficiency
BES	Building Energy Solutions Ltd
RTU	Rooftop Unit
FCU	Fan Coil Unit

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