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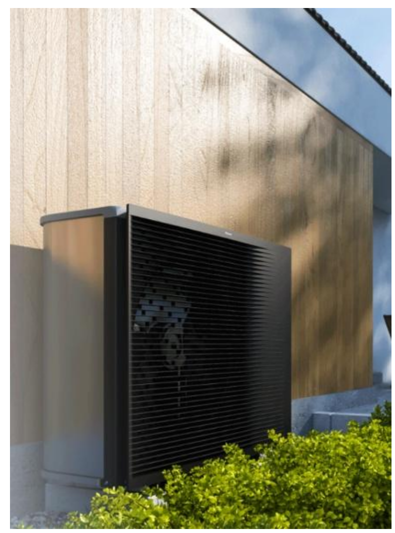
Evaluation of Tri-Mode Air-to-Water Heat Pumps for Residential Applications



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EXECUTIVE SUMMARY

GTI Energy conducted laboratory tests to assess a cold climate air-to-water heat pump (A2WHP), which is a tri-mode combi system designed for heating, cooling, and hot water supply in single-family residences. The study evaluated both steady-state and seasonal performance of the A2WHP—including indoor and outdoor units—for space conditioning (heating and cooling) and domestic water heating (DHW) applications. Simulated 24-hour use (load-based evaluation) was also performed to reflect the operational performance of the A2WHP for combined space conditioning and water heating loads. These tests were conducted at GTI Energy's laboratory in Des Plaines, IL. The resulting performance data were used to generate maps in EnergyPlus for the Northern Illinois region, enabling comparisons between the tri-mode heat pump system and other advanced technologies. The evaluation also contributed to identifying potential adoption strategies for the A2WHP within the ComEd service area, guided the development of future method-of-test protocols, and provided input for upcoming utility-sponsored field demonstrations and initiatives.

Key Findings

A market scan identified a wide range of tri-mode A2WHP products available from various manufacturers. While tri-mode systems represent a newer product category, they were found to be most applicable to single-family residences in both new construction and retrofit applications. Some benefits and challenges of A2WHPs are summarized in the table below.

Table 1. Benefits and Challenge Considerations for Air-to-Water Heat Pumps in the Market

Benefits of A2WHPs	Challenges for A2WHPs
Better energy efficiency, especially during cold and transitional seasons. Even higher efficiencies are possible with improved control strategies.	Backup electric resistance heat is usually needed at lower ambient temperatures
Potentially better fit for electrifying hydronically heated homes or older homes with substantial heating loads that require multiple air-to-air heat pumps with significantly more backup heating capacity and usage.	Existing hydronic radiators should be used for heating-only applications and should not be used with A2WHP cooling modes.
Energy and operating cost savings to consumers, particularly if time-of-use rate structures are employed.	Higher installed costs than other heat pumps due to early market maturity.

Benefits of A2WHPs	Challenges for A2WHPs
No refrigerants being handled during installation; no EPA license required for installers.	Plumbing complexities and components may challenge conventional HVAC installers.
Readily supports new refrigerants like propane (R290), ammonia, CO2, and others to improve efficiency and reduce environmental impact.	Driving towards lower impact refrigerants requires federal policy leadership.
Integration of water storage allows for load shifting space and/or water heating to reduce peak demand and provide grid services, further enabling renewable generation.	Emerging technologies are in early stages of leveraging thermal storage.

Steady-state evaluations in a laboratory environment of the representative A2WHP system validated the Original Equipment Manufacturer's (OEM) performance data. More specifically, GTI Energy's steady-state heating testing of the selected 18kW A2WHP system showed good alignment within ±3% of OEM published data across the range of test conditions even at high hot water supply temperatures. Furthermore, the test data confirms and even slightly exceeds the OEM published data for steady-state cooling evaluation.

The DHW Evaluation measured a First Hour Rating (FHR) of 73 gallons and a Uniform Energy Factor (UEF) of 2.57 for the A2WHP system, using a high-usage draw pattern in testing[1]. The system was evaluated under daily load-based space conditioning and water heating loads. For space heating and water heating load-based testing, the balance point for part-load conditions was identified to be approximately 15°F, below which point the heat pump would require backup heat to meet the building heating load. Likewise, part-load conditions influenced the heat pump's performance as will be discussed in more detail later in the report.

An energy modeling analysis was performed to compare the annual tri-mode performance of the A2WHP system to other mixed fuel and all-electric baseline technologies. The performance mapping derived from the daily load-based space conditioning and water heating loads was used to inform the performance estimation of the A2WHP. The simulations were performed for two different capacities or models of the A2WHP across two single-family home sizes with peak heating loads of roughly 38,000 BTU/h (2,378 sq. ft. 2006 IECC vintage) and 62,000 BTU/h (2,000 sq. ft. 1980 vintage) chosen to represent various insulation levels and vintages representing

[1] Test methods were based on 10 CFR Part 430, Subpart B, Appendix E, but conditions may not fully match official UEF specifications. Reported FHR and UEF values are research estimates, not certified lab results.

northern Illinois. To accomplish the simulations, the performance mapping generated from the laboratory testing of the 18kW unit (12kW with 6kW backup heat) was scaled to the 12kW unit (10kW with 2kW backup heat). The modeled tri-mode A2WHP systems, 18kW and 12kW units, showed potential energy cost and GHG emission savings in both simulated building types. Table 2 and Table 3 list the annual energy consumption and reduction for the tri-mode A2WHP system relative to a) federally code compliant mixed fuel baseline of a 13.4 SEER2 central AC, 80% AFUE gas furnace and 0.67 UEF storage gas water heater, and b) federally code compliant electric baseline of a 14.3 SEER2/7.5 HSPF2 electric air-to-air heat pump and 0.88 UEF electric water heater.

Table 2 Annual Energy Consumption for the Tri-Mode A2WHP System relative to Baseline Equipment

Tri-mode A2WHP system and building model	**A2WHP System** 18kW system 1980 vintage 2,000 sq. ft. home/ 12kW system 2006 IECC 2,378 sq. ft. home	**Mixed Fuel Baseline** 13.4 SEER2 AC + 80 AFUE Furnace + 0.67 UEF Gas WH	**All-Electric Baseline** 14.3 SEER2 + 7.5 HSPF2 Heat Pump + 0.88 UEF Electric WH
1980 vintage 2,000 sq. ft. home	21,742 kWh	3,647 kWh and 1,818 therms	26,533 kWh
2006 IECC 2,378 sq. ft. home	13,900 kWh	2,510 kWh and 1,240 therms	17,997 kWh

Table 3 Annual Energy Reduction for the Tri-Mode A2WHP System relative to Baseline Equipment

Tri-mode A2WHP system and building model	**Mixed Fuel Baseline** 13.4 SEER2 AC + 80 AFUE Furnace + 0.67 UEF Gas WH	**All-Electric Baseline** 14.3 SEER2 + 7.5 HSPF2 Heat Pump + 0.88 UEF Electric WH
A2WHP 18kW system 1980 vintage 2,000 sq. ft. home	18,095 kWh added and 1,818 therms reduced	4,791 kWh reduced
A2WHP 12kW system 2006 IECC 2,378 sq. ft. home	11,390 kWh added and 1,240 therms reduced	4,097 kWh reduced

Table 4 lists the projected annual energy cost savings for the tri-mode A2WHP system relative to a) federally code compliant mixed fuel baseline of a 13.4 SEER2 central AC, 80% AFUE gas furnace and 0.67 UEF storage gas water heater, and b) federally code compliant electric baseline of a 14.3 SEER2/7.5 HSPF2 electric heat pump and 0.88 UEF electric water heater. gas water heater, and b) federally code compliant electric baseline of a 14.3 SEER2/7.5 HSPF2 electric heat pump and 0.88 UEF electric water heater.

Table 4 Annual Energy Cost Savings for the Tri-Mode A2WHP System relative to Baseline Equipment

Tri-mode A2WHP system and building model	Mixed Fuel Baseline 13.4 SEER2 AC + 80 AFUE Furnace + 0.67 UEF Gas WH	All-Electric Baseline 14.3 SEER2 + 7.5 HSPF2 Heat Pump + 0.88 UEF Electric WH
A2WHP 18kW system 1980 vintage 2,000 sq. ft. home	\$284/year (9.1%)	\$623/year (18.1%)
A2WHP 12kW system 2006 IECC 2,378 sq. ft. home	\$319/year (15%)	\$533/year (22.8%)

Table 5 lists the projected annual GHG emission reduction for the tri-mode A2WHP system relative to a) federally code-compliant mixed fuel baseline of a 13.4 SEER2 central AC, 80% AFUE gas furnace and 0.67 UEF storage water heater, and b) federally code-compliant electric baseline of a 14.3 SEER2/7.5 HSPF2 electric heat pump and 0.88 EF electric water heater.[2]

Table 5 Annual GHG Emission Reduction for the Tri-Mode A2WHP System relative to Baseline Equipment

Tri-mode A2WHP system and building model	Mixed Fuel Baseline 13.4 SEER2 AC + 80 AFUE Furnace + 0.67 UEF Gas WH	All-Electric Baseline 14.3 SEER2 + 7.5 HSPF2 Heat Pump + 0.88 UEF Electric WH
A2WHP 18kW system 1980 vintage 2,000 sq. ft. home	13,480 tons of CO_2e/year (46.3%)	3,441 tons of CO_2e /year (18.1%)
A2WHP 12kW system 2006 IECC 2,378 sq. ft. home	9,879 tons of CO_2e /year (49.7%)	2,943 tons of CO_2e /year (22.8%)

While this system outperformed the baselines tested and would lead to energy cost savings for the customers those baselines represent, this specific system in its design did not outperform a high-end ccASHP GTI has tested in other research and may cost more to install than a set up with both a ccASHP and HPWH. As such, other benefits of this technology might be most helpful for ComEd and its customers in the near term, such as providing load shifting potential beyond what's possible with air-to-air HP, more easily enabling low-GWP refrigerants at scale, or potentially outperforming a ccASHP/HPWH set up with proper A2WHP improvements (e.g., improved controls and A2WHP design or with improved installed cost research, including considerations of panel upgrades).

[2] Sourced from https://cmic.gti.energy/residential (Accessed June 2025), where the electric grid emission factors are based on the eGRID 2022 dataset for baseload generation.

While this system outperformed the tested baselines and would lead to energy cost savings for the customers those baselines represent, its design did not surpass a high-end cold climate air-source heat pump (ccASHP) that GTI Energy has evaluated in other research. Additionally, it may cost more to install than a setup with both a ccASHP and a heat pump water heater (HPWH). Therefore, other benefits of this technology might be more advantageous for ComEd and its customers in the near term. These benefits include providing load-shifting potential beyond what is possible with air-to-air heat pumps, more easily enabling low-global warming potential (GWP) refrigerants at scale or potentially outperforming a ccASHP/HPWH setup with proper A2WHP improvements, such as enhanced controls and design or with improved installed cost research, including considerations of panel upgrades.

Recommendations

Manufacturers of cold-climate air-to-water heat pumps (A2WHPs) should design and configure systems to primarily load-follow the building's thermal demand and integrate low-temperature central air handler units capable of operating with the lowest possible water temperatures.

Currently, forced air delivery A2WHPs typically load-follow by targeting water supply temperatures and monitoring hydronic temperature variances. While these parameters can indicate changes in thermal load, they do not track indoor air temperature deviations from the setpoint as some cold-climate air-source heat pumps (ccASHPs) do. Load-based testing revealed cycling penalties from the A2WHPs as a result. By incorporating indoor temperature feedback, A2WHPs could reduce cycling penalties and extend runtime and modulate output more precisely in response to actual space heating demand.

Low-temperature central air handler units, however, remain rare because they require a larger coil surface area to transfer the same amount of heat at airflow rates like ASHP systems. Integrating such air handler designs would allow A2WHPs to operate with lower water setpoints while still meeting thermal loads—improving efficiency compared to conventional air handler configurations.

Load-based testing and modeling revealed that oversizing the heat pump to avoid backup heat may help avoid costly electric resistance heating in extreme cold weather, but will be detrimental to A2WHP seasonal efficiency over the course of the heating season with low part-load efficiency and cycling penalties affecting the estimated seasonal heating efficiency factor. Improved manufacturer controls for part-load conditions could allow seasonal efficiencies to align with high steady-state efficiencies more closely.

Considering the findings from load-based testing and the projected savings potential of tri-mode A2WHPs, conducting pilot installations in northern Illinois is recommended to validate and substantiate the anticipated energy savings. These pilots should include a representative sample across various manufacturers to assess the range of performance, installation and sizing best practices in heating dominated climates, and to evaluate market transformation factors such as installer and contractor challenges, as well as customer acceptance.