Home Heating in Cold Regions: Synergistic Benefits of Advanced HVAC and Weatherization

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ABSTRACT

Cold regions have unique challenges for residential space heating; to improve energy efficiency and occupant comfort, both the building envelope and heating equipment can be evaluated for upgrades. One such technology, advanced cold temperature heat pumps (CCHPs) are pushing the boundaries of efficiency and reliability in extremely cold regions and outperform traditional residential heat pumps. As new advanced CCHP products are commercialized, understanding their performance in real-world settings is crucial. While advanced CCHPs can deliver high efficiency in sub-zero temperatures, integrating weatherization measures can yield additional energy performance and cost benefits for homeowners. This study examines synergistic benefits of advanced dual fuel, air source CCHPs combined with weatherization upgrades. The key research question this study addresses is: What are the energy and operational cost-benefit implications for homeowners when integrating advanced dual fuel CCHPs with weatherization? A case study approach combining field performance data of three advanced CCHP installations over the 2025-2026 winter with a utility-bill informed energy assessment was employed to investigate this question. The estimated weatherization impact varied from a 24% heating energy reduction at one site to almost no reduction at another site. The combined retrofit impacts were much more significant, ranging from 51% to 56% heating energy reduction across the three sites. Despite the reduction in energy consumption, the retrofits did not decrease utility costs, largely because of high local electricity prices and low natural gas prices. When using national average utility rates instead of local utility rates, these advanced CCHPs with the weatherization upgrades were estimated to reduce heating utility costs by 2% to 9% in the three homes.

Introduction

Heating challenges in cold regions

Space heating is one of the most energy-intensive and expensive end-uses for residential buildings in cold regions (EIA 2024). Many areas in the U.S. experience prolonged periods of sub-freezing outdoor temperatures and large quantities of heating degree days that place high demands on mechanical heating systems. In many homes, inadequate insulation levels, uncontrolled air infiltration, and thermal bridging exacerbate heating loads and can contribute to occupant discomfort. Under these conditions, heating systems must not only deliver sufficient heat during cold events, but do so reliably, efficiently, and in a manner that maintains thermal comfort for occupants. Achieving these objectives is particularly challenging in existing homes with antiquated envelope construction.

Advanced cold temperature heat pumps (CCHPs) and dual fuel backup

Heat pumps are a technology that has expanded the limits on traditional heating, ventilation, and air conditioning (HVAC) systems. By transferring heat rather than generating it, refrigerant cycle heat pump systems can produce heat outputs that are greater than the input energy of the system, providing coefficients of performance (COPs) greater than 1. However, conventional residential heat pumps typically experience declines in heating capacity and efficiency at very low outdoor temperatures (Konrad and MacDonald 2023). These limitations pose a barrier to their widespread installation. In response, advanced CCHPs have been developed to maintain high heating capacity and operational efficiency at outdoor air temperatures down to 5°F and below. Higher performing heat pump technology has been driven by many factors including, but not limited to, improvements in variable-speed compressors, enhanced vapor injection, optimized refrigerant circuits, and more sophisticated defrost and control algorithms. Studies have shown that advanced CCHPs can provide heat efficiently even when outdoor temperatures fall well below freezing. A review by Wan and Hwang (2023) of ten CCHP studies found the COPs ranged from 1.0 to 2.5 with a mean around 1.5 for cold outdoor air temperatures from 5°F to -22°F (-15°C to -30°C). Another review by Konrad and MacDonald (2023) found similar results, with COPs of 1.75 to 2.25 at 5°F (-15°C) for market-available residential CCHPs.

As the performance of advanced CCHPs has improved, they have been increasingly adopted by contractors as primary heating systems in regions traditionally dominated by furnaces and boilers. However, the economic feasibility of advanced CCHPs remains a key consideration for widespread adoption. In colder regions, the average American household using propane or fuel oil to heat their home spends over $1,850 annually in heating costs alone (EIA 2023). Some field demonstrations have shown that advanced CCHPs can reduce overall household energy consumption; however, operational cost savings depend heavily on local energy prices. For example, a monitored installation in Minnesota reported that a CCHP system provided a 50% *energy* use reduction compared to the previous natural gas system, but the overall utility *costs* increased (Schoenbauer 2018). Even if a heat pump is performing with COPs greater than 1, it still may cost more than heating with an all-natural gas system, depending on electric and gas utility rates.

Very cold temperatures can degrade heat pump performance, decreasing the COP, and eventually the capacity will drop below the building's heating demand. Due to this drop in capacity, heat pump systems typically require a supplemental heating source, such as an electric resistance heater or fuel backup system. Dual fuel configurations—pairing a CCHP with a backup furnace—are one strategy to reduce utility costs compared to electric resistance auxiliary heating in regions where natural gas is cheaper than electricity. Outdoor temperature-based switchover controls or demand response signals enable the system to prioritize heat pump operation for conditions where the advanced CCHP can meet the heating demand at rated efficiencies, and switch to the alternate heating system at lower outdoor temperatures or when the advanced CCHP cannot meet the full heating demand. This study specifically investigates dual fuel, cold temperature-optimized air source heat pumps in a residential application.

Weatherization and interaction with advanced CCHPs

Energy code for new construction has steadily reduced heating and cooling loads of newly built homes since about 1990 (DOE n.d.) but typically, code does not apply to non-structural retrofit projects like air sealing, window replacement, or adding insulation (ICC 2025). Nearly 60 million U.S. homes have "leaky" envelopes with air infiltration rates greater than or equal to 10 ACH_{50} (NLR n.d.) and more than 60 million have less than R-11 wall insulation or are not insulated at all.[1,2] This indicates that tens of millions of homeowners can benefit from weatherization upgrades. This is especially true in more extreme temperature regions, where building heating or cooling demand is high, and the discomfort of conductive and infiltrative heat transfer is substantial (ASHRAE 2020). Insulation and air sealing are common energy efficiency interventions (IRS 2026) in International Energy Conservation Code (IECC) zones 4 through 8 that also improve comfort by reducing drafts and heat transfer around the building exterior and reduce disruptive noise from outdoors.

Replacing heating and cooling equipment is a large investment and is often precipitated by equipment failure, when there is little time to make consequential, long-lasting decisions. When HVAC equipment is replaced, Air Conditioning Contractors of America (ACCA) Manual J[3] recommends that sizing should be determined by inputting detailed building and occupancy characteristics (including the performance of each envelope component) into a building energy modeling tool. Weatherization measures such as air sealing, wall and roof insulation, and high-performance windows not only reduce heating loads and utility bills but potentially enable purchase of a smaller, less expensive HVAC unit if the improved performance of the envelope components is reflected in the Manual J calculations.

Study objectives and research questions

Despite technological innovations and growing market acceptance, there remains a need for comprehensive field assessments of advanced CCHPs, particularly in combination with envelope retrofits. Laboratory studies and manufacturer performance curves provide essential benchmarks, but they do not fully capture the variability that results from installation, envelope performance, occupant behavior, or controls implementation that shape real-world outcomes. This study attempts to address these gaps by examining the synergy between advanced CCHPs and weatherization strategies in homes. Specifically, the study investigates the following

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[1] The "leakiness" of a building's enclosure is typically measured in air changes per hour (one air change represents the entire volume of the building) using a blower door assembly to impose a pressure differential of 50 pascals compared to ambient outdoor pressure, referred to as ACH_{50}. In the United States, newly built houses in cold regions are typically constructed with air leakage rates of no more than 3 ACH_{50}.
[2] The letter "R" denotes a measure of thermal resistance to conductive heat flow. Walls, roofs, foundations, and windows with low R-values allow heat to pass through more readily, imposing a greater thermal load on the HVAC system. In the United States newly built houses in cold regions are typically constructed with insulation levels between R-20 and R-30.
[3] ACCA Manual J® https://www.acca.org/standards/technical-manuals/manual-j

research question: *What are the energy and operational cost-benefit implications for homeowners when integrating advanced CCHPs with weatherization?*

To answer this question, a case study approach is employed, combining field performance data of three advanced dual fuel CCHPs during the 2025–2026 winter and a utility bill-informed energy analysis to compare pre- and post-weatherization conditions. By integrating these data sources, this study aims to provide actionable insights for program administrators, contractors, and homeowners seeking optimized, whole-home heating solutions for cold regions.

Study Background

Overview of advanced CCHP technology and research efforts

The Department of Energy (DOE) partnered with industry and key stakeholders in 2021 to develop and commercialize advanced CCHPs; specifically, residential, centrally ducted, electric-only, air-to-air heat pumps with nominal cooling capacities between 2 tons of refrigeration (TR) (24,000 British Thermal Units [Btu] per hour) and 5 TR (65,000 Btu per hour). Eight HVAC manufacturers developed prototypes that met the thresholds set by DOE to exceed commercially available products at the time. Prototype development was followed by independent performance testing in the laboratory and in the field. More details on the field performance of the pre-commercial prototype units developed by the HVAC manufacturing partners are described in Mendon et al. 2024. In 2025, three manufacturers brought commercialized versions of their advanced CCHP prototypes to the market. This study aims to evaluate the performance of one of these commercialized advanced CCHP products, installed in three different homes, in conjunction with weatherization upgrades.

Participating homes

Three single-family detached homes, all located in Wisconsin in IECC zone 6, were selected from a larger pool of 24 candidates. The research team prioritized homes that had central ducting, were suitable in size for the available advanced CCHP products (2-4 TR models), were suitable for weatherization measures that could be installed quickly and were geographically co-located to reduce travel. Each homeowner was provided with informed consent forms developed through the Institutional Review Board (IRB) process. Additional details of the participating homes are described in Table 1.

Table 1. Pre-weatherization home characteristics.

Home ID	Existing heating	Year built	Conditioned floor area (sq.ft.)[1]	Construction type	Cooking fuel type
1	Natural Gas Furnace (96-97% efficiency)	1984	2,906	Wood frame with vinyl siding over poured concrete basement	Natural Gas
2		1955	3,030		Electric
3		1975	2,786		Electric

[1] Including finished, conditioned basements, common in the northern midwestern states.

Weatherization and audit process

A local WI firm performed energy audits for each of the three participating homes in September 2025, focusing on energy use, construction materials, and installation. The audit reports noted the following items of concern and the recommended mitigation measures for each home (Table 2). Measures that were ultimately not implemented are marked with footnotes in the table.

Table 2. Summary of weatherization issues and upgrades.

Home ID	Item of concern	Recommended measure
1	Some room for improvement with regard to air leakage.	General air sealing including attic, above fireplace, and around water heater flue.
	Attic floor insulation levels inadequate and vertical insulation sagging at knee walls.	Blown cellulose insulation and rigid foam board/spray foam to address knee walls of partial cathedral ceiling[1].
	Infrared imaging shows thermal leaks in area above kitchen pantry.	Add insulation and repair.
	Basement sill boxes have inconsistent and poorly installed insulation.	Apply closed cell spray foam insulation to basement sill boxes where accessible.
	Original kitchen exhaust fan has been removed; bathroom fan flowrates are less than recommended.	Add exterior exhaust vent to microwave and replace and re-vent bathroom exhaust fans.
	The door between the garage and the home does not fit tightly.	Use a Q-lon style weather-stripping or replace the locking mechanism to create a tight seal when closed.[2]
2	Measured air leakage is high; homeowner reports drafts throughout.	Caulk around doors and windows.
	Deficient exterior wall insulation.	Add dense-pack cellulose insulation (drill-and fill from interior) to all accessible exterior walls.
	Poorly insulated rim joists, gaps and cracks.	Apply closed cell spray foam to basement rim joists (as accessible).
	Uninsulated exterior doors.	Weather-strip exterior doors.[3]
3	Some room for improvement with regard to air leakage.	Repair insulation and seal: attic, old water heater flue, plumbing vent stack, chimney.

Home ID	Item of concern	Recommended measure
	Inadequate attic insulation. Some areas in the attic have moisture stains or black spots.	Blow cellulose insulation into the attic to meet R-50. Insulate / weather-strip attic hatch to prevent transfer of humid air.
	Knee wall above basement stairs is poorly insulated, lacks top plate.	Replace this existing fiberglass batt insulation with 3" of closed cell foam.
	Existing recessed lights are thermal bridges and are leaking air.	Install insulated covers and seal with spray foam.
	A couple sections of the basement sill boxes are missing insulation.	Spray foam treatment of basement rim joists (unfinished areas).
	The kitchen duct is uninsulated; two bathroom exhaust fans use flex duct and don't meet recommended flowrates.	Insulate kitchen duct with high temperature rated materials. Re-vent bathroom fans with 4" rigid metal ducts.
	The original exterior doors are uninsulated.	Weather-strip exterior doors with Q-lon style strips to create a tight seal.

[1] Only 50% of this work was completed due to the discovery of a protected bat species in this area of the attic.
[2] Homeowners chose to replace the locking mechanism as a do-it-yourself project and was not completed by the professional contractor.
[3] Homeowners chose to weatherstrip their exterior doors as a do-it-yourself project and was not completed by the professional contractor.

Table 3 shows additional information for each home provided by the energy auditor to the research team. Pre- and post-weatherization air leakage rates were measured with a blower door test. The following reductions in infiltration (ACH_{50}) were observed:

- Home 1: 4.20 to 3.97 (-5%)
- Home 2: 7.56 to 6.56 (-13%)
- Home 3: 4.38 to 3.24 (-46%)

The contractor used Manual J to calculate heating design loads for both before and after recommended weatherization. The audit report included estimated pre-retrofit, whole-home energy use, and savings for both energy and utility costs for implementing each measure. Savings for the measures that were not implemented by the contractor are not included in the savings estimates in Table 3. For Home 1, where the contractor found a protected bat species nesting in the attic, the analysis reduces the estimated savings for the attic measures by the approximate percentage of the task that could not be completed without interfering with the nest. In Table 3, the utility cost savings are lower than the energy savings because the weatherization upgrades primarily drive natural gas heating reduction, and the cost of natural gas is significantly less than the cost of electricity for these homes.

Table 3. Auditor-provided estimated design loads and annual energy and cost savings associated with weatherization upgrades.

Home ID	Pre-upgrade design heating load (Btu/h)	Post-upgrade design heating load (Btu/h)	Pre-upgrade design cooling load (Btu/h)	Post-upgrade design cooling load (Btu/h)	Pre-retrofit whole-home energy use (MMBtu/yr)	Estimated whole-home energy savings	Estimated whole-home utility cost savings
1	47,658	42,546	23,077	20,183	109.5	12%	7%
2	41,552	32,490	21,346	17,734	93.4	16%	6%
3	35,895	30,864	15,025	13,438	115.1	7%	3%

CCHP selection and installation

The CCHP installations all occurred in December 2025 at the same time the weatherization upgrades took place. The advanced CCHP product installed in all participating homes was the same make and model 2-TR (24 kBTU/h) unit, which was right sized to completely meet the cooling design loads in Table 3 above. A natural gas furnace rated for 66 kBTU/h and 97% efficiency with a variable speed blower was installed as part of the system. The furnace was sized to completely meet the heating design loads in Table 3 above. Because 2-TR unit is the smallest model available for this product and there was only one size natural gas furnace available to go with this product, there were not any possible first cost savings for reducing HVAC equipment size associated with weatherization in these cases.

The HVAC installers programmed all CCHPs with a standard outdoor air switchover temperature (the temperature below which the system is designed to use the furnace for heating[4]) of 25°F even though the installed advanced CCHP units were designed to operate efficiently at much colder temperatures. Upon noticing this, the research team asked the homeowners to modify their thermostat settings to an outdoor air switchover temperature of 5°F, the outdoor temperature used for the CCHP Challenge specification, to gather more heat pump operation data at colder temperatures.

Methodology

The object of the analysis was to compare the isolated impact of each upgrade–weatherization and CCHP–as well as their combined effect. For all three cases, savings related to both heating energy use and heating energy cost are of interest. In this analysis, only heating season data was available, so cooling savings are not included. Savings in the results section are expressed as a percentage of annual space heating energy rather than whole-home annual energy use. The weatherization and CCHP retrofits were conducted within one month of each other, making it impossible to measure their impact separately and directly. Instead, a hypothetical

[4] It should be noted that the furnace was often activated above the switchover temperature at the homes in this study, presumably when the controls signaled a delta between the setpoint and thermostat temperature resulting from a manual or programmed setpoint change.

scenario where the weatherization upgrades occurred but the CCHP was not installed was modeled by converting the heat output of the CCHP system to a furnace energy using the rated efficiency value of the existing furnace. This savings analysis assumes no change in occupant behavior (e.g., setpoint changes). The savings were normalized by outdoor air temperature by aggregating the savings value for each 1-degree temperature bin across typical (average of last four years) winter temperatures.

Data collection and performance monitoring

Prior to weatherization and CCHP installations, the only data available are monthly utility bills that include electricity and natural gas consumption. The three homeowners provided 12 months of pre-retrofit monthly natural gas usage from October 2024 through September 2025. After the installations in December 2025, the homes were equipped with sensors that collected raw data at 1-second intervals, and the data was logged and transmitted to the research team using eGauge devices and a cellular modem. Table 4 summarizes the post-retrofit data points collected for each home in this study.

Table 4. Post-retrofit monitoring equipment, product specifications, and data points collected.

Parameter	Product	Sensor	Sensor location
Power circuit	DENT CT-HSC	Split core block-hinged current transducer	Outdoor compressor
			Indoor fan
			Indoor unit
Voltage	Magnelab SPT-0375	Potential voltage transformer	Reversing valve
Temperature/ Relative Humidity	Monnit ALTA MNS2-9-W2-HU-RH-L03	Thermocouples and Silicon based digital humidity transducer	Outside ambient
			Supply air duct
			Return air duct
			Indoor spaces (x3)
Pressure	Grainger 616KD-01	Dwyer differential transmitter signal adapter	Furnace inducer fan
Volumetric Airflow	TrueFlow Grid	Multi-point differential pressure sensors	Return air duct

The resulting data was used to measure power input and heat output of the CCHP and furnace, which was in turn used to estimate the energy and cost savings. Power input for the CCHP was measured directly at the outdoor compressor and the indoor supply fan with a current transducer. Power input of the backup furnace was calculated using the pressure of the furnace fan inducer as a proxy to determine furnace fuel usage. A strong correlation was identified between the furnace inducer fan, which is the mechanism that draws fuel into the furnace chamber, and the heat output of the furnace (which was used to calculate natural gas flow rate using the rated efficiency of the furnace) during steady state, furnace-only heating operation. A linear regression equation was established to estimate the natural gas flow rate and power input of the furnace at every timestep based on the furnace fan pressure.

For heat output of the CCHP and furnace, which was used to estimate how much natural gas would have been needed from a furnace-only scenario to meet the same load, a TrueFlow meter and its digital application were used during installation of the monitoring equipment to correlate the volumetric supply airflow to supply fan power. Heat output ($\dot{Q}_{heating}$), in Btu per hour, was calculated using Equation 1, below, using the CCHP supply and return air temperature and relative humidity fields and the volumetric airflow.

$$\dot{Q}_{heating} = \rho_{dry} * \dot{V}_{blower} * C_{p,sup} * (T_{sup} - T_{ret}) \quad (1)$$

where ρ_{dry} = the air density of dry air in supply air, lb/ft^3

$\dot{V}_{blower}$ = is the blower volumetric airflow rate, ft^3/hour

$C_{p,sup}$ = is the specific heat capacity of the supply air, Btu/ºF-lb

T_{sup} = is the temperature of the supply air, ºF

T_{ret} = is the temperature of the return air, ºF

In addition to the utility data and monitoring equipment data that was used to estimate the energy savings of the weatherization and advanced CCHP retrofits, three surveys were completed by each homeowner for supplementary, qualitative data points. The first was a pre-qualification survey sent to 24 potential candidates to capture basic information on their home, their current HVAC systems, and their interest in participating in the study. Six of these field study candidates received a second pre-installation survey in September of 2025, about three months prior to installation that contained 32 questions about the home, occupancy characteristics, and the pre-existing heating and cooling systems. Three of these homeowners were selected for the study with upgrades completed in December of 2025. Participants received an 18-question homeowner satisfaction survey in March 2026 after the first winter, including questions on thermal comfort, noise, humidity, system faults or failures, and utility expenditures.

Analysis methods

In this study, utility data was collected from each site and modeled against historic outdoor air temperature using EEmeter. EEmeter[5] is an open-source software package that uses CalTrack methods to estimate utility loads as a function of outdoor temperature. The methods assume that building load is a piecewise linear function with respect to outdoor air temperature.

Additional processing steps were necessary to isolate the space heating end use from the natural gas utility data to compare directly to the post-installation monitoring data. All three homes used natural gas for water heating. Home 1 used natural gas for cooking, and the other two homes had electric cooking equipment. Home 1 also had a natural gas fireplace. The natural gas usage during the summer months—presumed to be only the water heating and natural gas cooking baseloads—was subtracted from the natural gas usage quantities. Residential water heating and cooking fuel use is not expected to change significantly by season, so the baseload usage in the summer months when there is no space heating load was expected to be the same as the usage for the end uses in the winter months.

[5] https://eemeter.readthedocs.io/index.html

To estimate the fireplace load for Home 1, which should vary by season unlike hot water and cooking end uses, the measured natural gas usage of the CCHP furnace and the baseload usage (the cooktop and the water heater) were removed from the utility charges of two post-retrofit months of utility data from the winter of 2026. The resulting difference was attributed to the fireplace consumption.

To account for any differences in weather conditions between the pre- and post-retrofit data collection periods, hourly outdoor temperature averages were taken over a four-year period. This data was provided by the Meteostat[6] python package. The outdoor temperature data was rounded to the nearest integer, and the average number of hours at each temperature across the four years was used to represent a typical year. Next, the heating load at each temperature was given by,

$$Q_i = \dot{Q}_{\mathrm{i}} \Delta t,$$

where Q_i is the expected yearly energy load at that temperature (in kBtu), $\dot{Q}_{\mathrm{i}}$ is the load at temperature i (in kBtu/hr), and Δt is the total amount of time spent in that temperature bin over a year (in hrs). Next, the total heating load of the building for an expected year is given by,

$$Q_{tot} = \sum_{i=T_{min}}^{T_{max}} \mathrm{Q}_{\mathrm{i}},$$

where Q_{tot} is the total building space heating load, and T_{min} and T_{max} are the minimum and maximum expected temperatures where heating occurs in a typical year.

Cost savings were calculated from energy savings using the local utility rates during this period. Effective January 1st, 2026, standard utility rates for Madison Gas and Electric were \$0.49 per day plus \$0.18 per kilowatt-hour (kWh) for electricity[7] and \$0.64 per day plus \$0.99 per therm for natural gas.[8] The per unit cost of natural gas for this utility was nearly 30% lower than the national average price of \$1.35 per therm in January 2026. The local cost of electricity was about 3% higher than the national monthly average price of \$0.17 per kWh in January 2026. If converted to the same units of energy, natural gas was nine times less expensive than electricity for this region at this time.

Results

Figure 1 shows three curves: (1) the pre-retrofit furnace, indicating the existing HVAC and envelope conditions (dashed green line, from utility data), (2) the post-weatherization only retrofit (solid blue, furnace only, no CCHP scenario), and (3) post-retrofit dual fuel CCHP and weatherization (solid black non-linear line). The shaded regions below the black curve show the individual contributions of the furnace (natural gas) and CCHP (electricity). The difference between curves (1) and (2) is an estimate for the heating energy savings resulting from weatherization alone. The difference between curves (2) and (3) is an estimate for the heating

[6] https://eeweather.readthedocs.io/en/latest/
[7] https://www.mge.com/my-account/rates/electric-rates/residential-electric-rates
[8] https://www.mge.com/my-account/rates/natural-gas-rates/residential-natural-gas-rates

energy savings from the advanced CCHP retrofit, and the difference between curves (1) and (3) represents the combined retrofit heating energy savings.

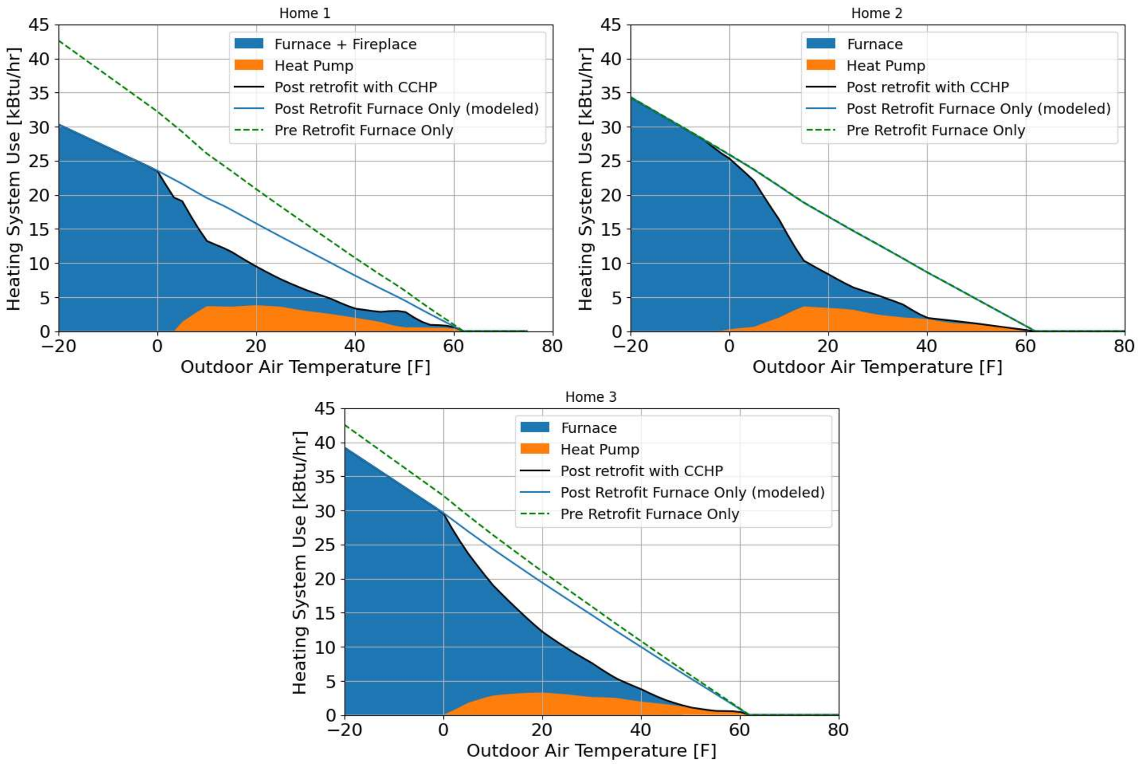

Figure 1. CCHP retrofit heating system use (split between heat pump and furnace) compared to furnace-only (no CCHP) projection.

Figure 1 shows significant savings for weatherization alone at Home 1, almost no weatherization-only savings at Home 2 (the solid blue and dashed green lines are almost indistinguishable), and modest weatherization-only savings at Home 3. Looking at the impact of the advanced CCHP system, there is a big gap between the solid black line (dual fuel) and solid blue line (furnace-only, no CCHP scenario) at temperatures where the heat pump is operating (5°F and above).

Table 5 sums the savings value from Figure 1 across a typical winter using historical weather data. The energy savings are significant across the three sites; however, for these three case studies, the utility costs increased as a result of the advanced CCHP and combined retrofits. The cost of natural gas was nine times cheaper per unit of energy than electricity for these sites. This makes it challenging for an electric heating system, even with the high COPs offered by advanced dual fuel CCHPs, to reduce utility costs over a natural gas-only heating system.

Table 5. Estimated heating season energy and utility savings from weatherization, CCHP, and combined retrofit.

Home ID	Pre-retrofit heating energy (MMBtu)	Pre-retrofit heating cost ($)	Weatherization savings		CCHP savings		Combined savings	
			Energy (%)	Utility (%)	Energy (%)	Utility (%)	Energy (%)	Utility (%)
1	76.1	$870	24%	21%	29%	-45%	52%	-25%
2	58.9	$701	0%	0%	56%	-15%	56%	-15%
3	73.0	$840	8%	7%	43%	-23%	51%	-16%

Table 6 shows the results using the January 2026 national average electricity and natural gas utility rates cited in the *Analysis Methods* section. Compared to Table 5, the utility savings for the CCHP and combined retrofit are on average 25% higher. In addition, two of the three homes show positive utility savings with national average rates from the advanced CCHP retrofit, and all three sites are estimated to experience utility savings from the combined retrofit. The significant impact is a result of differences between local and national averages, with local gas pricing nearly 30% lower than the national average and local electricity pricing about 3% higher than the national average.

Table 6. Estimated heating season savings from weatherization, CCHP, and combined retrofit with national average utility rates.

Home ID	Pre-retrofit heating energy (MMBtu)	Pre-retrofit heating cost ($)	Weatherization savings		CCHP savings		Combined savings	
			Energy (%)	Utility (%)	Energy (%)	Utility (%)	Energy (%)	Utility (%)
1	76.1	$1,144	24%	21%	29%	-20%	52%	2%
2	58.9	$913	0%	0%	56%	8%	56%	9%
3	73.0	$1,103	8%	7%	43%	0%	51%	7%

The three homeowners participated in a survey to evaluate their satisfaction and overall experience with the CCHP installations. The occupants did not note any concerns with thermal comfort or the unit's ability to maintain setpoint temperatures. Despite significant reduction in natural gas usage, the post-installation electric bills were noted as a main concern by the three homeowners. One homeowner noted that it was an abnormally cold winter after the installation.

Conclusions

Summary of findings

This field study investigated the energy and cost-benefit impacts of a retrofit that paired a weatherization upgrade with a new advanced dual fuel CCHP for three homes in Wisconsin. Utility data was leveraged for pre-retrofit energy use, and monitoring instrumentation was installed at the air handler to assess post-retrofit energy use. For each of homes 1, 2, and 3 the estimated combined retrofit heating energy savings were substantial: 52%, 56%, and 51%, respectively. The isolated CCHP heating energy savings were also significant: estimated to be 29%, 56%, and 43%, respectively. The estimated heating energy savings from the weatherization retrofit alone were more modest: a 24%, 0%, and 8% reduction, respectively.

Although the estimated energy savings of the combined retrofits were significant, the overall heating season utility bills were estimated to increase at the three sites: an increase of 25%, 15%, and 16%, respectively, relative to the pre-retrofit heating energy cost. The energy unit cost of electricity was nine times more expensive than natural gas for these sites in winter 2026, so the added electricity cost of the advanced CCHP outweighs the overall cost reduction associated with natural gas. When using national average utility rates, the estimated utility savings became positive at all three sites for the CCHP plus weatherization upgrade: 2%, 9%, and 7%, respectively. This suggests that advanced CCHPs could be more cost-effective in locations where the ratio of electricity rates to gas rates is more favorable to electricity.

Overall, the survey results highlight a disconnect between advanced CCHP technical performance and customer experience. While the CCHPs demonstrated significant energy savings, utility bills were mentioned as a concern from the three homeowners. In other words, technology may perform well from an energy-efficiency standpoint, but customer satisfaction is strongly influenced by whether those savings translate into lower monthly utility costs. Thus, a key lesson from the survey is the importance of setting clear expectations before installation. Future participants should be informed that energy savings may not always result in immediate utility bill savings, especially in areas with high electricity prices relative to gas prices or during unusually cold winters. Providing this context up front could help avoid surprise, improve participant understanding, and support more accurate perceptions of system performance.

Limitations

This study took the approach of allowing homeowners latitude in operating their new systems. Field studies such as this work provide notable advantages over laboratory studies by capturing real-life conditions, including the effect of varied occupant activities and interactions. However, it also introduces more uncontrolled variables that present a challenge for generalizing conclusions. The results are a case study of three homes, rather than a large-scale study. There are several factors that make these homes unrepresentative, including the single weather region (WI, IECC zone 6), the larger-than-median household sizes, and the limited equipment (single manufacturer, same model, same sizing, same backup heat energy source). Some additional limitations of this work include:

- A full life cycle cost assessment of the retrofits was not included. A more realistic purchasing process, getting multiple quotes and considering multiple products to reduce first costs would result in a more reliable assessment. There would also need to be a business-as-usual cost component, including multiple quotes for replacement furnaces that would typically have been installed in the standard “like-for-like” approach.
- For pre-retrofit performance modeling, only 12 monthly data points (utility bills) were available. This lack of granularity introduced some uncertainty to the pre-retrofit regression models.
- These are the savings for how these particular advanced CCHP units were operated by these homeowners specifically, and the proprietary control settings for this single advanced CCHP product.

Future Work

This research effort is ongoing, and more homes will be investigated next winter. Additional considerations for future work include:

- Thermostat Data: Changes in schedules and setpoints to meet occupant needs can vary daily, weekly, or at random. Without knowledge of these patterns and ad hoc changes, the analysis lacks precision and does not convey full confidence. Future work will include working with homeowners and manufacturers to collect timestamped thermostat data.
- Switchover Temperatures: In one case the homeowner manually changed the switchover temperature from the recommended 5°F to 15°F in mid-January, after seeing their first utility bill post-retrofit. Different switchover temperature settings and the energy and cost implications could be investigated and optimized.
- Cooling Performance: At the time of this publication, no post-retrofit cooling data is available. Both the weatherization and advanced CCHP have cooling season savings implications, and reducing the summer electricity load could make a difference for the cost-benefit results. Future work will include investigating total annual energy and cost savings of the retrofits, as well as seasonal implications.

Future expansions of this work, including increased sample size and additional modeling, will help explore the impact of more variables on heating costs. This will include more variation in geographic location of the homes, home types and sizes, and advanced CCHP equipment to provide data and analysis that is more conclusive and actionable.

Acknowledgements and References

This research is funded by US DOE Building Technologies Office. The authors are thankful for the guidance of Wyatt Merrill and Payam Delgoshaei. Other contributors to this work include Joel Pertzsch, Jake Millette, and Zack Thompson from Michaels Energy.

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