Hydronic Fluid Additive Final Report

Project Number ET23SWG0011

GAS EMERGING TECHOLOGIES (GET) PROGRAM
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Acknowledgements

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Executive Summary

This report evaluates the energy savings potential of a Hydronic Fluid Additive in commercial hydronic heating systems under the Statewide Gas Emerging Technologies (GET) Program. The additive, designed to enhance heat transfer efficiency by reducing surface tension in water-based fluids, was tested at two commercial office buildings in Northern California (Climate Zone 03 - CZ03) over multiple heating seasons. The study initially followed the International Performance Measurement and Verification Protocol (IPMVP). The planned Option B (Retrofit Isolation: All Parameter Measurement) was supplemented by Option C (Whole Building Approach) due to metering issues, using existing Building Automation System (BAS) data, and outside air temperature (OAT) data from the California Measurement Advisory Council (CALMAC).

Key findings include:

- **Energy Savings**: At Site #1, gas savings were 10.7% using Option C - PG&E gas meter data normalized by heating degree days (HDD, base 80°F). At Site #2, initial gas energy savings were measured at 29% using Option B - OAT-binned analysis normalized by HDD (HDD, base 80°F). Further normalizing by the heating hot water (HHW) output per bin to isolate boiler-level thermal efficiency gains resulted in a 5% decrease indicating a slight decrease in boiler efficiency under similar operating conditions. To isolate the additive's impact on system thermal efficiency, a weighted average post-to-base HHW output ratio of 0.68 (weighted by post-installation OAT bin frequency) was applied to Site #2's unadjusted 29% gas savings, yielding an adjusted savings of 19.8%, reflecting system-level gains despite a 5% decrease in boiler efficiency.
- **Surface Tension Reduction**: The additive reduced measured surface tension by 40-50% (from baseline values of approximately 70 mN/m to 35-45 mN/m), falling short of the manufacturer's claim of 60% reduction.
- **Cost and Installation**: Material costs ranged from $13,500 to $20,000 per site, with easy installation. Payback periods varied, with customers requiring a maximum return -on-investment (ROI) of three years for adoption.
- **Customer Feedback**: Satisfaction was moderate; Site #2 reported positive results and a likelihood of adoption, while Site #1 noted low savings and emphasized the need for incentives. Also, customers were concerned about product lifetime. No interruptions to service or occupant complaints occurred.

The additive demonstrated energy consumption reduction by reducing the required HHW energy output to meet the same "level-of-service" or heating demand (primarily in colder conditions below 50°F). However, the additive did not consistently improve system thermal efficiency. Post-installation models showed unpredictable behavior (i.e., poor energy model fits) to be used for comparison and system efficiencies at similar OAT bins did not show an increase based on Site #2 using Option B approach.

The hydronic fluid additive outperforms the incumbent baseline technology, standard water-based hydronic fluids (e.g., standard water without specialized energy-saving additives) in reducing energy consumption. However, it faces barriers like a lack of awareness, unknown ROI in milder climates, and unclear fit into energy efficiency (EE) measure categories (e.g., behavioral, retro-commissioning, operational (BRO) or Add-on Equipment (AOE)). The results from this study do not clearly support the adoption of this technology for standard EE programs due to inconclusive nominal efficiency gains. Further studies in varying climates (mild and cold) are recommended to verify results and support broader market penetration.

Introduction

The energy consumption in commercial buildings accounts for about 17% of the total U.S. energy consumption, with space heating accounting for 32% of the total energy consumption for all U.S. commercial buildings in 2018 [1] [2]. Hydronic heating systems, which circulate hot water or steam through pipes to radiators or coils, are widely used in commercial facilities for space heating due to their efficiency and ability to provide consistent heating. A hydronic heating system uses a boiler to heat water, and the heated water or steam is circulated to heat distributors located across the building. The heat distributors can be radiators, baseboard heaters, radiant tubing, or air handling units (AHU). When an AHU is used, this is sometimes referred to as a "hydro-air" or "hydronic forced-air" system, as the AHU uses fans to flow air across the hot water coils to provide heating to building zones. In this context, both types of systems are referred to as "hydronic" systems since both use water to transport heat across a building [3]. These systems face challenges such as heat loss, inefficient heat transfer, and high operational costs, particularly during extended heating seasons. The heat transfer efficiency within the heat distributor affects how quickly a zone meets its heating temperature set point. These systems typically already use high-efficiency condensing, gas-fired boilers. Thus, any additional improvements to the performance of hydronic systems are necessary to reduce energy consumption further, lower greenhouse gas emissions, and maintain sustainability goals in commercial settings [4].

Hydronic heating systems generally use water or water-glycol mixtures as the heat transfer fluid. While effective, these fluids have limitations in thermal conductivity and heat retention, leading to inefficiencies in heat transfer and increased energy use to maintain desired temperatures. Over the past few decades, research has focused on enhancing heat transfer fluids with "hydronic additives" to improve system efficiency [5]. Additives like corrosion inhibitors, antifreeze agents, and surfactants have been introduced to address issues such as pipe corrosion, freezing, and scaling, but these are not designed to improve efficiency or reduce energy consumption.

Emerging technologies, such as advanced fluid additives, are aimed at reducing energy consumption by improving the thermal properties of the fluid itself. One such innovation is a Hydronic Fluid Additive designed to enhance heat transfer efficiency in hydronic heating systems. This additive works by reducing the surface tension of the hydronic water-based fluid, improving heat transfer rates via several heat transfer mechanisms, which can lead to reduced energy consumption by boilers or pumps. One manufacturer claims that their hydronic additive product has been proven to reduce surface tension and maximize the heat transfer efficiency in the heat distributors, resulting in zones meeting temperature set points faster, reducing boiler cycling and overall run time, thereby saving energy. This type of additive was introduced in the early 2010s and has gained attention in the commercial sector for its potential to reduce energy use by retrofitting existing hydronic systems without requiring major infrastructure changes. The manufacturer claims 7-15% energy savings, supported by over ten case studies conducted by various third-party organizations across universities, hospitals, commercial buildings, and multifamily buildings. This product doesn't perfectly fit into any measure application type (MAT) in California; however, it is considered to fall BRO because it improves energy efficiency without enhancing the nominal efficiency, and it can be reasonably expected to produce multi-year savings [6]. Additionally, this product may be considered as an AOE measure, which involves installing new equipment on an existing host system to improve its performance or reduce energy use by improving the nominal efficiency of the host system.

The purpose of this project is to evaluate the energy savings potential of the Hydronic Fluid Additive in a commercial hydronic heating system across multiple heating seasons. With rising energy costs and regulatory pressure to reduce carbon footprints, commercial facilities are increasingly seeking retrofit solutions to optimize existing systems and meet sustainability goals. This study addresses the need to quantify the actual energy savings of the hydronic additive compared to the incumbent standard water-based hydronic fluids (e.g., standard water or water-glycol mixtures without specialized energy-saving additives), providing data to inform its viability for broader market adoption. The hydronic fluid additive was implemented at two commercial sites with gas-fired hydronic heating systems, using real-time Building Automation Software (BAS) data to assess performance under varying weather conditions. By verifying savings, this project aims to guide facility managers, energy service companies (ESCOs), and policymakers on the efficacy of the additive as a scalable energy conservation measure (ECM) for commercial applications, potentially influencing future retrofit strategies and energy efficiency programs.

As part of the GET Program, the boundaries of this assessment for this project focus on a specific subset of the possible hydronic systems for evaluation. This includes limiting the study to field testing at commercial sites in California with natural gas boilers that already have existing BAS systems providing sufficient baseline data. Hydronic heating systems are commonly found in commercial buildings in California. The Database for Energy Efficiency Resources (DEER) has hydronic heating systems in the following California building types:

1. Education - Secondary School
2. Education - Secondary School
3. Education - Community College
4. Education – University
5. Health/Medical – Hospital
6. Health/Medical - Nursing Home
7. Lodging – Hotel

8. Office – Large
9. Office – Small
10. Retail - Multistory Large
11. Residential Multifamily

Further, the Study Team has observed hydronic heating systems at many multifamily sites in California through auditing experience in other energy efficiency programs. Since the fluid additive impacts the efficiency of hydronic heating systems, it has a large potential for energy savings in the California market.

Technical Potential

The most recent gas heating energy use intensity and floor stock values from the applicable building types in the California Commercial End-Use Survey (CEUS) are presented in Table 1 to assess the technical potential of the hydronic additive in the commercial sector.

Table 1: CEUS Heating End Use Data for Selected Building Types

Building Type	Natural Gas Heating Energy Use Intensity (kBtu/ft^2-yr)[1]	Floor Stock (kft^2)[2]	Total Consumption for Heating (kBtu/h)
Small Office (<30kft2)	8.6	361,584	3,109,622,400
Large Office	17.2	660,429	11,359,378,800
Retail	3.0	702,053	2,106,159,000
School	10.0	445,106	4,451,060,000
College	19.8	205,942	4,077,651,600
Health	32.7	232,606	7,606,216,200
Lodging	7.3	270,044	1,971,321,200
Weighted Average			**5,291,481,983**

[1] Table 8-5 of CEUS Executive summary

[2] Table 8-1 of CEUS Executive Summary

If it is assumed that 75% of the overall heating for these building types is from hydronic boilers, the total statewide Therm consumption from hydronic heating is:

$$5{,}291{,}481{,}983 \left[\frac{kBtu}{h}\right] * \frac{1\ therm}{100kbtuh} * 75\% = \mathbf{39,686,115\ therms}$$

The average savings when using the fluid additive product from the provided case studies is 8% savings. The measure life for a BRO measure is 3 years. If it is assumed that the market penetration is 1% for the first year, this product becomes a measure; the total lifetime savings over the 3-year measure life is:

$$39{,}686{,}115\ therms * 8\%_{Therm\ Savings} * 1\%_{market\_penetration} * 3_{Year\_life} = \mathbf{95,247\ therms}$$

Table 2 shows an estimated market penetration of 17.5% and lifetime savings for this product of 10.9 million therms, assuming that the market penetration goes up to 1.5% in years 4-6 and 2.5% in years 7-10.

Table 2: Cumulative Savings over 3-Year Measure Life

Year	Therm Savings	Market Penetration %	Annual Therm Savings	Measure Life	Lifetime Therm Savings over 3-year Measure Life
1	8%	1.00%	189,431	3.00	624,265
2	8%	1.00%	189,431	3.00	624,265
3	8%	1.00%	189,431	3.00	624,265
4	8%	1.50%	284,146	3.00	936,398
5	8%	1.50%	284,146	3.00	936,398
6	8%	1.50%	284,146	3.00	936,398
7	8%	2.50%	473,577	3.00	1,560,663
8	8%	2.50%	473,577	3.00	1,560,663
9	8%	2.50%	473,577	3.00	1,560,663
10	8%	2.50%	473,577	3.00	1,560,663
Total		**17.50%**			**10,924,644**

Analysis Approach

For this study, the incumbent technology is a standard water-based hydronic heating system without energy-saving additives, operating with a natural gas boiler at the commercial site. The assessment is a field study, conducted over multiple heating seasons, following the IPMVP. The planned Option B (Retrofit Isolation: All Parameter Measurement) was supplemented by Option C (Whole Building Approach) due to metering issues at Site

#1, using existing BAS data (e.g., boiler energy consumption, supply and return temperatures, flow rates, etc.) before and after the addition of the Hydronic Fluid Additive. The baseline system performance was established using historical BAS energy data and normalized using nearby weather station data from the CALMAC to account for climatic variations across heating seasons. This documentation ensures transparency and replicability, allowing stakeholders to accurately assess the energy savings attributable to the Hydronic Fluid Additive.

Background

The term "hydronics" was officially coined in 1946 by the Institute of Boiler and Radiation Manufacturers (IBR) to describe the science of heating buildings with water, marking a shift toward modern water-based systems in hydronic heating systems [7]. Hydronic baseboard heating gained popularity in the 1950s, providing efficient and consistent heat distribution in commercial and residential HVAC [8]. By the mid-20th century, heat transfer fluids evolved to include water-glycol mixtures for freeze protection, with additives like corrosion inhibitors and antifreeze agents such as ethylene or propylene glycol becoming standard to address issues like pipe corrosion and scaling [9]. In the post-World War II era, influences from aviation and industrial hydraulics led to the adoption of synthetic, fire-resistant fluids, inspiring thermal stability enhancements in HVAC hydronic [10]. By the late 20th century, research emphasized advanced additives, including surfactants, viscosity improvers, and anti-wear agents (typically 0.5-2% of the fluid), to optimize flow and heat transfer without changing the base fluid and improving overall HVAC performance [10].

In the early 2010s, specialized energy-saving Hydronic Fluid Additives emerged for HVAC retrofits, incorporating technologies like surface tension reducers to enhance thermal properties, reduce boiler cycling, and achieve quicker responses to changes in demand [11] [12] These additives have been developed to lower energy consumption in hydronic heating by improving the delivery of heat to spaces, reducing system differential temperature, and reducing boiler run times [12].

Compared to the incumbent baseline technology (i.e., standard water-based fluids without additives), the evaluated Hydronic Fluid Additive provides improved performance in HVAC applications. Baseline water-based fluids offer cost-effective heat capacity but result in inefficiencies like reduced thermal conductivity, higher corrosion risk, and suboptimal flow, leading to increased energy use and maintenance. In contrast, the additive reduces surface tension for better heat transfer, minimizes boiler demand, and supports energy savings, while remaining compatible with existing systems.

Emerging Technology/Product

The assessed emerging technology is a Hydronic Fluid Additive for commercial hydronic heating systems. This additive is a chemical formulation introduced into the water-based heat transfer fluid of closed-loop hydronic systems to enhance thermal performance and reduce energy consumption. It is designed as a retrofit solution, meaning it can be added to existing systems without requiring significant modifications to existing equipment, such as boilers, pipes, or heat emitters like radiators or AHUs. The additive targets applications in commercial buildings, where hydronic systems are common for space heating, and aims to deliver verifiable energy savings across multiple heating seasons, via IPMVP Option B or C approach [13].

Physics Behind the Technology/Product

The physics underlying Hydronic Fluid Additives revolves around modifying the thermophysical properties of the hydronic water to optimize heat transfer processes. Standard water, as the base fluid, has a high specific heat capacity (approximately 4.18 kJ/kg·K), which allows it to store and transport significant thermal energy but can result in slower thermal responsiveness due to the energy required to change its temperature [11]. The additive reduces surface tension (typically by 60% according to the manufacturer), which enhances surface wetting and minimizes bubble formation on heat exchanger surfaces. This improves convective heat transfer by increasing the heat transfer coefficient, as smaller bubbles depart more frequently, enhancing near-surface mixing [11] [13]. These changes in thermodynamic properties improve the hydronic system's ability to transfer heat more efficiently, reducing the overall energy input needed for heating.

How This Technology/Product Works

The Hydronic Fluid Additive is mixed into the system's circulating hydronic water at a low concentration (typically 0.5-2% by volume) [14]. Once introduced, it alters the fluid's properties to improve heat conduction at the boiler and delivers at heat emitters. By reducing surface tension, the fluid achieves better contact with metal surfaces, preventing thermal-insulating air pockets and enhancing heat exchange efficiency [15]. This results in quicker attainment of zone temperature set points, as more heat is transferred per cycle. Consequently, the boiler experiences less demand, leading to reduced cycling and runtime. The process is passive after installation, requiring no ongoing adjustments beyond standard system maintenance, and it maintains compatibility with common hydronic components like pumps and valves [11] [16].

Incumbent Technologies/Products

The incumbent technology for heat transfer in hydronic heating systems in CA is standard water or without specialized energy-saving additives. Standard water (i.e., tap or mineral water without filtration of impurities) is commonly used for its high heat capacity and low cost in temperate climates, such as CA, while water-glycol blends (e.g., with ethylene or propylene glycol) are used in colder climates for freeze protection and basic corrosion inhibition. Glycol reduces the heat transfer efficiency of water primarily due to its lower thermal conductivity, higher viscosity, and lower specific heat capacity compared to standard water reducing heat transfer efficiency by 10–20%, depending on flow conditions and system design. [17] The reduction in heat transfer efficiency should be taken into account when using water-glycol mixtures, as it can significantly impact system performance and the interpretation of additive effectiveness.

These baseline fluids may include minimal additives like corrosion inhibitors or antifreeze agents, but they lack advanced formulations for optimizing heat transfer efficiency. It is important to maintain a balanced water treatment to prevent excessive foaming due to bubbles or foam that naturally occurs due to entrained gases resulting from heating or pressure changes. Excessive foaming is generally undesirable, as it can lead to reduced efficiency, air locks, pump cavitation, or noise.

Advantages Over Incumbent Technology

Compared to standard water or water-glycol fluids, the Hydronic Fluid Additive offers several advantages. It has been shown to reduce energy consumption by 7-15% through enhanced heat transfer from manufacturer case studies using water-glycol mixtures in cold climates, which lowers boiler runtime, required heating output, and operational costs [13] [16]. This leads to increased system productivity, as space heating zones reach set points faster, improving occupant comfort and reducing wear on auxiliary hydronic components like pumps and valves due to less cycling [11]. It also supports environmental benefits, such as lower greenhouse gas emissions from reduced energy consumption, and is non-toxic in modern formulations. Unlike the incumbents, it can produce multi-year savings without hardware upgrades, enhancing overall system quality and reliability.

Market Barriers

Despite its potential, the adoption of Hydronic Fluid Additives faces several market barriers:

1. Lack of Awareness: A primary challenge is the lack of widespread awareness and information about additive performance in milder climates. More field studies based in CA are needed to reduce skepticism among end users and validate the 7-15% savings claimed by the manufacturer. The (10) available case studies from the

manufacturer were conducted in colder climates and do not readily provide the source data to cross-validate claimed savings.

2. Unknown Payback Period: Economic barriers include upfront costs for the Hydronic Fluid Additive and installation, as well as the need to demonstrate a clear ROI, which can vary by system and climate.
3. Regulatory and incentive issues: The technology may not fit neatly into standard measure application types (MAT) in regions like California, though it aligns with BRO categories.
4. Technical barriers: Modern hydronic fluid additives must ensure compatibility with existing systems and overcome market preference for familiar water or water-glycol mixtures without additives which are preferred due to familiarity.

Assessment Objectives

Research Objectives

The objectives of this field study are:

1. Determine hydronic boiler gas savings from installing the fluid additive product by comparing pre- and post-installation gas consumption at the same level of service, or the same heating output. Also, the measured savings are compared against manufacturer claims (7-15%), ensuring cost estimates align with standard ROI thresholds (e.g., payback period under 5 years).
2. Determine the cost to install the fluid additive product by collecting vendor quotes for materials and labor costs associated with additive dosing and chemical validation testing.
3. Identify barriers and opportunities for the implementation of fluid additives as an EE measure by assessing an increase in system energy efficiency after installing the additive and conducting customer surveys to assess customer satisfaction and recommendations.
4. This project is primarily a technology assessment, as it evaluates the performance and viability of the Hydronic Fluid Additive through a field study to verify energy savings and costs in real-world commercial settings. However, it also includes additional work to remove market barriers and improve market penetration by identifying implementation challenges (e.g., awareness gaps, regulatory fit) and opportunities (e.g., incentives, scalability), providing data that can inform utility programs, rebates, and stakeholder education to accelerate adoption.

Technology/Product Evaluation

The technology being evaluated is a Hydronic Fluid Additive designed to enhance heat transfer efficiency in commercial hydronic heating systems. This additive is compared to the incumbent baseline technology: standard water-based hydronic fluids (e.g., standard water using corrosion and other standard inhibitors without specialized energy-saving additives). The comparison focuses on gas energy savings and cost-effectiveness while maintaining the same level of service, or the same heating output under similar weather conditions.

This is a field-technology assessment conducted at a customer site. It is an ideal choice of assessment because hydronic systems operate under real-world conditions influenced by variables like occupancy, weather, and hot water demand, which cannot be fully replicated in a laboratory assessment. The field testing provides valuable real-world data and insights on potential energy savings in varying climates that are not readily available from the (10) case studies provided by the manufacturer. Also, a field assessment allows for the collection of relevant material and labor costs related to the Hydronic Fluid Additive. This will help to address the market barriers of a lack of awareness and an unknown

The field assessments are at (2) commercial office building sites in Northern California, equipped with gas-fired, hydronic heating systems, as California's climate variability allows for relevant testing of the hydronic heat transfer fluid additive in milder climates compared to the colder climates used in most of the manufacturer's case studies.

Site Selection and Criteria

Standard Requirements

It was necessary to perform site screening to ensure the selected commercial sites are compatible with the Hydronic Fluid Additive based on recommendations from the manufacturer. Based on these recommendations, the following standard requirements were used to screen for eligible commercial sites to perform the field assessments (see Appendix A: Site Eligibility Form for more information):

1. Must be a multifamily or commercial site with an existing hydronic space heating system with a central boiler.
2. Must be served by SoCal Gas, SDG&E, or PG&E for gas utility.
3. A water treatment company must regularly maintain hydronic system water.
4. The hydronic boiler must serve only space heating loads (i.e. must not serve domestic hot water heating or pool heating).

5. The hydronic boiler (s) must be natural gas-fired boilers.
6. The hydronic heating system must not have external non-gas heat sources (Solar, combined heat and power, electric, etc.).
7. The hydronic heating system must not be connected to any indirect heating sources.
8. The hydronic boiler must be in good working condition without any current non-routine maintenance issues, as reported by the site representative.
9. The hydronic piping system must be free from any visible water leaks.
10. The water treatment company must confirm that the hydronic system is free of leaks.
11. The hydronic system must have an easily accessible chemical water treatment system
12. The hydronic system must use water that has the following characteristics per the manufacturer, unless the facility's water treatment company confirms that the existing water is in an acceptable range:

a. Hardness of less than 200mg/l (confirm with maintenance records or on-site testing).
b. Iron oxide (Fe_2O_3) concentration of less than (2) ppm (confirm with maintenance records or on-site testing)
c. Water uses a chemical corrosion inhibitor that follows dosage guidelines specified by the manufacturer (confirm with maintenance records or on-site testing)
d. pH of 8-9.5 for copper/steel systems and a lower pH of 7.5-8.5 for aluminum systems (confirm with maintenance records or on-site testing).

13. If M&V is accomplished using the facility's existing BAS system, the BAS system must have the following points logged in no less than 1-hour intervals for at least 1 year prior to establishing the baseline performance:
    a. Boiler System Natural Gas Usage (CFH or equivalent)
    b. Hydronic Boiler System Inlet Temperature (°F)
    c. Hydronic Boiler System Outlet Temperature (°F)
    d. Hydronic Boiler System Flow Rate (GPM), derived using one of the following:
        i. Direct Flow Rate Measurement with existing flow meter (GPM)
        ii. Constant Speed Pump Flow Rate from Test and Balance Report or Design Documents, and pump status (on/off).
        iii. Variable Speed Drive (VSD) Pump Flow Rate from Test and Balance Report (TAB) or Design Documents, and VSD Speed (%VSD)

iv. Regression between measured flow rate (GPM) and %VSD, assuming the relationship is linear and provides acceptable goodness-of-fit metrics (GOF) per ASHRAE Guideline 14-2023. ($R^2 > 0.7$, CV(RMSE) < 25%, NMBE < 0.05)

Ideal Requirements

The following tentative requirements were defined that would ideally meet to participate in this GET study. However, these requirements were left up to the discretion of the Study Team and ICF project managers based on limited site availability.

1. Customer has property Wi-Fi available for use with the M&V datalogger equipment with stable connectively in mechanical spaces, if the BAS is not present.[3]
2. If Wi-Fi is not available, there is acceptable cell coverage in the boiler rooms.
3. If no BAS is present, there is easy access to supply and return water piping with ample straight pipe for flow meter installation (8 diameters before meter and 5 diameters after meter + 6 inches for meter)
4. The hydronic heating system uses an easily accessible chemical pot feeder.
5. The hydronic heating system uses a pre-water-softening/filtration treatment system.
6. The hydronic Boiler is connected to a utility meter dedicated solely to the gas supply for the Boiler, with no other gas-consuming equipment connected to it.
7. The hydronic space heating system serves only one (1) building.
8. Existing boilers are made by one of the following certified boiler manufacturers (additive does not void warranty of the following boiler manufacturers):
    a. Worchester – Bosch Group
    b. BAXI
    c. Ideal
    d. De Dietrich
    e. Lochinvar
    f. Viessmann.

[3] Recent Onset RX3000 dataloggers use 4G LTE cellular connections, and do not provide the option for Wi-Fi.

Staff and Qualifications

Lincus is a qualified consultant with experience in energy efficiency and emerging technologies, including:

- Designing and implementing M&V plans.
- Analyzing energy savings and emissions reductions.
- Past and ongoing GET studies.

Additionally, ICF provided project oversight and quality control, while qualified on-site maintenance personnel at each site performed the BAS data extractions and installation of the Hydronic Fluid Additive following manufacturer guidelines.

Assessment Activities

1. **Existing Site Qualifications**: The Study team used the site screen tool described in the Site Selection and Criteria section to select (2) commercial sites. (see Appendix A: Site Eligibility Form for more information).
2. **Baseline Surface Tension Testing:** Samples of the incumbent baseline technology, standard hydronic water without additives, for each site were sent to a third-party laboratory for liquid surface tension measurements to determine the baseline liquid surface tension.
3. **Baseline Data Collection:** Existing BAS data was used, supplemented by M&V equipment where needed as backup, to analyze the incumbent system's natural gas energy input and hydronic HHW energy output for a sufficient baseline period (at least 90% CZ2022 weather coverage factors).
4. **Post-Installation:** The Study Team coordinated with on-site maintenance personnel and the manufacturer to dose the Hydronic Fluid Additive into the system, including necessary auxiliary steps (system flushing, additive mixing, circulation verification, and minor piping adjustments).
5. **Post Surface Tension Testing:** Samples of the hydronic fluid with additives for each site were sent to a third-party laboratory for liquid surface tension measurements to determine the change in liquid surface tension due to the Hydronic Fluid Additive.
6. **Post-Installation Monitoring**: BAS data was collected after the installation of the additive for a sufficient post-installation period (at least 90% CZ2022 weather coverage factors, see Baseline Data Periods section for more information on weather coverage factors).

7. **Performance Comparison**: The post-installation system performance is evaluated against the baseline data under normalized weather conditions.
8. **Customer Surveys**: The customers from each site are asked to complete a short survey to assess customer satisfaction and their likelihood of pursuing this technology, given there are incentives.

By selecting customer sites and conducting a detailed field assessment, this study ensures actionable insights into the real-world feasibility and benefits of the Hydronic Fluid Additive technology.

Technical Approach/Test Methodology

The selected IPMVP option for this Measurement and Verification (M&V) study is Option B – Retrofit Isolation: All Parameter Measurement. For this option, savings are determined by measurement of all relevant performance parameters, which define hydronic system energy use and efficiency. The seasonal performance and energy consumption values of the baseline and post-installation hydronic systems were characterized during "real world" operation at the (2) commercial sites where they were installed.

Field Testing of Technology

Site Descriptions

Project Site #1

Site #1 is a large office building located in San Francisco, CA, primarily used for educational services. The building operates on a standard weekday schedule (8:00 AM to 5:00 PM), with minimal occupancy on weekends except for occasional special events. The facility spans approximately 251,000 sq. ft. across (7) floors. The building is served by a central hydronic space heating system comprising of (2) condensing, gas-fired hot water boilers located on the rooftop, each with a capacity of 2.0 MMBtu/hr and 92% thermal efficiency (TE). The space heating system serves (8) primary air-handler units (AHU). Table 3 summarizes the key building characteristics for Site #1.

Table 3: Site #1 Description

Attribute	Details
Site Name	Site #1
CA Climate Zone	CZ03
Building Type	Large office building

Attribute	Details
Building Use	Educational services
Size	251,000 sq. ft, (7) floors
Hydronic Heating System	(2) 2.0 MMBtu/h condensing gas-fired hot water boilers (92% TE)
Heating Components	(8) primary air-handling units (AHU)
Occupancy Pattern	Weekdays 8:00 AM–5:00 PM, minimal weekend use except for special events

The hydronic heating system at Site #1 is controlled by a central BAS that records most data points at 15-minute intervals, except for natural gas flow data which is limited to 24-hour intervals due to reliance on the PG&E gas meter, which does not allow for higher-resolution savings analysis on an hourly basis. Table 4 summarizes the relevant BAS data points collected from Site #1 used for the data analysis, including units and data logging intervals. Since these are taken from a commercial BAS system, it is assumed that all data measurements meet ANSI/ASHRAE standards.

Table 4: BAS data points collected from Site #1.

BAS Data Point	Units	Data Interval
HHW Natural Gas Flow	therms	24-hour
HHW Btu Meter Flow Rate	GPM	15-minute
HHW Supply Temperature	°F	
HHW Return Temperature	°F	
HHW Pump VFD Speeds	%	

The weather station data for Site #1 was taken from CALMAC using the following weather station information:

Table 5: Weather Station Information used for Site #1.

Weather Station ID	WMO	Distance from site	Parameter	Data Interval
San-Francisco-IAP	724940	10 miles	OAT (°F)	1 hr

Project Site #2

Site #2 is a large commercial building located in Menlo Park, CA, contains approximately 100,000 square feet of mixed-use space, including open office spaces, training rooms, a full-service kitchen, and special event spaces. The hydronic heating system consists of (3) gas-fired condensing boilers, each with a capacity of 2.0 MMBtu/hr, supplying hot water to a combination of (8) primary air-handling units. The BAS at Site #2 provides comprehensive data logging at 15-minute intervals for all parameters, including natural gas consumption, boiler firing rates, water flow rates, water temperatures, hot water valve (HWV) positions, and OAT from CALMAC. Unlike Site #1, Site #2 experienced a significant shift in occupancy trends starting in September 2023, when the facility transitioned to full in-person operations, resulting in consistent daily heating demands that did not change relative to OAT. This change informed the baseline period selection summarized in Table 6.

Table 6: Site #2 Description

Attribute	Details
Site Name	Site #2
CA Climate Zone	CZ03
Building Type	Mixed-use office-space
Building Use	Includes open office spaces, training rooms, a full-service kitchen, and special event spaces.
Size	178,432 sq. ft. single story
Hydronic Heating System	(3) 2.0 MMBtu/hr condensing, gas-fired hydronic boilers (94% TE)
Heating Components	(8) Air-handling units (AHUs)
Occupancy Pattern	Weekdays 8:00 AM–5:00 PM, minimal weekend use except for special events

Table 7 summarizes the relevant BAS data points collected from Site #2 used for the data analysis, including units and data logging intervals. Since these are taken from a commercial BAS system, it is assumed all data measurements meet ANSI/ASHRAE standards.

Table 7: BAS data points collected from Site #2.

BAS Data Point	Units	Data Interval
HHW Natural Gas Flow	therms	15-minute
HHW Btu Meter Flow Rate	GPM	
HHW Supply Temperature	°F	
HHW Return Temperature	°F	
HHW Pump VFD Speeds	%	

The weather station data for Site #1 was taken from the CALMAC using the following weather station information:

Table 8: Weather Station Information used for Site #2.

Weather Station ID	WMO	Distance from site	Parameter	Data Interval
Palo-Alto-AP	724937	10 miles	OAT (°F)	1 hr

Baseline Data Periods

The baseline data period is defined to be long enough to represent a full range of operating conditions for both sites. The baseline periods were intended to cover at least (1) complete heating season. However, due to the significant BAS data losses at each site, the baseline periods include multiple years of heating and cooling season data to establish reliable baseline energy consumption.

The daily CZ2022 temperature and time coverage factors are considered to evaluate the potential effects of the data losses on the baseline periods and determine if the baseline period covers the CZ2022 normal conditions temperature range. For the days that are not covered, the energy savings will not be claimed, which should not significantly affect the overall results, if the CZ2022 weather coverage factors[4] are at least 90% for both sites.

The baseline periods for both sites were established after thoroughly cleaning missing or invalid data readings. After completing the data scrubbing, there was a significant data loss for both sites (~57% for Site #1 and ~59% for Site #2) due to erroneous meter readings and gaps in the raw data due to many stalled or malfunctioning gas meter readings, i.e., the meters were not showing any change in readings for several hours, or there were sudden changes in meter reading magnitude, indicating a meter reset due to communication issues. Table 9 and Table 10 list the complete baseline characteristics, including reporting dates, data loss information, daily weather conditions, and the associated daily CZ2022 Temperature and Time coverage factors:

Table 9: Baseline period characteristics for Site #1.

Project Site #1	
Baseline Period Date(s)	11/29/2022-9/24/2024
Total Days of Complete Data	376
% Data Loss	57%
Minimum Daily OAT [°F]	44.8

[4] The temperature coverage factor indicates the extent to which the OAT range of the normalization CZ2022 period falls within the expanded baseline training period temperature range (10% beyond the maximum and 10% below the minimum). The time coverage factor represents the proportion of time in the normalized CZ2022 weather dataset during which OAT remain inside this extended baseline range. Please refer to the Southern California Edison ET15SCE1130 Report for more information on how to calculate these factors. [16]

Project Site #1	
Maximum Daily OAT [°F]	73.9
Average Daily OAT [°F]	58.4
Daily CZ2022 Temperature Coverage Factor	96%
Daily CZ2022 Time Coverage Factor	99%
Days not covered	2

Table 10: Baseline period characteristics for Site #2.

Project Site #2	
Baseline Period Date(s)	9/2/2023-9/24/2024
Total Days of Complete Data	159
% Data Loss	59%
Minimum Daily OAT [°F]	48.0
Maximum Daily OAT [°F]	73.1
Average Daily OAT [°F]	62.5
Daily CZ2022 Temperature Coverage Factor	86%
Daily CZ2022 Time Coverage Factor	98%
Days not covered	6

For Site #1, the total number of complete days of data is (376) data. The daily CZ2022 temperature and time coverage factors are 96% and 99%, respectively (the acceptable range is at least 90%), with only 2 days not covered. This establishes a good baseline reporting period encompassing most typical weather conditions for a year. Additionally, since the facility typically operates on weekdays during regular business hours (8:00 AM to 5:00 PM) and only on weekends for special occasions, the baseline analysis was divided into weekday vs. weekend bins to provide better baseline energy consumption model fits.

For Site #2, the occupants reverted to in-person work in September 2023. Thus, it was determined that starting the baseline period after this change in occupancy trends would provide more reliable predictions for the subsequent post-period. It is noted that the (159) days of complete data result in a low temperature coverage factor of 86%. However, the high time coverage factor of 98% most days of the year, with only (6) days not covered under normal CZ2022 weather conditions. For the (6) days not covered, the savings are at the minimum and maximum extreme normal weather conditions, which are likely to have high savings potential. However, the savings that are estimated using uncovered days will be excluded in this analysis to avoid potential extrapolation errors since there are only (6) uncovered days and it is not expected to affect the overall results significantly.

Baseline Non-Routine Events

Project Site #1

As previously mentioned, a data inspection was performed on the existing BAS data to check for missing or incorrect data readings. For Site #1, the following days were excluded from the data models due to incomplete BAS data or incorrect gas energy data that did not match the PG&E utility data.

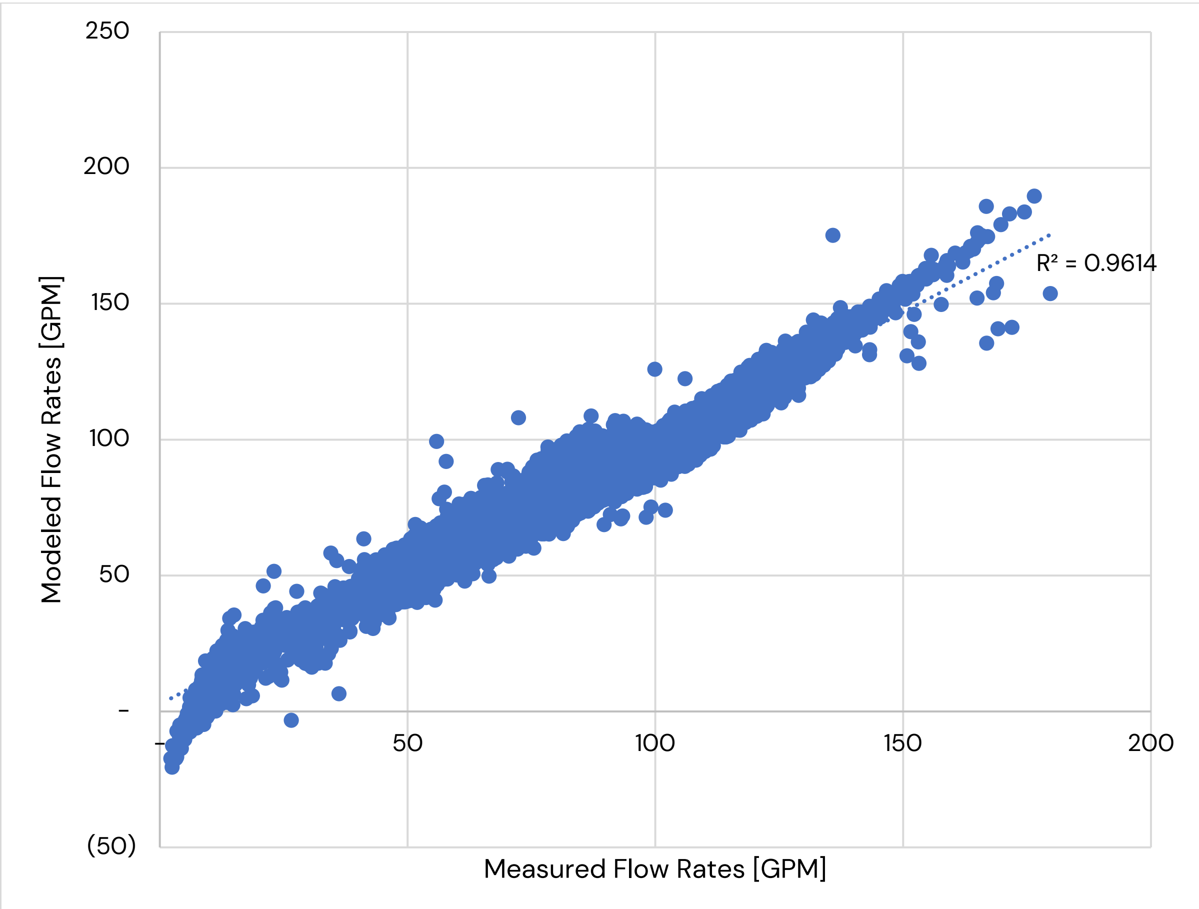
Dates: 12/1/2022-12/3/2022, 12/23/2022, 1/15/2023, 2/9/2023, 2/26/2023 - 3/4/2023, 3/9/2023 - 3/18/2023, 3/27/2023 - 3/30/2023, 4/10/2023, 4/17/2023 - 4/18/2023, 6/17/2023, 7/12/2023 - 7/17/2023, 8/12/2023, 8/16/2023 - 8/17/2023, 8/20/2023 - 8/22/2023, 9/30/2023, 10/1/2023, 10/4/2023 - 10/6/2023, 10/19/2023, 11/28/2023 - 7/2/2024, 7/19/2024, 7/24/2024, 7/29/2024, 7/31/2024, 8/4/2024, 8/10/2024 - 8/11/2024, 8/29/2024, 9/18/2024, 9/23/2024

From October 2023 to December 2023, the flow data from the BTU flow meter shows exceedingly high flow rates, resulting in overall daily thermal efficiencies greater than 100%. After consulting with site management, it was confirmed that the BTU flow meter had a faulty transducer, which resulted in inaccurate meter readings during a recent check. For these reasons, the analysis did not include the BTU meter flow rate data during the observed malfunctioning period after October 2023. The temperature data was still usable, so estimating the expected flow rate was necessary to salvage those days. This was done by establishing a flow rate regression model using the following BAS data points on 15-minute intervals before October 2023, when the pump was functioning correctly: VFD pump speed, pump power, and % boiler firing rate. Table 11 shows the model goodness of fit metrics with an exceedingly high R^2 value and acceptable CV(RSME) and NBME criteria per ASHRAE Guideline 14 and IPMVP. As a result, the flow rate regression model was used to replace the faulty high flow-rate readings from October 2023 to November 2023 with the 3-parameter flow regression model. The BAS VFD motor speed data was unavailable for December 2023 for unknown reasons. Consequently, that month was excluded from the baseline period. Figure 1 below directly plots the Modeled vs Measured Flow Rate values against each other, which shows a strong correlation between flow rates between 20-140 GPM. The flow model has a noticeable standard error for values outside of the range. The average flow rate at Site #1 is 45 GPM, so this does not significantly affect the overall results.

Table 11: Goodness of fit metrics for flow rate regression.

R^2	CV(RMSE)	NMBE
0.96	8%	0.0000%

Figure 1: Modeled Flow Rate as a function of %VSD vs Measured Flow Rate at Site #1.



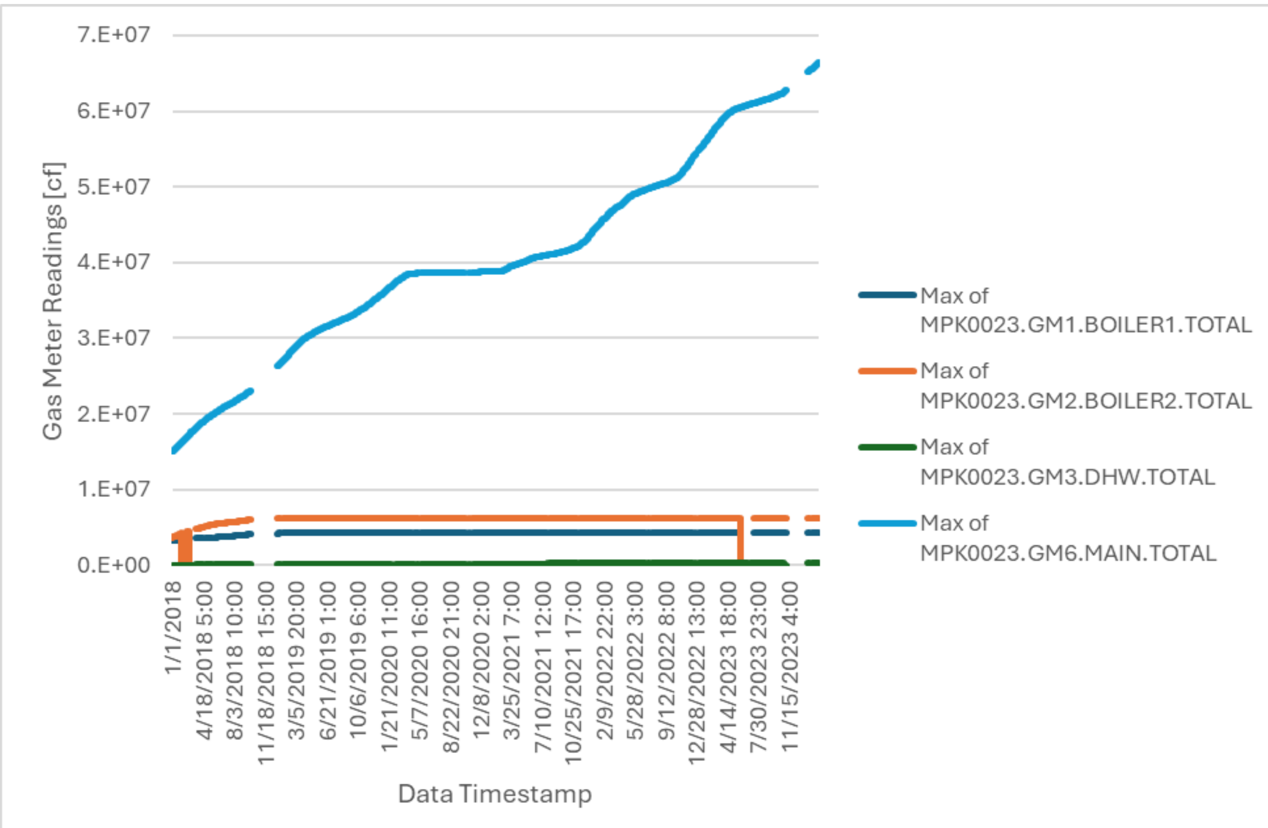
Project Site #2

For Site #2, the following days were excluded from the data models due to incomplete BAS data or incorrect gas meter reading data due to faulty gas meter equipment or scheduled maintenance.

Dates: 9/26/2023, 10/4/2023 - 10/9/2023, 10/19/2023, 10/27/2023 - 11/1/2023, 11/8/2023 - 2/11/2024, 3/1/2024 - 7/3/2024, 7/13/2024 - 7/14/2024, 8/1/2024, 9/1/2024, 9/2/2024, 9/25/2024

Figure 2 below shows the gas meter reading trends for the (4) different gas meters from 1/1/2018 to 2/29/2024. The GM6 data point represents the total primary gas usage and includes all building gas end-uses. GM3 represents DHW usage for the kitchen and staff locker rooms, which is negligible (less than 0.12% of the total building gas usage). The boiler gas meters, GM1 and GM2, represent the total hydronic gas usage. However, the boiler gas meters show constant readings throughout 2019-2023, except for a small duration in 2018. This indicates that the boiler gas meters were operational pre-pandemic and did not record correctly afterward. This was brought to the attention of on-site staff, and after further investigation, it was found that the meters were disconnected from the power source, putting the sensors in a "boot loop" that resulted in constant meter readings. The power disconnect is shown in Figure 2 by the data gap for all gas meter data readings at the end of 2018. Thus, it was concluded that the boiler gas meter data was not helpful during the selected baseline period (9/02/2023-02/29/2024), and an alternative method, as discussed in the following paragraph, was adopted to estimate the hourly boiler gas flow.

Figure 2: Gas meter readings trend for all available gas meter data.



The facility maintenance repaired the boiler gas meters shortly after discovering the power issues. This allowed the Study Team to obtain a week of complete BAS data (4/11/2024 to 4/17/2024) with valid boiler gas flow values used to establish a correlation between boiler gas flow and boiler firing rate. Figure 3 below shows the total boiler gas flow for both boilers vs the boiler firing rate. Table 12 shows the regression model fit metrics with an R^2=0.97 and

CV(RMSE) = 23%, which was used for estimating the boiler gas flow rate during the baseline period in place of the faulty meter readings for Site #2.

Figure 3: Regression model for boiler gas flow rate vs % firing rate for valid gas meter readings at Site #2.

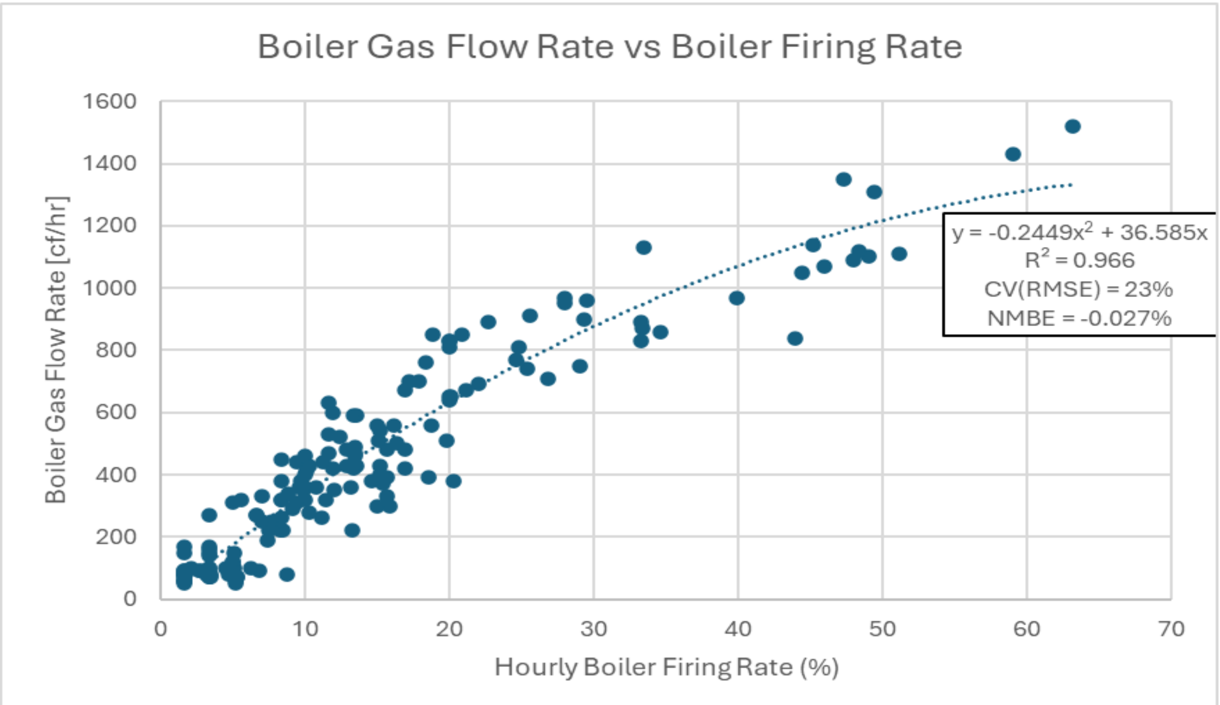


Table 12: Goodness of fit metrics for boiler flow rate regression model.

R^2	CV(RMSE)	NMBE
0.966	23%	-0.027%

Baseline Performance Summary

Table 13 and Table 14 summarize the baseline performance parameters for Site #1 and Site #2, respectively (refer to Appendix B: M&V Equations for detailed equations used to calculate the Gas Energy Input and HHW Energy Output).

Table 13: Baseline performance summary for Site #1.

Performance Parameter	Value	Units
Average OAT	58.84	°F
Average Flow Rate	45.83	GPM
Average Supply Temperature	125.48	°F
Average Return Temperature	109.83	°F

Performance Parameter	Value	Units
Average Delta T	15.65	°F
Average Gas Energy Input	12,290.88	kBtu/day
Average HHW Energy Output	10,716.09	kBtu/day
Overall Thermal Efficiency (TE)	87%	%

Table 14: Baseline performance summary for Site #2.

Performance Parameter	Value	Units
Average OAT	62.47	°F
Average Flow Rate	68.29	GPM
Average Supply Temperature	118.32	°F
Average Return Temperature	112.87	°F
Average Delta T	5.45	°F
Average Gas Energy Input	6,539.98	kBtu/day
Average HHW Energy Output	4,981.22	kBtu/day
Overall Thermal Efficiency (TE)	76%	%

Baseline Models

Figure 4 and Figure 5 show the baseline regression models for HHW energy output vs. OAT and gas energy input vs OAT for the Weekday and Weekend, respectively, for Site #1. Similarly, Figure 6 shows the baseline regression models for HHW energy vs. OAT and gas input energy vs OAT for all days of the week overall for Site #2.

Figure 4: Baseline Weekday HHW Energy and Gas Energy vs OAT for Site #1.

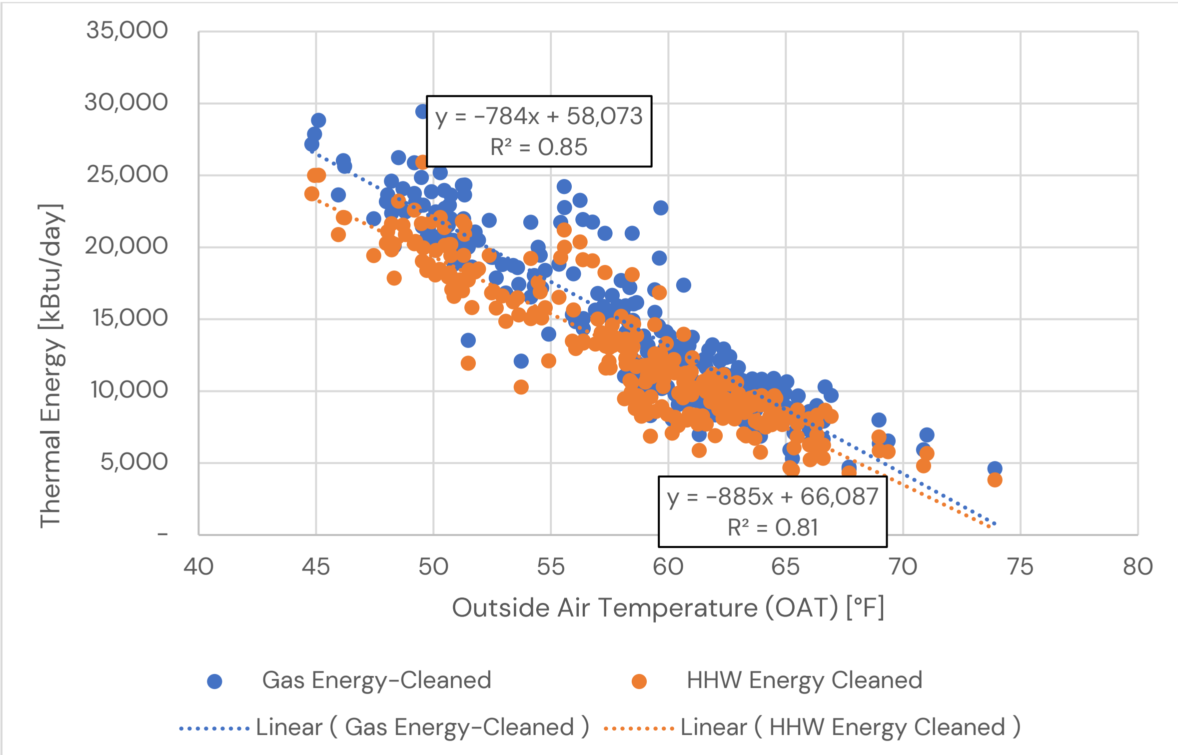


Figure 5: Baseline Weekend HHW Energy and Gas Energy vs OAT for Site #1.

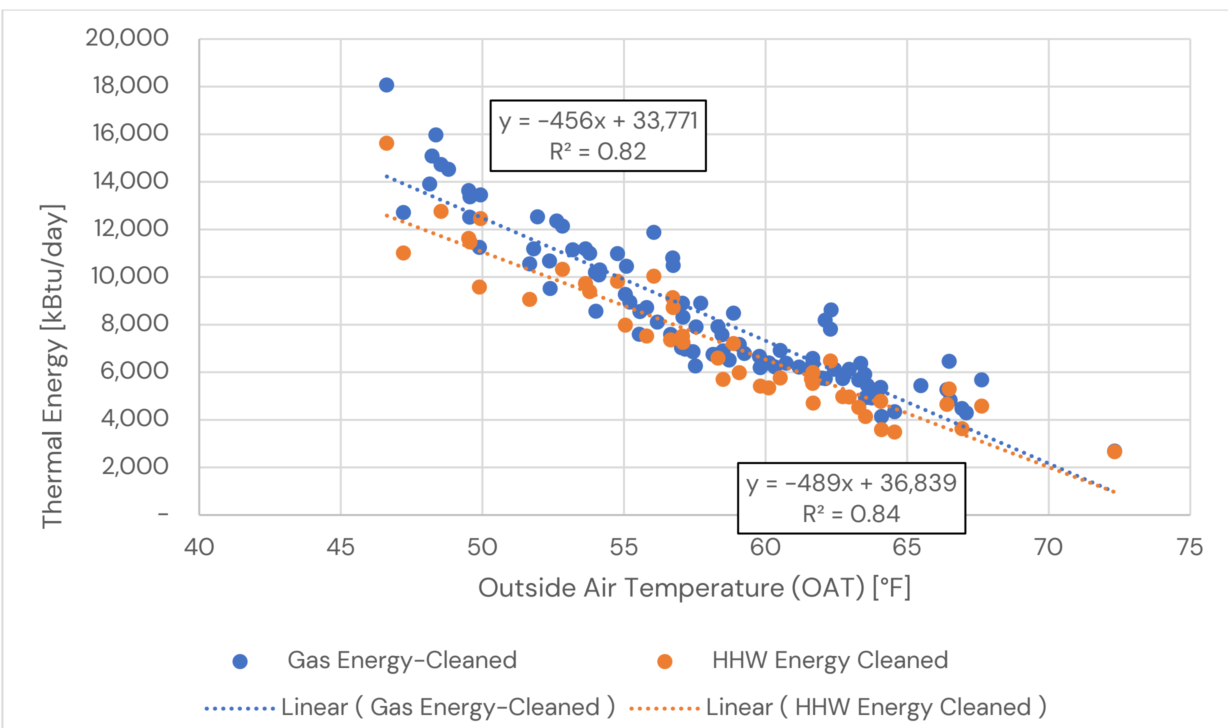


Figure 6: Baseline Daily HHW Energy Output and Gas Energy vs OAT for Site #2.

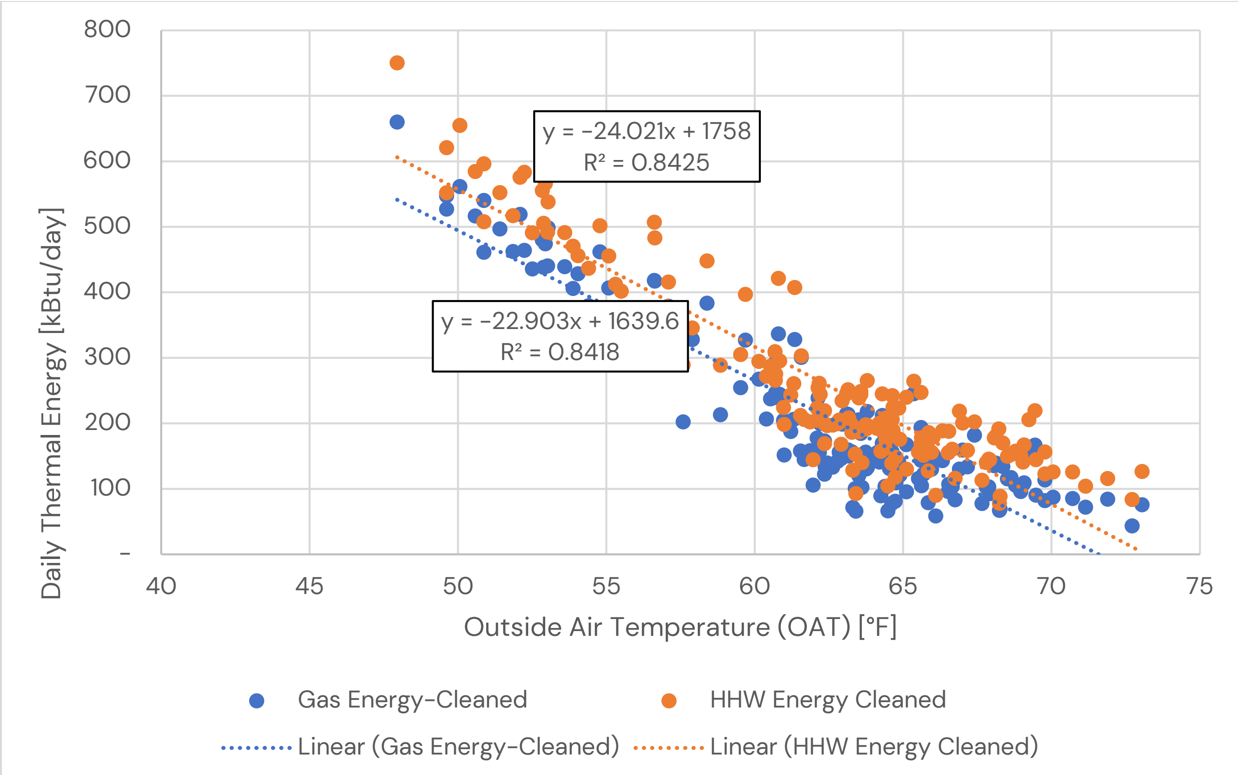


Table 15 and Table 16 summarize the goodness of fit modeling metrics for each baseline regression model at Site #1 and Site #2. For Site #1, the modeling was performed separately for the weekdays and weekends based on the building's occupancy trends, which provided inadequate modeling fit parameters to fit all days together.

Table 15: Goodness of Fit Modeling metrics for Site #1.

Model	R^2	RMSE	CV(RSME)	NMBE
$Q_{HHW,weekday}$ = f(OAT)	0.85	1,850.08	15%	0.0000%
$Q_{Gas,Weekday}$ = f(OAT)	0.81	3.60E+03	17%	0.0000%
$Q_{HHW,weekend}$ = f(OAT)	0.82	1,142.63	15%	0.0000%
$Q_{Gas,Weekend}$ = f(OAT)	0.84	1.16E+03	15%	0.0000%

Table 16: Goodness of Fit Modeling metrics for Site #2.

Model	R^2	RMSE	CV(RSME)	NMBE
$Q_{HHW,daily}$ = f(OAT)	0.84	1,304.99	26%	0.0000%
$Q_{Gas,daily}$ = f(OAT)	0.84	1,437.63	22%	0.0000%

The industry standard goodness-of-fit (GOF) metrics are used to determine the accuracy of the baseline models, specifically the coefficient of determination (R^2), coefficient of variation of the root mean squared error (CV(RSME)), and the normalized mean bias error (NMBE). Based on the ASHRAE Guideline 14 and IPMVP, the acceptable criteria for these metrics are:

1. $R^2 > 0.7$
2. CV(RMSE): Less than 25%
3. Absolute NMBE: Less than 0.5%

System Installation & Costs

The installation of the Hydronic Fluid Additive was performed by qualified on-site maintenance personnel at both sites to ensure accurate dosing per the manufacturer's guidelines. Table 17 summarizes the required volume of Hydronic Fluid Additive for each site (determined with guidance from the manufacturer) and the associated materials costs.

Table 17: Hydronic Fluid Additive Volume and Material Costs by Site.

Project Site	Total System Volume (gallons)	Required Volume (gallons)[5]	Additive Costs ($)
Site #1	2700	27	$14,165.80
Site #2	n/a	8	$5,050.00

[5] Recommended concentration of Hydronic Fluid Additive is 1% of the total system volume, per manufacturer guidelines. However, the participating water treatment company at Site #2 that installed the additive determined the required volume based on design flow rate of the hydronic system, so the total system volume is not available.

Figure 7: Installation of Hydronic Fluid Additive by qualified personnel at Site #1.

Post-Installation Data Periods

The Hydronic Fluid Additive was installed on 09/25/24 for both sites, so the post-installation period starts on 9/26/24. Table 18 and Table 19 summarize the post-installation period characteristics for Site #1 and Site #2, respectively.

Table 18: Post-Installation period characteristics for Site #1.

Project Site #1	
Baseline Period Date(s)	9/26/2024 – 5/9/25
Total Days of Complete Data	160
% Data Loss	71%
Minimum Daily OAT [°F]	47.5
Maximum Daily OAT [°F]	77.9
Average Daily OAT [°F]	56.24
Daily CZ2022 Temperature Coverage Factor	87%
Daily CZ2022 Time Coverage Factor	99%
Days not covered	5

Table 19: Post-Installation period characteristics for Site #2.

Project Site 2#2	
Baseline Period Date(s)	9z/26/24 – 3/5/25
Total Days of Complete Data	160
% Data Loss	0%
Minimum Daily OAT [°F]	42.9
Maximum Daily OAT [°F]	78.4
Average Daily OAT [°F]	54.3
Daily CZ2022 Temperature Coverage Factor	100%
Daily CZ2022 Time Coverage Factor	100%
Days not covered	0

Post-Installation Non-Routine Events

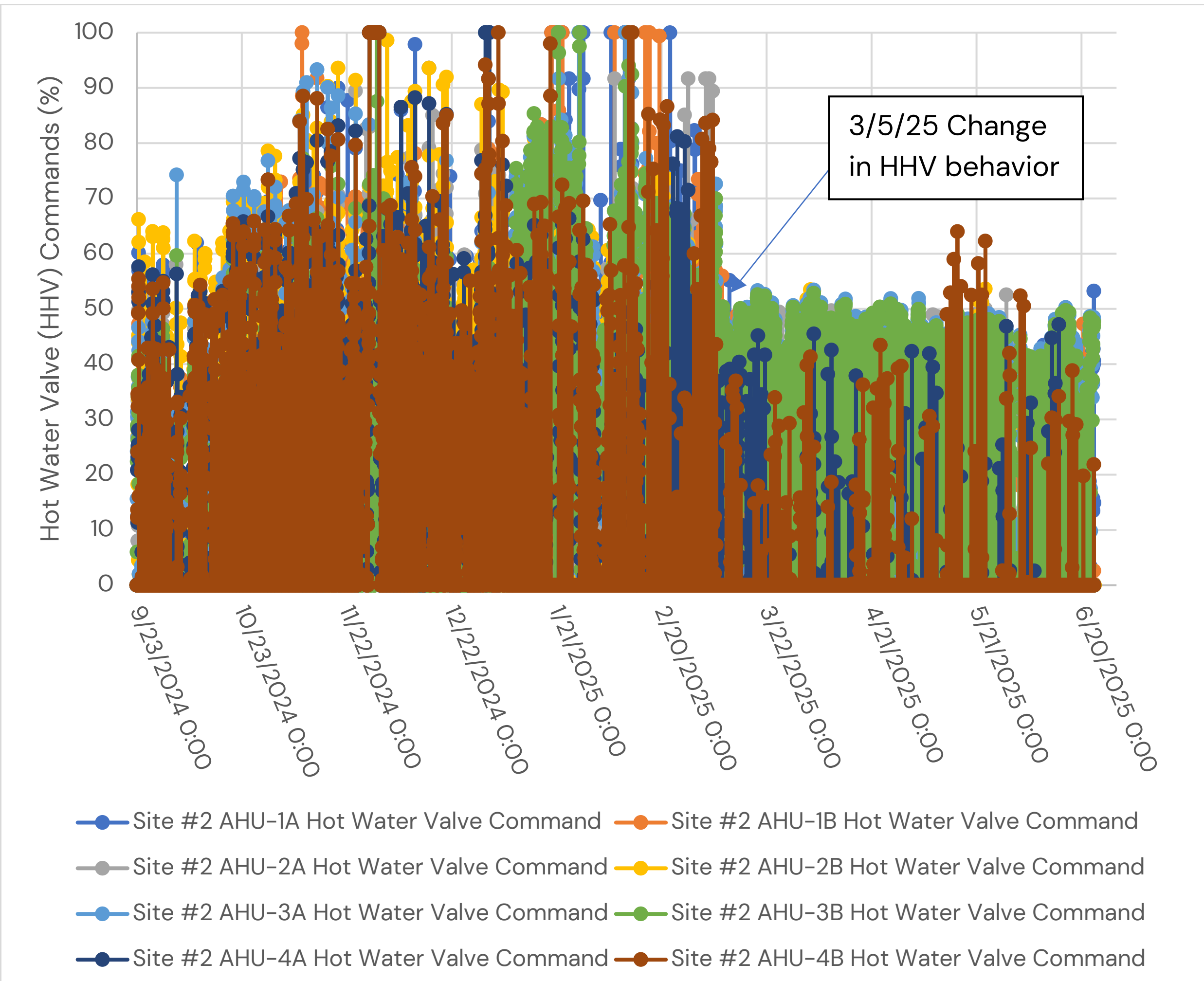
Project Site #1

The post-installation period for Site #1 has a 71% data loss due to the BAS loss of communication to the HHW Pump VFD Speeds from 11/13/2024 to 1/7/2025. The Study team notified the on-site maintenance personnel within a week after the data went offline, and it took multiple months for the communication issue to be resolved. This resulted in a loss of colder-weather data (less than 44.8°F), lowering the CZ2022 temperature coverage factor to 87% (below the target of 90%). However, the time coverage factor shows the post-period covers 99% of the hours in the year represented by the CZ2022 normal conditions data, with only (5) days not covered. The post-period continued until 5/9/25, providing (160) data points.

Project Site #2

The post-period for Site #2 did not experience any data losses; however, there was a change in hot water valve (HWV) control method on 3/5/25 that resulted in a significant decrease in HHW energy output that is unrelated to the Hydronic Fluid Additive. For this reason, the post-period does not consider days beyond this change, as it would result in an overestimation of savings due to a change in the "level-of-service" or heating output.

Figure 8: Hot Water Valve (HWV) trends for Site #2.



Post-Installation Performance Summary

Table 20 and Table 21 summarize the baseline performance parameters for Site #1 and Site #2, respectively (refer to Appendix B: M&V Equations for detailed equations used to calculate the Gas Energy Input and HHW Energy Output).

Table 20: Post-installation performance summary for Site #1.

Performance Parameter	Value	Units
Average OAT	56.24	°F
Average Flow Rate	58.92	GPM
Average Supply Temperature	120.04	°F
Average Return Temperature	106.51	°F
Average Delta T	13.54	°F
Average Gas Energy Input	14,496.21	kBtu/day
Average HHW Energy Output	11,670.09	kBtu/day
Overall Thermal Efficiency (TE)	81%	%

Table 21: Post-Installation performance summary for Site #2.

Performance Parameter	Value	Units
Average OAT	54.27	°F
Average Flow Rate	85.62	GPM
Average Supply Temperature	122.82	°F
Average Return Temperature	116.43	°F
Average Delta T	6.39	°F
Average Gas Energy Input	8,687.26	kBtu/day
Average HHW Energy Output	7,117.76	kBtu/day
Overall Thermal Efficiency (TE)	82%	%

Post-Installation Models

The same energy models used for the baseline were applied to the post-installation periods for both sites. Figure 9 and Figure 10 show the weekday HHW Energy Output and Gas Energy Input as functions of OAT for the weekdays and weekends, respectively, for Site #1. The behavior of the hydronic heating systems has become more difficult to model after the addition of the hydronic fluid additive, resulting in poor post-installation models (R^2 ~ 0.18-0.30 for Site #1, and R^2 ~0.62-0.63 for Site #2). Figure 11 shows the daily HHW Energy

Output and Gas Energy Input as functions of OAT for the post-period for Site #2. Compared to the baseline models with high R^2 = 0.81-0.85, these post models also show that the hydronic system behavior has become less predictable. The unpredictable behavior from both sites may be due to the ability of the hydronic fluid additive to allow space heating setpoints to be reached quicker, as the system can be more responsive to dynamic space heating demands, instead of performance being directly influenced by the OAT.

Figure 9: Post Weekday HHW Energy Output and Gas Energy Input vs OAT for Site #1.

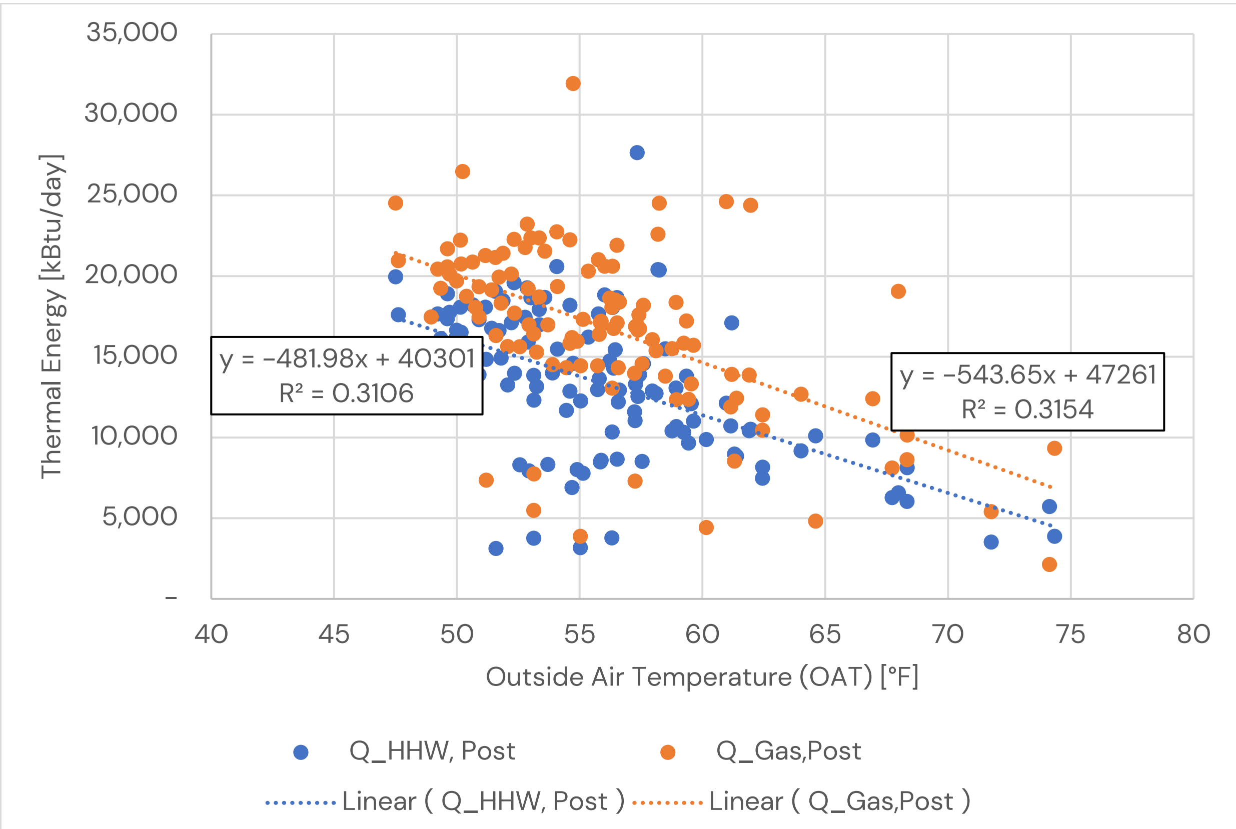


Figure 10: Post Weekend HHW Energy Output and Gas Energy Input vs OAT for Site #1.

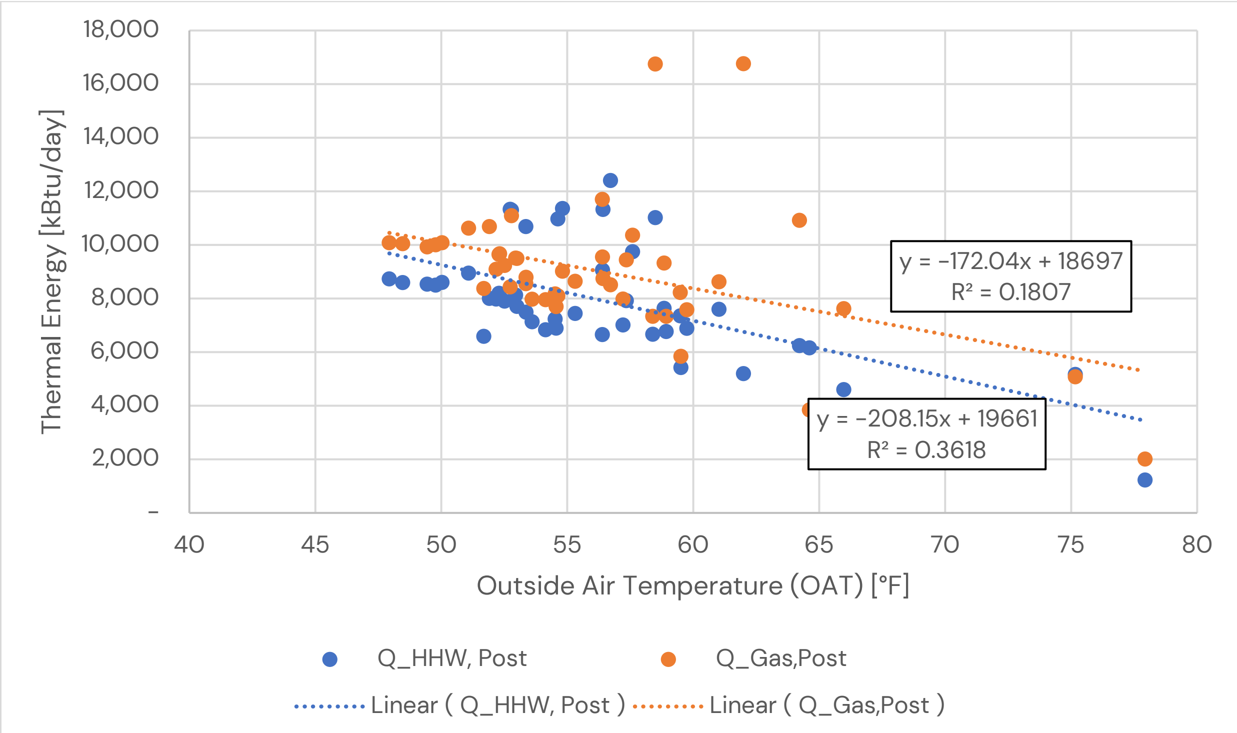
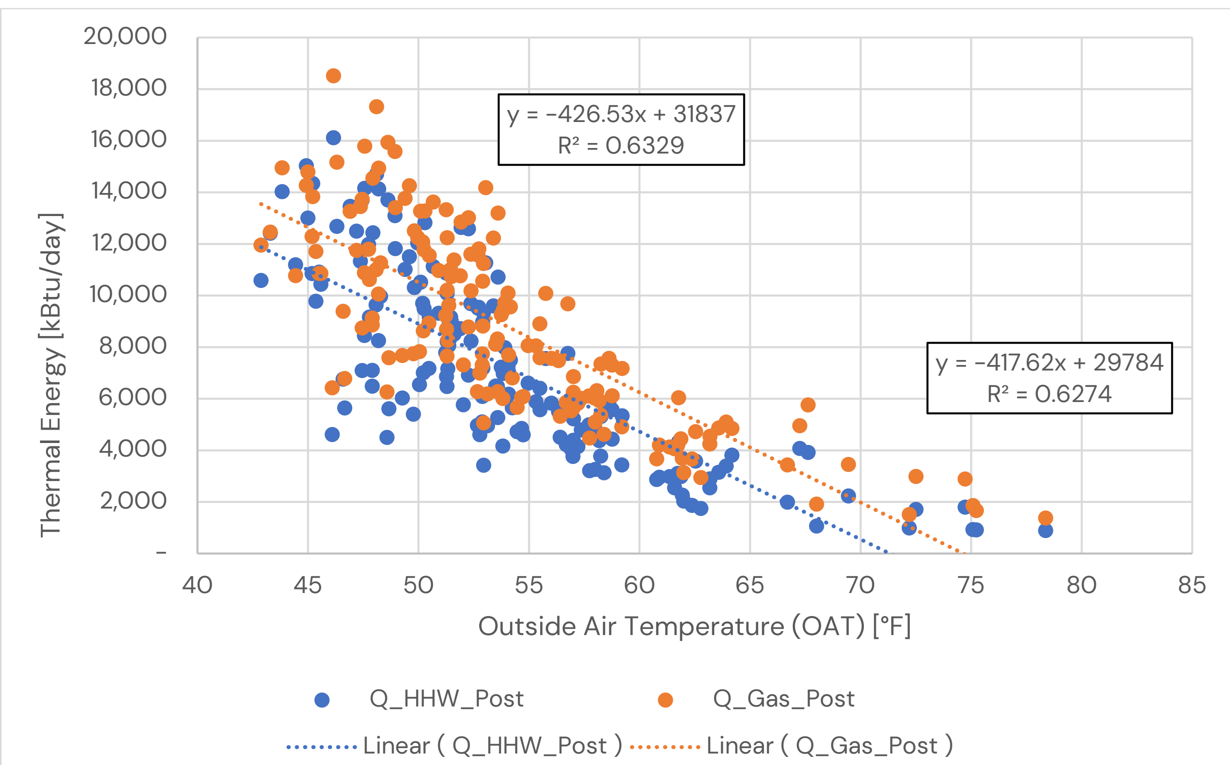


Figure 11: Post Daily HHW Energy Output and Gas Energy Input vs OAT for Site #2.



Testing Procedure/Savings Analysis

The post-installation models did not provide acceptable fits according to ASHRAE Guideline 14 and IPMVP criteria. Therefore, the energy models were not used to compare energy consumption between the baseline and post-installation periods directly. This can be expected, as factors like occupancy schedules, building management practices, and thermostat settings introduce unpredictability in heating demand.

However, it is still expected that gas usage is higher in colder months, even with the addition of the hydronic fluid additive. Based on fundamental physical principles and energy trends observed in previous GET projects, OAT has a direct impact on hydronic heating gas consumption due to the following reasons:

1. **Increased Heat Demand:** OAT affects hydronic heating load by affecting the temperature of the returning water. During colder months, lower OAT conditions result in increased heating demand to maintain the same set point temperatures, resulting in lower return water temperature and higher gas energy consumption. This effect is location-dependent and is more pronounced in colder climates. According to the U.S. Energy Information Administration (EIA), space heating accounts for a significant portion of energy use in commercial buildings, with demand peaking in colder months due to lower OAT necessitating higher indoor temperatures for occupant comfort [18].
2. **Usage Patterns**: It is reasonable to assume that space heating demand increases during colder seasons solely due to comfort preferences. ASHRAE Standard 55 defines acceptable thermal environmental conditions for human occupancy, including operative temperature ranges based on factors like clothing and activity levels. These factors tend to be different in warm vs cold climates. However, these behavioral trends are anecdotal, may vary widely among commercial buildings, and are not always predictable or linear.

To account for these seasonal differences, an OAT-binning method is used. This approach normalizes gas consumption based on similar OAT conditions (using 5°F OAT-bins per ASHRAE guidelines), allowing for more accurate and meaningful comparisons of system performance between baseline and post-installation periods. Additionally, HDD is used to normalize energy consumption in each OAT-bin, which provides another measure of heating demand by integrating the duration and amount of heat load required relative to a base temperature (defined as the boiler lockout temperature of 80°F for both sites).

Metering Issues

It was found, after establishing the baseline period for Site #1, that the flow meter regression used to predict the baseline flow rates yielded thermal efficiencies above 100%. This indicates that the flow meter regression is not reliable to use for the baseline and post-installation analysis, which may indicate that other datapoints from the BAS are unreliable, as well. Instead, the PG&E gas meter data was used for the OAT-bin analysis without considering the BAS data points, which required changing the M&V approach to Option C – Whole Building Approach. This also allows the Study Team to recover days that were initially scrubbed due to missing or incomplete BAS data.

Results

The OAT-binning method was used to compare gas energy consumption for similar operating conditions between baseline and post-installation periods for both sites. The reporting days were binned into 5°F OAT-bins per ASHRAE guidelines using the total gas energy consumption per bin and total HDDs to normalize the energy consumption in each bin in terms of kBtu/HDD. The normalized gas energy rate per bin is calculated by dividing total gas energy by the total HDDs for each bin, using a base OAT of 80°F, expressed in units of kBtu/HDD. The normalized gas energy savings rate per bin is determined as the difference between the baseline and post-installation normalized gas energy rates per bin. The predicted baseline gas energy under post-installation conditions is estimated by multiplying the baseline normalized rate by the post-installation HDD per bin, projecting the baseline performance onto post-installation weather conditions to isolate the impact of the Hydronic Fluid Additive. The measured gas energy savings per bin are calculated as the difference between the predicted baseline gas energy under post-installation conditions and the actual measured post-installation gas energy per bin.

Data Analysis

Table 22 shows the OAT-bin analysis summary for Site #1. Due to the metering issues, only Option C with PG&E utility data was used along with the CALMAC weather data, instead of using the BAS gas energy data. This provides more reporting period days in the baseline and post-installation period than using BAS data. The resulting savings are 10.7%, and it should be noted that the PG&E meter is dedicated only to monitoring the hydronic gas supply.

The savings increase at lower OAT-bins, with negative savings above 60°F. This implies that the Hydronic Fluid Additive saves more energy at lower OATs and does not reduce energy at higher OATs. Also, the (10) case studies from the manufacturer were conducted in cold climates (typically below 50°F), where the most savings are realized. This would support the implementation of this technology in colder climates to achieve reasonable energy savings.

Figure 12 shows the binned gas energy trend with OAT for Site #1. (see Appendix C. OAT-Bin trend charts.)

It is also noteworthy that the Post-Installation Gas Energy per HDD rises from 6.80 to 8.83 when comparing the 60°F-65°F bin to the 65°F-70°F bin. This increase may stem from system variability under low heating demands, in which the economizer boosts airflow to cool certain sections of the building while space heating remains necessary in others. The increased airflow can destabilize the heating system by creating inconsistent temperature gradients across the building, potentially leading to inefficiencies that negate energy savings at higher temperatures. The weighted impact on the overall savings is negligible as only (6) five data points in the post-installation 65°F-70°F are considered in the savings calculations.

Table 22: OAT-Bin Post-Installation Savings Summary for Site #1 (PG&E and CALMAC weather Data only)[6]

OAT-BIN	Baseline Data Count	Post-Install Data Count	Baseline Total HDD per Bin	Post-Install Total HDD per Bin	Baseline Normalized Gas Energy Rate [kBtu/HDD]	Post-Installation Normalized Gas Energy Rate [kBtu/HDD]	Gas Energy Savings Rate per Bin [kBtu/HDD]	Predicted Baseline Gas Energy Under Post Conditions per Bin [kBtu]	Measured Post-Installation Gas Energy Use per Bin [kBtu]	Measured Gas Energy Savings per Bin [kBtu]
40°F-45°F	2	#N/A	70.23	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
45°F-50°F	58	14	1,835.80	433.07	7.40	5.34	2.06	3,203.27	2,312.41	890.86
50°F-55°F	241	95	6,576.98	2,598.59	7.12	5.68	1.45	18,506.78	14,749.11	3,757.67
55°F-60°F	324	132	7,255.19	2,988.65	6.01	5.96	0.05	17,963.42	17,799.39	164.03
60°F-65°F	247	28	4,341.90	510.19	6.25	6.80	(0.55)	3,188.58	3,467.35	(278.77)
65°F-70°F	88	6	1,186.99	74.68	6.15	8.83	(2.67)	459.52	659.13	(199.61)
70°F-75°F	14	3	116.60	19.76	#N/A	8.52	#N/A	#N/A	#N/A	#N/A
75°F-80°F	5	2	15.50	6.89	#N/A	10.27	#N/A	#N/A	#N/A	#N/A
Total	**958**	**275**	**21,399.18**	**6,631.81**	**6.59**	**7.34**	**0.52**	**9,462.59**	**8,090.07**	**1,010.52**

The overall gas energy savings for Site #1 using the normalized OAT-BIN approach is calculated using the total predicted baseline gas energy under post conditions [kBtu] and the total measured gas energy savings [kBtu] as follows:

$$S_{Gas,site\#1} = \frac{1,010.52}{9,462.59} = 10.7\%$$

[6] The greyed-out values in each OAT-Bin are shown here for reference but are not used in the savings analysis because these bins do not have at least 5 data points in both baseline and post-installation.

Table 23 presents the Option B OAT-bin analysis summary for Site #2, showing all measured data bins for the baseline and post-installation periods (40°F–80°F).

Table 23: OAT-Bin Post-Installation OAT-Normalized Savings Summary for Site #2.[7]

OAT-BIN	Baseline Data Count	Post-Install Data Count	Baseline Total HDD per Bin	Post-Install Total HDD per Bin	Baseline Normalized Gas Energy Rate [kBtu/HDD]	Post-Installation Normalized Gas Energy Rate [kBtu/HDD]	Gas Energy Savings Rate per Bin [kBtu/HDD]	Predicted Baseline Gas Energy Under Post Conditions per Bin [kBtu]	Measured Post-Installation Gas Energy Use per Bin [kBtu]	Measured Gas Energy Savings per Bin [kBtu]
40°F-45°F	#N/A	5	#N/A	180.59	#N/A	#N/A	#N/A	#N/A	64,384.68	#N/A
45°F-50°F	3	39	92.81	1,262.88	526.47	367.87	158.60	664,863.48	464,571.47	200,292.02
50°F-55°F	19	59	522.02	1,629.89	490.28	349.48	140.80	799,106.70	559,796.13	225,536.04
55°F-60°F	14	30	319.52	677.91	433.15	290.61	142.55	293,639.32	197,004.56	96,634.76
60°F-65°F	73	17	1,245.13	300.24	318.59	241.27	77.32	95,654.04	72,438.38	23,215.66
65°F-70°F	44	5	558.14	60.95	327.44	319.90	7.54	19,956.10	19,496.42	459.68
70°F-75°F	6	3	50.42	20.54	341.33	359.02	(17.70)	7,011.72	7,375.27	(363.54)
75°F-80°F	#N/A	3	#N/A	11.29	#N/A	#N/A	#N/A	#N/A	4,895.45	#N/A
Total	156	114	2,788.04	4,116.19	392.37	300.31	92.05	1,194,581.63	848,735.50	345,846.13

[7] The greyed-out values in each OAT-Bin are shown here for reference but are not used in the savings analysis because these bins do not have at least 5 data points in both baseline and post-installation.

The overall gas energy savings using the normalized OAT-BIN approach is calculated using the total predicted baseline gas energy under post conditions and the total measured gas energy savings as follows:

$$\boldsymbol{S_{Gas}} = \frac{\mathbf{345,846.13}}{\mathbf{1,194,581.63}} = \mathbf{29.0}\%$$

The total measured energy savings are 29.0% over an OAT-bin range of 50°F-70°F. There are not enough data points in the post-installation period to assess savings at higher OATs. However, the Hydronic Fluid Additive appears to save more energy at lower OATs. Based on the trend, it seems the savings are minimal, above an OAT of 70°F.

It makes sense to further normalize for reduced HHW output in M&V for a hydronic fluid additive if the goal is to isolate specific efficiency gains (e.g., at the boiler level, such as gas input per unit HHW output) rather than capturing the full system-wide savings, as this adjustment compares performance at equivalent output levels while accounting for the additive's impact on heat transfer efficiency. The study team found it necessary to normalize the savings by adjusting based on the difference in HHW energy output in each bin. It was observed that the HHW energy output decreased in the post-installation period compared to the baseline in each bin, indicating the Hydronic Fluid Additive reduced the heating load required to maintain the same space heating temperature setpoints by allowing spaces to reach setpoints more quickly, thus reducing boiler runtimes and decreasing demand on the hydronic heating system. To evaluate the additive as an energy efficiency measure (EEM) with respect to boiler-level efficiency, it is necessary to compare baseline and post-installation periods at the same HHW energy output, defined as the "level-of-service." This adjustment was applied by calculating the HHW output ratio using Equation (1):

$$R = \frac{\text{Post Normalized HHW Energy Rate [kBtu/HDD]}}{\text{Baseline Normalized HHW Energy Rate [kBtu/HDD]}} \tag{1}$$

Then, this adjustment ratio was used to scale the measured post-installation gas consumption to compare at baseline output levels using Equation:

$$\text{Adj Measured Post Gas Energy Savings [kBtu]} = \frac{\text{Measured Post Gas Energy Use [kBtu]}}{\text{R}} \tag{2}$$

Table 24 summarizes the OAT-normalized savings that have been adjusted based on the difference in HHW load per HDD in each bin.

Table 24: OAT-Bin Load-Adjusted OAT-Normalized Savings for Site #2.2

OAT-BIN	Baseline Data Count	Post-Install Data Count	Baseline Total HDD per Bin	Post-Install Total HDD per Bin	Average OAT-BIN Temperature [°F]	Predicted Baseline Gas Under Post Conditions per Bin [kBtu]	Baseline Normalized HHW Energy Rate [kBtu/ HDD]	Post Normalized HHW Energy Rate [kBtu/ HDD]	HHW Energy Rate Adjustment Ratio, R	Measured Post-Installation Gas Energy Use per Bin [kBtu]	Adjusted Measured Post-Installation Gas Energy Savings per Bin [kBtu]
40°F - 45°F	#N/A	5	#N/A	180.59	43.88	#N/A	#N/A	#N/A	#N/A	64,384.68	#N/A
45°F - 50°F	3	39	92.81	1,262.88	47.72	664,863.48	#N/A	#N/A	#N/A	464,571.47	#N/A
50°F - 55°F	19	59	522.02	1,629.89	52.42	799,106.70	411.53	284.38	0.69	559,796.13	810,074.95
55°F - 60°F	14	30	319.52	677.91	57.33	293,639.32	352.80	215.51	0.61	197,004.56	322,496.59
60°F - 65°F	73	17	1,245.13	300.24	62.83	95,654.04	231.82	163.16	0.70	72,438.38	102,924.31
65°F - 70°F	44	5	558.14	60.95	67.37	19,956.10	222.90	217.59	0.98	19,496.42	19,971.91
70°F - 75°F	6	3	50.42	20.54	72.12	7,011.72	#N/A	#N/A	#N/A	7,375.27	#N/A
75°F-80°F	#N/A	3	#N/A	11.29	76.24	#N/A	#N/A	#N/A	#N/A	4,895.45	#N/A
Total	**156**	**114**	**2,788.04**	**4,116.19**	**58.36**	**1,194,581.63**	**304.76**	**220.16**	**0.68**	**848,735.50**	**1,255,467.75**

The resulting boiler-level thermal efficiency difference between the baseline and post-installation period after normalizing HHW output is calculated as follows:

$$\eta_{boiler,diff} = \frac{\mathbf{1,194,581.62 - 1,255,467.75}}{\mathbf{1,255,467.75}} = -\mathbf{5}\%$$

The decrease in boiler-level thermal efficiency of 5% is likely due to the reduced HWW output, indicating no improvement in boiler thermal efficiency. The weighted HHW energy rate adjustment ratio of 0.68 (weighted by post-installation OAT-Bin data count to reflect the actual operating conditions of the heating system after the additive is introduced) shows that the post-installation system reduced the heating load per HDD compared to the baseline, only providing 68% of the same HHW load per bin. As mentioned previously, this may be due to the Hydronic Fluid Additive reducing heating demand to meet the same zone setpoints while maintaining the same occupancy comfort, or "level-of-service." This will result in an overestimation of gas energy savings, as a decrease in the required heat load will result in a decrease in gas energy input regardless of the Hydronic Fluid Additive. Thus, the adjustment factor is used to normalize the effects of the decrease in heating load from the additive between baseline and post-installation. The final adjusted energy savings are 19.8%, calculated as follows:

$$S_{\%Gas,adjusted} = \mathbf{0.68} * \mathbf{29.0}\% = \mathbf{19.8}\%$$

This per-bin normalization resulted in a 5% boiler thermal efficiency decrease, indicating a slight decrease in boiler thermal efficiency. Subsequently, an overall HHW ratio of 0.68, weighted by CZ2022 days, was applied directly to the total unadjusted measured savings (29.0%) to derive the adjusted savings of 19.8%, ensuring a conservative estimate that avoids overattributing demand reductions to boiler efficiency.

Surface Tension Results

The surface tension was measured by a third-party laboratory using the Wilhelmy Plate test method. Table 25 shows the baseline and post-installation sample surface tension in mN/m, and the percent change. The manufacturer claimed the additive can reduce the surface tension by 60%.

Table 25: Surface tension testing results for both sites.

Site	Baseline Surface Tension (mN/m)	Post Surface Tension (mN/m)	% Change
Site #1	65.36	28.92	-55%
Site #2	71.12	34.56	-49%

Customer Survey Results

Project Site #1

Based on the customer completed survey for Site #1, the following feedback was provided:

- Customers are not likely to adopt this technology in other buildings without financial support due to relatively low savings estimates (10.7%). They need deemed incentives to be established to provide more confidence in energy efficiency decision-making.
- The Installation process was easy, but it took longer 10-15 minutes, as advertised by the manufacturer, due to the high volume of additive (27 gallons).
- The customer provided a maximum ROI of 3 years, which would be considered for adopting this type of technology.
- The customer will recommend this technology to other industry contacts or colleagues due to the low risk involved in installation and the potential for higher savings in colder climates.
- There was no interruption to the space heating service while installing the additive.
- There were no complaints from building occupants or staff after the implementation of the additive.

Project Site #2

Based on the customer completed survey for Site #2, the following feedback was provided:

- The customer is likely to install the additive at other sites due to the resulting savings of 19.8%.
- The Installation process was easy, and the product seems to be paying for itself. Also, the customer was able to have the water treatment company supply and install the additive.
- The customer will recommend this technology to other industry contacts or colleagues due to the low risk involved in installation, and the potential for higher savings in colder climates.
- The cost of the additive is reasonable ($500/gallon).
- The customer would like to verify the savings at other buildings and see if there is a change in energy savings over time. They are worried about the reliability of the product.
- There was no interruption to the space heating service while installing the additive.

- There were no complaints from building occupants or staff after the implementation of the additive.

Discussion

The field assessment of the Hydronic Fluid Additive revealed mixed results in achieving the manufacturer's claims of 7-15% energy savings and 60% surface tension reduction. At Site #1, the measured gas energy savings were 10.7%, which required a shift in analysis to IPMVP Option C using whole-building PG&E gas data due to metering issues, which may have masked additive-specific impacts on the reduced heating load. It could be possible that the heating load per HDD has increased for Site #1, and savings need to be adjusted using the HHW output ratio or other adjustment factors. The energy savings trended higher in colder OAT bins (<50°F), aligning with manufacturer case studies conducted in colder climates, but the negligible savings above 60°F suggest minimal saving potential in mild climates.

At Site #2, the 29.0% initial weather normalized savings (adjusted to 19.8% after HHW load normalization) exceeded claims, driven by reduced heating demand—evidenced by a 67% lower HHW energy output per HDD—indicating faster zone setpoint attainment and reduced boiler runtimes.

However, post-installation models for both sites showed poor fits (R^2 ~0.31-0.63 vs. baseline R^2 ~0.81-0.85), suggesting the additive made system performance more responsive to dynamic factors like occupancy rather than strictly OAT-dependent, complicating direct comparisons.

Barriers to meeting the expected goals included significant BAS data losses (57-59% baseline, up to 71% post-installation), which necessitated OAT-binning and HDD normalization for analysis, and faulty sensors (e.g., flow meters yielding >100% efficiencies), which required using Option C - Whole Building for Site #1. Tools used included BAS data loggers for gas flow, temperatures, and flow rates; third-party lab testing (Wilhelmy Plate method) for surface tension; regression modeling (e.g., flow rate vs. VFD speed, R^2>0.9); and CALMAC weather data for normalization. These ensured replicability per IPMVP and ASHRAE Guideline 14, though data gaps reduced temperature coverage factors (e.g., 87% at Site #1 post-installation).

Based on the results from Site #2, the additive provides 19.8% gas energy savings by enhancing heat transfer (via lower surface tension), reducing runtime, and minimizing cycling with increased savings at lower OATs. However, it was not shown to improve the boiler's energy efficiency per OAT-bin with a HHW adjusted savings of -5% at the boiler level. The increase in efficiency occurs at the AHUs, which are outside of the M&V system boundaries, allowing the heat transfer to be more efficient, but the study did not show an increase in hydronic system efficiency. For this reason, the Hydronic Fluid Additive can only be considered an AOE measure with a host system including the AHUs.

Compared to incumbents (standard water without specialized energy saving additives), it is "better" in retrofit ease, multi-year savings potential without hardware changes, and environmental gains (lower GHG emissions). Beyond energy benefits, it offers improved occupant comfort (quicker heating) as there were no complaints from the building occupants during the study and provides compatibility with existing systems as no warranties were voided and installations were low-risk.

The following market barriers were identified:

- Low awareness in mild climates (e.g., California vs colder regions where most prior case studies are from)
- Need for ROI (minimum ROI >3 years at Site #1 to be considered at other buildings without incentives)
- Installation costs ($500/gallon) and longer-than-advertised dosing times deter adoption without incentives.

Conclusions

The Hydronic Fluid Additive reduces energy consumption in commercial hydronic heating systems, with verified savings of 10.7-19.8% across two sites, primarily by improving heat transfer efficiency and reducing heating demand in colder conditions. The technology meets the manufacturer's claims (7-15% savings, 60% surface tension reduction); however, it does not enhance the nominal thermal efficiency of the hydronic boilers, as post-installation efficiencies mirrored baseline levels. Performance is temperature-dependent, with greater benefits in cold OATs (<50°F) than higher ones, and system behavior becomes less predictable to model post-additive, likely due to faster responsiveness to dynamic loads. The assessed technology outperforms the incumbent (i.e., standard water or water-glycol mixtures without specialized energy-saving additives) in retrofit simplicity, demand reduction, and non-energy benefits like reduced maintenance and improved comfort, but data quality issues and variable results highlight the need for more robust monitoring in future assessments. While promising for commercial applications, broader adoption of the technology requires addressing awareness gaps and incentive structures to overcome economic and regulatory barriers.

Recommendations

This technology reduces energy consumption through enhanced heat transfer and reduced boiler demand, offering verifiable savings in commercial hydronic systems. However, it does not increase boiler energy efficiency.

We do not recommend immediate adoption into California EE programs due to inconclusive results in mild climates and the need for further validation. The assessment provides partial information but lacks sufficient data from diverse conditions to support statewide scaling.

Future work should include additional studies in varying climates (mild, like California, and cold, like the Northeast U.S.) to verify these results, quantify savings variability, and cross-validate manufacturer claims with transparent source data. A Phase 2 field testing with more sites (e.g., 5-10), improved metering (dedicated sub-meters), and longer monitoring (2+ full seasons) is recommended to refine ROI estimates and address data loss issues. Related technologies, such as advanced corrosion inhibitors or nanoparticle-enhanced fluids, should be considered for follow-up studies to compare holistic performance in hydronic systems to address customers' concerns of product lifetime.

Appendices

Appendix A: Site Eligibility Form

Purpose

This document outlines the Site Eligibility Requirements for GET Project ET23SWG011: Hydronic Space Heating Fluid Additive Field Study.

Requirements

A customer site must meet all of the following requirements in order to participate in this GET study.

- Must be a multifamily or commercial site with an existing hydronic space heating system with a central boiler ◯ **yes** ◯ **no**
- Must be served by SoCal Gas, SDG&E, or PG&E for gas utility ◯ **yes** ◯ **no**
- An authorized representative from the site must confirm that there have been no major complaints about space heating within the year ◯ **yes** ◯ **no**
- A water treatment company must regularly maintain a hydronic system water ◯ **yes** ◯ **no**
- Name of Company: ______________________________
- The hydronic boiler must serve only space heating loads (i.e. must not serve domestic hot water heating or pool heating)◯ **yes** ◯ **no**
- The hydronic boiler must be natural gas-fired ◯ **yes** ◯ **no**
- The hydronic heating system must not have external non-gas heat sources (Solar, combined heat and power, electric, etc.) ◯ **yes** ◯ **no**
- The hydronic heating system must not be connected to any indirect heating sources ◯ **yes** ◯ **no**
- The hydronic boiler must be in good working condition without any current non-routine maintenance issues, as reported by the site representative ◯ **yes** ◯ **no**
- The hydronic piping system must be free from any visible water leak ◯ **yes** ◯ **no**
- The water treatment company must confirm that the hydronic system is free of leaks ◯ **yes** ◯ **no**
- The hydronic system must have an easily accessible chemical water treatment system ◯ **yes** ◯ **no**

- The hydronic system must use water that has the following characteristics, unless the facility's water treatment company confirms that the existing water is in an acceptable range
  - Hardness of less than 200mg/l (confirm with maintenance records or on-site testing) ◯ **yes** ◯ **no**
  - Iron oxide (Fe_2O_3) concentration of less than (2) ppm (confirm with maintenance records or on-site testing ◯ **yes** ◯ **no**
  - Water uses a chemical corrosion inhibitor that follows dosage guidelines specified by the manufacturer (confirm with maintenance records or on-site testing ◯ **yes** ◯ **no**
  - pH of 8-9.5 for copper/steel systems and a lower pH of 7.5-8.5 for aluminum systems (confirm with maintenance records or on-site testing) ◯ **yes** ◯ **no**
  - The hydronic heat load distribution piping must have enough clearance to be physically accessible for the installation of data logging temperature sensors for differential temperatures. ◯ **yes** ◯ **no**
  - IF M&V will be accomplished using the facility's existing BAS system, the BAS system must have the following points logged in no less than 1-hour intervals for at least 1-year prior:
    - Boiler System Natural Gas Usage (CFH or equivalent) ◯ **yes** ◯ **no**
    - Hydronic Boiler System Inlet Temperature (°F) ◯ **yes** ◯ **no**
    - Hydronic Boiler System Outlet Temperature (°F) ◯ **yes** ◯ **no**
    - Hydronic Boiler System Flow Rate (GPM), derived using one of the following: ◯ **yes** ◯ **no**
      - Direct Flow Rate Measurement with existing flow meter (GPM)
      - Constant Speed Pump Flow Rate from Test and Balance Report or Design Documents, and pump status (on/off).
      - Variable Speed Drive (VSD) Pump Flow Rate from TAB or Design Documents, and VSD Speed Percentage (%VSD)
      - Regression between measured flow rate (GPM) and %VSD, assuming the relationship is linear and provide acceptable goodness-of-fit metrics (GOF) per ASHRAE Guideline 14-2023. ($R^2 > 0.7$, CV(RMSE) $< 25\%$, NMBE < 0.05)

Ideal

A customer site will ideally meet the following additional requirements to participate in this GET study. However, this is up to the discretion of the Study Team and ICF project managers.

- Customer has property Wi-Fi available for use with the M&V datalogger equipment with stable connectively in mechanical spaces , if the BAS is not present.
  ◯ **yes** ◯ **no**
- The hydronic space heating system uses a BAS (Building Automation System)
  ◯ **yes** ◯ **no**
- If no BAS is present, there is easy access to supply and return water piping with ample straight pipe for flow meter installation (8 diameters before meter and 5 diameters after meter + 6 inches for meter) ◯ **yes** ◯ **no**
- The hydronic heating system uses an easily accessible chemical pot feeder
  ◯ **yes** ◯ **no**
- The hydronic heating system uses a pre-water-softening/filtration treatment system ◯ **yes** ◯ **no**
- The hydronic boiler is connected to a utility meter dedicated solely to the gas supply for the boiler, with no other gas-consuming equipment connected to it.
  ◯ **yes** ◯ **no**
- The hydronic space heating system serves only one (1) building ◯ **yes** ◯ **no**
- Existing boilers are made by one of the following certified boiler manufacturers:
  - Worchester – Bosch Group
  - BAXI
  - Ideal
  - De Dietrich
  - Lochinvar
  - Viessmann.

Property Information

Site Name		Site Contact Name	
Site Address		Site Contact Phone	
Hydronic System Name		Site Contact E-mail	
Gas Utility (SoCalGas, SDG&E, PG&E)		Gas Utility Meter & Account #	

Building Information

	BLDG #1	BLDG #2	BLDG #3
Building Address or Designation (i.e. BLDG 1, BLDG B, etc.)			
Building Type			
Year Built/Vintage			
Number of Building Stories			
Total Gross Conditioned Floor Area (ft^2)			
Number of Dwelling Units (if multifamily building)			
Total In-Unit Floor Area[8] (if multifamily building) (ft2)			
Average % Occupancy (if multifamily building)			
Property Wi-Fi Available [Y/N]			

Hydronic Pipe Insulation BLDG #1 (Supply/Return)

Supply/Return	Insulation Thickness (No Insulation or Inches)	Pipe Diameter & Material Type	Pipe Length	Insulation Condition (Good or Poor)

[8] Floor area of ALL units combined

Hydronic Pipe Insulation BLDG #2 (Supply/Return)

Supply/Return	Insulation Thickness (No Insulation or Inches)	Pipe Diameter & Material Type	Pipe Length	Insulation Condition (Good or Poor)

Hydronic Pipe Insulation BLDG #3 (Supply/Return)

Supply/Return	Insulation Thickness (No Insulation or Inches)	Pipe Diameter & Material Type	Pipe Length	Insulation Condition (Good or Poor)

Pictures/Documents to Collect

- Hydronic Space Heating System
- Hydronic Space Heater/Boiler Nameplate(s)
- Hydronic Piping Sizes/Materials
- Hydronic Integrated Controls/Thermostats
- Heat Distributors (radiators, baseboard heaters, radiant tubing, or AHUs)
- Water Treatment System (Chemical Pot Feeder, Water Conditioner, Inhibitor, etc.)
- Water Testing Information (pH level, Iron Oxide ppm, hardness)
- Hot Water Pump(s) Nameplate
- Floor Plans/Site Plans/Mechanical Plans
- Test and Balance Report (TBR), if available
- Design Diagram and Schedule, if available

Hydronic Boiler Information

	Boiler #1	Boiler #2
Location (inside/outdoor)		
Which System is this connected to?		
Gas Fired (Y/N)		
Manufacturer		
Model #		
Thermal Efficiency or Energy Factor		
Boiler System Age		
Input & Output Capacity (kBtu/h)		
Supply Water Set Point (°F)		
Building Automation System (BAS) [Y/N]		
Boiler Control Type		
OAT Reset Controller [°F]		
OAT Sensor [Y/N]		

Hydronic Storage Tank Information

	Storage Tank #1	Storage Tank #2
Which system is this connected to?		
Storage Tank Capacity (gallons)		
• Is Hydronic Tank Insulated? • If Yes, what thickness of insulation? • If Yes, is the tank poorly or well insulated?	• Y/N • Insulation Thickness ________ • Poor/Well Insulated	• Y/N • Insulation Thickness ________ • Poor/Well Insulated

Water Treatment Information

	System #1	System #2
Water Treatment Device Type		
Inhibitor Type (manufacturer/model)		
Inhibitor Dosage Level (mg/L or ppm)		
pH Level		
Hardness Level (mg/L or ppm)		
Iron Oxide Concentration (ppm)		

Maintenance Questionnaire

1. Is the Hydronic Heating System in good working condition? When was the last service?
2. Are the hydronic and water treatment pipes free of leaks? Including distribution lines?
3. Have there been any complaints about space heating in the last (6) months?
4. How are the Hydronic Boilers controlled? Are there advanced integrated controls, such as outdoor ambient sensors, reset controllers, or space-heating modulation?
5. When was the last service for the hydronic water treatments (inhibitor, pH, hardness, etc.)?

Hot Water (HW) Pump Information

	HW Pump #1	HW Pump #2
HW Pump Manufacturer		
HW Pump Model		
HW Pump HP		
Pump Controls/Settings		
Number of Pumps (if multiple)		

Diagram of Hydronic System (Including distance from Boiler to all buildings)

Diagram of Boiler Supply Water Piping

(Include measurements of pipe length and pipe diameter and include pipe material)

Diagram of Boiler Return Water Piping

(Include measurements of pipe length and pipe diameter and include pipe material)

Diagram of Boiler Natural Gas Piping

(Include measurements of pipe length and pipe diameter and include pipe material)

Appendix B: M&V Equations

HHW Energy Equations

The following equations are used to calculate the hourly heating hot water (HHW) energy output [Btu/h] using the measured water flow rate, hot supply temperature, and return water temperature recorded every 15 minutes.

$$\dot{Q}_{HHW,hr}\left[\frac{Btu}{h}\right] = \sum_{i=1}^{60/\Delta t} \dot{Q}_{HHW,min,i} \tag{2a}$$

$$\dot{Q}_{HHW,min}\left[\frac{Btu}{min}\right] = \dot{Q}_{supply} - \dot{Q}_{Return} \tag{2b}$$

$$\dot{Q}_{supply,min}\left[\frac{Btu}{min}\right] = \dot{v}_{water,supply} * \rho_{water} * \bar{c}_{water} * \left(T_{Supply} - T_{ref}\right) \tag{2c}$$

$$\dot{Q}_{Return,min}\left[\frac{Btu}{min}\right] = \dot{v}_{water,return} * \rho_{water} * \bar{c}_{water} * \left(T_{return} - T_{ref}\right) \tag{2d}$$

$$\dot{v}_{water,supply} = \dot{v}_{water,return} \tag{2e}$$

Then, the hourly HHW energy output is summed over each day to calculate the total daily HHW energy output.

$$\dot{Q}_{HHW,day}\left[\frac{Btu}{day}\right] = \sum_{i=1}^{24/\Delta t} \dot{Q}_{HHW,hr,i} \tag{3a}$$

Gas Energy Equations

The natural gas line pressure for each boiler has not been measured for this analysis. Alternatively, the monthly Btu Factor (B_{factor}) and a pressure factor of 1 were used from the PG&E utility bills to estimate the hourly natural gas input energy using the following equations:

$$NG_{Input,hr}[Btu] = \sum_{i=1}^{60/\Delta t} \dot{NG}_{Input,i} \tag{4a}$$

$$\dot{Q}_{Gas,min}\left[\frac{Btu}{min}\right] = \dot{v}_{NG} * B_{factor} * P_{factor} \tag{4b}$$

Where:

$\dot{\boldsymbol{Q}}_{\boldsymbol{Gas,hr}}$ is the sum of natural gas input to the HW boiler system over an entire hour in Btu/h.

$\dot{\boldsymbol{v}}_{\boldsymbol{NG}}$ is the hourly volumetric flow of natural gas into the boiler, in $\frac{ft^3}{h}$

$\boldsymbol{B}_{\boldsymbol{factor}}$ is the high heating value of gas from monthly gas bills in $\frac{BTU}{ft^3}$

$\boldsymbol{P}_{\boldsymbol{factor}}$ is the pressure factor from a recent PG&E utility bill

$\Delta\boldsymbol{t}$ is the monitoring interval (expected to be 5 or 15 minute intervals)

Then, the hourly HHW energy output is summed over each day to calculate the total daily HHW energy output.

$$\dot{\boldsymbol{Q}}_{Gas,\boldsymbol{day}}\left[\frac{\boldsymbol{Btu}}{\boldsymbol{day}}\right] = \sum_{\boldsymbol{i=1}}^{\boldsymbol{24/\Delta t}} \dot{\boldsymbol{Q}}_{Gas,\boldsymbol{hr,i}} \tag{5a}$$

Where:

$\Delta\boldsymbol{t}$ is the hourly monitoring intervals

Then, the total HHW Energy and Gas Energy for each reporting period is calculated by summing up the total daily HHW Energy and Gas Energy over all reporting day:

$$\boldsymbol{Q}_{HHW,\boldsymbol{total}}[\boldsymbol{Btu}] = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n/\Delta t}} \dot{\boldsymbol{Q}}_{HHW,\boldsymbol{day,i}} \tag{6a}$$

$$\boldsymbol{Q}_{Gas,\boldsymbol{total}}[\boldsymbol{Btu}] = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n/\Delta t}} \dot{\boldsymbol{Q}}_{Gas,\boldsymbol{day,i}} \tag{6b}$$

Where:

$\boldsymbol{Q}_{HHW,\boldsymbol{total}}$ is the total HHW Energy Output for the complete reporting period.

$\boldsymbol{Q}_{Gas,\boldsymbol{total}}$ is the total Gas Energy Input for the complete reporting period.

$\boldsymbol{n}$ is number of reporting period days.

$\dot{\boldsymbol{Q}}_{HHW,\boldsymbol{day}}$ is calculated using Equation (2a)

$\dot{\boldsymbol{Q}}_{Gas,\boldsymbol{day}}$ is calculated using Equation (5a)

The baseline and post-installation system thermal efficiencies (TE) are calculated using the following equations:

$$\boldsymbol{\eta}_{\boldsymbol{T,Base}} = \boldsymbol{100} * \frac{\boldsymbol{Q}_{HHW,\boldsymbol{total,Base}}}{\boldsymbol{Q}_{Gas,\boldsymbol{total,Base}}} \tag{6a}$$

Where:

$\boldsymbol{\eta_{T,Base}}$ is the thermal efficiency of the existing HW boiler system during the baseline period without using hydronic fluid additives

$\boldsymbol{Q_{HHW,total,Base}}$ is calculated using Equation (6a)

$\boldsymbol{Q_{Gas,total,Base}}$ is calculated using Equation (6b)

$$\boldsymbol{\eta_{T,Post} = 100 * \frac{Q_{HHW,total,Post}}{Q_{Gas,total,Post}}} \tag{7a}$$

Where:

$\boldsymbol{\eta_{T,Post}}$ is the thermal efficiency of the HW boiler system of the post-installation system using hydronic fluid additives

$\boldsymbol{Q_{HHW,total,Post}}$ is calculated using Equation (6a)

$\boldsymbol{Q_{Gas,total,Post}}$ is calculated using Equation (6b)

The baseline and post-installation energy models are linear functions using OAT as the independent variable using the following equation:

$$\boldsymbol{Q_{Output,RG} = f(OAT)} \tag{8a}$$

Where:

$\boldsymbol{OAT}$ is the measured OAT from nearby weather stations within 10 miles, in °F

Appendix C: OAT-Bin trend charts.

Figure 12: Bin-Specific Average Daily Gas Usage (therms) vs OAT for Site #1.

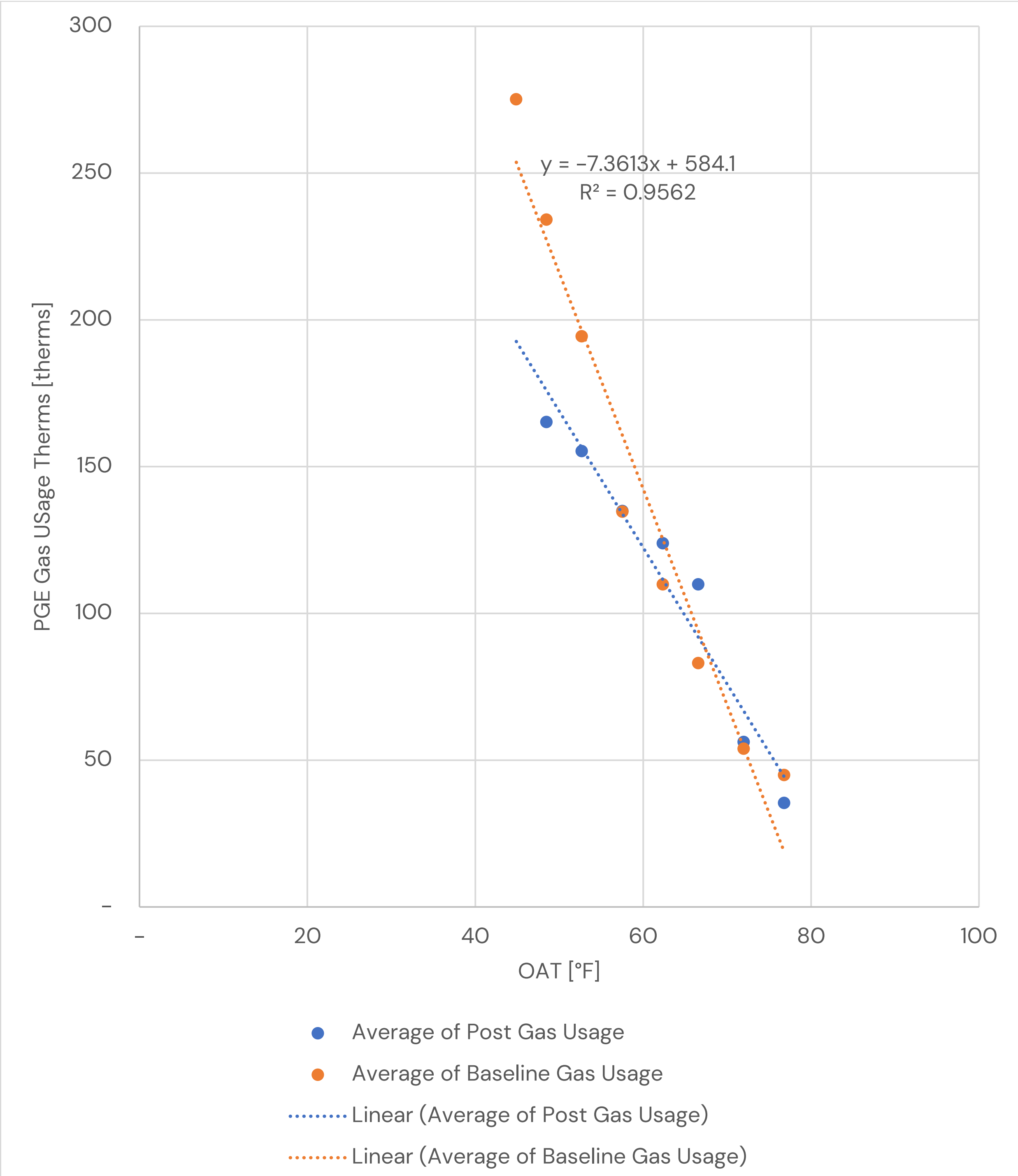


Figure 13: Bin-Specific Average Daily Gas Usage (kBtu) vs OAT for Site #2.

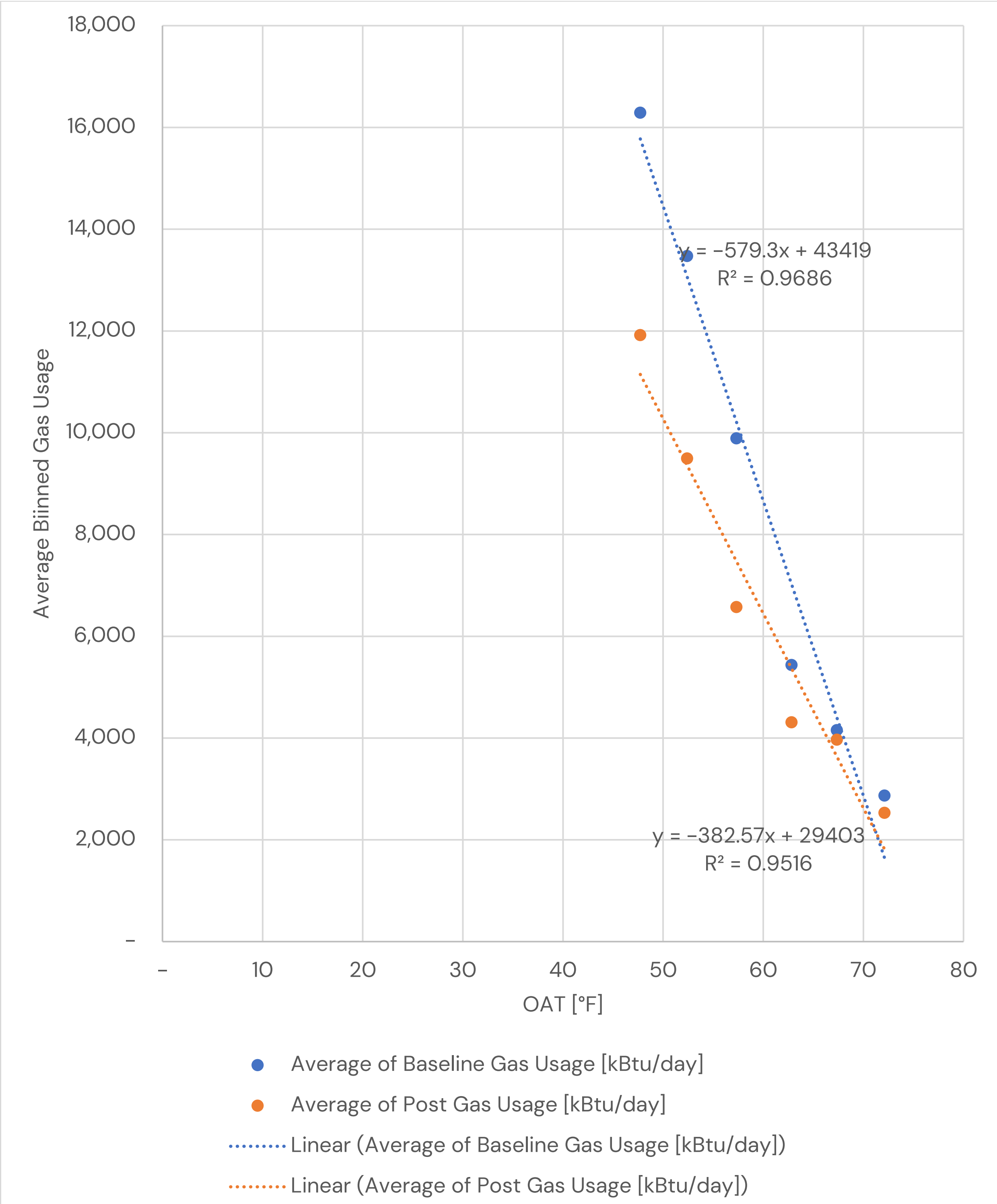
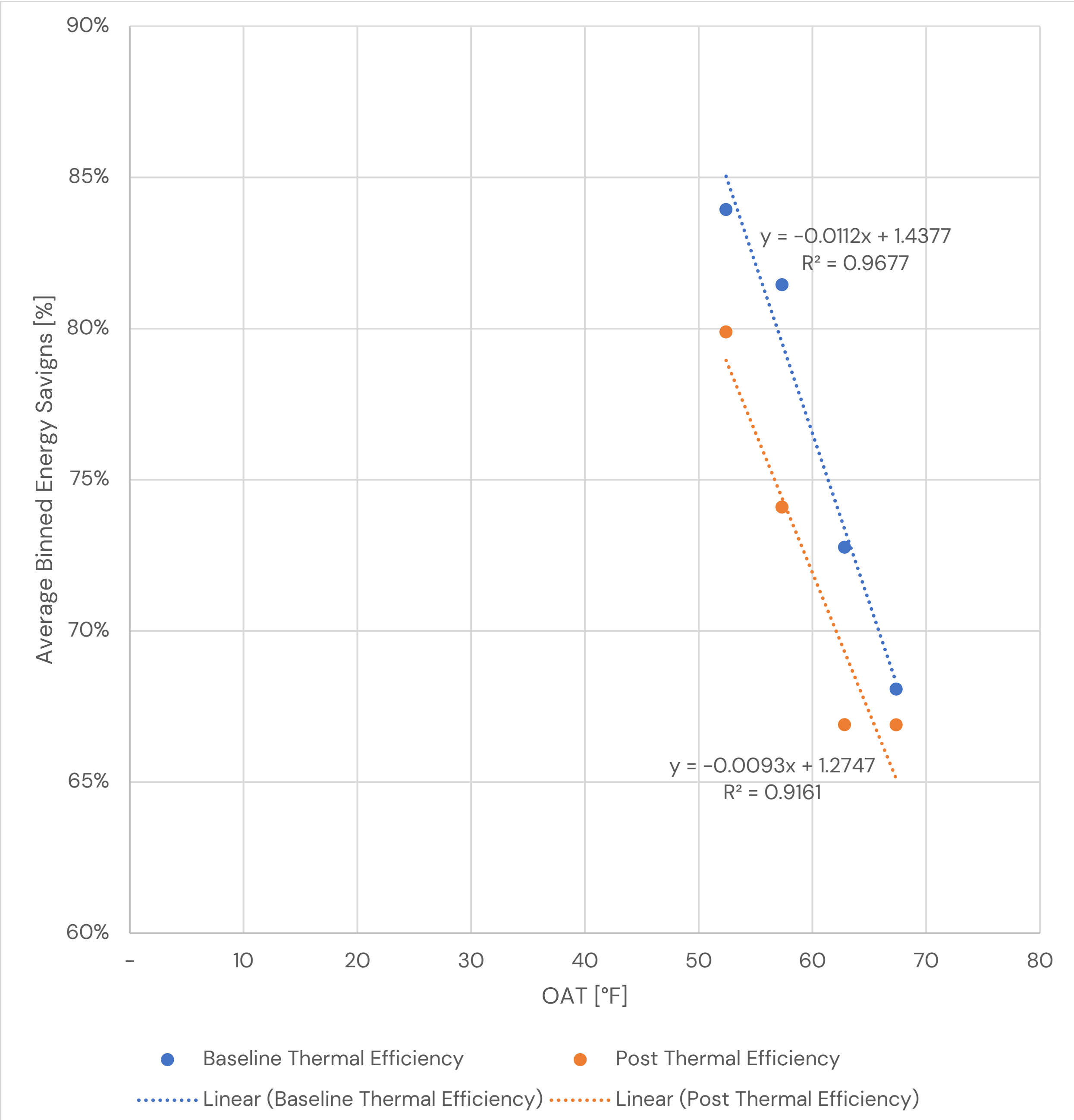


Figure 14: Bin-Specific Energy Savings Percentage vs OAT for Site #2



Appendix D: Customer Survey Questions

On a scale of 1-5 with 5 being the highest, how satisfied are you with the new hydronic additive you received?
Quality and Performance
On a scale of 1-5 with 5 being the highest, how would you rate the quality of the additive?
On a scale of 1-5 with 5 being the highest, How would you rate the ease of installation in the hydronic heating system?
Was the installation process completed within the expected timeframe (e.g., 10-15 minutes as advertised)
Have you experienced any performance issues?
Did you encounter any challenges or disruptions to normal operations during the installation of additive? [yes/no/maybe/unsure]
Have you noticed any changes in the operational efficiency of the hydronic heating system (e.g., reduced runtime, improved heat transfer)?
Value for Money
The cost of this additive was $500 per gallons. Do you feel the product is worth the price?
If no, what cost do you feel is worth the price?
If yes, what is the maximum cost you would be willing to pay for this product?
Would you purchase this additive without an incentive?
If not, how much incentive is necessary to influence your decision to use this additive in other buildings?
Did you notice a drop in your gas bills after this equipment was installed?
Have building occupants or facility staff reported any changes in thermal comfort since the addition of hydronic fluid additive?
Comparison to Comptetitors
How does this equipment compare to other water heating equipment?
Likelihood to Recommend
How likely are you to recommend this equipment to an industry contact or colleague? Or likelihood to use in other facilities? Scale of 1-5
Other Comments
Is there anything else you want to share about this experience?
What additional support or information would have improved your experience with the additive?

References

[1] U.S. Energy Information Administration, "2018 Commercial Buildings Energy Consumption," EIA, April 2022.

[2] U. E. I. Administration, "Monthly Energy Review," www.eia.gov/mer, April 2024.

[3] U.S. Department of Energy, "Optimizing Hydronic System Performance in Residential Applications," Office of Scientific and Technical Information, October 2013.

[4] U.S Department of Energy, "Balancing Hydronic Systems in Multifamily Buildings," July 2014.

[5] Maryam Rabiu Aliyu, Huzaifa Umar, Michael Adedeji, Ali Shefik, Dilber Uzun Ozsahin, Mustafa Dagbasi, "Performance improvement of an HVAC system using water and ethylene glycol-based ternary hybrid nanofluids with green-synthesized Fe-Cu-Fe2O3 nanoparticles," *National Library of Medicine,* vol. PLoS One, no. 20(5):e0323539. doi: 10.1371/journal.pone.0323539., May 2025.

[6] Pacific Gas and Electric Company Southern California Edison Company SoCalGas Company San Diego Gas & Electric Company , "2021 Investor Owned Utility Customized Offering Procedures Manual for Business," Version 1.0 .

[7] D. Holohan, "Dan Holohan: The two sides of hydronics - A history lesson on the two profitable sides of hydronic heating.," Supply House Times, 11 August 2021. [Online]. Available: https://www.supplyht.com/articles/104195-dan-holohan-the-two-sides-of-hydronics.

[8] John Siegenthaler, P.E., "Hydronic Baseboard Basics," Journal of Light Construction, 2025. [Online]. Available: https://www.jlconline.com/how-to/hvac/hydronic-baseboard-basics_o.

[9] R. K. Beach, "The use of ethylene glycol solutions in heating systems," National Research Council Canada, 1963.

[10] D. N. Canter, "Heat transfer fluids: Growing in visibility and importance," Society of Tribologist and Lubrication Engineers, December 2021. [Online]. Available: https://www.stle.org/files/TLTArchives/2021/12_December/Cover_Story.aspx.

[11] D. A. Williams, "EndoTherm Hydronic Heating System Additive: How It Works," [Online]. Available: https://rtf.nwcouncil.org/media/filer_public/15/22/15223a69-75fa-4271-8d06-a40d7ab1afa3/EndoTherm-Hydronic-Heating-System-Additive-Technical-Summary-How-It-Works-v1_3.pdf.

[12] D. Edginton, "UES Measure: Hydronic Additives," Regional Technical Forum, [Online]. Available: https://rtf.nwcouncil.org/measure/hydronic-additives/.

[13] Wilson, Will, "A Guide To Energy Saving Hydronic Additives," Pace Solutions, 2023.

[14] Michael P. Weberski, Jr.; Bingzhi Chen, "Next Generation Closed Loop Corrosion Inhibitors: Increasing Reliability & Decreasing Environmental Impact," in *CORROSION 2021, Virtual, April 2021*, April 19 2021.

[15] D. A. Williams, "Changing the properties of water to improve energy efficiency.," Endotherm, [Online]. Available: https://www.endotherm.com/how-it-works/.

[16] BC Housing Research Centre, "Improving Efficiency in Hydronic Radiant Heating Systems," Builder Insight.

[17] V. W. Technologies, "Water Handbook, Chapter 32: Closed Recirculating Cooling System," in *Handbook of Industrial Water Treatment*, McGraw-Hill Water Management & Pollution Control Series.

[18] U.S. Energy Information Administration (EIA), "Use of energy explained: Energy use in commercial buildings," 29 June 2023. [Online]. Available: https://www.eia.gov/energyexplained/use-of-energy/commercial-buildings.php.

[19] K. Gasljevic, E.F. Matthys, "On saving pumping power in hydronic thermal distribution systems through the use of drag-reducing additives," *Energy and Buildings,* vol. 20, no. 1, pp. 45-46, 1993.

[20] Center for Energy and Environment, "Air-to-Water Heat Pumps A Cold Climate Solution for High-Efficiency Cooling, Space Heating, and Water Heating," Center for Energy and Environment, Minneappolis, MN, 12/18/2023.

[21] Emerging Products , "Normalized Metered Energy Consumption Savings Procedures Manual Version 1.01," Southern California Edison, December 2017.

Glossary

Coefficient of Determination (R^2): represents the proportion of variance in the dependent variable that can be explained by the independent variables in a model. It indicates how well the model's predictions align with the actual observed data.

Coefficient of Variation of the Root mean-Square Error CV(RMSE): a metric used as an indication of how much variation or randomness there is between the data and the model, calculated by dividing RMSE by the average energy use.

Normalized Mean Bias Error (NMBE): a metric used to assess the bias in a forecasting model by measuring the average difference between forecasted and actual values, normalized by a characteristic value like the mean or standard deviation. It helps determine if a model is systematically over or under-predicting and is particularly useful when comparing models with different scales.