High Efficiency Dehumidification System Field Study

Final Report

ET22SWE0040

Prepared by:

Akane Karasawa ASK Energy
Daniela Grassi AESC
David Moell AESC
Sonia Ronquillo Perez ASK Energy

May 27, 2025

Disclaimer

Executive Summary

This project evaluated the in-field performance of a high efficiency dehumidification system emerging technology. The high efficiency dehumidification system is a patented dehumidification technology that consists of large cooling and energy recovery coils that can reclaim up to 100 percent of the dehumidification-related reheat energy. The cooling and energy recovery coils have increased surface area, enabling greater heat exchange between supply air and chilled water at reduced chilled water flow. The design allows the chilled water to capture additional heat from the supply air, which is subsequently used to efficiently reheat the original air. Thus, the technology reduces both cooling and heating coil loads and saves energy compared to the typical dehumidification process that has separate, dedicated, higher-flow cooling and reheat coils.

In this field test, the high efficiency dehumidification system technology was evaluated based on an installation at a fine art museum in San Diego, California. The museum replaced constant air volume air handler with the variable air volume high efficiency dehumidification system technology in 2022 to provide heating, ventilation, and air conditioning, as well as dehumidification, to the entire building. Since the technology was already installed and operating when the study initiated and the performance of the preexisting baseline system was not available, the project team structured the field study to evaluate the technology's performance against simulated baselines. The team completed the following four test scenarios:

1. Simulated baseline for a constant air volume system where the high efficiency dehumidification system energy recovery was turned off and the fan ran in constant air volume.
2. Ran a constant air volume system with the high efficiency dehumidification system energy recovery where the high efficiency energy recovery was turned on and the fan ran in constant air volume.
3. Simulated baseline for a variable air volume system where the high efficiency dehumidification system energy recovery was turned off and the fan ran in variable air volume.
4. Ran a variable air volume system with high efficiency energy recovery where the high efficiency dehumidification system energy recovery was turned on and the fan ran in variable air volume.

The tests were conducted in two separate monitoring periods, summer and winter, to collect representative data for cooling and heating operations of the technology. Each monitoring period lasted 13 weeks and included the four test scenarios described above.

Using the data collected from the field test, the project team developed regression models to estimate the annual energy consumption for each test scenario and used the typical weather file, CZ2022 for California Climate Zone 7, for this exercise. Table 1 summarizes the total reductions for the four tested scenarios: 1) a constant air volume baseline to be used for comparison, 2) a high efficiency dehumidification system running a constant air volume, 3) a variable air volume baseline

to be used for comparison, and 4) a high efficiency dehumidification system running a variable air volume.

The field test results showed that high efficiency dehumidification system has the potential to substantially reduce both electricity and gas consumption, as well as the greenhouse gas emissions of any traditional dehumidification system running in constant or variable air volume. To accelerate the market adoption of this technology and help California achieve its energy goals, the project team recommends that utilities should consider this technology for rebates or incentives through an energy efficiency program. Additional work — such as modeling simulations — will likely be required to validate the consistency of the technology's performance with different air handler unit sizes, climate zones, and building load types to establish the rebate or incentive amount. The technology may also be a key to electrifying dehumidification systems, as it greatly reduces required reheat energy and therefore makes it possible for a system to be retrofitted with heat pumps. A follow-up study to investigate this possibility may help accelerate electrification in sectors that are typically considered difficult to electrify.

Table 1: Estimated Annual Energy Uses and Savings

Test Scenario	Electricity Use (kWh)	Natural Gas Use (therms)	GHG** Emission (tons of CO_2)	Electricity Savings (kWh)	Natural Gas Savings (therms)	GHG Savings (tons of CO_2)
1. Constant air volume	463,000	22,000	1,360	–	–	–
2. Constant air volume with HEDS**	303,000	5,000	370	160,000 (35%)	17,000 (77%)	990 (73%)
3. Variable air volume	222,000	10,000	600	–	–	–
4. Variable air volume with HEDS	98,000	2,000	140	124,000 (56%)	8,000 (80%)	460 (77%)
Site Savings*				**365,000 (79%)**	**20,000 (91%)**	**1,220 (90%)**

*Savings calculated as the difference between Test Scenario 1 and 4.
**Greenhouse gas (GHG); high efficiency dehumidification system (HEDS)

Source: Project team.

Abbreviations and Acronyms

Acronym	Meaning
A	amps
AHU	air handling unit
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CF	cubic feet
CZ	climate zone
ECM	electronically commutated motor
ET	emerging technology
GHG	greenhouse gas
GPM	gallons per minute
HEDS	high efficiency dehumidification system
HHW	heating hot water
HVAC	heating, ventilation, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
IOU	investor-owned utility
kW	kilowatt
kWh	kilowatt-hour
OAT	outside air temperature
PF	power factor
PG&E	Pacific Gas and Electric

Acronym	Meaning
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SFMOMA	San Francisco Museum of Modern Art
T	temperature
RH	relative humidity
V	voltage
VAV	variable air volume

Contents

Tables

Figures

Introduction

While the efficiency of air conditioners has improved over the last century, less focus has been given to improving dehumidification efficiency. Global humidity loads contribute an estimated 600 million metric tons of CO_2 equivalent ($MtCO_2eq$) per year and the emissions are expected to be five times larger by 2050 (Woods, et al. 2022). A warming climate, growing population with expanding adoption of air conditioners, and increasing ventilation requirements for improving public health will all contribute to this growth. Advancements in dehumidification and humidity control technologies have the potential to contribute to significant energy savings and reduce strain on the grid.

In this study, the project team conducted a field test to evaluate the performance of a high efficiency dehumidification system (HEDS) emerging technology. This new and patented dehumidification technology was developed in Southern California for air handlers with chilled water cooling and hot water, steam, or electric reheat systems. The HEDS includes an energy recovery coil that can recover heat from the chilled water return line to be used for reheating. This novel design reduces both cooling and heating coil loads and saves energy over the typical dehumidification process that has separate, dedicated coils for higher-flow chilled water cooling and hot water reheating.

In 2024 and 2025, the project team conducted the field test on a HEDS installed in a fine art museum in San Diego, California. The museum installed and has operated the technology since 2022 to provide heating, ventilation, and air conditioning (HVAC), as well as dehumidification, to the entire building. Since the performance data of the preexisting HVAC system prior to the technology installation was not available, the technology's performance during the summer and winter was evaluated against simulated baselines by adjusting its fan operations from variable air volume (VAV) to constant air volume (CAV) and turning the HEDS's energy recovery feature on and off.

Background

Dehumidification is a critical function of the HVAC system in buildings where excess moisture poses increased risk to occupants and facilities. Numerous studies have demonstrated the interaction of occupant health and moisture content or relative humidity (RH). Per a 2023 literature review, the viability of the influenza virus appears to increase in dry air with an RH of less than 50 percent and in high humidity with an RH of greater than 70 percent. Additionally, high RH is associated with increased allergen loads such as pollen, mites, and mold (Guarnieri, et al. 2023). A 2019 study on RH and workplace wellbeing also showed a correlation between higher stress and exposure to RH outside of the 30 to 60 percent RH range established by ASHRAE 55-1989 (Razjouyan, et al. 2020).

Several dehumidification technologies have been introduced over the years. For example, a mechanical dehumidifier with a passive desiccant wheel uses a moisture-absorbing material that cools and dries the incoming air. The passive desiccant can be more affordable to operate than other technologies. However, it requires an exhaust air stream, and its performance depends on the exhaust air being drier than the outdoor air. Another example is a mechanical dehumidifier with a sensible heat exchanger, which does not need exhaust air but instead has an air-to-air heat exchanger to precool and reheat the outdoor air.

This method allows the system to operate any time the humidity is above the setpoint, but due to the increased operating hours and the extra work of the supply fan, it can be more costly to operate. A two-stage desiccant and mechanical dehumidifier combines these previous two technologies to use them at optimal points of performance. The heat that would otherwise be wasted in a mechanical dehumidifier is reused to dry the desiccant wheel, leading to greater performance in all weather conditions and lower operating costs. However, the air temperature leaving the system is not consistent because it depends on how much moisture the desiccant can absorb (Harriman III and Judge 2002).

The HEDS technology proposes a novel approach to the dehumidification system, which can replace up to 100 percent of the dehumidification-related reheat energy without the need for a desiccant or an exhaust air stream. The system uses heat recovered during the cooling process for reheat, which can greatly reduce the reheat load and the cooling load on the chiller plant. Furthermore, while dehumidification systems are traditionally operated in CAV mode, HEDS can operate in VAV mode to save additional energy during low-load conditions.

The original design of this technology was field demonstrated at two military bases in Oklahoma and North Carolina in 2016. Those field tests showed significant electrical savings of 20 to 30 percent in 24/7 applications, as well as partial or even complete offset of gas hot water reheat loads. The technology design has changed and improved significantly since 2014, including:

- New fin design for increased heat transfer
- Electronically commutated motor (ECM) fan wall technology
- New air filtration system and ultraviolet germicidal irradiation to reduce biological growth on the coil faces and the spread of biological pathogens in the airstream
- Completely updated HVAC optimization control system with added building pressure control

The modeling of this new design has shown savings of 30 to 40 percent in cooling load for 24/7 applications and partially or even completely offsets the reheat loads (Duncan and Chu 2018).

Incumbent Technology

In commercial HVAC systems, dehumidification is typically carried out by moving air over a series of cooling and reheat coils in an air handling unit (AHU) or remotely located reheat coils. Figure 1 below illustrates the traditional dehumidification process. To remove moisture from the air entering the system (2), the supply air is cooled below the dewpoint temperature, typically set around 55°F dry bulb or lower, to cause condensation at the cooling coil (5). If the moisture-saturated cold supply air (3) is delivered to the space as-is, it would cause water to condense on the surfaces of ducts and ceilings, leading to mold growth. In addition, the supply air delivered to the spaces would be too cold for the occupant’s comfort. To avoid this, a reheat coil (6) is added to the air handler to achieve comfortable humidity and temperature levels (4). This process is effective but inefficient, resulting in significant energy consumption and carbon emissions.

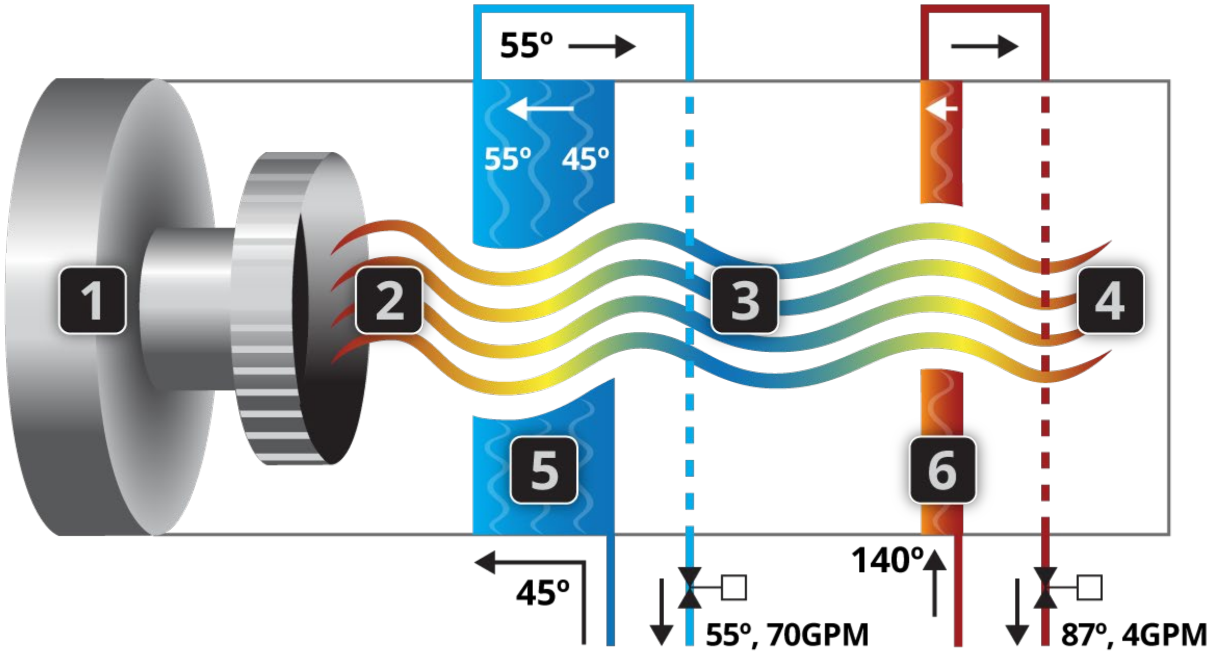

Figure 1: Typical AHU dehumidification process.

Source: Manufacturer's website.

Emerging Technology: HEDS

The evaluated emerging technology, HEDS, was first developed for the U.S. Department of Defense to address indoor air quality and biological growth issues. It has since evolved to include other energy efficiency benefits. HEDS encompasses a novel approach to dehumidification by introducing large cooling and energy recovery coils that can reclaim up to 100 percent of the dehumidification-related reheat energy. The patented cooling and energy recovery coils have increased surface area, enabling greater heat exchange between supply air and chilled water at reduced chilled water flow, typically less than half of what is required by the traditional system. This design also allows the chilled water to capture additional heat from the supply air, which is subsequently used for reheating the same supply air. Thus, the technology reduces both cooling and heating coil loads and saves energy compared to the typical dehumidification process that has separate, dedicated coils for higher-flow chilled water cooling and hot water reheating.

Figure 2 below shows the dehumidification process of HEDS with an energy recovery coil. Like a typical dehumidification process, the air entering the system (2) is dehumidified by cooling the supply air below its dewpoint temperature to cause condensation (5). The cooling coil absorbs heat from the supply air passing through, increasing the temperature of chilled water leaving the cooling coil up to 70°F. The return line of chilled water is then routed to reheat the supply air using the energy recovery coil (6) to be delivered to the spaces. As shown in the example in Figure 2, the HEDS can provide the same amount of cooling and dehumidification with less than half the chilled water flow compared to a typical dehumidification process.

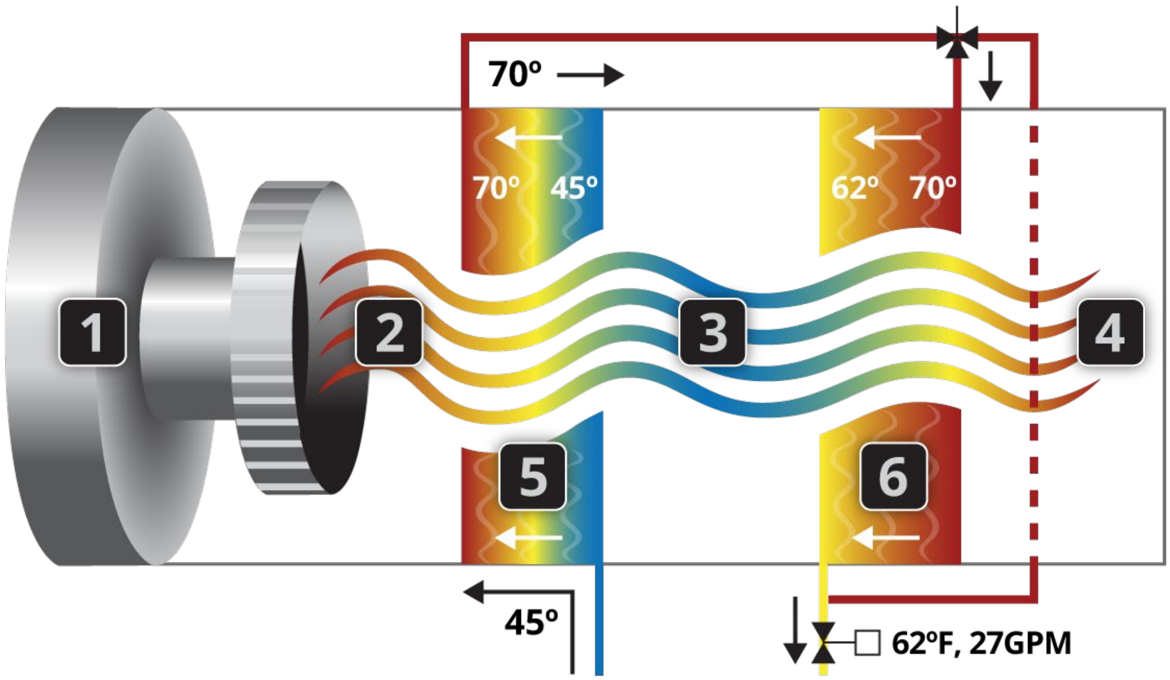

Figure 2: High efficiency dehumidification system.

Source: Manufacturer's website.

The HEDS can be installed in new construction or retrofitted in existing facilities. Existing AHUs can also be modified with the HEDS technology by installing a properly sized new cooling coil and the HEDS controller with optimization logic. In these retrofit applications, the cooling coil can also be used as the energy recovery coil, but it may be undersized. The HEDS optimization software is factory-built, installed, and tested, and can make use of existing sensors. Additionally, the system allows new sensors to be added to the existing direct digital control (DDC) system and fed into the HEDS controller. The software installation does not require DDC code re-writes, and the control software is designed to tolerate sensor fault. In other words, the system can continue running even when a sensor fails, using slightly more energy than when it is fully optimized.

The HEDS is commercially available but currently custom designed and built for each application. The manufacturer estimates the useful life of the technology to be 30 to 40 years. The cost varies from site to site but is roughly equal to the cost of a standard AHU of the same size (measured by airflow rate and supply air temperature). The labor cost to install and retrofit a HEDS unit into an existing space will be slightly higher than a standard AHU due to added cooling and energy recovery coils, as well as added piping for those coils. The manufacturer estimates the equipment and installation cost to be less overall than for other dehumidification systems, such as ones with energy recovery wheels and heat pipes. Those systems require a significantly larger footprint and use bigger components — such as a larger fan, chiller, and chilled water pump, which all contribute to a higher installation cost — to achieve the same airflow and capacity as an equivalent HEDS unit.

Market Share and Energy Use

Dehumidification systems are commonly found in commercial buildings with stringent indoor air quality requirements, such as hospitals, art museums, and libraries. Since the HEDS can retrofit existing systems, the market share could be significant: there are 393 hospitals (California Health Care Foundation 2013), over 1,500 art museums (CAM 2025), and 1,127 libraries in California (California State Library 2023). Appendix B provides a sample list of hospitals, art museums, and libraries in California, along with each building's square footage. To estimate the market share of this technology, the total annual energy use of these three building types was estimated using information summarized in Table 2. HVAC energy use accounts for about 32 percent of total art museum and library energy use and about 40 percent of total hospital energy use (Itron, Inc. 2006).

Table 2: Energy Use of Buildings that Require Dehumidification

	Hospitals	Art Museums	Libraries
Total number of buildings in California	393	> 1,500	1,127
Average size (ft^2)	954,666	102,806	109,000
Energy use intensity (kWh/ft^2)	28.8	13.2	15.7
Estimated annual energy use (MWh)	27,494	1,357	1,710
Estimated HVAC energy use (MWh)	10,998	434	547

Source: Project team.

Hospitals, specifically inpatient healthcare facilities, can also benefit as a HEDS target market. The average size of a hospital in California, based on the sample listed in Appendix B, is about 954,666 square feet. According to the Commercial Buildings Energy Consumption Survey (CBECS), hospitals use about 28.8 kWh/ft^2/year (EIA 2018). As a result, hospitals in California use approximately 27,494 MWh/year.

Art museums, specifically exhibition or indoor gallery space in art museums, vary in size. The project team estimated the annual energy use of building activities that could benefit the most from the emerging technology based on the building's average square feet. The average size of an art museum in California is about 102,806 square feet based on the sample listed in Appendix B. According to the CBECS, art museums use about 13.2 kWh/ft2/year (EIA 2018). As a result, art museums in California use approximately 1,357 MWh/year.

California has about 1,127 public libraries (California State Library 2023), which vary in size from 4,000 to 500,000 square feet. The average size of a library in California, based on the sample listed in Appendix B, is about 108,975 square feet. Based on the CBECS, libraries use about 15.7 kWh/square feet per year (EIA 2018). As a result, libraries in California use approximately 1,710 MWh/year.

Additionally, the HEDS technology can be installed across a variety of facility types that maintain 40% to 60% relative humidity in the conditioned spaces, including but not limited to commercial offices, schools, laboratories, multifamily buildings, fulfillment centers, and AI data centers.

Objectives

The goal of this study is to evaluate the in-field performance of the HEDS and measure its energy savings and GHG reduction potential. The project team established several objectives:

1. Quantify energy (both electric and gas) and GHG impacts and benefits of the technology compared to typical gas hot water reheat.
2. Evaluate the cost-effectiveness of HEDS compared to incumbent technology.
3. Evaluate non-energy impacts such as improvement of indoor humidity as it relates to indoor air quality and occupant comfort.
4. Evaluate market barriers and provide recommendations for utility programs and pathways to support broader market adoption.

To accomplish these objectives, we developed a testing plan adhering to International Performance Measurement and Verification Protocol (IPMVP) principles. The methodology is outlined in the following sections and was designed to directly measure technology performance as well as other relevant factors.

Methodology and Approach

The project team conducted a field test to evaluate the performance of HEDS. The following section details the specifics of the field assessment.

Site Information

The project site is a fine art museum located in San Diego, California, which is in California Climate Zone (CZ) 7. The building has approximately 10,400 square feet of conditioned space, including a lobby and a main gallery consisting of six showrooms.

Table 3: Test Site Characteristics

Characteristics	Site Details
Location	San Diego, California

Characteristics	Site Details
California CZ	7
Building type	Museum
Building area (ft^2)	10,400 of conditioned space
Year built	1965
Hours of operation	Monday: Closed Tuesday: Closed Wednesday–Sunday: 10 a.m.–5 p.m.
Space type	Lobby, gallery, and showrooms

Source: Provided by the site host.

The museum installed the HEDS air handler in 2022. The AHU consists of the patented energy recovery coil and a fan wall, comprised of six variable-speed ECM fans. Chilled water to the system is provided by a 50-ton air-cooled scroll chiller while a natural gas boiler provides heating hot water (HHW) for reheat when required, and both the chiller and boiler are in the basement. Below, Table 4 details the equipment specifications, while Figure 3 and Figure 4 provide views of the equipment itself.

Table 4: Equipment Specifications

Characteristics	AHU	Chiller	Boiler
Make	Air Enterprises (custom-built)	Trane	Raypak
Model	6341-1	CCAD050	H1-1125
Manufacturing year	2021	2002	2002
Type	HEDS	Scroll, air-cooled	Natural gas
Rated capacity	12,500 cubic feet per minute (CFM)	50 tons	1,124,720 Btu/h
Rated efficiency	n/a	1.15 kW/ton	82%

Source: Project team.

Figure 3: HEDS air handler and chilled water and HHW pipes going into the unit.

Source: Project team.

Figure 4: Fan wall in the HEDS air handler.

Source: Project team.

Test Plan

The project team developed a test plan to help achieve the assessment objectives and included field testing of the technology at a fine art museum in San Diego, California. We structured the field study to evaluate the technology's performance against simulated baselines by adjusting its fan operations from VAV to CAV and turning the HEDS's energy recovery feature on and off, and completed the following test scenarios:

1. Simulated baseline for a CAV system where the HEDS's energy recovery was turned off, and the fan ran in CAV.
2. CAV system with the HEDS energy recovery where the HEDS's energy recovery was turned on, and the fan ran in CAV.
3. Simulated baseline for a VAV system where the HEDS's energy recovery was turned off, and the fan ran in VAV.
4. VAV system with the HEDS energy recovery where the HEDS's energy recovery was turned on, and the fan ran in VAV.

To collect representative data for the technology's cooling and heating operations, the project team conducted the tests in two separate monitoring periods, summer and winter. Each monitoring period lasted 13 weeks and included the four test scenarios above. The detailed testing schedule for both summer and winter monitoring periods is available in Appendix A.

Instrumentation Plan

The study followed IPMVP protocols by using Option B, Retrofit Isolation: All Parameter Measurement (IPMVP). The key parameters and logging instrumentation the project team used were continuously monitored and recorded on an interval basis; they can be found below in Table 5. The project team recorded the chiller power and fan current at one-minute intervals to capture any compressor or fan cycling, while continuously monitoring and logging temperature on an interval basis. Additionally, we referenced weather data from a nearby weather station.

Table 5: Equipment List

Variable	Measurement	Instrument	Accuracy	Frequency
Chiller power	V, A, PF, kW, kWh	DENT ELITEpro XC	±1% of full scale	1-minute average
AHU fan current	A	CTV-C 100-amp current sensor HOBO U12-013 data logger	±4.5% full Scale	1-minute average

Variable	Measurement	Instrument	Accuracy	Frequency
Condenser fan current	A	CTV-B 50-amp current sensor HOBO U12-006 data logger	±4.5% full Scale	1-minute average
Return air temperature and relative humidity	T, RH	T/RH sensor	±0.63°F, ±2.5% RH	2-minute average
Mixed air temperature and relative humidity	T, RH	T/RH sensor	±0.63°F, ±2.5% RH	2-minute average
Outside air temperature and relative humidity	T, RH	T/RH sensor	±0.63°F, ±2.5% RH	2-minute average
Temperature and relative humidity of air exiting cooling coil	T, RH	T/RH sensor	±0.63°F, ±2.5% RH	2-minute average
Temperature and relative humidity of air exiting energy recovery coil	T, RH	T/RH sensor	±0.63°F, ±2.5% RH	2-minute average
Supply air temperature and relative humidity	T, RH	T/RH sensor	±0.63°F, ±2.5% RH	2-minute average
Chilled water flow	Gallons per minute (GPM)	Ultrasonic flow meter	±2% of full scale	2-minute average
HHW flow	GPM	Ultrasonic flow meter	±2% of full scale	2-minute average
Boiler natural gas consumption	CF	Rotary type gas displacement meter	±1% of full scale	2-minute interval

Source: Project team.

The data were collected for approximately three months in each monitoring period to evaluate the system performance. This ensured the capture of seasonal variations adequate for annualization and extrapolation; it also provided enough time to mitigate any instrumentation errors, testing challenges, or non-routine events without compromising the study's goals.

The project team used the collected data to build regression models to quantify demand and energy savings resulting from the technology. Any changes to the building operating schedule, HVAC operating schedule, thermostat setpoints, and occupancy patterns were recorded, and nonroutine adjustments were made accordingly.

Findings

Summer Testing Results

To evaluate the performance of the HVAC system operating in the cooling mode, summer testing data were collected from June 11, 2024 to September 3, 2024. The project team compared the operational profiles of the four test scenarios to analyze the HEDS's energy savings capabilities.

CAV Performance

First, the team evaluated the performance of the HEDS operating as a CAV system and charted the power draws of the chiller, condenser, and fans in the HEDS air handler over a two-week period during the summer testing, presented in Figure 5. From July 2 to July 9, the system operated as a traditional CAV system (Scenario 1), with the HEDS features disabled and the energy recovery coil bypassed. On the morning of July 9, all the HEDS features were enabled (Scenario 2), highlighted in yellow below, including the energy recovery coil, and the system operated as CAV with the HEDS.

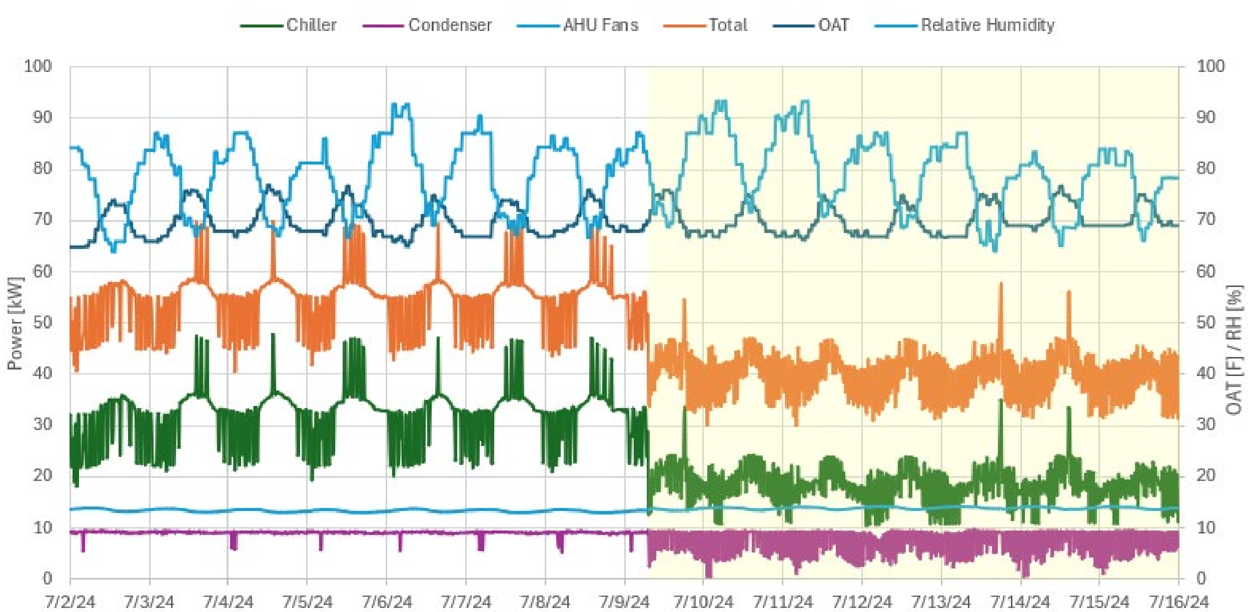

Figure 5: The operational profiles of chiller, condenser, and AHU fans during the two-week summer testing period in July.

Source: Project team.

As shown in Figure 5, there was a significant drop in chiller power when the HEDS features were enabled on July 9. As a comparison, the chiller power averaged 31.9 kW without the HEDS and 18.5 kW with the HEDS during this time frame, resulting in a 42 percent reduction. With the HEDS features enabled, the condenser fan load was also reduced and the condenser fan cycled on and off more frequently. On the other hand, the fan power remained relatively constant, which was expected because no change was made to the fan operation. Note that there was no significant difference in ambient condition, both in temperature and humidity, during the two-week period. Table 6 summarizes the average power values of system components operating with and without the HEDS features enabled. In total, the system running in CAV saw a 26 percent average power reduction after the HEDS features were enabled.

Table 6: The Comparison of System Average Power Values During the Two-Week Summer Testing Period

Test Scenario	OAT (F)	RH (%)	Fan (kW)	Chiller (kW)	Condenser (kW)	Total (kW)
CAV	69.9	78.5	13.4	31.9	9.1	54.4
CAV with HEDS	70.0	79.5	13.9	18.5	7.5	39.9
Difference			**−0.5 (−4%)**	**13.4 (42%)**	**1.6 (18%)**	**14.5 (26%)**

Source: Project team.

Figure 6 shows chilled water supply and return temperatures, as well as chilled water flows through the cooling coil during the same two-week testing period. The project team did not observe any significant change for chilled water supply temperature. However, the chilled water return temperature decreased by approximately 10°F after the HEDS features were enabled, indicating that the heat was transferred from the chilled water to the supply air flowing through the energy recovery coil for reheating. The chilled water flow through cooling coil decreased slightly from averaging 27.3 GPM before activation and 24.6 GPM after the HEDS features were activated.

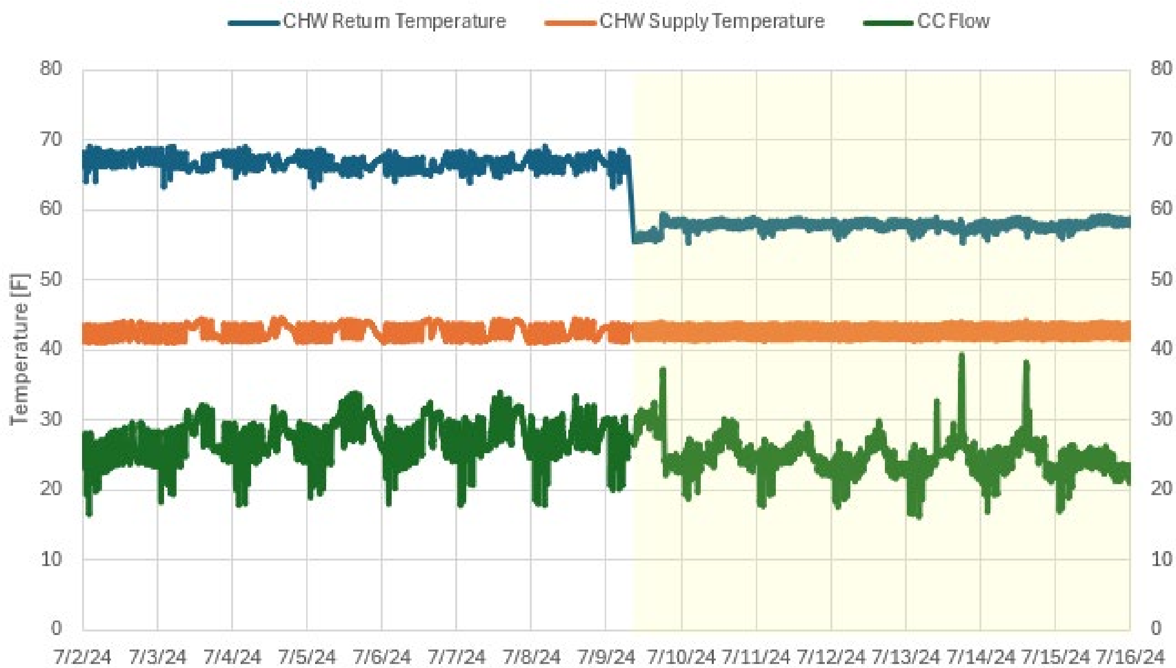

Figure 6: Chilled water supply and return temperatures and flow during the two-week summer testing period in July.

Source: Project team.

Figure 7 shows the temperature and the RH of supply air exiting the HEDS AHU during the same two-week testing period. Before the HEDS features were enabled, the supply air temperature averaged around 52°F. Once the HEDS reheat feature was activated, the supply air temperature rose to 60°F as it absorbed heat from the chilled water flowing through the energy recovery coil. Meanwhile, the RH decreased from nearly 100 percent to 70 percent due to the increase in supply air temperature.

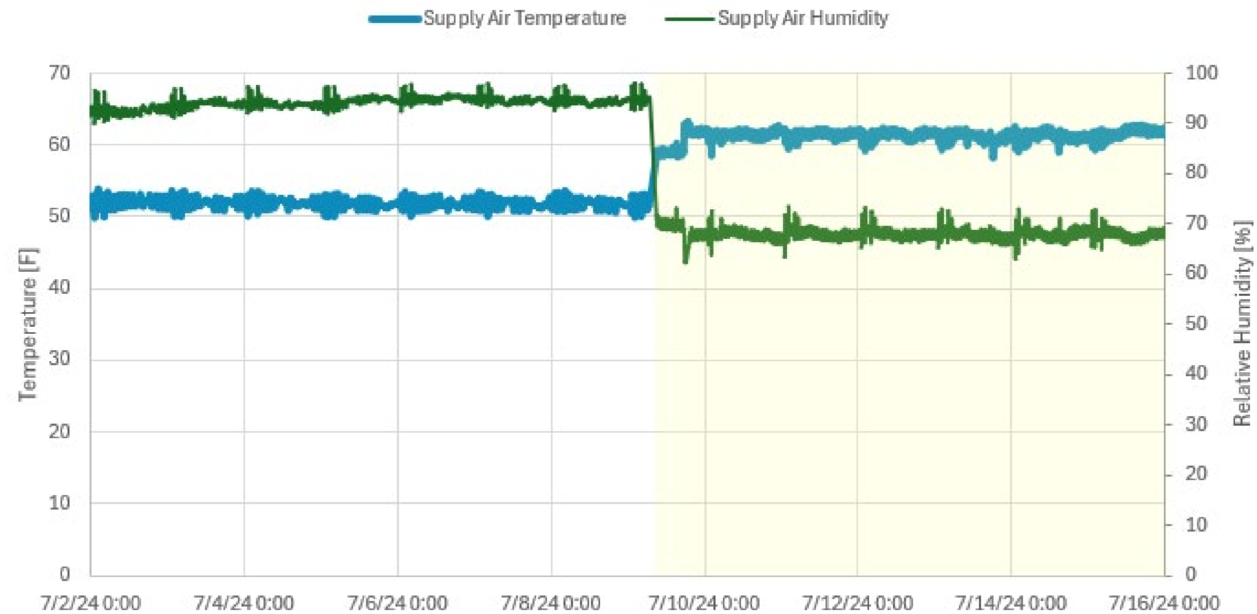

Figure 7: Supply air temperature and RH during the two-week summer testing period in July.

Source: Project team.

The hourly natural gas consumption of the boiler providing HHW to the reheat coil during the same two-week testing period is shown in Figure 8 below. As evident from the figure, gas consumption decreased substantially after the HEDS features were enabled on July 9.

Figure 8: Gas consumption of HHW boiler during the two-week summer testing period in July.

Source: Project team.

The project team evaluated the HEDS's ability to maintain the facility's required temperature and humidity levels by comparing the space air temperature and humidity with and without the HEDS features enabled (Scenario 1 and 2, respectively). Because the test facility was a museum, the temperature and humidity requirements could vary according to the type of art exhibited at that time. Fortunately for the study, the museum had the same requirements throughout the testing period.

The system was required to maintain the space temperature between 65°F and 75°F and the RH level between 45 and 55 percent. Figure 9 illustrates the space's air conditions during the two-week testing period in July when the system operated as CAV. The yellow highlighted area in the figure corresponds to the museum's required space air conditions, bounded by the space temperature and humidity limits. In both cases, the system was able to maintain the required conditions. However, the system running with the HEDS features enabled appeared to have controlled the humidity levels more tightly, with the space temperature ranging from 68.4°F to 72.2°F and relative humidity ranging from 46.1 to 52 percent. On the other hand, the baseline system appeared to have controlled the space temperature more tightly, with the space temperature ranging from 69.5°F to 72.4°F and 46 and 55.9 percent RH.

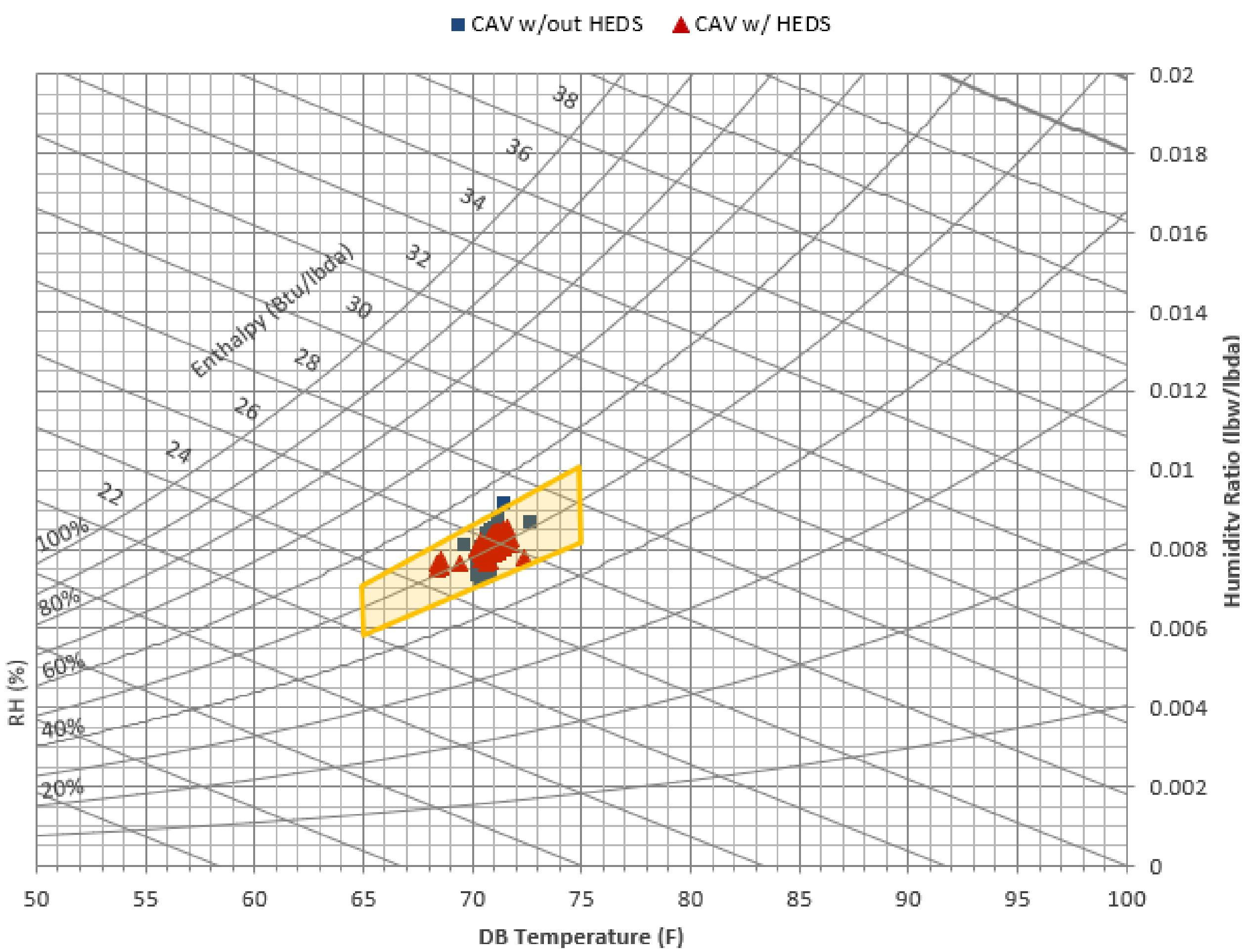

Figure 9: Space temperature and RH conditions during the two-week summer testing period in July.

Source: Project team.

VAV Performance

Next, the project team evaluated the performance of HEDS operating as a VAV system. Figure 10 illustrates the power draws of the chiller, condenser, and AHU fans in the HEDS air handler from August 7 to August 20. For Scenario 3, the system operated as a VAV system from August 7 to August 13, with the HEDS features disabled and energy recovery coil bypassed. For Scenario 4, on the morning of August 13, all HEDS features were enabled, including the energy recovery coil, and the system operated as VAV with the HEDS.

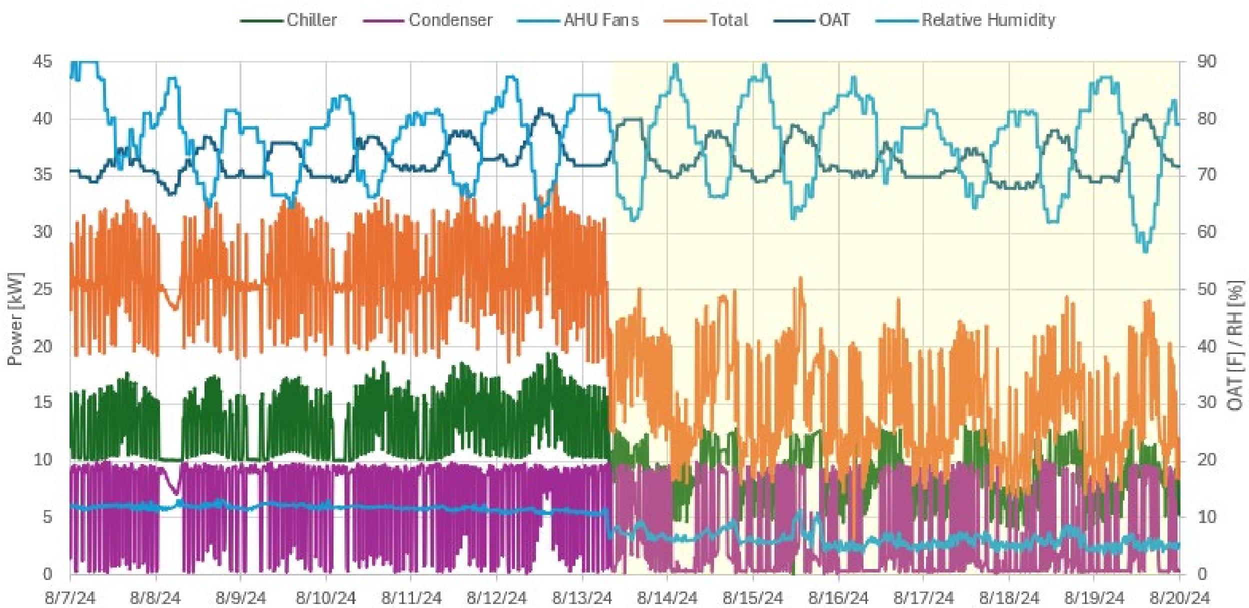

Figure 10: The operational profiles of chiller, condenser, and AHU fans during the two-week summer testing period in August.

Source: Project team.

As shown in the figure, chiller power decreased, and the cycling of condenser fan increased when the HEDS features were enabled on August 13. As a comparison, which is illustrated in Table 7, the chiller power averaged 13.2 kW without the HEDS and 8.7 kW with the HEDS during this time frame, resulting in a 34 percent reduction. Similarly, the condenser power decreased from 7.2 kW to 2.8 kW, a 61 percent reduction. The AHU fan load also decreased slightly because the HEDS's features included static pressure reset. Overall, the total system power decreased by 11.8 kW, or 45 percent from the VAV baseline.

Table 7: The Comparison of System Average Power Values During the Two-Week Summer Testing Period

Test Scenario	OAT (F)	RH (%)	Fan (kW)	Chiller (kW)	Condenser (kW)	Total (kW)
VAV	73.1	76.8	5.9	13.2	7.2	26.3
VAV with HEDS	72.6	76.1	3.0	8.7	2.8	14.5
Difference			**2.9 (49%)**	**4.5 (34%)**	**4.4 (61%)**	**11.8 (45%)**

Source: Project team.

Figure 11 shows the change in chiller water supply and return temperatures and chilled water flow through the cooling coil during testing. As illustrated, the chilled water supply temperature remained relatively constant before and after the HEDS features were activated. However, the chilled water return temperature decreased by approximately 10°F after the HEDS features were enabled, indicating that the heat was transferred from the chilled water to the supply air flowing through the energy recovery coil for reheating. Although the chilled water flow through the cooling coil fluctuated more, it decreased overall: the chilled water flow averaged 13.2 GPM before and 10.9 GPM after the HEDS features were activated.

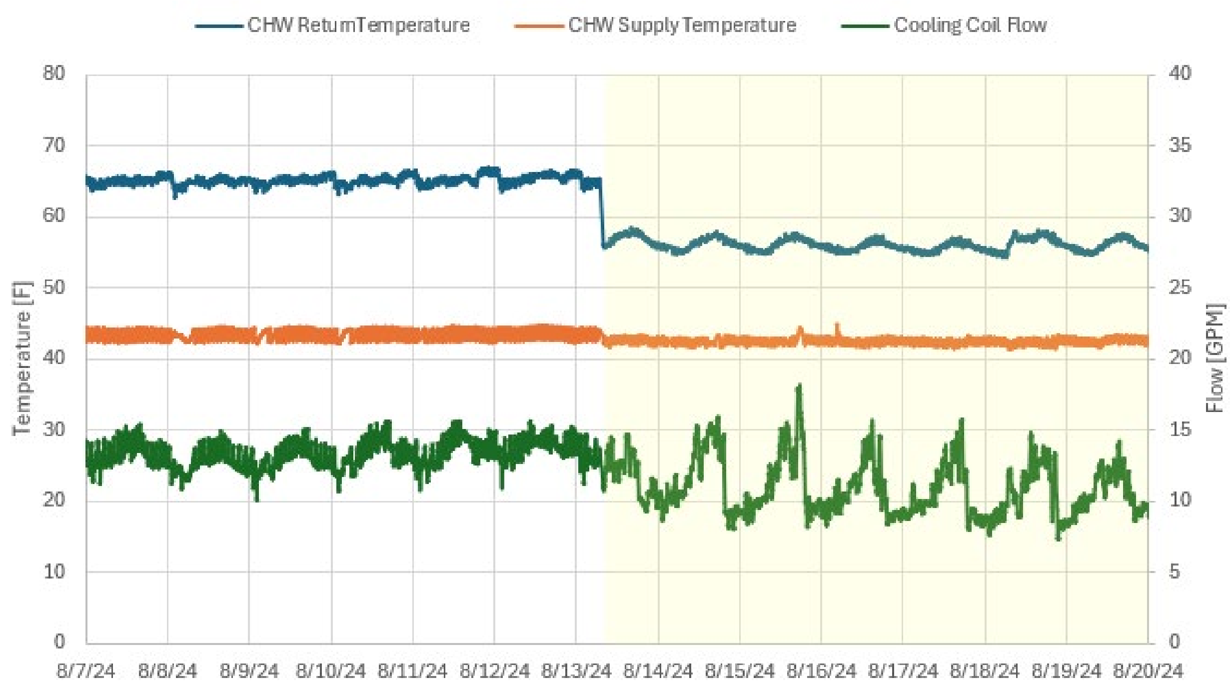

Figure 11: Chilled water supply and return temperatures and flow during the two-week summer testing period in August.

Source: Project team.

Figure 12 shows the temperature and the RH of supply air exiting the HEDS AHU during the same two-week testing period. Before the HEDS features were enabled, the supply air temperature averaged around 52°F. Once the HEDS reheat feature was activated, the supply air temperature rose to 60°F as it absorbed heat from the chilled water flowing through the energy recovery coil. Meanwhile, the RH decreased from nearly 100 percent to between 65 to 75 percent due to the increase in supply air temperature.

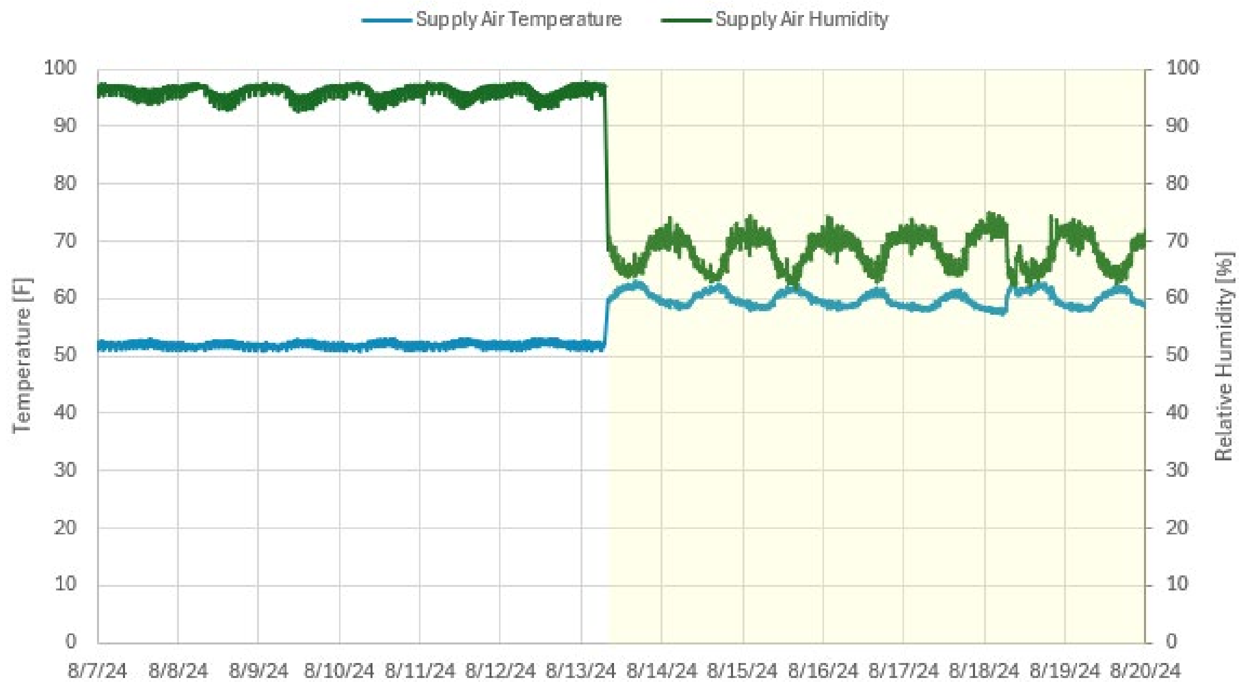

Figure 12: Supply air temperature and RH during the two-week summer testing period in August.

Source: Project team.

The hourly natural gas consumption of the boiler providing HHW to the reheat coil during the same two-week testing period is shown in Figure 13 below. There was little boiler usage after the HEDS features were fully enabled on August 13; it only turned on once for a couple of hours during the test period.

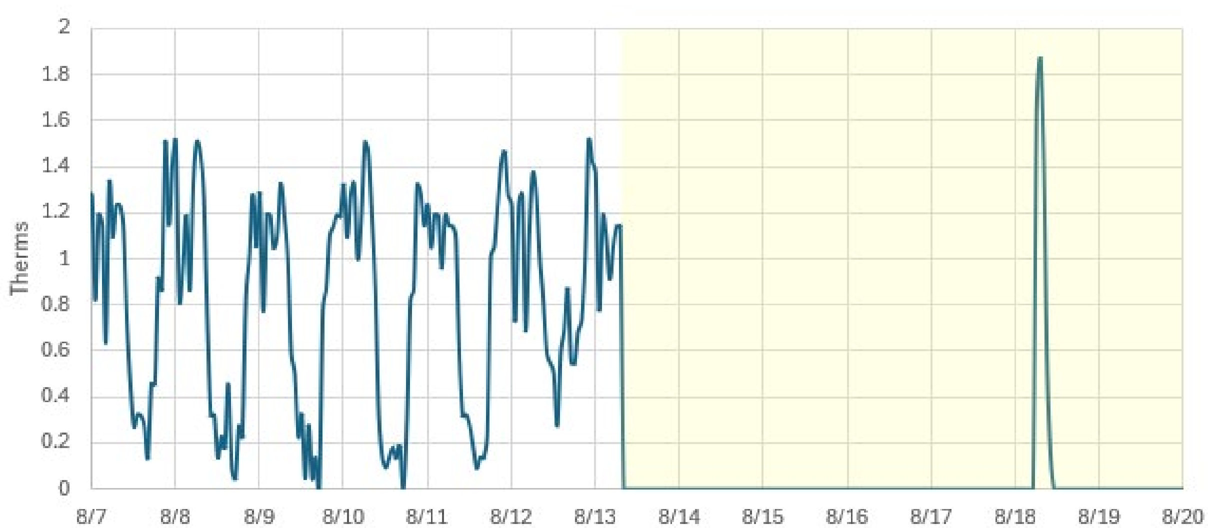

Figure 13: Gas consumption of HHW boiler during the two-week summer testing period in August.

Source: Project team.

The project team evaluated the ability of the HEDS to maintain the facility's required temperature and humidity levels by comparing the space air temperature and humidity with and without the HEDS features enabled (Scenario 3 and 4, respectively). Figure 14 illustrates the space air conditions during the two-week testing period in August when the system operated as VAV. The yellow highlighted area in the figure corresponds to the museum's required space air conditions, bounded by the space temperature and humidity limits.

In both cases, the system was able to maintain the required conditions. Similarly to the CAV test results, the system running with the HEDS features enabled appeared to have controlled the humidity levels better, with space temperatures ranging from 69.1°F to 74.1°F and RH ranging from 46.7 to 54.3 percent. The baseline date ranged from 70.1°F to 72.3°F in space temperature and 50 to 55.6 percent in RH, slightly exceeding the required limit of 55 percent.

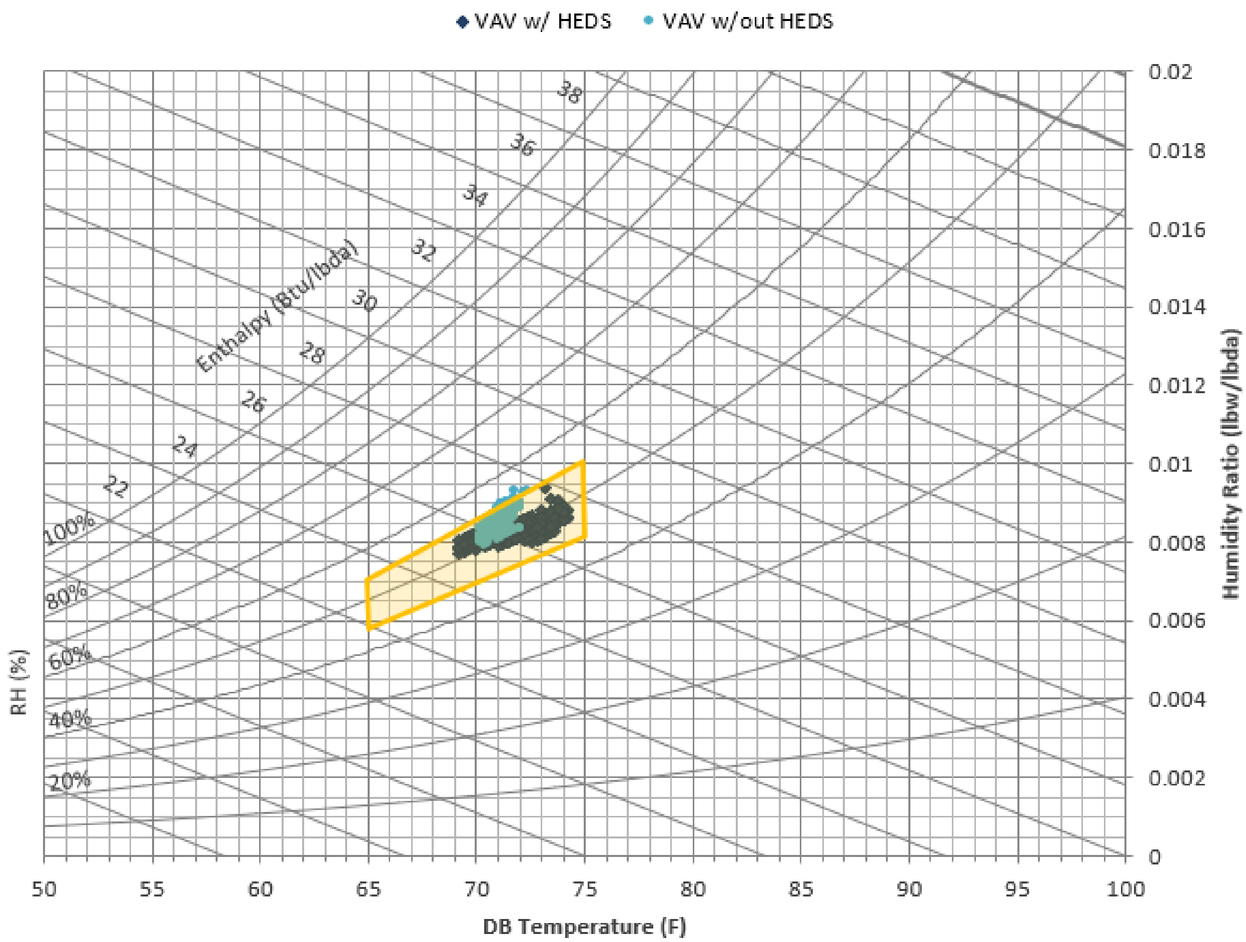

Figure 14: Space temperature and RH conditions during the two-week summer testing period in August.

Source: Project team.

Regression Modeling

The team compared the hourly average system power demand in all four test scenarios, calculated as the total of the chiller, condenser, and AHU fans. As shown in Figure 15, the demand increased with rising outside air temperature (OAT) in all four cases, but the demand was highest when the system was operating in CAV without HEDS (Scenario 1, shown in blue). When the HEDS features were enabled while still operating in CAV (Scenario 2, shown in orange), the system demand decreased notably. When the system operated as a typical VAV system (Scenario 3, shown in purple), the total system demand was further reduced. The total system demand was the lowest with the system operated in VAV with the HEDS features enabled (Scenario 4, shown in green).

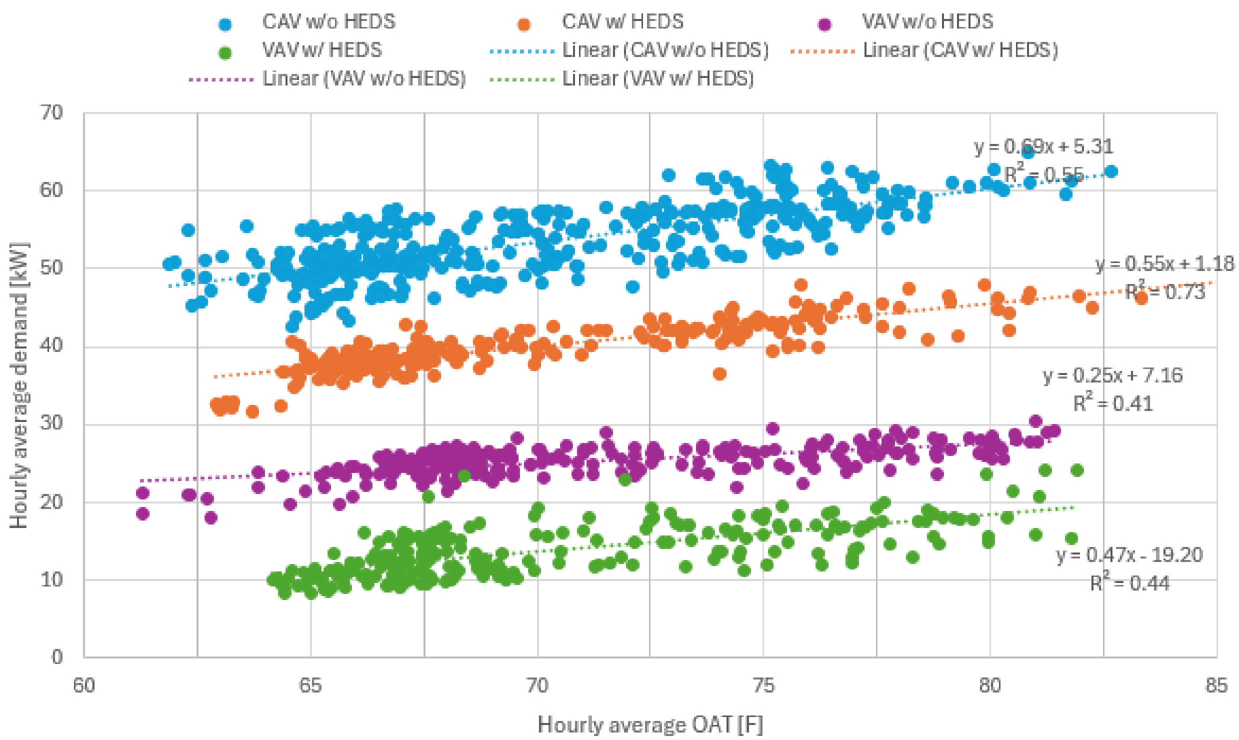

Figure 15: Hourly average total system power demand plotted against hourly average OAT at four different test scenarios.

Source: Project team.

To evaluate the system performance as it relates to both sensible and latent loads, the project team plotted the hourly average power demand against the hourly average enthalpy of ambient air in Figure 16. There are similar trends for all four cases, with demand increasing with rising enthalpy. When compared to the previous regression models with OAT as an independent variable, the model fit with enthalpy as an independent variable was better for Scenario 3, when the VAV system operated without the HEDS. The same model fit was worse for Scenario 1, when the system operated in CAV without the HEDS. However, it was comparable for Scenario 2, when the system operated in CAV with the HEDS, as well as Scenario 4, when the system operated in VAV with the HEDS enabled.

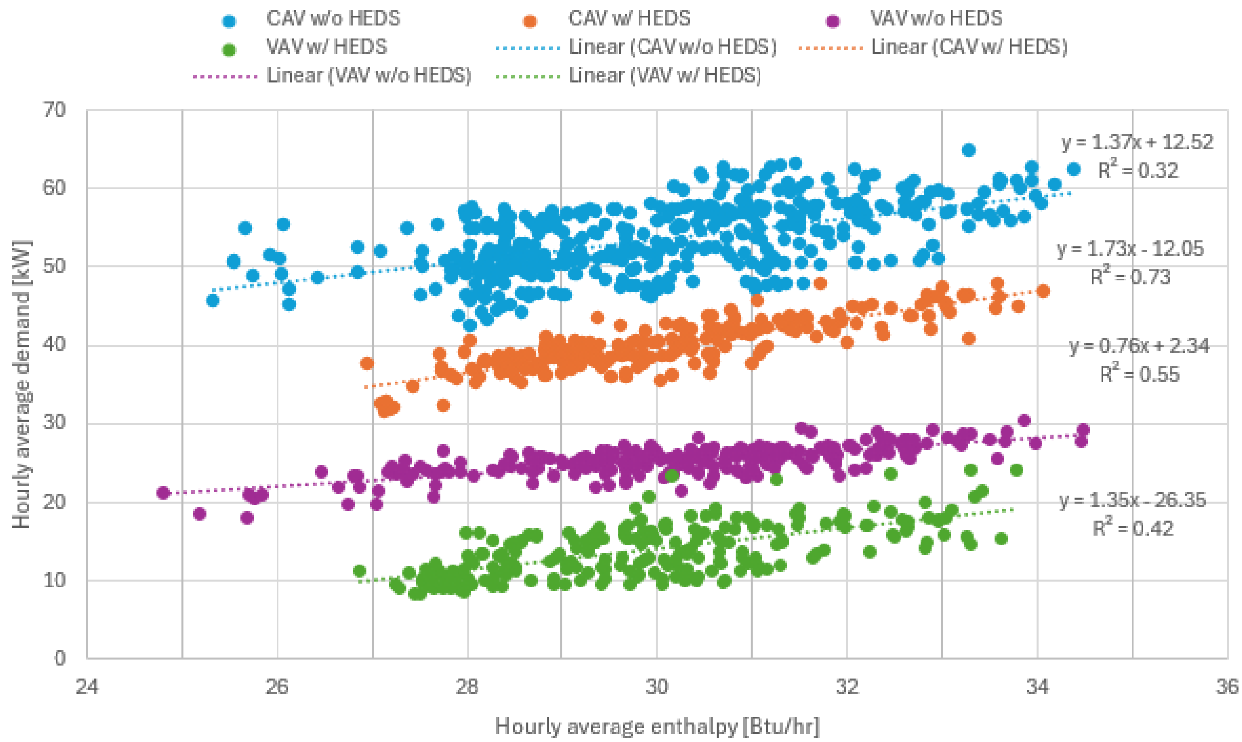

Figure 16: Hourly average total system power demand plotted against hourly average enthalpy of ambient air at four different test scenarios.

Source: Project team.

Figure 17 compares the daily natural gas consumption of the HHW boiler for all four scenarios. As expected, the system consumed the most gas when it was operating in CAV (Scenario 1, shown in orange). Daily consumption decreased significantly when the HEDS features were enabled while still operating in CAV (Scenario 2, shown in dark blue). When the system operation was switched to VAV (Scenario 3, shown in green), daily natural gas consumption reduced even further. With VAV and the HEDS enabled (Scenario 4, shown in light blue), the boiler consumed less than 10 therms per day, reducing the daily usage by more than 85 percent when compared to the CAV baseline.

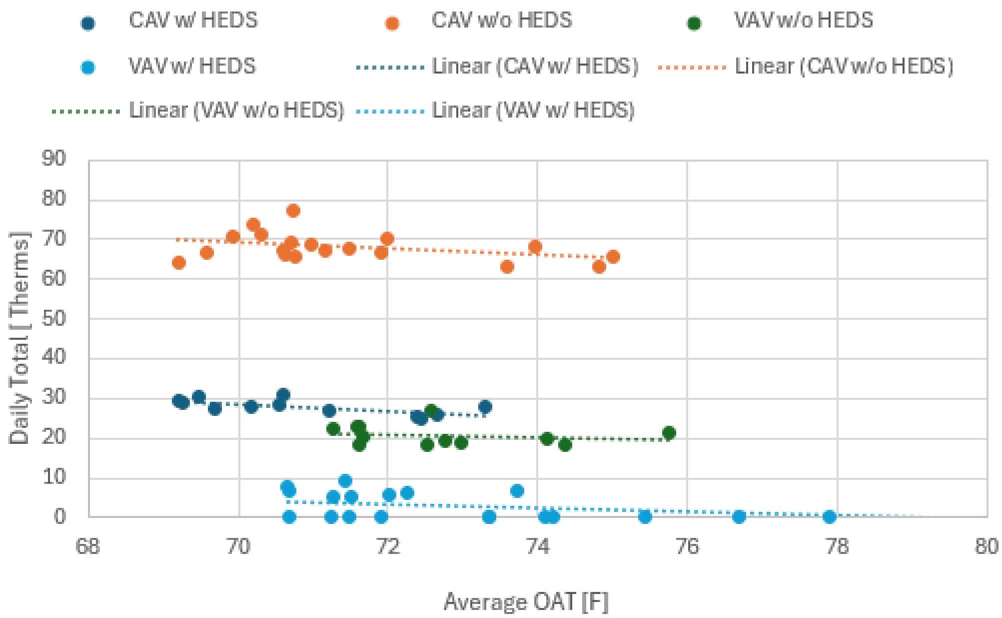

Figure 17: Daily natural gas consumption of the HHW boiler at four different test scenarios during the summer testing.

Source: Project team.

Winter Testing Results

To evaluate the performance of the HVAC system operating in heating mode, winter data were collected from December 18, 2024 to March 11, 2025. As with the summer testing, the project team compared the operational profiles of the four test scenarios to analyze the HEDS's energy savings capabilities.

CAV Performance

First, the test evaluated the performance of the HEDS operating as a CAV system. The team charted the power draws of chiller, condenser, and fans in the HEDS air handler over a two-week period during the winter testing, presented in Figure 18. From January 28 to February 3, the system operated as a traditional CAV system, with the HEDS features disabled and energy recovery coil bypassed (Scenario 1). On the morning of February 4, all the HEDS features were enabled, including the energy recovery coil, and the system operated as CAV with the HEDS (Scenario 2, highlighted in yellow).

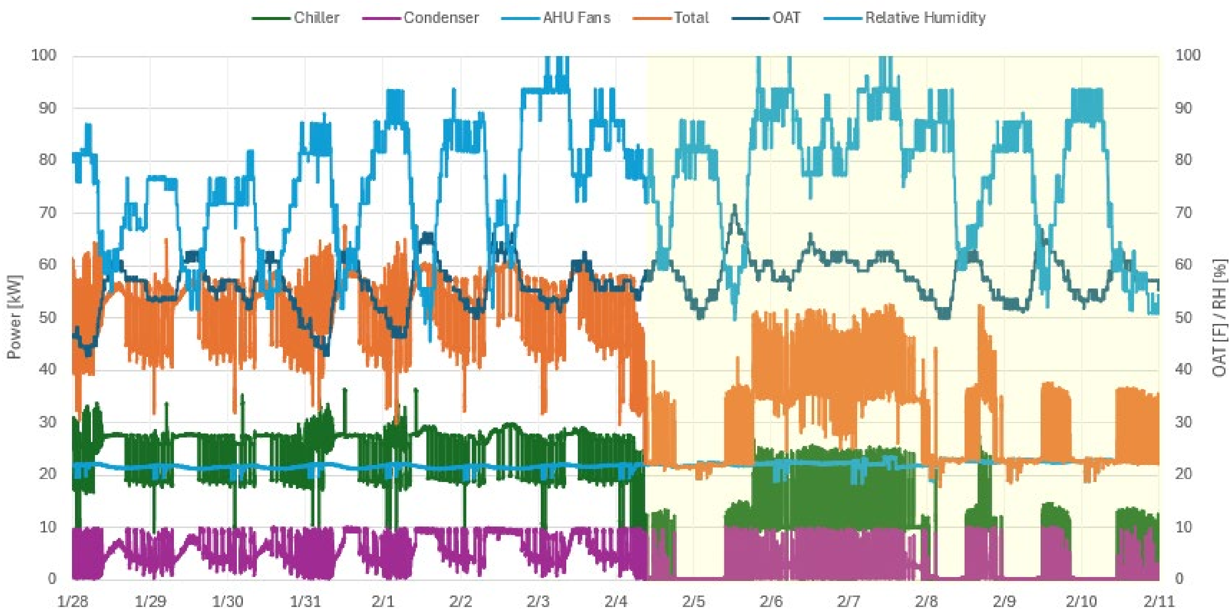

Figure 18: The operational profiles of chiller, condenser, and AHU fans during the two-week winter testing period in January and February.

Source: Project team.

Like the summer testing, there was a significant drop in chiller power when the HEDS features were enabled on February 4. As a comparison, the chiller power averaged 16.9 kW without the HEDS and 6.5 kW with the HEDS during this time frame, resulting in a 59 percent reduction. With the HEDS features enabled, condenser fan load was also reduced and the condenser fan cycled on/off more frequently, resulting in another 59 percent reduction. The fan power remained relatively constant, as expected, because no change was made to the fan operation.

Note that there was a change in OAT and relative humidity patterns on February 6 and February 7, causing the system to operate in cooling mode. As illustrated in Figure 18, this caused the increase in chiller power draw, as well as condenser cycling. There was no other significant difference in ambient condition during the testing period. Table 8 summarizes the average power values of system components operating with and without HEDS features enabled. In total, the system running in CAV saw an average 21 percent power reduction after HEDS features were enabled.

Table 8: The Comparison of System Average Power Values During the Two-Week Testing Period in the Winter When the System Operated in CAV

Test Scenario	OAT (F)	RH (%)	Fan (kW)	Chiller (kW)	Condenser (kW)	Total (kW)
CAV	55.7	74.9	21.6	16.1	3.9	38.3
CAV with HEDS	58.3	78.4	22.2	6.5	1.6	30.4

Test Scenario	OAT (F)	RH (%)	Fan (kW)	Chiller (kW)	Condenser (kW)	Total (kW)
Difference			−0.7 (−3%)	9.6 (59%)	2.6 (59%)	7.9 (21%)

Source: Project team.

Figure 19 illustrates the hourly natural gas consumption of the boiler providing HHW to the reheat coil during the same two-week testing period. The boiler's gas consumption decreased substantially after the HEDS features were enabled on February 4. The increase in gas consumption on February 6 and 7 can be explained by the change in ambient condition described above. During this time, the system operated in cooling mode and needed to reheat the cold, dehumidified supply air, resulting in an increase in HHW demand. On average, the boiler consumed 61 therms per day without the HEDS and 12 therms per day with the HEDS, representing an 81 percent reduction in natural gas consumption.

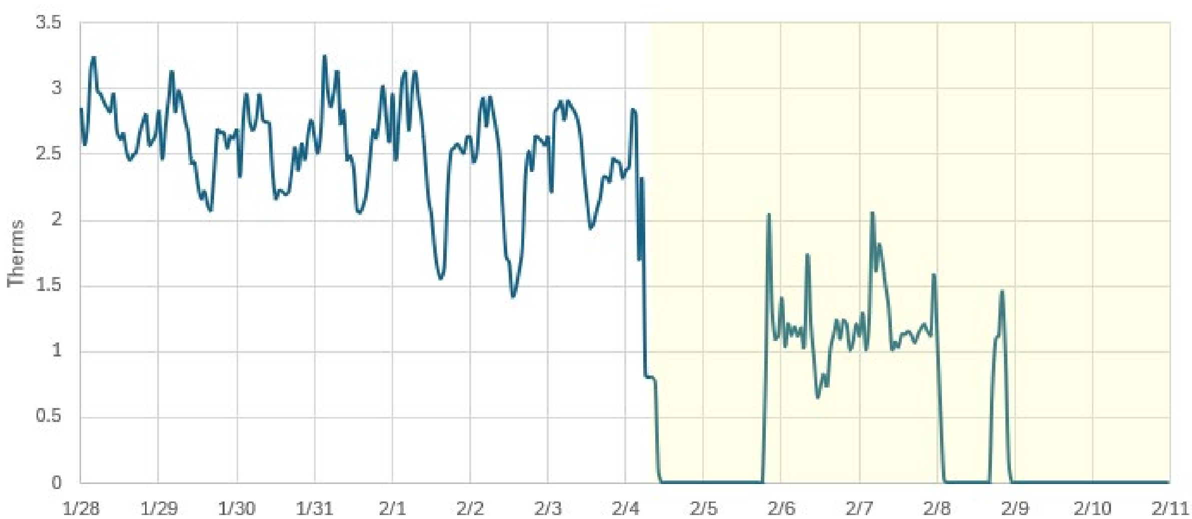

Figure 19: Gas consumption of HHW boiler during the two-week winter testing period in January and February.

Source: Project team.

The project team evaluated the HEDS's ability to maintain the facility's required temperature and humidity levels by comparing the space air temperature and humidity with and without HEDS features enabled (Scenario 1 and 2, respectively). The museum's space air requirements did not change during the winter testing; the system was required to maintain the same space temperature between 65 °F and 75 °F and RH levels between 45 and 55 percent. The space air conditions during the two-week testing period in January and February when the system operated as CAV were plotted in the psychrometric chart in Figure 20. The yellow highlighted area in the figure corresponds to the museum's required space air conditions, bounded by the space temperature and humidity limits. In both Scenario 1 and 2, the system was mostly able to maintain the required conditions. However, the system running with the HEDS features enabled appeared to have controlled the humidity levels better with the space temperature ranging from 68.9°F to 73.6°F and the RH ranging from 43.4 to 53.2 percent. The baseline system controlled the space temperature more tightly, with space temperature ranging from 69.7°F to 70.9°F, but the RH ranged from 41 to 53.8 percent, falling slightly below the required level 12 percent of the time.

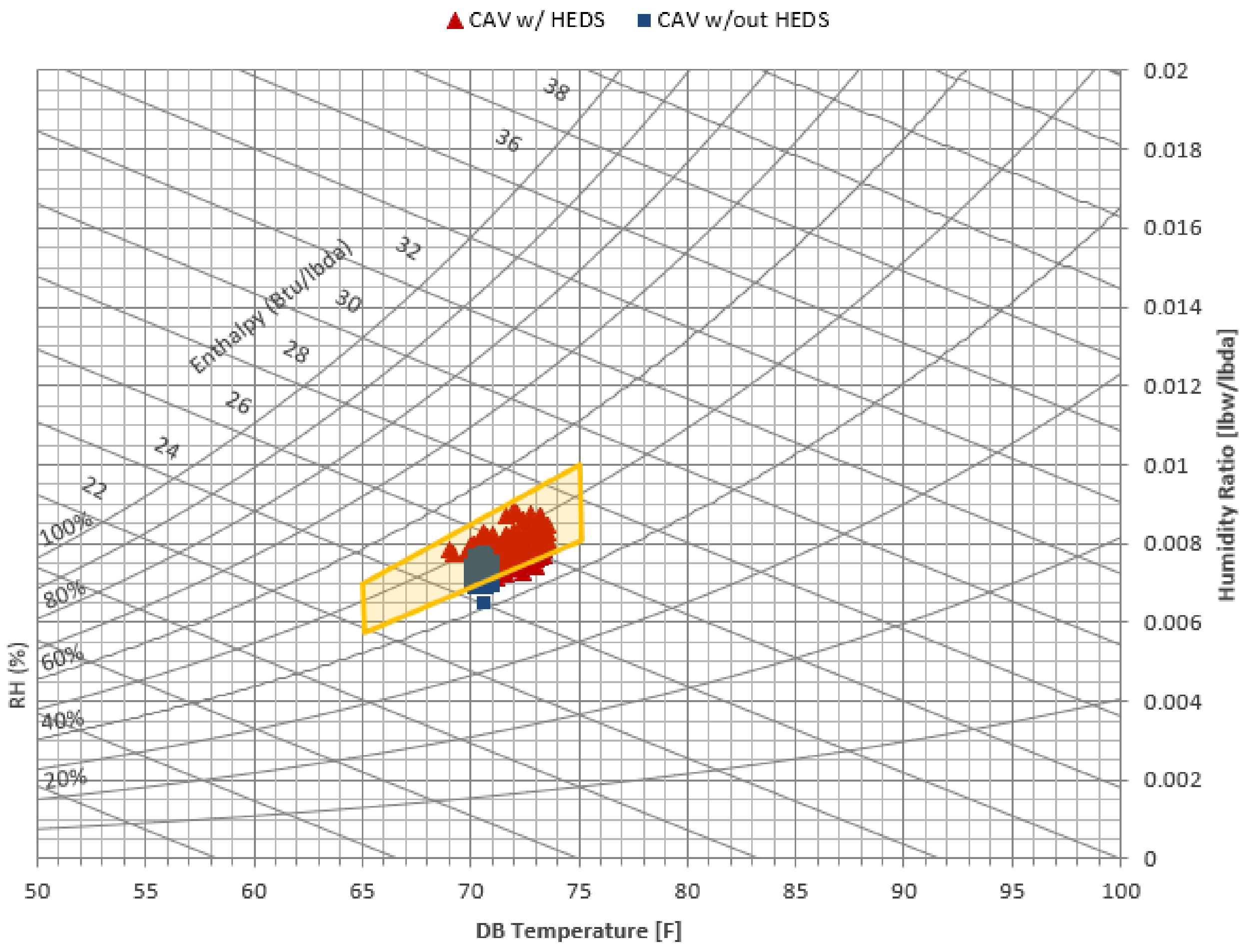

Figure 20: Space temperature and relative humidity conditions during the two-week winter testing period in January and February.

Source: Project team.

VAV Performance

Next, the team evaluated how the HEDS performed when operating as a VAV system. Figure 21 illustrates the power draws of chiller, condenser, and AHU fans in the HEDS air handler from February 26 to March 11. The system operated as a VAV system (Scenario 3) from February 26 to March 3, with the HEDS features disabled and the energy recovery coil bypassed. On the morning of March 4, all the HEDS features were enabled, including the energy recovery coil, and the system operated as VAV with the HEDS (Scenario 4).

Figure 21: The operational profiles of chiller, condenser, and AHU fans during the two-week winter testing period in February and March.

Source: Project team.

As shown in Figure 21, the chiller and condenser barely came on after the HEDS features were enabled on March 4. Before the switch, the chiller power averaged 11.9 kW, which decreased to 0.7 kW with the HEDS, resulting in a 94 percent reduction. The average condenser power also decreased from 2.9 kW to 0.2 kW, a 94 percent reduction. Again, the AHU fan power decreased slightly because the HEDS's features included static pressure reset. Overall, the total system power decreased by 15.5 kW, or 74 percent from the VAV baseline, as shown in Table 9.

Table 9: The Comparison of System Average Power Values During the Two-Week Summer Testing Period

Test Scenario	OAT (° F)	RH (%)	Fan (kW)	Chiller (kW)	Condenser (kW)	Total (kW)
VAV	58.4	67.3	6.3	11.9	2.9	21.0
VAV with HEDS	56.9	69.8	4.6	0.7	0.2	5.5
Difference (%)			**1.7 (27%)**	**11.2 (94%)**	**2.7 (93%)**	**15.5 (74%)**

Source: Project team.

Figure 22 lays out the hourly natural gas consumption of the boiler providing HHW to the reheat coil during the same two-week testing period. The HHW demand decreased after the HEDS features were enabled on March 4, especially during the day. On average, the boiler consumed 30 therms per day without the HEDS and 8 therms per day with the HEDS, representing a 75 percent reduction in natural gas consumption during this two-week testing period.

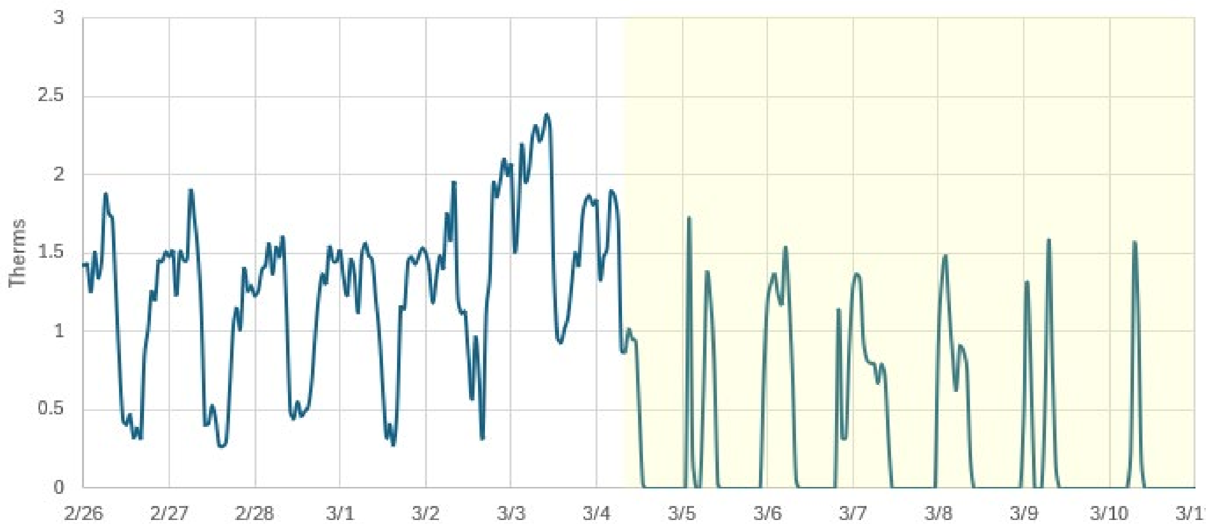

Figure 22: Gas consumption of HHW boiler during the two-week winter testing period in February and March.

Source: Project team.

The team plotted the space air conditions during the two-week testing period in February and March in a psychometric chart (Figure 23). The yellow highlighted area in the figure corresponds to the museum's required space air conditions, bounded by the space temperature and RH limits. The space temperature ranged from 67.5°F to 71.3°F and RH ranged from 42.5 to 54.6 percent when the system operated as the baseline VAV system. When the HEDS features were enabled, space temperature ranged from 68.5°F to 73.8°F and RH ranged from 41.5 to 53.3 percent. In both cases, the space temperature stayed within the required limits, while the RH went below the required 45 percent. However, the HEDS mostly maintained the required space conditions, only slightly deviating from the low RH level (5 percent and 6 percent of the time, respectively).

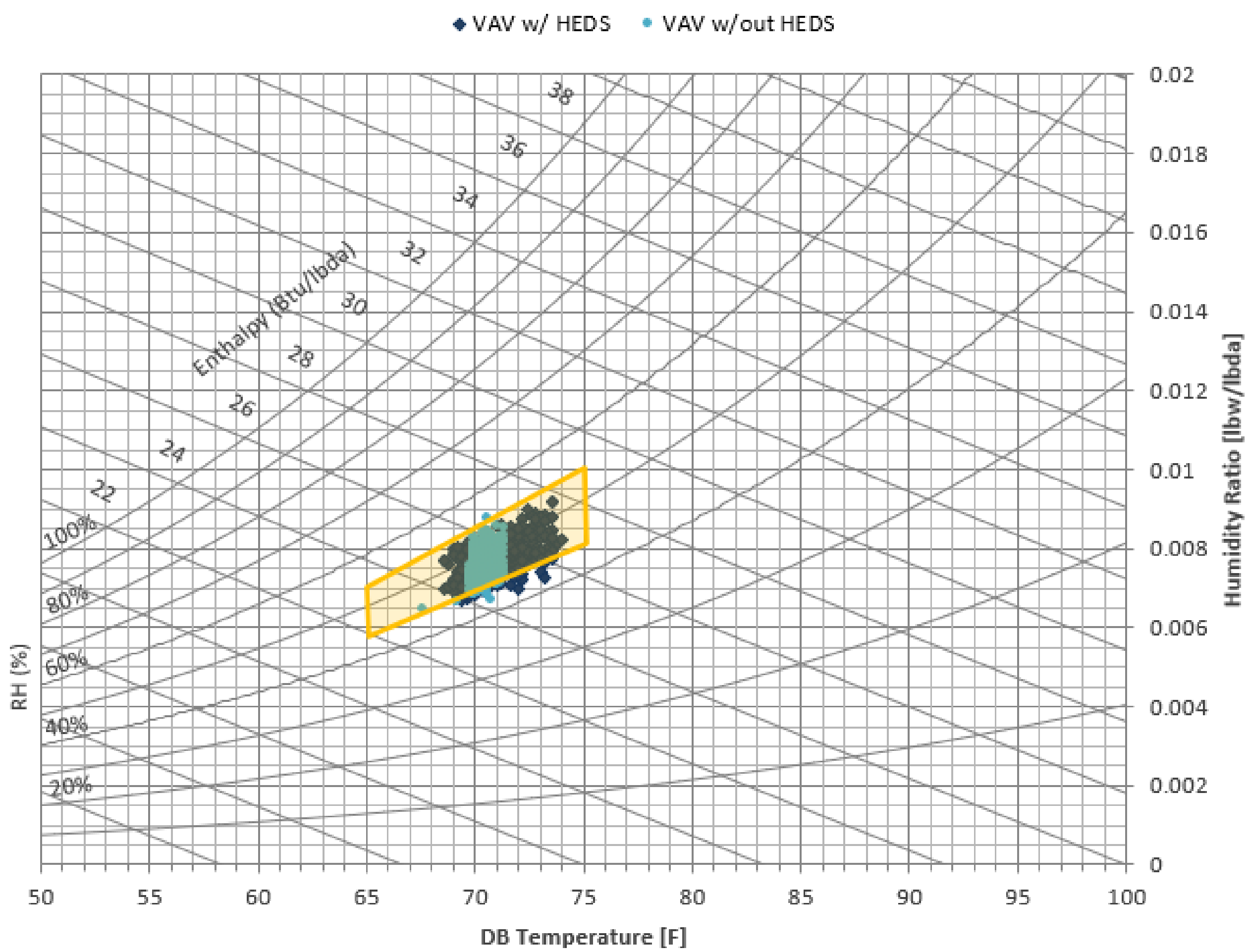

Figure 23: Space temperature and RH conditions during the two-week winter testing period in February and March.

Source: Project team.

Regression Modeling

The team compared the hourly average system power demand in all four test scenarios — calculated as the total of the chiller, condenser, and AHU fans — in Figure 26. As was the case for the summer testing, the highest demand occurred when the system operated in CAV (Scenario 1, shown in blue), while the lowest demand occurred when the system ran as VAV with the HEDS enabled (Scenario 4, shown in green). Interestingly, the demand was in similar range for the system operating in CAV with the HEDS features enabled (Scenario 2, shown in orange) and the system operating as a typical VAV system (Scenario 3, shown in purple). In all four test scenarios, the system demand remained relatively constant because the system operated mostly in heating mode, only requiring the AHU fans to run. There is a slight upward trend above 60°F OAT, indicating cooling was required on some days.

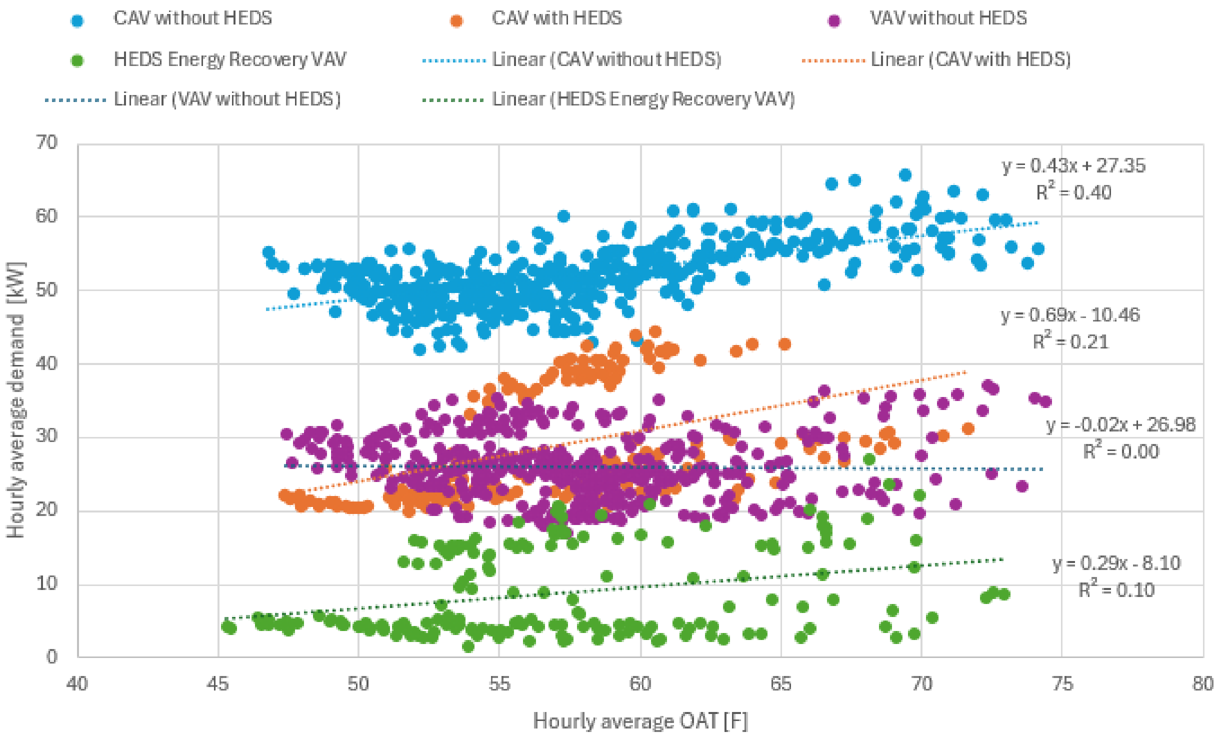

Figure 24: Hourly average total system power demand at four different test scenarios.

Source: Project team.

In Figure 25, the team plotted the hourly average power demand against the hourly average enthalpy of the ambient air to evaluate the system performance for both sensible and latent loads. Only two test scenarios with the HEDS features enabled — CAV with HEDS (Scenario 2) and VAV with HEDS (Scenario 4) — are shown, as the other two scenarios did not yield meaningful regression results. In both Scenario 2 and Scenario 4, the demand remained relatively constant until an enthalpy value of about 20 Btu/h. After that, the demand increased with rising enthalpy, indicating the system operated in either cooling or dehumidification mode. The superior model fit of these two scenarios to enthalpy indicates that the HEDS responds to latent cooling load better than traditional systems.

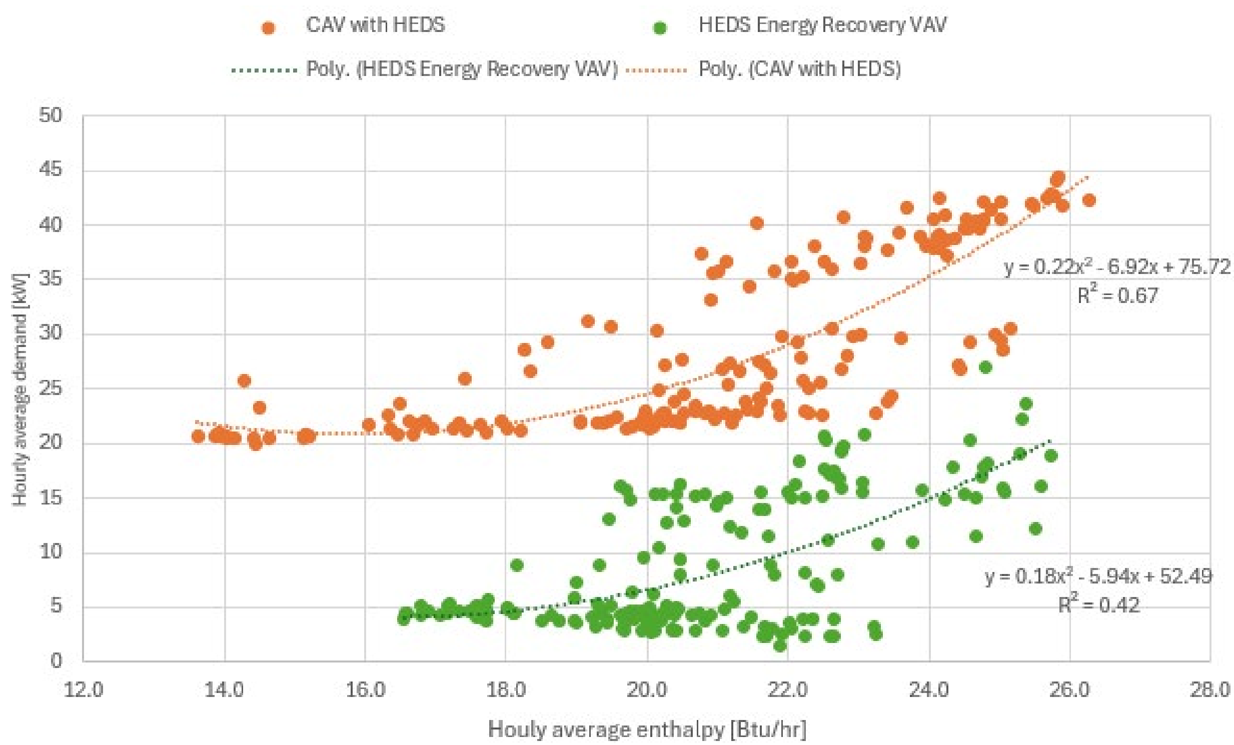

Figure 25: Hourly average total system power demand plotted against hourly average enthalpy of ambient air for test scenarios with HEDS features enabled (Scenario 2 and Scenario 4).

Source: Project team.

Figure 26 compares the daily natural gas consumption of the HHW boiler for all four scenarios. As expected, the system consumed the most gas when it was operating in CAV (Scenario 1, shown in orange). The daily consumption decreased significantly when the HEDS features were enabled while still operating in CAV (Scenario 2, shown in dark blue). In fact, the HEDS operating in CAV consumed the least gas during this testing, averaging 5 therms per day, which is a 91 percent reduction from the CAV baseline. When the system operation was switched to VAV (Scenario 3, shown in green), the daily natural gas consumption was about half of the consumption in Scenario 1. With VAV and the HEDS enabled (Scenario 4, shown in light blue), the boiler consumed about 10 therms per day, reducing the daily usage by more than 86 percent when compared to the CAV baseline and 75 percent when compared to the VAV baseline.

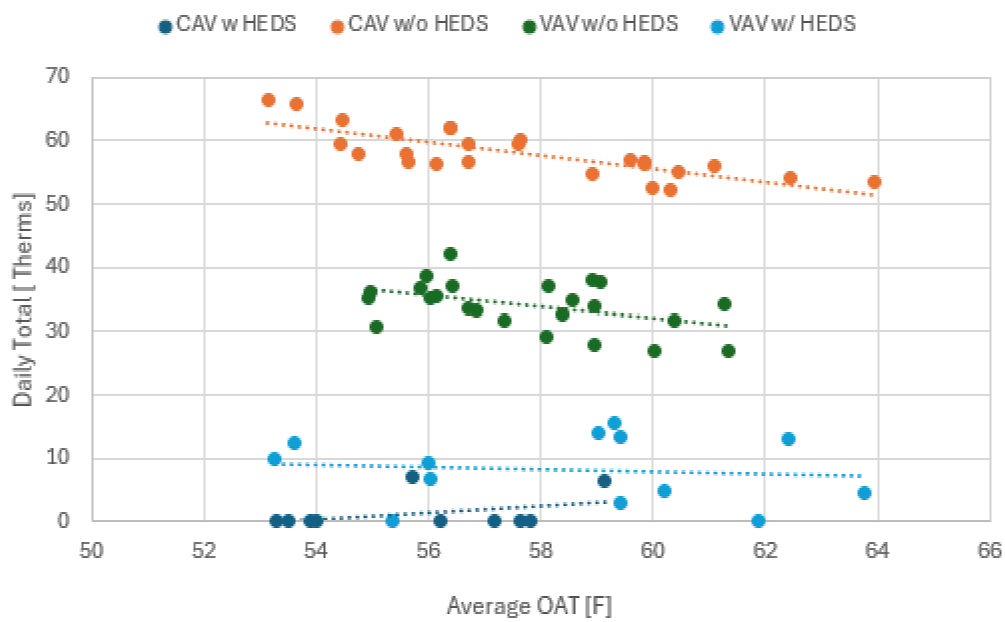

Figure 26: Daily natural gas consumption of the HHW boiler at four different test scenarios during the winter testing.

Source: Project team.

Annualized Savings

The project team used the test results to estimate the HEDS's annual energy savings and GHG emissions reduction. To analyze the savings, the team looked at regression model results from summer and winter testing, as well as the CZ2022 weather data for Lindberg Field in San Diego, California, the closest available weather station to the studied site. The team estimated annual electricity use by applying the regression model coefficients obtained from each test to either hourly OAT or enthalpy. We used linear regression models with OAT as the independent variable in all cases except for the CAV with HEDS and VAV with HEDS scenarios in winter, where regression models with enthalpy as the independent variable had better statistical fit. The team applied the regression models from the summer test results to OAT equal to or greater than 65°F, and the regression models from the winter test results to OAT below 65°F.

The project team estimated annual natural gas use based on the results from both summer and winter testing. Again, the team applied the regression models from the summer test results to OAT equal to or greater than 65°F and applied the regression models from the winter test results to OAT below 65°F.

To estimate annual GHG emissions, we used the latest hourly emissions data for San Diego Gas & Electric (SDG&E), obtained from the California Self-Generation Incentive Program (SGIP) website.[1]

[1] Download Data - SGIP GHG Signal

We calculated the GHG emissions for natural gas using the conversion factor of 0.0053 metric tons CO_2/therm.[2]

Table 10 below summarizes the estimated annual energy uses and savings.

Table 10: Estimated Annual Energy Uses and Savings

Test Scenario	Electricity Use (kWh)	Natural Gas Use (therms)	GHG Emissions (tons of CO_2)	Electricity Savings (kWh)	Natural Gas Savings (therms)	GHG Savings (tons of CO_2)
1. CAV	463,000	22,000	1,360	–	–	–
2. CAV with HEDS	303,000	5,000	370	160,000 (35%)	17,000 (77%)	990 (73%)
3. VAV	222,000	10,000	600	–	–	–
4. VAV with HEDS	98,000	2,000	140	124,000 (56%)	8,000 (80%)	460 (77%)
Site Savings*				**365,000 (79%)**	**20,000 (91%)**	**1,220 (90%)**

*Savings calculated as the difference between Test Scenario 1 and 4

Source: Project team.

[2] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references

Discussions

Field testing results showed that the HEDS could significantly reduce both the electric and natural gas consumption of a traditional dehumidification system. In all tests, both summer and winter, we observed a significant drop in chiller power draw when the HEDS features were enabled. The condenser fan load was also reduced when the system enabled the HEDS features, with the condenser fan cycling on/off more frequently. For example, during the summer testing, the total average system power draw of a system running in VAV decreased from 21.0 kW without the HEDS down to 5.5 kW with the HEDS features turned on, resulting in a 74 percent reduction. The natural gas consumption of the boiler providing HHW to the reheat coil also saw a substantial decrease after the HEDS features were enabled. In the same testing period, the boiler consumed 61 therms per day without the HEDS and just 12 therms per day with the HEDS features enabled, representing an 81 percent reduction in natural gas consumption.

The HEDS reduced overall energy consumption while maintaining the facility's required temperature and humidity levels. In all test scenarios, the system was mostly able to maintain the required conditions. However, the system running with the HEDS features enabled appeared to have controlled the humidity levels better overall. The museum staff reported that several museum visitors commented about the quality of air, stating that it felt "cleaner."

Beyond energy savings, the HEDS offers several non-energy benefits, including:

- Reducing HVAC equipment runtime, lowering maintenance costs, and extending equipment life. Additionally, the HEDS was designed from scratch to be the lowest possible maintenance HVAC system, enhancing long term value for the facility owner.
- Reducing chiller runtime and water consumption for evaporatively-cooled or water-cooled chillers.
- Improving air quality by maintaining steady space temperature and humidity. HEDS also comes standard with ultraviolet germicidal irradiation, which reduces fungal and biological growth that negatively impacts human health.
- Less expensive than other dehumidification systems and being comparable in cost to a standard AHU of the same size. This makes HEDS the most cost-effective, high-performance dehumidification option available in the market today. Moreover, the HEDS allows chilled water and HHW systems to be downsized by 20 percent or more, further reducing capital costs and maintenance needs.

Despite the large energy saving potential and benefits, HEDS technology currently faces numerous barriers that need to be overcome for wide market adoption. Table 11 summarizes these barriers by grouping them into three categories: current market status, misconceptions and misperceptions, and installation. These barriers highlight the need for increased awareness, training, and incentives to promote the adoption of HEDS technology. Addressing these issues can lead to significant energy savings, improved indoor air quality, and financial benefits for building owners.

Table 11: Technology Barriers

Category	Barrier Name	Description
Current market status	Market players	Large, established companies resist changes that could erode their market share.
	Lack of code clarity	Design engineers need specific code language to confidently design and use HEDS technology.
	Cost-effectiveness	High initial costs and long payback periods deter adoption.
	Lack of utility incentives	Carbon and energy reduction incentives can motivate owners, but "do nothing" remains a cost-free option.
	Lack of knowledge	There is a lack of system familiarity among engineers and contractors with HEDS technology and its benefits.
	Lack of training	There is a lack of education on facilities that have a natural fit for HEDS technology such as laboratories, manufacturing, hospitals, and other mission-critical load facilities whose failure or operational disruptions can significantly impact the facility's core functions.
Misconceptions and misperceptions	Physical size	HEDS units are only slightly larger than standard AHUs but require smaller mechanical rooms than other dehumidification technologies. In most cases, a HEDS unit can fit into the existing HVAC mechanical equipment rooms.
	Climate suitability	The technology is effective in both mild and extremely humid climates.
	Retrofit vs. new construction	The technology is suitable for both new construction and retrofit applications. Existing HVAC systems can be modified to incorporate HEDS, reducing first cost.
	Software requirements	HEDS optimization software does not require significant reprogramming. Existing sensors can be used, and new sensors are added to existing DDC systems and fed into the HEDS controller.
	DOAS dependency	HEDS can function without a dedicated outdoor air system (DOAS). Eliminating DOAS can reduce the overall project cost and reduce operational costs for the life of the facility.
	Savings uncertainty	Some modeling approaches fail to accurately calculate the savings from the HEDS energy recovery system.

Category	Barrier Name	Description
Installation	Lack of recognition	HVAC original equipment manufacturers, contractors, and equipment sales teams lack awareness with the HEDS technology and direct engineers and contractors to already-familiar technologies.
	Familiarity	Contractors are unfamiliar with the simplicity and performance of HEDS installation.

Source: Project team.

Recommendations

The field test proved that the HEDS has the potential to significantly reduce the energy consumption of a traditional dehumidification system operating in CAV or VAV. Moreover, the technology could help achieve California's energy goals in the coming years. With these findings in mind, the project team recommends the following items as next steps.

- **Incentive:** Although the technology cost is comparable to the cost of standard AHU of the same size, replacing or upgrading an AHU is capital-intensive. Thus, AHUs are often operated past their effective useful life (EUL) and not replaced frequently. Consequently, utilities should consider a rebate or incentive for the technology. This would accelerate the replacement and offset HEDS' high capital cost, relieving financial burden to the customer. We suggest two potential pathways:
    - **Energy efficiency deemed or custom incentive program:** The National Renewable Energy Laboratory (NREL) is currently developing an EnergyPlus simulation model based on the results obtained from the past U.S. Department of Defense and national lab test results. The results from this study will also inform the model development. Once complete, the EnergyPlus model can be used to run multiple test scenarios in various climate zones to establish an energy efficiency measure for the potential incentive for this technology. Note that the manufacturer estimates the lifecycle on HEDS equipment to be 30 to 40 years. Therefore, an incentive program should also consider the extended EUL of the HEDS.
    - **Normalized Metered Energy Consumption (NMEC) program:** The technology could easily be integrated into an NMEC program due to its significant energy savings. Additionally, the technology should fit well with total system benefit (TSB) metrics because it has both demand and gas savings during high value hours, i.e., time with high energy demand, and considers various factors — including generation capacity, transmission and distribution capacity, GHG benefits, and more (CPUC 2021). Conversely, the incentive payment structure of a typical NMEC program may be a barrier, as the technology has a high initial cost.

- **Electrification:** The technology allows a HHW boiler to be downsized because it significantly reduces hot water demand. Since the size reduction may allow the electrification of a natural gas boiler that is otherwise not possible, the system designer should also consider electrification aspect along with the technology's efficiency impact.
    - The HEDS can allow a highly efficient heat pump system to be installed cost-effectively over a relatively short period of time, with a two-phase approach.
        - **Phase 1:** Install the HEDS to reduce loads and electricity and fossil fuel use, lowering the cost of operation and GHG emissions. Over time, the cost savings associated with the HEDS energy recovery and energy efficiency can cover much of the cost of the replacement heat pump equipment.
        - **Phase 2:** Replace chillers and boilers with heat pumps.
    - The HEDS in heat pump configuration should offer the same cooling and dehumidification energy savings, along with the added benefits of electrification. However, the HEDS in a

heat pump configuration has not yet been studied or tested. Therefore, the project team recommends field testing or modeling of the HEDS with heat pumps to validate its energy savings and performance.

- **Education and training:** Another barrier to adoption of the technology is the lack of knowledge about the technology among HVAC designers and building owners. Publication of case studies like this one and the presentation of study findings at utility-sponsored conferences, webinars, and seminars may help spread the knowledge and correct information about this technology.

Appendix A: Testing Schedule

Table 12: Summer Test Schedule

Test Name	Approximate Start of Test Period	Approximate End of Test Period	Transition Times to Next Test Mode	Duration
HEDS energy recovery VAV (normal operation)	June 11 ~ 10 a.m.	June 25 ~ 7 a.m.	June 25 ~ 7 a.m. to 10:00 a.m.	2 weeks
CAV without HEDS	June 25 ~ 10 a.m.	July 9 ~ 7 a.m.	July 9 ~ 7 a.m. to 10:00 a.m.	2 weeks
CAV with HEDS	July 9 ~ 10 a.m.	July 16 ~ 7 a.m.	July 16 ~ 7 a.m. to 10:00 a.m.	1 weeks
CAV without HEDS	July 16 ~ 10 a.m.	July 30 ~ 7 a.m.	July 30 ~ 7 a.m. to 10:00 a.m.	2 weeks
CAV with HEDS	July 30 ~ 10 a.m.	August 6 ~ 7 a.m.	August 6 ~ 7 a.m. to 10:00 a.m.	1 week
VAV without HEDS	August 6 ~ 10 a.m.	August 13 ~ 7 a.m.	August 13 ~ 7 a.m. to 10:00 a.m.	1 week
HEDS energy recovery VAV (normal operation)	August 13 ~ 10 a.m.	August 20 ~ 7 a.m.	August 20 ~ 7 a.m. to 10:00 a.m.	1 week
VAV without HEDS	August 20 ~ 10 a.m.	August 27 ~ 7 a.m.	August 27 ~ 7 a.m. to 10:00 a.m.	1 week
HEDS energy recovery VAV (normal operation)	August 27 ~ 10 a.m.	September 3 ~ 7 a.m.	n/a	1 week for data, then leave in this mode until winter

Source: Project team.

Table 13: Winter Test Schedule

Test Name	Approximate Start of the Period	Approximate End of the Period	Transition Times to Next Test Mode	Duration
HEDS energy recovery VAV (normal operation)	Dec 3 ~ 10 a.m.	Dec 17 ~ 7 a.m.	Dec 17 ~ 7 a.m. to 10 a.m.	2 weeks
VAV without HEDS	Dec 17 ~ 10 a.m.	Dec 31 ~ 7 a.m.	Dec 31 ~ 7 a.m. to 10 a.m.	2 weeks
CAV without HEDS	Dec 31 ~ 10 a.m.	Jan 14 ~ 7 a.m.	Jan 14 ~ 7 a.m. to 10 a.m.	1 weeks
CAV with HEDS	Jan 14 ~ 10 a.m.	Jan 21 ~ 7 a.m.	Jan 21 ~ 7 a.m. to 10 a.m.	2 weeks
CAV without HEDS	Jan 21 ~ 10 a.m.	Feb 4 ~ 7 a.m.	Feb 4 ~ 7 a.m. to 10 a.m.	1 week
VAV with HEDS	Feb 4 ~ 10 a.m.	Feb 11 ~ 7 a.m.	Feb 11 ~ 7 a.m. to 10 a.m.	1 week
VAV without HEDS	Feb 11 ~ 10 a.m.	Feb 18 ~ 7 a.m.	Feb 18 ~ 7 a.m. to 10 a.m.	1 week
HEDS energy recovery VAV (normal operation)	Feb 18 ~ 10 a.m.	Feb 25 ~ 7 a.m.	Feb 25 ~ 7 a.m. to 10 a.m.	1 week
VAV without HEDS	Feb 25 ~ 10 a.m.	Mar 4 ~ 7 a.m.	Mar 4 ~ 7 a.m. to 10 a.m.	1 week
HEDS energy recovery VAV (normal operation)	Mar 4 ~ 10 a.m.	Mar 11 ~ 7 a.m.	n/a	1 week for data, then leave in this mode.

Source: Project team.

Appendix B: Market Share and Energy Use Additional Notes

The market share and energy use evaluation estimated the average square footage of art museums, libraries, and hospitals in California based on the sample below.

Art Museums

Name	Building Size
Getty Museum	170,000 ft^2 of exhibition and gallery space
San Francisco Museum of Modern Art (SFMOMA)	50,000 ft^2 of exhibition space
Crocker Art Museum	88,444 ft^2 of gallery space
Asian Art Museum	185,000 ft^2
Oakland Museum of California	110,000 ft^2
De Young Museum	84,000 ft^2
Berkeley Art Museum/Pacific Film Archive	25,000 ft^2 of indoor gallery space
Los Angeles County Museum of Art	110,000 ft^2 of galley space

Libraries

Name	Building Size
Los Angeles Public Library Central Library	538,000 ft^2
Gilroy Library	53,000 ft^2
Artesia Library	10,850 ft^2
Cambria Library	5,800 ft^2
Montebello Library	31,097 ft^2
Martin Luther King, Jr. Library	15,100 ft^2

Hospitals

Name	Building Size
Cedars-Sinai Medical Center Los Angeles	1,600,000 ft^2
Sharp Memorial Hospital San Diego	315,000 ft^2
University of California San Francisco Helen Diller Medical Center	878,000 ft^2
Scripps Mercy Hospital San Diego	635,000 ft^2
University of California Davis Medical Center	1,100,000 ft^2
Community Regional Medical Center Fresno	1,200,000 ft^2

References

Itron, Inc. 2006. *California Commerical End-Use Survey.* Consultant Report, California Energy Commission.

California Health Care Foundation. 2013. *California Hospitals: Buildings, Beds, and Business.* January. https://www.chcf.org/wp-content/uploads/2017/12/PDF-CaliforniaHospitals2013.pdf.

California State Library. 2023. *California Public Library Statistics.* Accessed Feb. 2025. https://www.library.ca.gov/services/to-libraries/statistics/.

CAM. 2025. *California Museums.* Edited by California Association of Museums. Accessed 2 21, 2025. https://www.calmuseums.org/Public/Public/ACT/CAM-s-Advocacy-Program/Museums-Week.aspx#:~:text=There%20are%20over%201%2C500%20museums,every%20county%20across%20the%20state.

Community Medical Center. n.d. *Community Medical Center.* Accessed April 2025. https://www.communitymedical.org/locations/community-regional-medical-center.

Definitive Healthcare. 2022. *Top 10 hospitals by facility square footage in California.* August 16. Accessed Feb. 2025. https://www.definitivehc.com/resources/healthcare-insights/top-hospitals-facility-square-footage-california.

Duncan, Scot M., and Dahtzen Chu. 2018. "U.S. Army Corps of Engineers Digital Library." *High efficiency dehumidification system.* August. Accessed 2 27, 2025. https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/8205/.

EIA. 2018. *Commericial Buildings Energy Consumption Survey (CBECS).* Accessed Feb. 2025. https://www.eia.gov/consumption/commercial/data/2018/.

Guarnieri, Gabriella, Bianca Olivieri, Gianenrico Senna, and Andrea Vianello. 2023. "Relative Humidity and Its Impact on the Immune System and Infections." *International Journal of Molecular Sciences* 11.

Harriman III, Lewis G., and James Judge. 2002. "Dehumidification Equipment Advances." *ASHRAE Journal* 6.

IPMVP. n.d. https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp.

Razjouyan, Javad, Hyoki Lee, Brian Gillian, Casey Lindberg, Hung Nguyen, Kelli Canada, Alex Burton, et al. 2020. "Wellbuilt for wellbeing: Controlling relative humidity in the workplace matters for our health." *Indoor Air* 13.