Field Evaluation of the High Efficiency Dehumidification System (HEDS) at the Timken Museum of Art – Summary of Measurement and Verification (M&V) Results from Summer 2023

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National Renewable Energy Laboratory

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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Field Evaluation of the High Efficiency Dehumidification System (HEDS) at the Timken Museum of Art – Summary of M&V Results from Summer 2023

Executive Summary – The **High Efficiency Dehumidification System** (HEDS) technology of the Timken Museum of Art's HVAC system in San Diego, California, was evaluated in August-September 2023. Data was collected for measurement and verification during several weeks in August and September 2023. The evaluation included operating the heating, ventilation and air conditioning (HVAC) system in both **constant air volume** (CAV) and **variable air volume** (VAV) modes, with and without the HEDS energy recovery technology enabled. The electricity consumption of the chiller and the gas-supplied reheat energy were measured to characterize savings achieved by the HEDS operation. Based on these measurements, the HEDS was responsible for chiller electrical load savings of 39% and 42% for the CAV and VAV operating modes, respectively. The corresponding reheat energy reductions due to the HEDS were 64% and 97% in CAV and VAV operating modes. The measurements indicated that chiller power consumption would be reduced by approximately 71% and gas consumption by 99% if a conventional CAV system were replaced with a VAV system configuration with the HEDS. The table below provides a summary of the measured energy savings.

Background – HVAC systems, which can be the largest creator of greenhouse gas emissions in the built environment, have traditionally operated in CAV mode, but most new and retrofitted HVAC systems today are designed to operate in VAV mode to save energy in low load conditions. The HEDS, which can be implemented in either CAV or VAV systems, was created to help the Department of Defense solve HVAC-related problems such as poor indoor air quality (IAQ), poor environmental control, excessive electrical & fossil fuel energy use, and biological growth.

The HEDS was one of three technologies selected to be part of the **U.S. Department of Energy (DOE) High Impact Technology Catalyst** (HIT) evaluation program in 2022. The **U.S. General Services Administration Green Proving Ground** (GSA-GPG) and DOE-HIT programs are designed to help identify, prioritize, and deploy cost effective, innovative energy efficiency solutions that can reduce or eliminate greenhouse gas production at the building level. Demonstrations are conducted to collect real building performance data and quantify the savings potential of selected technologies with an end goal to accelerate implementation and market acceptance of promising energy saving technologies.

At the request of the Department of Energy, HEDS is being field tested by the **National Renewable Energy Laboratory** (NREL). NREL recently completed an analysis of summer 2023 data collected at the Timken as an initial assessment of the system performance of the HEDS energy recovery, energy efficiency, and building decarbonization/electrification technology.

The following table shows the energy savings generated by HEDS during NREL's 2023 summer evaluation, where HEDS was compared to non-HEDS performance in three common operating modes.

Operating Mode Comparison	Chiller electrical load savings	Reheat energy (natural gas) savings
CAV HEDS compared to CAV baseline	38.6%	64.0%
VAV HEDS compared to VAV baseline	41.9%	97.0%
VAV HEDS compared to CAV baseline	71.5%	99.1%

NOTE: Additional data will be generated during ongoing winter and spring evaluation.

Field Evaluation of the Conservant High Efficiency Dehumidification System (HEDS) at the Timken Museum – Summary of Measurement and Verification (M&V) Results from August-September 2023

The National Renewable Energy Laboratory (NREL) recently completed analysis of data collected at the Timken Museum in San Diego, California as an initial assessment of the system performance of the Conservant High Efficiency Dehumidification System (HEDS). Data was collected for the summer measurement and verification (M&V) during several weeks in August and September 2023 while operating the Timken Museum's HVAC system in several operating modes. Additional data collection and analysis are planned for winter and spring seasons to further assess the HEDS performance in different operating conditions.

Figure 1 shows the configuration of the air handling unit (AHU) for the HEDS system. A primary feature of the HEDS is the use of a high efficiency cooling coil (CC in the schematic) and cooling recovery coil (CRC) that operate together to perform dehumidification and reheat of the supply air stream, offering the potential to strongly reduce or eliminate the need for additional reheat energy while providing effective relative humidity (RH) control.

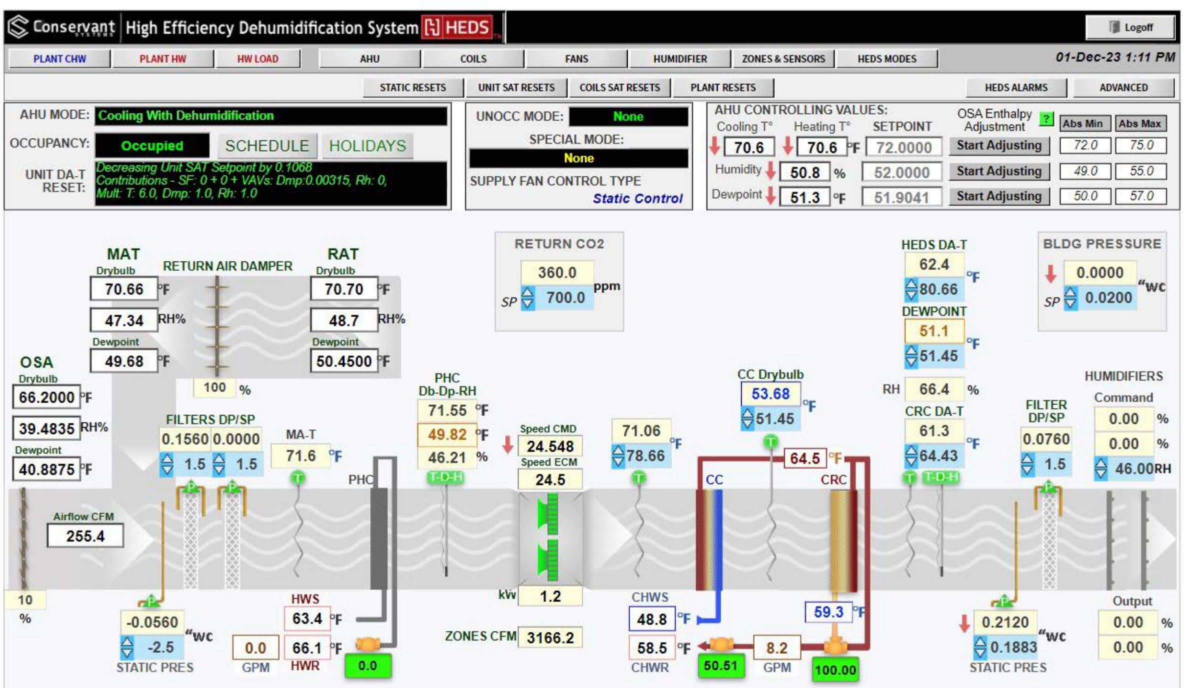

Figure 1. Schematic showing the HEDS system configuration

For the conditions shown in Fig. 1, the air is cooled in the cooling coil from 71.06 °F (Air_inlet) to 53.68 °F (CC Drybulb) while the chilled water is heated from 48.8 °F (CHWS) to 64.5 °F (CRC_inlet) while passing through the CC. This dehumidifies the air but leaves it in an overcooled state for temperature control. The CRC therefore uses the water from the CC outlet to reheat the air. The chilled water is cooled back to 59.3 °F (CRC_outlet) while flowing through the CRC, while the outlet air from the cooling coil is reheated from 53.68 °F to 61.3F (CRC DA-T).

The normal HEDS operation is similar to a variable air volume (VAV) HVAC system with the addition of the recovery coil and optimized control strategy mentioned above. The proprietary control system is designed to control the HVAC operating parameters to maintain temperature and humidity within specified levels while minimizing energy consumption. For the performance assessment, it is desirable to compare the normal operation of the HEDS with other conventional HVAC systems. The Timken Museum's HVAC system was operated during part of the evaluation in a manner consistent with how a typical constant air volume (CAV) system would be run, while for other test periods it was run in a manner consistent with operation of a conventional VAV system. The HEDS recovery coil was alternately enabled and disabled for periods of both the CAV and VAV system operation to allow comparisons between different baseline configurations and the optimized HEDS operating modes. Although some system design features of the HEDS AHU unit are different than what would normally be implemented in conventional CAV or VAV systems, the comparisons between these four operating modes provide a reasonable estimation of differences in energy use that can be expected between the operation of the different HVAC system configurations. The following table summarizes the operating modes evaluated during different periods for the summer field evaluation:

Table 1. HVAC system operating modes evaluated

Operating mode:	Start of evaluation period	End of evaluation period	Fan mode	Recovery Coil Operation	Control settings
VAV w/ HEDS (normal operating mode)	August 12, 12:00 PM	August 20, 12:30 PM	Variable Flow	Enabled	Optimized
CAV baseline, w/o HEDS	August 21, 12:00 PM	August 28, 2:00 AM	Constant flow	Disabled	Baseline
CAV w/ HEDS	August 28, 8:00 AM	September 4, 2:00 AM	Constant flow	Enabled	Optimized
VAV baseline, w/o HEDS	September 4, 11:30 AM	September 11, 2:00 AM	Variable Flow	Disabled	Baseline

Results from the M&V during the Timken Museum field evaluation

Figure 2 shows a comparison of several key performance metrics recorded during the M&V that characterize the HVAC system operation in the different operating modes. It is evident that the different operating modes have quite different characteristics, which consequently results in differences in energy use. A clear difference is apparent in the nature of the zone and supply air temperatures for the VAV HEDS mode compared to the other three modes. The average zone temperature is maintained nearly constant at about 70 °F in modes other than VAV HEDS, while the controls in that mode accept a setback in the range of 67-72 °F. The supply air temperature is a direct result of the dewpoint set point and CRC operation, so the HEDS supply air temperature variations are also a result of the control strategy. Note that the estimated VAV box supply air temperature is calculated based on an energy balance using the HEDS supply air temperature, the VAV reheat coil load and the total air supply flow rate.

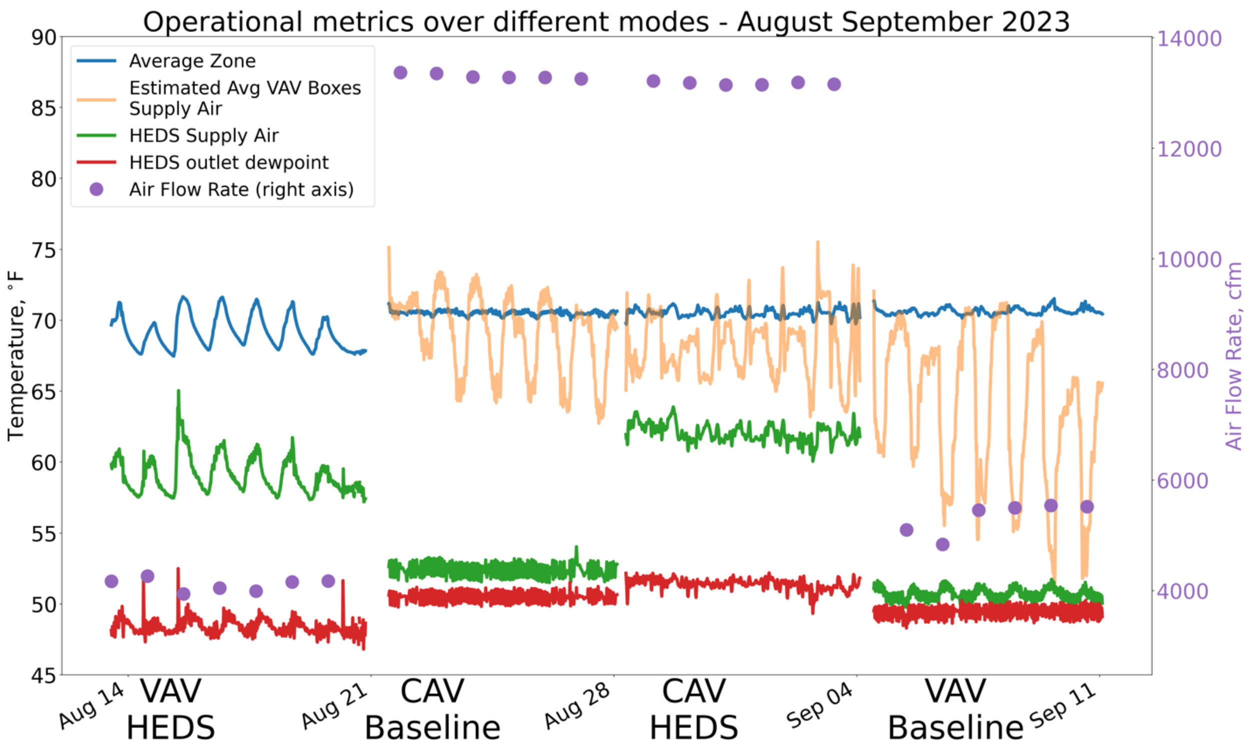

Figure 2. Measured air side temperatures and air flow rate. Air flow rates are over 50% lower in the VAV modes than in the CAV modes. Note that the supply air temperatures to the VAV boxes in the VAV HEDS mode is equivalent to the HEDS supply air temperature since there is virtually no VAV reheat in this operating mode.

According to Conservant literature, the reheat coil recovers 20-40% of the energy extracted from the air during the cooling and dehumidification process. The air reheating that occurs using the reheat coil directly avoids the need to provide reheating through other means, which can reduce or eliminate natural gas use for reheat. Furthermore, the same amount of energy returned to the air stream by the recovery coil is removed from the chilled water stream, yielding a lower chilled water return (CHWR) temperature and thus a reduced load on the chiller, which provides additional energy savings.

An important objective of NREL's research is to quantify the energy savings in the boiler and chiller due to the HEDS operation. The M&V effort included evaluating several load metrics that characterize various energy transfers in the HVAC system, and these metrics were calculated for each operating mode. The five metrics include the following:

1. *SpaceLoad* is the net thermal load required to provide space conditioning for the building, including cooling and dehumidification.
2. *VAV_reheat_energy* is the measured thermal load supplied to the VAV reheat coils, which are used to maintain the zone temperatures. This heat is supplied via a natural gas boiler, so it is an important metric for the HEDS operation to quantify the reduction in natural gas use.
3. *Fan_power* is the measured fan electrical power, which acts as an additional thermal load to the air stream.
4. *Calc_misc_load* includes any loads from outside air blending and the preheat coil.
5. *CRC_water_reheat* is the amount of chilled water load recovered using the HEDS recovery coil. This results in a reduction in both the chiller load and the reheating required by the VAV reheat coils.
6. *AHU_net_water_side_load* is the thermal load provided by the AHU, calculated for the water side of the coils. This is the sum of *SpaceLoad*, *VAV_reheat_energy*, *Fan_power*, and *Calc_misc_load*.

Table 2 lists the average value of each metric for each of the operating modes, and Figure 3 shows a stacked plot comparing the above load metrics across the four operating modes. The zone temperature setpoints for the different operating modes are also shown in Table 2 for comparison, as are the average chiller power for each operating mode. Note that there was a brief period (approximately 30 minutes) when data was not available/lost during the VAV HEDS mode evaluation. The gap/white space shown in the plot during the VAV HEDS operation is a result of the missing data.

Table 2. Average load metrics

	Operating Mode			
Metric (mean values)	**VAV HEDS**	**CAV Baseline**	**CAV HEDS**	**VAV Baseline**
SpaceLoad, kW	26.4	23.4	24.2	34.2
VAV reheat energy, kW	0.6	70.1	25.5	21.8
Fan, kW	1.8	19.2	16.3	4.5
Calc misc load, kW	1.2	1.7	6.5	0.0
CRC water reheat, kW	10.2	0.0	31.8	0.0
AHU net water side load, kW	30.0	114.5	72.5	60.4
Zone temperature, °F	67-72	70	70	70
Average chiller electrical power, kW	11.8	41.4	25.4	20.3

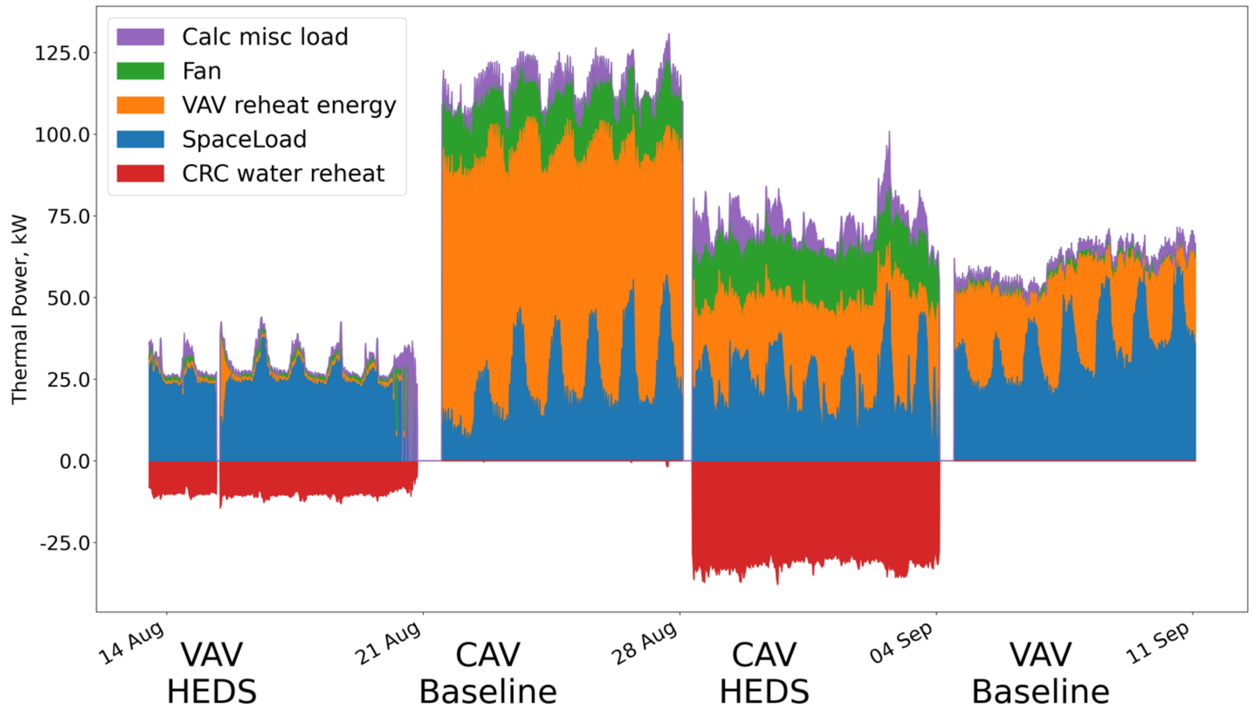

Figure 3. Operational load metrics during the four operating modes. With the HEDS operation, the CRC water reheat provides a direct offset to the VAV reheat energy required, and the total thermal load provided by the chiller is significantly reduced.

Referring to Figure 3, the space demand profiles look very similar for the HEDS and corresponding baseline modes, except for the VAV HEDS mode. The reason for this difference in the building load profile in the VAV HEDS mode is that the average zone temperature is allowed to be set back to 67°F, whereas it is held much more constant at approximately 70°F in the other modes, as was seen in Figure 1. Since the evaluations were performed during normal operations at the museum with variations in building occupancy as well as daily weather variations, there are differences in the loads that are not accounted for in this data. Figure 4 shows a comparison of the outside air, return air, and mixed air temperatures during all measurement periods. The temperature of the mixed air is quite similar to that of the return air, indicating that the outdoor air (ventilation) load is very minor. This provides an indication of the consistency of weather conditions throughout the evaluation, but there are clear differences in trends evident in the data of Fig. 3 between the operating modes that remain quite consistent throughout each evaluation period. The qualitative trends presented are expected to be valid, but the percentage of energy savings listed in this report may not be fully representative of the HEDS performance. We note that this was an initial evaluation, and the NREL team plans to conduct more detailed evaluations via modeling in the future to make direct comparisons in simulations under identical operating conditions.

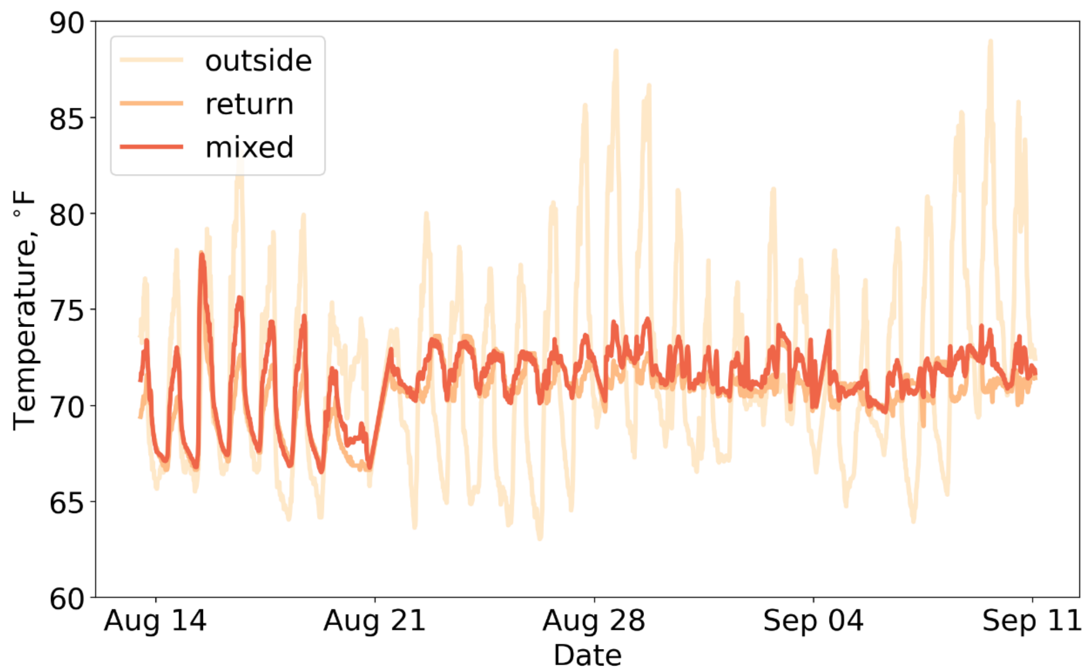

Figure 4. Temperature measurements for the outside, return and mixed air.

The results in Figure 3 clearly show the benefits of the HEDS operation during the field evaluation at the Timken Museum. With the recovery coil enabled in both the VAV HEDS and CAV HEDS modes, the reheat coil loads at the VAV box decreased significantly compared to the corresponding baseline modes. It is seen that the CRC reheat, which is shown as a negative value in Figure 3, provides a very direct offset to the total cooling load requirement (AHU net water side load) from the baseline configurations. For the periods evaluated, the CRC reheat coil recovered, on average, approximately 25% of the cooling coil load in the VAV HEDS mode and 30% in the CAV HEDS mode (total cooling coil load includes the CRC reheat and the net AHU load).

It is noted that the air flow rate in the CAV modes is more than double that employed in the VAV modes (Figure 2). This results in very significant overcooling of air in the CAV modes to achieve the desired dehumidification, which must be compensated for by the VAV reheat energy. In addition, there is a significant load from the fan itself in the CAV modes (16-17%) that is substantially smaller (4-7%) in the VAV operating modes. This results in a significant quantity of wasted energy in the CAV operating modes. The operation of the HEDS reheat coil provides an even greater reduction in the total cooling load and the VAV box reheat energy for the CAV modes than for the VAV modes, but the reheat energy load is virtually eliminated for the VAV HEDS mode.

In the VAV HEDS mode, all loads contributing to the total cooling load are minimized, with a net result that the chiller thermal cooling load is only 14.0% greater than the space cooling load, and the VAV box reheat (corresponding to natural gas use) needed was only 2.4% of the space cooling load. For comparison, in the other modes evaluated, the chiller thermal cooling load exceeded the space cooling load requirement by 77% for the VAV baseline mode, 199% for the CAV HEDS mode and 389% for the CAV baseline mode. The VAV box reheat requirement as a percentage of the space cooling load was 64% for the VAV baseline mode, 105% for the CAV HEDS mode, and 300% for the CAV baseline mode.

Percent Energy Savings Observed between Operating Modes during the Summer Field Evaluation:

Comparing the energy use between operating modes, the HEDS yielded impressive reductions. The following table summarizes the measured energy savings performance for the chiller power use and VAV reheat energy from the chiller and the reheat energy (which is closely related to the natural gas use).

Table 3. Percent energy savings measured for HEDS system operation relative to baseline mode

Percent Savings			
	Chiller thermal load	Chiller electrical load	VAV reheat energy (natural gas use)
CAV HEDS relative to CAV baseline	36.7%	38.6%	63.7%
VAV HEDS relative to VAV baseline	50.4%	41.9%	97.0%
VAV HEDS relative to CAV baseline	73.8%	71.5%	99.1%

Since a primary objective of the analysis is to demonstrate the benefit of the HEDS relative to operation with a conventional HVAC system, it is important to provide comparisons that correspond to the same operating conditions. For future analysis, we plan to evaluate through modeling how significant the impact of these different operating conditions is on the energy consumption. We note once again that the variation in weather, occupancy, and other factors during the evaluation influence the energy consumption from the HVAC system. As a result, the percentage of energy savings listed in this report may not be fully representative of the HEDS performance, but the qualitative trends are expected to remain valid.