Hot Mess or Cool Tech?
Secrets to Success for Advanced Building Controls Integration

Nathan Hinkle, Randy Mead, and Brandon Kirlin; Cadmus

ABSTRACT

Integrating controls between lighting and HVAC systems has significant untapped potential for improving commercial building energy efficiency and occupant comfort, but effective integration is much more challenging than marketing might imply. Cadmus evaluated controls integration projects in five commercial buildings that included university, health care, municipal government, and commercial office uses. Each project installed a new networked lighting control system and integrated that system with the existing HVAC building management systems and new plug-load receptacle controls. Savings were driven by modifying control sequences and setpoints in response to luminaire-level lighting control sensors.

We used a combination of traditional temporary data loggers and novel smart data sources integral to the control systems to collect lighting, plug load, occupancy, HVAC, and building performance data for over one year through baseline, installation, commissioning, and post-installation periods. We used these data sources to develop weather-normalized models of controls savings for each project. This paper discusses the challenges and opportunities presented by Big Data in this project, including the innovative techniques we used to analyze millions of datapoints collected over this multiyear study and the issues to be aware of when using control system data for evaluation.

This paper also details the specific control strategies implemented by each project and the resulting energy savings, which varied dramatically. We share lessons learned on both the technical building and equipment characteristics—and human factors—that can make or break a controls integration project.

Introduction

HVAC and lighting account for over 50% of total energy usage in commercial buildings (EIA 2012), and controls represent a key opportunity for saving energy from these end uses. HVAC and lighting control systems are offered by many manufacturers and feature a variety of configuration options that can be adapted to different building types or spaces. Lighting controls may include luminaire-level lighting controls (LLLC), which use motion and/or ambient light sensors on individual fixtures to allow each fixture to respond dynamically to the occupancy and natural daylight levels in its immediate surroundings. Some LLLC systems are configured to run independently on each fixture. Others are installed in conjunction with a networked lighting control (NLC) system, which can enable deeper energy savings with features like flexible zone grouping, adjustable user controls, HVAC integration, and data reporting. Approximately 14% of all U.S. commercial buildings, and over 70% of those over 100,000 square feet (EIA 2012), already have an HVAC building management system (BMS) installed, which can be commissioned with a wide range of energy-saving control strategies that seek to reduce heating, cooling, and fan energy consumption throughout the building.

NLCs are a relatively new technology that have seen slow adoption, particularly in existing building retrofits (Energy Solutions 2020). Prior research by Cadmus and the Pacific Northwest National Laboratory has shown that NLC systems with LLLC sensors can achieve a 20% to 50% reduction in lighting energy consumption with task tuning, occupancy, and daylight harvesting controls (PNNL 2018). NLC systems can also improve occupancy comfort, give facilities managers insight into maintenance issues and lighting system performance, and simplify the process of reconfiguring spaces for new uses. Recent NLC systems offer the capability to communicate with BMS and other equipment using standard communications protocols like BACnet or Modbus, enabling the BMS to view zone occupancy status then adjust HVAC system setpoints and shut off plug loads to reduce energy consumption.

Cadmus and the Pacific Northwest National Laboratory conducted an *in situ* measurement and verification (M&V) study of new HVAC, plug load, and lighting controls installations at five existing commercial buildings in the Minneapolis, Minnesota, area. Cadmus configured BMS trend data exports and installed temporary occupancy loggers, power meters, and plug-load loggers to thoroughly evaluate the operational behavior and energy consumption of the baseline systems and newly installed integrated controls. With this in-depth M&V effort, Cadmus assessed the potential energy savings from a variety of controls strategies and highlighted the strengths and limitations of the technology itself and of the commissioning process. Project design, installation, and commissioning were performed by contractors unaffiliated with the M&V study.

Summary of Control Strategies

Implementation details and energy-savings potential from HVAC controls are very dependent on the type of system installed, including the distribution type (local zone systems, central multizone systems, or some combination), primary heating source (local boiler plant, central plant, natural gas burners, etc.), primary cooling source (local chiller, central chilled water system, packaged cooling, etc.), the presence and type of zone reheat, and the ventilation control (constant volume, variable volume with variable frequency drive [VFD] motor control, variable volume with damper control, etc.). Each system is unique, and potential savings depend on the combination of components present, available control setpoints and instrumentation, and existing control strategies.

HVAC controls can save energy by reducing heating or cooling load and by reducing equipment run time. Common strategies include scheduled temperature setback/setup, economizer control, static pressure reset, and supply air temperature reset. The most common NLC integration controls the unoccupied zone temperature setback/setup mode dynamically using the LLLC occupancy sensors with a configurable time-out period rather than a fixed schedule. This reduces the heating or cooling load on the HVAC system and reduces fan energy consumption if the system is equipped with a VFD because less conditioned air is required. Systems with demand control ventilation can also reduce outside air requirements when the space is unoccupied. A similar control scheme can be achieved by integrating stand-alone occupancy sensors wired directly into the BMS; however, using LLLC sensors with an NLC system does not require installing separate sensors and instead allows for much greater flexibility in configuring occupancy zones that closely match the layout of HVAC zones.

Plug-load control requires switched receptacles, which are not common in commercial buildings. Retrofits typically involve installing receptacles and have half the receptacles in each location switched and half always on. Equipment that must remain powered on (like computers, refrigerators, and lab equipment) is connected to the always-on receptacle, and loads that can be safely shut off (like displays, sound systems, and desk accessories) are connected to the controlled receptacle. The control system monitors the LLLC occupancy sensors and shuts off controlled receptacles when the space has been unoccupied for the configured amount of time. NLCs allow for customizing which motion sensors and receptacles belong to each zone and can set a different time-out period for each zone depending on its needs.

Data Collection

Cadmus installed temporary data loggers and exported trend data from building control systems at each site to inform the M&V analysis. We installed all temporary data loggers before the retrofit process began at each site to capture a representative baseline. Meter installations varied depending on the timing of each project, but they typically covered several months in the shoulder season to include both heating and cooling performance. We planned to remove meters for each project several months after controls commissioning was completed, but this timeline was complicated due to the COVID-19 pandemic.

We installed power meters at the breaker panel on individual lighting circuits in all buildings and on HVAC system supply fans where BMS trend data did not capture fan speed. Our power meters directly measure current and voltage to accurately calculate true power. Cadmus configured these power meters to log data once per minute for the duration of the study and to send that data back over cellular modem to a cloud storage system. We developed a system of Python scripts to automatically retrieve data from the cloud and check for consistency on a weekly basis, allowing us to identify sensor failures, unexpected changes in performance, and other events in near-real-time.

We also installed plug-through energy loggers on a sample of controllable plug loads at each site. We documented the equipment on each logger at the time of meter installation and removal and noted whether any loads had been added or removed. Cadmus only used plug-load data from loggers where the installed loads did not change during the study. This reduced the amount of viable plug-load data but was necessary to ensure a consistent comparison between the baseline and post-installation periods after users had reconfigured some loads and, in many cases, had even moved controllable loads to always-on receptacles. We configured these meters to log instantaneous power and cumulative energy consumption once per minute. Data were stored directly on the device and needed to be downloaded manually when the meter was retrieved. The logger would stop recording when memory was full.

Cadmus installed stand-alone motion-activated occupancy loggers in a sample of spaces in each building. We chose occupancy sensor locations to maximize the coverage of large spaces while also representing all space types. These loggers also needed to be downloaded manually. Storage capacity varied because the occupancy sensors log each state change as it happens; as such, the memory on loggers in high-use areas fills faster. We intended to export occupancy sensor trend data from the newly installed NLC system after it was commissioned and use our temporary occupancy sensor data to validate the NLC trend data and provide baseline occupancy data from before the new LLLC motion sensors were installed. However, the high-resolution data export functionality had not yet been fully implemented by the NLC vendor when we conducted the analysis, so instead we relied on our temporary occupancy sensors for all occupancy-related analysis.

BMS trend data collection is discussed in more detail on a project-by-project basis in the Buildings and Systems Evaluated section below. Cadmus coordinated with the facilities manager or controls vendor for each site to configure trend logs for all relevant points available in each BMS. The typical datapoints we trended include space temperature setpoints for each zone, supply and return air temperatures, supply fan speed and/or airflow measurement, terminal unit airflow measurement or zone damper position, heating or cooling mode command, terminal reheat valve position or enabled flag, outdoor air damper position or airflow measurement, and duct static pressure. Available trend points and data logging frequency varied by system, but most logs were configured for five- to 10-minute data resolution. Some BMS allowed for remote online data access, while others required manually exporting each log from a terminal on the site.

Savings Analysis Methodology

Cadmus developed and performed several techniques to estimate energy savings on lighting, plug loads, and HVAC systems from installing the various controls. For each site, we defined the baseline period as the first Monday of the metering period to the last Sunday before the changes were observed for the respective system. We defined the post-installation period for each site as the first Monday after the final system commissioning to the last Sunday before the meters were removed. Depending on the site and occupant schedules, we also developed schedule profiles, such as weekday, weekend, and holiday, to ensure equal representation of all hours and days of the week in each period. We defined the difference in total energy consumption between the baseline and the post-installation period as the energy savings achieved for the study period, which we then weather-normalized (if applicable) and extrapolated to one year to estimate the annual energy savings achieved.

Plug Loads

Cadmus developed an analysis methodology to estimate plug-load savings using the logged baseline and post-installation period plug-load performance. Many receptacles at each site did not exhibit a change in behavior in the post-installation period because either the final commissioning could not be completed due to COVID-19 complications or the occupant intervened. We reviewed the performance of each logged plug-load receptacle to determine which were successfully affected by the integration, calculated the energy consumption in each period, then extrapolated those results to annual energy consumption. We then calculated the annual energy savings as the difference between the annualized energy consumption from the baseline and post-installation periods. In cases where we did not see a behavior change in the post-installation period, we also incorporated occupancy loggers in the analysis that had been installed in the same space, only including savings during periods when the plug-load logger reported greater than a 1-watt load and the room had been unoccupied for at least as many minutes as the configured time out.

For systems that did not exhibit any behavioral changes in the post-installation period, Cadmus used the post-installation occupancy sensor profiles per plug-load zone to determine the potential savings as if the system integration had been functioning optimally. For each plug-load logger installed in a room where an occupancy sensor was also installed, we calculated the energy use of the plug load when the occupancy sensor detected vacancy in the room for a period of at least five, 10, 15, 20, 25, and 30 minutes to simulate various time-out options. The energy use of the plug loads during these vacant periods are the savings potential for the plug-load and occupancy-system integration.

HVAC

Cadmus estimated the HVAC system savings attributable to integrating the NLC with the HVAC BMS. First we cleaned and performed an initial review of the BMS trend data available at each site. We could not use the HVAC data from two sites due to either negligible changes in system operations or incomplete short-term trend data that would yield inconclusive results.

For sites with sufficient trend data, Cadmus selected the baseline period based on the data availability and quality and selected the post-installation period from when all equipment was installed and final commissioning was completed for all systems at the site. Due to COVID-19 stay-at-home orders, some buildings had very little normal use during the post-installation period and posed additional challenges to performing standard baseline versus post-installation analysis.

To isolate the savings achieved due to the NLC integration, Cadmus developed a unique analysis methodology for each site's HVAC equipment to account for the nuances and existing control strategies, such as supply air static pressure reset, supply air temperature reset, air-side economizers, scheduling, and occupancy sensor–influenced variable air volume (VAV) control.

If a site's study area exhibited little heating or cooling during the post-installation period due to COVID-19 impacts, we used the occupancy logger data prior to any changes in operation and developed schedule profiles for each zone to establish the average minutes of vacancy per day during normally occupied hours. The profiles included subtracting five- or 30-minute delays per vacancy instance to account for the timeout before the VAV box would go into standby mode. We estimated the energy savings attributable to the NLC integration by developing a standby minutes factor, which was the ratio of the average unoccupied to occupied time for each hour of the week per schedule profile as measured by the occupancy sensors, minus the systems' programmed timeout period. We multiplied the baseline energy consumption by the standby minutes factor to estimate the energy savings achieved by the NLC integration assuming the VAV box went into standby mode during the unoccupied periods.

For buildings that continued to operate as usual during the COVID-19 pandemic, Cadmus was able to estimate energy consumption in the post-installation period and did not need to use the standby minutes factor. We calculated the energy savings achieved at the component level of each system, including air-handling unit (AHU) supply and return fans, VAV box fans, AHU heating, AHU sensible cooling, and VAV box reheat.

The following sections describe the energy consumption formulas for each component of the sites' HVAC equipment, which each used some combination of the variables defined below:

kWh = Estimated electrical energy consumption [kWh]
Btu = Estimated natural gas energy consumption [Btu]
$Flow$ = Instantaneous VAV box airflow [CFM]
$Power_{fan}$ = VAV box rated fan power [kW]
$StbyRatio$ = Standby minutes factor, as defined above [%]
k = CFM unit conversion multiplier (1.08 [Btu/(°F hr CFM)])
incorporating the product of the specific heat of air (C_P 0.24 [Btu/lb °F]), the
density of air (ρ 0.075 [lb/ft^3]), and minutes per hour (60 [minutes/hour])
$VlvPct$ = Hot water valve open percentage [%]
ΔT = Mixed air temperature – Discharge air temperature [°F] if cooling
Discharge air temperature – Mixed air temperature [°F] if heating
P = AHU fan power per cubic feet per minute of flow [kW/CFM]
ρ = Density of water [lb/gallon]

C_p = Heat capacity of water [Btu/(lb °F)]
i = Minutes per data interval; two to 10 minutes depending on the data source
1/60 = Hours to minutes conversion [hours/minutes]
ε_c = System cooling efficiency [Btuh/W]
ε_h = System heating efficiency [%]

AHU fan. Cadmus calculated the portion of AHU fan energy attributable to the airflow delivered to each affected zone. The general equation we used to determine AHU fan energy consumption is defined below and was only applied when the trend data indicated that the AHU fan was operating and the relevant zone was enabled:

$$kWh = Flow \cdot P \cdot i \cdot 1/60$$

VAV box fan. Cadmus calculated VAV box fan energy use if the VAV boxes in the system were fan-powered. The general equation used to determine VAV box fan energy consumption is defined below and was only applied at times when the VAV box fan speed exceeded a specified minimum:

$$kWh = Power_{fan} \cdot i \cdot 1/60$$

Heating and cooling. Cadmus calculated AHU heating and sensible cooling energy consumption when the following criteria were met:

- The system’s heating or cooling stage was on.
- The outdoor air temperature was greater or less than a setpoint specific to the site’s operational parameters.
- The AHU heating or cooling valve was open more than a specified percentage.
- The AHU discharge air temperature was greater or less than a temperature specific to the system’s operational parameters.
- The AHU fan speed was greater than a percentage specific to the system’s operational parameters.

The general equations used to determine AHU energy consumption are:

$$kWh_{sensible\ cooling} = \frac{Flow \cdot k \cdot \Delta T \cdot i}{60 \cdot \epsilon_c} \quad \text{or} \quad Btu_{heating} = \frac{Flow \cdot k \cdot \Delta T \cdot i}{60 \cdot \epsilon_h}$$

Cooling calculation limitations. Study limitations required us to make simplifying assumptions when estimating HVAC cooling energy consumption. Relative humidity was not available in the BMS trend data; thus, we could only calculate sensible heat and not latent heat. Including latent heat could increase the cooling consumption estimates by approximately 20 to 50%; however, latent heat savings would be approximately proportional to sensible heat savings because these control measures effectively increase indoor space temperature and reduce equipment runtime without altering outdoor air intake or humidity levels.

For systems cooled by a central chilled water supply we used a flat kilowatt per ton typical cooling efficiency for the chiller plant to estimate energy consumption from measured cooling load. For systems with packaged cooling, we used the manufacturer’s reported energy efficiency ratio. Actual cooling energy consumption may be lower than estimated because the efficiency under typical conditions generally exceeds design conditions. The cooling energy consumption estimated in this analysis provides useful context for the range of possible outcomes for this technology, but should not be considered statistically representative of expected savings outside of this limited pilot study.

VAV box reheat. For systems with hydronic reheat in the VAV boxes, we calculated VAV box reheat energy when specific conditions were met**:**

- The AHU fan power or fan speed was greater than a value specific to the system's operational parameters.
- The system was calling for steam or hot water and the hot water pump was on.
- The VAV was in heating mode and the reheat valve was open.

The general equation we used to determine reheat energy consumption is shown below:

$$Btu = \frac{Flow \cdot VlvPct \cdot \rho \cdot C_p \cdot \Delta T \cdot i}{60 \cdot \epsilon_h}$$

Energy savings calculation.

Cadmus estimated savings from actual pre- and post-retrofit performance in cases where the site's HVAC equipment operated as usual during the COVID-19 pandemic and post-installation data were available. In cases where the HVAC equipment observed little to no use during the post-installation period due to COVID-19 restraints, we estimated savings using the sum of the baseline energy consumption multiplied by the standby minutes ratio, which represents the fraction of time that the equipment ran in the baseline but would not be running under the new control scheme because the space was unoccupied. The general equations we used to determine energy savings are shown below.

$$kWh_{estimated\ savings} = \sum kWh_{baseline} - \sum kWh_{post}$$

or

$$kWh_{estimated\ savings} = \sum (kWh_{baseline} \cdot StbyRatio)$$

Analysis Tools

All the data Cadmus collected, including the HVAC data trends from each site's BMS, logged plug loads, and metered lighting power, contained over one year of high-frequency data for many parameters. This massive amount of data from various sources and formats needed to be standardized to a universal format for analysis. We knew the large, complex datasets and the methodology we proposed to calculate energy consumption and savings were too large to review and analyze in an organized fashion using Microsoft Excel workbooks. Therefore, Cadmus decided to use the Python programming language in Jupyter notebooks with the Pandas library for analysis. Python allowed us to develop standardized, reusable modules and scripts for each site's analysis. We used the Plotly library to generate interactive visualizations for review and exploration, allowing us to quickly select baseline and post-installation periods, develop the prerequisite parameters defined above, and determine which systems and receptacles were not affected by NLC integration in the post-installation period.

Buildings and Systems Evaluated

Cadmus evaluated five existing commercial buildings that included university, health care, municipal government, and commercial uses in *International Energy Conservation Code* Climate Zone 6A (ICC 2021). Each was retrofitted with new LED luminaires with LLLC sensors, a new NLC system, new controllable plug-load receptacles, and controls updates to the existing digital BMS. Lighting was replaced like-for-like to maintain illuminance levels, and no changes were made to the existing HVAC equipment. Each building studied is summarized in Table 1, with additional details described below.

Table 1. Summary of buildings and equipment studied

Site	A	B	C	D	E
Description	University admissions building	Municipal traffic operations center	Mixed use office tower	Health care facility	Transportation maintenance station
Year built	1901	1986	1984	2006	1999
Floors	4	1	18	1	1
Floor area (ft^2)	24,000	60,500	287,000	12,364	74,000
Study area (ft^2)	12,000	16,000	7,300	12,364	11,000
Study area space types	Offices, computer labs, classrooms, meeting rooms, restrooms, student lounges	Lunchroom, private and open offices, work areas, reception area, locker room	Health clinic with lab, pharmacy, exam room, break room, fitness center (with workout area, classroom, lockers)	Reception, exam room, physical therapy room, X-ray room, conference room, offices, break room	Private and open offices, locker rooms, lunchroom, classroom, shared workspaces
Primary HVAC system	Two multizone AHUs with supply fan VFDs	Single- and multizone AHUs with constant volume fans	Two multizone AHUs with supply and return VFDs	Single- and multizone rooftop units (RTUs) with constant volume fans	Single AHU with VFD supply fan
Heating fuel	Campus steam	Natural gas boiler	Natural gas boiler	Natural gas	Natural gas boiler
Cooling source	Campus chiller	Packaged direct expansion	Central chiller	Packaged direct expansion	Packaged direct expansion
HVAC zones	VAV boxes with hydronic reheat	Dual hot/cold decks with zone dampers	VAV boxes with hydronic reheat	Variable volume and temperature (VVT) control	VAV boxes with hydronic reheat
Economizer	Yes	Yes	Yes	No	No
Existing temperature setback schedule	Yes	Yes	Yes	Yes	No
Existing static pressure reset	Yes	No	Yes	No	Yes
Existing supply air temperature reset	Yes	No	Yes	No	Yes

Sites A, C, and E each had a similar HVAC system with one or more variable volume central AHUs and had VAV boxes with terminal reheat in each zone. An example of a typical configuration for this type of system is illustrated in Figure 1.

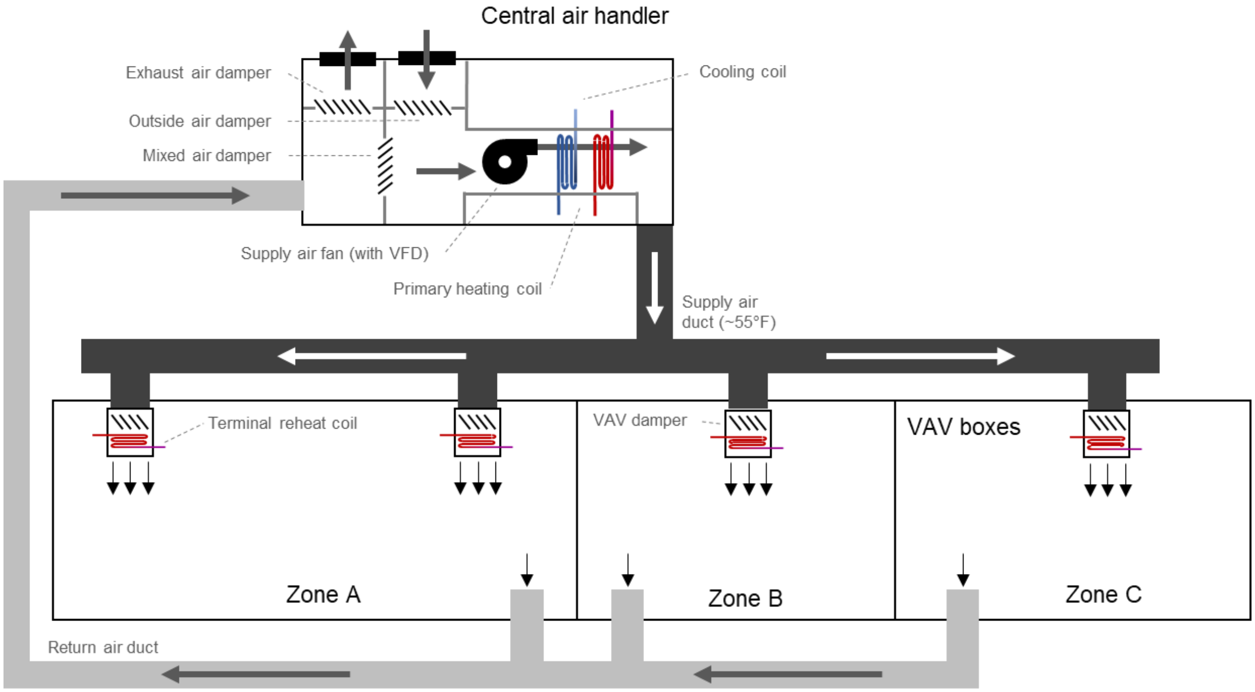

Figure 1. Example of a typical variable volume central AHU with multizone VAV control and terminal reheat.

Site A: University Admissions Building

Unique factors. Approximately 10% of the zones representing 50% of the space had existing occupancy sensors integrated to the BMS to allow for reduced flow and setpoint changes when no occupants were detected during normally occupied hours. During the retrofit, the existing occupancy sensors were disabled and the new lighting control system was integrated to the BMS, enabling it to monitor fixture-level occupancy status across all zones. AHU sequences were also changed to include trim-and-respond static pressure reset and demand-controlled ventilation. Occupancy sensor status could be used in a demand control ventilation sequence, but this had not been implemented at the time the study was concluded.

Results. Cadmus evaluated HVAC and plug-load energy savings using the estimation methodology described above. With a 30-minute occupancy time-out, the HVAC controls integration reduced annual VAV reheat energy consumption by 89 MMBtu (31%), reduced AHU cooling energy consumption by 57 MWh (42%), and reduced AHU fan energy consumption by 4.7 MWh (22%). We estimated plug-load savings for four spaces and found that annual energy savings ranged from approximately 0% to 26%; however, the approximate total annual energy consumption of controllable plug loads throughout the building was only 740 kWh. Most plug loads were not controllable or already had built-in sleep modes that minimized standby power.

Site B: Municipal Traffic Operations Center

Unique factors. The HVAC system comprises two constant volume multizone AHUs and one constant volume single-zone AHU. The single-zone AHU is controlled by a zone thermostat, and a downstream hot water reheat coil serves a locker room that is controlled by a separate heating-only thermostat in that zone. The two multizone systems, illustrated in Figure 2, are constant volume AHUs that condition the air with separate hot and cold "decks" that are each set to maintain a specific temperature at the sensor in that deck. Downstream from the hot and cold decks are a pair of mechanically linked zone dampers for each of four thermostatically controlled zones. These dampers blend the hot and cold deck streams to maintain the temperature at the zone thermostat while maintaining constant airflow volume to each zone. Baseboard heaters, fed by the same boiler system that serves the AHUs, provide supplemental heat to some areas.

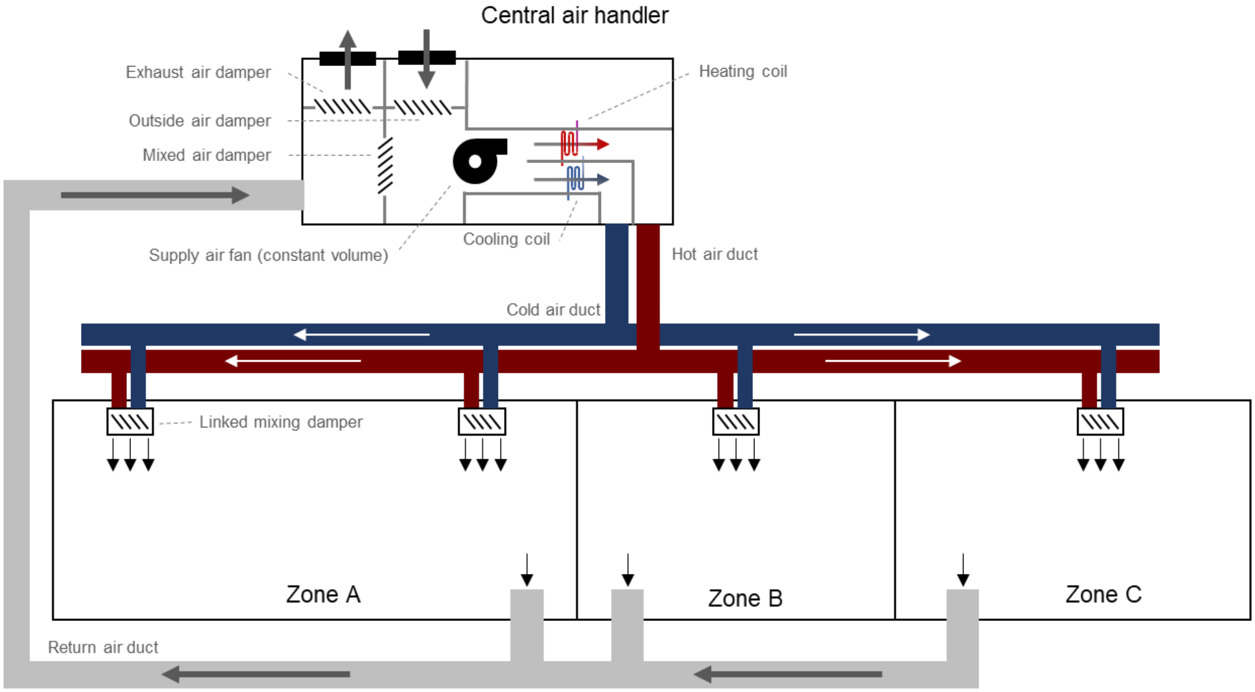

Figure 2. Multizone AHU with dual hot/cold deck temperature control. Mechanically linked zone dampers blend hot and cold air to achieve the desired space temperature in each room while supplying a constant volume of air.

During the retrofit, the lighting control system was integrated to the BMS, enabling the BMS to monitor fixture-level occupancy status in the zones served by the AHUs and baseboard heaters. The occupancy sensor data were used to change zone temperature setpoints when the space was unoccupied during normally occupied hours, as defined by the BMS schedule. This integration was reflected in the BMS trend data. AHU sequences were also changed to add supply air temperature reset. The intent was to also shut down the AHUs entirely when all zones for a given AHU were unoccupied; however, this condition rarely presented in the post-retrofit data. A control strategy was proposed to reduce outside air to a minimum when all zones were unoccupied, but this change was not reflected in the trend data. An additional control strategy was proposed to reduce hot water baseboard heater zone setpoints when the zones were unoccupied, but this strategy was not implemented.

Results. HVAC energy consumption was negligibly affected by the NLC sensor integration. Only one multizone AHU achieved measurable savings, reducing supply fan energy by approximately 1,500 kWh per year (11%) by shutting off the constant volume supply fan when all zones were unoccupied. Due to the hot/cold deck configuration and constant volume design, the total heating and cooling energy required to maintain the supply air temperature of each deck was not influenced by the slight, brief adjustments to room temperature setpoints.

Cadmus was able to evaluate plug-load savings for eight spaces where the receptacles correctly shut off when the space was unoccupied and metered plug loads were not tampered with during the study. Plug-load savings varied significantly between these spaces. An office with low occupancy had the highest percentage of plug-load savings but only moderate energy savings due to very small controllable loads. In contrast, another office yielded a lower percentage of savings but higher total energy savings because of a higher connected load. Overall, plug-load control integration reduced plug-load energy consumption by 38% to 80% but resulted in only 615 kWh of total annual energy savings across all eight spaces analyzed.

Site C: Mixed Use Office Tower

Unique factors. The 18-story Class A office building with some retail space is conditioned by two large central AHUs, served by central chillers and natural gas boilers. The study areas for this project are a fitness center and an outpatient health clinic located on the first floor. The study area in the building is served by VAV boxes that are downstream from central AHUs. The NLC system was only installed in the 7,300 square-foot project area.

Results. Due to COVID-19 restrictions, commissioning was substantially delayed and the building was largely unoccupied after the controls integration was completed. Minimal heating season data and no cooling season data were available post-installation. Cadmus was unable to verify whether the controls were fully integrated, and instead we estimated HVAC and plug-load savings using the assumed occupancy time-out method described above.

With a 30-minute occupancy time-out, the HVAC controls integration reduces annual VAV reheat energy by 83 MMBtu (75% in the study area), reduces VAV fan energy by 5 MWh (74% in the study area), reduces AHU cooling energy by 3 MWh (55% in the study area), and reduces AHU fan energy by 560 kWh (3% of the total area). The heating, cooling, and VAV fan savings apply only to energy consumption by terminal units in the study area, while the AHU fan savings apply to the entire system because the AHU also serves zones outside the study area (fan energy consumption is nonlinear and thus cannot be separated from the total energy consumption). High cooling, reheat, and terminal box fan savings are a result of baseline VAV occupancy schedules following the general building business hours rather than the substantially lower operating hours of the clinic area. AHU fan savings are minimal because each AHU also serves many other spaces outside the study area.

We estimated plug-load savings for 22 circuits in the study area and estimated total annual energy savings of approximately 900 kWh with a 30-minute time-out. Fitness center equipment offered the highest plug-load savings because some equipment is rarely used and has high standby power. Most clinic equipment was not controllable, and the few controllable loads primarily consisted of computer displays with built-in standby power mode.

Site D: Health Care Facility

Unique factors. The HVAC systems at the clinic are RTUs with either single zone control or VVT control. A VVT system, illustrated in Figure 3, supplies a single duct with conditioned air and zone dampers to control the airflow to each zone. The RTU switches back and forth between heating and cooling mode depending on whether more zones are above or below their temperature setpoint. Excess air is bypassed through a damper to the return air duct. VVT is inherently inefficient and often results in operational issues and lower occupant comfort (Mead 2012). Both system types at the site have constant volume supply fans with on/off natural gas heat and on/off direct expansion cooling. As such, energy savings can primarily be achieved by turning off the fan or adjusting the temperature setpoints in unoccupied zones. Sequences such as supply air static pressure reset and supply air temperature reset do not apply to these types of systems because they do not have variable capacity control.

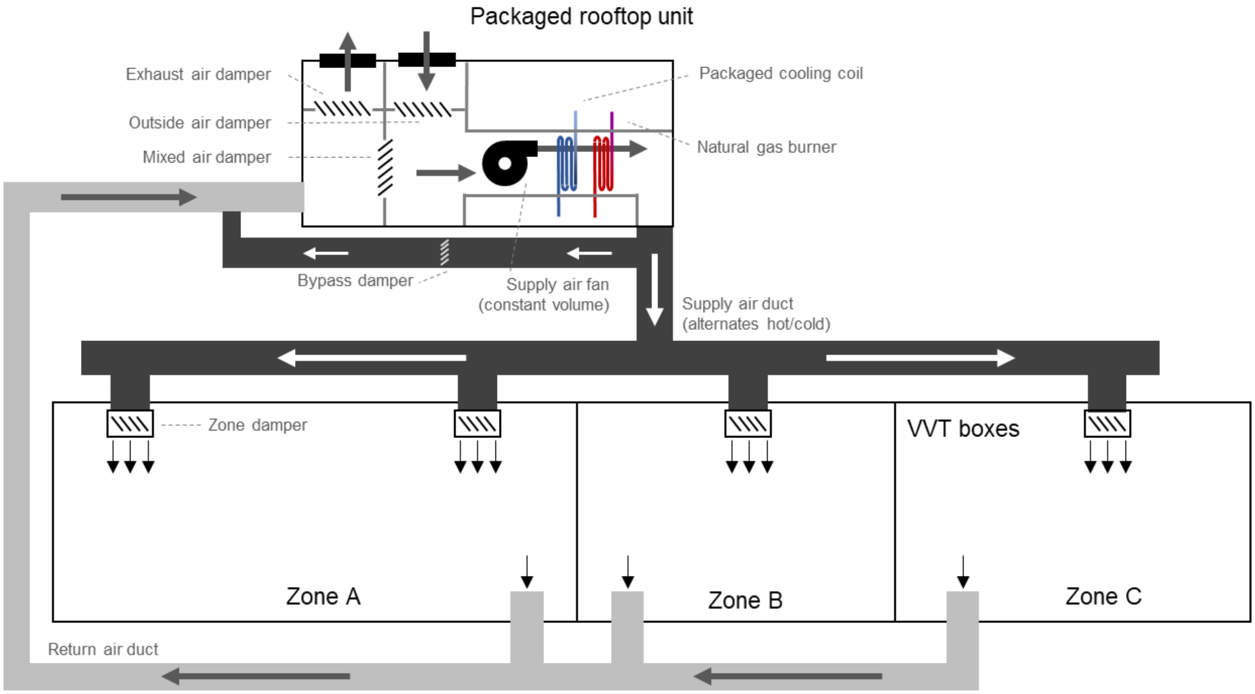

Figure 3. Multizone HVAC system supplied by a packaged RTU with VVT zone control. The constant volume RTU switches between heating and cooling mode, and zone dampers adjust airflow to each zone depending on whether it requires heating or cooling. Excess air is bypassed through a damper to the return air duct.

The clinic has a limited digital BMS that controls the RTUs and VVT boxes, and the BMS was not configured to collect trend data for the zone setpoints or occupancy status of the HVAC equipment from the baseline period. During the retrofit, the lighting control system was physically connected to the BMS; however, we were unable to detect any programming changes showing that the NLC occupancy sensors impacted the operation of the HVAC equipment. The building operator had reported that trend data would be available but was unaware that the BMS has a limited storage capacity and that data were being overwritten after one month.

Results. Cadmus thoroughly reviewed the limited BMS trend data available and was unable to identify any changes to the HVAC controls and operation as a result of the project; therefore, we could not quantify any HVAC-related energy savings. We did identify 10 metered receptacles where plug-load control was successfully implemented and could be seen in the plug-through power logger data. The plug-load occupancy control saved approximately 570 kWh per year (53%), with the greatest savings coming from a treadmill in the physical therapy gym (140 kWh per year, 75%). The controls substantially reduced the plug-load energy consumption on a relative basis, but the absolute savings are very small due to the minimal controllable loads.

Site E: Department of Transportation Maintenance Station

Unique factors. The baseline controls configuration included supply air static pressure reset and temperature reset, but the building operator often manually overrode those resets. In the baseline, a standby setpoint was configured but never enabled by the BMS schedule due to the 24/7 operation of the station. After integrating the occupancy sensors, trend data showed the VAV boxes entering standby mode and reducing the airflow and heating/cooling demand.

Results. Controls integration and thorough trend data collection were successful in this project, allowing Cadmus to extrapolate actual performance during the metering period to annual HVAC and plug-load savings. HVAC controls integration reduced annual AHU cooling energy use by 4.8 MWh (57%), reduced boiler heating energy serving the AHU by 2.5 MMBtu (2%), and reduced AHU supply fan energy use by 122 MWh (92%). AHU heating energy savings are minimal because most heating energy is provided by the terminal reheat coils. High supply-fan savings are due to significantly reduced VFD fan speeds on the AHU after the control sequence was changed to not constantly supply conditioned air to every zone. VAV terminal units in the study area saved 18 MWh (81%) of fan energy and 14.6 MMBtu (11%) of reheat coil boiler heating energy.

Plug-control integration was also successful. Some plug-through loggers were tampered with during the study, but we were able to calculate savings for seven spaces where controlled loads remained consistent throughout the study. Annual plug-load energy savings ranged from 50% for frequently used desk equipment like monitors and speakers to 99% for audiovisual equipment in an infrequently used classroom. We estimated overall plug control savings of 774 kWh per year (71%).

Findings and Conclusions

This controls integration study showed that significant energy savings can be achieved by integrating LLLC occupancy sensors with HVAC and plug-load controls but that potential savings are highly dependent on the equipment present and space occupancy patterns. Furthermore, the level of engagement and attention to detail in the installation and commissioning process can effect both the magnitude of savings achieved and the success of M&V activities.

As shown in Table 2, all sites showed potential for at least a 50% reduction in plug-load standby energy on controlled devices, but the actual magnitude of these savings is trivial, with no site saving more than 1,000 kWh per year. This can be simply explained by two main factors: most plug loads with high power draw in commercial buildings (from computers, refrigerators, lab equipment, etc.) cannot be safely powered off at the outlet, and most plug loads that can be safely powered off have low power draw to begin with or automatically enter a low-power standby mode (such as computer monitors). The plug loads with the greatest controls savings were for exercise equipment, large audiovisual equipment in conference rooms, and some frequently used plug-in task lights, but even these devices with relatively higher savings are a negligible portion of the total energy consumption at each site.

Table 2. Estimated annual energy savings from plug-load controls

Site	Occupancy Time-Out	Baseline kWh/yr	Post kWh/yr	Savings kWh/yr	Savings %
A	Est. 30 min	353	178	175	50%
B	Actual	1,092	478	614	56%
C	Est. 30 min	1,975	1,046	929	47%
D	Actual	1,075	507	568	53%
E	Actual	1,083	309	774	71%

Cadmus only estimated plug-load control savings for receptacles that were metered and not tampered with during the study. We estimated savings based on an assumed time-out for some sites where meters were removed before final controls integration was completed, and we used actual behavior for sites where full data were available.

HVAC controls integration yielded notable savings at sites with suitable equipment and successful integration. Table 3 summarizes the evaluated HVAC savings for each of the studied sites. Sites A and C were not fully commissioned at the time the analysis was conducted but showed strong potential savings using the approach described above. Only Site E was fully commissioned, had sufficient data available to evaluate actual performance, and demonstrated significant reductions in heating, cooling, and fan energy. Site B showed minimal savings from reduced fan energy only, and Site D never demonstrated any data showing HVAC energy savings related to the controls integration.

Table 3. Estimated annual energy savings from HVAC controls integration

Site	AHU Heating kBtu/yr	AHU Sensible Cooling kWh/yr	AHU Fan kWh/yr	VAV Reheat kBtu/yr	VAV Fan kWh/yr
A*	N/A	57,244 (42%)	4,676 (22%)	88,689 (31%)	N/A
B	N/A	N/A	1,500 (11%)	N/A	N/A
C*	N/A	3,003 (55%)	565 (3%)	83,329 (75%)	5,097 (74%)
D	N/A	N/A	N/A	N/A	N/A
E	2,572 (2%)	4,808 (57%)	122,664 (92%)	14,673 (11%)	17,753 (81%)

AHU fan savings apply to the entire air handler, which may serve zones outside the study area. Heating, cooling, and VAV savings apply only to energy used to serve zones in the study area.

* NLC data at these sites were not fully integrated or commissioned in the HVAC BMS at the time the analysis was conducted. These savings were modeled assuming a 30-minute occupancy time-out.

Sites A, C, and E were the only projects with significant HVAC controls savings, and all featured multizone AHU systems with VAV terminal reheat units and variable speed supply fans with static pressure reset. Variable volume systems are key to achieving high HVAC savings in multizone environments: a constant volume system can only save fan energy if all zones are fully satisfied and the fan can shut off completely. Multizone systems without terminal reheat (such as those at Sites B and D) also have limited heating savings potential because they must maintain a high supply air temperature any time any zone requires heat.

In addition to the limitations imposed by the equipment itself, various logistical issues posed challenges to the controls integration process and hampered the M&V evaluation effort. The HVAC evaluation relied on thorough BMS trend data for all key datapoints across the full baseline and post-installation periods. Facilities managers at some sites were not fully aware of the datapoints in their BMS or the limitations of the trending capabilities. Cadmus did not have live access to most BMS in the study and, in several cases, was unable to identify data quality issues until after critical data had already been overwritten or omitted altogether. Some expected datapoints were unavailable in the BMS, necessitating simplifying analysis assumptions. Whole-building utility billing analysis was not a feasible alternative due to inconsistent operation during COVID-19 and the simultaneous changes to lighting, HVAC, and other building systems. Long project timelines and many separate contractors and building stakeholders made communication challenging, and it was difficult to clearly identify what changes had been implemented, when those changes were made, or whether changes had been implemented at all. Inconsistent zone and equipment labeling between disparate control systems also caused confusion.

Recommendations

Despite the challenges in this pilot study, the controls integration technologies evaluated show strong potential for reducing commercial building energy consumption when applied to the right use cases. The ongoing shift of many organizations to a hybrid work environment has disrupted traditional schedule-based occupancy adjustments and particularly highlights the value of dynamic occupancy sensing with easily reconfigured zone assignments. To support energy efficiency experts who are interested in deploying and evaluating controls integration, Cadmus has developed several recommendations and best practices to ensure successful projects:

- Carefully evaluate the building characteristics and available savings before commencing a project. Integrating retrofit controls into an existing building is complicated and can be expensive, so it is important to select buildings that have strong potential for savings.
- Select buildings with HVAC systems that consist of either multiple small single-zone systems or variable volume multizone systems with terminal reheat.
- Ensure the HVAC system has direct digital control with a modern BMS that has a graphical user interface that allows for ongoing monitoring and adjustment. The BMS must support the ability to add the occupancy sensor inputs using BACnet, Modbus, or other standard communication protocol supported by the NLC system.
- Thoroughly review the existing controls and trend data to understand the baseline operation of the system. Check for existing control strategies that may already be achieving similar results and thus diminish the opportunity for new savings. For example, if the HVAC system already has conventional stand-alone occupancy sensors to control setpoints, adding NLC occupancy sensors may not yield significant additional savings.
- Evaluate whether receptacle control is feasible and economical for the plug loads present. Plug devices can be controlled only if they can be safely powered off at the outlet and are not tampered with and moved to uncontrolled outlets by occupants. Plug loads also must have high standby power and variable usage to achieve worthwhile savings.

A well-organized project team with a shared commitment to achieving savings is paramount to success.

- Ensure that the building owner or facility manager remains engaged throughout the project to facilitate access, share knowledge of the building systems, and understand how the new controls operate and maintain savings over the long term.
- Structure implementation vendor contracts to account for the complex and lengthy integration process. Allow sufficient time for necessary communication and coordination

between vendors, build follow-up visits and adjustments into the contract, and set clear acceptance criteria that require demonstrating that the desired control sequences have been implemented and are affecting equipment operation.
- Identify a project champion who is the primary point of contact for all stakeholders, can regularly visit the site in person throughout the project, and who will host regular meetings with all stakeholders to ensure consistency and coordination across teams.
- Involve an occupant representative to ensure that new control sequences reflect occupants' needs and to educate occupants on the changes in building operation so they can benefit from new features without disabling or overriding them.

Evaluation needs must be prioritized from the outset of the project to ensure accurate M&V and to quantify evaluated savings.

- Review sample trend data extracts as soon as possible and validate the data regularly to ensure they contain the necessary datapoints and are being collected and not overwritten.
- Understand the limitations of the available data and develop a practical evaluation plan that is based on the available data sources. Draft analysis calculations from initial data samples and install additional instrumentation if necessary to cover unavailable data.
- Thoroughly consider what baseline to use for the savings comparison and understand if the existing building systems are operating properly prior to commencing the project.
- Consider the timing of data collection. If possible, schedule data collection for the shoulder season to capture both heating and cooling performance.

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