CampusCoach Handbook

A Practical Guide to Tuning Your Campus HVAC for Energy Savings

BUILDING performance LAB

CUNY THE CITY UNIVERSITY OF NEW YORK

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

The development of the CampusCoach Handbook was made possible through the collective effort, expertise, and dedication of our partners, advisors, and visionaries. We are grateful to everyone who contributed to this resource.

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For more information from NYSERDA, visit www.nyserda.ny.gov

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Executive Summary

Driving up a campus' energy efficiency and reducing carbon emissions requires funding and expertise in energy management. Colleges, universities, and other campuses often lack the funding and/or expertise to get it done. And yet, there is increasing pressure to reduce greenhouse gas emissions from recent and emerging policies, student-driven sustainability efforts, and administrators' mandates to reduce energy costs. It's a conundrum that few have solved without access to abundant resources.

The City University of New York Building Performance Lab (CUNY BPL), with an award from NYSERDA's Clean Green Schools Initiative[1] worked with facilities managers and operators at the City College of New York (CCNY) campus to identify opportunities for operational improvements to reduce energy consumption, energy costs, and greenhouse gas emissions. This was accomplished through investigations of central plant operations and specific HVAC building systems that consume a significant portion of campus energy. In addition to the work with CCNY, CUNY BPL has coached many building operators to optimize their building operations since 2016.

This is a "how-to" handbook intended for facilities staff to guide their energy management efforts. It is designed primarily for building operators and energy managers, but it can also guide engineering faculty and students in their supporting role. It leverages CUNY BPL's experience in using data to coach operators to optimize operations. This handbook describes affordable methods to reduce energy consumption on campuses, with a strong emphasis on identifying no-cost/low-cost measures that typically offer an attractive return on investment.

The strategies in this handbook are fundamentally based on the Building Re-tuning™ (BRT) methodology developed by the Pacific Northwest National Laboratory (PNNL). At the building level, these strategies have demonstrated an average reduction in energy consumption of 14%[2]. Notable additional benefits include improved occupant comfort and a strong educational experience for the participating facilities staff.

1 Awarded when it was the 'REV Campus Challenge Program'.

2 Katipamula, Srinivas, and Nick Fernandez. "PNNL-SA-156277 Improving Commercial Building Operations through Building Re-tuning™: Meta-Analysis." Slide show, n.d. https://buildingretuning.pnnl.gov/documents/PNNL-SA-156277_Re-tuningMeta-Analysis_2020-09-05.pdf

There are three models we detail to execute the methodologies herein. Facilities managers can:

1. **Take the initiative to execute these methods within their own organization,**
2. **Engage on-campus faculty members and students to find the opportunities and meet regularly to share recommendations, or**
3. **Engage a third party, such as CUNY BPL or others, to apply these methods and act as coaches to campus operators.**

The first model clearly requires additional effort within the facilities management organization. However, there are sometimes funding opportunities available through government agencies, NGOs, and utilities (e.g., NYSERDA's Program Opportunity Notice 3701, which subsidizes On-site Energy Manager costs at the time of this writing). Funding sources and incentive programs are dynamic, and the user is encouraged to check for the latest available programs. The second model invites faculty members with on-campus students to conduct the analyses and share their findings, and the third model engages a third party to apply these methods. The second and third models significantly reduce the effort required of facilities managers to find and pursue opportunities.

By using these no-cost/low-cost measures that reduce operating costs, this handbook can create an affordable campus energy management program that facilities organizations can leverage year over year to keep energy consumption and costs down.

Steps to Success

For this program's success, the person who is responsible for campus operations must be engaged. This requires long-term buy-in, as the overall process is akin to 'ongoing commissioning' - a continuous process of identifying and pursuing opportunities to optimize operations season after season/year after year. The head of facilities management or their delegate is then the Program Manager.

Once up and running, there are activities at the central plant, campus, and building levels. Work done on the central plant and at the campus level requires more customized analysis, whereas at the building level, the work is more clearly prescribed through Building Re-tuning™ based methods described herein. Here's a brief description of the steps in the process that is depicted in *Figure 1* (page 4).

TEAM AND DATA EFFORTS

1. **Build and maintain the team:** The Program Manager identifies the individuals taking ownership of the steps in the process.
2. **Acquire/maintain data:** Building documents must be gathered, including mechanical and controls drawings for the central plant and campus-level systems (e.g., chilled water loops), as well as documentation for the buildings to be addressed in the program. Audits and maintenance records can also provide helpful information. Next, access to Building Automation System (BAS) data is provided to all participants involved in the optimization efforts.

CAMPUS-LEVEL EFFORTS

3. **Analyze performance and find opportunities:** Given the wide variation of campus-level and central plant designs, this is a customized analysis that identifies opportunities to optimize operations. Critically, identifying opportunities must be driven by the campus facilities managers' priorities, which can vary by campus. While maintaining or improving occupant comfort, typical priorities include minimizing either energy costs or greenhouse gas emissions.
4. **Develop and run Campus-level Workshops:** Analysis of site-specific findings is shared with plant/campus operators in a collaborative two-way discussion.
5. **Implement measures:** There are nearly always opportunities, even at this level, that are no-cost/low-cost. Efforts are made here to realize those opportunities.

BUILDING-LEVEL EFFORTS

6. **Coaching / investigative sessions:** There are three approaches to this work that map to the three models above:
   - Facilities personnel (e.g., a controls team) independently apply the Building Re-tuning™ concepts to identify opportunities, and monthly or so sharing sessions occur with the operators. This work includes both investigations at the building-system level and monitoring of the central plant and campus-level operations.
   - Faculty/student teams independently apply the Building Re-tuning™ concepts to identify opportunities, and monthly or so sharing sessions occur with the facilities personnel (e.g., a controls team) and operators. This work includes both investigations at the building-system level and monitoring of the central plant and campus-level operations.
   - More experienced coaches, e.g., from CUNY BPL, run occasional coaching sessions with the operators to review the performance of the various systems and identify opportunities.
7. **Implement measures:** Efforts are made here to realize the opportunities. Getting the work done is a mix of operators changing schedules and setpoints, performing repairs on sensors, existing controls, and mechanical systems, and sometimes implementing low-cost upgrades to controls to incorporate better-performing sequences of operations.

The rest of this handbook will provide in-depth instructions and examples for implementing each step described above. We at CUNY BPL hope this serves your facilities operations by identifying opportunities for energy savings, reductions in GHG emissions, and cost savings that can financially justify the effort, and by fostering a clean, green culture on your campus.

CUNY BPL would be happy to hear from you regarding this program. Feel free to reach out by writing to us at bpltraining@ccny.cuny.edu.

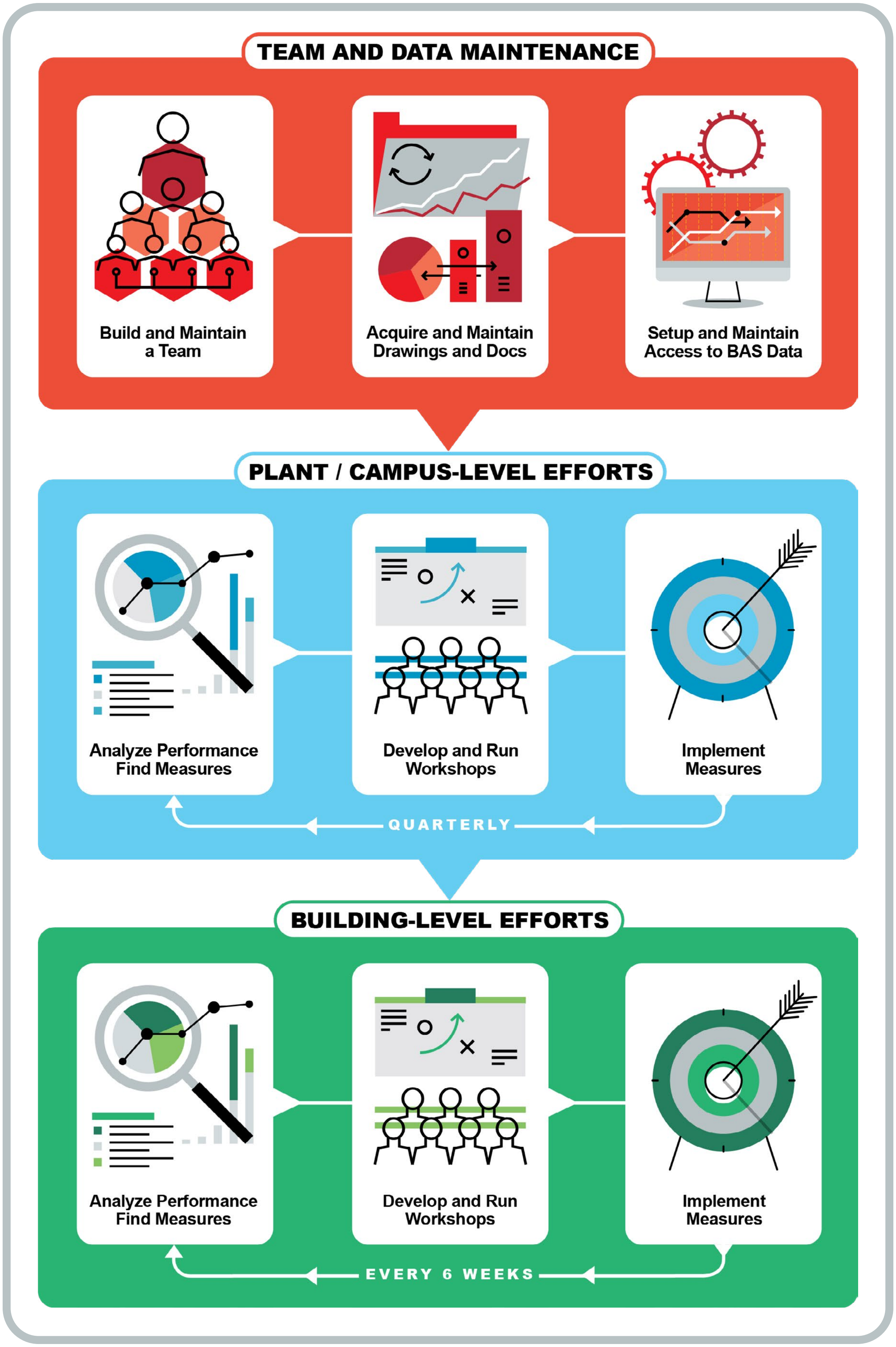


Figure 1. Building Re-tuning Steps

Getting Started

City University of New York Building Performance Lab's (CUNY BPL) achievements over the past four years with the City College of New York (CCNY) campus operators and facilities managers were done through a developed systemic controls-based procedure that increased their ability to effectively manage major energy-consuming systems and conduct a form of ongoing commissioning of their campus equipment. This process has been refined and shaped so that it is easily accessible and adaptable for other campuses.

Part of the refinement includes the influence of an ongoing project developed by CUNY BPL: BuildingCoach.

BuildingCoach is a project developed and piloted by CUNY BPL as a data-driven coaching methodology to help operators understand how to adjust operations and/or effect no-cost/low-cost repairs or upgrades to their building's HVAC systems to reduce energy consumption. The operational optimization method used is based on the Building Re-tuning™ approach developed by the Pacific Northwest National Laboratory. It is those similar end goals of each project that created the CampusCoach process.

The CampusCoach process includes the main aspects of the work completed at CCNY, such as data collection, campus-level analysis, Campus-level Workshops, and documentation of implementation and persistence through monthly meetings with facilities operators.

Through the lessons learned from both the Clean Green Schools Initiative and the BuildingCoach project, it was found that the combination of installing the Building Operator Coaching Solution ("the BOCS") and having one-year live training and coaching will not only increase the outcomes but also create a team that can fully adapt the process to their daily operation on campus. BOCS is a technology that extracts the data from the control network and presents it as prescribed for coaching.

We decided on one year of live training and coaching, as it will address Central Plant and HVAC system issues while being tested and stressed across the heating, shoulder, and cooling seasons. The following sections in this handbook will explain step by step how you can build a team and conduct the CampusCoach process on your campus.

STEP 1

Build/Maintain Team

THREE TEAM MODELS

An essential part of the CampusCoach process is building your team, and there are three different models that you can use to proceed with your project. To identify what model would best fit your institution, you can ask yourself the following questions: Can you currently collect data from your Building Automation System (BAS)? Do you have access to campus equipment lists/ plans? Do you have an energy manager in your facilities team? Are your facilities staff knowledgeable and are they able to have access to the BAS and data?

MODEL 1 FACILITIES STAFF

This model could already be available. An established team on your campus should have access to all data and information related to the BAS and building operations and be able to implement recommendations.

MODEL 2 STUDENTS, FACULTY, AND STAFF

The second model consists of creating a team from students, faculty, and staff. This team should include people who are not only interested in reducing energy consumption at your campus but are also willing to invest over a year of their time in this project. A year might seem like a long commitment, but students and faculty are a great resource and would make a great addition. Upper-level undergraduate and master's students are great candidates for team members. They have begun to view the world in terms of job opportunities and career choices and have a certain amount of elective flexibility in their program of study. We have found that some first and second-year students can be quite career-directed and have recruited such participants with surprising frequency. Exposure earlier in students' academic careers is undoubtedly desirable, as they can begin to consider energy as a potential career, plot an academic pathway towards it, and gain more experience on their resumes. If students have not taken courses related to HVAC or have not been exposed to the field through an internship, they can and should complete the instructional program outlined later in this section.

Specific roles and responsibilities are duplicated because the task lead needs support; therefore, it is recommended to have at least two team members responsible for those tasks.

Facility staff may initially be reluctant to join the project due to concerns about the level of commitment required. If this issue arises, it is strongly advised that the university and student team involve them from the very beginning. Engaging facilities staff during the planning and initiation phases will help shape the overall project plan with their invaluable operational insights. It is crucial to clearly communicate the project's vision, objectives, and alignment with the campus's broader goals and values. Furthermore, it should be explicitly stated that they will have autonomy and decision-making authority within their areas of expertise, as many project decisions will directly affect their work. Assigning clear roles and responsibilities is equally essential, as it helps everyone understand what is expected of them and how their work contributes to the project's overall goals. Fostering a culture of open dialogue and providing regular updates on progress, challenges, and any changes will build trust and secure their crucial buy-in.

MODEL 3 OUTSIDE CONSULTANT/CONTRACTOR

If funding is available, the project itself can be outsourced to experts who can take the lead in the CampusCoach process. When hiring a third party, you need to consider the campus engineering staff. Engineering staff are commonly unionized, with work rules that make their attendance at training classes difficult and costly, unless they are made part of regular shift time. Engineering staff are commonly overseen by Facilities management staff, who control work assignments and duties. Therefore, it is crucial to gain the support of these managers. If managers do not see the value of the training, it can be challenging for operations staff to use it. The engineering staff will play the most significant role not only in providing you with insight into campus operations, but also in implementing and/or overseeing the operational changes you recommend.

The relationship between your team and the campus building operators is essential, and constant communication with them will be key to achieving energy savings. They should participate in each step of the process: verifying the significant equipment inventory, agreeing to the operating strategies developed, and participating in the facilities training.

Once the team has been established and the roles and responsibilities are confirmed, initial planning can begin.

The CampusCoach process includes Data Gathering, Campus-Level Analysis, Campus-level Workshops, BOCS Installation and Deployment, and Live Training and Coaching. Each step of the process will be explained within this manual in its respective sections.

The size of the team can vary depending on the level of interest in the project, but it is recommended that there be at least six team members. The following table shows the different roles of each team member and their responsibilities:

MODEL 1 - FACILITY STAFF				
PROJECT RESPONSIBILITIES				
DATA GATHERING	**BOCS INSTALLATION AND DEPLOYMENT**	**CAMPUS-LEVEL ANALYSIS**	**CAMPUS-LEVEL WORKSHOPS**	**LIVE TRAINING AND COACHING**
Facilities assistant to update/create a major equipment inventory Facilities engineers to develop and track KPI metrics for the campus	Facilities manager to discuss with the chief facilities office to either hire a third party, to install and deploy BOCS OR, if available, work with the campus controls team to make sure trending is available on the BAS	Chief facilities officer to work with the facilities engineers to conduct the following: ▪ Create baselines ▪ Operating Strategies ▪ Trending and analytics (KPI) ▪ Dashboard	N/A	Facilities assistant to set up monthly meetings to go over any findings observed through trend charts and keep tracking of any recommendations or implementations with the facilities engineers and chief facilities officer

MODEL 2 - STUDENTS, FACILITY STAFF				
PROJECT RESPONSIBILITIES				
DATA GATHERING	**BOCS INSTALLATION AND DEPLOYMENT**	**CAMPUS-LEVEL ANALYSIS**	**CAMPUS-LEVEL WORKSHOPS**	**LIVE TRAINING AND COACHING**
Lead faculty member to assign a student to gather documentation to create a major equipment inventory with the collaboration of Facility Staff Lead faculty member to develop and track KPI metrics for the campus with the assistance of the students and guidance of the Facility Staff If available, lead faculty member to work with the campus controls team to make sure trending is available on the BAS	If funding is available, lead faculty member to collaborate with the Chief Facilities Officer to hire a third party, to install and deploy BOCS	Lead faculty member to collaborate with the Chief Facilities Officer to conduct the following: ▪ Create baselines ▪ Operating Strategies ▪ Trending and analytics (KPI) ▪ Dashboard The students should assist with filling out dashboards while referring to the CampusCoach Handbook for guidance	Lead faculty member to review Campus-Level Workshops templates for guidance to creating their own with the support of students and insight of Facility Staff	Lead faculty member to review weekly trend charts from either the BAS or BOCS for findings and recommendations with the Facility Staff. Students should be maintaining the tracking sheet. Students to set up monthly meetings with the Facility Staff to go over recommendations and update the tracking sheet for any updates or implementation

MODEL 3 - OUTSIDE CONSULTANT/CONTRACTOR				
PROJECT RESPONSIBILITIES				
DATA GATHERING	**BOCS INSTALLATION AND DEPLOYMENT**	**CAMPUS-LEVEL ANALYSIS**	**CAMPUS-LEVEL WORKSHOPS**	**LIVE TRAINING AND COACHING**
Campus representative to work with the consultant group to gather documentation to create a major equipment inventory. This will include site visits to the campus. The consultant group to develop and track KPI metrics for the campus	The consultant group to conduct the BOCS installation and deployment	The consultant group to conduct the following and present to the campus representative and Facility Staff: ▪ Create baselines ▪ Operating Strategies ▪ Trending and analytics (KPI) ▪ Dashboard	The consultant group to create and conduct four Campus-Level Workshops that will be specific to the campus's Central Plant	The consultant group to review weekly trend charts from BOCS for findings and recommendations, and maintain the tracking sheet The consultant group to set up monthly meetings with the Facility Staff to go over recommendations and update the tracking sheet for any updates or implementation

Once a team model is chosen, the following structured timeline can be used as a reference for the estimated time each step could take:

MONTHS 1 - 3

Assemble Team

Action

- The Project Manager identifies participants who will own different steps in the process.

MONTHS 1 - 6

Acquire & Maintain Data (simultaneous with BOCS Installation and Deployment if Model 3 is chosen)

Actions

- Gather building documents (i.e., mechanical, controls drawings).
- Collect documentation for central plant and campus systems.
- Retrieve audits and maintenance records.
- Ensure access to Building Automation System (BAS) data for all participants.

MONTHS 7 - 10 and beyond

Campus-Level Analysis & Engagement

Actions

- Analyze campus and central plant performance.
- Identify optimization opportunities based on campus priorities (i.e., energy cost, emissions)
- Develop and run workshops to share findings and foster collaboration.
- Review central plant and campus-level performance quarterly (models 1 and 2)

MONTHS 11 - 20 and beyond

Live Training and Coaching

Actions

- Conduct coaching/investigative sessions using one or more models:
  - Facilities personnel-led
  - Faculty/student team-led
  - External coach-led
- Monitor building systems.
- Hold monthly sharing sessions.
- Review building-level performance every six weeks per building (models 1 and 2)

Instructional Program for Students and Faculty

This handbook demonstrates highly technical analysis and recommendations for facilities operations. Thus, an instructional program has been developed to implement and sustain improvements with well-informed, trained operators, facility management staff, and matriculated students.

We expect priorities and issues expressed at CCNY to be generally representative across facility organizations at large campuses, and the engagement and listening process to be similarly applicable. We developed a campus-specific training approach for CCNY. Although the strategy is tailored to address specific campus circumstances and priorities, the core materials apply to all facilities. The Educational Training Materials (ETMs) convey concepts for operational energy-efficiency optimization that will serve as a template for other campuses.

Since these ETMs are available for students and faculty, they include theoretical, textbook, and current research backgrounds. However, they are still oriented around practical topics in energy data, HVAC systems, and energy efficiency improvements. We have developed elements of study and project work that can be introduced into the work of matriculated students and will enable them to pursue study in this field, which is usually not well represented in course offerings.

While achieving this intent may be possible with entirely new courses, it is generally unlikely at most universities, given the established program foci and constraints on faculty hiring. The best way to introduce our methods into academic programs for matriculated students is through self-study modules and adding project/paper/exercise topics into existing courses. Faculty, perhaps motivated by student interest or their own concerns for relevance, can be supported in introducing new material in limited doses and then further supporting students as they follow their own interests more deeply through independent study, projects, and supervised internships. Formulated opportunities for Senior capstone and Master 's-level projects are an essential way for interested students to delve more deeply into suggested and sample topics and to get started.

There are two required class modules, and the material covers topics such as energy policy and laws, energy data and benchmarking, building science, HVAC systems and automated controls, and Building Re-tuning™ (BRT). These are available to anyone at the university interested in this field. For further information needed by the CampusCoach team, this handbook also includes study guides that go in-depth into the technical aspects of HVAC and BRT. Finally, there is a list of available student project areas of study, including BAS trending, field studies, and the application of BRT techniques.

In-Class Modules

The intent of the educational training materials (ETM) for study and project work is to introduce them to matriculated students and enable them to pursue study in the fields of building science, HVAC systems and operations, and energy efficiency. This may be a relevant addition to existing courses, but more likely it will be a first introduction to this field of study for students, as it is common for universities to lack a thorough representation of these topics in their course offerings.

The target audience for this instructional program is upper-level undergraduate and Master's students, as they should have a sufficient base of technical knowledge and are in the mindset of preparing to specialize in a field for study and/or future work. For students who are interested in further work with the project team, there is also an extensive onboarding process outlined below. Suppose the project team follows Model 2 (as mentioned above, students and faculty staff). In that case, this "Engaging Students" section is relevant to bringing the team up to speed on the basics needed to implement this project on their campus. These ETMs may also be used to onboard Facilities Staff who are joining the project team but may not be as familiar with the listed fields above.

From previous experience, CUNY BPL has found that the implementation of brand-new courses is generally unlikely at most universities. Thus, the project team recommends introducing new material in limited doses and allowing students to follow their own interests more deeply through independent study, capstone projects, and/or internships within CUNY BPL or similar entities.

The first type of ETM was developed as two slide decks to be taught in two 45-minute sessions, with an accompanying homework assignment between the sessions, within an existing university course, with the professor's permission. A project team member with sufficient technical knowledge and teaching experience would work with a professor to either hand over the materials with teaching notes or teach as a guest lecturer themselves.

Below is a summary of the module topics and learning objectives:

MODULE 1 (45-minute in-class module)

Topics

- New York's Energy Policies*
- Building Science

Learning Objectives

- Describe the major state and city laws and codes regarding building energy usage and carbon emissions.
- Review the major systems that contribute to building energy usage and do an example calculation for space heating load.

Homework

- Watch this video on the basics of HVAC: https://youtu.be/klggop60vlM

MODULE 2 (45-minute in-class module)

Topics

- Building Management
- Energy Management

Learning Objectives

- Understand the energy management process as an organizational issue.
- Identify ways to optimize energy efficiency using Building Re-tuning™ techniques.
- Dissect the control loops involved in operating HVAC systems.

**Note: These modules were written for the CCNY campus. The energy policies discussed in Module 1 should be updated for the appropriate location and jurisdiction of the campus being investigated.*

Since the implementation of these modules is contingent on the type of class and at the professor's discretion, they focus on the very basics of the field to gauge student interest. Suppose the professor and/or students are interested in further study. In that case, they can pursue the project topics discussed in the next section, and/or additional modules can be developed as described below:

ADDITIONAL MODULES (each one should be a 45-minute in-class module)

- Building Automation System Basics
  - for computer/mechanical/electrical engineering, and architecture majors
- Energy Data Visualization for FDD
  - for engineering, computer science, and design majors
- Building Science Basics
  - for architecture, physics, and engineering majors
- Energy Laws and Benchmarking
  - for social science and environmental science majors

The in-class modules can be found through this link:
Instructional Program for Students and Faculty: In-Class Modules.

Independent Study Guides

Interested students may also be integrated into the campus project team as interns and thus would need further educational materials. The following are study guides developed by the project team for its interns on the CCNY campus.

The students are given a checklist of materials to study over an average period of 6 weeks, which run them through the basics of building science, HVAC systems and operations, as well as learning how to navigate CCNY's Building Automation System (BAS) using the Student Access Monitoring System (SAMS). Below is a summary of the study materials and learning objectives:

FUNDAMENTALS OF HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)

(15 hours of study time)

Study Materials

- "Mechanical and Electrical Systems in Buildings" by Janis & Tao, chapters 1-7
- The Engineering Mindset's YouTube playlists:
  - HVAC training
  - Mechanical Ventilation
- "Piping Layouts for Hydronic Heat" by John Siegenthaler

Learning Objectives

- Describe control loops throughout a cooling system, including zones, VAVs, AHUs, Chilled Water loop, Chiller Plant, Condenser Water loop, and Cooling Towers
- Describe control loops throughout a heating system, including zones, VAVs, AHUs, Hot Water loop, Boiler Plant, and Perimeter Hot Water and Perimeter Steam

INTRODUCTION TO BUILDING RE-TUNING (BRT) TECHNIQUES (15 hours of study time)

Study Materials

- Pacific Northwest National Laboratory BRT Guides (in text form)
- Pacific Northwest National Laboratory BRT Guides (in video form)

Learning Objectives

- Understand the BRT Process and the use of trend charts in analysis.
- Understand the recommendations for each of the nine (9) original BRT measures:
  1. Air-Side Economizer Operation
  2. AHU Static Pressure Control
  3. AHU Discharge-Air Temperature Control
  4. Occupancy Scheduling
  5. Zone Heating and Cooling Control

6. Central Utility Plant Cooling Control
7. Central Utility Plant Heating Control
8. AHU Minimum Outdoor-Air Operation
9. AHU Heating and Cooling Control

USING THE CAMPUS BAS AND TRENDING (5 hours of study time)

Study Materials

- Live or video playback of BAS walk-through

Learning Objectives

- Know how to navigate around the BAS to see the different systems' graphics and settings pages.
- Know how to access and set up trending on the BAS for systems based on the PNNL BRT Guides
- Use the BAS graphics and trends to analyze data using BRT techniques.

YOU MAY ALSO CONTACT THE AUTHORS AT CUNY BPL'S BRT TEAM for free access to additional materials developed as self-paced modules on the fundamentals of HVAC controls and ideal sequences of operation called "BuildingCoach Core Curriculum" (designed for the Department of Energy's E-Train Remote Learning Project).

After reviewing the onboarding materials, the students are asked to complete a "closing" project to demonstrate their learning. This project assesses their proficiency in using the BAS to pull building HVAC data as trend charts and analyze these charts to diagnose issues, as well as coherently present their findings and recommendations for energy efficiency to a panel of project team members acting as the building operators. The hope is that these materials will equip any motivated student intern with the knowledge and skills necessary to be an effective member of the project team.

After reviewing these materials, the student should be included in project meetings with the Facilities Staff to build good working relationships and be given the chance to share some of their work/ findings.

Student Projects

Students who are highly motivated to pursue further study after completing the Class Modules are encouraged to undertake a project that uses data gathered from the campus. At CCNY, the Facilities Staff approved the use of campus BAS data for student projects. However, they requested that the project team create a separate computer interface to minimize conflicts with facilities operating staff over the use of the same computer. This led to the development of CCNY's Student Access Monitoring Station (SAMS), a view-only mirror of the CCNY BAS on a computer in a separate office on campus, which two Master's students completed as part of their Capstone project. Additional details about SAMS are provided in the Engaging Students section below.

Once access to BAS data is available, students may be interested in developing independent study and/or capstone projects. A few project topics are listed below, but students should also be encouraged to work with the Facilities Staff and the project team to develop their own ideas for using the BAS data.

Using BAS trending and field study to do commissioning of major sensors, for example:

- Campus loop flow meters and pumping
- All outside air temperature / relative humidity sensors

NOTE: Sensor accuracy tests and calibration should be done with the BAS contractor, if available.

Using BAS trending to apply Building Re-tuning™ (BRT) techniques on:

- Central plant operations
- Campus loop operations
- Individual building's HVAC operations

Developing new dashboards on the BAS to promote energy-efficient operations, for example:

- Hot water reset dashboard
- Condenser water reset dashboard

Doing ROI analysis for potential projects that the Facilities Staff are considering, for example:

- Replacing old equipment with new energy-efficient ones
- Adding new technologies like VFDs, VRFs, heat pumps, etc.
- Adopting new operations that affect the whole campus, like a chilled water reset

Creating marketing materials (flyers or website articles, or social media posts) to help facilities get messages about their energy reduction work and how the campus can help

- There should be some emphasis on what low/no cost measures that building occupants can take- i.e., close windows and doors, power down lights and computers when not needed, limit plug loads, report energy waste, etc.

Examples of successful student engagement initiatives

GABBY & DITJON

The first pair of student interns involved in the CCNY REV CC project were Master's students working with one of our project team members, Michael Bobker, on their Capstone project. They were introduced to building science and energy management from an existing class taught by Mr. Bobker and given an earlier version of the Study Guides for further study. Their Capstone project aimed to "create a monitoring tool that will enable facility managers to perform ongoing commissioning using City College's North Campus as our test subject. We will identify the key elements and equipment for continuing commissioning to reduce energy use.

This project was the origin of the Student Access Monitoring System (SAMS), which is another instance of CCNY's Automated Logic BAS. With the help of CCNY IT and the third-party controls contractor, CSG, SAMS was set up to pull points from the BAS to an iMac running Linux in the CCNY project team's office. This computer has view-only access to the BAS graphics and HVAC systems' data points, allowing students and the project team to create trend charts for analysis.

NINAD

Another Master's student involved in the CCNY REV CC project came as an intern and was onboarded using the final form of the Study Guides described above. As mentioned, the onboarding process primarily involved studying HVAC systems, understanding their functions, and how they interact. A key aspect of this was analyzing BAS data and using UT3 software to generate trend charts for visualization. Each chart corresponded to specific measures that helped evaluate performance levels. Making these charts enabled him to understand the various measures used to compare each system's performance against a benchmark for optimal operation. These initial steps established the foundation for his work with the CCNY project team. Below are two tasks he worked on as a student intern:

> **EC3:** *"I analyzed the energy data for four CCNY buildings, performing calculations related to their monthly energy consumption and associated costs. The goal was to gain insights into how and where energy was being used in each building, and to use this information to identify potential energy-saving measures, aiming to reduce costs."*
>
> **Thermal Lag Experiment:** *"The test involved monitoring the chilled water (ChW) supply and return temperatures at different points in the system over time to observe changes. The objective was to identify patterns and discrepancies between the measured and actual temperatures. This test was conducted for the NAC building chiller plant at CCNY."*

The project team would like to note that Ninad has now been integrated into the project team as a full-time staff member of the CUNY Building Performance Lab after his graduation. This is an exciting development, as he already has the knowledge base to run CampusCoach at CCNY and will be a core member in applying it to other campuses as part of the next phase of this project.

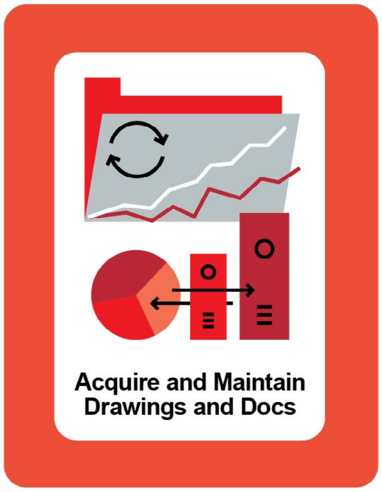
MAMADOU

The most recent intern addition to the project team was an undergraduate student who also went through the Study Guides as part of his onboarding process. He describes the task he worked on below:

"I joined the REV project at CCNY out of curiosity for how our work could benefit CCNY campus buildings. I'm glad I had the chance to work with Kelly on reviewing mechanical drawings of the NAC building. As part of the intern onboarding process, I learned how HVAC systems work, how they interact, where they are located, and which areas they serve in buildings. It made it easier for me to identify which VAVs were served by which AHUs in the NAC building. Thanks to my onboarding experience with the BRT Team, I learned how to read HVAC coverage plans and understood HVAC zoning techniques through this project."

STEP 2A

Acquire / Maintain Documentation



TAKING AN INVENTORY

The templates and recommendations provided here serve as a guide for documenting the various inventories needed to conduct a comprehensive campus-level analysis. These inventories are essential for understanding your facility's current equipment state and identifying opportunities for optimization.

The following data needs to be documented for this analysis:

1. **Controls Drawings, Mechanical Drawings, Building Automation System (BAS) Schematics, and Energy Audits:** Should be collected and organized to facilitate a clear understanding of equipment schedules, sequences of operation, BAS logic, etc. Any audit reports done in the past - Retro-Commissioning/ Energy Audits, NYSERDA Flextech Audits, etc. - should be gathered in this step. They help supplement your understanding of the building's systems and give you a sense of any previously suggested energy efficiency measures.
2. **Heating, Ventilation, and Air Conditioning (HVAC) Equipment Inventory:** A list of all HVAC equipment on campus - including chillers, boilers, pumps, air handling units, terminal units, etc - along with relevant nameplate information on units.
3. **BAS Capabilities and Trending Points Inventory:** A list of all the capabilities of the BAS on campus, as well as a list of all trending points that are being monitored.
4. **Metering Information:** A list of all energy meter and sub-meter numbers and what each meter serves.
5. **Notes from Conversations with Facilities Staff:** Crucial for gathering valuable insights on the operation of the BAS/HVAC systems and understanding the challenges and opportunities from the perspective of those who operate and maintain the campus facilities.
6. **Documentation from Field Surveys:** For Models 2 and 3 - where the project team is made of either Faculty and Students or a Third Party - field surveys will be a necessary step in the documentation process. They will provide opportunities for the team to gather first-hand observations and verify data.

By leveraging the templates and recommendations in this section and collecting the required data, you can gain a comprehensive view of the campus' HVAC systems and controls. This enables data-driven decision-making for finding operational changes that yield energy savings.

Gathering Documentation

Collecting data connectivity documents — control drawings, mechanical drawings, BAS schematics, etc. — is a required step for both the campus-level analysis and BOCS setup. These documents are necessary to complete your HVAC and BAS inventories. They contain sequences of operations and control logic that will inform you of your recommendations for energy savings opportunities. They help form the foundation of your understanding of campus HVAC systems. These documents will also be instrumental for the BOCS installation and deployment process, detailed later in this guideline.

Types of documentation include:

- Control Drawings
- Mechanical Drawings
- Sequences of Operation
- As-Builts
- BAS Schematics
- Energy Audits/Commissioning Reports
- Equipment Manuals
- Equipment Logs/Records

The information in these documents should be verified throughout the inventory and data-gathering process. Meetings with Facilities Staff, documenting conditions during site visits, and reviewing the systems on the BAS can all provide opportunities to update any information gathered in this initial step.

Documenting Major HVAC Equipment

Taking an inventory of your HVAC equipment is the first step in the data gathering process. This guidebook provides a spreadsheet template for entering HVAC data, including equipment type, model, age, size, and location. An accurate HVAC inventory is important for prioritizing systems to investigate energy savings opportunities, as the plan will be based on equipment size and energy use.

The HVAC equipment that should be inventoried is detailed in the spreadsheet template and includes:

Campus Level Equipment:

- Central Heating/Cooling Plants
- Hot Water/Chilled Water Distribution

Building Level Equipment:

- Heating Plant: Boilers, Heat Exchangers, Hot Water Pumps, etc.
- Cooling Plant: Chillers, Chilled Water Pumps, Cooling Towers, etc.
- Air Distribution: Air Handling Units (AHUs), Rooftop Units (RTUs), Exhaust Fans, etc.
- Terminal Units: Variable Air Volume Boxes (VAVs), Hydronic Unit Heaters, Cabinet Unit Heaters, etc.

This list contains commonly found equipment but is not exhaustive. Any other relevant HVAC equipment (Cogen systems, compressed air systems, etc.) should be captured in the HVAC inventory.

EQUIPMENT INVENTORY TEMPLATE

We have provided a spreadsheet template for collecting an inventory of the HVAC equipment on campus. The template includes a tab for the central plant equipment as well as multiple tabs for building-specific equipment. The building equipment tabs can be duplicated as needed if you are taking an inventory of more than three buildings.

The central plant tab contains tables for capturing the equipment data for the central heating and cooling plants, as well as the heating/cooling distribution systems. The building tabs have tables for capturing data for any heating, cooling, and air distribution systems each building may have, as well as terminal units. This template is designed to be comprehensive, so it contains tables for multiple types of each system. The only tables that need to be filled out for your documentation are those corresponding to the system configurations on your campus; the rest can be ignored or deleted.

Example of Central Plant Equipment Inventory tables:

BPL *CAMPUS NAME* - **CENTRAL PLANT** UPDATED: *Date*

CHILLERS

UNIT NO.	TYPE	SERVICE	LOCATION	MANUFACTURER	MODEL #	SERIAL # *Note, we are going to try to get part load curve info with just model #,	FLOWRATE (GPM, CFM)	CAPACITY (each) (TONS, HP, PPH)	EFFICIENCY (%)	RATED INPUT (THERMS, KW)	RATED OUTPUT (THERMS, KW)	YEAR INSTALLED	OPERATING SCHEME	OPERATING SCHEDULE	OPERATING STRATEGIES	BAS TRENDING?	NOTES

PRIMARY CHILLED WATER LOOP

UNIT NO.	TYPE	SERVICE	LOCATION	MANUFACTURER	MODEL #	SERIAL # *Note, we are going to try to get part load curve info with just model #,	FLOWRATE (GPM, CFM)	CAPACITY (each) (TONS, HP, PPH)	EFFICIENCY (%)	RATED INPUT (THERMS, KW)	RATED OUTPUT (THERMS, KW)	YEAR INSTALLED	OPERATING SCHEME	OPERATING SCHEDULE	OPERATING STRATEGIES	BAS TRENDING?	NOTES

SECONDARY CHILLED WATER LOOP

UNIT NO.	TYPE	SERVICE	LOCATION	MANUFACTURER	MODEL #	SERIAL # *Note, we are going to try to get part load curve info with just model #,	FLOWRATE (GPM, CFM)	CAPACITY (each) (TONS, HP, PPH)	EFFICIENCY (%)	RATED INPUT (THERMS, KW)	RATED OUTPUT (THERMS, KW)	YEAR INSTALLED	OPERATING SCHEME	OPERATING SCHEDULE	OPERATING STRATEGIES	BAS TRENDING?	NOTES

Figure 2. Example of Central Plant Equipment Inventory Table

Example of Individual Building Equipment Inventory tables:

AIR DISTRIBUTION - AIR HANDLING UNIT

UNIT NO.	TYPE	SERVICE	LOCATION	MANUFACTURER	MODEL #	TYPE (CAV / VAV)	OA CONTROL (DCV / DRY-BULB ECONOMIZING / ENTHALPY ECONOMIZING / NO CONTROL)	HEATING ELEMENT (HEATING COIL - HOT WATER / HEATING COIL - STEAM / BURNERS)	COOLING ELEMENT (COOLING COIL - CHILLED WATER / COMPRESSORS)	HUMIDITY CONTROL (HUMIDIFICATION / DEHUMIDIFICATION)	YEAR INSTALLED	OPERATING SCHEME	OPERATING SCHEDULE	OPERATING STRATEGIES	BAS TRENDING?	NOTES

AIR DISTRIBUTION - ROOF TOP UNIT

UNIT NO.	TYPE	SERVICE	LOCATION	MANUFACTURER	MODEL #	TYPE (CAV / VAV)	OA CONTROL (DCV / DRY-BULB ECONOMIZING / ENTHALPY ECONOMIZING / NO CONTROL)	HEATING ELEMENT (HEATING COIL - HOT WATER / HEATING COIL - STEAM / BURNERS)	COOLING ELEMENT (COOLING COIL - CHILLED WATER / COMPRESSORS)	HUMIDITY CONTROL (HUMIDIFICATION / DEHUMIDIFICATION)	YEAR INSTALLED	OPERATING SCHEME	OPERATING SCHEDULE	OPERATING STRATEGIES	BAS TRENDING?	NOTES

AIR DISTRIBUTION - DOAS

UNIT NO.	TYPE	SERVICE	LOCATION	MANUFACTURER	MODEL #	TYPE (CAV / VAV)	OA CONTROL (DCV / DRY-BULB ECONOMIZING / ENTHALPY ECONOMIZING / NO CONTROL)	HEATING ELEMENT (HEATING COIL - HOT WATER / HEATING COIL - STEAM / BURNERS)	COOLING ELEMENT (COOLING COIL - CHILLED WATER / COMPRESSORS)	HUMIDITY CONTROL (HUMIDIFICATION / DEHUMIDIFICATION)	YEAR INSTALLED	OPERATING SCHEME	OPERATING SCHEDULE	OPERATING STRATEGIES	BAS TRENDING?	NOTES

Figure 3. Example of Building Equipment Inventory Table

Documenting BAS Capabilities

Once you've completed your HVAC inventory, the next step is to document your BAS's capabilities. BAS trend data is used to find many opportunities from operational changes that increase energy efficiency to Sequences of Operation/Control Loops that may need tuning. You must fully understand your BAS's ability to leverage it in the CampusCoach process. By taking an inventory, you can identify opportunities to improve the monitoring and control of your systems. To assist with this process, this guidebook provides a spreadsheet template detailing the BAS points to aid your analysis and tracking of Key Performance Indicators (KPIs).

Vital information to document during this process includes:

- **What points exist on your BAS?**
  - Of those points, which are already trending?
  - What are the trending settings for those points? (frequency, # of points stored, etc)
- **Which points need trending enabled for your analysis?**
- **Which points need to be added to your BAS?**
- **Are there any manual overrides?**
- **Are there any sensors out of range? Are any sensors known to require calibration?**

Taking inventory of your BAS points is also particularly important to the BOCS tagging process and gives insight into what points should be added for better visibility.

Documenting Meter and Submeter Information

Meter and submeter information is another good source. Make sure to document meter numbers and the systems/equipment that each meter serves whenever possible. Having this information will help you distinguish between accounts that are central plant vs. building-specific sub-meters, natural gas vs. electric meters, etc., when performing your energy data analysis. It will also help with reporting energy savings by fuel type, equipment, system, and building when energy savings opportunities are implemented.

Collaboration with Facilities Staff (Models 2 and 3)

IDENTIFY AND INVENTORY KEY CAMPUS EQUIPMENT

The campus Facilities Staff should be engaged during the data collection process to help identify key pieces of HVAC equipment. Their firsthand knowledge and experience with the systems provide valuable insights that may not be readily apparent from your HVAC and BAS inventories. Conversations with the Facilities Staff allow for a more comprehensive understanding of their HVAC systems, which can help identify equipment with the greatest potential for energy savings.

Facilities staff can also give your team access to handwritten documentation they keep on-site, such as facility logs (chiller, boiler, etc.) and maintenance logs. These logs can provide valuable supplemental information on any overrides that were implemented and on which control devices and/or equipment are not operative.

By combining the staff's practical expertise with data from the HVAC and BAS inventories, a more accurate assessment of the systems and their controls can be made. You can then plan how you want to prioritize equipment to maximize energy-saving opportunities. Involving Facilities Staff in the data collection process not only enhances inventory accuracy but also fosters a sense of ownership and responsibility among staff, which can contribute to the long-term success of energy conservation efforts on campus.

REVIEW THE ACCURACY OF EXISTING EQUIPMENT KNOWLEDGE

Nobody knows the buildings and systems better than the campus' facilities staff. Their experience is invaluable in understanding the pain points of their systems and the challenges they face in bringing comfort to a wide range of occupants/spaces.

Meetings should be organized with the Facilities Staff during the data collection process. They have intimate knowledge of their HVAC systems and are likely already aware of opportunities to save energy and improve system performance. They also understand the unique requirements of different campus zones, such as temperature and humidity controls for specialized facilities. Additionally, the Facilities Staff can provide insights into their day-to-day operations and challenges. This will help you bridge the gap between documentation and everyday operations, leading to informed decision-making and improved energy efficiency.

The Facilities Staff also have a deep understanding of how the equipment is reflected on their BAS. They can provide valuable information regarding which sensor readings are accurate and reliable and which may be missing from the BAS. This input is essential for addressing BAS issues and ensuring it provides accurate, actionable data.

In these meetings, it is also essential to gather information on the history of each building on campus - including changes of use in any buildings/zones, any equipment that has been replaced, and any SOOs that may have changed.

By engaging the facilities staff, you can use their expertise to ensure accurate and comprehensive inventories, optimize the BAS for your analysis, and identify existing opportunities for operational improvements. This collaborative approach fosters a culture of continuous improvement and enables you to make informed decisions that enhance the efficiency, reliability, and sustainability of their facilities.

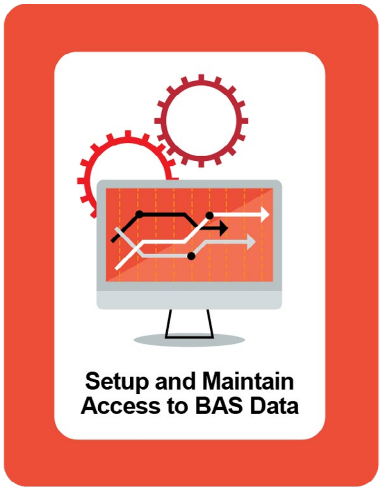
Facilities Records and Field Surveying

Site visits should be organized as needed to verify the accuracy of information obtained from HVAC and BAS inventories. These visits allow you to inspect the equipment and BAS in person, identify any discrepancies between your documentation and the actual systems, and document any notes or records the staff may have. Field surveys also provide opportunities to document any systems not in the original drawings or other conditions that Facilities Staff highlight. Information collected on site can be used to update both your and the Facilities Staff documentation.

Field surveys often uncover opportunities for improved maintenance of central plant and building equipment. While this document is data-focused, it is crucial to make sure your equipment is running efficiently mechanically. Ensuring that all members of your staff check for issues such as dirty coils, dirty filters, leaky valves, combustion efficiency, and more will help ensure your equipment and system performance do not degrade over time and can improve efficiency in some cases. For example, if you have dirty filters, your fans are working harder and using more energy than what is normally required to meet the duct static pressure setpoint.

STEP 2B

Set Up / Maintain Access to BAS Data



The ability to trend BAS data is required to monitor key KPIs at the campus and building levels. Most BAS's in the HVAC industry can trend, but we've found they're lacking in presentation, readability, flexibility, and data storage.

The inconsistency of BAS installations led us to create both SAMS, a student data monitoring system introduced in the previous section, and BOCS, a combination of technological solutions that enables remote data access, visualization, and trend analysis. We recommend installing BOCS or a similar trending system; however, we will cover the requirements for multiple data access setups below.

How the data should be trended will depend on the storage capabilities of the BAS on site, the workstation access preferences of Facilities Staff and campus energy personnel, and whether other groups will lead the data analysis process.

Trending With Existing Workstation

If a member of the campus' Facilities Staff will oversee monitoring the KPI's and implementing Building Re-tuning, the native BAS workstation can be set up for trending if it meets the requirements below:

- The BAS workstation has enough storage capability and computer resources to trend at least 3 AHUs and the central plant simultaneously. It should have enough storage to trend points every 15 minutes for at least two weeks. If there is not enough storage or processing power, you can ask your control contractor if an upgrade is available.
- Trend charts must have clear axes labels, precise timestamps, clear point labels or point legend, and distinct colors for each point.
- Trend charts are recommended to have the ability to show two Y-axes, the ability to zoom or scroll over points for granular analysis, and the ability to add or remove points from a trend easily.

An example of a hard-to-read and a clear and easy-to-read trend chart is shown below:

Crowded and difficult to read trend chart

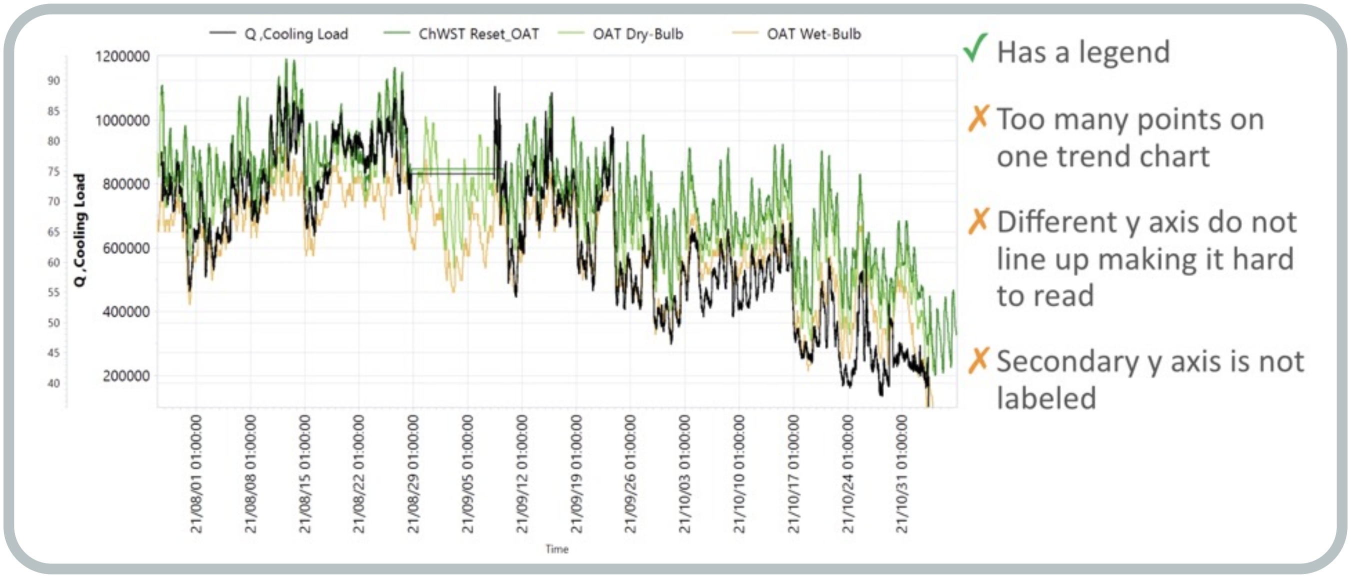


Figure 4. Example of crowded and difficult to read trend chart

Clear and easy to read trend chart

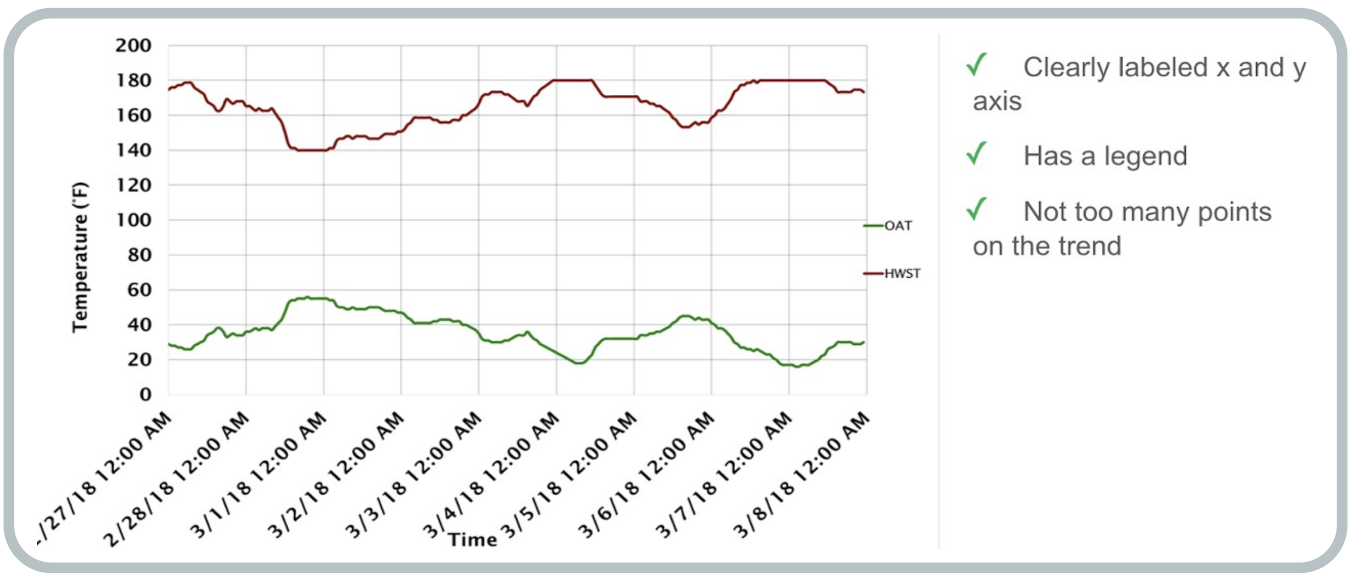


Figure 5. Example of clear and easy to read trend chart

Using the existing BAS workstation remains an option if students, faculty, or a third party are involved in data analysis; however, this will require periodic access to the local workstation or remote access to the workstation. The pros and cons of all the trending setups are covered in the following section.

Trending Options: Pros and Cons

Suppose a student, faculty member, or campus coach will oversee monitoring the KPIs and making recommendations. In that case, the Facilities Staff must approve access to BAS data, which can be accessed in 3 ways. The pros and cons of the first option also apply to Facilities Staff trending at the local BAS workstation.

1. **Grant periodic access to the BAS workstation for screenshots of system schematics and export of trended data. The analysis of the data will be done "offline," away from the BAS workstation.**
   - **Pros:** No cost solution, familiar interface to show trends to building operators, no IT involvement.
   - **Cons:** Storage capacity, potentially computer resource intensive, trends are only available locally, and coordination with operations staff is required for access, likely a limitation on the number of systems that can be trended simultaneously, and visuals are restricted to the local trending interface presentation and readability.

2. **Grant remote view-only access to the BAS. All trends are stored on the stationary engineer's BAS workstation but can be viewed remotely at any time by the Project Team.**
   - **Pros:** Minimal or no cost, no coordination with operations staff is required to access data, data gathering can be done off-site
   - **Cons:** Could require IT cooperation for initial access, trend storage is still on the local workstation, likely a limitation on the number of systems that can be trended simultaneously, and visuals are restricted to the local trending interface presentation and readability.

3. **Grant remote view-only access to system schematics. All trending will be done on another computer or in the cloud. SAMS and BOCS are examples of this setup. The process for installing SAMS and BOCS is covered in the next section.**
   - **SAMS Pros:** Remote access to and analysis of trends, removes storage and processing burden from local workstation, all necessary trends can be set up.
   - **SAMS Cons:** Will require IT cooperation, can be expensive to install as a vendor will likely charge per point, and will be a mirror of the local trending interface unless it is configured differently.
   - **BOCS Pros:** Cheaper than SAMS, trending data is stored in the cloud, removing local trending burden, Building Re-tuning™ trend charts are pre-configured, flexibility to add and remove points easily, ability to change point colors, easy to scan trend charts.
   - **BOCS Cons:** Likely requires IT cooperation and will need a physical trending device installation or virtual machine (VM) installation. Requires proper documentation, such as mechanical drawings, control drawings, and/or As-builts, for setup.

Installing an alternative trending workstation, such as SAMS, or installing BOCS, are both viable and recommended options for facilities staff. For example, if you have a Supervisory Control and Data Acquisition (SCADA) system that stores data, access can be given to students, faculty, or a third party. An existing SCADA system can reduce both the cost and time for third-party integration and for students and faculty; however, the data needs to be correctly tagged and delivered in a helpful format.

SAMS INSTALLATION AND DEPLOYMENT

As written in the "Engaging Students" section, the Student Access Monitoring System (SAMS) was created as part of a Master's Capstone Project at CCNY. SAMS is a view-only copy of the main BAS workstation for trending and monitoring.

Installing SAMS may differ on your campus, depending on the structure of your BAS network and the relationship between the Facilities Staff and IT. Due to the BAS network infrastructure, the CCNY project team had to work with CCNY IT and CCNY's BAS controls contractor, CSG, to pull data from the main workstation to a designated SAMS computer in the project team office, away from the Facilities Staff office. The SAMS computer at CCNY is an iMac running Linux, but a computer with Windows can also be used. CSG worked in phases to pull data points for the systems identified by the project team and manually rebuilt the system schematic views and the trending capabilities for those points. Since there was pending work being done on the CCNY cooling plant, which included adding more points to the main BAS, the SAMS data pulls had to be reviewed and updated to match.

If you choose to install another workstation like SAMS to manage trending, you need to determine the following:

- The HVAC systems and HVAC schematics you want to copy over to SAMS.
- Trending intervals for all the points, we recommend 15 minutes for temperature data and change of state for status points or equipment that cycles frequently.
- Data storage capacity. We recommend a storage capacity of at least 2-3 years to enable a baseline comparison of system performance.

BOCS INSTALLATION AND DEPLOYMENT

The BOCS has different installation methods, each with its own benefits and advantages. The different installation methods are explained below. Campus energy personnel, operations staff, and IT departments must work together to determine their preferred installation method.

Data connectivity for the BOCS is a one-way connection, with BAS points pulled from the BACnet network and sent to the cloud for trending and data tagging. The BOCS only has read access to the BAS and can only communicate with BACnet networks to receive data. If you have a legacy or proprietary system, a gateway needs to be installed to convert legacy or proprietary devices to BACnet.

BOCS installations are customized to suit existing IT policies and infrastructure; however, there are two main ways installations occur. There are physical installations that require a small device that connects to the main BACnet controllers via Ethernet to discover all the BACnet devices and points. This device has Normal Framework (a trending software) installed on it and sends BAS points to the cloud for tagging and visualization. The second option, to set up a virtual machine (VM) with trending, requires that the BAS be on the IT network.

Physical Installation

Physical installations use two methods to send data to a secure cloud. The options are detailed below.

OPTION 1

If the BAS is not on the IT network, a cell modem is connected to the device to send the data to the cloud. A strong cell service connection in the room(s) with the central BACnet controller(s) is required. This method does not require assistance from the IT beyond sending the internal IP addresses of the BACnet controllers. If facilities or operations staff have this information, they can send it directly to the installer instead. Typically, IT networks want visibility into outbound data, so energy personnel must decide whether this method is best for them.

OPTION 2

If the BAS is on the IT network, the data must be sent out through the network. In this scenario, clearance from and ongoing coordination with IT are mandatory for installation. The following information is needed to install:

- Assigned IP address for IPC (device that is installed)
- Access point for IPC (device installed) to the IT network (Ethernet port)
- 110V electrical outlet for IPC (device that is installed)
- External IP address we can use to open our firewall.

Data Tagging and Verification

Once installation is complete, the QA (quality assurance) and QC (quality control) process begins. This process requires remote VPN access to the BAS or screen-sharing sessions with staff at the local BAS to ensure that points are appropriately tagged. Remote access is preferred because it allows installers to connect without requiring an operations staff member, energy personnel, student, or faculty member to be present at the BAS. If remote access is not possible, then scheduled Zoom screen-sharing calls are required for the QA and QC process. Screen sharing will be used to confirm that all necessary points are trending in the cloud and properly tagged. This is necessary because backend point naming in the controllers often does not match what is stored on the frontend. The naming of the points can be obscure, so a QA and QC process is mandatory.

Virtual Machine Installation

VM installations require IT departments to install a pre-built VM with Normal Framework provided by an integrator, or to build their own VM and install a Normal Framework package that is sent to them. Either method requires clear communication with your IT department throughout the installation process. The advantages of virtual machine installation are:

- No physical device installation is required for on-site staff.
- IT can control access and revoke access at any time.
- All the data can be collected from one central location.

A diagram of the virtual machine setup for IT departments is provided below.

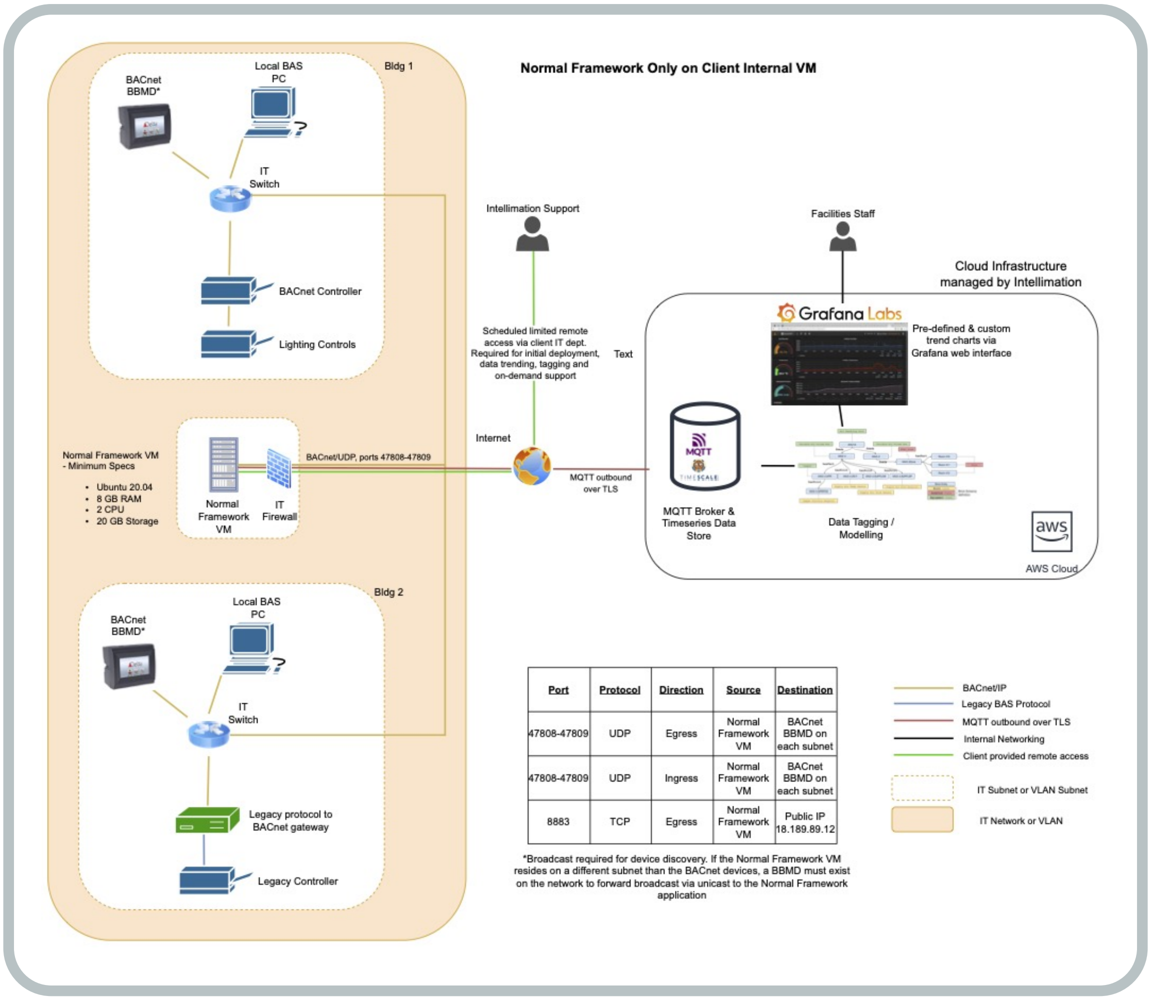


Figure 6. Diagram of the virtual machine setup for IT departments

Once the virtual machine is installed the same QA/QC process that was outlined for a physical installation must be followed.

If there are additional questions about installing SAMS and/or BOCS, please reach out to bpltraining@ccny.cuny.edu.

Confirm all Key Performance Indicators (KPIs) & Required BAS points Are Trending

The purpose of this step is to establish a baseline energy use for your campus and provide data points to track and quantify/visualize energy savings after implementing measures. This section provides examples of the different data you can use, either as KPIs or to calculate KPIs, and should be used in conjunction with the provided KPI spreadsheet template.

The template is designed to help you determine what KPIs and BAS points would be most helpful to track for your campus. It has separate tabs for documenting your central plant BAS points, your individual building BAS points, and your meter information. The goal here is to document the kinds of data you have access to and can track, which will inform the development of your KPIs.

Review the example list of KPIs and BAS points below - if you have the BAS points/meter information available to track any of these, you can use them for your campus. Depending on the types of projects you are looking to implement, you may want to focus on some KPIs over others. For example, if you are primarily focused on chiller plant improvements, you may want to track Chilled Water Pump Speeds or Chilled Water Supply Temperature Resets. Keep in mind that BPL developed this list of KPIs and BAS points for CUNY City College's systems, and there may be other data not listed that would also be useful for you to track. In general, you will want to choose KPIs and BAS points that track the progress and potential savings of your specific implementation measures.

Examples of KPIs include:

Campus-Level Energy BAS Points and KPIs

- Monthly Building/Central Plant Energy Use (kWh, Therms, ccf, Mlbs steam, Gallons of oil, etc.)
- Annual Building/Central Plant Energy Use (kWh, Therms, ccf, Mlbs steam, Gallons of oil, etc.)
- Daily Load Profiles for Building/Central Plant Energy Use
- Chilled and Hot Water Flow Meters (gpm)
- Energy Use Intensity (kBTU/sf)
- EnergyStar Score

Central Plant Equipment BAS Points and KPIs

- Chiller Plant Efficiency - COP, EER, SEER, Integrated Part Load Value (IPLV, see Campus Level Strategy 2 for more details)
- Boiler Plant Efficiency
- Hot and Chilled Water Supply & Return Temperature - Setpoints, Resets, Delta T (oF)
- Hot and Chilled Water Secondary Pump Variable Speed Operation (% speed)

- Chilled Water Primary and Condenser Water Pump Speeds (% speed)
- Condenser Water Temperatures, Setpoints, and Resets (oF)
- Cooling Tower Fan Status (On/Off) and VFD Fan Speeds (% speed)
- Steam usage (Mlbs). Examples of steam metering include a Vortex meter for high-pressure steam and a condensate bucket meter for low-pressure steam.

Building-Level Equipment BAS Points and KPIs

- Outside Air Temperature (oF) and Relative Humidity Sensor Data (% RH)
- Building Occupancy Schedules
- Building Chiller, Boiler, and/or Heat Exchanger Status (On/Off), Supply and Return Temperatures, and Resets (oF)
- Air Handler points as available - Fan Status (On/Off)/Speeds (% speed), Duct Static Pressures (in. w.c.), Damper Positions (% open or % closed), CO2 Levels (ppm), Economizing Status (On/Off or Enabled/ Disabled), Heating and Cooling Status (On/Off)/Positions (% open or % closed), Air Temperatures and Setpoints (oF), etc.
- Zone points as available - Variable Air Volume Damper Positions (% open or % closed), Reheat Status (On/Off or Enabled/Disabled)/Positions (% open or % closed), Zone Temperatures and Setpoints (oF), etc.
- Perimeter Heating Status (On/Off or Enabled/Disabled)/Positions (% open or % closed), Discharge Air Temperatures and Setpoints (oF), Zone Temperatures and Setpoints (oF), etc.
- Chilled and Hot Water Flow Meters (gpm)

Because we are using data to find energy savings opportunities, it is of the utmost importance that the data be accurate. Ideally, sensors and meters would be tested for accuracy before any building data is analyzed.

Campus-level energy KPIs can be tracked by collecting utility and energy-use data. The central plant and building-level equipment KPIs can be tracked by ensuring that trending is enabled for the BAS points listed above. The provided KPI template should be used to document the status of these data points and identify any gaps in your data capabilities. Be sure to address any issues with trending your BAS points or accessing your energy data, as they are required to perform the campus-level analysis.

STEP 3

Central Plant and Campus-Level Optimization

Finding low-cost and no-cost operational changes to support your energy management goals is central to an effective energy management program. Much of this handbook is dedicated to finding those potential changes. This section will focus on optimizing at your central plant as well as other campus-level considerations.

But if you start by analyzing your campus-level energy usage data, you'll be equipped to answer three fundamental questions:

1. How is our campus-level, year-over-year performance?
2. Are we turning on our boilers and/or chillers under the right conditions?
3. How sensitive is our energy usage to changes in weather?

The types of campus-level data you'll need to analyze will include a baseline year of energy usage data, the central plant equipment inventory and other documentation (from Step 2), and your BAS central plant data.

The goal of the campus-level optimization is to identify opportunities for energy savings, improved comfort, and financial savings by tweaking major campus systems. However, sometimes buildings on a campus dictate the heating, cooling, and pumping needs, and therefore must be considered at this step of the campus coach process. Generally, this does not require a full analysis of the buildings that drive campus energy usage, but it does require identifying the constraints these buildings impose on campus-level systems.

The upcoming sections walk through the process of setting up and performing a campus-level analysis. At the end of the campus-level analysis, workshops will be conducted to discuss and review findings.

Baselines Template and Guidelines

CHOOSING YOUR BASELINE YEAR OF ENERGY DATA

The baseline year serves as the reference point for comparison, representing the energy usage before implementing one or more energy efficiency measures. There are a few factors to consider when choosing your baseline year. You will want to choose a recent year where your monthly energy usage was typical for the campus. Energy usage was affected in 2020 and 2021 due to the COVID pandemic making those years poor choices as a baseline. Choosing a more recent year reflecting typical usage will ensure that the baseline estimation will be accurate to the energy usage of your campus' current mechanical systems and controls.

You will also need to select a year where you have access to that full years' worth of energy data. It is important that baselines for each month and season can be estimated accurately.

WEATHER-NORMALIZING ENERGY DATA

To get a reliable estimate of year-over-year performance, use "weather-normalization" to eliminate the change in energy performance due to, say, a particularly hot summer. You can do this manually with a spreadsheet, or you can use a publicly available tool called the Energy Star Portfolio Manager (ESPM) that is developed and maintained by the U.S. Environmental Protection Agency (EPA). The KPI for campus-level energy performance is your weather-normalized "site energy use intensity" (site EUI). Entering the required data in the ESPM will give you this KPI for as many years as you have data. Guidance documents on using ESPM and generating the weather-normalized site EUI graphs can be found in the template folder shared alongside this handbook. Appendix A provides a tutorial on how to calculate it without the ESPM.

It's also helpful to know how your campus performs relative to the median, and the EPA provides this value. For colleges and universities, the median site EUI (corresponding to an Energy Star Score of 50) is 84.3 kBTU/sf[3].

Having weather-normalized data, whether via ESPM or by hand calculations, enables you to see how your campus' energy usage changes year over year independent of changes in annual weather. The percentage difference between the estimated and actual energy usage will show you how much better (or worse) your campus is performing. As always, changes in performance can be due to tightened operations, changes in space use, and myriad other factors. Appendix A provides guidance on calculating the "business as usual" scenario and comparing it to actual energy usage for a given year.

CREATE BASELINES

The weather-normalization step may be enough data analysis for you, but you can go further by performing a regression analysis. Doing so will help you answer the second and third questions (are you

3 "U.S. Energy Use Intensity by Property Type", Energy Star Portfolio Manager Technical Reference, August 2024. https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf

turning on your heating/cooling systems under the right conditions, and how sensitive is your energy usage to changes in weather).

The regression analysis used by the BPL team yields models that separate energy usage into three categories based on OAT: heating, cooling, and "baseload" energy use. Baseload energy is defined as any energy that is not for heating or cooling and includes distribution system losses, lighting, computers, appliances, etc. Appendix B outlines the steps for this regression analysis.

These regression analyses have multiple advantages:

- They will determine the outdoor air temperatures at which you start your heating and cooling systems.
- If you choose to weather-normalize your data without the help of Portfolio Manager, the temperatures at which you start your heating and cooling systems can also be used as the constant you use to calculate your Heating and Cooling Degree Days (See Appendix A for more details).
- They can quantify the sensitivity of your heating and cooling systems to changes in outdoor air temperature.
- If your buildings are individually metered, you can perform these analyses on the buildings on campus to see which ones are the most sensitive to changes in outdoor air temperature.

This could influence your thinking regarding your priorities for energy management, as described in the following section.

INTERPRETING YOUR BASELINE ANALYSIS

As mentioned above, modeling your campus' energy use data with regression analysis has several advantages. NOTE: Your models must be statistically reliable to be useful (See Appendix B for more details on validating your models).

Seeing the OAT at which you start your heating and cooling systems can also help you reconsider when to start them. Changing weather patterns may require you to start your systems earlier or later in the year than you usually would.

Using the actual OAT at which you bring your heating/cooling systems online as the constants for calculating Degree Days will make the weather-normalization step of your data analysis more accurate to your specific campus than if you were using the common constant of 65°F.

Visualizing energy use data with change-point models (or other models of your choice) can help you understand where energy is used most. A steep cooling or heating slope on one of these models indicates that your heating or cooling system is more sensitive, and energy use increases dramatically with changes in outdoor air temperature. This could mean that your cooling or heating systems are using more energy than intended, which can direct you towards specific systems to analyze for opportunities.

If you have the data, performing this modeling analysis on each building can highlight which buildings have the most opportunities for savings. Identifying buildings that are more sensitive to changes in outdoor air temperature can inform your plan for finding opportunities on campus.

In addition, breaking down your campus energy use by category will help you quantify energy savings more accurately. Once you have a regression method to extract the cooling, heating, and baseload energy use from your usage data, you can analyze your data before and after implementing changes. Combining the regression analysis results with your weather normalization, you can quantify the energy savings associated with specific heating or cooling system improvements. See Appendices A and B for more guidance on how to use both analyses in tandem.

Analyze Performance / Find Opportunities for Campus Level

A meta-study performed by the Pacific Northwest National Lab (PNNL) of 151 buildings found that typically, no-cost and low-cost measures can yield 5 to 20% energy savings[4] (Katipamula, 2020). The following is a packet of no-to-low-cost strategies, convergent with the PNNL measures, which were recommended to the operating engineers at CUNY City College. The measures were developed by BPL through conversations and meetings with CCNY operating engineers, but not all the measures were ultimately implemented.

This list is an example of the types of strategies that will be identified to achieve savings through the CampusCoach analysis. Some of these strategies may apply to your campus, but others may not.

The strategies below are all data- and documentation-driven. If BAS trend data or documentation is needed for any strategy, it will be listed in the guidance for finding opportunities with that strategy. If you have equipment-level energy-use data, you can also take the experimental route, where you can apply strategies for short periods and check the energy data to see whether you saved energy. This route may not apply to every strategy, but some experimentation may lead to real savings. You may discover different equipment configurations or sequences that save energy while still meeting the load.

Once you have completed the steps of collecting documentation and setting energy baselines for analysis, you can begin building a packet of strategies specific to your campus. During the data analysis process, measures specific to your campus will be identified. Those measures can range from no-cost and low-cost measures to capital projects.

Note: Any recommendation must be discussed with operating personnel to ensure there are no unintended consequences of implementation.

4 Katipamula, S. 2015. "Improving Commercial Building Operations thru Building Re-tuning: Meta-Analysis: Updated 2020." PNNL-SA-156277

Chiller Plant Strategies

1. HYBRID CHILLER PLANT OPTIMIZATION (use of electric vs gas/steam)

Chiller plants with systems that use different fuels and chillers with varying efficiencies offer a unique opportunity for optimization. By strategically selecting and prioritizing which chillers (and fuels) to use at various times of the year, you can meet demand while reducing energy use, peak demand, on-site carbon emissions, and costs. This strategy can be applied to any hybrid chiller plant (any combination of different chillers – air-cooled, centrifugal, absorption, screw, reciprocating, etc.).

Steps for finding opportunities:

1. Determine the efficiency and capacity of each chiller in the plant.
   - Chiller efficiency curves and capacity should be available from the manufacturer of each chiller.
   - When looking at chiller efficiency curves from the manufacturer, make sure to note what data points you would need to track the efficiency of your chillers. That is a potential KPI for a chiller plant!
2. Determine the number and type of chillers in use at various times throughout the year.
   - Chiller capacity and efficiency curves come into play here. Determining your optimal chiller staging configuration will depend on which chillers are most efficient at different loads.
   - BAS data should be used to monitor and analyze chiller activity (chiller on/off status, chilled water supply and return temperature, etc).
   - If you are implementing this strategy alongside Strategy # 2 (Chiller Part-Loading Optimization), you will also want to collect Condenser Water Supply and Return Temperatures as part of an analysis on the part-load efficiencies of your chillers. See Strategy # 2 for more details.
3. Using your methods from steps 1 and 2, compare costs and energy usage under different chiller staging configurations during on- and off-peak times throughout the year.
   - Make sure to document any staging configurations you try and collect BAS data from each testing period.
   - Use past energy usage to compare and evaluate potential energy, cost, or carbon savings when implementing each configuration.

Recommendations from BPL:

1. Lead with the most efficient chillers as often as possible.
   - For example, if you have both electric- and steam-powered chillers, lead with the electrics.
   - If you have any chillers with variable speed drives, lead with them.
   - If you have multiple types of electric chillers, follow the steps above and determine which is the most efficient at various times of the year.
2. If you have an absorption chiller, you can plan to lead with them as a peak demand shaving strategy during demand response events[5] (PNNL O&M Best Practices).

5 O&M Best Practices https://www.pnnl.gov/projects/om-best-practices

2. CHILLER PART-LOADING OPTIMIZATION

This operating strategy should be implemented alongside Operating Strategy #1 to optimize chiller plant staging further. However, it can be implemented regardless of whether the chiller plant is hybrid or if all the units use the same fuel. Understanding the performance of the individual chillers requires knowing how efficient each chiller is at full load and how efficiency is affected as it is unloaded. Understanding individual chiller performance may give insight into how to operate the chiller plant consistently and efficiently at part-load conditions. This may also inform general prioritization for chiller selection in a hybrid chiller plant. For example, if your chillers operate better at lower part load, there are times when you should consider running multiple chillers if the minimum flow requirements through each chiller can be met.

Steps for finding opportunities:

1. Determine the efficiency of each chiller in the plant.
   - Chiller efficiency curves should be available from the manufacturer of each chiller.
   - When looking at chiller efficiency curves from the manufacturer, make sure to note what data points you would need to track the efficiency of your chillers. That is a potential KPI for a chiller plant!
   - In addition to manufacturer chiller efficiency curves, you can use your BAS data to estimate the load on the chiller plant. The points you'll need include Chilled Water Supply & Return Temperatures and Chilled Water Flow (gpm). This can help to inform decisions about how many chillers need to be brought online on a given day. To calculate the heat load (in BTU/hr) at any given time, use the following equation:

     $$h = cp*\rho*q*dt$$
     $$= (1 \text{ Btu/lbm oF})*(8.33 \text{ lbm/US gal})*q*(60 \text{ min/h})*dt$$
     $$= 500\ q\ dt$$

     where

     h = heat load (Btu/h)
     cp = specific heat, 1 (Btu/lbm oF) for water
     ρ = 8.33 (lbm/US gal) for water
     q = water volume flow rate (GPM)
     dt = temperature difference between CHWST and CHWRT (oF)

   - Another valuable metric to calculate is each chiller's Integrated Part Load Value (IPLV). IPLV helps compare the average efficiency of chillers of different makes, models, and capacities. To calculate the IPLV, use the following equation:

     $$IPLV = 0.01A+0.42B+0.45C+0.12D$$

     Where the variables A, B, C, and D are either the COP or EER at a given part load, when calculating the IPLV, the COP or EER must be used consistently:

     A = EER/COP @ 100% Load, assumed to be 1% of the time the unit is running
     B = EER/COP @ 75% Load, assumed to be 42% of the time the unit is running
     C = EER/COP @ 50% Load, assumed to be 45% of the time the unit is running
     D = EER/COP @ 25% Load, assumed to be 12% of the time the unit is running

2. Using the chiller efficiency curves and IPLV, you can determine which chillers are the most efficient under different load conditions.
3. Try to plan out which chillers should be brought online under different load conditions based on their part-load efficiencies or IPLV. The operating staff likely already knows each chiller's "sweet spot" in terms of efficiency, and that should be considered in any plan. The analyses in steps 1 and 2 of this strategy may augment that knowledge or present opportunities to modify the existing chiller staging sequence. Changes may include updated guidance on when to bring additional chillers online on hot days or using chillers that are more efficient at 75% or 50% load on milder days. The key here is to understand each chiller's efficiency so that informed decisions can be made when chillers need to be brought online.
   - While it is recommended to make these decisions as often as possible, that may not be realistic. Try to plan ahead when you can - daily is ideal, but weekly may be more achievable.
   - A predictive approach can be applied here to give operators a few days ahead of time to make decisions. See Appendix C for a recommended approach.

3. IMPROVE VFD CONTROL OF SECONDARY CHILLED WATER PUMPS

The intent of the primary-secondary loop configuration on a chilled water distribution system is to allow the secondary chilled water pumps (SCHWPs) to be independently varied for light loads while maintaining minimum required flows across chillers via the primary loop. VFD control in the secondary loop enables significant pumping efficiency, taking advantage of the Power Laws under which the pump's energy use reduces by the cube of the pump speed. Since energy use is a cubic function of pump speed, controlling pump speed is highly impactful on energy use.

Steps for finding opportunities:

1. Collect BAS data on primary/secondary chilled water pump speeds, chilled water supply temperature setpoint, primary/secondary chilled water temperatures, loop differential pressure setpoints, freeze protection setpoints, and points on the terminal units that are dependent on your chilled water supply temperature (cooling coil valve positions, for example).
2. Analyze the BAS data for opportunities to slow down the secondary chilled water pumps. The points used in your analysis will change based on your configuration. In general, you will find opportunities by looking at the behavior of the terminal units served by the chiller plant.
   - For the example of chilled water serving cooling coil valves, you might find opportunities to slow down your secondary chilled water pumps during times when the cooling coil valves are throttling.
   - Note where terminal units have three-way valves instead of two-way valves, as you may not be able to slow the secondary chilled water pumps as much in those cases

Note: This strategy can also be applied to hot-water heating distribution pumps. In this case, you will want to analyze BAS data related to your hot water distribution system and terminal units served by that system (hot water supply temperatures, hot water distribution pump speeds, heating coil valve positions, etc).

4. CHILLED WATER SUPPLY TEMPERATURE-SETPOINT RESET

You can achieve energy savings by resetting the chiller plant's Chilled Water Supply Temperature Setpoint (CHWST-SP) when conditions allow. The higher you can reset the CHWST-SP while still meeting your campus's cooling and dehumidification requirements, the greater your energy savings.

Steps for finding opportunities:

1. Collect BAS data similar to Operating Strategy #3. You will want to monitor your CHWST, CHWST-SP, CHWRT, Zone Temperatures, and their Setpoints, as well as the points on the terminal units that depend on your CHWST.
2. Using the example of chilled water serving cooling coil valves, monitor your cooling coil valve positions for times during off-peak conditions when they are throttling. You can raise the CHWST-SP during those times. If you are monitoring zone temperatures as well, check whether they meet their setpoints when you raise the CHWST-SP.
   - If valve positions are not available, you can monitor Chilled Water Return Temperature instead
3. As part of this strategy, an analysis should be done to determine when savings from increasing the CHWST breaks even with the increased pumping required to meet what is required at the AHUs.
   - Raising your CHWST-SP will result in higher chilled water pump speeds and, therefore, increased pumping energy. Conversely, lowering your CHWST-SP will result in lower chilled-water pump speeds and reduced pumping energy. Shifting the load from the chillers to the pumps typically saves energy, but the pump penalty should still be calculated for your campus equipment. A good number to keep in mind is that chiller power consumption is reduced by 1.0 – 1.5% for every degree Fahrenheit the CHWST-SP is raised[6].

Note: This strategy can also be used to implement a reset of the potential hot water supply temperature setpoint. See Operating Strategy #11 for more details.

5. IMPLEMENT CHILLER DEMAND LIMITER CONTROLS

Peak-demand charges can be avoided by leveraging on-board chiller controls. Many chillers have demand limiters and pull-down demand limiters, which serve different functions. A demand limit setpoint will prevent compressors from turning on when the setpoint is exceeded. For example, a demand limit setpoint of 50% will stop 50% of the compressors from turning on (see Figure 7). Pulldown demand limiters function similarly but can set a limit on each compressor motor for a specified period after they come online. Depending on your chiller's capabilities, you may be able to limit the compressors for up to a few hours after coming online.

As long as the cooling load is met, you can experiment with different demand-limit setpoints to avoid peak-demand charges during the day. Some energy savings can also be achieved by preventing over-cooling.

6 Doty, Steve, 2016. Commercial Energy Auditing Reference Handbook, 3rd Edition, Lilburn, GA: The Fairmont Press, p.270.

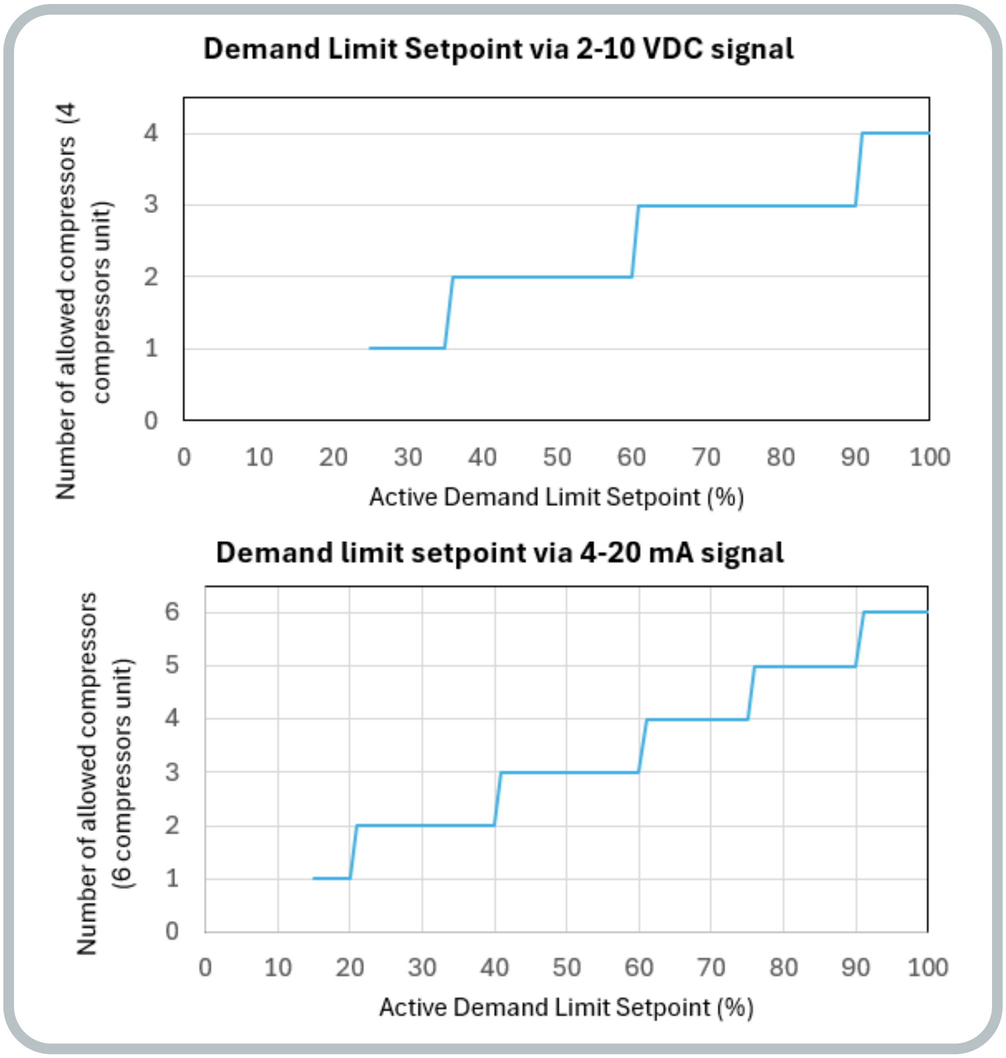


Figure 7. Example of a demand limit setpoint of 50% that will stop 50% of the compressors from turning on

This strategy can be improved upon by implementing a predictive response strategy. The BPL team analyzed CCNY's chiller plant operations and developed a method to predict the plant's cooling load based on a 3-day wet-bulb temperature forecast. See Appendix C for more details on this analysis. A predictive response strategy can empower your team to make decisions ahead of time about when to set demand limits on your chillers, as well as what optimal demand limit setpoints to use during those times.

6. CONDENSER WATER SUPPLY TEMPERATURE (CWST) DYNAMIC RESET

Chillers consume less energy when they receive lower temperature water from the cooling towers. Condenser Water Supply Temperature (CWST) resets can significantly reduce chiller plant energy consumption with little to no capital investment[7] (ASHRAE, 2013). A commonly recommended dynamic reset to achieve savings sets CWST to 7°F above the outdoor air wet-bulb temperature. It is estimated that there is a 1.5 % reduction in chiller full load energy usage for every one degree the CWST is dropped up to a CWST of outdoor air wet bulb plus 7°F[8] (ACHR News, 2004).

7 ASHRAE. (2013). Energy standard for buildings except Low-Rise residential buildings. ASHRAE/ANSI.

8 https://www.achrnews.com/articles/92941-maximizing-chiller-efficiency

Energy savings result from the compressor having to overcome lower refrigerant pressures from the cooler condenser water to satisfy evaporator loads. The increased cooling-tower fan energy required to achieve these lower CWSTs needs to be considered but is more than offset by the reduction in chiller energy.

Recommendations from BPL:

- **Option 1.** Implement a dynamic CWST reset based on wet-bulb temperature. As mentioned above, setting the CWST-SP to be equal to wet-bulb temperature plus 7°F is a common strategy. Your team can also experiment with different dynamic resets across a range of wet-bulb temperatures to determine which resets work for your specific buildings and systems.
- **Option 2.** Program an alert into your BAS to manually change your CWST-SP based on changes in wet-bulb temperature.

For either option, you should consult the chiller manufacturer's documentation for guidance when determining the minimum allowable Condenser Water temperature. It is also essential to keep in mind that an overly aggressive CWST-SP can result in Cooling Tower fans always running at 100% speed, which can impact energy savings from the CWST-SP reset you're implementing. Cooling Tower fan energy should be considered when deciding on the right CWST-SP reset strategy.

7. COOLING TOWER LOAD SHARING (with improved VFD fan speed control)

The recommended strategy is to implement load sharing among your Cooling Tower fans. You can achieve energy savings by:

- ensuring that when any of your CT fans are running, they are running at the same speed.
- experimenting with adding more CT fans online while reducing the speed of the fans.

When adding extra cooling towers, one must consider the principle of diminishing returns. Your team can use the steps below to determine the balance between adding extra cooling towers and achieving energy savings.

Steps for finding opportunities:

1. Collect and monitor the following BAS points to ensure that any CT fans online are running at the same speed.
    - CT fan speed
    - CT fan status
    - CT fan feedback
2. Experiment with adding more CT fans online and reducing their overall speed.
    - To estimate the energy savings of each configuration of number and speed of fans, use the following logic:

      According to the Affinity Laws, fan power is equal to the cube of its speed. If you reduce a fan's speed by 50%, its power is reduced to about 12.5%.

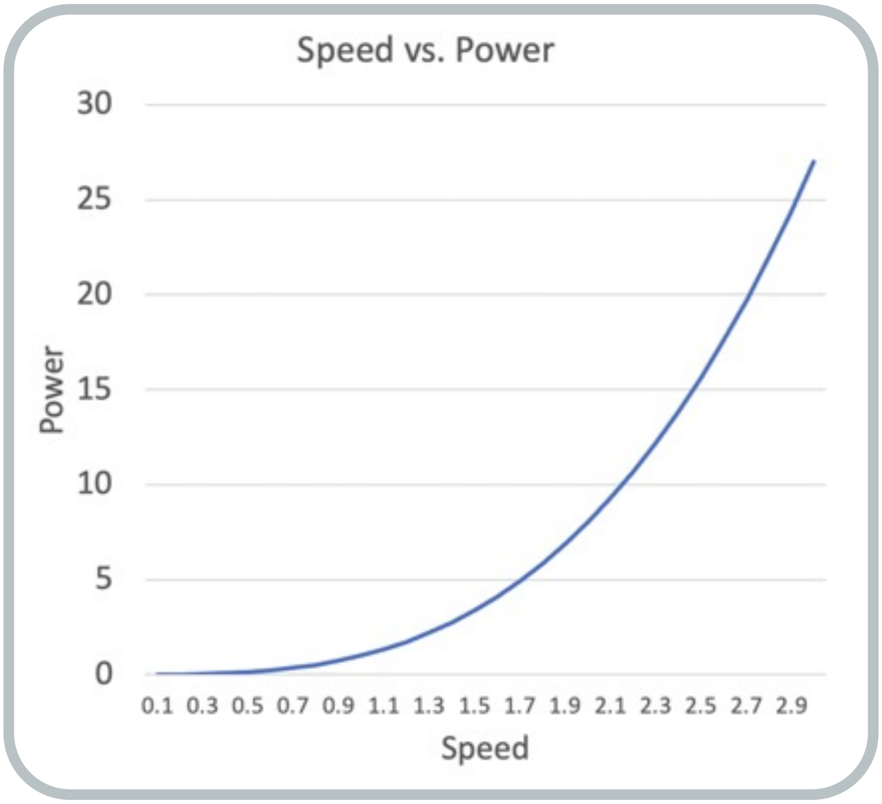


Figure 8. Example of the Affinity Laws for speed and power.

Changing from one fan running at 100% speed to two fans running at 50% will save 75% of your total fan energy (12.5% + 12.5%). Adding another fan will save 8% more energy (11.1%+11.1%+11.1% - 12.5%+12.5%).

- When implementing cooling tower fan load sharing, additional condenser water pumping may be required to meet minimum CT flow rates. Keep this in mind when deciding how many CT fans to run.
- Additional considerations here include the minimum allowable speed that your cooling tower fans can achieve, as well as the changes to Condenser Water flow when bringing more Cooling Towers online. Typically, the flow across a tower can be reduced by only about 50% unless the tower includes low-cost modifications, such as weirs or nozzle cups.

8. WATER-SIDE ECONOMIZER OPERATION

A water-side economizer bypasses the vapor-compression cycle in the chiller and uses the condenser water loop to directly cool the chilled water loop (See figure below). The condenser water loop is piped to a heat exchanger to allow the bypassing of the chiller. The heat exchanger may be piped in parallel or series with the chiller (see figure below). When in parallel, the water-side economizer provides all the cooling for the primary chilled water loop. When in series, the water-side economizer can provide cooling on its own or be used to pre-cool the chilled water loop, reducing the work required by the chillers.

Note: To use the WSE to pre-cool the chilled water loop, the chiller needs to see CWST above a specific temperature, especially older chillers, so you might need a separate injection loop to keep the CWST going to the chillers high enough. Check the documentation for your WSE and chiller to see if this is a feasible option.

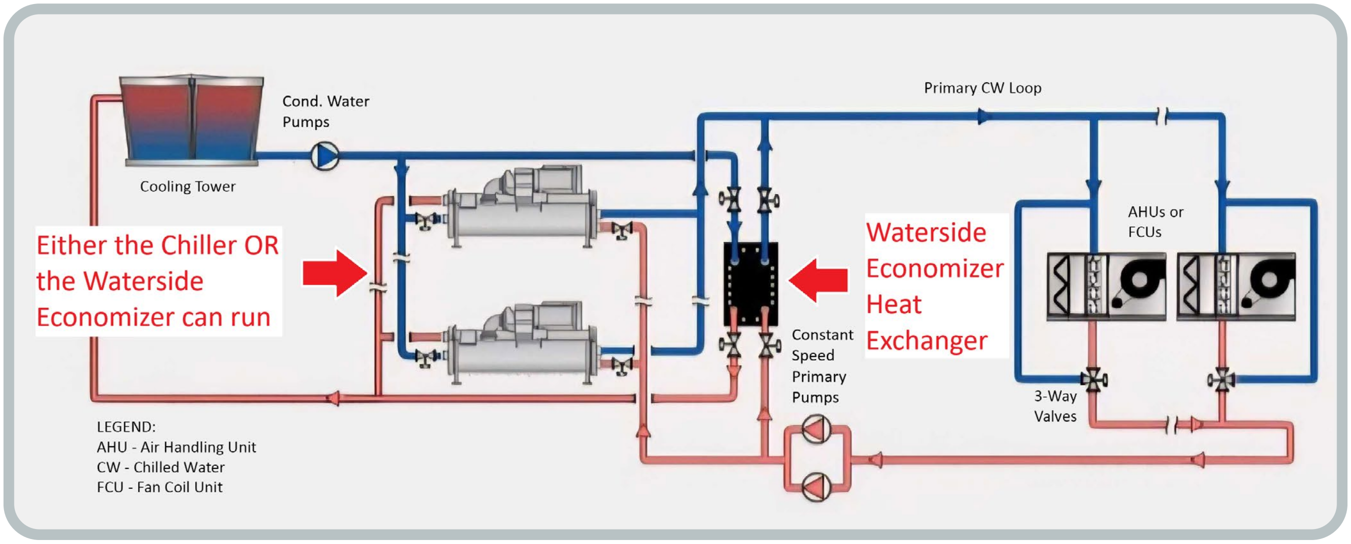


Figure 9. Non-integrated Waterside Economizer - WSE and Chillers are piped in parallel
Image Source: "How to Model a Waterside Economizer Application." Carrier Engineering Newsletter, vol. 4, no. 1, 2016, p. 13.

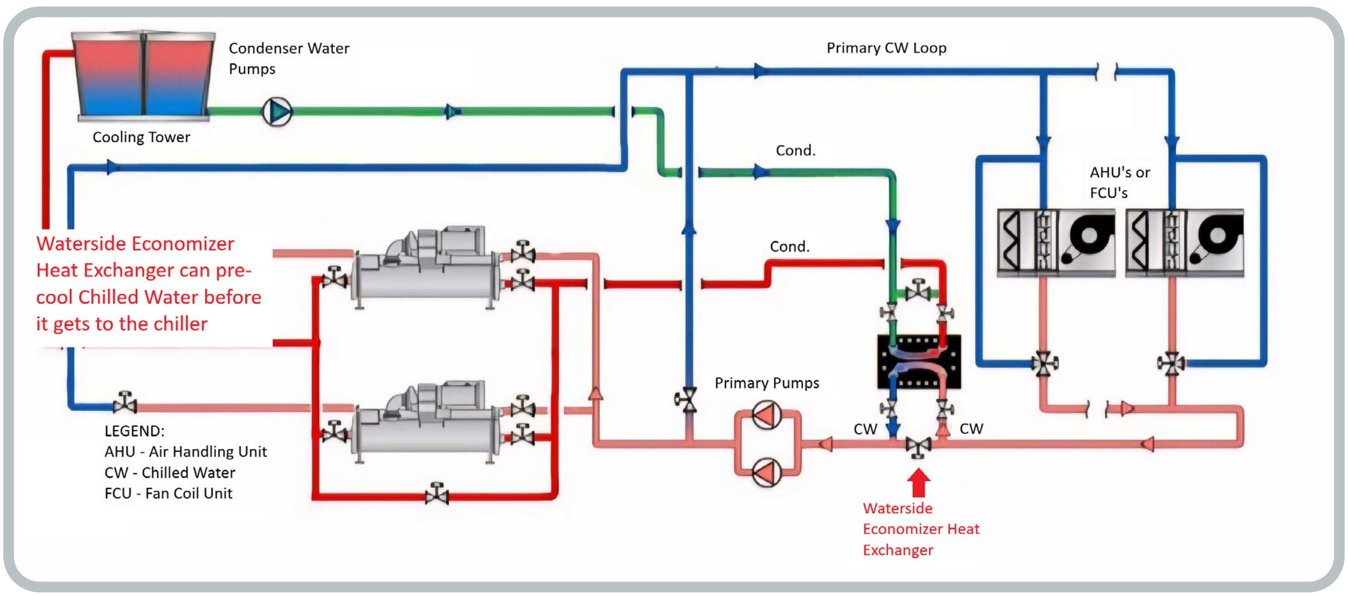


Figure 10. Integrated Waterside Economizer - WSE and Chillers are piped in series
Image Source: "How to Model a Waterside Economizer Application." Carrier Engineering Newsletter, vol. 4, no. 1, 2016, p. 13.

Significant savings can be achieved if your water-side economizer is used correctly and under the right conditions. Below are recommended control sequences to achieve savings, depending on the piping configuration of your economizer.

Recommendations from BPL:

For an integrated economizer configuration (your chillers and heat exchanger are in series and can operate simultaneously), implement the controls sequence below. This sequence is recommended by ASHRAE Guideline 36 (starting on page 15 of GL36), which requires implementing advanced BAS logic and controls. If you are unable to implement these steps in your BAS logic, you may need a more relaxed control sequence for switchover.

1. Enable Water-Side Economizer if Chilled Water Return Temperature is greater than the Predicted Heat Exchanger Leaving Water Temperature + 2 degrees (CHWRT > PHXLWT + 2°F)
2. Disable Water-Side Economizer if it does not reduce the CHWRT by at least 1°F or, of course, if the load is not met.

For a non-integrated economizer configuration (your chillers and heat exchangers are in parallel, and only one can operate at any given time), implement the controls sequence below. This sequence is recommended by ASHRAE Guideline 36 (starting on page 15 of GL36), which requires implementing advanced BAS logic and controls. If you are unable to implement these steps in your BAS logic, you may need a more relaxed controls sequence for switchover.

1. Disable chillers when the Heat Exchanger Leaving Water Temperature (Chilled Water Supply) is less than or equal to the Chilled Water Supply Temperature Setpoint (HXLWT is ≤ CHWST-SP) by an amount that is approved by the operating staff
2. Enable chillers when the Chilled Water Supply Temperature is greater than the Chilled Water Supply Temperature Setpoint (CHWST > CHWST-SP)
3. Run as many tower cells as tower minimum flow limits will allow.
4. Control Condenser Water flow such that it responds appropriately to changes in Chilled Water flow but reduces to maintain a minimum of 5°F range.
5. Typically, Condenser Water flow rates exceed Chilled Water flow rates by 25-50%. Recommended flows for each loop are commonly:
   - Chilled Water flow - 1.8 GPM/Ton
   - Condenser Water flow - 2.3-2.5 GPM/Ton
6. Tower Speed Control:
   - When WSE is disabled, control fan speeds to maintain (dynamic) CWST-SP
   - When WSE and chillers are enabled, run fans at 100% speed.
   - When chillers are disabled, control fan speed to maintain HXLWT at ChWST-SP

For both sequences above, recommendations for when to switch over on days when outdoor air conditions are milder should be left to the discretion of the operating staff.

Heating Plant Strategies

9. HOT WATER DISTRIBUTION TUNING - HOT WATER PUMP SPEED CONTROL & LOW DELTA T

Part of tuning your hot water distribution system is ensuring that your delta+ T – the difference between your hot water supply and return temperatures – is appropriate. A good dT can be anywhere from 10-20 degrees depending on the design intent of your hot water plant. There are various causes for low delta T issues:

- Open Bypasses
- Dirty or blocked heat exchange surfaces
- Excessive Hot Water Supply Temperature (See Operating Strategies #11 and #12)
- Over-pumping - Pump is too large or imbalanced.
- Under-pumping - Possible causes are the Hot Water Pump Speed controls need tuning or Differential Bypass Valves on the HW Distribution need adjusting.

This operating strategy will focus on monitoring your system for dT issues and optimizing the controls of your hot water distribution pumps.

Steps for Finding Opportunities:

1. Collect BAS data on Hot Water Supply Temperature (HWST), Hot Water Return Temperature (HWRT), Hot Water flow, Differential Pressure on the hot water loop, and pump speeds for the hot water pumps. If you can, set up a digital point that calculates delta T every time the BAS records HWST and HWRT.
   - If your hot water distribution system has a primary/secondary loop configuration, you will only need to collect temperature, pressure, and pump speed data on the secondary loop.
2. Look for any times where dT is below 10 degrees and check the pump speeds at those times. If the pump VFDs are not responding to changes in the dT, that is an opportunity to diagnose the issue with the VFD controls logic and achieve savings.
   - In general, you will want to see the pumps slowing down when dT is too low.

NOTE: When lowering the pump speeds, monitor the zone temperatures in the buildings that are hydraulically the furthest away from the heating plant. It's important to make sure those zones are still satisfied when tuning the hot water distribution.

10. HOT WATER DISTRIBUTION TUNING - HOT WATER SUPPLY TEMPERATURE RESET

This strategy applies to typical hot water systems with hot water temperatures of 180°F or below.

While tuning the hot water distribution system, you can achieve further savings by implementing a Hot Water Supply Temperature Setpoint (HWST-SP) Reset (or optimizing an existing reset). The most common way to implement a dynamic HWST-SP Reset is to change the setpoint based on outdoor air temperature. The higher the OAT, the lower the HWST-SP. If you have zone temperature points enabled on your BAS, you can also implement a HWST-SP Reset based on zone temperature feedback.

Steps for Finding Opportunities:

Check your BAS or on-board boiler controls for any existing HWST-SP Resets. If none exist, implement one based on either OAT or Zone Temperature Feedback.

Collect BAS data on Hot Water Supply Temperature (HWST), Hot Water Return Temperature (HWRT), Outdoor air temperature (OAT), Zone Temperatures, and Zone Temperature Setpoints. Monitor these points to ensure any implemented HWST-SP Resets are working correctly.

11. LOWERING HWST ON CENTRAL BOILER PLANT TO LOWER LOSSES THROUGHOUT CAMPUS

You may be able to minimize heat loss in your heating hot water distribution system by lowering the HWST-SP on your central boiler plant. This strategy can be implemented alongside Operating Strategies #10-12 on tuning your hot water distribution system.

Fourier's Law of Heat Conduction states that conduction increases as the differential temperature at opposite ends of a system increases. The hotter your HWST, the greater the conduction losses in your hot water distribution system.

Steps for Finding Opportunities:

1. Collect BAS data on HWST, HWRT, HCV positions, Zone Temperatures, and Zone Temperature Setpoints
2. Lower your HWST-SP by 5 degrees. Monitor the HCV positions to see if they are starved (open > 85%) and your Zone Temperatures to know if they are meeting their setpoints. If all is well, lower your HWST-SP by another 5 degrees. Go as low as you can, as long as your zones are satisfied, and you will reduce losses in your hot water distribution system while saving energy.

Note: Losses will also be reduced by insulating as much of the hot water distribution piping as possible. Payback periods for pipe insulation are typically short.

12. STEAM PLANT OPTIMIZATION

A significant part of steam plant optimization lies in maintaining the steam boilers and the steam distribution system. Your steam boilers should be tuned before the heating season begins and again halfway through the heating season to ensure maximum efficiency. This regular maintenance should include minimizing excess air intake and blowdown, and visually inspecting the boilers for leaks or damage.

You should also have a plan to test the steam traps in the distribution system regularly. Document the number, location, and age of the steam traps at your terminal units and on the distribution piping and keep that documentation as up to date as possible. Steam traps last about 3-5 years on average and can cause balancing issues if they are not replaced as they fail. In general, it is good to keep an eye out for some of the signs that your distribution system may have failed traps. Some examples include an increased failure rate of condensate receiver seals or a condensate return temperature close to or above 212° F.

Additionally, you can achieve energy savings by reducing the steam pressure as much as possible. Check the design documentation and sequences of operation for guidance on how low you can set your steam pressure while still meeting your heating load.

Campus-Level Workshops

Once the project team identifies the operating strategies that they would like the campus to implement, and with sufficient input from the facilities' upper management on the feasibility of each approach, it is time to set up the Campus-level Workshops sessions to explain and discuss these strategies with the broader facilities team.

It is vitally important that these Campus-level Workshops be an "open forum" style, and that the project team's attitude be to impart knowledge to the operators rather than to endow them with it; instead, be open to the operators' input as you discuss the various strategies for their campus systems. They have the best technical background for their systems; thus, the team should make it clear to the operators that these sessions are collaborative, with both the facilities team and the project team learning from each other. This attitude and the setting of expectations will build solid rapport and a good working relationship between the two teams and increase the chances of implementation. The outline of each session includes this consideration below.

The project team suggests holding at least four sessions throughout the year, with topics aligned with the seasons; for example, two sessions in the cooling season to discuss chiller plant operations, and two more in the heating season to discuss boiler plant operations. Of course, this can be changed based on campus-level analysis and operating strategies arising from discussions with Facilities' upper management and/or other project stakeholders.

Each Campus-level Workshop session should be no longer than 90 minutes, with at least half the time devoted to discussion with operators.

1. Introduction
2. The Project Team should run through each operating strategy in this manner:
   - Review the HVAC fundamentals related to the strategy.
   - Explain how it can be done at that campus, including considerations of campus systems constraints
   - Show the energy efficiency benefits of the measure.
3. Give metrics for tracking the strategy on the BAS via trending.
4. Open the floor to Facilities Staff to talk about the feasibility of implementation of all measures.
   - The project team should be taking notes here to refine the strategies for better chances of implementation.
   - For more expensive recommended measures, discuss the campus' options for advantageous incentives that are available from the state and utilities.

The following is an example outline of the first two Campus-level Workshop sessions held at CCNY:

Campus-level Workshop #1: Setting Expectations

- Participant Introduction
  - Make this interactive!
- Project Introduction
  - Who is the Project Team?
  - What is CampusCoach?
  - Project Plan / Timeline
- Campus-level Workshops - All Objectives
- Campus-level Workshop #1 Objectives
- Discussion on Campus Energy Analysis
  - target need for change based metric that the Facilities Staff resonate with most; could be local laws, decarbonization/sustainability initiatives, campus energy use vs local area, energy budget, etc.
- List of upcoming Campus-level Workshop session topics and scheduling.

Campus-level Workshop #2: Operating Strategies for Condenser Water Loop

- Campus-level Workshop #2 Objectives
- Definition of Chiller Lift
- Ideal Cooling Tower Operations
- ASHRAE Guidance on CWST Reset
- Manufacturer Guidelines on CWST Reset
- Campus Constraints on CWST Reset
- Operating Strategy Recommendation: Implement a CWST-SP Reset
  - How to implement — manual or dynamic
- Metrics for tracking CWST Reset on the BAS
  - Points to Trend
  - Questions for Analysis
- A note on Sensor Calibration
- Discussion
  - Is this recommendation feasible to implement?
  - Can this be done dynamically or manually?
  - Next Steps

Other tips for the Project Team when preparing for these sessions are:

- Work with Facilities' upper management to identify the participants who should be attending the sessions. These should be key operating staff who oversee the systems under discussion and are involved in implementing the strategies. Depending on the facilities staff's relationship with the BAS/ controls contractor(s), they may also be invited to attend the workshops.
- Work with the campus to reserve a room for all sessions. It is suggested that the team choose a space that is "neutral ground," such as a classroom, and not the facilities or the project team's offices. It is also essential to ensure there are no distractions in the space, such as loud equipment or students using the space during the reserved time.
- Ask Facilities Staff for dietary restrictions for lunch orders.
- Assign different project team members to explain each operating strategy, if possible, to keep it fresh for the staff and to avoid having the feel of a "lecture style" class. Of course, the team member(s) who developed the strategy would be best placed to explain it.
- Although there may be multiple speakers, all session PowerPoints should be done in the same format, preferably with consistent style and branding as all project documents.

Depending on the level of comfort of the Facilities Staff members, recording a session is not recommended. There should be a designated project team member assigned to take notes on the discussions at each session.

NOTE: Check out the Dashboard section (pg.63) for guidance and examples for data visualization.

Measure Implementation at the Campus Level

This handbook focuses on getting the most out of the HVAC equipment you already have. While the primary focus is on optimizing existing equipment, there may be instances where upgrading or replacing a component is necessary. We will provide a tracking sheet for categorizing, which will be covered in more detail in the best practices section.

There are low-cost to no-cost measures that Facilities Staff can typically implement on their own, such as adjusting the chilled water supply temperature setpoint, the loop differential pressure setpoint, or chiller sequencing.

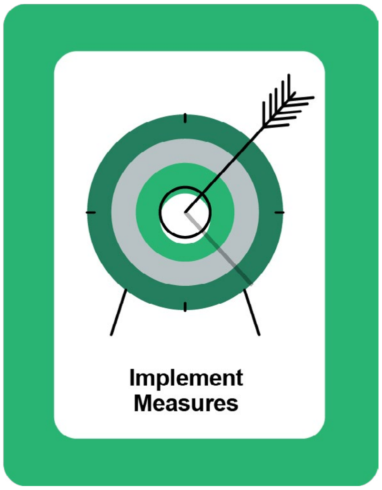
Some low-cost to no-cost measures may require a controls technician for implementation, such as implementing new sequences for cooling tower load-sharing, hot supply temperature reset, or a condenser water supply temperature reset.

There are also capital or large-expenditure measures that may require presenting a case for the associated energy and/or comfort savings. Findings from the campus-level analysis, Campus-level Workshops, and KPI monitoring can serve as supporting evidence to justify funding. The process for acquiring funding will vary by organization, so be sure to follow your organization's specific guidelines.

At the campus level, any changes to setpoints will affect buildings across campus. Building zone temperatures, supply air temperatures, and relative humidity levels should be monitored following any shift in campus-level temperature or pressure. As long as these comfort conditions remain satisfied, the changes can be considered successful.

STEP 4

Ongoing Building Re-tuning and Monitoring Campus-Level Optimization



The critical term here is "ongoing". Specific opportunities can only be found during the heating season, others only during the cooling season, and yet others only during the shoulder seasons. The ongoing efforts described here, season over season and year over year, capitalize on the easiest and most affordable energy-efficiency opportunities.

As every facilities manager knows, schedules and set points change over time, equipment fails, control systems require maintenance, and new technologies frequently emerge to improve operational efficiency. This is the step in the process designed to become ingrained as a regular yet somewhat infrequent activity to ensure that operations and HVAC systems remain well-tuned.

This section describes technical tactics for identifying and implementing opportunities in building systems, as well as monitoring the efficiency of the central plant and campus loops. Some potential measures can only be found during certain seasons of the year.

Exactly how this work is done depends on which of the three models is chosen to assign roles and responsibilities.

In all cases, at the building-system level, the three critical activities are to:

- **Review specified trend charts to find opportunities for improved operations,**
- **Monitor the central plant and campus-level systems for adherence to tactics for optimum operation.**
- **Implement opportunities.**

For the first model, wherein the Facilities Staff (and possibly a controls team) executes the process independently, the Facilities Staff is responsible for all three activities.

In the second model, faculty and engaged students regularly analyze and monitor the performance data and develop recommendations, i.e., activities 1 and 2 above. Facilities Staff meet with them monthly to share recommendations and then determine which opportunities will be pursued.

In the third model, Facilities Staff participate in a coaching session about once every six weeks to review the trend charts and both find and discuss the opportunities. Again, Facilities Staff pursue the priority opportunities.

Note on Sensor Verification

It is recommended that campuses establish a regular schedule for checking and maintaining sensor calibration and/or verifying BAS data. This is typically done with the BAS or controls contractor, as accurate sensors are essential for proper building operation. Data analysis using Building Re-tuning methods, as described in this section, can also highlight issues with sensors and data readings. Note that sensors that are used in cascading systems control loops need to be checked more often, for example, outside air temperature and relative humidity, CO2 level, and zone temperature sensors.

Ongoing Building Re-tuning

General Tactics

1. OUTSIDE AIR TEMPERATURE / RELATIVE HUMIDITY SENSOR VERIFICATION

Many of the systems in a building, from the central plant to the air handling equipment, use Outside Air Temperature (OAT) and/or Outside Air Relative Humidity (OAH) as control parameters. Thus, it is essential that these sensors are working and calibrated correctly, and that no other heat sources are distorting their data.

Steps for Finding Opportunities:

1. Collect available BAS data on OAT and OAH for all systems.
2. Collect OAT and OAH data from a reliable weather station close to your building.
3. Plot both data sets together and compare.
   - If the BAS data is consistently above or below but is still tracking the general shape of the weather station data, then this may mean a calibration is needed for the BAS sensor.
   - If the BAS data is stuck on a number or not reading at all, then the sensor needs to be fixed, replaced, or checked for a communication error.
   - If the BAS OAT data is spiking at specific points of the day, check to make sure the sensor is not exposed to the sun and/or near a source of heat like a smokestack or a cooling tower basin.

Note: RH sensors often require frequent calibration.

2. BUILDING-LEVEL SCHEDULING AND SETBACKS

Scheduling and setbacks are the lowest-hanging fruit in building-level operating strategies. For large campuses and facilities with many AHUs/RTUs, it is common to find systems that do not follow their schedules and/or have opportunities for more aggressive scheduling. Furthermore, proper zone temperature setbacks should be used to ease heating and cooling loads during unoccupied times. To determine whether systems run only when needed, create and monitor trend charts of the systems' key parameters.

Steps for Finding Opportunities with Scheduling:

1. Collect BAS data on Occupancy Schedule, Supply Fan Status or Speed (SFS), Supply Air Temperature (SAT), and Return Air Temperature (RAT).
   - Alternatively, use Supply Air Flow Rate or Duct Static Pressure (DSP) if SFS is not available, and/or Discharge Air Temperature (DAT) if SAT is not available.
2. Check to make sure that the AHU/RTU fan is turning off during unoccupied times and before warm-up or cool-down periods. SAT and RAT are used to verify that the unit is, in fact, turning off, since these temperatures should drift closer to ambient temperature when the unit is off.
   - If the unit has setbacks, then follow the additional steps outlined below.
3. In addition to monitoring trends, all AHU/RTU should be checked for scheduling overrides. If one is in place and no longer needed, make sure that it is removed, and the unit is set back to Auto.

Steps for Finding Opportunities with Setbacks:

1. Collect BAS data on the same parameters above as well as the Zone Temperatures (ZT), ZT Occupied Setpoint, and ZT Unoccupied Setpoint (aka setback temperature).
2. If the unit has setbacks, then the fan may turn on during unoccupied hours to meet the ZT setback setpoint, which is good operation. Check to make sure the fan turns on only when the setback temperature is reached.
3. If the BAS allows you to have a reduced DSP setpoint during unoccupied hours, significantly reduce the DSP setpoint during unoccupied times. This will reduce fan energy.
4. Check also that the zones have the proper setback temperatures for heating and cooling seasons. This may vary by location, but CUNY BPL recommends 60°F for heating season and 80°F for cooling season.

Schedules should be available for all air systems, down to the VAV/zone level. If not, consider upgrading to controls to enable scheduling. For even more energy savings, consider using an "optimal start" strategy.

Air System Optimization Tactics

3. OUTSIDE AIR CONTROL

Minimizing ventilation while maintaining healthy indoor air quality significantly affects energy efficiency. Here, we discuss three tactics that help to achieve this goal: minimum outside air damper position, demand-controlled ventilation, and air-side economizing.

Note that some buildings have separate minimum economizer dampers. So, the Outside Air Damper (OAD) position below refers to the total outside air intake.

MINIMUM OUTSIDE AIR DAMPER POSITION

It is often the case that the minimum OAD position is set too high, and over-ventilation occurs during occupancy, even when the occupancy load is at its maximum. Reducing the minimum OAD position saves on heating and cooling, thereby creating an opportunity for increased energy efficiency. Refer to ASHRAE 62.1[9] for guidance on ventilation for occupied zones.

Steps for Finding Opportunities:

1. Collect BAS data on the Occupancy Schedule, SFS, OAD Position, and CO2 Levels of densely occupied zones.
   - Alternatively, use Supply Air Flow Rate or DSP if SFS is not available.
   - Alternatively, use CO2 of return air if the air handling unit serves a single zone, such as an auditorium or gymnasium.
2. Check that the CO2 sensors are calibrated adequately by making sure that CO2 tends close to 420 (+/-75) ppm during unoccupied times. If not, calibrate or replace the sensor to ensure the associated control loops use the correct data.
3. Check that the maximum CO2 level of the highest-occupied zone does not go above 900 PPM - 1,100 PPM for more than 1 hour. If it goes above this threshold, consider increasing the minimum OAD position setpoint. If the max CO2 never reaches close to the threshold during occupied times, then consider lowering the minimum OAD position setpoint.

Demand Controlled Ventilation

Demand Controlled Ventilation (DCV) is a strategy that automatically adjusts the amount of ventilation supplied to a space based on the actual occupant load. This is commonly achieved by using carbon dioxide (CO2) sensors to measure the air's CO2 concentration and then adjusting the outdoor air damper position (or the VAV damper position for zone-level DCV) accordingly. In addition to resetting damper positions based on CO2, there is usually an opportunity to reduce the minimum OAD position. A reduced minimum OAD position is critical to realizing the potential energy savings.

Steps for Finding Opportunities:

1. Collect BAS data on Occupancy Schedule, SFS, OAD Position, CO2 level of densely occupied zones, and VAV damper positions for densely occupied zones.
   - Alternatively, use Supply Air Flow Rate or DSP if SFS is not available.
   - Alternatively, use CO2 of return air if the unit serves a single zone, such as an auditorium or gymnasium.
2. Typically, a DCV sequence opens the OAD when needed for more ventilation based on a maximum CO2 setpoint. When you have DCV, make sure your minimum OAD position is as small as possible; it will open to ventilate as the CO2 concentration approaches the setpoint. As the occupant density decreases, the OAD position will decrease.

9 ANSI/ASHRAE Standard 62.1-2022, "Ventilation and Acceptable Indoor Air Quality".

Air-side Economizing

Air-side economizing saves energy by using outdoor air to cool the building, thereby offsetting some of the energy used for mechanical cooling. When the outdoor air temperature and humidity allow for economizing, the outside air damper will open as needed. Sometimes called "free cooling", economizing usually still requires some mechanical cooling, just not as much as without economizing.

Steps for Finding Opportunities:

1. Collect BAS data on Occupancy Schedule, SFS, and OAD Position.
   - Alternatively, use Supply Air Flow Rate or DSP if SFS is not available.
   - Alternatively, use OAT, MAT, RAT to approximate the OAD Position, if not available. The OAD Position can be approximately equal to the Outside Air Fraction (OAF), which can be calculated by: OAF = (OAT-RAT) / (MAT-RAT). Note that this formula is not reliable when OAT is within a few degrees of RAT or when MAT is within a few degrees of RAT.
2. Ensure that OADs are closed during unoccupied times unless needed for economizing for setbacks or any required air changes during start-up. If not, then make sure that the OAD is following the scheduled programming for the air-handling unit.
3. Check to see if the OAD is following the correct sequence when economizing is enabled. If in cooling mode and the OAT is within the economizing range (typically 50-65°F, adjustable), the OAD should open beyond the minimum position to allow for "free cooling". Otherwise, the OAD should be at the minimum position.

4. DUCT STATIC PRESSURE RESET

Many air handlers and rooftop units with VAV boxes operate with a fixed Duct Static Pressure Set Point (DSP-SP). Typically, DSP is significantly higher than needed to satisfy the zone requirements for many hours of operation. Thus, the VAV dampers are often set to minimum positions to achieve the required airflow to the zones, and the fans run faster than needed.

Steps for Finding Opportunities:

1. Collect BAS data on Occupancy Schedule, SFS, DSP, and its setpoint, VAV Damper Positions. Alternatively, use Supply Air Flow Rate or DSP if SFS is not available.
2. Check to make sure that the DSP meets its setpoint. If not, be sure that there are no leakages in the ductwork or dampers.
3. A simple way to save energy is by having a DSP-SP reset based on time of day and/or Occupancy Schedule. During occupied times, this can be used when zone loads are easily predicted, such as low loads for the first and last hour or two of occupancy. A time-based reset is especially effective when there are setbacks, as lowering the DSP-SP during unoccupied periods can reduce fan energy use when the system turns on to meet the setback temperature.

4. A more advanced way is to have a dynamic DSP-SP reset, as now required by the energy code in some states and municipalities. Control techniques can differ and yet still meet the energy code. One control strategy is specified in ASHRAE Guideline 36-2024[10]. The specifics of the sequences of operations vary depending on the type of VAV boxes used, but the overarching strategy is to “trim and respond.” With this technique, the static pressure is automatically reduced incrementally until a specified number of “requests,” i.e., calls for more duct static pressure, is reached. At this time, the DSP automatically increases it. The DSP rises until there are no more requests, and the cycle begins again. This is a relatively “low-cost” upgrade if the required points are already visible to the BAS.

5. AHU VALVE CONTROL

AHU heating and cooling valves should be checked for proper operation. Checking the valves will also help determine whether any unnecessary simultaneous heating and cooling is occurring.

Steps for Finding Opportunities:

1. Collect BAS data on Occupancy Schedule, SFS, Heating Coil Valve (HCV), and Cooling Coil Valve (CCV) positions.
   - Use Supply Air Flow Rate or DSP if SFS is not available.
   - Alternatively, use the temperatures after the HHV and/or CCV if the valve positions are not available.
2. Check whether the CCV and/or HCV modulate.
   - If not, then have the controls vendor repair the control loop between the valves and the Supply Air Temperature Setpoint (SAT-SP) or the CCV and the relative humidity set point if humidity control is used.
   - Alternatively, the valve itself may need to be repaired or replaced.

If the chillers, boilers, and their pumps are running and the air handler’s HCV and CCV are opening simultaneously, this indicates simultaneous heating and cooling. If this occurs outside a dehumidification system, energy is being wasted. Be sure to check for and fix any sensor, control sequence, valve, or override issues on the heating and cooling lockouts.

Other Equipment Tactics

6. PERIMETER AND AIR

In perimeter zones, i.e., zones with exterior walls, many buildings have both perimeter heating and an air system that together provide heating and ventilation. It is often the case that either the systems are not controlled together or the operators are not trained to pick setpoints that optimize operations. This can cause several issues in perimeter zones, including overheating, simultaneous heating and cooling, and/or reliance on the less efficient system for heating. While overheating is uncomfortable, the other two issues can be perfectly comfortable for occupants, but they use more energy than is needed.

10 ASHRAE, “Guideline 36-2024, “High-Performance Sequences of Operations for HVAC Systems”

We focus here on an operating strategy for the heating season. There are many types of perimeter heating systems (e.g., hot water fin and tube, steam radiators, fan coil units, and packaged terminal heat pumps to name a few). Regardless, the critical determinant in selecting an operating strategy is whether the zone thermostat controls the perimeter system or the air system to meet the zone temperature set point.

When the zone thermostat controls the perimeter system, typically the best approach is to:

1. Set zone thermostat set points to meet a comfortable zone temperature during occupied hours.
2. Set zone thermostat setback set points to allow zones to cool down during unoccupied hours.
3. Schedule the air system to be off during unoccupied times.
4. Set the air system's SAT (or the VAV DAT) to be at least 5°F cooler than the occupied zone temperature setpoint — typically 60 - 65°F.

   For this configuration, CUNY BPL's recommendations are to:

   - Collect data for the occupancy schedule, ZT-SP, ZT, SFS, SAT (or VAV DAT), whichever applies.
   - Alternatively, use Supply Air Flow Rate or DSP if SFS is not available.
   - Check whether zone temperatures are being met according to schedule and that aggressive setbacks are in place.
   - Ensure that the air system delivers air that is cooler than the ZT-SP during occupied hours, and that the air system shuts down during unoccupied hours.

When the zone thermostat controls the air system, the perimeter system often provides some heat, but not enough to reach the ZT-SP. In this case, we assume a hot-water fin-and-tube perimeter system. Should this be the case, typically the best approach is to:

1. Set zone thermostat set points to meet a comfortable zone temperature during occupied hours.
2. Set zone thermostat setback set points to allow zones to cool down during unoccupied hours.
3. Be sure that the air systems SAT (or the VAV DAT) does not exceed 90°F to help prevent stratification, i.e., temperature layers within the zones.

   For this configuration, CUNY BPL's recommendations are to:

   - Collect data for the occupancy schedule, ZT-SP, ZT, SFS, SAT (or VAV DAT, whichever applies).
     - Alternatively, use Supply Air Flow Rate or DSP if SFS is not available.
   - In addition, collect data for the occupancy schedule, HWST, and HW pump status.
   - Check whether there are setbacks for unoccupied times and that the space cools to approach those setbacks.
   - Make sure that the perimeter system is not overheating in zones. If it is, adjust the HW perimeter system to prevent this, and check that the air system is not switching to cooling mode to offset the overheating.

7. CONDENSING BOILER

The key to maximizing energy efficiency when running a condensing boiler is to minimize the HWRT. If the HWRT is above about 130°F, a condensing boiler cannot condense products of combustion in the flue gas, so the boiler is not operating in condensing mode and is not as efficient as designed. Furthermore, the lower the HWRT, the better the efficiency — the opportunity here can be more than 8% in efficiency. The effort is well worth it. Figure 11 shows the relationship between Boiler Inlet Water Temp (aka HWRT) and Boiler Efficiency. *Note: The boiler can also have a summer domestic hot water mode, so confirm that the boiler is in heating mode for this opportunity.*

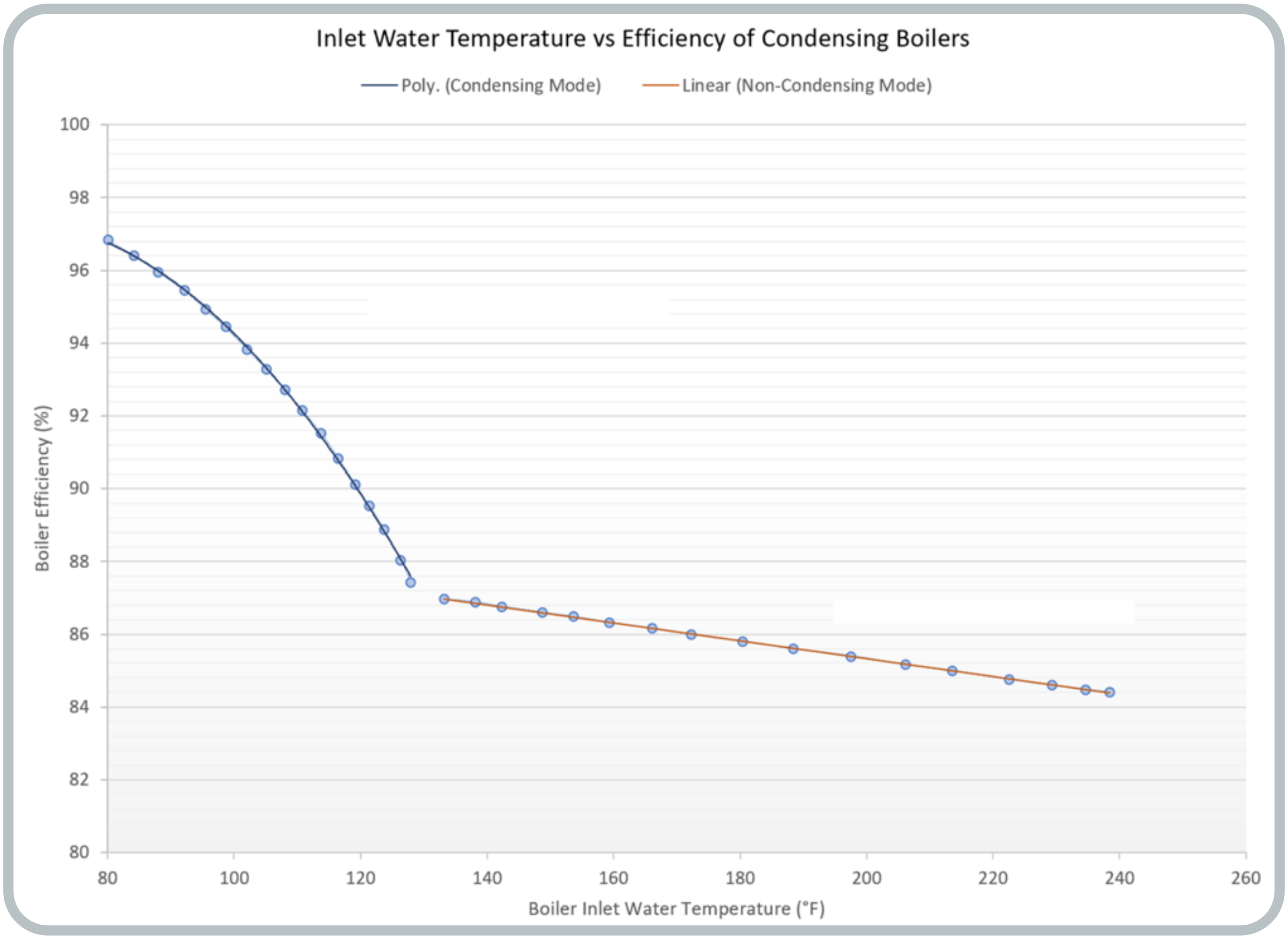


Figure 11. Relationship between a Boiler Inlet Water Temp (aka HWRT) and Boiler Efficiency

Condensing boilers usually have a "hot water reset schedule" that is set by the operator. These set points are two pairs of extremes from the selected OAT and HWST ranges. The colder it is outdoors, the warmer your hot water needs to be.

Here is an example of a hot water reset schedule. You may select an OAT range of 20°F to 60°F, and a HWST range of 110°F to 140°F. Then the two setpoint pairs are:

1. HWST = 140°F for OAT = 20°F, and
2. HWST = 110°F for OAT = 60°F

Whether these HWST setpoints can adequately heat the space is found by trial and error. When experimenting with set points, the operator should monitor the zone temperatures. If not, “cold call” complaints could increase.

Another consideration is the energy required to pump hot water. For larger systems, a dynamic reset that minimizes the pump speed based on heating valve positions is ideal. This will reduce the HWRT temperature (by maximizing “delta T”, the drop in HW temperature), lending greater efficiency. For smaller systems, there will usually not be a VFD on the pump motor. The check here, when reducing the HWSTs in the hot water reset schedule, is to ensure that the most open heating valve closes but does not fully open.

Note: Using more efficient equipment, like an ECM circulator, should be considered.

Steps to finding opportunities:

There are three ‘checks’ for this strategy, and they are to (i) check that the hot water reset is working, (ii) check that the hot water reset is as aggressive as possible, and (iii) check that the hot water pumping is adequate.

1. Collect BAS data on the Occupancy Schedule, HWST, and its setpoint, HWRT, and OAT.
2. Check that the hot water reset function is working correctly (OAT and HWST should ‘mirror’ each other.
3. Collect BAS data on ZTs and ZT-SPs.
4. Check for an increasingly aggressive hot water reset schedule that zones meet their setpoints. It is best to check this, if possible, when the OAT is at the extremes of the HW reset schedule range. As in the example above, this would mean checking for OATs at 20°F and 60°F.
5. Collect BAS data on HW pump speed and heating valve positions.
6. Check that heating valves do not open fully when the load is most significant.

Measure Implementation at the Building Level

To implement the measures at the building level, there are several ways to do so. You can make the changes yourself, either by adjusting the schedule or the set point. These low-cost or no-cost changes can be made through the BAS, an on-board control panel on the building system itself, or even just by manually changing the start-up or shut-down schedule.

Operational Changes

Your BAS may be limited in its ability to schedule specific equipment. This can vary, for example, from not being able to schedule the outside air damper separately from the planned air handlers, which can be scheduled to turn on at a specific start-up time. In this case, some would prefer the OAD to remain closed during start-up and then open it at the beginning of occupancy. Although this might seem like the best option given the limited BAS capabilities, it is recommended that you work with your controls contractor to enable the OAD schedule separately. If there is an opportunity that requires a change in controls, your controls contractor will need to implement the change.

Low- to No-Cost Measures

The opportunities can range from tuning a control loop to changing the sequence of operations for a cooling tower control. There are cases where your team can implement those control changes itself, and, if possible, we recommend it. We do recommend that, whether you are making the control changes yourself or the controls contractor, the trend chart that helped you identify the issue in the first place should be shown. This will not only help show the problem clearly but also shows that you will know what to look for later to check if it is working correctly.

Small Repairs/ Calibration

There will be opportunities found that could include calibrating, replacing, or adding a sensor; a leaky heating coil valve; or a VFD not responding to commands. For these kinds of findings, placing a work order should be the most efficient way to get the work done. It might seem like a simple solution, but there are times when either the budget is not there or the follow-up to get the work done is lengthy. If placing a work order is possible, it is recommended. Upon job completion, be sure to restart trends to ensure they are running correctly. Often, fixing these types of issues can reveal other opportunities.

Low-Cost Controls Upgrades

In recent years, many high-performance sequences of operations have been developed and published. A prominent example is ASHRAE Guideline 36-2024[11]. These sequences are designed to operate systems with significantly less energy automatically.

Upgrading control sequences for operations can be expensive when deploying a large number of new sensors and integrating them into the BAS. Still, in many cases, all the points required for a high-performance sequence are already in place. Upgrading then becomes a software deployment and commissioning process that can be both affordable and yield significant energy savings.

CAPITAL MEASURES

For larger projects requiring more than a work order or a change to the control operation, an energy manager should be contacted if not already involved. There are several programs with funding to support these larger projects. The programs have a broad scope and can include steam trap replacements, control overhauls, RTU replacements, etc. Other programs are longer-term projects that can cover replacing older systems. These programs depend on the city where your campus is located, so contacting your energy manager should be the first step. Here are some organizations that may have funding opportunities for capital projects: NYSERDA, Con Edison, and the Department of Energy. There may also be regional incentives like: TELP financing, the NY Green Bank, and EaaS arrangements. Additionally, you can visit the Database of State Incentives for Renewables & Efficiency (DSIRE) website for state-specific policies and incentives.

Monitoring Campus-Level Optimization

In Step 3, Campus-level Analysis, the focus was on identifying changes to optimize campus-level operations. The identified measures were either implemented immediately or prioritized for future action. As part of the ongoing tuning efforts, central plant and campus-level performance, along with any pending measures, should be regularly reviewed to ensure continued alignment with the initial optimization goals.

Additionally, new opportunities for analysis and optimization may arise over time. These could emerge as upgrades to the central plant are completed (e.g., with the new chiller featuring magnetic bearings, we may need to evaluate when it is more efficient to use water-side economizing), or from studies that haven't been initially considered but are now viable.

The facilities team, faculty-led student teams, or a third-party organization can conduct this work.

11 ASHRAE, "Guideline 36-2024, "High-Performance Sequences of Operations for HVAC Systems"

Best Practices and Guidance

Tracking Sheet and Include Template of the Tracker

An important document strongly recommended for tracking all findings, recommendations, and implementations is the Tracking Sheet. The tracker will keep everything organized in one document and show the process of a finding through the next steps and toward implementation, with dated notes and screenshots. An example of the tracker can is below:

TABLE OF CONTENTS

SCREENSHOTS	FINDINGS + NEXT STEPS	UPDATES / FEEDBACK FROM OPERATOR	WORTH PURSUING?
	[Note] • **Recommendation:** [note]		Not yet
	[Note] • **Recommendation:** [note]		Not yet
	[Note] • **Recommendation:** [note]		Not yet
	[Note] • **Recommendation:** [note]		Not yet
	[Note] • **Recommendation:** [note]		Not yet
	[Note] • **Recommendation:** [note]		Not yet
	[Note] • **Recommendation:** [note]		Not yet

Figure 12. Example of the Tracking Sheet Table of Contents

The table of contents organizes all findings related to each BAS screenshot and keeps the operators' updates/feedback up front, making it easy to find for future use.

The "Worth Pursuing?" column has three options: "Not yet," "Yes," and "No." This will indicate whether the recommendation can be implemented, based on the operators' feedback. The operator's feedback is key to understanding which recommendations to pursue, depending on budget, ongoing work, or the urgency of implementation.

Below the "Table of Contents" section is the "Live Notes" section, which will store the screenshot of the BAS that was analyzed, and the findings found when it was reviewed with the team and notes from when it is reviewed with the operators.

LIVE NOTES

***KEY**: **black** = prep findings | **blue** = meeting notes*

BAS Screenshot Title [Link to Table of Contents]

Prep Findings (mm/dd/yy):

1. [note]

Meeting Notes (mm/dd/yy):

1. [note]
    a. [note]

Figure 13. Example of Tracking Sheet Live Notes section

The template for this tracking sheet is available for download and should be used during your monthly meetings with the operators. This is a building-focused tracking sheet that can be customized to your campus' needs.

A Tracking Sheet for Model 2 is also available. The tracking sheet is designed to record findings and recommendations discussed during monthly meetings that analyze trend charts or BAS schematics. It will track progress in implementing recommendations to ensure they are pursued and completed. It should also provide accurate implementation dates for energy analysis, making it easier to determine energy savings. It will serve as a central hub for documentation, findings, and next steps during review meetings.

The spreadsheet consists of two tabs:

- Equipment Summary
- Recommendations

1. EQUIPMENT SUMMARY TAB

This tab lists all equipment details and provides quick access to relevant documents. It contains seven columns:

- *Equipment Category*: General category or classification of equipment (e.g., HVAC, Boiler, Chiller).
- *Equipment*: Name or specific identifier of the equipment being analyzed.
- *Details*: Any additional descriptive information about the equipment (e.g., model number, location).
- *BAS Graphic*: A link to the BAS (Building Automation System) graphic related to the equipment.
- *BAS Setpoints*: A link to the BAS setpoints for the equipment.
- *Mechanical Drawing*: A link to the mechanical drawing of the equipment.
- *Sequence of Operations*: A link to the sequence of operations document.

How to Use:

1. Fill in the first three columns (Equipment Category, Equipment, and Details) with the relevant information for the building or site being analyzed.

2. Add corresponding document links in the remaining four columns (BAS Graphic, BAS Setpoints, Mechanical Drawing, Sequence of Operations).
    - Ensure all links are up-to-date and functional for quick access during meetings.
3. Not Yet on Remote Trending Software Section:
    - Use this section to list equipment not yet integrated into a remote trending software or another monitoring platform (e.g., BOCS).
    - Include links to columns 4-7 (BAS Graphic, Setpoints, Drawings, and Operations) for the listed equipment.

2. RECOMMENDATIONS TAB

This tab is where findings and recommendations are documented and tracked. It consists of eight columns:

1. *Equipment:* The specific equipment being analyzed.
2. *Trend Chart:* The trend chart points are being evaluated. If a third party is involved, use their trend chart names here.
3. *Finding(s):* A detailed description of the findings or observations related to the equipment and trend charts.
4. *Next Step(s):* Actions or steps that need to be taken based on the findings.
5. *Owner:* Dropdown list to assign responsibility for the next steps.
   Options include Building Engineer, Energy Manager, Contractor, Third Party CampusCoach Team, and N/A.
6. *Priority:* Dropdown list to indicate the urgency of the next steps.
   Options include Low, Medium, High, and N/A.
7. *Status:* Dropdown list to track the progress of next steps.
   Options include Not Started, In Progress, Completed, Deferred, and N/A.
8. *Updates:* Additional notes or progress updates related to the recommendation.

How to Use:

1. *Equipment*: Record the equipment being investigated.
2. *Trend Chart*: Input the trend chart being analyzed. For third-party projects, use the corresponding third-party names for the trend charts.
3. *Finding(s)*: Write down any observations, issues, or findings discussed during the meeting.
4. *Next Step(s)*: Define actionable items or steps needed to address the findings.
5. *Owner*: Assign responsibility for the next steps using the dropdown list.
6. *Priority*: Use the dropdown list to prioritize the following steps based on urgency (Low, Medium, High, or N/A).

7. *Status*: Update the status of the following steps using the dropdown options:
   - Not Started
   - In Progress
   - Completed
   - Deferred
   - N/A
8. *Updates*: Add notes or progress updates during subsequent meetings to ensure transparency and accountability.
9. *Estimated Costs*: If recommendations are considered for implementation, the estimated cost should be added here.
10. *Actual Costs*: Once the recommendations are implemented, the actual costs should be added here.
11. *Estimated Labor Hours*: If recommendations are considered for implementation, the estimated labor hours should be added here.
12. *Actual Labor Hours*: Once the recommendations are implemented, the actual labor hours should be added here.

Example Entry:

EQUIP	TREND CHART	FINDING(S)	NEXT STEP(S)	OWNER	PRIORITY	STATUS	UPDATES	ESTIMATED COSTS	ACTUAL COSTS	ESTIMATED LABOR HOURS	ACTUAL LABOR HOURS
SESSION X - Date											
Equip-ment	BOCS Trend Chart (Dates)	Findings notes while reviewing the trend charts	Next Steps instructions	N/A	N/A	N/A	Updates on the Next Steps	$10,000	$11,500	75	63

Figure 15. Example of a Tracking Sheet Entry

3. USER INTERACTIONS

1. Entering Data:
   - Input equipment details and findings during or immediately after meetings.
   - Ensure that all relevant links and notes are updated to maintain accuracy.
2. Updating Progress:
   - Use the Owner, Priority, and Status dropdown lists to manage and track action items.
   - Regularly update the Status column to reflect ongoing or completed work.
3. Referencing Documents:
   - Use the links provided in the Equipment Summary tab to quickly access BAS graphics, setpoints, mechanical drawings, and sequences of operations.

4. Tracking Implementation Dates:
    - Record findings and updates in the Recommendations tab to ensure the correct timelines are available for future energy savings analysis.

You should constantly update the spreadsheet during or immediately after meetings to ensure accurate records. It is essential to verify that all links are functional and accessible to relevant stakeholders. Priority management is crucial, so use the Priority column effectively to address critical recommendations first. Review and update the Status and Updates columns during each meeting to monitor progress. Accountability for implementing the recommendations is essential; clearly assign owners for each next step to ensure tasks are pursued and completed.

Dashboards

A core principle of Building Re-tuning™ is making HVAC data easily accessible and digestible for building operators and energy managers. Customized dashboards that are tailored to facilities' needs can help operators troubleshoot issues and identify opportunities for energy savings. At CCNY, we created Excel templates for dashboards to monitor KPIs and reset strategies that resulted from the Campus-level Workshops and campus-level analysis. The dashboards were created as an example of what can be added to the BAS for monitoring. In our experience, operators can more easily track KPI's and opportunities for improvement if they are clearly incorporated into the BAS.

Below is the list of dashboards we created, along with an example dashboard. The Excel workbook with all the files will be made available for download as a companion to handbook. As mentioned, these dashboards are examples of what can be done, and they can and should be customized to fit the KPI's that are important to a given campus.

1. Condenser Water Supply Temperature (CWST) Reset
2. Chilled Water Supply Temperature (ChWST) Reset
3. Steam vs Electric Chiller Usage for Off-Peak Periods
4. Steam vs Electric Chiller Usage for ON-Peak Periods
5. Primary-Secondary Pumping and VFD Control

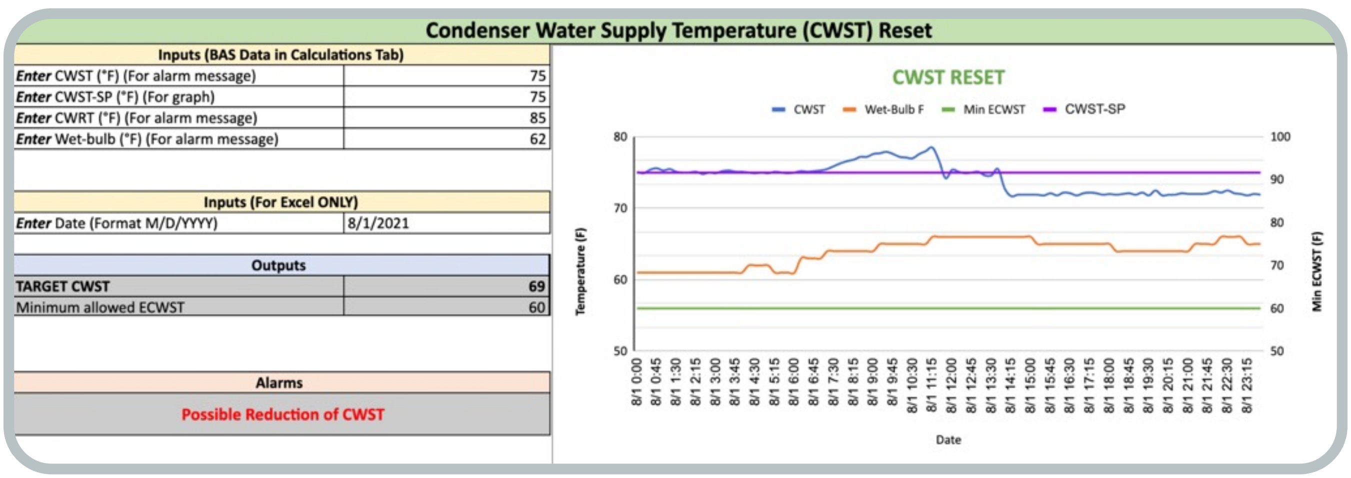


Figure 16. Example of the Condenser Water Supply Temperature (CWST) Reset Dashboard

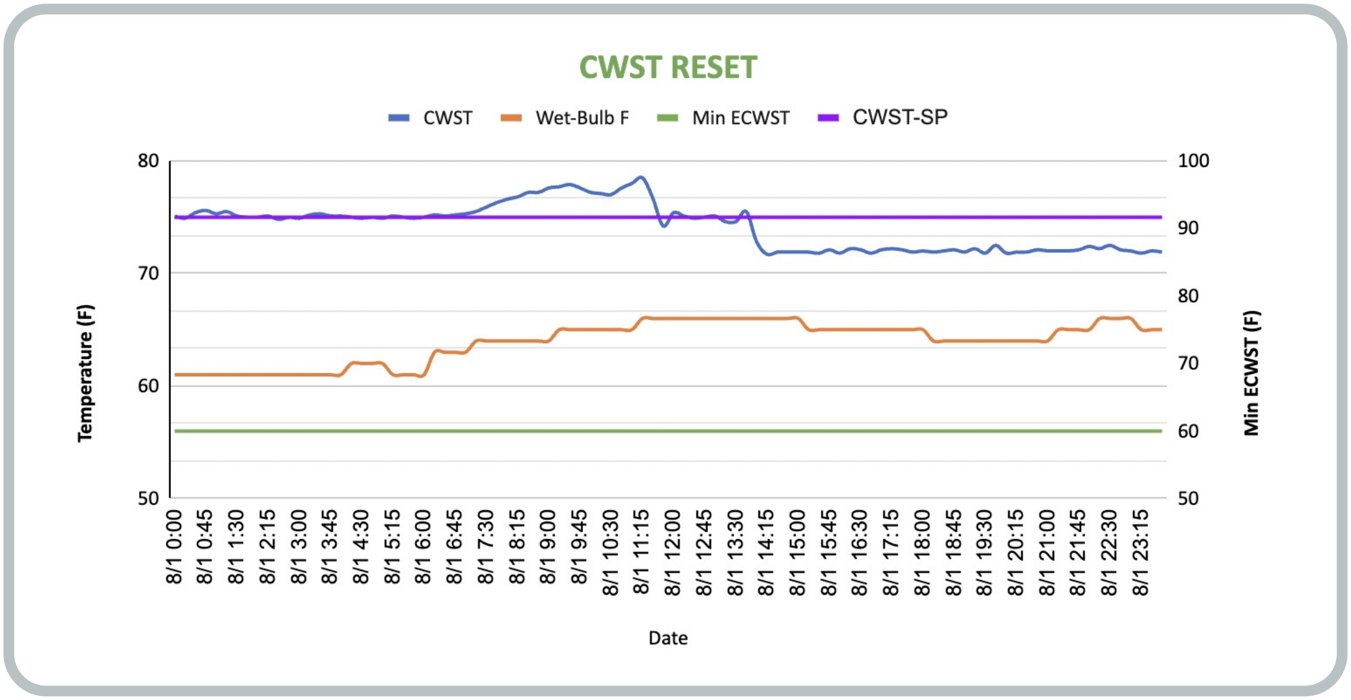


Figure 17. Example of a CWST Reset Trend Chart

Inputs (from BAS data)	
Enter CWST	75
Enter CWST-SP	75
Enter CWRT	85
Enter Wet-bulb (F)	62
Inputs (For Excel ONLY)	
Enter Date (Format M/D/YYYY)	8/1/2021
Outputs	
TARGET CWST	**69**
Minimum allowed ECWST	60
Alarms	
Possible Reduction of CWST	

Figure 18. Example of the Condenser Water Supply Temperature (CWST) Reset Dashboard Entry

The dashboards created for CCNY would ideally be added to the BAS. If your campus can make updates to the BAS through an existing service contract, we recommend updating dashboards to monitor newly identified KPI's. If your buildings do not have a summary dashboard, we recommend that a controls contractor create one. These dashboards are used to monitor the most critical KPIs for campus and building-level operating strategies. As mentioned in the operating strategies guideline section, specific parameters can vary by building, but the provided list is a good starting point for what to monitor.

Two examples of what a summary dashboard can look like are provided below:

Figure 19. Example 1: Summary Dashboard

This dashboard provides a summary of the chilled water temperatures, hot water temperatures, zone temperatures, AHU Fan command and status, duct static pressure, and discharge air temperature. Fan speed is another metric to monitor.

When one of the listed parameters is clicked on, the dashboard will take the user to a related trend chart. Operators can use this function to investigate any issues they notice on this dashboard. This function is useful because it reinforces the value of using trend charts to find the root cause of observed operational issues.

Figure 20. Example 2: Summary Dashboard

This dashboard shows zone temperatures, CO2 levels, hot water temperatures, heat exchanger temperatures, heat pump status, fan status, discharge air temperature, and discharge air pressure.

In summary, the benefits of adding a custom summary dashboard are:

- Easy access to essential KPIs
- Reaffirms the connection between troubleshooting and trend charts.
- Operators are more likely to use a dashboard tailored to their needs consistently.
- Whole campus no/low-cost strategies

Collect and Document in Writing Word-of-Mouth SOOs

This strategy will be implemented as needed to ensure that operational staff have written SOOs for their systems. The analysis team will document what they learn about the SOOs through conversations with staff and analysis of BAS data trends.

The analysis team will collate these into written SOOs, which will be reviewed by facilities management for accuracy.

Appendices

APPENDIX A. Weather-Normalization Guide

Normalization is the process of adjusting data to account for varying effects, such as weather or occupancy. By doing so, two different datasets can be analyzed even though they have different climates or occupancy patterns.

Normalization ensures that “before” and “after” energy usage data are on the same numerical scale, allowing for a fair comparison of energy savings. HVAC energy usage is heavily dependent on weather conditions, which vary from year to year.

A common approach is to use a multi-year average of Heating & Cooling Degree Days to normalize energy usage. Heating Degree Days (HDDs) and Cooling Degree Days (CDDs) are measurements used to quantify the effect of weather on HVAC energy consumption. HDDs measure how cold the temperature was on a given day, and therefore how much heating was needed. They can be calculated by subtracting the daily average temperature from a constant. 65°F is commonly used in North America, but this constant should be determined based on the temperature at which the campus’ heating plant comes online. CDDs measure how warm the temperature was on a given day, and therefore how much cooling was needed. They can be calculated by subtracting a constant from the daily average temperature. 65°F can also be used as the constant for CDDs, but it should be determined based on the temperature at which the campus’ cooling plant comes online. The weather data used to calculate Degree Days is typically obtained from reliable sources such as the National Oceanic and Atmospheric Administration (NOAA), which provides accurate information on temperature, humidity, wind speed, etc.

One method for determining the constants used to calculate HDDs and CDDs is to model your campus’s fuel use with 3-, 4-, or 5-point change-point models. The “Create Baselines” and “Interpreting your Baseline Analysis” sections in Step 3 and Appendix B have more information on these models and their advantages.

A 10-year average of Degree Days has been used in similar analyses. However, as climate change produces increasingly hotter summers each year, a 10-year average may no longer be the most realistic approach to weather-normalizing your campus’s energy data. You may want to consider a shorter period of 3-5 years. This decision will be affected by your data source, the location of your campus, and the degree to which your local climate has changed over the last decade.

Once you have decided how many years of weather data to use, normalizing energy usage should follow this general process. For this example, 65°F will be used as the constant for calculating HDDs and CDDs. Collect X years of weather data from your source. The most recent year of the dataset should be your baseline year, and weather data should be in the form of average daily temperatures for this analysis.

Heating Degree Days

For each year of your weather dataset:

1. Determine your constant for calculating Heating Degree Days (see “Create Baselines” and “Interpreting your Baseline Analysis” sections for guidance)
2. Calculate daily Heating Degree Days using the average daily temperatures.
   - Subtract each daily average temperature from your constant (65° will be used in this example) to calculate the Heating Degree Days for each day of the dataset.
     - $C - T = HDDs\ (Heating\ Degree\ Days)$,

       Where T is the average daily temperature, and C is the constant. Since we are using 65 for this example, the equation becomes

$$65 - T = HDDs$$

   - Heating Degree Days cannot be negative. If $65° - T$ would be a negative number; the HDDs for that day would be equal to 0.
3. Calculate the monthly sum of Heating Degree Days for each month of the dataset.

Once you have your monthly HDD sums for each year of your weather data, calculate the multi-year average of the monthly Heating Degree Days for each month of the dataset.

Cooling Degree Days

For each year of your weather dataset:

1. Determine your constant for calculating Cooling Degree Days (see “Create Baselines” and “Interpreting your Baseline Analysis” sections for guidance)
2. Calculate daily Cooling Degree Days using the average daily temperatures.
   - Subtract your constant (65° will be used in this example) from each daily average temperature to calculate the Cooling Degree Days for each day of the dataset.
     - $T - C = CDDs\ (Cooling\ Degree\ Days),$

       Where T is the average daily temperature, and C is the constant. Since we are using 65 for this example, the equation becomes

$$T - 65 = CDDs$$

   - Cooling Degree Days cannot be negative. If $T - 65$ were a negative number, the CDDs for that day would be equal to 0
3. Calculate the monthly sum of Cooling Degree Days for each month of the dataset.

Once you have your monthly CDD sums for each year of your weather data, calculate the multi-year average of the monthly Cooling Degree Days for each month of the dataset.

The last step is to divide your monthly energy usage by the multi-year average monthly CDD and HDD figures. These figures are your normalized energy use for each month.

The normalized energy use will be measured in units of energy per HDD and CDD. Example: kBTU/HDD, kWh/HDD, Therms/HDD, etc.

You can use your weather-normalized energy figures to estimate annual energy use in a given year. This estimation will give you a "business as usual" energy estimate for each month of a given year, which will show you approximately how much energy you would be using if you operated your systems the same way you did in your baseline year.

For each month n during heating season:

$$Estimated\ Energy\ Use(n) = WN(n) * HDD(n)$$

Where:

$WN(n)$ is the weather-normalized figure from your baseline year for the month

$HDD(n)$ is the number of Heating Degree Days for the month

For each month n during the cooling season:

$$Estimated\ Energy\ Use(n) = WN(n) * CDD(n)$$

Where:

$WN(n)$ is the weather-normalized figure from your baseline year for the month.

$CDD(n)$ is the number of Cooling Degree Days for the month

These monthly estimated energy figures can be used in two ways. If you want to look at your year-over-year performance, you can compare the estimated energy use with the actual energy use. This will give you an indication of whether your campus is doing better or worse than your energy baseline. If you are planning to implement energy-saving measures, you can compare estimated energy use with actual energy use to quantify savings. In this case, the "business as usual" estimated energy use represents how much energy you would have used without the energy savings measures.

For each month n:

$$Energy\ Savings(n) = Estimated\ Energy\ Use(n) - Actual\ Energy\ Use(n)$$

You can also calculate annual savings by subtracting the total annual actual energy use from the total annual estimated energy use.

$$Energy\ Savings(annual) = Estimated\ Energy\ Use(annual) - Actual\ Energy\ Use(annual)$$

APPENDIX B. Regression Analysis Guide

The BPL team implemented a Python-based code solution to perform this step at CUNY City College. The code used energy data to develop models that show the relationship between energy usage and outdoor air temperature. 3-, 4-, and 5-point change-point models were created to separate energy usage into three categories based on OAT: heating, cooling, and “baseload” energy use. Baseload energy is defined as any energy that is not for heating or cooling and includes distribution system losses, lighting, computers, appliances, etc.

3-point change-point models

3-point change-point models consider three parameters:

- energy usage
- the slope of the plotted energy usage graph
- the “changepoint” where the slope of the graph changes.

Figure (a) shows a “3PC” change-point model for the cooling season. The change-point can be viewed as a segmenter, and at the change-point temperature, the model’s characteristics change. This can be interpreted as: at all points below the change-point temperature, energy is used only for baseload. For all temperatures above the change-point, energy usage can be attributed to cooling. Figure (b) shows a “3PH” change-point model for the heating season. For all temperatures below the change-point, the energy can be associated with heating.

Note: 3-point change-point models are more appropriate for campuses that have separate heating and cooling distribution systems. Having a model for each system gives you a better understanding of the losses unique to each distribution system. A 4-point change-point model would only have one baseload figure for both systems, which would be less accurate in these cases.

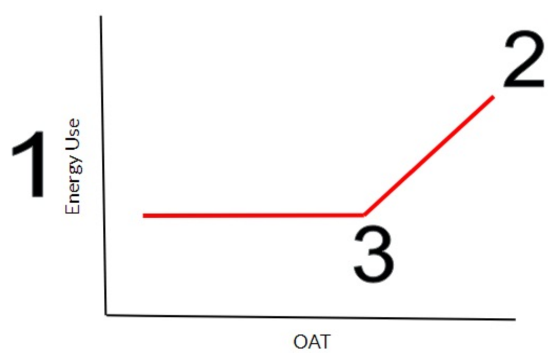


Figure 21. 3PC change-point model (for cooling season)

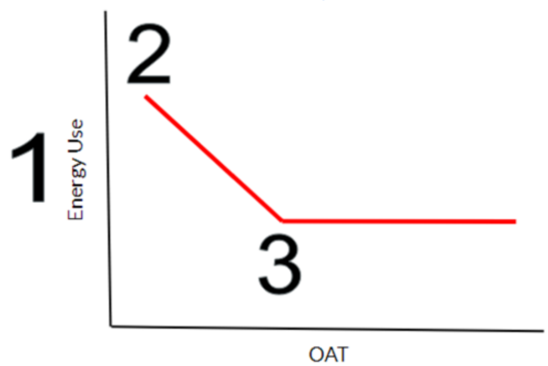


Figure 22. 3PH change-point model (for heating season)

4-point change-point models

4-point change-point models have an additional parameter; similar to 3-point models, they have energy usage and change-point parameters, but they have two slopes instead of one. These models are used to differentiate between heating and cooling energy within the dataset. In this case, we interpret the model as such:

- For all temperatures below the changepoint, energy is used for both baseload and heating.
- For all temperatures above the change point, energy is used for both baseload and cooling.

Note: As previously mentioned, 4-point changepoint models have only one baseload figure for both heating and cooling and would be more appropriate for campuses without separate distribution loops for heating and cooling.

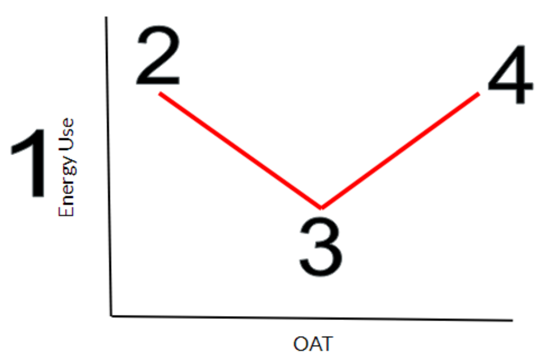


Figure 23. 4-point change-point model

5-point change-point models

A 5-point change-point model works the same as a 4-point change-point model, with one exception. They also include both heating and cooling energy in one model, but with a 5-point change-point model, there is a horizontal line (3-4) between the heating and cooling slopes (2-3 and 4-5, respectively). This can be interpreted as: for any temperatures below the heating change point (3), energy is used for both baseload and heating. For any values between the two change points (3-4), energy is just used for baseload. For any values above the cooling change-point (4), energy is used for both baseload and cooling.

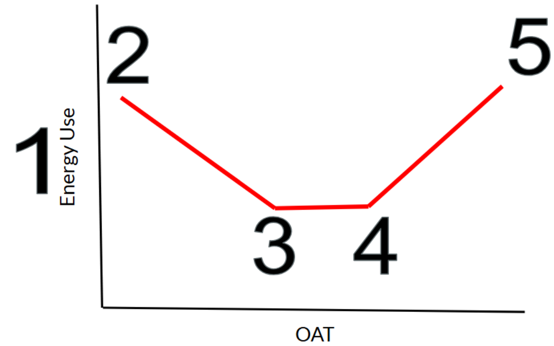


Figure 24. 5-point change-point model

Your methods may vary once you have chosen your baseline year. The regression models described above are a common way to break down the campus energy use into categories. Still, there may be other applicable regression models that can achieve similar results. Regardless of the methods you use, you will want to validate the results of your baseline analysis.

The two metrics the BPL team used to determine their model's statistical validity were:

1. *R-Squared - the Coefficient of Determination.* This is a measure of how related energy usage is to OAT (i.e., is temperature actually a good independent variable to use for modeling this campus' consumption?). A model is considered statistically valid when its R-squared is greater than or equal to 0.75. The closer R-squared is to 1, the more reliable your model.
2. *CV-RMSE - the Coefficient of Variation of the Root Mean Squared Error.* This is a measure of the spread of the data about the generated model (i.e., how well does the model "fit" the data?). A model is considered statistically valid when its CV-RMSE is less than or equal to 25% for electricity or less than or equal to 50% for fuel.

In addition to the two metrics above, the following can be used to validate your model further:

- Compare your results to the actual energy usage of your baseline year
- Check the results against your equipment inventory to ensure that they are realistic to the size and output capacity of your HVAC equipment.

APPENDIX C. Implement Thermal Response Predictive Control Strategy

Peak-demand charges can potentially be avoided by producing additional cooling capacity during non-peak hours. Conceptually, this strategy is about planning out when to prevent peak-demand charges and uses two analyses: understanding the thermal lag of your plant (how long it takes your chiller plant to respond to changes in the Chilled Water Supply Temperature Setpoint) and using predictive analysis to anticipate when your peak chiller load is going to occur.

Steps for finding opportunities:

1. Experiment to determine the thermal lag in your chilled water distribution system. You can record the timing of each step by monitoring the temperatures on the BAS or through BAS trend data
   - Raise your Chilled Water Supply Temperature Setpoint. Record the amount of time it takes for the chiller plant to meet that setpoint
   - Lower your ChWST-SP back to its original setpoint. Record the amount of time it takes for the chiller plant to return to its original setpoint
2. Once you have a good idea of how long it takes your chiller plant to respond to changes in ChWST-SP, you will need to implement a strategy to predict the load on your chiller ahead of time. BPL developed the following approach to predict wet-bulb temperature and chiller load:
   - Collect BAS data to calculate the load on your chiller plant: chilled water flow rate, Chilled Water Supply Temperature, and Chilled Water Return Temperature. Collect OAT (wet bulb if possible) data from your BAS as well. Using a full cooling season's worth of data is recommended for this analysis

For water systems, load can be estimated using the following equation:

$$Load = 500 \text{ x } Flow\ Rate\ (GPM) \text{ x } Delta\ T\ (degrees\ F)$$

If your system does not use water (e.g., Glycol), you can use the general form of the equation to estimate load:

$$Load = Flow\ Rate\ (GPM) \text{ x } specific\ heat\ of\ the\ fluid \text{ x } delta\ T\ (degrees\ F)$$

- Plot chiller load vs wet-bulb temperature to see if there are any outliers in the dataset. If there are, meet with the operators to find the cause of the outliers. They may be indicative of times where operation can be optimized, or they may be one-off occurrences that can be removed from the dataset for the rest of the analysis
- Perform a linear regression analysis to find the relationship between chiller load and wet-bulb temperature. BPL performed this analysis using Excel
- *Note: Removing outliers can make the results of the regression more accurate*
- Using the linear equation from the regression analysis, you can now predict the load on the chiller based on forecasted wet-bulb temperatures.
- BPL created a Python-based solution to pull weather forecast data online and use it to generate a wet-bulb temperature and chiller load forecast chart. Partway through the predictive controls experiment, a condenser water temperature forecast was added to the predictive charts. The BPL team generated this chart every 3 days during the cooling seasons of 2023 and 2024

Combining the analyses from steps 1 and 2, you will be able to look ahead several days at a time and see when peak-load hours will occur. Now that you know the thermal lag in your chiller distribution system, you can plan to lower the ChWST-SP and produce additional cooling capacity ahead of peak hours. If you are also employing Operating Strategies # 1 and #2, you can take it a step further and ensure the most efficient chiller staging sequence ahead of peak hours.

Glossary

ACRONYM	TERM	DEFINITION
ACH	**Air Changes per Hour**	The number of times the total volume of air in a space is replaced with fresh air in one hour.
AHU	**Air–Handling Unit**	Equipment that heats, cools, ventilates, and sometimes controls humidity as part of an HVAC system.
ASHRAE	**American Society of Heating, Refrigerating, and Air-Conditioning Engineers**	Organization that develops HVAC standards and guidelines.
	Balance Point	Outdoor air temperature at which a building's heat gain equals its heat loss.
	Base Load	Portion of energy consumption that remains constant regardless of weather or occupancy.
	Base–to–Peak Load Ratio	Metric comparing near-baseload energy use to near-peak demand.
	Benchmarking	Evaluating building energy performance against peers or historical data.
BAS / BMS	**Building Automation / Management System**	Centralized computerized system for monitoring and controlling building systems.
BOCS	**Building Operator Coaching Solution**	Software that analyzes BAS data to identify operational and energy-saving opportunities.
BRT	**Building Re–tuning**	Ongoing commissioning process to identify and correct operational inefficiencies.
CAV	**Constant Air Volume**	Air system that maintains a fixed airflow rate.
CCNY	**City College of New York**	Public college within the CUNY system.
CCV	**Cooling Coil Valve**	Valve regulating chilled water flow through a cooling coil.
ccf	**Hundred Cubic Feet**	Unit for measuring natural gas consumption.
	Changepoint	Outdoor temperature at which the slope of energy use vs. temperature changes.
ChW	**Chilled Water**	Water cooled by a chiller and circulated for space cooling.

ACRONYM	TERM	DEFINITION
ChWLDP	**Chilled Water Loop Differential Pressure**	Pressure difference between chilled water supply and return.
ChWLDP–SP	**Chilled Water Loop Differential Pressure Set Point**	Target pressure difference for the chilled water loop.
ChWRT	**Chilled Water Return Temperature**	Temperature of chilled water returning to the chiller.
ChWST	**Chilled Water Supply Temperature**	Temperature of chilled water leaving the chiller.
ChWST–SP	**Chilled Water Supply Temperature Setpoint**	Target chilled water supply temperature.
CO_2	**Carbon Dioxide**	Gas used as an indicator for ventilation control and indoor air quality.
COP	**Coefficient of Performance**	Ratio of heating or cooling output to energy input.
	Cooling Load	Amount of heat that must be removed to maintain indoor conditions.
	Cooling Season	Time of year when cooling systems are predominantly used.
CSG	**Controls Solutions Group**	BAS/controls contractor working with CCNY.
CUNY BPL	**CUNY Building Performance Lab**	Research and training lab focused on building performance.
CW	**Condenser Water**	Water used to reject heat from the chiller condenser.
CWRT	**Condenser Water Return Temperature**	Temperature of condenser water returning from heat rejection equipment.
CWST	**Condenser Water Supply Temperature**	Temperature of water supplied to the condenser.
CWST–SP	**Condenser Water Supply Temperature Set Point**	Target condenser water supply temperature.
DA RH	**Discharge Air Relative Humidity**	Relative humidity of air leaving an air handling unit.
DA RH SP	**Discharge Air Relative Humidity Set Point**	Target discharge air relative humidity.
DAT	**Discharge Air Temperature**	Temperature of air leaving the air handling unit.
DAT–SP	**Discharge Air Temperature Set Point**	Target discharge air temperature.
DCV	**Demand Controlled Ventilation**	Ventilation strategy based on CO_2 concentration.
DD	**Degree Day**	Weather metric estimating heating or cooling

ACRONYM	TERM	DEFINITION
DOAS	**Dedicated Outdoor Air System**	HVAC system designed to condition outdoor air separately.
DR	**Demand Response**	Program incentivizing reduced power use during peak demand.
DSP	**Duct Static Pressure**	Pressure within air supply ductwork.
dT	**Delta Temperature**	Temperature difference between two points in a system.
EC3	**Energy Cost Control and Conservation**	NYC platform for municipal energy cost and usage reporting.
ECM	**Energy Conservation Measure**	Action taken to reduce energy use, emissions, or cost.
	Economizer (Air–Side)	Uses outdoor air to reduce mechanical cooling demand.
EER	**Energy Efficiency Report**	Report documenting audit results and recommended ECMs.
EIS	**Energy Information System**	System for collecting and analyzing building energy data.
	Energy Demand	Rate at which energy is consumed.
ERV	**Energy Recovery Ventilation**	System that recovers energy from exhaust air.
ETM	**Educational Training Materials**	Instructional materials on HVAC and building science.
EUI	**Energy Use Intensity**	Metric measuring building energy efficiency.
	Evening Setback	Adjusting temperature setpoints during unoccupied periods.
	Evening Shoulder	Period of declining energy use due to reduced occupancy.
	Face and Bypass Dampers	Dampers that regulate airflow through or around coils.
	Fall–Time	Time required for load to decrease from peak to baseline.
FDD	**Fault Detection and Diagnostics**	Identification of system faults using operational data.
GHG	**Greenhouse Gas**	Gases that trap heat in the atmosphere.
gpm	**Gallons per Minute**	Unit of water flow rate.
HCV	**Heating Coil Valve**	Valve controlling hot water flow through a heating coil.

ACRONYM	TERM	DEFINITION
	Heating Load	Heat energy required to maintain indoor conditions.
	Heating Season	Period when heating systems are predominantly used.
	High–Load Duration	Time a building operates near peak load.
HumV	**Humidification Valve**	Valve controlling humidification demand.
HW	**Hot Water**	Water heated for space heating applications.
HWLDP	**Hot Water Loop Differential Pressure**	Pressure difference between hot water supply and return.
HWLDP–SP	**Hot Water Loop Differential Pressure Set Point**	Target hot water loop pressure difference.
HWRT	**Hot Water Return Temperature**	Temperature of water returning to the boiler.
HWST	**Hot Water Supply Temperature**	Temperature of water leaving the boiler.
HWST–SP	**Hot Water Supply Temperature Set Point**	Target hot water supply temperature.
HVAC	**Heating, Ventilation, and Air Conditioning**	Systems that regulate indoor environmental conditions.
HX	**Heat Exchanger**	Equipment that transfers heat between fluids.
IT	**Information Technology**	Department managing computer systems and networks.
KPI	**Key Performance Indicators**	Metrics used to evaluate system performance.
kWh	**Kilowatt Hour**	Unit of electrical energy consumption.
LDP	**Loop Differential Pressure**	Pressure difference between supply and return piping.
LDP–SP	**Loop Differential Pressure Set Point**	Target loop pressure difference.
LP	**Load Profile**	Graph showing power demand over time.
MAT	**Mixed Air Temperature**	Temperature of mixed outdoor and return air.
mlbs	**Thousand Pounds**	Unit for measuring steam consumption.
NAC	**North Academic Center**	CCNY building housing the central plant and classrooms.
NGO	**Non-Governmental Organization**	Organization independent of government control.
OAD	**Outside Air Damper**	Damper controlling outdoor air intake.
OAF	**Outside Air Fraction**	Percentage of outdoor air in an air stream.

ACRONYM	TERM	DEFINITION
OAH	**Outside Air Humidity**	Humidity level of outdoor air.
OAT	**Outside Air Temperature**	Temperature of the outdoor air.
OMM	**Operations & Maintenance Measure**	Low- or no-cost operational energy improvement.
Peak Load	**Peak Load**	Highest building load in a defined time period.
PNNL	**Pacific Northwest National Laboratory**	National research laboratory.
PTAC	**Packaged Terminal Air Conditioner**	Room-level heating and cooling unit.
QA	**Quality Assurance**	Verification of data accuracy before release.
QC	**Quality Control**	Correction of data or visualization issues after release.
RH	**Relative Humidity**	Ratio of water vapor in air to saturation level.
RTU	**Rooftop Unit**	Packaged HVAC unit mounted on a roof.
SAT	**Supply Air Temperature**	Temperature of air supplied to zones.
SEER	**Seasonal Energy Efficiency Ratio**	Average cooling efficiency over a season.
SOO	**Sequence of Operations**	Detailed description of how a system should operate.
VAV	**Variable Air Volume**	Terminal unit with adjustable airflow.
VFD	**Variable Frequency Drive**	Device that controls motor speed.
VRF	**Variable Refrigerant Flow**	HVAC system using variable refrigerant control.
ZT	**Zone Temperature**	Temperature measured within a building zone.