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Pacific Northwest
NATIONAL LABORATORY

PNNL-29599

Delivering Energy Efficiency and Grid Services for Commercial Buildings on an IoT-Platform

Field Evaluation Plan

January 2020

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R Underhill
A Wagner

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Summary

Commercial buildings in the United States consume over 18 Quads of energy. Even buildings that have building automation system (BASs) do not always or consistently use best practice control sequences and consume more energy than they need. Although commercial buildings are responsible for about 20% of the total U.S. energy consumption, they contribute almost 40% to the peak electricity consumption. Therefore, commercial buildings also represent a major opportunity for more effectively balancing electricity supply, demand and costs.

In 2006, to address this challenge, Pacific Northwest National Laboratory (PNNL) developed the Re-tuning™ process to help building owners and portfolio managers improve energy efficiency (Brambley and Katipamula 2009). Recently, the PNNL-developed Automated Identification of Re-tuning (AIRCx) measures and integrated it with the VOLTTRON™[1] platform. Integration of AIRCx with VOLTTRON allows for continuous improvement of the energy efficiency of an individual building or collection of buildings via a Cloud deployment.

Also, as part of a previous Building Technologies Office-Emerging Technologies (BTO-ET) funded project, PNNL developed Intelligent Load Control (ILC), which offers a solution for achieving this balance. The ILC is an algorithm, or a set of actions, deployed using the VOLTTRON platform. The ILC technology can automatically adjust building energy use by coordinating heating and cooling, lights, and other building functions, while minimizing the negative effects to occupant comfort.

In fiscal year 2020 (FY20), the Commercial Buildings Integration Program (CBI) within Building Technologies Office (BTO) has funded PNNL to conduct a field evaluation of the AIRCx and ILC using an Internet-of-Things (IoT) platform, VOLTTRON. The primary goal of the project is to show that software solutions deployed and delivered through an IoT-platform can identify energy efficiency opportunities and manage peak load (beyond the traditional demand response) in commercial buildings. There are also two secondary goals: 1) show that the energy efficiency solutions will result in identification of significant savings (10% to 30%) opportunities as well as energy cost reductions (10% to 15%) by managing the peak load in commercial buildings, and 2) show that an IoT-based software solution is more cost-effective in meeting the Re-tuning/retro commissioning[2] (RCx) mandates and there is a pathway for broader adoption of this approach. The following approach will be used to execute this project:

PNNL will draft a test plan (this report), which will describe how the field evaluations will be conducted, including recruiting energy services providers, selecting buildings and locations, and the timeline for the field evaluations.

PNNL will enhance the software solution and provide an IoT-technology-based solution to meet retro-commissioning mandates and also manage building peak load.

Field evaluations will be conducted by two or more energy service providers (for example, Intellimation, JouleSmart, and McKinstry). PNNL will recruit and work with the selected energy service providers to deploy the IoT-technology-based solution in a few buildings to highlight the potential cost savings in a cybersecure manner.

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[1] VOLTTRON^{TM} is sponsored by the Department of Energy and Pacific Northwest National Laboratory, 2016.

[2] Traditional RCx approach is mostly manual and measures that they implement during that process may not persist for a long time.

PNNL will draft a final report, which will include results from the field evaluations as well as feedback from building owners/occupants and energy services providers.

The expected outcomes from this project include:

- Show that an IoT-based platform can deliver energy efficiency and peak load management services simultaneously and cost-effectively.
- Show that automated and continuous identification of energy efficiency opportunities can be delivered at lower cost than traditional RCx efforts and will result in persistence of efficient building operations.
- Show that use of AIRCx algorithms will result in energy and cost savings (between 10% and 20%) if the Re-tuning measures identified are corrected and will lead to scaling the city mandates to mitigate climate change.
- Demonstrate a fully automated, cost-effective peak load management solution to enhance electric grid reliability and resiliency.
- Show that peak load management will result in energy cost savings of up to 20% for building owners/operators and help increase the hosting capacity of distributed renewable generation.
- Documenting the energy service provider experience in deploying and maintaining the IoT-platform and the building owner/manager experience.

This report details how the field evaluation will be conducted, including what enhancements will be made to the software technologies (VOLTTRON, AIRCx, AFDD, ILC), how PNNL will recruit energy service providers, types of buildings where the technology will be evaluated, metric of success for the field evaluation, and how the metric of success will be measured.

VOLTTRON is an open-source distributed sensing and control IoT-platform for buildings and the power grid that provides secure and robust integration of buildings with the grid to support deployment of energy efficiency and transactive energy services. The VOLTTRON platform has four primary functions:

- A reference platform for researchers to quickly develop, deploy, and test supervisory control and energy efficiency applications in a simulation environment and real buildings.

A reference platform with flexible data storage support for energy analytics applications, either in academia or in commercial enterprise.

A platform from which commercial enterprise can develop products without license issues and easily integrate them into their product line.

An accelerator to drive industry adoption of energy efficiency, transactive energy, and advanced building energy analytics.

AIRCx automatically identifies BAS control improvement opportunities, without human intervention, (reducing costs) while continuously identifying improvement opportunities in near-real-time, as they occur. AIRCx interprets the data and provides reliable, actionable recommendations. The three primary areas for AIRCx focus include:

- Identify problems with scheduling of building equipment (e.g., heating, ventilation, and air conditioning (HVAC) systems and lighting systems) where equipment is running for significantly longer periods than the building is occupied.

- Identify problems with the air handling units (AHU) discharge temperature (setpoint is too high, too low, or does not automatically reset).
- Identify problems with the AHU discharge static pressure (setpoint is too high, too low, or does not automatically reset).

Enhancements to AIRCx will include similar analysis of the following:

1. Chilled water and hot-water systems (loop temperatures – too high or too low).
2. Long-term overrides that are left in place for controlled equipment (valves, dampers, 2-state equipment) and setpoints.
3. Missing (or failed) temperature resets for chilled water and hot-water systems.
4. Missing (or failed) differential pressure resets for chilled water or hot-water loops (VFD-driven pumping systems).
5. Equipment running when the building is vacant or there is no need for those systems.
6. Develop a web-based user interface (UI) to allow AIRCx configuration of algorithms.
7. Develop a web-based UI for AIRCx results visualization.

AFDD (automated fault detection and diagnostics) automatically identifies equipment faults in two major areas:

- Economizer-related failures (insufficient outdoor air, excess outdoor air, economizing when it should not be and not economizing when it should be).

Temperature sensor faults (related to the AHU mixed-air temperature and return-air temperature sensors and the outdoor-air temperature sensor).

Enhancements to AFDD will include the following:

- Automated (or manually activated) simulation of conditions, designed to confirm the correct response of controlled systems.
- Validation of the outdoor-air temperature sensor via comparison to local weather station data.
- Develop a web-based UI to allow AFDD configuration of algorithms.
- Develop a web-based UI for AFDD results visualization.

Intelligent Load Control (ILC) algorithm manages peak demand in a building while minimizing negative effects on occupant comfort. The ILC automatically manages/controls electrical loads in buildings to enable the following grid responses:

- Manage peak electricity load.
- Manage peak electricity load in response to a demand response event.
- Manage building electricity consumption under time-of-use (TOU) and critical peak pricing (CPP).
- Support capacity bidding.

To manage building peak consumption to a given target, ILC generates supervisory control actions, which are transmitted to the electrical loads via BAS or another mechanism.

Enhancements to ILC will include the following:

The ILC algorithm is ready for field evaluation but currently does not have a good visualization tool for viewing the results. This effort will develop a modest visualization tool with the following features:

- Ability to view the performance of ILC in managing the building peak under the target demand.
- Comparison of baseline[1] consumption with the actual consumption.
- Zone temperature profile, zone temperature set point changes, and controllable load status during the demand response event.
- Computing the demand reduction and displaying it on the graph in real-time.

The project will recruit two or more energy service providers to support field evaluations of AIRCx, AFDD, and ILC algorithms using the VOLTTRON platform. The evaluations will be conducted in multiple buildings in multiple locations that represent multiple climate zones.

Criteria for Selecting Energy Service Providers will include the following minimum qualifications for service provider selection:

- Active participation in BAS commissioning.
- Adequate staffing employed to support the field evaluations.
- Proximity to selected sites.
- Demonstrated willingness to deploy the technology at other sites (beyond the evaluation sites).
- Have a basic familiarity with Linux and Python.
- Administer surveys of both evaluation sites as well as participate in self-surveys.

Criteria for Selecting Building Types and Climate Locations will include the following minimum qualifications for building types and locations:

- Buildings and/or campus sites with BACnet-based (or Modbus) BASs.
- BASs no older than 15 years will be preferred.
- Buildings with BASs that are not constrained (e.g., planned upgrades in the near-term, legacy BAS having vendor support issues, performance contracts in place, extensive legacy pneumatic controls still in place).
- Reliable real-time power metering at each building that is integrated to either the BAS or capable of being integrated to VOLTTRON.

Preference will be given to buildings that meet these minimum qualifications, but also have the following site capabilities:

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[1] Normal consumption if ILC were not managing the electrical loads.

- Buildings or campus sites with readily-available interval metered data.
- Buildings or campus sites with distributed renewable power generation and storage (e.g., solar and battery).
- Locations where there is a current need for grid services or areas where utilities have programs that simultaneously promote energy efficiency and peak load management
- Buildings or campus that include office, education, and/or retail sites.
- Buildings or campus sites that represent diversity in climates across different geographical locations.

One of the objectives of the field evaluation is to gather and document the feedback and experience of the energy service providers, building owners as well as the building occupants. Because each of these three categories of people will provide different feedback, three surveys will be developed. For the energy service providers, the survey would cover installation experience (e.g., how long it took to install various hardware and software pieces, how easy was it to install and configure, and how easy or difficult was the ongoing maintenance of the software). For the building owners/operators, the survey would include questions on cost vs benefits and the likelihood that they would continue to use the software. The survey for the building occupants will be aimed at gathering feedback on such items as effect on occupant comfort. After the field evaluation is complete, PNNL will administer the surveys, analyze the survey data, and compile a report to document the findings.

The project, which began in October 2019, has a 24-month duration. The following timeline will be used to execute the field evaluations and document the results and feedback.

- Complete drafting the detailed test plan – 1/31/2020.

Complete selection of energy services providers – 4/30/2020.

Prepare the AFDD, AIRCx, and ILC software field evaluation – 6/30/2020.

Select buildings and locations for field evaluation – 7/30/2020.

Begin field evaluations in selected buildings and locations – 8/31/2020.

Make an interim presentation on how the field evaluations are going on – 1/31/2021.

Complete field evaluations – 6/30/2021.

Draft a final report and presentation – 10/30/2021.

Acknowledgments

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Acronyms and Abbreviations

AFDD	Automated Fault Detection and Diagnostics
AHU	Air Handling Unit
AHP	Analytical Hierarchal Process
AIRCx	Automated Identification of Re-tuning™ Measures
BAS	Building Automation System
BACnet	Building Automation and Controls Network
BTO	Building Technologies Office
CBI	Commercial Buildings Integration
CPP	Critical Peak Pricing
DER	Distributed Energy Resource
DOE	Department of Energy
DOAS	Dedicated Outdoor Air System
ERV	Energy Recovery Ventilator
ESPC	Energy Savings Performance Contract
ET	Emerging Technologies
FCU	Fan Coil Unit
FY20	fiscal year 2020
GUI	Graphical User Interface
HVAC	Heating, Ventilation, and Air Conditioning
ILC	Intelligent Load Control
IoT	Internet-of-Things
JSON	JavaScript Object Notation
MEL	Miscellaneous Electric Loads
NUC	Next Unit of Computing
OpenEIS	Open Energy Information System
PNNL	Pacific Northwest National Laboratory
RCx	Retro Commissioning – Re-tuning
RTU	Rooftop Unit
SAT	Supply air temperature
TOU	Time-of-Use
UI	User Interface
VAV	Variable air volume
VFD	Variable-Frequency-Drive
VRF	Variable Refrigerant Flow

Contents

Figures

1.0 Introduction

Commercial buildings in the United States consume over 18 Quads of energy. Many studies have shown that these buildings use between 10% and 30% excess energy because of operational problems (Claridge et al. 2000; Fernandez et al. 2017 and 2017a). Even buildings that have building automation system (BAS) do not always or consistently use best practice control sequences; therefore, they consume more energy than they need to. These issues can be easily identified and corrected to reduce energy consumption and improve operating efficiency. In 2006, to address this challenge, Pacific Northwest National Laboratory (PNNL) developed the Re-tuning process to help building owners and portfolio managers improve energy efficiency (Brambley and Katipamula 2009). Re-tuning is a systematic process to identify low- and no-cost energy efficiency measures using data from the BASs. The original Re-tuning approach was a semi-automated process that used spreadsheet analysis to identify energy saving opportunities.

Over the last decade, many cities (e.g., Seattle, New York, Los Angeles, New Orleans) started mandating periodic Re-tuning or retro commissioning (RCx) of commercial buildings (NYC 2017 and Seattle 2016). These mandates will result in significant energy savings, if all the Re-tuning opportunities are identified and corrected, and if the corrections persist over time. However, traditional retro-commissioning approaches to meeting these mandates may be costly for smaller (<100,000 sf) buildings and also may not result in persistence of energy efficient operations that the cities are looking for.

To address the challenge of cost and persistence, the Emerging Technologies (ET) Program within the U.S. Department of Energy's (DOE's) Building Technologies Office (BTO) funded PNNL to create the automated identification of the Re-tuning (AIRCx) measures and integrate them into two open-source platforms: VOLTTRON™ and OpenEIS (Open Energy Information System). Although the VOLTTRON version of the algorithms can be deployed to continuously improve energy efficiency of an individual building or collection of buildings via a Cloud deployment, the OpenEIS version helps retro-commissioning providers to improve the commissioning process by conducting an offline analysis of the data collected from the BAS. In both cases, measures to improve operational efficiency are detected automatically. When these measures are corrected, significant (up to 20%) reductions of building energy consumption is possible.

Although commercial buildings are responsible for about 20% of the total U.S. energy consumption, they contribute almost 40% of peak electricity consumption. Therefore, commercial buildings also represent a major opportunity for more effectively balancing electricity supply, demand and costs. As part of a previous BTO-ET funded project, PNNL developed Intelligent Load Control (ILC), which offers a solution for achieving this balance. ILC is an algorithm, or a set of actions, deployed using the VOLTTRON platform. The ILC technology can automatically adjust building energy use by coordinating heating and cooling, lights and other building functions, while minimizing the negative effects on the occupant comfort.

In FY20, the Commercial Buildings Integration Program (CBI) within BTO has funded PNNL to conduct field evaluation of the AIRCx and ILC using an Internet-of-Things (IoT) platform, VOLTTRON. This report details how the field evaluation will be conducted, including how PNNL will recruit energy service providers, types of buildings where the technology will be evaluated, metric of success for the field evaluation, and how the metric of success will be measured.

1.1 VOLTTRON

VOLTTRON is an open-source distributed sensing and control IoT-platform for buildings, the power grid, and integration of buildings with the grid to support deployment of energy efficiency and transactive energy services. VOLTTRON applications are referred to as agents because VOLTTRON provides an agent-based programming paradigm to ease application development and minimize the lines of code that need to be written by domain experts (such as building engineers). The VOLTTRON platform has four primary roles; it serves as:

A reference platform for researchers to quickly develop, deploy and test supervisory control and energy efficiency applications in a simulation environment and real buildings.

A reference platform with flexible data storage support for energy analytics applications, either in academia or in commercial enterprise.

A platform from which commercial enterprise can develop products without license issues and easily integrate them into their product line.

An accelerator to drive industry adoption of energy efficiency, transactive energy and advanced building energy analytics.

VOLTTRON serves as a single point of contact for interfacing with building devices (e.g., rooftop units, air handling units (AHU), other building systems, meters), external resources (e.g., weather, utility transactive signals), and platform services such as data archival and retrieval. VOLTTRON provides a collection of utility and “helper” classes, which simplifies agent development. VOLTTRON connects devices and external signals from the power grid to agents implemented in the platform and/or in the Cloud.

An overview of the VOLTTRON platform components is illustrated in Figure 1.1. The VOLTTRON platform comprises several components and agents that provide services to other agents. Of these components, the Information Exchange Bus (IEB) is central to the platform. All other VOLTTRON components communicate through the IEB using the publish/subscribe paradigm over a variety of topics. For example, the weather agent would publish weather information to a “weather” topic to which interested agents would subscribe. The platform itself publishes platform-related messages to the “platform” topic (such as “shutdown”). Topics are hierarchical following the format “topic/subtopic/sub-subtopic/…/…” and allowing agents to be as general or as specific as desired with their subscriptions. For example, agents could subscribe to “weather/all” and get all weather data for a location or subscribe to “weather/temperature” for only temperature data. VOLTTRON incorporates several open-source projects to build a flexible and powerful platform.

A few of the key services/applications provided by VOLTTRON include the following:

- Actuator agent – manages the control of external devices by agents within the platform.
- Drivers – communicates with devices controlled by the platform. Drivers abstract device-specific protocols from the rest of the platform by publishing device data to and taking commands from the message bus. Although VOLTTRON supports a number of protocols, the two that are relevant to buildings are the BACnet and Modbus protocols.
- Historian – enables the storage of device data obtained by the drivers and application analysis results in a database (currently, SQLlite, CrateDB, MySQL, and MongoDB databases are supported). Multiple historians can run on the platform at the same time.

- Management Interface – A web-based user interface allows the administration of VOLTTRON nodes (and the agent/applications) running on the VOLTTRON nodes on one or more networks.
- Message Bus – All agents and services can publish and subscribe to topics on the message bus. The message bus provides a single and uniform interface that abstracts the details of devices and agents from each other. Agents and components running on the platform publish and subscribe messages and/or events. The agents decide how agents produce events and how they process received events.

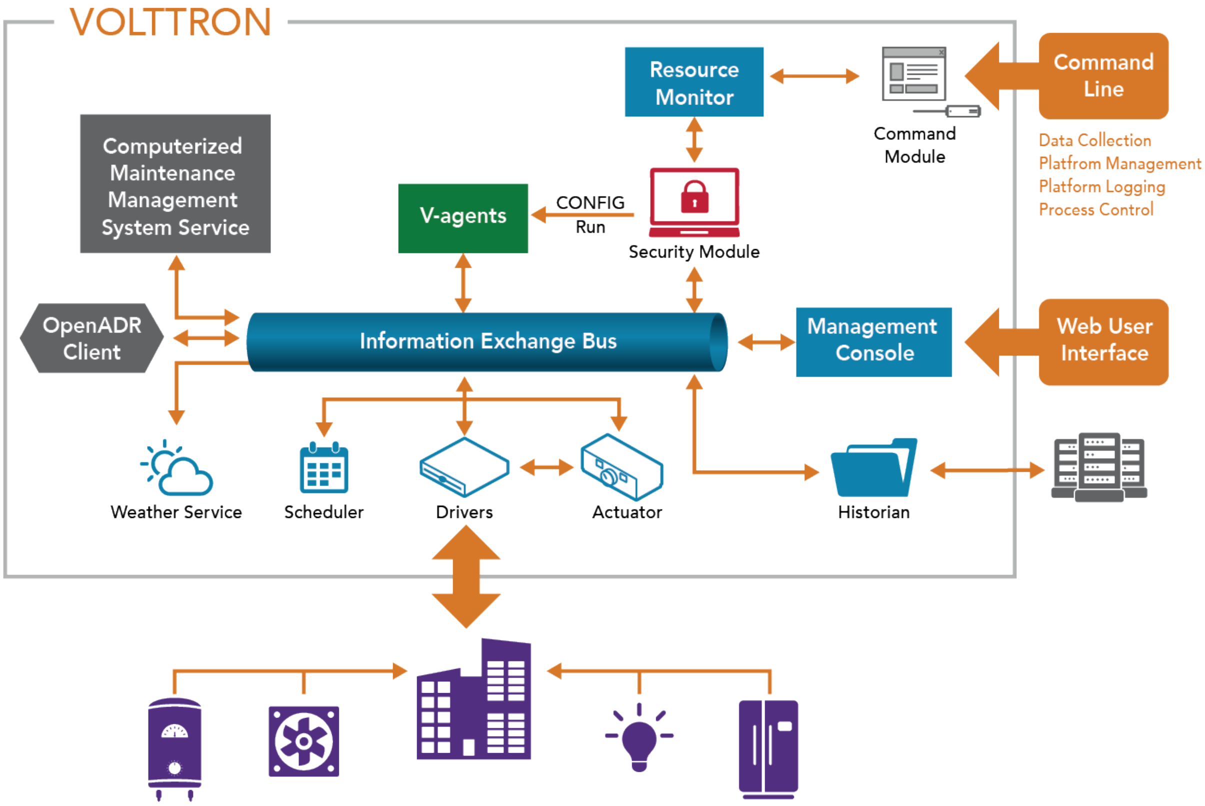

Figure 1.1. Schematic of the VOLTTRON Platform

VOLTTRON provides security against unauthorized access to system data and unauthorized exercise of control functions. VOLTTRON isolates applications running on the platform from each other (if needed) and enforces resource utilization limits on the applications to ensure stability of the computational platform. VOLTTRON uses well-established and widely accepted security mechanisms including elliptic-curve encryption, authentication, and authorization. VOLTTRON agents use authorization to selectively limit which peers can call which methods based on each peer's granted permissions. VOLTTRON authorization gives agent authors and platform owners precise control over who can use their agents and how their agents can be used. Additionally, communications with other VOLTTRON platforms use authentication and authorization functions to ensure that only legitimate transactions are performed. Access to the system through local management interfaces is also protected by similar security measures.

The hardware requirements of the VOLTTRON platform depend on the intended role for each instance. The platform software itself consumes few resources, but the applications deployed into it and the services provided determine where the instance should run. An instance collecting data from a handful of devices could comfortably run on a single-board computer (such as a Raspberry Pi or Beagle Bone). However, an instance supporting applications that analyze data from multiple buildings to aggregate grid services or optimize energy use across a campus could require the resources of a server. VOLTTRON's only requirement is that it runs in a Linux environment with needed prerequisites such as Python.

No changes to the VOLTTRON platform are necessary for hosting the AIRCx, automated fault detection and diagnostics (AFDD), and ILC algorithms. In most cases, the deployment can be handled with an Intel® Next Unit of Computing (NUC) or an equivalent hardware device. These devices typically cost between $200 and $300.

1.2 AIRCx and AFDD Algorithms

There is general agreement that Retro Commissioning or Re-tuning existing commercial buildings saves between 10% and 30% of energy consumed. However, RCx as it is practiced today is perceived as expensive with no guarantee of persistence. PNNL developed a scaled-down RCx process to address some of the issues associated with RCx (Brambley and Katipamula 2009). The process is referred to as Re-tuning, which is a systematic process of detecting, diagnosing, and correcting operational problems with systems and their controls. Although the Re-tuning process can lower the cost for RCx, to ensure persistence, the Re-tuning process has to be applied periodically. Many operational problems that are identified during Re-tuning can be detected automatically and continuously, allowing the buildings to operate near optimally, leading to a lower RCx cost and increased persistence. Therefore, PNNL automated the detection of the measures, which is referred to as the AIRCx process (Katipamula et al. 2018). Just as the manual Re-tuning process relies on BAS data, the automation of the Re-tuning process also relies on data collected from the BAS to detect and diagnose operational problems that can be corrected with no-cost or low-cost investment. Automation of Re-tuning has the potential to tap into 60% to 80% of the savings attributed to RCx with very little investment; more importantly unlike the RCx process it ensures persistence of savings.

In addition, PNNL also developed AFDD algorithms to detect and diagnose faults with rooftop (RTUs) and air handling units (AHUs). These AFDD algorithms, when deployed, can result in significant savings. Use of RTU and AHU AFDD is not new, and a number of researchers, including PNNL researchers, have been developing algorithms for a number of years. A typical AFDD deployment runs continuously and detects and diagnoses problems as they occur. Recently, PNNL extended the AFDD algorithms to run on periodically rather than continuously. In this new approach, the algorithms have the ability to command the RTU or AHU to take specific actions (e.g., closing dampers 100% or opening dampers 100%) to isolate the faults. These set of AFDD algorithms are referred to as proactive AFDD algorithms.

1.3 Intelligent Load Control Algorithm

To manage behind-the-meter distributed energy resources (DERs) to deliver transactive energy services, PNNL designed, developed, and validated ILC algorithm/software. The ILC algorithm supports traditional demand response as well as transactive energy services. It manages controllable loads/DERs while also mitigating service-level excursions (e.g., occupant comfort, minimizing equipment ON/OFF cycling) by dynamically prioritizing available loads for curtailment using both quantitative (deviation of zone conditions from set point) and qualitative rules (type of zone). It uses the analytical hierarchy process (AHP) to prioritize loads for curtailment.

The AHP is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology (Saaty and Vargas 2012). The process can generate a numerical score to prioritize each controllable load being considered for curtailment based on associated decision criteria. The AHP algorithm is ideal when it is difficult to aformulate a goal using quantitative criteria alone for evaluation, because it uses both qualitative and quantitative criteria to solve complex decision-making problems (Cheng and Li 2002).

The primary goal of the ILC process is to prioritize controllable loads for curtailment to keep a building's dynamic electric demand from exceeding the target demand, while simultaneously ensuring the service levels (e.g., comfort, minimizing frequent ON/OFF cycling). Although the ILC process supports a number of grid service use cases, all of them result in a peak demand target for ILC to manage. ILC decomposes the problems into a hierarchy of elements influencing a system by incorporating three levels: the *goal*, *criteria*, and *alternatives of a decision*. The ILC process has the ability to prioritize a set of criteria used to rank the alternatives of a decision and distinguish, in general, the more important factors from the less important factors. Pair-wise comparison judgments are made with respect to the attributes of one level of hierarchy given the attribute of the next higher level of hierarchy from the main criteria to the sub-criteria (Crowe and Noble 1998).

The first step in AHP is to decompose the decision-making problem into a hierarchical structure that consists of the elements of the decision model. As shown in Figure 1.2, AHP has three major elements—1) the goal, 2) the criteria, and 3) the alternatives. In this section, an application of the ILC approach to manage the peak electricity demand of a building that has a set of rooftop units (RTUs) is explained. Load curtailment options are determined by comparing alternatives with respect to a set of criteria.

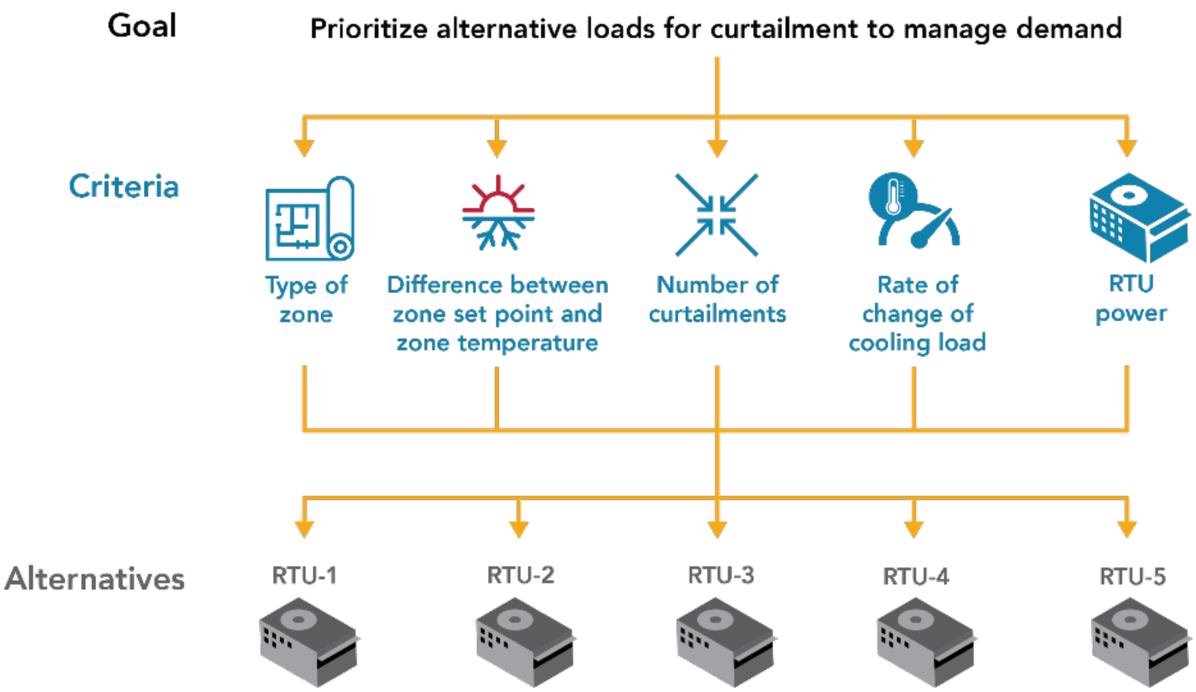

Figure 1.2. An Example of the AHP Process that Uses RTU Loads to Manage Building Peak Load

The goal of the AHP, in this example, is to generate the dynamic load curtailment priority of individual RTUs for managing building electricity consumption to a target level. In this example, five decision criteria are used to manage building electricity consumption without significantly affecting occupant comfort. Additional criteria can be easily added or existing criteria modified or removed. For a decision criterion to be effective, it must be able to capture important characteristics that have a direct affect on control. In this example, one qualitative (type of zone) criterion and four quantitative criteria are used.

First, a pair-wise comparison is conducted to determine qualitatively which criteria are more important and then assign a weight to each criterion. The last layer in Figure 1.2 consists of different decision alternatives, which are multiple RTUs that can be controlled to manage the building energy consumption to the desired target. The ILC process selects RTUs with the highest priority level that can be curtailed for the longest duration of time without a comfort penalty during the event period. Because ILC will strictly enforce comfort limits, it is possible that sometimes the building consumption will exceed the target limit, especially if the target is aggressive compared to the comfort excursions. The ILC technology has been successfully tested in many commercial buildings. To date, these tests have focused on three capability areas: 1) management of peak loads, 2) capacity bidding, and 3) transactive control. A more detailed description of the ILC process is provided by Kim et al. (2016), Kim and Katipamula (2017) and Kim et al. (2019).

1.4 Project Purpose and Scope

The primary goal of the project is to show that software solutions deployed and delivered through an Internet-of-Things-based (IoT-based) platform can identify energy efficiency opportunities and manage peak load in commercial buildings. There are two secondary goals: 1) show that the energy efficiency solutions will result in identification of significant savings (10%

to 20%) opportunities as well as energy cost reductions (10% to 15%) by managing the peak load in commercial buildings, and 2) show that an IoT-based software solution is more cost-effective in meeting the Re-tuning mandates than traditional retro commissioning and there is a pathway for broader adoption of this approach.

As noted previously, many cities are mandating periodic Re-tuning or retro commissioning of commercial buildings. Business-as-usual retro-commissioning approaches can be expensive and may not result in persistence of building operations. Meeting these mandates by deploying AIRCx software on an IoT-based platform will be cost-effective, persistent, and continuous. This innovative IoT technology will also address numerous non-technical barriers for deployment. For example, many building owners are reluctant to install IoT platforms to avoid cybersecurity risks.

In this project, PNNL will use VOLTTRON, an IoT-platform that supports distributed sensing and controls and can deliver solutions to an individual building or a network of buildings. The VOLTTRON IoT-platform communicates with BACnet/Modbus-based BASs or devices to securely collect data from sensors, meters, and equipment. The data can be processed by the AIRCx and AFDD algorithms, which provide automated insights to drive operational improvements. Both the AIRCx and AFDD algorithms can be deployed on an individual building or a network of buildings using VOLTTRON. In addition, the VOLTTRON platform was built with cybersecurity best practices. Although cybersecurity is not the primary focus of the effort, we can demonstrate how this deployment uses best practice cybersecurity principles to minimize potential attack vectors.

An IoT-based platform to deliver energy efficiency improvements will have an initial cost and an ongoing operational cost; therefore, it is imperative to maximize the revenue stream to accelerate the rate of return on the initial investment and the ongoing operational cost. One way to do this is to simultaneously deliver both energy efficiency and grid services on the same platform. Therefore, the project will validate peak load management while simultaneously delivering energy efficiency. VOLTTRON can also be used to deploy the ILC algorithm to manage the peak load in the building. The ILC algorithm leverages the BACnet/Modbus services that VOLTTRON provides to monitor controllable loads and issue control actions to manage controllable loads in response to real-time power meter demand readings.

Although commercial buildings are only responsible for about 20% of the total U.S. energy consumption, they contribute almost 40% of peak electricity consumption. Most commercial buildings pay a demand (kW) charge in addition to the energy (kWh) charge[1]. The cost associated with peak load can range between 0% and 35% of the total electricity cost. The demand charges vary across the U.S. with $5/kW in the Northwest to over $30/kW (e.g., New York, California, Massachusetts, Arizona, Nebraska, Illinois)[2]. Therefore, commercial buildings also represent a major opportunity for more effectively balancing electricity supply, demand, and costs. The ILC is an algorithm, or a set of actions, deployed using the IoT-platform VOLTTRON. The ILC technology can automatically adjust building energy use by coordinating heating and cooling, lights, and other building functions, while minimizing the negative effects on occupant comfort. In addition to bringing flexibility and responsiveness to building energy consumption, ILC benefits the grid by turning buildings into resources that assist in balancing electricity supply and demand. This could help address some of the challenges of adding intermittent resources such as wind and solar power to the energy supply mix.

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[1] https://www.nrel.gov/docs/fy17osti/66832.pdf

[2] https://www.nrel.gov/solar/assets/pdfs/2017-us-demand-charges-webinar.pdf

The following approach will be used to execute this project:

- PNNL will draft a test plan, which will describe how the field evaluations will be conducted, including recruiting energy services providers, selecting buildings and locations, and the timeline for the field evaluations.

PNNL will enhance the software solution and provide the IoT-technology-based solution to meet Re-tuning or RCx mandates and also manage building peak load.

Field evaluations will be conducted by one or more energy service providers (e.g., Intellimation, JouleSmart, and McKinstry). PNNL will recruit and work with the selected energy service providers to deploy the IoT-technology-based solution in a few buildings to highlight the potential cost savings in a cybersecure manner.

PNNL will draft a final report, which will include results from the field evaluations as well as feedback from building owners/occupants and energy services providers.

The expected outcomes from this project include:

- Show that an IoT-based platform can deliver energy efficiency and peak load management services simultaneously and cost-effectively.

Show that automated and continuous identification of energy efficiency opportunities can be delivered at lower cost than traditional RCx efforts and will result in persistence of efficient building operations.

Show that use of AIRCx algorithms will result in energy and cost savings (between 10% and 20%) if the Re-tuning/RCx measures identified are corrected and will lead to scaling the city mandates to mitigate climate change.

Demonstrate a fully automated, possibly cost-effective peak load management solution to enhance electric grid reliability and resiliency.

Show that peak load management will result in cost savings of up to 15% for building owners/operators and help increase the hosting capacity of distributed renewable generation.

Documenting the energy service provider experience in deploying and maintaining the IoT-platform and the building owner/manager experience.

1.5 Report Content and Organization

The enhancements to the AFDD and AIRCx algorithms that will be needed are described in Section 2.0 and enhancements to ILC are described in Section 3.0. The criteria that will be used to select energy service providers, building types and locations for field evaluations is described in Section 4.0. In Section 5.0, we describe how we will document the energy service provider and the building owner/manager experience. A detailed project timeline is presented in Section 6.0. The list of references is provided in Section 7.0.

2.0 AFDD and AIRCx Algorithms

In this section, the enhancements to AFDD and AIRCx algorithms will be highlighted. In addition, we currently do not have a good way to present or visualize the results to the building operator. Therefore, a specification for a visualization tool will also be presented in this section.

2.1 Building System Requirements for AFDD and AIRCx

The AFDD algorithms focus on airside economizer systems for RTUs or AHUs. The AIRCx algorithms detect Re-tuning or RCx opportunities in a single-duct variable air volume (VAV) AHU system and chilled and hot-water distribution systems. Because these algorithms rely on continuously monitored data from the building systems, a BAS is also required. In addition, any control actions for proactive diagnostics will be initiated through the BAS.

2.2 Enhancements to AFDD and Integration of AFDD Proactive Diagnostics Algorithms with VOLTTRON

Economizers use controllable dampers to mix outdoor air and return air in appropriate quantities to provide the right mixed-air or supply air temperature that will either offset part of all of the entire cooling load. An economizer that is fully integrated with the mechanical cooling system can supply all of the building's cooling requirements using both outdoor air and mechanical cooling individually or concurrently. Non-integrated economizers are operated separately from the mechanical cooling system (one or the other operators – not both). The economizer AFDD algorithms will work with the following economizer types: high-limit dry-bulb or differential dry-bulb. The algorithms could easily be modified to work with differential enthalpy as well.

Detecting and diagnosing problems with economizers is crucial because faulty economizer operations do not always result in comfort problems, they are generally masked by the system and they can result in significant energy and cost impact. For example, if the outdoor-air damper is stuck closed while it is being commanded to economize during conditions favorable for economizing, the occupants will generally not suffer because the air stream will be mechanically cooled instead. The economizer AFDD algorithms are designed to monitor conditions of the system not normally experienced by occupants and alert the building operator when there is evidence of a fault as well as indicate the potential cause of the fault.

The detected faults can be grouped into five categories: 1) inadequate ventilation, 2) energy waste, 3) temperature sensor problems, 4) miscellaneous control problems, and 5) missing or out-of-range inputs. The problems associated with energy waste are related to conditions when the economizer should be ON (favorable for economizing), but it is OFF and when the economizer should be OFF, but it is ON (not favorable for economizing).

The temperature sensor problems are of two types: 1) missing and 2) out-of-range or incorrect values. The algorithms use rules derived from engineering principles of proper and improper AHU operations. The five algorithms that will be deployed include:

1. Detect AHU sensor faults (outdoor air, mixed-air, and return-air temperature sensors).
2. Detect if the AHU is not economizing when it should.
3. Detect if the AHU is economizing when it should not.
4. Detect if the AHU is using excess outdoor air.

5. Detect if the AHU is not providing sufficient ventilation air.

Currently the economizer AFDD diagnostics utilize a passive diagnostic structure, i.e., the algorithms continuously monitor and collect the data and detect faults when conditions permit. The AFDD process can also be proactive, where control actions can be automatically initiated to cause or to simulate operating conditions that may not occur for some time, thus producing results that otherwise might not be available for months. Such tests could be automated to cover a more complete range of conditions or to deepen diagnosis beyond what might be possible without this capability. The proactive diagnostic process can help diagnose and isolate faulty operations to a much greater extent than passive diagnostics, but it is intrusive. Some building owners and operators may consider this to be disruptive to the normal operation of their systems. They may be more receptive, however, if such proactive tests can be conducted during unoccupied periods. Proactive diagnostic procedures are capable of providing continuous persistence of performance if they are frequently triggered (e.g., once a day, once a week or once a month). These procedures might be scheduled to occur during building startup hours or at the end of the day to further reduce their intrusiveness or they could be configured to be “on demand” so the building owner/operator can witness the diagnostic.

To enable a robust and easily deployable application solution the AFDD algorithms will be enhanced. These enhancements include:

- For the passive diagnostic process, refining the current diagnostic messages to provide more specific actionable information, including estimation of energy and cost impacts resulting from faulty operation.
- Development of a new diagnostic to validate the outdoor-air temperature sensor by comparing it with the outdoor-air temperature from a local weather station.
- Development of a web-based user interface (UI) to easily configure AFDD algorithms.
- Development of a web-based UI for visualization of the AFDD results.
- Integration of the proactive AFDD algorithms with VOLTTRON.

2.3 Enhancements to AIRCx Algorithms

Re-tuning is a systematic process of identifying improvement opportunities and implementing corrective actions in commercial buildings that use BASs. The opportunities identified by Re-tuning typically requires no-cost or very little cost to implement. The opportunities identified as part of this process include:

- Excessive temperatures (too high, too low) for various heating, ventilation and air conditioning (HVAC) systems, including supply air, chilled water, and hot-water systems.
- Overrides on set points and equipment (intended for short periods of time) but forgotten and left in place (for long periods of time).
- Resets on set points for supply air temperature (SAT) and static pressures that are not working or are locked (too high, too low, fixed).
- Resets on set points for chilled-water supply temperatures and chilled-water loop differential pressures that are not working or locked (too high, too low, fixed).

- Resets on set points for heating hot-water supply temperatures and heating hot-water loop differential pressures that are not working or locked (too high, too low, fixed).
- Equipment running under low load conditions (low delta-T—difference between supply and return water) for hot-water and chilled-water systems.
- Equipment running when the building is not occupied and there is no demand for those systems (e.g., AHU, chiller plant, heating hot-water plant).

The Re-tuning process can be applied using a semi-automated process to identify opportunities and implement corrective actions. This approach lowers the cost for RCx but may not ensure persistence of building operations. To ensure persistence, the Re-tuning process has to be applied periodically. In some cases, these efforts may require re-programming of existing control sequences or adding new control sequences to remedy problems identified above (manual correction or replacement of faulty equipment).

The AIRCx uses algorithms to ensure that buildings operate continuously at optimal efficiency. AIRCx ensures that the building staff focus on activities for which their intervention is essential (e.g., replacing components that have physically failed or degraded, thereby reducing efficiency and increasing the cost of operation) and corrects operational problems that can be corrected without operator intervention, leading the way to self-correcting control systems.

The following seven Re-tuning measures are selected for automation and integration in VOLTTRON:

1. Detection, diagnosis, and correction of high duct static pressure in VAV AHUs.
2. Detection, diagnosis, and correction of low duct static pressure in VAV AHUs.
3. Detection and diagnosis of constant duct static pressure set point reset in VAV AHUs (no reset).
4. Detection, diagnosis, and correction of high SAT in VAV AHUs.
5. Detection, diagnosis, and correction of low SAT in VAV AHUs.
6. Detection and diagnosis of constant SAT set point reset in VAV AHUs (no reset).
7. Detection and diagnosis of excessive night/weekend operation for AHU supply fan.

To enable a robust and easily deployable application solution, the AIRCx algorithms will be enhanced. These enhancements include:

- For the passive diagnostic process, refining the current diagnostic messages to provide more specific actionable information.
- Development of a web-based UI to easily configure AIRCx algorithms.
- Development of a web-based UI for visualization of the AIRCx results.
- Integration of the proactive AIRCx algorithms with VOLTTRON.

2.4 Enhancement of Visualization Tool for Viewing AFDD and AIRCx Results

We currently have a rudimentary browser-based visualization tool for viewing the results from either AFDD or AIRCx algorithms (Figure 2.1). As part of this effort, we plan to make some modest enhancements, including:

- Redesigning the workflow to select buildings, systems, and diagnostic algorithms.

Redesigning the presentation of the results, including providing additional data (e.g., raw data) to reinforce the finding.

Implement the new redesigned workflow and visualization methods.

Currently, the results are processed locally on a VOLTTRON node in a building, but they are stored in the Cloud. We plan to make it possible to store the results locally, in the Cloud or in both places.

Site PNNL Building SEB Unit AHU4
Diagnostic EconomizerAIRCx
Start Date
End Date
Sensitive Level normal

⚫ Inconclusive 🟢 Normal 🔴 Fault ○ Unit is Off

	Dec 04	Dec 05	Dec 06	Dec 07	Dec 08	Dec 09
Insufficient Outdoor-air Intake Dx	⚫	🟢	⚫	🟢	🟢	⚫
Excess Outdoor-air Intake Dx	⚫	🟢	⚫	🟢	🟢	⚫
Economizing When Unit Should Not Dx	⚫	🟢	⚫	🟢	🟢	⚫
Not Economizing When Unit Should Dx	⚫	🟢	⚫	🟢	🟢	⚫
Temperature Sensor Dx	⚫	🔴	🔴	🔴	🔴	⚫

Site PNNL Building SEB Unit AHU1
Diagnostic AirsideAIRCx
Start Date
End Date
Sensitive Level normal

⚫ Inconclusive 🟢 Normal 🔴 Fault ○ Unit is Off

	Dec 04	Dec 05	Dec 06	Dec 07	Dec 08	Dec 09
Operational Schedule Dx	🔴	🟢	🟢	⚫	⚫	⚫
No Supply-air Temperature Reset Dx	🟢	🟢	🟢	🟢	🟢	⚫
High Supply-air Temperature Dx	🟢	🟢	🟢	🟢	🟢	🟢
Low Supply-air Temperature Dx	🟢	🟢	🟢	🟢	🟢	🟢
Supply-air Temperature Set Point Control Loop Dx	🟢	🟢	🟢	🟢	🟢	🟢
No Static Pressure Reset Dx	🟢	🟢	🟢	🟢	🟢	⚫
High Duct Static Pressure Dx	🔴	🔴	🔴	🔴	🔴	🔴
Low Duct Static Pressure Dx	🟢	🟢	🟢	🟢	🟢	🟢
Duct Static Pressure Set Point Control Loop Dx	🟢	🟢	🟢	🟢	🟢	🟢

Figure 2.1. Presentation of AFDD Results (left) and AIRCx Results (right)

2.5 Development of UI to Create AFDD and AIRCx Configuration Files

Both AFDD and AIRCx algorithms use text-based configuration files that are in the JSON (JavaScript Object Notation) format. Creation of these configuration files or modifying them is a manual process that is time consuming and error prone (typos or JSON syntax errors); therefore, a pair of web-based configuration tools will be created.

The AFDD and AIRCx configuration tools are utility interfaces available to make the task of creating and maintaining configuration files simpler. They provide a graphical user interface (GUI) capable of producing the configuration files used by AFDD and AIRCx agents. The configuration tools require access to the Master Driver (agent responsible of interactions with BAS) agent configuration files and automatically load critical values from it such as devices (e.g., RTUs, AHUs) and points (e.g., temperatures, pressures). The configuration tools will also provide just-in-time error checking and pre-population of critical fields to cut down on lengthy trial and error debugging. In short, the AFDD and AIRCx configuration tools are available to make the process of configuration simpler and less error prone. A preview pane will show exactly the output of changes made to ensure that the generated configuration files reflect exactly what is intended.

3.0 ILC Algorithms

An ILC algorithm can manage peak load in a building while minimizing negative effects on occupant comfort. It has been fully tested and validated in a simulation environment as well as in real buildings to:

- Manage peak electricity load.

Manage electricity load in response to a demand response event.

Manage building electricity consumption under time-of-use (TOU) and critical peak pricing (CPP).

Support capacity bidding.

The ILC algorithm is ready for field evaluation; however, we currently do not have a good way to present or visualize the results to the building operator.

3.1 Building System Requirements for ILC

The ILC can be used with any controllable end-use loads, such RTUs, VAV boxes, and dimmable lighting fixtures. Because ILC prioritizes among available loads, the building should have multiple loads from which to select (e.g., multiple RTUs, or multiple VAVs or multiple lighting devices). To manage the building peak consumption in a building to a given target, ILC generates supervisory control actions, which will have to be transmitted to the loads/devices via BAS or other mechanism.

3.2 Development of a Tool to Visualize ILC Results

We currently do not have a visualization tool for viewing the results for ILC. As part of this effort, we plan to develop a modest visualization tool with the following features:

- Ability to view the performance of ILC in managing the building peak load under the target demand.

Comparison of baseline consumption (if ILC was not managing load) with the actual consumption (with ILC managing load).

Zone temperature profile, zone temperature set point changes, and controllable load status during the demand response event.

Computing the demand reduction and displaying it on the graph in real-time.

4.0 Selection of Energy Service Providers, Building Types and Location for Field Evaluation

The project will recruit two or more energy service providers to support field evaluations of AIRCx, AFDD, and ILC algorithms using the VOLTTRON platform. The evaluations will be conducted in multiple buildings in multiple locations. In this section, we outline the criteria that will be used to select energy services providers, buildings, and locations for the field evaluations.

4.1 Criteria for Selecting Energy Service Providers

The role of the energy service providers is to help PNNL with the field evaluation of the energy efficiency (AIRCx and AFDD) and peak load management (ILC) algorithms in commercial buildings. After training on how to deploy the VOLTTRON platform and the energy efficiency and peak load management algorithms, the energy service providers will deploy the solution in the field and will also be responsible for the day-to-day operations of the deployment. Therefore, the following criteria will be used in selecting the service providers:

- Potential service providers that serve large commercial buildings should be actively involved in the commissioning of the BASs and should have a portfolio of between 10 and 20 buildings.
- Service providers that are actively serving small commercial buildings without BASs, should have alternative way of deploying energy efficiency (AFDD) and peak load management algorithms. Delivery of peak load management services will require the ability to control the loads as well.
- Potential service providers should show that they have the required commitment from building owners to not only deploy passive energy efficiency algorithms but also a peak load management algorithm, which automatically control devices to manage peak electricity load.
- Potential service providers should have an adequate number of staff who can support this effort.
- Proximity of potential service providers to deployment sites is not an absolute criterion, but service providers who are close to the buildings that they are serving will be preferred. During the life of the project, more than one visit to the site may be required to meet the critical milestones and other project tasks.
- Potential service providers should be keen to deploy the technology at other buildings beyond this project’s lifecycle.
- The service providers should have basic familiarity with the Linux operating system and Python software.
- Service providers will administer surveys at the end of the project, to gather feedback/experience from the building owner/operator and building occupants. In addition, the service providers will also need to complete a self-survey.

PNNL will select multiple energy service providers to cover the diversity of locations and building types. The service providers could be serving both large and small commercial buildings. Preference will be given to energy service providers in areas where there is a current need for grid services or areas where utilities have programs that simultaneously promote energy efficiency and peak load management.

4.2 Criteria for Selecting Building Types and Locations

There is significant diversity in commercial building stock in the U.S. Because the scope and budget for the project are limited, it is critical that we pick the right mix of building types so that the results can be generalized across the building sector. Also, there is significant diversity of climates in the U.S., which means the locations of the field evaluations will be critical as well. The following criteria will be used for selecting buildings and locations:

- Individual buildings and/or campus sites with BACnet-based (or Modbus) BASs. Buildings with BASs that are configured with proprietary/other protocols **will not** be selected. For small commercial buildings that do not have BASs, other means of monitoring and controlling the devices will be needed. The other means should support either BACnet, Modbus, WIFI-based, or other open communication protocols.
- Buildings with less than 15 year old BASs will be preferred. Therefore, before potential buildings or campus sites are selected, the service providers shall document the following information:
    a. BAS vendor (make, model, software version) and size (number of physical hardware points and overall number of objects).
    b. Any constraints with the BAS – either internal to the BAS or due to the physical design of the BAS. Examples of constraints can include (but not be limited) to the following:
        i. Planned BAS upgrade in the next 6 to 12 months (server, supervisory controllers and/or field-level controllers).
        ii. Planned building retrofit (demolition of major systems and components) in the next 6 to 12 months.
        iii. Energy savings performance contract (ESPC) that affects the buildings under consideration.
    c. Laboratory systems (specialized exhaust, fume hoods, biological, chemical, radiological or other hazards).
- Based on the review of description for each building BAS-connected or BAS-integrated HVAC system provided by the service provider. This description should include the following:
    a. Chilled water or hot-water plant configuration – number of chillers (and size), number of boilers, number of cooling towers (and size) and descriptions of the ancillary systems that support the plant (pumps, variable-frequency-drives [VFDs], steam heat exchangers, process chilled water, dry coolers) or district steam and district chilled water (where steam or chilled water is generated and delivered from offsite):
        i. Include age of equipment, size (e.g., nominal tons for cooling, horsepower rating for boilers).
        ii. Describe specialized loads that are not related to comfort heating or cooling (e.g., data center cooling, process cooling, snow melt systems, humidification systems).
    b. AHUs and RTUs.

        i. Number of AHUs and RTUs, including fan motor size, VFDs (if provided), single zone or multiple zone (VAV terminal boxes).
        ii. Describe specialized AHUs or RTUs that may perform specific functions.
            (1) Dedicated outdoor-air system (DOAS), energy recovery ventilator (ERV), Garage Ventilation, other.
            (2) Variable refrigerant flow (VRF) systems.
    c. Zone terminal equipment.
        i. VAV boxes.
        ii. Fan Coil Units (FCUs).
        iii. Perimeter Heating (fin tubes).
        iv. Radiant heating or cooling (chilled beam – active or passive).
        v. Dual Duct mixing boxes.
        vi. Multi-zone.
    d. Legacy controls – including pneumatic, stand-alone thermostats and stand-alone BASs that are no longer supported by the vendor, etc.

Based on the review of the description for each building BAS-connected or BAS-integrated lighting system that is provided the service provider. This description should include the following:

    e. Lighting technology (fluorescent, light emitting diode [LED], Other) and percent of total controlled load.
    f. Dimmable or ON/OFF control.
    g. Estimated lighting load that can be controlled.

- Based on the review of the description for each building BAS-connected or BAS-integrated miscellaneous electric loads (MELs) provided by the service provider. Typical miscellaneous loads could include the following:
    a. Electric hot-water heaters.
    b. Electric radiant heaters.
    c. Exhaust fans.
    d. Electric snow or ice-melt systems.
    e. Circulating pumps.
- Potential buildings or campus sites shall describe their current level of real-time metering. Peak load management algorithm requires the following real-time metering:
    a. Reliable, real-time whole building power metering that is integrated to the BAS (cannot be stand-alone or part of a separate metering networked system)
    b. Reliable, real-time, sub-metering of selected systems may be advantageous (but not required).
- If available, potential buildings or campus sites shall provide two years (or any available) of whole building interval metered data as well as monthly electrical bills for the same period as the interval data and a description of the current utility rate structure.

- Potential buildings or campus sites with distributed renewable power generation and storage (thermal and battery) will be preferred, but a potential site without this capability will still be considered.
- The following building types will be preferred: office, small box retail, big box retail, schools, colleges, and supermarkets. Other building types may also be considered but will be given lower preference.
- Locations where there are existing utility programs to engage buildings to provide grid services (e.g. California, Northeast, mid-west) will be preferred. Again, other locations may also be considered but will be given lower preference.
- To include diversity in climates, buildings from different geographical regions will be considered.

5.0 Documenting Energy Service Provider and Building Owner/Manager Experience

One of the objectives of the field evaluation is to gather and document the feedback/experience of the energy service providers, the building owners as well as building occupants. Because each of these three categories of people will provide different feedback, three surveys will be developed. For the energy service providers, the survey would cover installation experience (e.g., how long it took to install various hardware and software pieces, how easy was it to install and configure, how easy or difficult was the ongoing maintenance of the software). For the building owners/operators, the survey would include questions on cost vs benefits and the likelihood that they would continue to use the software. The survey for the building occupants will be aimed at gathering feedback on items such as comfort impact.

The following process will be used to develop, implement, and document the feedback/experience from the field evaluation:

- First, three surveys will be drafted; these surveys will be based on experience gained from the lighting surveys that PNNL previously conducted.
- The draft surveys will be reviewed by the entire project team (PNNL, DOE, and energy service providers) to get broader input.
- Based on the feedback from the project team, the surveys will be finalized.
- We will then apply to the PNNL's Institutional Review Board for approval and certification.
- After the field evaluation is complete, PNNL will administer the surveys, analyze the survey data, and compile a report to document the findings.

6.0 Field Evaluation Timeline

The project, which began in October 2019, has a 24-month duration. The following timeline will be used to execute the field evaluations and document the results and feedback.

- Complete drafting the detailed test plan – 1/31/2020.

Complete selection of energy services providers – 4/30/2020.

Prepare the AFDD, AIRCx, and ILC software field evaluation – 6/30/2020.

Select buildings and locations for field evaluation – 7/30/2020.

Begin field evaluations in selected buildings and locations – 8/31/2020.

Sponsor a presentation on how the field evaluations are proceeding – 1/31/2020.

Complete field evaluations – 6/30/2020.

Draft a final report and presentation – 10/30/2021.

7.0 References

Brambley MR and S Katipamula. 2009. Commercial building re-tuning: a low-cost approach to improved performance and energy efficiency. ASHRAE Journal, 51(10), 12–23.

Cheng EWL and H Li. 2002. “Construction partnering process and associated critical success factors: quantitative investigation.” Journal of Management in Engineering 18(4), 194–202.

Claridge DE, CH Culp, M Liu, S Deng, WD Turner, JS Haberl. (2000). “Campus-wide continuous commissioning^{SM} of university buildings.” Proceedings of the 2000 ACEEE summer study, Washington, DC.

Crowe TJ, and JS Noble. 1998. “Multi-attribute analysis of ISO 9000 registration using AHP.” International Journal of Quality and Reliability Management 15(2), 205–22.

Fernandez N, S Katipamula, W Wang, Y Xie, M Zhao, C Corbin. (2017). Impacts of commercial building controls on energy savings and peak load reduction. Richland, Washington: PNNL-25985, Pacific Northwest National Laboratory.

Fernandez N, S Katipamula, W Wang, Y Xie, M Zhao. 2017a. “Energy savings potential from improved building controls for the US commercial building sector”. Energy Efficiency 11, 393–413 (2018) https://doi.org/10.1007/s12053-017-9569-5.

Katipamula, S, RG Lutes, RM Underhill, and S Huang. 2018. Automatic Identification of Retro-Commissioning Measures. Richland, Washington: PNNL-27338, Pacific Northwest National Laboratory.

Kim W, S Katipamula, RG Lutes. 2019. “Application of intelligent load control to manage building loads to support rapid growth of distributed renewable generation”. Sustainable Cities and Society. https://doi.org/10.1016/j.scs.2019.101898

Kim W, and S Katipamula. 2017. "Development and Validation of an Intelligent Load Control Algorithm." Energy and Buildings 135. PNNL-SA-116744. https://doi.org/10.1016/j.enbuild.2016.11.040

Kim W, S Katipamula, RG Lutes, RM Underhill. 2016. Behind the Meter Grid Services: Intelligent Load Control. PNNL-26034, Pacific Northwest National Laboratory, Richland, Washington.

NYC (New York City Mayor’s Office of Sustainability). 2017. LL87: Energy audits & retro commissioning. https://www1.nyc.gov/html/gbee/html/plan/ll87.shtml. Accessed 12 December 2019.

Saaty, T. L., and L.G. Vargas. 2012. Models, methods, concepts and applications of the analytic hierarchy process, Vol. 175. Springer Science & Business Media.

Seattle (Seattle Building Tune-Ups Ordinance). 2016. City of Seattle Municipal Code Chapter 22.930. https://www.seattle.gov/environment/climate-change/buildings-and-energy/building-tune-ups/about-building-tune-ups. Accessed 12 December 2019.

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