U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Control Product Performance Evaluation and Reporting (CoPPER) Roundtable

Report for Emerging Technologies

August 28, 2023

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Disclaimer

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Comments

The Department of Energy is interested in feedback or comments on the materials presented in this document. Please write to Brian Walker, DOE Technology Manager for Controls and Grid-Edge Decarbonization:

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List of Acronyms and Abbreviations

BOPTEST	Building Operations Testing Framework
BTL	BACnet Testing Laboratories
BTO	Building Technologies Office
DER	distributed energy resource
DOE	U.S. Department of Energy
GEB	grid-interactive efficient buildings
HVAC	heating, ventilation, and air-conditioning

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1 Introduction

The Building Technologies Office (BTO) within the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) successfully facilitated a comprehensive virtual roundtable discussion, centering on the innovative Control Product Performance Evaluation and Reporting (CoPPER) project concept. The event saw active participation from forty-two eminent subject matter experts, including a balanced representation from both DOE and national laboratories, and the industry, with 26 and 16 participants respectively. The roundtable followed a structured format, commencing with insightful opening remarks from DOE leadership, which set the stage for subsequent presentations that showcased the extensive capabilities of the national laboratories involved. Additionally, leaders of two Connected Communities projects shared invaluable insights and potential use cases for both virtual and mixed hardware/software hybrid testbeds, elucidating their critical role in supporting interoperability testing across Building/DER/Grid systems. The event culminated in a vibrant group discussion, moderated expertly, with participants actively contributing both verbally and in writing via the meeting's chat function.

Context

Digital building controls have long promised a cost-effective solution for saving energy, claiming short payback periods and low capital expense relative to other energy conservation measures. Controls extract operational performance from HVAC equipment by minimizing time spent in low-efficiency operational modes. They enable the integration of storage, the implementation of grid response, and the coordination of multiple systems to achieve whole-building energy and demand goals, which subsequently enable efficient grid operations. Controls also play a critical role in maintaining system performance over time.

For building technologies and systems, such as HVAC, Windows, and LEDs, there exists a robust framework of standards for test procedures and performance evaluation, predominantly established by DOE. These standards have been widely used to ensure product compliance, mitigate misleading claims about capabilities or performance, and provide the market with trustworthy information. However, when it comes to embedded equipment, field-installed equipment, and supervisory building controls, there is a notable scarcity of such test procedures and performance evaluation guidelines. This gap is a particularly significant barrier to adoption of any specific control system, as we witness a growing trend in smart buildings towards multi-system integration. This trend is not limited to the integration of a building's internal systems such as HVAC, energy, security, and life safety, but also extends to the integration of distributed energy resources (DERs), their associated DER management systems (DERMS) and the broader distribution electric grid (via advanced distribution management systems [ADMS]). The absence of comprehensive interoperability testing specifications is a major contributing factor to the challenges faced in systems integration, which, in turn, adversely affects performance testing and evaluation of building control systems. For industry participants, lack of test specifications and the resulting low confidence in performance are commonly cited barriers preventing service contractors, energy managers, and other customers from adopting an otherwise cost-effective, energy-saving technology.

The CoPPER project is strategically positioned to tackle these prevalent industry challenges. It aims to achieve two primary objectives: First, to provide clear and dependable information for potential customers exploring advanced building controls; and second, to lay the groundwork for future DOE initiatives, encompassing strategies, research and development projects, building codes and standards, as well as expediting demonstration and deployment activities. The realization of these objectives is anticipated to substantially enhance technology adoption, potentially leading to a 10–15% reduction in energy consumption.

Objective

BTO's primary objective in organizing the CoPPER roundtable was to garner valuable feedback from a diverse spectrum of stakeholders, spanning industry, academia, and research institutions. Participants were brought together to critically evaluate the project's current trajectory, identify any existing capability gaps, prioritize areas for additional investment, and suggest compelling and impactful use cases. Through this collaborative and engaging forum, the BTO aimed to ensure that the CoPPER project is optimally aligned with industry needs and poised to make a meaningful impact in the field of building technologies and systems.

Key Comments and Recommendations

The subject matter expert participants provided several general comments and recommendations on the CoPPER project concept and future direction. Many of the comments coalesced around a few key concepts: system interoperability testing, industry training and education, and control-application testing and certification.

Interoperability

Many participants spoke to the importance of interoperability. During the main presentation, one of the Connected Communities project leads stated that interoperability is a principal issue and one of the key barriers to enabling innovation and scaling of DER integration for the benefit of building owners, service providers, utilities and communities. This concept was consistent during the discussion portion of the meeting; one participant stated that BTO needs to focus on building-grid integration and solving interoperability challenges before DER integration can be fully scaled. Another participant specified that semantic interoperability needs to focus on control sequences and applications, and not just equipment and hardware devices.

One speaker mentioned that control sequences are at the heart of the interoperability challenge and are key to system performance optimization. While standard control sequences (e.g., ASHRAE Guideline 36) have been field-tested in demonstration projects, additional evaluation could extend their use to additional facility types and applications (e.g., within manufacturing facilities).

Lastly, one participant noted that interoperability needs to be tested in a real-world scenario, as opposed to a controlled laboratory environment. To truly test interoperability, it needs the complexity of real-world scenarios to address the challenges experienced in the field. This speaker reiterated that it would be valuable to see case studies, publications, and education resources about project delivery and interoperability best practices in the real world.

Training and Education

Speakers emphasized the significant role of virtual testbeds in the training and education of both students and field technicians in the domain of control applications. Field technicians can immensely benefit from these testbeds as they offer a practical and controlled environment to learn and practice troubleshooting, a skill that can be challenging to acquire in the diverse and complex real-world settings of buildings and systems.

For students, especially at the graduate and undergraduate levels, grasping control algorithms is a fundamental aspect of their education. Virtual testbeds provide a unique opportunity for them to not only build and understand the logic behind these algorithms but also to test and apply their knowledge in a dynamic, real-world-like environment. This hands-on experience is crucial for enhancing their skills in controller programming, tuning, commissioning, and understanding system integration.

Moreover, there is a wealth of building data being collected from various control systems installed in buildings. It was suggested that there should be a concerted effort to characterize, anonymize, and make this data available for educational purposes. This would enable students to engage with real data, further enriching their learning experience and providing them with valuable insights into the practical aspects of building control systems.

Platforms like BOPTest are highlighted as valuable tools in this educational journey, providing a means to showcase the complexity of control systems and offer a practical, hands-on learning experience. Through such platforms, students and technicians can gain a deeper understanding of control tuning, system integration, and performance benchmarking, bridging the gap between theoretical knowledge and practical application.

Control Application Testing and Certification

The roundtable discussions underscored a pressing need for systematic evaluation in control application testing, particularly emphasizing the significance of testing controls within their operational context. Various aspects of control application testing were highlighted, including interoperability, protocols, data models, performance evaluation, cybersecurity, and application integration testing. The discussions also pointed out the necessity of small-scale demonstrations and practical applications in the testing processes. Various laboratories and testbeds, such as LBNL, NREL, ORNL, and PNNL, were mentioned as key players in conducting diverse forms of control testing and development. These facilities also play a crucial role in addressing the challenges and improvements needed in control application testing, such as the lack of accessible building automation systems and the need for more comprehensive testing facilities and tools. The importance of understanding and addressing testing requirements across different scales and scopes was also emphasized.

The need for certification in control applications was acknowledged as a crucial step towards facilitating the introduction of devices into the market and applying pressure on companies to avoid proprietary technologies. A self-certification model was proposed, allowing vendors to use provided testbeds and standards to self-certify their products. Emphasizing the importance of adherence to open-source platforms and industry standards, the discussions highlighted the role of certification in ensuring the portability and adaptability of solutions. ASHRAE Guideline 36 was brought into focus as a significant effort in standardizing controls programming. The text called for support in expanding and implementing this guideline, underscoring the need for independent testing of control programs, particularly those based on factory G36 programming, to ensure compliance and robustness. Additionally, the necessity of field testing for project-specific control implementations was highlighted to ensure functionality consistent with design intent.

2 Meeting Logistics

Agenda

Introductions and CoPPER Overview/Use Cases	Brian Walker
CoPPER open-source S/W components	Amir Roth
LBNL Testbed Activities	David Blum
NREL Testbed Activities	Bethany Sparn
ORNL Testbed Activities	Jamie Lian
PNNL Testbed Activities	Srinivas Katipamula
Connected Community Opportunities	Seth Hoedl, Post Road Foundation
Connected Community Opportunities	Easan Drury, Edo Energy
Discussion:	Clay Nesler (moderator)
1. What are other compelling use cases?	
2. Where should BTO Prioritize further investment?	
3. How should BTO engage with industry on S/W tools?	
Last word of advice	
Next Steps and Adjourn	Brian Walker

Participants

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Timothy Unruh	NAESCO
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3 Roundtable Introduction

The DOE group introduced themselves and described the intent behind the CoPPER project.

Opening Remarks

DOE leadership provided additional opening remarks:

- Our aim is to provide transparent information to customers of advanced controls. We'll talk about the new testbed activity DOE is developing. BTO has briefed up to leadership earlier this year on this project with the vision of fitting CoPPER into the overall BTO perspective around open-source platforms.
- Overall, the goal is to provide transparent information to end-users, customers specifically working with advanced controls. We'd like to deliver something realistic, and not introduce a new problem. We see a need for systematic evaluation.
- We'd like to use this call to identify activities related to controls that fall in the gaps not yet covered.
- A goal is to provide smoother demonstration projects, with reliable product information that produces less frustration. We anticipate this can be done by addressing systems that have not interoperated or function well and by introducing transparency into the system.

DOE leadership continued their remarks by highlighting the potential use cases as defined by BTO:

- BTO notes that test controls need to be done in context within a control system.
- CoPPER isn't necessarily focused on performance, but instead on interoperability, protocols, and getting basic functionality with pieces talking together
- BTO has access to facilities, tools, and small-scale demonstrations that can be deployed in the field. A notable gap is the lack of a building automation system and access to its source code.
- BTO is interested in learning what combinations of activities would add value to industry: testing interoperability, protocol harnesses, capabilities for performance evaluations, facilities for testing cybersecurity, and software platforms for application integration testing, and more.

Lab Capabilities and Testbed Activities

Part of the meeting framework was to see where the lab capabilities are aligned and to see where investment is necessary to continue making progress. The four participating national laboratories summarized their current and planned testing capabilities during five-minute slide presentations. The full set of slides is available in the appendix.

Connected Community Partners

BTO introduced two representatives from Connected Communities projects to hear real-world examples of how CoPPER could be utilized. Each speaker provided a brief overview of their projects, and highlighted areas of frustration or challenge because of limited system and device interoperability. Their comments are summarized below.

Seth Hoedl – Post Road

- Evaluating transactive energy for rural America could benefit from CoPPER.
- Focused on transactive energy, developing prices-from-devices transactive energy in rural America.
- The project is set up to coordinate DERs across three separate communities. The DERs themselves put bids to buy or sell in the market in real time (<5 minutes). To do this effectively, low-latency, high-reliability communication is critical.
- DER communication options have issues. The more expedient options are unreliable, as vendors can change their offerings. It can also be costly, making it difficult to scale. Utilities are hesitant to use vendor cloud services due to high costs.
- An alternative communications option would be a home hub, but not all DERs allow for local controls.

- A near-term challenge is validating communications links before putting DERs in field. They need to validate because marketing materials often oversell the capabilities, and may not have capabilities that are being implemented.
- Another concern with some DERs is that even if they claim compliance, they may not actually comply in a meaningful way. These devices need to be tested to ensure the DERs' interoperability is verified before being placed in the field.
- Interoperability is a principal issue and one of the key barriers to enabling innovation and scale of DER coordination for the benefit of utility customers, the utilities, and our collective climate energy goals.

Easan Drury – Edo Energy

- Project is focused on one substation serving four different neighborhoods. It touches on all facets of control, making it a unique project.
- We're trying to see what is the actual value brought by controls is to a utility and building owner. The incremental revenues we expect to see from demand flexibility isn't equal to the revenues we're seeing from energy efficiency savings.
- This brings up the question of what systems are we are trying to control, and how deep into buildings should we be going, since there may not be a huge increased revenue stream associated to offset the cost. We want a realistic view of how much value is there.
- One frustration is that vendor solutions change over time, for example, Ecobee, whose offerings changed after being bought. This brings up the question of how much should we rely on vendors? What standards do we need to develop so that we can reliably implement?
- Building automation system data is very messy given the detailed level of information.
- I'm looking for a hardware component – what hardware can we drive down the cost of? What do tools look like for a control test bed? How can we automate performance testing of an existing building? We leverage BOPTEST, we want it extended into more building types
- There is a need to test assumptions in a simulation environment.

4 Recommendations From Discussion

After hearing from the laboratory leads and Connected Community partners, Clay Nesler led a group discussion among call participants. He noted that during previous roundtables, participants had discussed the need to verify interoperability of distributed energy resources with building controls systems as well as the need to verify the performance of control applications and sequences before installing them in real, complex buildings.

What Are Other Compelling Use Cases?

Guideline 36 and Sequence Test Bed Use Case

- There was a discussion on Guideline 36. As a background, Guideline 36 is an optimized sequence of controls for HVAC systems, often focused on larger systems. What are the opportunities to take advantage of virtual test beds to test real controllers and software to compliance to various control strategies?
- Current buildings are able to be connected; interoperability is not a major issue. The issue is the control sequences themselves. Another gap is the inability to monitor and trend systems. Sequences are key to determining optimization. They have been tested, although further testing could be used to further optimize sequences. The larger issue is to assure that the sequences are implemented properly. A test bed would be helpful in addressing this gap to evaluate whether the sequences are running properly (e.g., within manufacturing facilities).

Training and Education Use Case

- One speaker recommended additional training to understand PI control tuning. Educators should highlight that tuning should occur more than once, as buildings are non-linear and complicated. This can be effectively taught through hands-on, experiential learning. Tools like BOPTest are terrific in showcasing the level of complexity to students.
- Understanding control algorithms is foundational for students. In existing training platforms, students are able to build code to learn the logic, but they are unable to test their logic in a real, dynamic environment.
- Current students learn data-driven strategies for grid-integration courses but would benefit from an inter-collegiate competition to further drive their understanding.
- One speaker advocated for allowing students access to test beds to teach real scenarios with complexities.
- Test beds could be very useful for field technicians to learn troubleshooting, which can be difficult to learn in the real world given the large size and complexity of many systems.
- One speaker recommended working with existing certification programs such as the National Coalition of Certification Centers (NC3) to assure that the trainers are learning best practices.
- One gap for entry-level technicians is understanding sequences of operations in benchmarking performance. One recommendation is to verify the CoPPER interfaces work with existing sequencing curriculum. Standardized sequencing would further address this understanding gap, as students could learn it once and know that it would be consistent across all buildings.
- The tools that are required to quality assess the point data from buildings and understand performance are tools that would benefit from additional training for technicians. The training tools should look like the natural toolset in a real building.
- Data from real buildings should be available for training, especially if its anonymized.

Other Feedback on Use Cases

- Industry, especially small startups, could benefit from testing in simulation, in a hardware-in-the-loop lab, to set products up for success upon entry into the market. Products that go from design to the field or market often fail.

- One speaker recommended that semantic interoperability focuses on sequences, and not just equipment and points. Being able to exchange metadata with other applications about sequencing is valuable.
- Interoperability challenges are not best tested in a lab environment but rather need the complexity of real-world scenarios to capture the challenges experienced in the field. It would be valuable to see case studies, publications, and education resources about delivery and interoperability in the real world.
- DOE should build off of EPRI's "Standards Harmonization" efforts, expanding on the number of devices, standards, and use cases that can be proven to work together in a lab.

How Should BTO Prioritize Investment?

To summarize the feedback of this discussion question, moderator Clay Nesler requested that participants submit their rankings of where BTO should prioritize investment. A summary of those comments is listed below.

- Education and training
- Test and certify Guideline 36 sequences
- Scalability test
- Building performance evaluation tools
- Testing and validating DER communication
- Large-scale real-world deployments
- Interoperability
- Simulation
- Control performance testing
- Harmonizing across standards
- Deploying building flexibility
- Working with industry
- Evaluating controller sequences versus standards
- Lab support for validation
- Reporting on full-stack deployments of GEBs in real world environments
- Microgrids for local community deployment

How Should BTO Engage With Industry?

- BTO could offer a certification that allows for trusted marketing. This could be styled like the BACnet test lab model. An alternative suggestion is to develop a self-certification model using a series of test beds and test standards. This self-certification model is a lower overhead for industry. This model is based on LonMark profiles.
- Build the test bed from open-source elements to allow people to build upon it, similar to BTL.
- One speaker cautioned against developing a DOE test bed and sticker certification. We have examples of industry-driven organizations (Bluetooth sync, Wi-Fi forum, IEEE 1547 SunSpec) that build test procedures and certifications, and allow testing laboratories like UL to do testing. This may be a better direction to go.

Last Words of Advice

- BTO should encourage testing before field deployments, and this should be built into standard experiment design for BTO-funded projects.
- Simplicity and support are enablers for other people to adopt the test bed.
- The biggest barriers to the market for the advanced grid interactive use cases are not technical; they are policy and procurement. People need resources and education to shift the market.
- Start with use cases and goals before platforms and solutions.
- BTO should focus on scale and how CoPPER can lower barriers to quickly scale DER deployment and use.
- BTO needs to focus on grid integration and solving interoperability challenges before grid integration can be fully scaled.
- BTO should be clear and transparent about their objectives.
- BTO should identify a controls process that moves from simulated controls test beds to the messy real-world data and controls.
- Benchmarking performance can help identify value in increased complexity.

- The lab can test the technical components, but there is a lack of education to procure these sources. How does this translate to business makers?
- How do we connect standards with requirements and close the loop? Codes and standards are often forgotten.
- Drive down costs, identify efficient processes to implement the solutions.
- Be clear with what the use case is for testing.
- Determine scalable “right questions to ask” for technologies.

Next Steps

DOE described the next steps as follows:

- DOE will distribute a report summarizing input received during this roundtable discussion. The report will support transparency and provide preliminary information about the process and substance of DOE/EERE/BTO work.
- Stakeholders should stay tuned for the forthcoming Research and Development Opportunities report.
- Stakeholders should also look forward to an invitation to two more roundtables in the coming months. The first will have a theme of integration of building systems and the grid. The second roundtable is being planned for the ASHRAE Winter Conference in Chicago. Stakeholders will be invited to attend the roundtable in person.

5 Presentation Slides

Control Product Performance Evaluation and Reporting (CoPPER)

Goal: provide transparent, reliable information for prospective customers of advanced controls, to support decisions and lay groundwork for further R&D/standards, leading to increased deployment and saving 10-15% of energy use

- **Problem: Windows, HVAC, and LEDs have standards for test procedures + performance (many set by DOE), which independent labs use to ensure product compliance, reduce false advertising, and provide clear information to the market**
  - Example: CALiPER program. BTO tested LEDs, reported on performance & extent to which they lived up to claims.
  - Example: BTL (BACnet testing lab). Certifies equipment for (full-stack) BACnet compatibility.
- **Other than BTL [limited to BACnet], such testing does not exist for controls, embedded or supervisory. Lack of reliable specs means many projects stall due to system integration challenges, before performance testing can even start. There is also no performance testing for products that advertise performance or service levels.**
- **Rock: testing/public reporting on control specs for components and (limited) integrated systems**
  - Leverages lab test facilities (including virtual), demonstration programs (HIT catalyst, GPG, CC), experience with testing protocols and programs (appliance standards, CALiPER, CalFlexHub, Stor4Build), and partnership with EPA
  - Flexible system scope: local controllers, HEMS, EMCS, DERMS, common system/multi-component configurations
  - Flexible testing scope: basic functionality (system requirements, protocols, interfaces), cybersecurity, performance
  - For performance, develop standard configurations and scenarios (physical testing if possible, but mostly virtual)
- **Success: faster, "smoother" demonstrations, reliable product information, less frustration**
  - Demonstration programs provide input (M2T) & benefit from output (T2M)
  - Content and support for other BTO programs/stakeholders
- **Connections**: CC, BPS, HP-RTUs, resilience, avoiding electrical upgrades, CBI's equity-focused M&V

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CoPPER – Potential Use Cases

Residential Buildings

- Evaluation of *smart thermostat control of variable speed residential heat pumps for EnergyStar certification*.

Small/Medium Commercial Buildings

- Evaluation of *smart thermostat control of unitary commercial HVAC equipment and systems* including on-site and cloud-based *supervisory control, automated commissioning, and demand flexibility*.

Large Commercial Buildings

- *Testing control applications (software libraries and embedded applications)* for proper implementation of standard control sequences (e.g., *ASHRAE Guideline 36*).

Connected Communities/Demand Flexibility

- Platform would provide a virtual and physical environment to *test and validate integration and control of EMCS, DERMs, DERs and utility communications* prior to implementation in connected communities projects.

Operator and Technician Training

- Development of a flexible, *hybrid physical (controllers and workstation) and virtual (HVAC equipment and building systems) training system for EMCS operators and technicians*.

Advanced Controls Challenge

- Researchers (e.g., university students, industry) use the testbed to *compete on developing the best control strategies*

EMCS Metrics Baseline Evaluation

- Use the testbed to *evaluate the baseline performance of current generation EMCS technology*

Advanced Controls Expertise and Stakeholder Engagement

MPC for K-12

Optimal Fault Free Controls

Manufacturer Controls

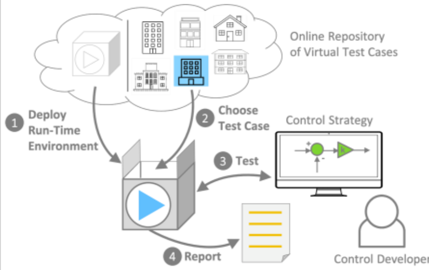
Load Shifting Controls

Connected Communities National Coordinator

Understand Testing Requirements Across Scales and Scopes

Device	Performance
Building	Communications
Aggregated	Interoperability
Grid	Functionality

Testbed Resources



BOPTEST is an open-source framework for sharing control-interactive virtual building emulators and benchmarking control performance.

FLEXLAB/FLEXGRID provides building and DER hardware and controls integration and comparison testing, as well as smart panels and other low-power electrification technology.

ASHRAE 223P

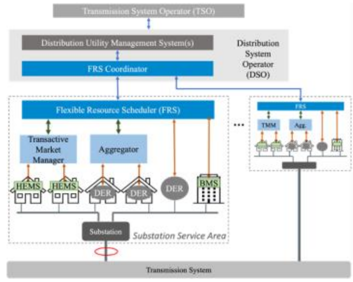
Project Haystack

Semantic Interop provides software for creating and accessing semantic models.

Stor4Build

U.S. DEPARTMENT OF ENERGY

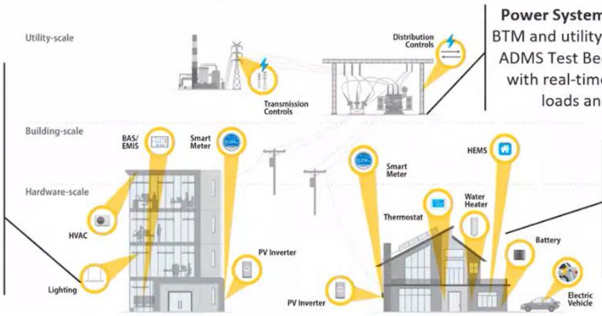
Store4Build provides modeling for thermal energy storage.



FAST-DERMS provides a DERMS-like environment that can send grid service signals to resources looking to test grid interactivity.

NREL: Integrated, End-to-End Energy Ecosystem

Commercial Building Research Infrastructure (CBRI) connects commercial DERs, BAS controllers, thermal energy storage, DC Fast Chargers to building simulations and grid simulations.



Power Systems Integration Lab (PSIL) includes BTM and utility-scale DERs, microgrid controllers, ADMS Test Bed, future DERMS test bed – along with real-time simulators to model simulated loads and simulated power systems

Systems Performance Lab (SPL) contains 3 homes with residential DERs, major appliances, smart controllers connected to building simulations and grid simulations

Flexible combination of laboratory hardware, advanced controllers and simulation tools allows for wide range of experiments:

1. De-risking: Making projects more successful
2. Proving Ground: Evaluate claims
3. Scaling: Extend results beyond a single project, from devices to buildings to grid

Current and planned use cases:

- SALMON Connected Communities: ADMS & DERMS in PSIL
- GSA GPG & NYC DCAS: Commercial BAS evaluation in CBRI
- Habitat for Humanity Basalt Vista and Glenwood Springs: HEMS evaluation in SPL
- Eaton: DER evaluation in SPL

Extensive experience working with industry partners and adapting open-source tools to different needs.

- OpenADR, CTA-2045, SunSpec, BACnet, IEEE 2030.5, ASHRAE 223
- Alfalfa, OCHRE, OpenStudio, EnergyPlus, OpenDSS, GridLab-D, HELICS, URBANOpt, ResStock, ComStock, BuildingMOTIF

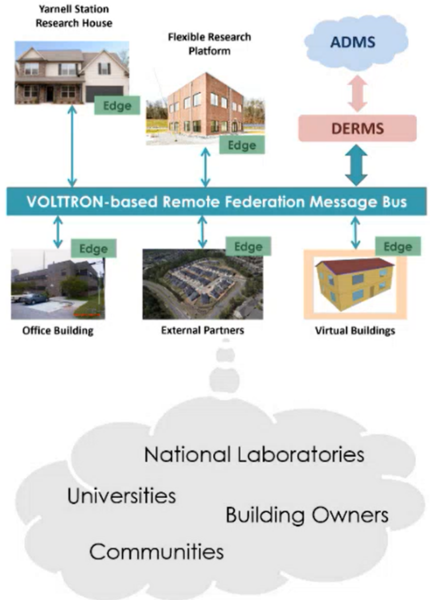
Industry partners:

- Manufacturers: Eaton, SPAN, Schneider Electric, Shifted Energy, Emerson, OSI, Oracle, Tridium, JCI, Trane
- Organizations: GSA, DoD, EPRI, NRECA
- Utilities: PGE, Duke, HECO, SDG&E, Xcel Energy, ComEd, Exelon, Southern Co.

NREL | 1

Building Controls & Integration Virtual Laboratory (B-CIViL) for Open-source, Reconfigurable, and Comprehensive Building Control Assessment

- **Objective**: Deliver a high-fidelity, flexible **grid-edge** platform with **real-building-in-the-loop** (r-BIL) simulation through the software modularization and hardware federation, and comprehensive testing procedures and KPIs
  - providing accessible, credible, and flexible building control testing results
  - facilitating development and adoption of advanced building controls
- **Current Approach:** Existing building control testing is usually ad-hoc with fixed settings, subjecting to challenges for broader adoption
  - high cost but low accessibility, credibility and scalability
  - Lack of transparency, repeatability and comparability
  - Limited test coverage and performance evaluation
- **Innovation:**
  - **Customizable control testing infrastructure** using APIs/templates for control deployment while leveraging other projects (e.g., VOLTTRON™, SC-SMB, OpenHEMS, BOPTEST, FAST-DERMS, GridAPPS-D, Code Compliance)
  - **Well-recognized testing procedure and KPIs** to offer a full picture of performance in a transparent manner
  - **Federation of testing facilities** across DOE labs and external partners to supporting remote accesses via secured communication tunnels
- **Why Care:** Control developers will benefit from reduced testing cost and increased test coverage; Building owners will benefit from credible testing results to support the decision making.

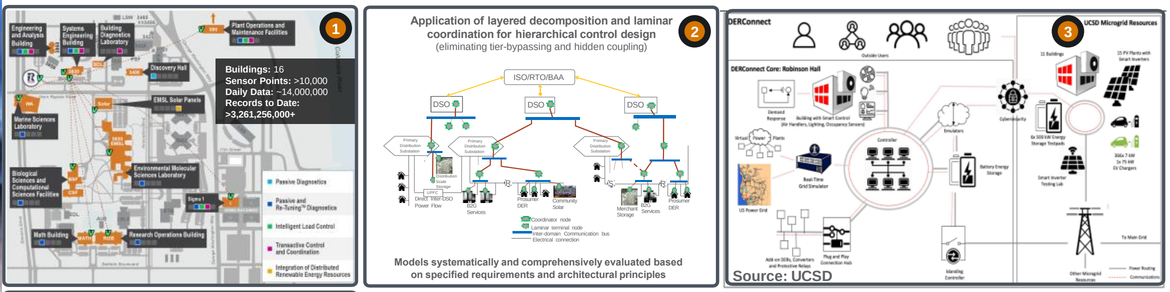


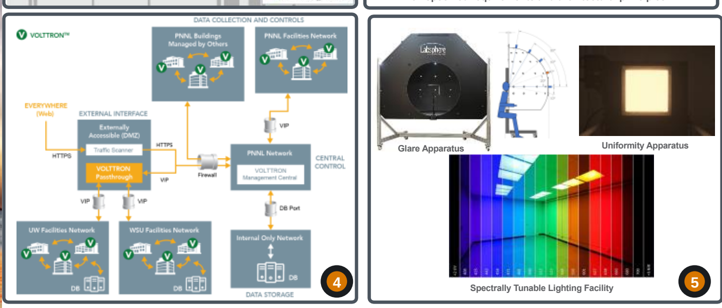
OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

PNNL CoPPER Testbed

Partners: Edo, Intellimation, ACE IoT, ecoLong, UCSD, Avista, PacifiCorp

Pacific Northwest NATIONAL LABORATORY





Other Testbed Related Activities

- Lab homes
- BOPTEST (Building Operations Testing)
- Codes compliance check for control
- Control score testbed
- Internet-of-things common operating environment
- Small commercial building testbed

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