U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Building Controls Roundtable

Report for Emerging Technologies

June 2024

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# Disclaimer

# Acknowledgments

The Department of Energy would like to thank Clay Nesler, The Nesler Group, for valuable guidance and input during the preparation of the Roundtable and assistance in authoring this report.


# Comments

The Department of Energy is interested in feedback or comments on the materials presented in this document. Please write to Dr. Cecilia Johnson-Hayman, DOE Technology Manager, Controls Portfolio:


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# List of Acronyms and Abbreviations

| | |
|---|---|
| BTO | Building Technologies Office |
| CEE | Consortium for Energy Efficiency |
| DOE | U.S. Department of Energy |
| EERE | Office of Energy Efficiency and Renewable Energy |
| EMCS | Energy Management and Control Systems |
| EMIS | Energy Management Information System |
| ESCO | Energy Service Company |
| ESPC | Energy Savings Performance Contracting |

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# 1 Introduction

On January 22, 2024, the Building Technologies Office (BTO) within the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) hosted a comprehensive roundtable discussion centering on the use of Energy Management and Control Systems (EMCS) as a platform for continuous building performance management. The event saw active participation from 49 subject matter experts from DOE, national laboratories, universities, and industry. The roundtable followed a structured format, commencing with opening remarks from DOE leadership, which set the stage for subsequent discussions.

## Context

BTO has identified accelerating the development and deployment of continuous building performance management systems in existing commercial buildings as a high priority opportunity for future EMCS research and development. Building professionals applying effective energy management processes and tools, while leveraging existing EMCS technologies, can deliver 10–30% building energy efficiency improvements[1] with minimal investment. This roundtable explored opportunities for integrating emerging digital technologies, such as advanced control sequences and data analytics, with enhanced standards, management processes and operator training to deliver continuous performance management in commercial buildings.

## Objective

BTO's primary objective in organizing the Controls roundtable was to gather valuable feedback from a diverse spectrum of stakeholders, spanning industry, academia, and research institutions. Participants were brought together to discuss how to accelerate development and deployment of building control systems as a platform for continuous building performance management systems in existing commercial buildings. Through this collaborative and engaging forum, BTO aimed to ensure that their work is aligned with industry needs and poised to make a meaningful impact in the field of building control systems and applications, building operations, performance-based energy services and utility programs.

## Key Comments and Recommendations

- Building controls have an opportunity to deliver large savings but only when buildings are designed, commissioned, and operated correctly. Building controls and performance management tools contain a lot of raw data but lack the schema to be able to easily share and analyze it. A new generation of building operators needs to be trained on data-centric performance management, as opposed to complaint-based and alarm-based performance management.

- A challenge in incorporating building controls into utility incentive programs are concerns over long-term energy savings persistence. Building operators can easily counteract energy savings when responding to occupant complaints or system complexity. Large commercial buildings are especially difficult to include in utility programs because they are generally custom engineered and programmed in the field. There needs to be an approach for determining deemed savings estimates for control projects.

- There is a big opportunity in finding ways that allow a mid-level engineer or contractor to make the building controls work without an expert having to monitor it full time. Operators are dealing with hundreds or even thousands of control alarms in the facility, so the systems have to be implemented in a way that makes them easy to operate and maintain. Retro-commissioning should verify proper control system operation and significantly reduce the number of alarms.

[1] Pacific Northwest National Laboratory, 2017. "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction." https://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf.

- A recent study[2] shows that only about 60% of building control measure savings persisted after three years and that most had changed scheduled start and stop times, lighting controls, zone airflow and ventilation rates from initial settings. Many of these changes were because of occupant complaints or operators that don't understand the original control logic and disable the functionality. Buildings with retro-commissioning training for staff have higher system performance because operators understand the design intent and functionality of the building systems and controls.

- Energy service companies (ESCOs) guarantee the savings of retrofit projects, using a rigorous — but manual — approach for measuring and verifying performance over time. While control upgrades are cost-effective savings measures, long-term performance is dependent on proper building and system operations. ESCOs are starting to develop tools to analyze real-time control system data and utility bills to perform a comprehensive building performance analysis and validate proper building operation over time.

[2] Gunasingh, S., S. Hackel, and X. Zhou, 2019. "Persistence in Energy Savings from Retro-Commissioning Measures." *ASHRAE Journal*. https://slipstreaminc.org/sites/default/files/2022-06/ashrae-rcx-study.pdf.

# 2 Meeting Logistics

## Agenda

| | |
|---|---|
| **Welcome and Introduction** | Dr. Cecilia Johnson-Hayman, DOE Technology Manager, Controls Portfolio |
| **Panel Discussion** | Clay Nesler (moderator) |
| Current EMCS/EMIS technical capabilities | Paul Ehrlich, Building Intelligence Group |
| Capability gaps/barriers for utility programs | Ryan Hamilton, Consortium for Energy Efficiency |
| Capability gaps/barriers for building operations | Chris Battisti, U.S. Army Corps of Engineers |
| Capability gaps/barriers for retro-commissioning | Joe Zhou, Slipstream |
| Capability gaps/barriers for energy performance contracting | Dr. Timothy Unruh, National Association of Energy Service Companies |
| **Group Discussion** | Clay Nesler (moderator) |
| High-priority technology development opportunities | |
| **Last Words of Advice for DOE** | Clay Nesler (moderator) |
| **Looking Ahead** | Dr. Cecilia Johnson-Hayman |

## Participants

| Name | Organization |
|---|---|
| **Chris Battisti** | U.S. Army Corps of Engineers |
| **Carys Behnke** | DOE-CBI |
| **David Blum** | LBNL |
| **Michael Brambley** | PNNL |
| **Lance Brown** | AKF Engineers |
| **Jayson Bursill** | Delta Controls |
| **Hwakong Cheng** | Taylor Engineers |
| **Mazen Daher** | Electric Power Research Institute |
| **Kelsea Dombrovski** | NREL |
| **Jon Douglas** | Johnson Controls |
| **Paul Ehrlich** | Building Intelligence Group |
| **Cary Faulkner** | PNNL |
| **Nick Gayeski** | Clockworks |
| **Scott Hackel** | Slipstream |
| **Ryan Hamilton** | Consortium for Energy Efficiency |
| **Katherine Hammack** | SC-B Consulting |
| **Xu Han** | University of Kansas |
| **Sen Huang** | ORNL |
| **Henry Huang** | Argonne National Lab |
| **Roderick Jackson** | NREL |
| **Yilin Jiang** | PNNL |

| Name | Organization |
|---|---|
| **Xin Jin** | NREL |
| **Dr. Cecilia Johnson-Hayman** | DOE |
| **Srinivas Katipamula** | PNNL |
| **Xuechen (Jerry) Lei** | PNNL |
| **Jamie Lian** | ORNL |
| **Xing Lu** | PNNL |
| **David Lunderberg** | DOE/AAAS Fellow |
| **James McNeil** | Edo Energy |
| **Chris Megede** | Delta Controls |
| **Alexi Miller** | New Buildings Institute |
| **Clay Nesler** | The Nesler Group |
| **Zheng O'Neill** | Texas A&M |
| **Gwelen Paliaga** | TRC |
| **Marco Pritoni** | LBNL |
| **Roger Quesnel** | SkyFoundry (and Project Haystack) |
| **Nikitha Radhakrishnan** | Siemens Financial Services |
| **Cindy Regnier** | LBNL |
| **Joe Rendall** | ORNL |
| **Andrew Rodgers** | ACE IOT Solutions |
| **Amir Roth** | DOE/BTO |
| **Nick Ryan** | DOE |
| **Chris Sala** | Slipstream |
| **Madelyn Shapiro** | PNNL |
| **Li Song** | University of Oklahoma |
| **Bethany Sparn** | NREL |
| **Henry (Rick) Stehmeyer** | Control Technologies Inc. |
| **Dr. Timothy Unruh** | National Association of Energy Service Companies |
| **Joe Zhou** | Slipstream |

# 3 Opening Remarks and Panel Discussion

## Opening Remarks

Dr. Cecilia Johnson-Hayman, DOE Technology Manager for Controls Portfolio delivered opening remarks:

- This is the fifth in our series of industry stakeholder roundtables supporting development of our Energy Management and Control Systems Research and Development Opportunities document.
- This roundtable will explore the opportunities associated with integrating building controls technology, people, and processes to deliver continuous building performance management in commercial buildings.
- We know that building re-tuning can deliver 10–20% improvements in building energy efficiency with minimal investments.
- We value your input, as it is key to helping us shape the future of our research and development (R&D) portfolios.

## Panel Discussion

Clay Nesler, the moderator for the event, then introduced the five topics for the panel discussion:

- Current EMCS/Energy Management Information System (EMIS) technical capabilities
- Capability gaps/barriers for utility programs
- Capability gaps/barriers for building operations
- Capability gaps/barriers for retro-commissioning
- Capability gaps/barriers for energy performance contracting

### Current EMCS/EMIS Technical Capabilities

The moderator introduced Paul Ehrlich from the Building Intelligence Group, who shared his perspective on current EMCS/EMIS technical capabilities.

- While existing building controls have the potential to improve building performance, there are a number of chronic issues that remain to be addressed including: buildings that don't have effective designs; designers who aren't creating optimized designs; how the designs are implemented; how the buildings are operated; and mechanical systems that don't operate correctly.
- Big savings are possible, but it requires lots of work and takes a lot of time and money. The work is also hard to scale because of the limited expertise that exists in the industry today.
- There are a lot of performance management tools being used, but they present a different problem — large amounts of data are available from EMCS systems without any semantics (i.e., data about data) associated with it. Owners need this semantic information in order to use the system data to manage building performance. Figuring out how to fix this problem, deploy it, and scale it quickly is critically important for improving building performance. Author's note: After the roundtable, ASHRAE has since released a first public review draft of Standard 232P[3] on Common Content and Specifications for Building Data Schemas.
- The other challenge is training operators to be data-centric in their approach to managing their buildings. Managing a building through real-time performance data is different — and much more effective — than managing by complaint, phone call, or alarm.

[3] ASHRAE, 2024. "BSR/ASHRAE Standard 232P, Public Review Draft: Common Content and Specifications for Building Data Schemas." https://osr.ashrae.org/Online-Comment-Database/ShowDoc2/Table/DocumentAttachments/FileName/4283-Std232_PPRDraft_20240125_chair_approved.pdf/download/false.

### Capability Gaps and Barriers for Utility Programs

The moderator introduced Ryan Hamilton from the Consortium for Energy Efficiency (CEE), who shared his perspective on capability gaps and barriers for utility programs.

- One of CEE's focus areas is transforming the market for new technologies, like advanced building controls, used in commercial and multi-family buildings.
- The big driver for designing, developing, and deploying utility programs is measure persistence, which is how long the energy savings improvements are expected to continue in the future.
- One challenge with building controls technology is that efficiency improvements are dependent on building operations effectively managing comfort and responding to occupant complaints without compromising long-term energy savings. Utility incentive programs have to have certainty about energy savings, and continuous building performance management would help assure the persistence of those savings.
- If we can identify the right utility program attributes, controls technology, and buildings to target, we could get quick traction in the market and start to scale these applications.
- The commercial building market is particularly challenging because these systems are often custom engineered and programmed in the field, which results in variable efficiency performance. Continuous performance management would be a prerequisite for successful utility programs in this sector.

### Capability Gaps and Barriers for Building Operations

The moderator introduced Chris Battisti from the U.S. Army Corps of Engineers, who shared his thoughts on capability gaps and barriers for building operations.

- The big opportunity for continuous building performance management is allowing a mid-grade engineer or contractor to effectively make the building controls work as designed without an expert having to monitor the system full time.
- Many times, operators are already dealing with hundreds or thousands of control system alarms in the facility, so the systems have to be implemented in a way that makes them easy to operate and maintain.
- If the retro-commissioning process is done right, you get a verification of the control system that can help prevent tons of alarms from going off.

### Capability Gaps and Barriers for Retro-Commissioning

The moderator introduced Joe Zhou from Slipstream, who shared perspective on capability gaps and barriers for retro-commissioning.

- In a field study on retro-commissioning[4] in 28 buildings, they found that after three years, only about 60% of control measure savings persisted, and only 50% after six years.
- 100% of those buildings had changed schedules for optimal start times and lighting controls, 80% had made zone airflow adjustments, and 70% had changed ventilation rates.
- Many operators change these settings because of occupant complaints, or for more complex systems, the facility operator doesn't understand the control logic, so they disable it or adjust the settings so much that it doesn't work properly.
- Buildings with major recent retrofits tend to have lower persistence of controls savings because they make modifications based on unexpected issues that come up (e.g., hot or cold areas of the building).
- In buildings operated by an external controls contractor, the contractor knew more than the internal staff about how the systems were designed and how to save energy. There is often a gap in training for internal staff by the controls contractor during system turn-over.

[4] Gunasingh, S., J. Zhou, and S. Hackel, 2018. "Persistence of Savings from Retro-Commissioning Measures." https://slipstreaminc.org/sites/default/files/2022-06/retrocommissioning-persistence-study-seventhwave-final-report.pdf.

- Buildings with retro-commissioning training for staff have higher system performance because they understand the building systems and controls.
- Another factor is staff turnover, as there isn't a good transfer of knowledge of the building systems and controls between outgoing and incoming operators.
- The controls technology we have is great, but the human factor is critical. You need building operators who understand the controls and know when — and when not — to adjust the settings.

### Capability Gaps and Barriers for Energy Savings Performance Contracting

The moderator introduced Timothy Unruh from the National Association of Energy Service Companies, who shared his perspective on capability gaps and barriers for energy savings performance contracting.

- Energy service companies (ESCOs) perform energy savings performance contracts (ESPCs) where they retrofit the building and have to guarantee the savings.
- Once the measures are installed, there is a rigorous approach for measuring and verifying energy performance over time.
- We've determined from the ESCO industry that a lot of improvement measures already have a lot of historical data predicting how they will perform. Instead of measuring things like lighting and water use that can be stipulated, it's more important to understand how the entire building is operating. This involves looking at both the control system and utility bills to figure out what isn't working and can be improved.
- While the technology is amazing, so much of it comes down to a people issue. The operator who invests time to learn how the system works and prioritizes energy savings is going to have a much higher performing building than the operator neglects the management of their system.
- ESCOs are trying to figure out how to go beyond alarms and develop software that analyzes the real-time data and determine not just that something is wrong, but that something could be working better. The ESCOs are developing these tools and algorithms, but they're doing it in proprietary ways that may only available to the ESCO or may not be available to building owners and operators after the contract performance period.
- Companies are using these systems in a more dynamic way, looking at streams of control system data and combining it with the utility bill information to perform a full building performance analysis to validate proper building operation.

## Q&A

The moderator asked participants to share additional thoughts or questions, summarized below.

- There is an apparent disconnect between the people who operate the building and the people who benefit from the financial outcomes of those operations. One participant is a proponent for having the financial consequences of an operator improperly overriding an air handler having a financial impact on that operator.
    - In response, another participant highlighted the industry's very critical position towards operators, which often characterizes them as breaking the system. In reality, it is the systems that are broken, and the operators are doing their best to try to fix it. Many system problems are actually design issues, not operator issues.
- Is there an opportunity to provide a post-installation utility incentive after verification of system energy performance and that is persistent for approximately five years?
    - Southern California Edison had a small building control program that paid half the incentive up front for the capital investment, and then the other half after one or two years of verified energy performance based on the actual measured and metered results. It was a pilot program that wasn't continued, likely because it's easier to incentivize measures with deemed savings that don't require post-installation performance verification.
    - One of the challenges with a performance-based type of program like this is that the contractor needs to know the savings up front since that forms the basis for the financial analysis and

guaranteed savings of the project. Some of the more advanced control-based savings may not be reflected in the energy model because they don't know how well it will perform.
    - Utilities have been looking at ways to get to deemed savings for controls retrofit projects and see lots of opportunities at improving the data models to predict savings more accurately. The other way to measure it is through "semi-deemed savings" approaches where a lot of research, often supported by DOE, can be used to create a simplified calculator to determine incentives. Pay-for-performance and ESCO models are great, but they're way more complex to implement and you're not going to get mass adoption of those in the utility industry.

## Group Discussion

The meeting then moved into the group discussion, also led by the moderator. Attendees were encouraged to bring up topics that weren't covered but they felt were important. The questions posed and related responses are paraphrased below, reflecting the informal nature of the discussion, and without providing verbatims.

- It's important not to forget about small facilities, small building owners, or small portfolios. We need technology pathways for people who have been running advanced energy data analytics for 10 years, but we also need pathways for people who only have two or three pieces of metadata about their system. They need to be able to leverage the data in these analytical tools, use them to help manage the building, and then add more data as they do other projects or replace equipment. Many times, these data standards are discussed in terms of a full-scale implementation, but many people don't have the resources to do that all at once. Many smaller portfolio owners lack the necessary the expertise to do this. It needs to be easier for owners to obtain and retain these data models and obtain the right resources so they don't have to build their own systems from scratch.
    - The energy as a service industry is tackling some of this. They control hundreds of small buildings remotely across the country and are now looking at how they can leverage those in a shared savings model. Their expertise is remotely running lots of buildings and optimizing energy use because they're paid based on the energy and operational performance.
    - There is an opportunity for utilities to become energy service providers to large and small building portfolios.
- Would a selection of buildings managed by a single entity leveraging common technology be a predictable energy savings opportunity for utilities?
    - Yes, utilities are trying to generate specs for connectivity for certain appliances. It's difficult to justify installing systems with building-level supervisory controls for small buildings. But if each piece of equipment were installed with open-source, non-proprietary connections, that could help in managing these small buildings.
    - In the retrofit persistence study[5] they found smaller buildings tended to persist better because their systems are simpler, so people understand them better and don't need to make complex adjustments.
- The discussion has been on improving building controls and reducing energy use, but more advanced building controls could also open up doors for utility programs in terms of load shifting. Is that something you hear utilities asking for?
    - Load shifting is front and center. One of the big changes that's happening in the utility industry is this change from focusing only on energy savings and moving to electrification and decarbonization. That's driving the effort to install and incentivize appliance-level controls and connectivity.
- The current metric for building control performance is energy, but we don't just care about energy per se. We're talking about cost, greenhouse gas emissions, and to some extent resiliency, thermal comfort, and other occupant metrics. We're using energy as a proxy for the things we actually care about. But it's hard to

[5] Gunasingh et al. https://slipstreaminc.org/sites/default/files/2022-06/ashrae-rcx-study.pdf.

program a smart control system to deliver both cost savings and greenhouse gas reductions. It would be great to see the ability to have an 80/20 solution and a slider so we can co-optimize both of these.
    - One of the big challenges is that we're living with legacy utility rate systems, which were designed a long time ago to do something completely different than what we want to do in the future. It's hard to design solutions and programs that are effective until we understand what the future rate structure will be like.
    - The market is sometimes getting the wrong incentive. As a research community, we should understand where we're trying to go. I'm not sure we know that, and we might be building the wrong solutions because we don't know.
- The observational studies that are gathering data to understand how people are installing and operating control systems is a good start. Does anyone have experience bringing human factors and human computer interaction expertise into the research loop?
    - Control system graphics standardization is big opportunity. We make graphics look similar across locations so people don't have to figure out where the data is.

## Last Words of Advice

The moderator then asked attendees to provide a few last words of advice, in the form of a short post, for the DOE building controls portfolio. A summary of their paraphrased verbal recommendations, organized by organization type are listed below:

- Industry Participants
    - For building control-related standard making, DOE could help bring people from different fields to contribute.
    - We need large-scale control benchmarking for different scenarios (building sizes, system types, sensor uncertainties, human factors, utility rates); device-level and system-level control; and control solutions for future utility rates.
    - Building commissioning is needed for control quality.
    - To the extent possible, transform building controls so that they require the absolute minimum qualifications and labor from building control vendors and O&M staff. The industry continues to not provide sufficiently qualified people. In the automobile industry, they accomplished this with black-box computers that cannot be altered or disabled. Similar solutions for building controls would be useful.
    - We need solutions for today, not just for 10–20 years from now. Low tech. Make it easier for designers and installers to do a good job, to sweat the details, and meet minimum code. Simple tools to make systems work better. Guideline 36, ctrl-flow, and their surrounding ecosystem can help. Manufacturer tools to make field installation easier.
    - Programs to encourage more standard/packaged solutions in commercial buildings. In other words, less field customization and more standard applications.
    - Provide a standardized metadata spec that allows for on-device storage, automated model composition, and support for multiple ontologies/vendor libraries. Probably should include an easy-to-interpret visual schema.
    - Explore different business models on how to transfer control design & implementation knowledge to facility operations and maintenance staff/team for effective building operation.
    - More building controls utility programs. Test procedures for systems vs. equipment. Building performance standards for benchmarking. Develop rate structures that support decarbonization.
    - Finish work on semantic data standards and build tools and programs to get them deployed to the existing building stock.
    - What is the process to use semantic models that drive actionable performance improvements throughout the life cycle?
    - I would like to suggest an improved user feedback system on residential or commercial buildings. Based on previous experience, people who never touch their thermostat may have more

room/tolerance for demand response control, but people that override their thermostat a lot have less tolerance for these types of controls. We need a control feedback system that would help us get more participation, as well as widespread use of the technology.
    - Technology design should work for the people — occupants, operators, owners, etc.
    - The industry is familiar with conventional rule-based control, so performance verification for such a type of control makes sense. However, to better support the entire building-grid ecosystem at the grid edge, more advanced controls are definitely necessary. In this case, automated deployment is more important.
    - De-risk novel deployment models for statistically verifiable utility incentive programs (LoRaWAN, multi-family, underserved).
    - DOE should invest: Study the benefit of building controls for the grid (power grid). The benefit should be part of the value stack of building control technology, so it is an incentive for both the building owners and the utility.
    - Tools and analysis to determine deemed savings for utility program incentives. Useability and user interface R&D to close the gap between users and smart building systems
    - Rate structures must be justified to commissioners that do not understand building controls. We as an industry need to help define rate structures, working with utilities, to drive decarbonization.
    - Simple tools for identifying opportunities within buildings that recognize the issues of diversity, complexity, and data quality that impact deploying at scale.
    - Develop standardized, simple demand flexibility controls and a validation procedure to enable "plug & play" style of controls for residential, small commercial & large commercial controls pathways.
- Industry Association Participants
    - I'd like DOE to help create standardized controls frameworks (design, operation, interface, semantics…) that create 80/20 outcomes that facilitate the co-optimization of operating cost and hourly (or better) locational GHG emissions, without significantly degrading comfort or other building services. These approaches should be baked into building controls by default so they require the bare minimum of operator engagement to succeed. DOE can facilitate standardization, fund pilots, and help deploy solutions.
    - Model calibration and troubleshooting is critical: research is needed to reconcile models with actual performance. Oftentimes efficiency and electrification measures can have financial repercussions that disproportionately affect low to moderate income communities.
    - Find additional funding for Project Haystack after DOE's semantic modeling project ends. Project Haystack is a 501c3 that can greatly benefit from additional funding. Funding can be for development, education, training, advertising…to name a few.
- University Participants
    - Develop implementable & secure control sequences for connected buildings.
    - Operator training is needed, especially for large, centralized HVAC systems. Some building operations are outsourced to vendors that mostly lack the necessary knowledge. The operational challenges of large, centralized HVAC are very complex. The training is difficult for operators who do not have engineering degrees.
    - Providing a user-friendly interface to provide building operators with guidance to operate buildings efficiently.
- DOE/National Laboratory Participants
    - Is it possible to promote VRF systems in the U.S. due to their advantages in energy efficiency and demand flexibility?
    - Understand training needs for the next-gen smart build technologies we are developing.
    - All building controls (legacy) should be able to communicate with each other and be open access, allowing innovators to innovate new solutions.
    - If feedback control in the building is always oscillating, how about using open loop control to directly give the command? Smart building control should consider device level limitations. High-

level and low-level controllers should talk? Campus-level building control is really bad. Videos available by QR code on the equipment to guide the homeowner? Provide standard instructions like how to use your washing machine.
    - The challenge will be to meet the current needs of the existing buildings infrastructure and value proposition, while transitioning the industry to the future, e.g., past > energy savings; future > demand flexibility.
    - Break the chicken-egg impasse between building owners procuring semantic models and software vendors leveraging the models to configure applications in a "plug-and-play" way.
    - Leverage machine learning to improve tools and enable mass customized building automation in solutions.
    - Development of cost-effective, scalable, and interoperable control solutions that work for all buildings – small, medium, and large (with or without BAS)! Autonomous building operations...
    - Support and incentivize buildings to fix and improve their systems and controls, especially those that cannot afford expensive services.
    - In order to improve data-driven capabilities, draw from data science/machine learning expertise that may come from outside the building controls community. Recommendation to facilitate this is to invest in workforce development/scientific communication resources e.g., "Building Controls 101" for SMEs (and for operators/occupants/owners) with bonus points for open source.
    - Work with utilities to design programs that encourage EMCs/EMIs to save energy, cost, and carbon emissions simultaneously i.e., use a "synthetic" price & carbon signal for EMCs to decarbonize buildings.
    - For more dynamic control systems (e.g., load shifting, predictive, co-optimization of objectives), understanding what complexity of implementation is good enough to provide good performance, so as not to have to spend more time than needed to implement.
    - Dump bunches of money into deploying solutions we know work.
    - Control is the key to realize various operational objectives. The current discussion seems to ignore the need from control developers. We need to involve them in the loop when we design tools/procedures to advance building control.
    - Take advantage of all the work that has gone into metadata, semantic definitions, etc. to make sure that deployment of advanced controls is as painless as possible. Minimum standard, requirements for utility programs, etc.
    - What DOE can do with the controls portfolio: Get clarity/provide advice focused on single/small buildings, small portfolios, and buildings in underserved communities. Align this work with Justice40 and other initiatives working toward equitable decarbonization, and make it attractive for companies/organizations/utilities/ESCOs to engage these groups in these efforts.
    - Having a way of standardizing and motivating the implementation of semantic models for buildings so interoperability of tools can be supported, and better data management can be achieved.

# 4 Next Steps

DOE thanked the roundtable participants and described the next steps as follows:

- Distribution of a report summarizing input received during this roundtable discussion.
- DOE is finalizing a forthcoming Energy Management and Control Systems Research and Development Opportunities report where Continuous Building Performance Management is identified as a key opportunity for further research and development.
- Stakeholders should also look forward to receiving invitations for future roundtables on key building controls opportunities.

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