Energy Management and Control Systems Workforce Development Roundtable

January 26, 2023

Building Energy R&D, Building Technologies Office, U.S. Department of Energy

Roundtable Summary

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Executive Summary

Introduction

The Building Technologies Office (BTO) within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) hosted a virtual roundtable discussion on energy management and control system (EMCS) workforce development. Twenty subject matter experts attended the meeting and participated in the discussion. The participants consisted of experts from higher education institutions, training and certification programs, industry, the national laboratories, and the DOE's BTO. The format consisted of opening remarks by the DOE team, followed by a group discussion. The discussion covered two main topics: 1) how BTO can best address EMCS workforce challenges, and 2) workforce-related EMCS metrics and targets. Throughout the roundtable discussion, the moderators asked questions and encouraged participants to provide input verbally and by written responses in the meeting's chat box.

Context

The roundtable discussion was a follow-up to DOE's Request for Information (RFI) on Research and Development Opportunities (RDOs) for EMCSs.[1] It also followed a December 7, 2022 roundtable on EMCS key performance indicators (KPIs).[2] The overarching purpose of the RFI, roundtables, and other related activities is to support the Biden-Harris administration's strategy to transition equitably to a decarbonized economy. Effectively implementing controls in new and existing buildings is imperative to enable the transition to a decarbonized energy infrastructure.

Market transformation must occur equitably across all building types, sizes, and locations in order to achieve increased implementation of affordable and effective EMCS technologies that extract building controls' full complement of benefits. A well-trained and sufficiently sized EMCS workforce will be necessary to attain this market transformation and sustain the beneficial impacts. One of the main themes in the responses to the RFI was the need for a strategic effort for developing the EMCS workforce. Specifically, stakeholder feedback stressed the need for more EMCS-trained workers and a greater number of effective training programs to teach relevant skills, along with advancements in EMCS technology to make the systems simpler to operate.[3]

Roundtable Objective

The objective of the roundtable discussion was to solicit input from subject matter experts on how BTO can best address EMCS workforce challenges, including how to measure workforce-related EMCS metrics and targets. The input will help refine BTO's strategy for the final EMCS RDO roadmap, scheduled for completion later in 2023.

Key Comments and Recommendations

Pulling from years of direct training program experience and applied EMCS industry experience, the participants provided BTO with valuable input on the current state of the EMCS workforce and future needs. They also offered recommendations and information resources for BTO to consider when addressing workforce gaps. Table ES-1 summarizes the EMCS workforce development discussion.

Next Steps

In addition to distributing this report on this January 26th roundtable, DOE representatives identified at least two other steps. The first step was a roundtable held on February 6th at the 2023 ASHRAE Winter Conference in Atlanta to discuss the KPI framework, metrics, targets, source materials, and related content.[4] The next step will

[1] See RFI Attachment.
[2] U.S. Department of Energy. Building Technologies Office. EMCS KPI Roundtable: Draft Framework and Metrics. Roundtable Summary Report. <include link>
[3] See Workforce Development Roundtable Pre-read handout.
[4] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2023 ASHRAE Winter Conference, Atlanta, GA, February 4-8, https://www.ashrae.org/conferences/2023-winter-conference-atlanta.

be publication of the EMCS roadmap, which will incorporate responses to the RFI and input received during each of the December 7th, January 26th, and February 6th roundtables.

Table ES-1. Summary of EMCS Workforce Development Discussion

DOE's Question Prompts	Summary of Participant Responses (see Group Discussion section for further explanation of these summary responses)
What types of jobs are the most in-demand in the EMCS industry? What are the preferred qualifications?	• EMCS job titles are hard to define; need to specify a set of roles and qualifications for various personnel that interact with building controls • High demand for skilled controls operators and system designers/engineers • Need more technicians with a basic understanding of building science • Need people with building management system specification experience • Need more contractors who can and will work with advanced, sophisticated controls, but some may be resistant to working with advanced controls
What are the missing skills you notice most in the EMCS workforce?	• Workforce lacks skills to identify the root cause of EMCS problems • Basic technician-level skills are missing (e.g., fundamentals of HVAC theory, controls concepts, and IT) • Controls operators not sufficiently patient with advanced controls and rely too much on overrides • Need people who understand the layers and interactions of multiple building systems • Need to teach managers how to retain qualified software engineers • Interdisciplinary skills are missing (e.g., hardware and software experience) • Practical on-the-job experience is missing
What are some future skill requirements for the EMCS workforce?	• Increased need for IT skills for internet-based controls • Increased need for electricians and electrical engineers as we move toward electrification • Skills to interpret building performance data from sophisticated controls • Need to recognize that the required skills take time to learn • Need better inter-organization communication to address future EMCS directives (executive-level through control system operators)
How can EMCS technology R&D address workforce challenges? Which technology areas need the most investment?	• Development of a minimum set of EMCS performance capabilities • Autonomous building controls • Application of modern user interface / user experience software design • Use of third-party service providers working with data from application programming interfaces • Need to recognize that not all buildings need high intelligence
Which workforce education gaps should BTO focus its efforts on? Are curriculum standardization and certifications an effective use of government funding?	• Training programs for consulting engineers and salespeople • Promoting best-in-class standards for long-term building performance • Just-in-time training • Control sequence standardization • Help address cultural challenges to minimize the gap between top and bottom ends of workforce chain
How can we measure EMCS workforce capacity and capabilities?	• There are resources for estimating the number of EMCS job openings • At least one training program has data on diversity of program participants • There is a lack of data on qualifications of people leaving the workforce • Productivity metrics may be helpful to assess workforce capabilities
How can we measure workforce-related EMCS capabilities and impact (progress)?	• Document the economic incentive value chain for the EMCS workforce • Avoid the automation trap; cannot deskill workforce with automation

DOE's Question Prompts	Summary of Participant Responses (see Group Discussion section for further explanation of these summary responses)
Do we need a different baseline and targets for different building types and application complexity?	• Time-to-revenue is important metric • Some metrics depend on EMCS application complexity • Some metrics depend on building type

Meeting Logistics

Time: January 26th, 2023, 2:00-3:30 pm EST
Location: Microsoft Teams Virtual Meeting

Agenda

- Welcome and objectives – 15 min
- Introductions – 10 min
- Group discussion – 45 min
- Key workforce-related EMCS metrics and targets – 15 min
- Wrap-up and next steps – 5 min

Participants

Table 1 lists the 20 participants that attended the meeting. The participants consisted of subject matter experts from higher education institutions, training and certification programs, industry, the national laboratories, and the DOE's BTO.

Table 1. EMCS Workforce Development Roundtable Participants

Name	Organization
Michael Bobker	The City University of New York, Building Performance Laboratory
Mark Bodenschatz	Penn State University, Facilities Engineering Institute
Brenda Cervantes	Lane Community College
Beth Clark	Penn State University, Facilities Engineering Institute
Melanie Danuser	Smart Buildings Center; Northwest Energy Efficiency Council (NEEC)
James Dice	Nexus Labs
Samy Faddel	ABB
Srinivas Katipamula	Pacific Northwest National Lab (PNNL)
Brian Marchionini	National Electrical Manufacturers Association (NEMA)
Kerry Meade	Smart Buildings Center
Clay Nesler (moderator)	The Nesler Group
Zheng O'Neill	Texas A&M University
Gwelen Paliaga	TRC
Roger Quesnel	SkyFoundry
Nikitha Radhakrishnan (moderator)	PNNL
Denise Ritzmann	PNNL
Steve Schiller	Lawrence Berkeley National Laboratory Affiliate
Tom Shircliff	Intelligent Buildings
Brian Walker (BTO host)	DOE's Building Technology Office (BTO)

Name	Organization
Phil Zito	Smart Building Academy

Welcome and Roundtable Objectives

Opening Remarks

Brian Walker, DOE's manager for Controls and Grid-Edge Decarbonization for BTO's Building Energy R&D group welcomed the subject matter expert participants and provided opening remarks:

- Thanked several individuals for organizing and carrying out the roundtable meeting.
- Thanked the group of subject matter experts for joining the roundtable discussion.
- Explained that the main purpose behind the roundtable is to think about how to approach the EMCS workforce and to refine BTO's strategy for the final EMCS RDO publication, scheduled for completion in 2023.
- Described how BTO's Building Energy R&D group works closely with other government departments involved in implementing the American Innovation and Jobs Act[5] and the Inflation Reduction Act.[6]
- Gave the example of how DOE has done much of the applied research for the Connected Communities[7] work related to controls, lighting, HVAC, appliances standards, etc.
- Explained that BTO has been soliciting input from stakeholders and has been hearing about some of the key challenges related to the EMCS workforce. As a result, BTO is interested in addressing the following questions, with an understanding that none of these areas can be pursued in isolation:
  - How to make control systems simpler, and what simplification looks like.
  - How to increase the pipeline of folks who are going into this field.
  - How to define this workforce field, making sure that we are defining job categories.
- Referred to recent discussions about what must happen for the grid to decarbonize. Cited estimates published on January 25 that state the number of grid interactive buildings worldwide is expected to grow almost 13% annually.[8]
- Discussed how job classifications for EMCS-related fields are not as up-to-date as needed. Described the need for finding the right partners and right models to get the right folks into the workforce with the right job classifications.
  - Gave the example of job classifications for an electrician and HVAC engineer on Apprenticeship.gov.[9]
  - Noted there is no clear connection between building control technicians and electricians and the folks needed to maintain or install these control systems.
  - Said this illustrates there is work to do by the BTO, DOE and with interagency engagement.
- Noted that the energy savings opportunity is real for building control systems, and they can be relatively inexpensive:
  - Estimated energy savings for the control systems alone can be 9 to 10%, and sometimes greater.

[5] S.749 - American Innovation and Jobs Act. 117th Congress (2021-2022). Senate Bill. Introduced in Senate (03/15/2021). Available here: https://www.congress.gov/bill/117th-congress/senate-bill/749/text.
[6] H.R.5376 - Inflation Reduction Act of 2022. 117th Congress (2021-2022). Public Law No. 117-169 (08/16/2022). Available here: https://www.congress.gov/bill/117th-congress/house-bill/5376/text.
[7] U.S. Department of Energy. Office of Energy Efficiency & Renewable Energy. Solar Energy Technologies Office. Connected Communities Funding Program. Webpage: https://www.energy.gov/eere/solar/connected-communities-funding-program.
[8] Utility Dive. "Number of grid-interactive buildings worldwide expected to grow almost 13% annually: Guidehouse." Jan. 25, 2023. Available here: https://www.utilitydive.com/news/grid-interactive-buildings-guidehouse-market-report/641206/.
[9] Apprenticeship USA, Apprenticeship Occupations: Electricians. Webpage: https://www.apprenticeship.gov/apprenticeship-occupations/listings?occupationCode=47-2111.00.

  - 10% is the International Energy Agency's estimate for what digitalization technologies can save in terms of total building energy consumption by the year 2040.
  - EMCSs can cost as low as $7.00 per square foot, perhaps even lower.
  - EMCSs can represent around 1% of overall building construction cost.
  - EMCS payback periods, which can be three to four years, compares favorably to other technologies one might consider putting into a building.
- Highlighted how EMCS solutions are an important frontier, particularly considering that ~80% of buildings do not have a building automation system, and that the workforce issue is a key hurdle to overcome.
- Concluded by reiterating that BTO is interested in hearing the subject matter experts' thoughts on these and other workforce development topics.

Overview of Roundtable Pre-Read Handout

After the opening remarks, the first moderator led the participants through the material provided in the pre-read handout to set up the discussion by noting:

- BTO received 45 responses from stakeholders on last year's RFI, which asked for input on what BTO's strategy should be in supporting efforts in the EMCS space. Responses will inform BTO's EMCS strategy.
- One of the strongest messages received was for more strategic investment in workforce development. The workforce-related input highlighted three main needs:
  1. More EMCS workers: More qualified staff and college graduates to choose EMCS-related fields.
  2. Relevant skills in the existing workforce: Existing workforce does not have access to the right types of training to keep up with changing technology.
  3. Operator-centric EMCS technology: Technology should be designed better for the workforce to install, operate and maintain.
- BTO does not have much influence on the first need category, number of workers, but the recent American Innovation and Jobs Act bill and Inflation Reduction Act provisions should be able to make a significant impact in that area.
- BTO could potentially influence the other two need categories, skills and technology needs, and most of the roundtable discussion would be focusing on those two areas.
- Described two broad BTO workforce initiatives. Figure 1 summarizes the initiatives.
  - Commercial sector - recognition program for credentialing organizations. Better Buildings Guidelines[10] are voluntary national guidelines aimed at improving the quality and consistency of workforce credentials in the commercial building sector. The guidelines cover the five jobs listed in Figure 1. DOE recognizes organizations that align with these guidelines; there are no training materials offered as part of this program. The program is active but is a few years old and largely stagnant. There is a list of certification programs that have received recognition.
  - Residential sector - course materials on a variety of topics. The materials are intended for use by any educator aligned with these topics. The materials are updated continuously. It is a highly active program. PNNL works with the textbook authors and industry partners to design the training modules. There are no workforce guidelines or recognition programs associated with the residential sector.

[10] U.S. Department of Energy. Office of Energy Efficiency & Renewable Energy. Building Technologies Office. Better Buildings Workforce Guidelines. Webpage: https://www.energy.gov/eere/buildings/articles/better-buildings-workforce-guidelines.

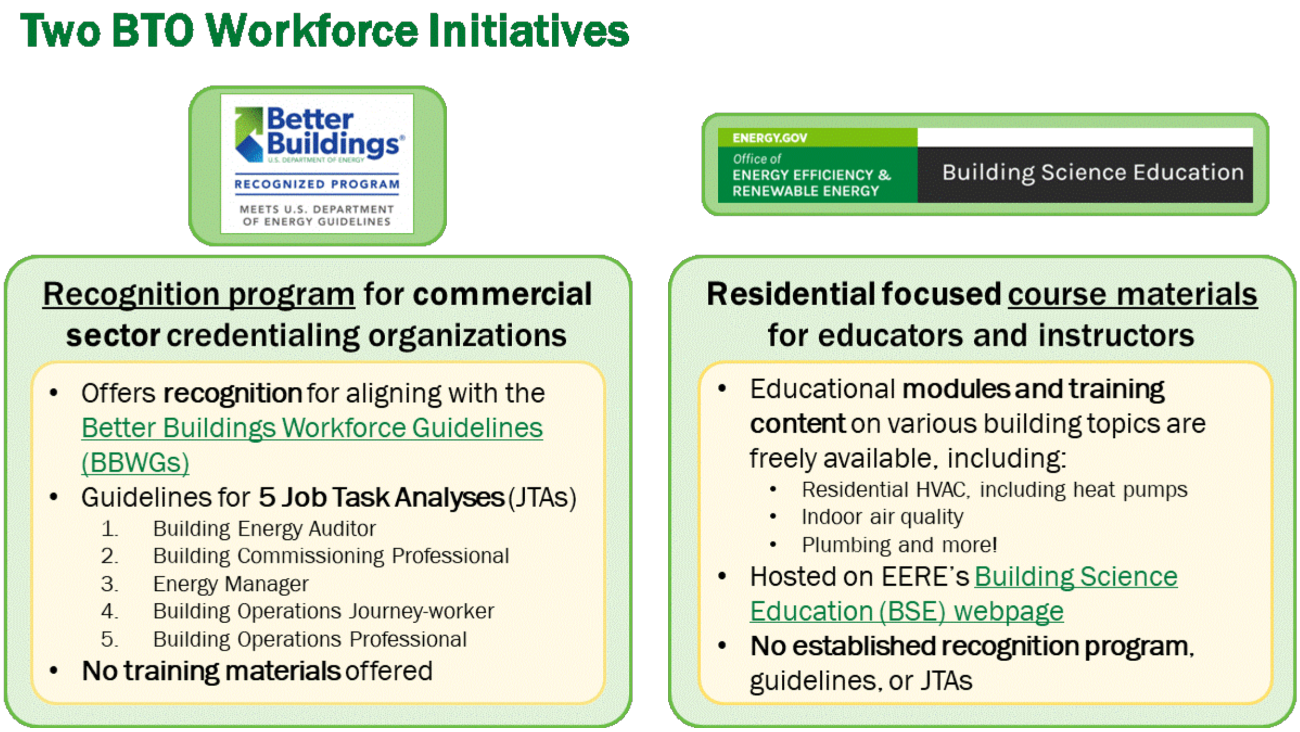

Figure 1. Two BTO Workforce Initiatives (see Presentation Slides)

Participant Questions on Pre-Read Material

The moderator asked participants if they had any clarifying questions before beginning the main group discussion.

- One participant asked why building technician was not on the list of job tasks in Figure 1.
  - The moderator noted that there were stakeholder engagement convenings to decide on the five job tasks in Figure 1 and agreed that the list could benefit from a review and update.
  - The participant pointed out that the meeting pre-read handout broke out the need for curriculum for future versus current EMCS technicians. He recommended training system and design technicians in the 179D Commercial Buildings Energy-Efficiency Tax Deduction[11] and implementing ASHRAE Guideline 36[12] for basic retrofits. He sees the need for people who understand how to work with application programming interfaces (APIs)[13] and related technology to deal with the grid interactive side of controls.
- Another participant suggested that the educational material in BTO's residential sector workforce initiative (Figure 1) should cover demand response, especially as the adoption of rooftop solar and transportation electrification increases.
  - The moderator agreed. She was not sure offhand how much demand response is currently covered in the course material.

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[11] U.S. Department of Energy. Office of Energy Efficiency & Renewable Energy. Building Technologies Office. 179D Commercial Buildings Energy-Efficiency Tax Deduction. Webpage: https://www.energy.gov/eere/buildings/179d-commercial-buildings-energy-efficiency-tax-deduction.

[12] ASHRAE Guideline 36-2021: High-Performance Sequences of Operation for HVAC Systems. Standard. Available here: https://www.techstreet.com/ashrae/standards/guideline-36-2021-high-performance-sequences-of-operation-for-hvac-systems?product_id=2229690.

[13] An application programming interface, or API, is a set of programming code that allows two or more software applications to communicate with each other.

Introductions

The DOE team and subject matter expert participants introduced themselves and described their background related to EMCS Workforce Development to provide context for their contributions to the discussion. Many of the participants have a background in education and training and others provide consulting services (see Participants). The bullet points below give a few anonymous examples of the organizations and work represented by some of the participants.

- A participant from one of the training organizations noted they have a DOE grant that is helping them get an online platform for their operator certification and building retuning programs. They find data acquisition to be an interesting hurdle in that realm.
- Someone else said their organization has 30 training programs and has trained about 13,000 students. They built an 11-week online program where they train people with varied backgrounds such as hotel lobby clerks or postal workers to become service technicians. They are trying to compress the program down to six to eight weeks. They are currently working with DOE on the online training programs. They understand the challenge of job descriptions and are working to rewrite O*NET codes[14] for building technicians as well as an energy technician apprenticeship. In this person's opinion, too many job listings require 4-year degrees when technicians are really needed.
- Another participant agreed. He said technicians can effectively do many tasks with only 90 days of training. He feels the beauty of building controls it that it is a largely repeatable processes that the industry has been doing for the past 30 years.
- A participant from one of the consulting companies mentioned supporting market adoption of ASHRAE Guideline 36 and advance control sequences by doing demonstration, deployment, and policy work in that area.
- A representative from a company that provides smart building consulting and managed services to larger projects and larger organizations described how they like to say they "go from the boardroom to the boiler room" so they can understand what goes on inside of a building and how that impacts the senior executive level.

Group Discussion: How Can BTO Best Address EMCS Workforce Challenges

The group discussion began with a series of questions on how BTO can best address EMCS workforce challenges. The participants responded by raising their virtual hand and by typing in the chat box. The following summarizes input received verbally and via the chat box.

In-Demand Jobs and Preferred Qualifications

DOE's Questions

What types of jobs are the most in-demand in the EMCS industry? What are the preferred qualifications?

Participant Responses

- Need for Skilled Operation Technicians and System Designers/Engineers: A representative from one of the training organizations finds that many of their customers are still trying to understand the 179D Commercial Buildings Energy-Efficiency Tax Deduction as well as a lot of the building regulations. Their customers are focused on keeping the buildings operated, which is difficult because of people leaving the workforce; their attention has not shifted to energy, except at the executive and director level. Operations technicians that can execute the work are in demand. In some cases, their customers are putting in significant overtime on

[14] According to the U.S. Department of Labor, the O*NET system is maintained by a regularly updated database of occupational characteristics and worker requirements information across the U.S. economy. It describes occupations in terms of the knowledge, skills, and abilities required as well as how the work is performed in terms of tasks, work activities, and other descriptors.

projects because they do not have the skilled staff. On the design side, he noted that they see a big focus on information technology (IT), including understanding how to interpret new Internet protocol (IP) architectures that will enable grid interactivity and how all the layers work together. There is a need for designers and engineers who can work well with customers and can also implement designs from the initial design through a sustained services perspective.

- More of a Role than a Job: One of the participants from industry views the need not necessarily as a job but more as a role that one or more people have. Those people could be internal or external to the organization that owns the building(s). There is a need for people that understand how all the many systems fit together. Most people are trained in the silos of their given fields and focus areas. But, for grid interactive buildings, we need to think about the entire building working as a system of systems. So, one way to look at the role is that each person that already has a related job in the organization (e.g., a facility manager) needs to be upskilled to see outside of those silos. They need to understand how to be the champion for the cause from a technology perspective.
- Train Operators to be Patient with Controls: Another participant agreed that it is important to train people for an hierarchical knowledge of how all the systems interact, but in his experience that is a challenge for the large bulk of building operators, even those who are intelligent mechanically. They tend to want to run the building themselves, like driving a car. He believes we need to train people to be more patient with control systems, especially as we move into the era of grid interaction and very sophisticated controls. For example, with the energy storage model, predictive control by the building system's complex control algorithms may not be intuitive to an operator. The operator response may be to override the controls, which is a major problem. How do we design our controls to avoid the override problem, and how do we train people to be a little more patient? He gave the example of using "idiot lights" on the controls to alert the operator.
- Need for Sophisticated Controls Contractors: A participant said the consulting firm she works for did work for the California Energy Commission on barriers and opportunities associated with ASHRAE Guideline 36 adoption. A finding from her interviews with controls contractors is that one of the contractors' challenges is they lack people with the enough background knowledge to develop controls/applications/programs that are new or complex. They tend to cut and paste from the last project. Many of the controls contractors either have one staff person that can do advanced control logic, or zero. It is often the lead or the CEO. In addition to needing some domain expertise in HVAC and control theory, more expertise in software and the Internet of Things (IoT)[15] is needed. She believes it is as much a technology problem as a workforce problem.
- Resistance by Controls Contractors to Become More Sophisticated: Another participant expressed the problem of ownership for small- and medium-sized controls contracting companies not knowing how to become more sophisticated as a company, or not wanting to. He believes it is not just about finding people. Even if these controls companies could find people, the company must create offerings and services associated with the more sophisticated capability.
- Need for Basic Understanding of Building Science: Another participant representing a training organization said they often hear from building owners and managers that a basic understanding of building science is needed for the incoming workforce to replace the outgoing workforce. The Building Operator Certification (BOC) program[16] responded to that need by creating coursework with fundamentals for people entering the workforce who just need to get a sense of the basics.
- High Demand for Trained Operators; Job Titles are Hard to Define: Someone else from the same training organization gave an example of a facility technician program that struggles to get enough students and to train them fast enough to fill all the employment opportunities. Students that complete the program have

[15] The Cambridge Dictionary defines the *Internet of Things* to be "objects with computing devices in them that are able to connect to each other and exchange data using the Internet." Kevin Ashton coined the phrase in 1999. Any devices that are connected to the Internet and can exchange data with other devices are part of the IoT, including smart phones, smart appliances, and other connected equipment and systems.
[16] Building Operator Certification. Website: https://www.theboc.info/.

multiple job offers in building operations. She also agreed that a job title per se can be hard to define depending on the building sector (e.g., a school's lead custodians might be responsible for operating and maintaining facilities). Thus, looking at training requirements from the perspective of the different roles and responsibilities of operating and maintaining various building systems is crucial, versus just the titles.

- Need for Proper Building Management System (BMS) Specification Experience: A representative of a standards developing organization discussed the importance of having the skills to properly specify a BMS and other data-integrated building systems. Proper specifications ensure the end user gets the building performance user experience they expect. Specification errors can cause additional costs, delays, and commissioning issues. The is a need for someone with experience in BMS specification and MasterFormat and the divisions (e.g., Division 25: integrated automation, Division 23: HVAC, and Division 21: fire suppression).[17] Sometimes the workforce does not look into those other systems.

Missing Skills in EMCS Workforce

DOE's Question

What are the missing skills you notice most in the EMCS workforce?

Participant Responses

- Workforce Lacks Skills to Identify the Root Cause of an EMCS Problem: A participant from one of the national laboratories visited over 200 buildings as part of a retuning program and found a vast range of skillsets. The bulk of people who manage the buildings do not have the skills to identify the root cause of the problem, hence system overrides happen. There are very few community colleges focused on developing curriculum and delivering courses that are specific to building automation systems (BAS) or EMCS, so we need more educational resources to help address the current situation.
- Basic Technician-Level Skills are Missing: One of the training providers thinks we do not necessarily need more software engineers; it may be simpler than that. Technical skill assessment areas that technician trainees typically have trouble with are basic HVAC theory, basic IT, and basic controls concepts. He gave the example of people who exit programs and cannot execute what they just went to school for (e.g., they cannot tune PID[18] loops or do basic BACnet[19] integrations). His organization's program has had good success in having people doing analysis and identifying what the Pareto principle[20] is related to the subject issue. For example, for a system technician, to goal may be just to get them to do point to point configuration and uploading / downloading controllers. He suggests focusing on training technicians to relieve the senior staff who are currently having to do the low-skill, low-profit tasks. That would free up integration engineers to do the more sophisticated work. He believes not everyone needs the Department of Defense level of cybersecurity or system integration. For example, in the person's opinion, the owner of a typical three-story office building is only going to implement a grid interactive building if and when it is mandated.
- Need to Understand the System of Systems: A participant from an education institution agreed with an earlier comment about the need to understand the systems of systems. He indicated that you can have a good control technician, but it is of little value to you if they do not know about HVAC systems. This person believes we need people who can innovate all sides. For example, there is a significant challenge with cybersecurity in institutional control systems due to the number of open backdoors and vulnerabilities that exist. The Cybersecurity & Infrastructure Security Agency (CISA) from Department of Homeland Security tracks substantial known vulnerabilities in the controls world that are creating significant problems for

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[17] The Construction Specifications Institute's MasterFormat consists of "50 Divisions" of construction information. This standard is used to organize specifications and other information for commercial and institutional building projects in the U.S. and Canada. See https://www.csiresources.org/standards/masterformat for more information.

[18] "PID" refers to a Proportional-Integral-Derivative controller. PID loops are commonly used in building control systems.

[19] "BACnet" refers to Building Automation and Control Networks. BACnet is a communication protocol standard for integrating different building automation and control products.

[20] According to Investopedia, the Pareto Principle, named after economist Vilfredo Pareto, specifies that 80% of consequences come from 20% of the causes, asserting an unequal relationship between inputs and outputs.

building owners and operators. In addition to looking at today's opportunities and challenges, we need to consider opportunities for the future. With the integration of big data, we will have control systems that are able to collect data and trend it, but having the artificial intelligence (AI) to analyze it and feedback to assist the controllers in troubleshooting is essential. He feels training will only become more complex for the operators that are managing it.

- Teach Hiring Managers how to Retain Software Engineers: A representative from a software solutions company said there is a need for software engineers that can work side-by-side with energy managers or along with building personnel. When considering the hire, train, and retain components for employees, employers do not understand what it takes to retain a good quality software engineer, so employee may get trained and then move on to what they consider to be a more desirable job. Therefore, it is not all about training the worker. Training the managers may be important as well.
- Interdisciplinary Skills are Missing: An industry representative agreed with others that interdisciplinary skills are missing. It takes a while to find candidates who understand controls but at the same time understand building operations.
- Practical On-the-Job Experience is Missing: One of the training organization representatives said that, in addition to a lack of foundational knowledge and a basic understanding of systems, practical on-the-job experience is missing. Most of the 300+ federal employees their organization trained in 2022 had less than one year of experience and were new to facilities and building operations and management.

Future Skill Requirements for EMCS Workforce

DOE's Question

What are some future skill requirements for the EMCS workforce?

Participant Responses

- Proposed Climate Regulation Would Require Increased Skillset and Better Inter-Organization Communication: A participant from a software solutions provider referred to a proposed Securities and Exchange Commission's (SEC's) rule for publicly traded company 2024 criteria.[21] If enacted, this person believes buildings will need to adopt EMCS at a greater speed. That will necessitate scalable systems and "boots on the ground" with the correct skillsets. Referring to the earlier "boardroom to the boiler room" comment, he said there is a big gap between the boots on the ground and the CFO, CEO, and the chief sustainability officers that are making net-zero promises and allocating dollars. Those two parties are not communicating with each other. He believes the newer EMCSs are going to be environmental resource planning systems. He views publicly traded multi-state and multi-site building portfolios are "impossible" to measure and manage due to enormous complexities. They have building level needs as well as needs at a much higher level. There is a substantial need to bridge the understanding and direction of the executive-level managers within a company (sometime referred as the "C-suite") and the staff managing the HVAC systems.
- Increased Need for IT Skills for Internet-Based Controls: One of national laboratory representatives said the industry is moving toward internet-based control systems, which requires a different set of skills to identify controller issues. The future technician would have to be an IT technician and not controller technician to meet some of the job requirements.
- Increased Need for Electrical Experience as we Move Toward Electrification: Another participant pointed out that there will be an increased need for a workforce with electrical experience compared to other systems as buildings become more electrified in the future.

[21] Securities and Exchange Commission (SEC). *Proposed Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors*. Available here: https://www.sec.gov/rules/proposed/2022/33-11042.pdf.

- Skills to Interpret Building Performance Data from Sophisticated EMCS Technology: A representative from one of the training organizations referred to a Job Task Analysis survey her organization conducted in 2021. From employers they surveyed, they found a list of skills that will be more important in the future workforce, including skills related to building tune-up and retro-commissioning practices, tracking and managing building energy use data, benchmarking tools, calculating energy and financial savings, and understanding dashboards, including being able to understand and interpret the building performance trend data that are being collected from the more sophisticated building management systems and automation systems.
- Required Skills Take Time to Learn: One participant expressed skepticism that we will achieve a workforce with the expertise needed to achieve the level of energy savings that are potentially available from smart buildings because the needed skills take time to learn.

How to Address Workforce Challenges with EMCS Technology R&D

DOE's Questions

How can EMCS technology R&D address workforce challenges? Which technology areas need the most investment?

Participant Responses

- Application of Modern User Interface / User Experience (UI/UX) Software Design: A representative from one of the consulting firms views the workforce challenge as a software problem. She feels that addressing software useability and user interface is a huge part of tackling the workforce gap. The individuals in the workforce that are trying to implement an advanced control sequence or trying to identify the root cause in a building and fix it are limited by their level of knowledge. She believes they could be more successful if we applied modern software usability and user interface design to the EMCS industry. This would include having dashboards and actions the operator can take without compromising the control system and without needing to reprogram it. She has observed that smart building vendors are advertising that they are solving this software problem, but the BAS industry is not.
- Use of Third-Party Service Providers Working with API-Derived Data: Another participant agreed with an earlier comment that we are unlikely to get highly skilled technicians into a large share of buildings. He stated that it is for the same reason the buildings do not have highly complex control systems, which is economics. He thinks we may see some development of third-party service organizations that aggregate the data and use specialized knowledge to interpret data. From a technology point of view, that suggests the issue is how to share data freely, which relates to the cybersecurity issue. It also speaks to the need for APIs that make data readily available in standardized forms (Haystack[22], Brick[23]). Third-party service providers working with API-derived data is a pathway to look at.
- Autonomous Building Controls: One participant used the analogy of automobile technology 50 years ago compared with today. Pretty soon we will have autonomous cars. In contrast, looking at building controls technology progress in last 50 years, there is lack of significant progress. If we make building controls autonomous, we reduce the number of building operators needed down to one or two to supervise the technology. Others reiterated that the supervisory control role is very important.
- Development of Minimum Set of Performance Capabilities: As an example, a representative from an education institution said they produced for NYSERDA a "minimum standard of care" for BMS upgrades that specified a set of performance capabilities.
- Not All Buildings Need High Intelligence: Another participant noted that there is a perception that smart buildings need to be pinnacles of intelligence. He finds that marketing tends to highlight the highly

[22] Haystack is "an open-source initiative to streamline working with IoT data." See Project Haystack: https://project-haystack.org/.

[23] "Brick is an open-source effort to standardize semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them." See Brick: https://brickschema.org/.

intelligent buildings and skips over the common buildings that have baseline integrations with a chiller or lights.

Workforce Education Gaps for BTO to Focus On

DOE's Questions

Which workforce education gaps should BTO focus its efforts on? Are curriculum standardization and certifications an effective use of government funding?

Participant Responses

- Training Programs for Consulting Engineers and Salespeople: A representative of a training organization described the need for training programs for consulting engineers and salespeople. The consulting engineers need to get the EMCS in the specifications. Otherwise, without regulations, little will happen unless EMCS technology is in the specifications. He suggests training engineers so they can give a compelling use case to building owners during the capital planning process. This person recommended training the salespeople to not be products people, but to sell solutions around analytics, sustainability, cybersecurity, etc.
- Promoting Best-in-Class Standards for Long-Term Performance: Another participant discussed measurement and verification (M&V) to ensure the control system is operating as it should be. M&V would go a step beyond bridging the gap from design and specification to operation and maintenance using tools such as commissioning, continuous commissioning, and retro-commissioning. The control system itself could alert when a system is outside of its operating parameters. He believes there are significant opportunities to promote best-in-class standards that consider the long-term operating life of the building beyond just the design and specification.
- Just-in-Time Training: One of the training institution representatives explained that some of the challenges around building operator training are that people are hard to reach—they may be time-strapped, transient, or they might not have buy-in from their management. Her view is there is lots of good course material but getting people into the training program to close the education gap is a challenge. One technique being considered is software designed for just-in-time training. For example, a "tool tip" could pop up when the operator is working on the system. It could help with the root cause and also be a training opportunity. That is a potential technology/software opportunity that BTO could contribute to. Another participant agreed and pointed out that online is such a great modality for training because you can do just-in-time training. He gave the example of installing and calibrating an temperature sensor and said his training group has a checklist on what to do with videos for each step. The technician can watch it from their phone while in the field.
- Control Sequence Standardization: One of the national laboratory participants said that beyond having more community college courses with standardized curriculum, we need standardization of specifications calling for best-in-class control sequences. He believes specifications can be so ambiguous that the controls engineer does not know what to do when implementing and that standardization would help. He used the example of the General Services Administration (GSA) and Department of Defense (DoD) developing a specification calling for BACnet as a standard building operation for their buildings. He suggests doing the same for controls specification. Unless the control sequences are specified correctly, he feels we will never solve this problem with just workforce training. Another participant suggested trying to figure out what specifications are needed now so that today's new building controls do not become tomorrow's costly retrofits.
- Addressing Contractual and Cultural Challenges: A participant from a smart building consulting firm said that most of the time they run into a cultural and contractual issue regarding EMCS, and not a lack of technology. If managing the EMCS is not specified in a given service provider's maintenance contract, culturally it will not happen. For example, the service provider may feel their work scope is to manage the BAS, but not the lighting, etc. He and another participant agreed that people who are making the buying decisions at the

director-level ("D-level") do not have the influence at the executive-level managers within a company ("C-suite") to affect the cultural change. He believes we need to train up and build up from the bottom, but also let regulatory and other factors push down from the top.

- Minimizing Gap between Top and Bottom Ends of Workforce Chain: A representative from an education institution pointed out that there will be a lag further down the workforce chain after the systems are built and commissioned. Companies will need to build, commission, and operate systems the way the sales engineers sold it and the consulting engineer specified it. There will need to be a coordinated effort between top-end management and the workforce. This person indicated that maybe the push will start at the top-end, but we cannot have the workforce too far behind to build, commission, and operate the systems.
- Work by Federal Building Personnel Training Act (FBPTA): A participant representing an education institution referred to great work being done with FBPTA regarding curriculum standardization and certification.[24] She agreed with gaps discussed by others, including the barrier of time to get employees trained. She suggests looking at different approaches to training, such as shorter videos and stackable modules, and building the actual credentials with clear career pathways.

Key Workforce-Related EMCS Metrics and Targets

How to Measure EMCS Workforce Capacity and Capabilities

DOE's Questions

How can we measure EMCS workforce capacity and capabilities? Below are a few potential metrics being considered by BTO for inclusion in future documents on this subject:

- Number of EMCS workers (e.g., engineering, installation, programming, commissioning, building operations, facility management)
- Number of new EMCS workers (e.g., entry level trade, secondary school programs, apprenticeship, community college, professional development, retraining)
- Equity and diversity of EMCS workforce (e.g., ethnicity, education, communities, retraining for displaced workers)
- Number of retiring EMCS workers (in which job categories)

The second moderator asked the subject matter experts to provide information and suggestions related to these and other metrics.

Participant Responses

- Number of EMCS Workers: One of the participants shared how his organization pays a group to review jobs online that fit certain job descriptions. Over the past year there have been ~113,000 BAS technician open requisitions per month. They do not have data on the average age of BAS technicians but would like that information to help predict whether it is the owner sector or the contractor sector who is leaving the field and when. There are a lot of operators who are more than just a technician. Another participant said the Association of Control Professionals (ACP)[25] will create reports that list the number of job vacancies for a geographical area. It is done by trolling through job requisition sites and gives an average vacancy broken down by employer. Her organization's report includes BAS and Building Energy Technicians, Building Energy Managers, and Building Application Engineers for the Portland Area. They use the data for their apprenticeship program.

[24] Federal Building Personnel Training Act (FBPTA) Industry Training and Resources website: https://www.fbpta-training.org/.
[25] Association of Control Professionals. Website: https://acp21.org/.

- Equity and Diversity of EMCS Workforce: Someone from another training organization said their building operator certification program has data on the diversity of program participants.
- Number of Retiring EMCS Workers: Regarding a retiring EMCS workforce, one participant noted that he is already seeing the beginnings of the generational demand as folks retire from the industry. A different participant pointed out that to get the full 179D incentive the project staff needs to be 15% apprentices by 2024 with prevailing wages, meaning that more newly skilled workers will be joining the workforce.
- Productivity Metrics: One of the national laboratory representatives suggested some productivity metrics could be helpful. He believes the metrics related to the number of EMCS workers do not on their own get to the issues discussed before about the skills the workers have and their level of competence.

How to Measure Workforce-Related EMCS Impacts

DOE's Questions

How can we measure workforce-related EMCS capabilities and impact (progress)? Below are a few potential metrics being considered by BTO:

- Hours (per sq. ft. or point) required to engineer and program a new EMCS
- Hours (per sq. ft. or point) required to install and commission a new EMCS
- Hours (per sq. ft. or point) required to operate and maintain an EMCS
- Hours (per sq. ft. or point) required to upgrade EMCS hardware and software

Do we need a different baseline and targets for different building types and application complexity?

- Large commercial/multi-family (central systems)?
- Small commercial/multi-family (packaged systems)?
- Basic EMCS, Advanced EMCS, Building Analytics and Optimization

Participant Responses

- Economic Incentive Value Chain: One of the smart building service providers described the need for documentation on the economic incentive value chain for the EMCS workforce. He gave the example of nursing where is it understood that someone who completes nursing school will get a well-paying job. He also suggested documenting the value for contractors—i.e., if they hire trained people and pay them well, they will get more facility service contracts because they can do more and will have more net operating income (NOI) and so forth.
- Avoid the Automation Trap: A representative from an education institution said BTO should avoid the "automation trap" when defining the metrics. This is where a company automates a building system and then de-skills their workforce to save money. That company may be able to reduce the number of lower-end people when they automate, but they really need to up-skill their workforce.
- Time-to-Revenue is Important Metric: Another training organization representative explained that time-to-revenue is one of the main things contractors and for-profit companies care about. He said it is the first question they get asked when training. How fast can you make someone billable. He noted that the focus shifts when working with owner-operators.
- Some Metrics Depend on Application Complexity: One participant said he is often asked if they cost systems per point, per square foot, or per piece of equipment. He said it depends. He gave the example of how an Amazon warehouse will look different than a U-Haul storage facility in terms of use-point density. The capabilities of the system must also be considered. There are two factors to consider: 1) often the same infrastructure is needed to do basic control as advanced control (a lot of the advanced control happens at the server layer and above), and 2) how much work does the owner/operator want to take on (Do we want to be our own building engineers? Do we want to do our own building engineer programming? Do we want to replace controllers and do retrofits?). As soon as a company implements building automation well, it will

remove low-level problems but will expose higher level problems that they can now resolve, depending on the vertical market they are in.

- Some Metrics Depend on Building Type: Another participant suggested that the diversity and economics in multifamily buildings needs a separate approach from other building types.

Summary Recommendations for Workforce Development

When asked what their highest priority advice to BTO would be to make progress on workforce issues, several expert participants provided some final thoughts in the meeting's chat box. The bullet points below summarize the recommendations organized by topic area.

Education and Training

- Standardize specifications, encourage more community colleges to have relevant curriculum, and work towards autonomous buildings operations.
- Career counselors in the K-12 space need to know that the future of sustainability depends on them.
- Whatever approach you ultimately take, take care to include the benefits to the workforce when you market training opportunities. Highlight the benefits to the individual as an investment in them.
- Develop and support UI/UX digital product design to bridge between EMCS and workforce knowledge.
- We need to start with a firm foundation of basics and build on them.
- A BAS technician is one of the few trades that can make a six-figure income in less than five years.
- Build a career and a greener world. Apply today! (The tag line for Lane Community College's two-year degree program for energy management building controls.)

Metrics and Targets

- Remember that "if you don't measure it, you can't manage it." At the outset, measuring more rather than less may be helpful. Once you have some usable data, look at what data you are using to drive decisions and continue with those metrics. It is also a balance with the idea of "data for the sake of data." You must be intentional in the things you decide to measure. Do not measure 15 different things if you think four metrics will be where you land; initially measure six to eight meaningful metrics and whittle down to four.
- Liberate the data so operators and technicians have ready access in standardized format. ("Liberate the data" = API as part of every EMCS.)

Wrap-up and Next Steps

Concluding Remarks

DOE's manager for Controls and Grid-Edge Decarbonization for BTO's Building Energy R&D group provided a few concluding remarks to summarize the discussion and thanked the participants again for their input. He noted that the discussion covered the role of many forces affecting the EMCS industry and workforce, including the following:

- Different modules for delivering training.
- Value of high-scale opportunities.
- Limitations of what can be learned before going on the job.
- Importance of regulation (top down).
- Technology development being drivers.
- Meeting people where they are.

- Good models for training.
- Accepting limitations about what can be done in advance.
- Importance of standardization and credentialling.
- Many workforces are changing, and many are evergreen.
- Unintended consequences in the changes that are happening.
- Moving more toward automation, which could actually have the effect of needing more skills in the workforce, not less.

Next Steps

The next steps include the following:

- A roundtable on February 6th at the 2023 ASHRAE Winter Conference in Atlanta to discuss the KPI framework, metrics, source materials, etc.
- Distribution of this report summarizing the EMCS Workforce Development Roundtable discussion and another report summarizing the December 2022 Roundtable on EMCS KPIs and metrics.
- Preparation of an RDO publication on the finished EMCS roadmap, which will incorporate responses to the RFI and input received during each of the December 7th, January 26th, and February 6th roundtables.

Appendix

Additional Questions in Slide Deck

The following questions, while listed in presentation slides, were not asked during the roundtable due to time limitations:

- How is your EMCS workforce trained now? What training strategies are most effective?
- Other than training programs, what resources are needed to educate EMCS workforce?

Attachments

RFI - "Research and Development Opportunities in Energy Management Control Systems"

Pre-read handout

Presentation slides

Participant-Recommended Resources

- NEMA. *Specifying Building Management Systems and Data-Integrated Building Systems*. NEMA BMS P2-2020. May 06, 2020. Available here: https://www.nema.org/standards/view/specifying-building-management-systems-and-data-integrated-building-systems.
- Nexus Labs and Keyframe Capital. *The Untapped 87%: Simplifying Controls Technology for Small Buildings*. White Paper. Available here: https://www.nexuslabs.online/untapped-87/.
- Securities and Exchange Commission (SEC). *Proposed Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors*. Available here: https://www.sec.gov/rules/proposed/2022/33-11042.pdf.
    - Aquicore. "The SEC's Proposed Climate Risk Disclosure Requirements & Deadlines." Blog article summarizing the requirements and deadlines associated with the proposed rule. Available here: https://www.aquicore.com/blog/secs-climate-risk-disclosure-deadlines.

DE-FOA-0002723

Request for Information (RFI): "Research and Development Opportunities in Energy Management Control Systems"

DATE: June 3, 2022
SUBJECT: Request for Information (RFI)

Description

Buildings are responsible for approximately three-quarters of all electricity use and typically more of peak power demand in the United States (U.S.) and offer a unique opportunity for cost-effective energy management as the nation's primary electricity users. Their energy demand results from a variety of electrical loads operated to serve occupants' needs. Many of these loads are flexible to some degree, and intelligent communications and controls can manage their use to enable energy and cost savings, thus making essential contributions to the decarbonization and economic growth of the U.S. built environment and energy economy (including through beneficial electrification) – while still meeting occupant productivity and comfort requirements.

Integrating state-of-the-art sensors and controls throughout the commercial building stock can lead to savings of as much as 29% of site energy consumption through a high-performance sequence of operations, optimized settings based on occupancy patterns, and correcting inadequate equipment operation or installation[1]. It can also enable 10%–20% of commercial building peak load reduction[2, 3].

The U.S. Department of Energy's (DOE) Building Technologies Office (BTO) invests in the research and development (R&D), validation, integration, and deployment of the next generation of affordable, high-performance, cost-effective tools and technologies that will result in significant energy savings for and decarbonization of the national building stock – both commercial and residential. A core technical area necessary for achieving this goal is the integration of sensing, computing, communication, and actuation for improved monitoring and control of the built environment. As such, BTO maintains an active portfolio in energy management control systems (EMCS). In tandem with building energy modeling, EMCS covers the energy management of cyber-physical infrastructure.

[1] Fernandez, N., Katipamula, S. et al., (2017). "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction." Pacific Northwest National Laboratory, PNNL-25985.
[2] Kiliccote, S., Olsen, D., Sohn, M. D. and Piette, M. A. (2016). "Characterization of demand response in the commercial, industrial, and residential sectors in the United States." WIREs Energy Environ., 5: 288–304.
[3] Piette, M.A., Watson, D.S., Motegi, N., Kiliccote, S. (2007). "Automated critical peak pricing field tests: 2006 pilot program description and results." Lawrence Berkeley National Laboratory, LBNL-59351.

This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.

This RFI is comprised of the draft "Research and Development Opportunities in Energy Management Control Systems" ("EMCS RDO" or "RDO"), followed by specific questions about the issue and the draft RDO. BTO is interested in receiving input on both the specific questions and any elements of the draft RDO.

Purpose

The purpose of this RFI is to solicit feedback from industry, academia, research laboratories, government agencies, and other stakeholders on issues related to building energy management systems (hardware, software, cybersecurity, and interoperability). This information will be used by BTO to update its R&D strategy and support energy savings, emissions reduction, and cost reduction goals, and inform future strategic planning and adjustments to its R&D portfolio. This is solely a request for information and not a Funding Opportunity Announcement (FOA). BTO is not accepting applications.

Disclaimer and Important Notes

This RFI is not a Funding Opportunity Announcement (FOA); therefore, EERE is not accepting applications at this time. EERE may issue a FOA in the future based on or related to the content and responses to this RFI; however, EERE may also elect not to issue a FOA. There is no guarantee that a FOA will be issued as a result of this RFI. Responding to this RFI does not provide any advantage or disadvantage to potential applicants if EERE chooses to issue a FOA regarding the subject matter. Final details, including the anticipated award size, quantity, and timing of EERE funded awards, will be subject to Congressional appropriations and direction.

Any information obtained as a result of this RFI is intended to be used by the Government on a non-attribution basis for planning and strategy development; this RFI does not constitute a formal solicitation for proposals or abstracts. Your response to this notice will be treated as information only. EERE will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. EERE will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that EERE is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind EERE to any further actions related to this topic.

Confidential Business Information

Pursuant to 10 CFR 1004.11, any person submitting information that he or she believes to be confidential and exempt by law from public disclosure should submit via e-mail, postal mail, or hand delivery two well-marked copies: one copy of the document marked "confidential" including all the information believed to be confidential, and one copy of the document marked "non-confidential" with the information believed to be confidential deleted. Submit these documents via e-mail or on a CD, if feasible. DOE will make its own determination about the confidential status of the information and treat it according to its determination.

Evaluation and Administration by Federal and Non-Federal Personnel

Federal employees are subject to the non-disclosure requirements of a criminal statute, the Trade Secrets Act, 18 USC 1905. The Government may seek the advice of qualified non-Federal personnel. The Government may also use non-Federal personnel to conduct routine, nondiscretionary administrative activities. The respondents, by submitting their response, consent to EERE providing their response to non-Federal parties. Non-Federal parties given access to responses must be subject to an appropriate obligation of confidentiality prior to being given the access. Submissions may be reviewed by support contractors and private consultants.

DRAFT RESEARCH AND DEVELOPMENT OPPORTUNITIES DOCUMENT

Chapter 1: Hardware

Building energy management hardware consists of sensors, sub-meters, and actuators that enable continuous monitoring and control of the built environment – both indoors and outdoors. Sensors collect data from the environment or object under measurement (e.g., energy consumption). Sub-meters provide a granular or resolute measurement of energy consumption data. Actuators control the electrical or physical states of equipment based on control signals or algorithms. This chapter focuses on sensors, sub-meters, and actuators that measure and monitor the built environment for aiding energy management and explicitly does not discuss hardware for other building functions (e.g., fire safety, security systems).

Commercial buildings often use a variety of sensors. These may include environmental sensors for temperature, occupancy, humidity, CO_2, air-quality sensors, or subsystem sensors relevant to equipment function such as duct pressure and airflow. The purpose of these sensors is to measure environmental and equipment conditions relevant to critical performance metrics such as occupant comfort, health, and productivity. Low-cost, wireless, and other advanced sensors are considered an "enabling technology" for a variety of building energy management strategies, including building commissioning, damper fault detection and diagnostics, demand-controlled ventilation, duct leakage diagnostics, and optimal whole-building control.

Residential buildings predominantly use a single sensor embedded in a centrally located thermostat to monitor and detect deviations in temperature from the desired set-point. The residential sector has dramatically benefited from smart thermostat technology advancements that automatically sense, communicate, and respond to ensure desired operations. These devices incorporate different sensors and algorithms that learn household occupancy, behavior, and comfort preferences to maintain comfort autonomously. Smart thermostats enable occupancy information-based algorithms that can save between 11% and 34% of energy without significantly risking the occupant's comfort level[4]. Aesthetics, convenience, and cost savings drive lighting control strategies by leveraging timers, dimmers, motion detection, or light detectors[5,6]. Emerging strategies include smart home hubs that integrate various technologies and smart home energy management systems to deliver occupancy-informed home energy use optimization.

Whole-building energy meters (e.g., electricity or natural gas meters) or sub-meters (e.g., plug-loads) aid in energy consumption monitoring of individual building systems and components and the building as a whole. Sensors and meters together inform environmental and equipment status at the whole-building, system, or component level.

The development of actuator technologies can advance building performance through improved energy efficiency, grid benefits, or enhanced comfort. Actuator technology developments are progressing from simple, bulky, loud, inaccurate, and less efficient technologies to scalable, integrated, quiet, precise, and novel alternatives for enabling improved awareness, communication, and synergistic coordination for control of energy devices.

1.1 Technical and Adoption Barriers

Current building management hardware has the following technical shortcomings and adoption barriers hindering the potential to save costs, energy, and emissions:

Cost
The cost to manufacture sensors, particularly at low volumes, can be prohibitive. Commissioning and maintenance expenses may result in an unattractive return on investment. Depending upon sensor placement, deployment in existing buildings can be cost-prohibitive or intractable. High hardware, installation, and maintenance costs can hinder the deployment of precise, variable actuators. Most existing sub-meter installations use traditional meters, requiring the exploration of retrofit pathways and increasing installation costs. High installation

[4] Wang, C., Pattawi, K., and Lee, H. (2020). Energy saving impact of occupancy-driven thermostat for residential buildings. Energy and Buildings, 211, 109791.

[5] CEE (2014). "Residential Lighting Controls Market Characterization." Consortium for Energy Efficiency.

[6] Based on Residential Building Energy Consumption Survey (RECS) data (2015). U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=32112

and maintenance costs limit the widespread adoption of new hardware technologies, particularly in retro-commissioning.

Interoperability

A significant challenge for the rapid penetration of advanced hardware technologies is the lack of device-level and application-level interoperability. Hardware deployments are limited in terms of ease of use and ability to communicate among building devices. Consumers' benefits may be limited unless they purchase an entire solution from one vendor (i.e., "vendor lock-in").

Size

Traditional actuators have a relatively large form factor that limits the number of installation locations and control points in the building, potentially limiting widespread adoption.

Veracity

Energy utility companies typically do not share real-time energy metering data with building owners at full temporal resolution. As a result, building owners may install additional power sensors to have high-fidelity energy data. The discrepancy between these readings, which can occur for many reasons (e.g., lack of time synchronization, accuracy/uncertainty of calibration, measurement methods), can lead to misinterpretation and detrimental actuation.

1.2 Research Areas

The next generation of building energy management hardware should combat the challenges mentioned above and have the following capabilities:

- Automated and continual commissioning - Automated and continual commissioning extends hardware life, reduces installation and maintenance costs, decreases the possibility of failures, improves sensor and actuator network scalability, and saves energy. Building energy management hardware should automatically recognize and share their identity, location, state, power use, and sensing capabilities to the connected network. Hardware should continuously self-diagnose for degradation and faults and trigger appropriate corrective mechanisms.

- Sustainable power - Efficient sensing and communication hardware with sufficient energy harvesting has the potential to enable long-lasting power sources, reduce manufacturing costs, eliminate maintenance costs, and minimize the deployment footprint of new sensor packages.

- Sensor placement - Optimized sensor placement can reduce the number of sensors and technical requirements of each sensor necessary to meet the measurement and control performance required for a specific use case. When combined with communication (e.g., mesh network) or plug-and-play functionality, installation and maintenance barriers can be significantly reduced. Additionally, the ability to easily mount and re-mount to any surface can significantly reduce installation costs when retrofitting existing buildings.

The following are potential priority research areas for building energy management system hardware:

Near-term research areas

- **Develop hardware technologies with reduced installation and maintenance costs.** Sensor, sub-meter, and actuator solutions that enable self-configuration and self-commissioning with little to no engineering effort reduce installation costs. Technologies that do not require periodic re-calibration and can self-diagnose faults minimize maintenance costs, especially for small and medium-sized commercial buildings.

- **Develop the fundamental aspects of optimal sensor placement and configuration algorithms.** A large number of sensor nodes can provide an accurate estimation of building parameters but increases costs. Optimal sensor placement algorithms can dramatically reduce the number of deployed sensors without significantly impacting improved building operations.

- **Develop sub-meters with flexible placement methods.** Incorporating metering in previously inaccessible spaces can expand the opportunity space for intelligent energy and demand management. Installation approaches that do not disrupt electrical power connectivity, existing networks, or building operations reduce installation costs and improves adoption.

- **Develop low-cost retrofit sensor technologies.** Retrofitting buildings with advanced sensor technologies without rewiring existing networks reduces installation costs and increases its adoption, especially in small and medium-sized commercial buildings. Low-cost wireless sensor networks with improved connectivity enable energy savings through advancements in control schemes in existing buildings.

- **Develop sensor technologies with long operational-power lifetimes.** More efficient computing hardware, energy-aware algorithms, and low-energy network topologies permit higher frequency sensing and automated operations. Longer-lasting power supplies through more efficient energy harvesting or higher capacity energy storage will improve the mean time between sensor power source replacement or recharge.

- **Develop advanced actuators.** Low-cost, low-power, miniaturized (small and lightweight), durable actuators that do not require resource-intensive re-calibration can enable highly granular building energy management. Intelligent actuators with two-way communication can provide enhanced operational performance and easy fault detection.

Long-term research areas

- **Design, develop, and create deployment pathways for autonomous and long-lasting sensor solutions.** Autonomous hardware solutions that are interoperable, self-configuring, self-commissioning, and can self-diagnose for faults or performance degradation can facilitate novel, low-cost deployment. Autonomous sensors with low-power sensor connectivity for cost-effective deployment and maintenance help realize scalable sensor networks in buildings.

- **Design, develop, and create deployment pathways for advanced sub-meters**. Energy measurements for installed building equipment and energy loads of interest at revenue-grade accuracy for residential and commercial buildings expand analytical capabilities that can lead to energy savings and more significant energy efficiency investments. Metering across relevant building energy consumption with self-calibration can significantly reduce costs and increase adoption.

- **Design actuators with embedded intelligence.** Next-generation actuators with embedded intelligence enable context-aware operations and two-way communications. They can proactively remedy fault modes and avoid performance degradation. Intelligent actuators could enable the cooperative and synergistic operation of multiple actuators for robust building automation.

Chapter 2: Software

Building management software is a combination of supervisory control algorithms, user interfaces, and communication networks. Together, it can automate the control of various building subsystems. Supervisory control algorithms manage whole energy systems and coordinate many local controllers. It implements high-level algorithms and strategies aimed at objectives like reducing energy costs. User interfaces enable owners and operators to monitor operations, provide feedback, and specify their needs. Communication networks facilitate information exchange and integrate the hardware and software components in a building energy management system. This chapter discusses supervisory control algorithms and user interfaces, while Chapter 4 discusses communication networks as part of Focus Area 4.

Large commercial buildings use energy management control systems (EMCS) to monitor and control heating, ventilation, and air-conditioning (HVAC). Some EMCS also integrate control of lighting and other subsystems. An EMCS incorporates information from a range of outdoor environmental (temperature, humidity), indoor environmental (temperature, humidity, CO2), and equipment (on/off state, inlet and outlet temperatures, flow rates) sensors. The information determines the implementation of schedules (e.g., thermostat set-points for occupied and unoccupied hours) and rules (e.g., economizer set-point resets based on the outdoor temperature and humidity) to reduce energy use. Newer, high-end EMCS may also include the ability to detect and diagnose HVAC equipment faults and provide actionable recommendations to the building operator. Medium and small commercial buildings often have several packaged unitary systems (e.g., rooftop units) instead of a central HVAC system. In these configurations, there may be lower operational and convenience benefits to a centralized EMCS, and the capital cost may become prohibitive.

Integrated energy management systems for homes have historically received little attention. However, there is currently rapid adoption of technologies such as smart thermostats that support energy management and voice-activated home assistants that integrate with "connected" water heaters, appliances, lighting, and electronics. This transformation makes widespread automated and integrated energy management a nearer-term proposition for homes than for small and medium commercial buildings[7]. Additionally, small commercial buildings may benefit from the same solutions applied to residential systems, including communicating thermostats and smart lighting controls.

Any advancements in supervisory building control technology should improve or have no impact on occupant comfort and productivity. The development of occupant-centric operations relies on improved monitoring of occupant conditions, improved understanding and modeling of occupant comfort, interactions, and behaviors, and incorporation of these parameters into control strategies. Collecting the time-varying and scenario-driven occupant preferences and priorities for building operations and understanding the level of detail required for incorporation into control algorithms is still an active area of research.

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[7] NEEP (2016). "The Smart Energy Home: Strategies to Transform the Region." https://neep.org/sites/default/files/resources/SmartEnergyHomeStrategiesReport_3.pdf

The current deployment of automated EMCS across the building sector focuses on energy efficiency and cost savings within occupant needs and comfort. Legacy systems do not focus on providing grid services by harnessing demand flexibility. Increased adoption and improvements in building sensing and control algorithms could improve demand response in terms of occupant experience, acceptability, and grid service provision capability.

2.1 Technical and Adoption Barriers

Current building management software has the following technical shortcomings and adoption barriers hindering the potential to save costs, energy, and emissions:

Optimal operations

Currently, building management operations are typically implemented as rules, such as thermostat set-point schedules for occupied and unoccupied hours or economizer set-point resets based on outdoor air temperature and humidity. Rule-based controllers are characterized by a large number of tuning parameters selected exclusively for each system and building and are often reset during seasonal transitions. Rule-based systems are intuitive but do not necessarily lead to optimal operation.

Managing uncertainty

Optimization-based methods are greatly affected by uncertainties in weather, occupancy, sensing, measurement, and communications, causing modeling errors. The errors jeopardize the reliability of optimization-based methods to provide energy-efficient operations and grid services.

Automated integration, coordination, and commissioning

The adoption of building commissioning processes is limited due to its labor-intensive nature and associated high costs. Lack of effective commissioning leads to incorrectly installed equipment, increasing energy costs.

Value proposition

Cost-benefit trade-offs for advanced control strategies are difficult to assess due to existing technical challenges, uncertainty in guaranteed savings stemming from implementation and verification errors, as well as uncertainty in model or training data accuracy requirements and corresponding computational efforts compared to projected cost savings from performance improvements.

Capital expenditure
Setting up building management infrastructure is often an expensive process. It typically relies heavily on multiple contractors with varying expertise, time-consuming installation procedures due to a lack of standardized data taxonomy, and tailored modeling and control design for each building system. Alternatives or dramatic cost reductions are necessary for installing building automation infrastructure in buildings without existing equipment due to a limited number of total zones and points that do not make the large up-front capital investment cost-effective.

Control interpretability
Currently deployed rule-based control algorithms automate traditional building-operator logic providing explicable solutions. In contrast, optimization-based methods may provide unintuitive solutions making it difficult for operators to interpret, tune, and adjust according to their needs.

Interoperability
One of the most significant obstacles to the penetration of autonomous and transaction-based building controls is the lack of standardized, interoperable hardware and software that can interconnect across multiple vendors, equipment types, and buildings. Automation and control systems' installation tends to be unique to each building and for each equipment manufacturer and therefore exhibits no economies of scale for later installations.

Building owner, occupant, operator engagement
Split incentives structures among owners, tenants and operators, and a lack of customer, owner and operator education, interest, and awareness in new product development and implementation are significant deployment barriers for new control technology. Additionally, comparing performance features across products is difficult without an established baseline, especially for risk-averse owners and operators.

2.2 Research Areas

To combat the above-mentioned challenges, the next generation of building energy management software is characterized by the following capabilities:

- Multi-objective optimization - The built environment can have multiple objectives at any given time, depending on trade-offs among user preferences (e.g., reduce energy costs, improve occupant comfort, provide resilient operations, reduce emissions, minimize equipment degradation, provide grid services). A multi-objective optimizer provides a solution as close as possible to the desired value of each of the set objectives.

- Predictive, adaptive, and robust control - Built environment operations are characterized by uncertainties in occupancy patterns and preferences, sensing measurements, weather, and energy demand, flexibility, and prices. Predictive control is the system's ability to anticipate trends in the various factors that influence the built environment. Adaptive control modifies system operations based on measured data to achieve optimal performance, while robust control guarantees performance requirements in the presence of uncertainties.

- Explainable solutions - Modern optimization methods provide solutions based on evaluating various factors and possibilities related to the built environment. While effective, they provide non-intuitive solutions that building operators find difficult to understand, tune, or trust. Building energy management software should provide transparency in algorithmic decision-making to promote acceptability by all stakeholders (owners, operators, and occupants).

- Automated and continuous commissioning - Automated and continual commissioning extends equipment life, reduces the possibility of failures, and saves energy. Systems components must automatically share their identity, status, and availability with advanced building controls and operate successfully as an integrated system when necessary. Some examples of contributing technology include self-identifying equipment, self-configuring controls, automatic installation verification, continual monitoring and testing, and self-diagnosis of faults and degradation.

- Usability and interaction - Building energy management system software need a human interface that accepts and dynamically incorporates real-time feedback from building operators and occupants. It enables users to provide their preferences or priorities and feel empowered to change or reverse situations they dislike.

- Market-based coordination - A EMCS plays a vital role in harnessing building demand flexibility. They should include market-based coordination techniques that securely negotiate with the grid to respond within a required timeframe and provide the requested service to the grid within acceptable occupant comfort and productivity constraints.

- Integration of HVAC, envelope, and lighting management - Multiple building systems can be integrated to share sensors and data for improved functionality and flexibility. Depending on the building needs, integration can influence space conditioning, thermal comfort, and energy savings.

- Integration with electricity generation and storage - Integration of building systems with on-site electricity generation and storage enables greater flexibility of energy use reducing energy costs and carbon emissions.

Based on the above discussion, the following are potential priority research areas in building EMCS software:

Near-term research areas

- **Develop the fundamental and practical capabilities of advanced control methods for commercial buildings.** Advances in the model acquisition, control architectures, adaptability, and robustness to uncertainty can manage building loads in a way that maximizes energy savings and the availability and responsiveness of load flexibility while minimizing occupant impacts. The control methods should adapt to available building hardware and maximize the equipment life cycle.

- **Evaluate control algorithms for residential and small commercial buildings through field tests.** Residential deployment of a predictive control framework faces fewer challenges than commercial buildings due to the reduced scale and complexity. The developed fundamental aspects need practical validation in actual buildings.

- **Develop methods for occupancy detection and integration of comfort and behavior measurements.** Occupant thermal comfort and preferences are key inputs to achieving building energy management objectives. Improved monitoring of occupancy conditions (e.g., presence, comfort, and adaptive behavior), improved understanding and modeling of occupant interactions and behaviors, convenient methods of registering occupant preferences, and incorporation of these parameters into the EMCS control algorithms can improve occupant comfort and productivity.

- **Standardize data pre-processing for data-driven techniques.** Data-driven approaches require a lot of data to make acceptable decisions in the control environment. Systematic pre-processing methods can significantly improve the performance of deployed algorithms.

- **Develop the capability to forecast aggregate building demand flexibility.** Buildings can support the clean energy transition by using inherent demand flexibility for grid services to support greater penetration of variable renewable energy sources. Accurate demand and demand flexibility forecasts are critical to reliable electricity supply and delivery, other power system operations, and infrastructure development.

- **Develop the practical capabilities of an automated and cost-effective market-based coordination package for grid services.** Transactive energy is a promising, market-based coordination approach to managing building-to-grid services. Advances are required in automated price-capacity curve estimation and open-source software development compatible with existing demand response programs and dynamic pricing structures.

Long-term research areas

- **Develop a co-design framework for HVAC system configurations, controls, and sensing.** Including HVAC system configuration, control strategies, and sensor configuration for different HVAC system types and different control applications in building design can improve performance and grid-service reliability. The framework should include varied applications like high-performance control (using either rules or models), fault detection and diagnostics, and load shedding and shifting for grid response.

- **Design, develop and create deployment pathways for autonomous building software solutions for commercial buildings.** Autonomous solutions are interoperable, self-configuring, self-commissioning, and adaptive to occupant and grid needs. They ensure "optimal" operation to maximize benefits to the building owners and the electric grid.

Chapter 3: Cybersecurity

The increasing connectivity and growing complexity of smart buildings increase the potential for vulnerabilities. Data published by IntelligentBuildings shows that half of the buildings they assessed in 2018 had Internet-connected devices that could be accessed remotely, and 95% of the buildings either had no disaster recovery plan or had not changed default configurations and ports.[8] This illustrates a lack of cybersecurity awareness and implementation of best practices by building operators. Cyber threats and vulnerabilities, or even the perception of increased risk,

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[8] Gordy, Fred. April 2019. "The State of BAS Cybersecurity." AutomatedBuildings.com. http://automatedbuildings.com/news/apr19/articles/ib/190318022808ib.html

could hinder the adoption of smart, connected technology in buildings and impede the realization of energy efficiency goals[9].

Commercial building control systems communicate using a mix of Information Technology (IT) and Operational Technology (OT) protocols over a dedicated field bus (mostly RS-485). Residential systems are a mix of IT and dedicated field bus wireless protocols such as Zigbee. Typically, an IT group is responsible for overall cybersecurity in enterprise systems and typically tasked with cybersecurity risk management. In contrast, OT groups are tasked with the well-being and function of individual building systems such as heating, ventilation, and air conditioning (HVAC), lighting, and elevators. OT staff are responsible for maintaining the operational status of building systems for occupant comfort and convenience. Service availability is most important to their mission, and cybersecurity is a relatively new concern. On the other hand, IT security staff are more familiar with cybersecurity risks and mitigation strategies but are often unfamiliar with OT systems and how they are becoming connected[10]. The connection of OT systems to IT networks has become quite common, and these systems have become both vectors (i.e., an entry point enabling access to broader enterprise IT systems) and occasionally direct targets of cyberattacks. It is now common for building HVAC (and possibly lighting) system controls to be IP-enabled, and there is a proliferation of Internet of Things (IoT) devices emerging to support energy-efficient building operations. Additionally, devices and systems like elevators that traditionally are not networked are increasingly becoming IoT devices because of the ease of use an Internet connection affords.

Numerous relevant cybersecurity resources and activities in the building domain and adjacent fields are available across federal agencies, industry organizations, and vendor and IoT best practices[11]. The following are some cybersecurity resources and guidance developed across the federal government:

1. National Institute of Standards and Technology (NIST) Framework for Improving Critical Infrastructure Cybersecurity (NIST-CSF) guides how organizations can assess and manage cybersecurity risk. It is not limited to any single sector and is flexible enough for use by organizations with mature cybersecurity postures and those with less developed programs.

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[9] Reeve et al (2020). "Challenges and Opportunities to Secure Buildings from Cyber Threats. Pacific Northwest National Lab (PNNL). https://www.energy.gov/eere/buildings/articles/challenges-and-opportunities-secure-buildings-cyber-threats

[10] Crowe et al (2019). "Summary of outcomes of the 2019 cybersecurity roundtable." Prepared for U. S. Department of Energy. https://betterbuildingssolutioncenter.energy.gov/resources/summary-outcomes-2019-cybersecurity-roundtable

[11] Reeve et al (2020). "Challenges and Opportunities to Secure Buildings from Cyber Threats". Pacific Northwest National Lab (PNNL). https://www.energy.gov/eere/buildings/articles/challenges-and-opportunities-secure-buildings-cyber-threats

2. DOE's BTO and the Federal Energy Management Program (FEMP) jointly funded the development of the Buildings Cybersecurity Framework (BCF).[12] Later, FEMP expanded the framework to become the Facilities Cybersecurity Framework (FCF)[13] to address cybersecurity in buildings across critical infrastructures by adapting the NIST Framework and other industry best practices for buildings stakeholders. The BCF and FCF provide guidance to facilitate building-cybersecurity risk-management efforts and increase an organization's cybersecurity posture by identifying security gaps and actionable advice.

3. The Building Cybersecurity Capability Maturity Model (B-C2M2) provides a methodology to self-assess and improve cybersecurity capabilities for building IT and OT systems[14].

3.1 Technical and Adoption Barriers

Current EMCS have the following cybersecurity technical and adoption barriers hindering the ability to address vulnerabilities in building systems:

Legacy systems
Many legacy building systems and technologies have limited computational, bandwidth, storage, and memory capabilities. This often limits the ability of devices to host cybersecurity solutions, such as monitoring and encryption, and lacks the availability of security patches that protect against cyberattacks.

Workforce education and training
The increasing responsibilities to respond to cybersecurity challenges are not accompanied by the necessary tools, technology, and workforce development to train and respond to a rapidly evolving cyber threat.

Lack of stakeholder cyber situational awareness
With rapid innovations in technology, there have been improvements in performance, cost, and functionality in building technology. However, cybersecurity awareness and preparedness have not kept pace, resulting in cybersecurity resource gaps that limit stakeholders' ability to identify and respond to the evolving cyber threat.

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[12] Mylrea, M., Gourisetti, S. N. G., and Nicholls, A. (2017). An introduction to buildings cybersecurity framework. In 2017 IEEE symposium series on computational intelligence (SSCI) (pp. 1-7). IEEE.
[13] Gourisetti, S. N. G., Reeve, H., Rotondo, J. A., & Richards, G. T. (2020). Facility Cybersecurity Framework Best Practices (No. PNNL-30291). Pacific Northwest National Lab. (PNNL), Richland, WA (United States). https://www.osti.gov/biblio/1660771
[14] Glantz, C., Somasundaram, S., Mylrea, M., Underhill, R. and Nicholls, A. (2016). "Evaluating the maturity of cybersecurity programs for building control systems." ACEEE Summer Study on Energy Efficiency in Buildings.

Risk evaluation and vulnerability assessments
Building technology stakeholders need tools and resources to understand how to evaluate and prioritize vulnerabilities to cyber threats within their equipment, systems, buildings, and facilities. They need to incorporate how they manage risk from cyber threats into a range of standard operating and business processes.

Detection and mitigation
Cyber-attacks are often not detected because of a lack of monitoring, logging, and visibility of critical cyber assets. Securing these systems requires proactive cyber risk management and new operational processes that will allow managers, operators, and owners of building technologies to identify, understand, and mitigate cyber threats appropriately.

3.2 Research Areas

Based on the above discussion, the following are priority research areas in building cybersecurity:

- **Develop retrofit solutions.** Legacy systems and infrastructure are often installed with an expectation of decade-plus lifespans and correspondingly may lack the ability to encrypt data and receive security updates due to lack of firmware capability (e.g., limited bandwidth or storage) or vendor support. Retrofitting existing technology to support defense against emerging cyber threats will require specialized attention and consideration.

- **Develop vulnerability assessments.** Vulnerability assessments help stakeholders quantify, evaluate, and test for the effectiveness and timeliness of different cybersecurity vulnerability mitigation technologies and strategies. R&D is required on hardware and software solutions for vulnerabilities in cyber-physical interactions, working to address vulnerabilities without impacting energy performance.

- **Develop threat detection algorithms.** Advanced intrusion and threat detection algorithms enable stakeholders to proactively instrument and monitor systems for effective response and mitigation efforts. Tools and methods must enable cyber analytics, merge information streams, and leverage threat intelligence to provide a complete picture of advanced adversary activity.

- **Develop cybersecurity standards.** Stakeholders need to understand better which existing standards can be applied to specific building technologies. Research on testing frameworks and procedures to help standardize and quantify protection capabilities will address gaps in cybersecurity standards, validating and strengthening outdated, conflicting, or underdeveloped standards as appropriate.

Chapter 4: Interoperability

Interoperability is the ability of devices and software systems to reliably exchange data and meaningfully interpret (and act on) that data. Interoperability is a critical technical and market gap/barrier to connected technologies in buildings.

Electronic communication is a hierarchy of protocols operating at different layers. Interoperability at a given layer requires compatible protocols within that layer and the layers below. The Open System Interconnection (OSI) model defines seven layers, but for this discussion, we group them into three. At the bottom are physical data layers that define the medium and the properties of signals exchanged. Ethernet, Wi-Fi, Bluetooth, and Zigbee are physical data layer protocols. In the middle are network layers that define the form, routing, and delivery of messages. Network protocols include Transmission Control Protocol/Internet Protocol (TCP/IP) and Secure Sockets Layer/Transport Layer Security (SSL/TLS). 6LoWPAN is an emerging standard for low-bandwidth IPv6 over low-power personal area networks with potential connected homes applications. On top are application layers that define the internal structure and semantics of the messages sent. HTTP (web), IMAP (e-mail), and SMS (text messaging) are examples of application layer protocols. BACnet (www.ashrae.org/technical-resources/bookstore/bacnet) is the most common application layer protocol for commercial building automation. At the device level, OpenHEMS is an emerging concept that works using APIs to integrate multiple devices. In the building space, most of the activity is taking place at and above the application layers.

BACnet allows building equipment and software to discover one another on a network and to exchange messages. It specifies the semantics of some parts of messages but attaches no semantics to others, leaving them to higher-level applications, specific vendors, or installations. One higher-level interoperability gap that has received recent attention is the need for standard semantic models of buildings and their systems. A semantic model is not a set of messages between entities in a building but rather an overarching description of those entities, their capabilities, and their relationships to one another. This type of model allows applications such as advanced control, monitoring, fault detection and diagnosis, and even grid services to automatically configure themselves to different buildings, allowing them to scale. We call this subset of interoperability "semantic interoperability." Ideally, semantic models would also support interoperability between applications across different stages in the building life cycle from planning, design, and architecture, engineering, and construction, to commissioning, maintenance, and operations.

Semantic modeling is well defined and fairly well established in building design and construction in the form of Building Information Modeling (BIM). BIM does not accommodate all the information needed to support all design and construction analyses and applications. In particular, it does not fully support energy analysis. After translation from BIM, energy-specific information is typically added to the energy analysis application. Semantic modeling is emerging in existing building applications such as energy auditing with schemas such as BuildingSync and CityGML/EnergyADE.

Semantic modeling in building operations is less standardized. Within EMCS, it is heterogeneous and highly dependent on vendor and installer. To the degree that semantic information is standardized and exchanged, it is in the form of naming conventions and sets of tags like the ones described in Project Haystack (https://project-haystack.org/). Haystack can describe entities and some relationships but is not based on a formal data modeling framework that supports generalized queries and automated conformance and completeness checking. Applications and services typically implement internal semantic models but do so in inconsistent, duplicative, and potentially conflicting ways[15]. The development and maintenance of semantic models and their use in configuring and deploying new applications is generally not automated and requires general expertise with the underlying software and knowledge of the specific building and its systems.

The recognition of the importance of semantic modeling and interoperability has redirected the ASHRAE Standard 223P to the proposed new title of "Semantic Data Model for Analytics and Automation Applications in Buildings." This proposed standard would develop a semantic modeling framework for building operations. The framework will draw from and extend existing building ontological frameworks such as Brick Schema (https://brickschema.org), Semantic Sensor Network (SSN) ontology (www.w3.org/TR/vocab-ssn/), Smart Appliance REFerence (SAREF) ontology (https://saref.etsi.org/), and others. The framework will support translation to-and-from existing Haystack models and perhaps other building relevant semantic models such as BIM and BuildingSync.

ASHRAE Standard 223P will also include an evaluation framework that can be used to test installations for conformance to the standard. To support specific use cases such as system-level fault-detection and diagnosis, Subsets or "model views" of the standard that are sufficient to

[15] Benndorf, G.A., Wystrcil, D. and Réhault, N. (2018). "Energy performance optimization in buildings: A review on semantic interoperability, fault detection, and predictive control." Applied Physics Reviews, 5(4), p.041501.

support those use cases will be defined. The evaluation framework can be parameterized to check for completeness against this model view in addition to conformance to the standard.

4.1 Technical and Adoption Barriers

Semantic interoperability in building faces the following technical and adoption barriers:

Proliferation of semantic data modeling frameworks
Bespoke (pseudo) semantic data models (e.g., naming conventions, other metadata) reflect the specialized needs of different industries (e.g., retail, healthcare, building controls, energy) and even of different building systems such as lighting, HVAC, plug loads, refrigeration, and rooftop photovoltaics (PV), electric vehicles (EVs), and stationary batteries. Different organizations are trying to create formal models that encompass subsets of these systems and use cases, but these efforts are themselves uncoordinated.

Large outdated installed base
Many installed BAS and EMCS are programmed with limited or even no semantic data models and would need to be upgraded to become conformant with a new standard.

Lack of semantic data model-driven applications and services
In a classic chicken-and-egg situation, there is little incentive to create semantic data models in new installations or to upgrade existing systems because there are no applications and services that can take advantage of semantic data models.

Vendors, operators, and installers engagement
The existing workforce is not familiar with semantic modeling, its capabilities, workflows, and applications.

4.2 Research Areas

Based on the above discussion, the following are priority research areas in semantic interoperability:

- **Harmonize semantic data model standards.** Select and promote an existing semantic modeling standard for building applications or create one that pulls together existing efforts and combines the best features of different systems to promote acceptance and adoption by their existing champions and user bases.

- **Develop minimum requirements for different use cases of semantic data modeling.** A common semantic modeling framework will support a wide range of applications. However, individual installations will not be interested in all these applications. Develop minimum semantic data modeling requirements for different applications and use cases to give vendors and installers precise targets for the information they need to represent.

- **Develop semantic data model conformance and completeness testing tools.** Develop open and trusted tools that can evaluate existing installations for conformance to the standard and completeness relative to target use-cases. These tools can also help guide and educate installers in creating conformant and complete models.

- **Develop translation tools that ease the transition to semantic data modeling for existing systems.** There is a significant installed base of BAS and EMCS that use limited or ad hoc semantic data modeling. Automating or even mostly automating the transition of these existing systems to true, complete, and conformant semantic modeling will lower barriers to adoption.

- **Engage stakeholders to promote semantic modeling and interoperability.** Existing market actors may have short-term incentives to resist the adoption of semantic interoperability. Engagement with a diverse group of stakeholders, including vendors, installers, building owners and operators, and standards and professional organizations focused on the benefits of semantic interoperability, is critical to the successful development and adoption of semantic interoperability.

Request for Information Categories and Questions

Category 1: Hardware

1. In reference to the Technical and Adoption Barriers listed in Section 1.1 of the above draft:
    a. Are there any missing technical and adoption barriers for advancing state-of-the-art building energy management hardware? If so, please describe.
    b. Have any of the listed barriers already been sufficiently addressed through current state-of-the-art? If so, please describe.
    c. Are there barriers in the adoption of state-of-the-art hardware specific to disadvantaged and/or underserved communities? If so, please describe.
2. In reference to the Research Areas listed in Section 1.2 of the above draft:

   a. Are there any missing high-level capabilities of next-generation building energy management hardware to combat the identified technical and adoption barriers in section 1.2? If so, please describe.
   b. Are there any missing near-term (5-10 years) research areas for building energy management system hardware? If so, please describe.
   c. Which research areas should BTO prioritize? Please justify in detail.
   d. Are there any missing long-term (>10 years) research areas for building energy management system hardware? If so, please describe.
   e. In your opinion, should any of the listed near-term and long-term research areas be omitted from this discussion? If so, please justify in detail.
   f. Are any of the identified research areas disproportionately less impactful to disadvantaged and underserved communities? If so, in what ways can the process be improved to remedy the inequities?
3. Please provide feedback on how Chapter 1 may identify/address equity considerations to ensure the benefits of R&D investments in EMCS hardware reach disadvantaged communities.

Category 2: **Software**

4. In reference to the Technical and Adoption Barriers listed in Section 2.1 of the above draft:
   a. Are there any missing technical and adoption barriers for advancing state-of-the-art building energy management software? If so, please describe.
   b. Have any of the listed barriers already been sufficiently addressed through current state-of-the-art? If so, please describe.
   c. Are there barriers in the adoption of state-of-the-art software specific to disadvantaged and/or underserved communities? If so, please describe.
5. In reference to the Research Areas listed in Section 2.2 of the above draft:
   d. Are there any missing characteristics of next-generation building energy management software to combat the identified technical and adoption barriers in section 2.1? If so, please describe.
   e. Are there any missing near-term (5-10 years) research areas for building energy management system software? If so, please describe.
   f. Are there any missing long-term (>10 years) research areas for building energy management system software? If so, please describe.
   g. Which research areas should BTO prioritize? Please justify in detail.
   h. In your opinion, should any of the listed near-term and long-term research areas be omitted from this discussion? If so, please justify in detail.

   i. Are any of the identified research areas disproportionately less impactful to disadvantaged and underserved communities? If so, in what ways can the process be improved to remedy the inequities?

6. Please provide feedback on how Chapter 2 may identify/address equity considerations to ensure the benefits of R&D investments in EMCS software reach disadvantaged and historically underserved communities.

Category 3: **Cybersecurity**

7. In reference to the Technical and Adoption Barriers listed in Section 3.1 of the above draft:
   a. Are there any missing technical and adoption barriers to addressing cybersecurity vulnerabilities in building systems? If so, please describe.
   b. Have any of the listed barriers already been sufficiently addressed through current state-of-the-art? If so, please describe.
8. In reference to the Research Areas listed in Section 3.2 of the above draft:
   c. Are there any missing research areas for building cybersecurity? If so, please describe.
   d. Which research areas should BTO prioritize? Please justify in detail.
   e. In your opinion, should any of the listed near-term and long-term research areas be omitted from this discussion? Please justify in detail.
9. Please provide feedback on how Chapter 3 may identify/address equity considerations to ensure the benefits of R&D investments in building cybersecurity reach disadvantaged and historically underserved communities.

Category 4: **Interoperability**

10. In reference to the Technical and Adoption Barriers listed in Section 4.1 of the above draft:
    a. Are there any missing technical and adoption barriers to achieving semantic interoperability in building systems? If so, please describe.
    b. Have any of the listed barriers already been sufficiently addressed through current state-of-the-art? If so, please describe.
11. In reference to the Research Areas listed in Section 4.2 of the above draft:
    a. Are there any missing research areas for semantic interoperability? If so, please describe.
    b. Which research areas should BTO prioritize? Please justify in detail.
    c. In your opinion, should any of the listed research areas be omitted from this discussion? Please justify in detail.

12. Please provide feedback on how Chapter 4 may identify/address equity considerations to ensure the benefits of R&D investments in building interoperability reach disadvantaged and historically underserved communities.

Category 5: **Other**

13. Is there any other feedback on the draft RDO or broader issue you would like to provide? As much as possible, please provide factual information with citations.
14. Do you have recommendations on additional studies, data, or research that could inform BTO strategy around EMCS? If so, please describe.

Request for Information Response Guidelines

Responses to this RFI must be submitted electronically to **emcs_rfi@ee.doe.gov** no later than **11:59 pm (ET) on July 18, 2022**. Responses must be provided as attachments to an e-mail. It is recommended that attachments with file sizes exceeding 25MB be compressed (i.e., zipped) to ensure message delivery. Responses must be provided as a Microsoft Word (.docx) attachment to the e-mail, and no more than six pages in length, 12-point font, 1-inch margins. Only electronic responses will be accepted.

Please identify your answers by responding to a specific question or topic if applicable. Respondents may answer as many or as few questions as they wish.

EERE will not respond to individual submissions or publish publicly a compendium of responses. A response to this RFI will not be viewed as a binding commitment to develop or pursue the project or ideas discussed.

Respondents are requested to provide the following information at the start of their response to this RFI:

- Company / institution name;
- Company / institution contact;
- Contact's address, phone number, and e-mail address.

This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.

Energy Management Control Systems Workforce Development Roundtable Convening: Pre-read for Stakeholders

Last year, the U.S. Department of Energy's (DOE) Building Technologies Office (BTO) issued a draft Research and Development Opportunities document, along a Request of Information (RFI) to solicit feedback from industry, academia, national laboratories and other stakeholders on strategy related to building energy management and control systems (EMCS). BTO received 45 responses from a variety of stakeholders. Along with roundtable input, the responses will inform future strategic planning and the EMCS portfolio, to support energy savings, emissions reduction, and other goals.

One of the main themes in the responses was the need for a strategic effort in developing the EMCS workforce. The responses highlighted three key needs related to workforce development:

1. Critical need for more workers: Stakeholders stressed that there is a lack of qualified staff to manage building operations and maintenance in small and large buildings. They identified a need for more college graduates in the HVAC and EMCS industries.
2. Lack of right skills in the existing workforce: There is a shortage of suitable training programs that can effectively upskill workers for advanced EMCS technology. Better trained workforce could improve the affordability of the technology and early development of curriculums for future EMCS technicians would facilitate the adoption of these technologies.
3. Making EMCS technology simple: With increasing complexity of EMCS technology, some hold unrealistic expectations of skills required of the workforce. Advanced solutions that are transparent in their actions and facilitate operator oversight can complement workforce training programs and further drive acceptance of the technology.

BTO has some existing and past workforce programs:

- Better Buildings Workforce Guidelines: DOE and the National Institute of Building Sciences (NIBS) worked with industry stakeholders to develop voluntary national guidelines to improve quality and consistency of commercial building workforce credentials for four key energy-efficiency related jobs. The industry-validated job task analyses (JTA) outlines key duties, tasks, knowledge, skills, and abilities.
- Department of Energy Recognition: The DOE recognized certification programs that are aligned with Better Buildings Workforce Guidelines, and which have received qualified accreditation by qualified accreditation bodies in compliance with ISO/IEC 17024:2012.
- Training Modules: DOE hosts educational resources on building science topics consisting of lecture notes, presentations, videos, and references.

Additionally, there may be relevant provisions in the Infrastructure Investment and Jobs Act and Inflation Reduction Act, both related to DOE activities and beyond.

U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Energy Management Control Systems Workforce Roundtable

Building Technologies Office, US Department of Energy

January 26, 2023

BTO's Request for Information received feedback on EMCS workforce development needs

BTO received 45 responses from stakeholders.
Responses will inform BTO's EMCS strategy.

Workforce input highlighted three needs:

- More EMCS workers
- Relevant skills in the existing workforce
- Operator-centric EMCS technology

Two BTO Workforce Initiatives

Recognition program for **commercial sector** credentialing organizations

- Offers **recognition** for aligning with the Better Buildings Workforce Guidelines (BBWGs)
- Guidelines for **5 Job Task Analyses** (JTAs)
    1. Building Energy Auditor
    2. Building Commissioning Professional
    3. Energy Manager
    4. Building Operations Journey-worker
    5. Building Operations Professional
- **No training materials** offered

Residential focused course materials **for educators and instructors**

- Educational **modules and training content** on various building topics are freely available, including:
    - Residential HVAC, including heat pumps
    - Indoor air quality
    - Plumbing and more!
- Hosted on EERE's Building Science Education (BSE) webpage
- **No established recognition program**, guidelines, or JTAs

Agenda

- Welcome and objectives – 15 min
- Introductions – 10 min
- Group discussion – 45 min
- Key workforce-related EMCS metrics and targets – 15 min
- Wrap-up and next steps – 5 min

Group discussion

- What types of jobs are the most in-demand in the EMCS industry? What are the preferred qualifications?
- What are the missing skills you notice most in the EMCS workforce?
- What are some future skill requirements for the EMCS workforce?
- How can EMCS technology R&D address workforce challenges? Which technology areas need the most investment?
- Which workforce education gaps should BTO focus its efforts on? Are curriculum standardization and certifications an effective use of government funding?

EMCS Workforce-related Metrics and Targets

- **How can we measure EMCS workforce capacity and capabilities?**
  - Number of EMCS workers (e.g., engineering, installation, programming, commissioning, building operations, facility management)
  - Number of new EMCS workers (e.g., entry level trade, secondary school programs, apprenticeship, community college, professional development, retraining)
  - Equity and diversity of EMCS workforce (e.g., ethnicity, education, communities, retraining for displaced workers)
  - Number of retiring EMCS workers (in which job categories)

EMCS Workforce-related Metrics and Targets

- **How can we measure workforce-related EMCS capabilities and impact?**
  - Hours (per sq. ft. or point) required to engineer and program a new EMCS
  - Hours (per sq. ft. or point) required to install and commission a new EMCS
  - Hours (per sq. ft. or point) required to operate and maintain an EMCS
  - Hours (per sq. ft. or point) required to upgrade EMCS hardware and software
- **Do we need a different baseline and targets for different building types and application complexity?**
  - Large commercial/multi-family (central systems)?
  - Small commercial/multi-family (packaged systems)?
  - Basic EMCS, Advanced EMCS, Building Analytics and Optimization

Final piece of advice?

THANK YOU!

Contacts

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Questions for extra time

- How is your EMCS workforce trained now? What training strategies are most effective?
- Other than training programs, what resources are needed to educate EMCS workforce?