EMCS KPI Roundtable: Draft Framework and Metrics

December 7, 2022

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 key performance indicators (KPIs[1]) for assessing BTO's energy management and control system (EMCS) research and development (R&D) efforts. Twenty-eight subject matter experts attended the meeting and participated in the discussion—12 representing the DOE or national laboratories and 16 representing industry. The format consisted of opening remarks by DOE leadership, followed by presentation slides showing DOE's draft framework of EMCS KPIs, metrics, and targets. Throughout the roundtable discussion, the moderator 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) in EMCSs.[2] The overarching purpose of the RFI, roundtable, and other related activities is to support the Biden-Harris administration's strategy to transition equitably to a decarbonized economy. When DOE describes decarbonization in buildings, they include the interaction of energy efficiency, electrification, and demand flexibility.[3] Controls play a crucial part. Effectively implementing controls in new and existing buildings is imperative to enable the transition to a decarbonized energy infrastructure. To that end, market transformation must occur equitably across all building types, sizes, and locations for the increased penetration of affordable and effective EMCS technologies to extract their full complement of potential benefits.

DOE leadership identified their understanding of the three biggest challenges associated with EMCS R&D:

- How do we transform not just large buildings but also small-to-medium buildings to use advanced EMCS technologies?
- How do we do low-cost retro-commissioning[4] so that utility programs are more successful, for example, as solid-state lighting was used in utility programs?
- How do we transform the edge-of-the-grid[5] to optimize and minimize the amount of infrastructure we have to put in the ground to make the electrification transition happen?

Objective

The objective of the roundtable discussion was to solicit input from subject matter experts on the draft KPI framework, the KPIs themselves, and the related metrics[6] and targets.[7] DOE asked participants to take a broad view of all the tasks EMCS technologies can and must accomplish, to think about value and cost metrics within the draft framework, and to consider how best to prioritize and set targets related to the KPIs.

Key Comments and Recommendations

General Framework

The subject matter expert participants provided several general comments and recommendations on the draft KPI framework. Participants recommended adding a descriptive narrative to the framework document to improve transparency, including defining terms and explaining the intended use. For example, participants

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[1] Key performance indicators (KPIs) are measurable values that demonstrates how effectively an initiative, in this case EMCS research and development, is achieving identified, primary objectives.

[2] See RFI Attachment.

[3] *Demand flexibility* is the capability of distributed energy resource to adjust a building's load profile across different timescales; energy flexibility and load flexibility are often used interchangeably with demand flexibility.

[4] EERE defines *commissioning* as "a quality-assurance process used to verify that a building performs according to the original design and intent and meets the needs of the owners and occupants." 42 U.S.C. 8253(f)(1)(G) defines *retro-commissioning* as "a process of commissioning a facility or system that was not commissioned at the time of construction of the facility or system." EMCS hardware and software are enabling technologies for retro-commissioning.

[5] Greentech Media define the *edge-of-the-grid* or *grid-edge* as comprising "technologies, solutions and business models advancing the transition toward a decentralized, distributed and transactive electric grid." EMCS can be considered a grid-edge technology.

[6] The terms metrics and KPIs are sometimes used interchangeably; however, in this context, metrics are considered data points that, when accumulated, make up a KPI.

[7] See Pre-meeting handout and Presentation slides attachments.

requested clarity on the difference between KPIs and metrics in the context of the framework.[8] Participants also suggested describing the intended use of the framework as a conceptual construct so as not to imply it is a mutually exclusive or collectively exhaustive categorization of KPIs, metrics, and targets across all building segments. Others recommended adding more dimensions to the framework to include variations in KPIs, metrics, and targets for different types of buildings. Some participants agreed that assigning prioritization for KPIs relative to each other and with respect to different building types and sectors would bring a valuable perspective to the framework. In addition, a recurrent comment was not to ignore the perspective of building operators and managers in the framework and to focus on the dynamics between operators, owners, and occupants.

KPIs to Add or Change

The framework currently consists of three high-level KPI categories—Economic Impact, Environmental Impact, and Social Impact—with several lower-level KPIs in each category. Several participants suggested KPIs to add to or modify in the framework. Within the Economic Impact category, recommended KPIs to add include EMCS maintenance, continual commissioning,[9] interoperability,[10] scalability, ease of installation, operation and maintenance (O&M) complexity, workforce training, adoption rate, and effective implementation. In addition, participants recommended combining the Electric Vehicle (EV) charging and Distributed Energy Resource (DER)[11] Integration KPIs within the Environmental Impact category. Within the Social Impact category, participants suggested adding energy equity,[12] safety, reliability, and privacy.

One participant recommended adding another high-level KPI category for enabling technologies that might not exist yet or are emerging, such as the Internet of Things (IoT),[13] edge computing,[14] cloud computing,[15] and quantum computation.[16] The rationale is that new technologies may solve current problems and should not be overlooked. Similarly, another participant referred to IoT as a solution to bring down cost and increase sophistication for integrating equipment and systems that already have embedded sensors and controls, for example, within heating, ventilation, and air conditioning (HVAC) systems.

Given its importance, one participant asked whether grid resiliency should be included as part of the high-level Economic and Environmental KPI categories as well as its inclusion in the Social (Occupant Impacts) category. Other participants suggested reducing the number of KPIs in the framework while adding more metrics to measure the reduced set of key KPIs.

KPIs for Different Building Types

When asked about the need for different KPIs for different building sectors and types, several participants expressed concern about the data challenge that too much segmentation would bring. Still, many agreed that some additional segmentation would be helpful. Some participants suggested segmenting by building sector, type, and vintage. Most agreed that building size is an important differentiator. For example, KPIs that may be relevant for small and medium buildings, such as rate of adoption and affordability, may be less important for large commercial buildings already installing EMCS technologies. Others noted that differentiating between

[8] See previous footnotes on current interpretation of how metrics collectively support assessment of KPIs.

[9] The U.S. Green Building Council describes *continual* or *ongoing commissioning* as a "process that includes planning, point monitoring, system testing, performance verification, corrective action response, ongoing measurement, and documentation to proactively address operating problems in the systems being commissioned."

[10] *Interoperability* is the capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively.

[11] A DER is a resource sited close to customers that can provide all or some of their immediate power needs and/or can be used by the utility system to either reduce demand or provide supply to satisfy the energy, capacity, or ancillary service needs of the grid.

[12] An *equitable* energy system is one where the economic, health, and social benefits of participation extend to all levels of society, regardless of ability, race, or socioeconomic status. Achieving energy equity requires intentionally designing systems, technology, procedures, and policies that lead to the fair and just distribution of benefits in the energy system. PNNL 2021, https://www.pnnl.gov/projects/energy-equity.

[13] 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.

[14] *Edge computing* involves distributed computing where computation and data storage is close to the input data sources.

[15] *Cloud computing* involves having computing services over the Internet ("the cloud").

[16] *Quantum computing* involves the use of quantum mechanics concepts for computations.

buildings with different levels of regulatory requirements might be a way to address KPI differences. For example, hospitals have very different regulatory requirements than office buildings, which impacts EMCS design and implementation.

Metrics

A common recommendation was to consider other cost metrics besides the current metric, which is cost per control point, when determining the economic impact. Suggestions include cost per system, cost per building, cost per square-foot, and return on investment (ROI). Consistent with feedback received during the RFI, several participants expressed the importance of workforce training. Two suggested metrics are the number of college graduates majoring in HVAC and EMCS-adjacent fields and the number of students in related continuing-ed programs. Other participants recommended having more metrics related to the ability of EMCS technologies to help integrate renewable energy; the current metric is the percentage of systems with solar photovoltaics (PV) and/or storage integration, but another metric could be CO_2 emission reductions.

Targets

There was general agreement in setting EMCS 2035 and 2050 targets to align with other DOE goals. For example, some suggested defining EMCS' target share of greenhouse gas (GHG) emission reductions as 10-15% of national reduction goals. In addition, at least one participant suggested setting milestones (e.g., annual targets) to ensure progress stays on track to meet the longer-term targets.

Research Needs

There was general agreement that field studies and additional data, including from anonymous cost surveys, are needed to validate costs and other metrics. The cost data should also be tied to EMCS performance. Many participants agreed that DOE needs to know the actual market penetration of EMCS technologies in different building segments to understand where to focus efforts and investments. Knowing the actual effectiveness is also important, especially in small and medium buildings where there is often limited operations support—having an EMCS being effective versus just installed can result in very different performance outcomes.

Attribution

Some participants view the separation of EMCS impacts from building-wide impacts as necessary because DOE needs to understand the degree to which impacts at the building level are attributable to improvements in the building controls versus other causes. However, others feel that separating the impacts may not be necessary if the industry transitions to meter-based pay-for-performance at the whole building level.[17]

Next Steps

In addition to distributing this report, DOE representatives identified at least three next steps. The first step will be a roundtable on February 6th at the 2023 ASHRAE Winter Conference in Atlanta[18] to discuss the KPI framework, metrics, targets, source materials, and related content. Another step will be a follow-up effort related to workforce development and training to address input received from the RFI on the importance of this topic. Then, later in 2023, there will be an RDO publication on the finished EMCS roadmap, which will incorporate responses to the RFI and input received during the December 7th, 2022 roundtable.

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[17] Meter-based pay for performance is a form of energy efficiency or demand management contracting where payments are based on savings quantified using metered energy consumption data.

[18] 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.

Meeting Logistics

Time: December 7th, 2022, 3:00-4:30 pm EST
Location: Microsoft Teams Virtual Meeting

Agenda

- Welcome and objectives – 5 min
- Agenda overview and group introductions – 10 min
- KPI framework diagram – 15 min
- Draft metrics and targets – 15 min
- Group discussion – 30 min
- Finalize recommendations for KPI framework and metrics – 10 min
- Next steps – 5 min

Participants

Table 1 lists the subject matter experts that attended the meeting. There were 28 participants: 12 representing the DOE and/or the national laboratories and 16 representing industry.

Table 1. EMCS KPI Roundtable Participants

Name	Organization
Tanya Barham	Community Energy Labs
Hwakong Cheng	Taylor Engineers
Celeste Cizik	Group14
Layne Clemen	Extensible Energy
Song Deng	Bee®
Paul Ehrlich	Building Intelligence Group LLC
Samy Faddel	ABB
Ben Garbers	Trane Technologies
Jessica Granderson	Lawrence Berkeley National Laboratory (LBNL)
Justin Hill	Southern Company
Cecilia Johnson	DOE
Reza Khalghani	Florida Polytechnic University
Teja Kuruganti	Oak Ridge National Laboratory (ORNL)
Theo Laughner	Lifescale Analytics
Shaina Li	Mesa by Google
Ricardo Moromisato	Copper Tree Analytics
Ramachandran (Ram) Narayanamurthy	DOE's Building Technology Office
Clay Nesler (moderator)	The Nesler Group
Robert Nirenberg	Metropolitan Community College
Stephanie Olson	Pacific Northwest National Lab (PNNL)
Kelly Parmenter	LBNL Consultant
Erik Paulson	Johnson Controls
Nikitha Radhakrishnan	PNNL

Name	Organization
Hayden Reeve	PNNL
Denise Ritzmann	PNNL
Steve Schiller	LBNL Affiliate
Benjamin Schreib	Siemens
Kim Trenbath	National Renewable Energy Lab (NREL)
Brian Walker	DOE's Building Technology Office

Welcome and Roundtable Objectives

DOE team members welcomed the subject matter expert participants and summarized the meeting objectives:

- Thanked the group for joining the roundtable meeting and for providing input on the RFI (see RFI).
- Explained there has been significant rethinking since issuing the original RFI and DOE is working on a final RDO publication, scheduled for 2023.
- Described the purpose of this roundtable is to get feedback from the group on the draft KPI framework and metrics and targets (see pre-meeting handout). Guidance provided to the attendees with respect to providing feedback included:
    - Take a broad view of all the jobs control systems must undertake in buildings.
    - When thinking about the value and cost metrics within the draft framework, describe all the values and costs in as much detail as possible.
    - Think about how to prioritize and set targets.
- Noted that DOE plans to have another roundtable specifically focused on workforce development and training. A common element in responses to the RFI was that there is a shortage of skilled workers to install, operate, and maintain EMCS technologies in new and existing buildings.
- Explained that the feedback received will inform the next version of the KPI framework that will be presented and discussed during the 2023 ASHRAE Winter Conference.

Agenda Overview and Group Introductions

Group Introductions

The DOE team and participants introduced themselves and described their EMCS background to provide context for their contributions to the discussion (see Participants).

Opening Remarks

DOE leadership provided additional opening remarks:

- Would like to see controls go the way of the solid-state lighting market in terms of rate of market adoption and market transformation. How do we do that with the controls market?
- We have been hearing about "low hanging fruit" around retro-commissioning for 25 years. We have been "plucking that fruit" but not sure how successful it has been.
- We have great statistics on the potential for controls to really drive energy efficiency. How do we make the transformation happen? It is imperative if we are going to drive decarbonization.
- When we talk about decarbonization, we mean the intersection of energy efficiency, electrification, and demand flexibility. Controls play a key part. We need to be able to extract the full potential of controls. What barriers stand in our way of doing that? We can do a lot of work on artificial intelligence[19] and

[19] As defined by the National Artificial Intelligence Initiative Act of 2020 (DIVISION E, SEC. 5001), "The term 'artificial intelligence' means a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments." https://www.ai.gov.

machine learning,[20] but if we cannot get that implemented in existing buildings, then we are not going to make the progress and the transformation that we need.

- Market transformation is not just needed for large buildings; it is also needed for residential and small commercial buildings. How do we transform the entire building stock to use controls?
- The other piece of controls relates to grid integration and grid interactivity. We have electrification coming, whether it is in buildings or transportation. Buildings are at the edge of the grid. Building energy loads and on-site renewables, vehicles, and storage hit right at the edge of the building. On the other side is the utility infrastructure. Controls have a role in this integration and interactivity, where we are not digging up direct buried cables that have been sitting underground for 50 years and where we are not trying to upgrade every transformer. How do we transform building controls to enable a more flexible grid of the future?
- The three big challenges are as follows:
    - How do we transform small-to-medium buildings to use EMCS?
    - How do we do low-cost retro-commissioning so that utility programs are more successful (like solid-state lighting was for utility programs)?
    - How do we transform the edge of the grid so we optimize and minimize the amount of infrastructure that we have to put in the ground to make the electrification transition happen?
- Looking forward to all of us working together as an industry and as a community to overcome these huge barriers and to achieve our goals over the next 20 years.

Agenda Overview

The moderator provided an overview of the agenda (See Agenda).

KPI Framework Diagram

The moderator introduced the draft EMCS KPI framework (see Figure 1[21] on the next page).

- The DOE team wanted the indicators to add up to substantial impacts; DOE wanted to be able to cascade indicators that would be leading indicators, driving action towards certain outcomes, to address ambitious executive orders from the federal government.
- DOE believes the areas for highest-level focus should be economics, the environment, and social issues.
- Social:
    - *Occupant Impacts* are the highest level and include consideration of building resilience as well as occupant comfort, health, and satisfaction.
    - The impact on occupants is equivalent in aggregate to the impact on communities, which is in aggregate the impact on our country and the planet.
- Economics:
    - Economics are very important. We not only need to reduce carbon emissions, use energy and water more efficiently, and manage other resources, but we also need to do so economically.
    - We will likely be pulling two levers to achieve end goals: a) making EMCS more effective (e.g., providing greater savings, less complexity, more scalability to small and medium buildings) and b) less expensive.
    - The pillars are *Installation Cost* and *Operational Cost*.
    - The highest level for economic impacts is *Systems Payback* – suggesting a systems life-cycle payback metric.

[20] Machine learning is the use of advanced algorithms to identify patterns and make inferences from data. https://www.energy.gov/eere/geothermal/machine-learning.

[21] All figures in this report are from the roundtable presentation slides. See the Presentation slides attachment for the complete set.

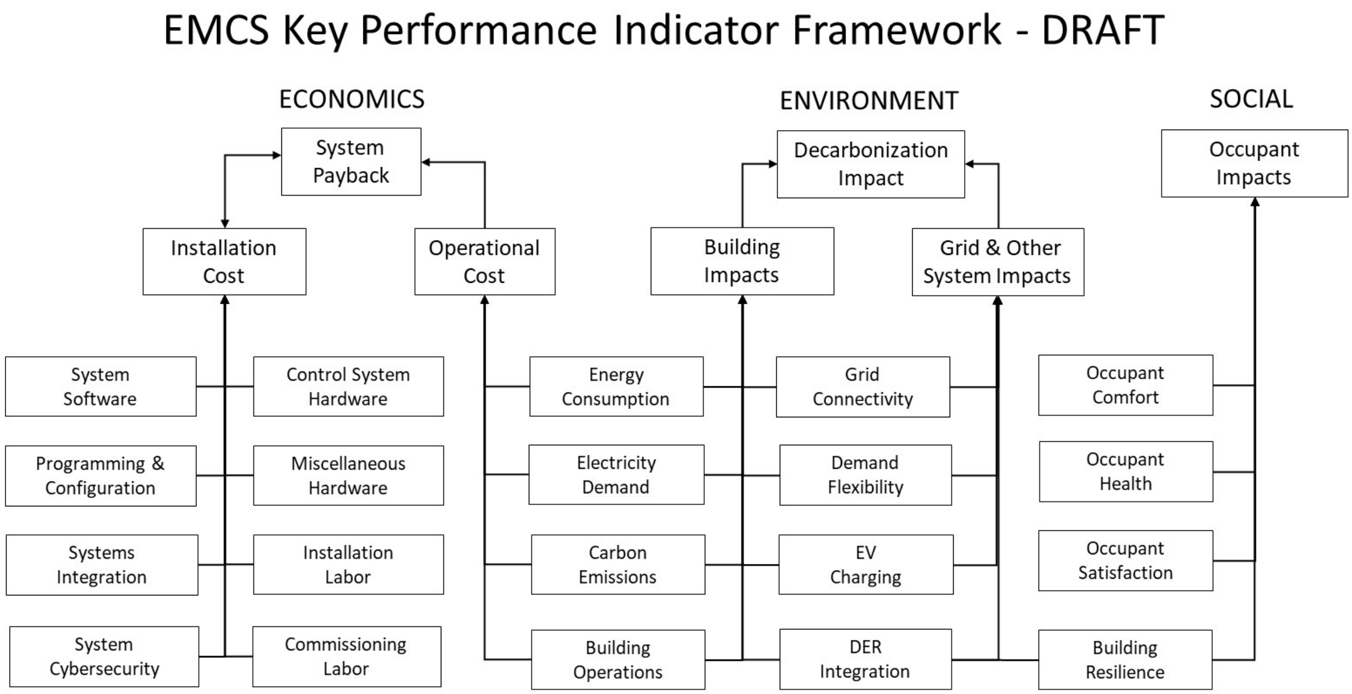

Figure 1. Draft EMCS KPI Framework

- Environment:
  - Energy consumption, electricity demand, carbon emissions, and building operations have both an *Operational Cost* impact within the *Economics* category, as well as an environmental impact by way of *Building Impacts*.
  - Did not want to limit the framework to the building as the boundary condition. Included EVs and DERs that are connected to the building under the *Grid & Other System Impacts* KPI. Grid impacts related to required supply, flexibility, reliability, resilience, etc. are significant.
  - Some boxes go in two directions; they are interconnected. The items in those boxes not only affect the building; they also impact the grid and then combine to have decarbonization impacts.
  - The highest level for environmental impacts is *Decarbonization Impact* – how much are we contributing to the decarbonization goals in buildings. For example, the U.S. Federal government wants to reduce greenhouse gas emission in the federal building stock by 50% by 2032.[22]

The moderator showed an illustrative idea for how the framework can focus on four different building types:

1) Large commercial,
2) Small commercial,
3) Multi-family residential, and
4) Single family residential.

Figure 2 shows the legend for illustrating the level of impact (high, medium, low) by building type. Figure 3 shows the KPI framework with the building type overlay.

[22] FACT SHEET: White House Takes Action on Climate by Accelerating Energy Efficiency Projects Across Federal Government, August 3, 2022, The White House Briefing Room, https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/03/fact-sheet-white-house-takes-action-on-climate-by-accelerating-energy-efficiency-projects-across-federal-government/.

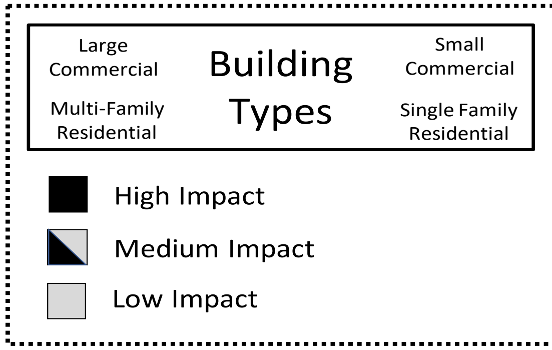

Figure 2. Legend for Illustrating Level of Impact by Building Type

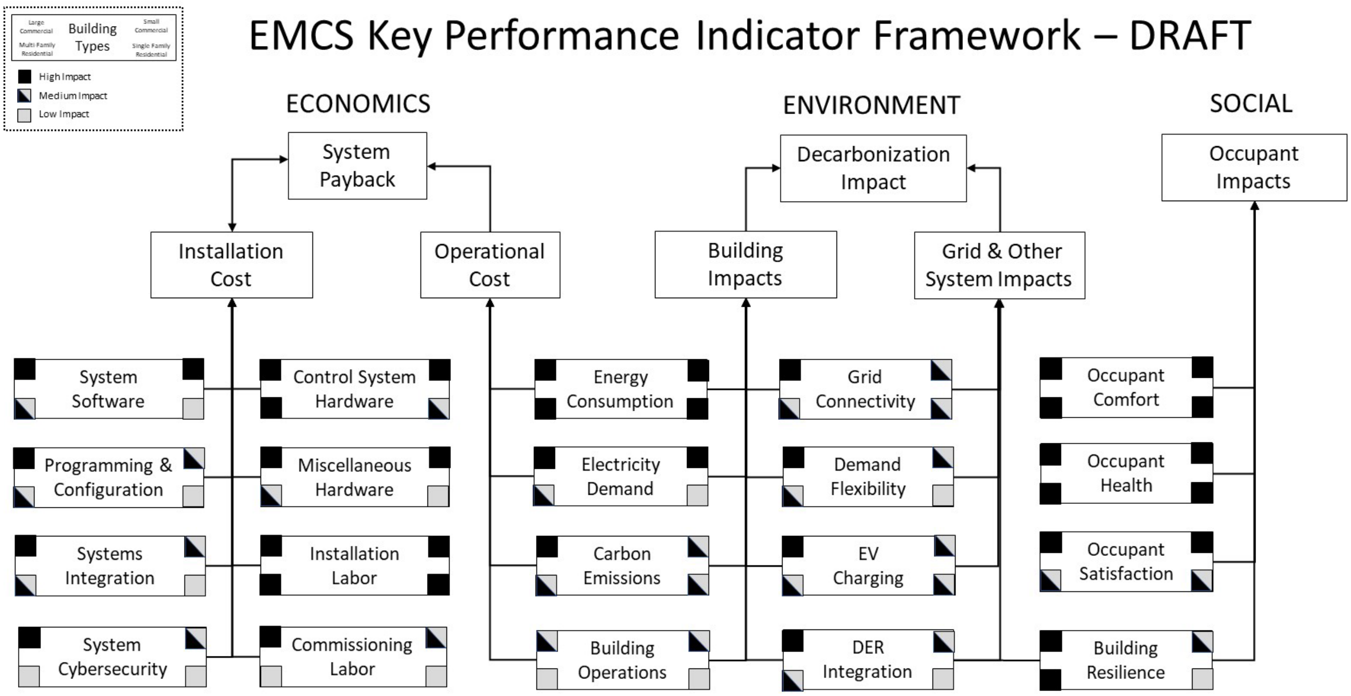

Figure 3. Draft EMCS KPI Framework with Level of Impacts by Building Type

Group Discussion

The meeting moderator encouraged participants to provide input throughout the group discussion by raising their virtual hand or typing in the chat box. The following summarizes input received verbally and via the chat box.

EMCS Key Performance Indicator Framework

Initial Reactions to the Framework

Prior to asking specific questions, the moderator asked participants for their general reactions to the framework. The sections below organize the comments received, by topic area.

Framework structure

- Some participants suggested providing definitions of terms alongside the framework, including defining the differences between KPIs and metrics.
- A few mentioned that some of the KPIs are not mutually exclusive, which presents disaggregation challenges. Along those lines, there was a suggestion to map the trade-offs or tension between the KPIs that

are not mutually exclusive and gave the example of "the best way to save energy costs is to *not* fix your HVAC when it breaks (occupant comfort be damned)."
- Some participants noted that external factors that influence the KPIs are going to come into play (e.g., regional differences in energy prices, grid emission factors, labor and material costs). Those regional differences are challenging to illustrate and address in a single, national framework for all building types and applications.
- One participant questioned how effective the framework would be over the next 5-10 years. Their perspective as a commissioning engineer is that control solutions are already available and affordable and what is important is commissioning and engineering quality control. They suggested thinking about how to drive maintenance and operation practices (e.g., using next generation technology like edge computing, cloud computing, quantum computation) to take advantage of the installation investment and to realize savings.

KPI for energy equity
- Several noted that energy justice / energy equity should be in the framework under the Social KPI. The moderator noted that it was in another version.
- One metric could be the penetration of controls systems in disadvantaged communities.
- Another asked how you balance the additional cost that is likely to be needed in disadvantaged communities (e.g., improving energy efficiency could be significantly impacted by better insulated windows).

Other KPI suggestions
- <u>Economics:</u> Consider adding costs for EMCS maintenance, continual commissioning, communications, and data storage.
- <u>Environment:</u> Merge EV charging with DER integration.
- <u>Social:</u> Explain how occupant satisfaction differs from occupant comfort.

Integrated controls
- One participant noted that some equipment has integrated controls (e.g., almost all systems used in new construction, and equipment like HVAC systems used in retrofits) and the incremental cost point for those controls is low since it comes with the equipment. So, we should think about solutions like IoT and how we can integrate systems to bring down cost and bring up sophistication.
- Another participant mentioned that proprietary systems are a challenge to integrate (e.g., smart thermostats[23] required to successfully operate variable refrigerant flow (VRF) cooling systems are inherently hard to integrate with unless the VRF system vendor specifically chooses to make integration a priority).

Scalability and affordability
- One participant expressed concern with the *Grid & Other System Impacts* column. This person represents both a small integrator, who is looking for scalability and affordability, and small and medium building owners. They feel that until more work is done with regulatory commissions to address the current state of interoperability and conflicting financial incentives for original equipment manufacturers (OEMs), property owners, and systems integrators, requirements related to those KPIs will be difficult to make cost-effective, especially for small and medium businesses.

DOE's Specific Questions for the Subject Matter Expert Participants

After receiving initial reactions to the KPI framework, the moderator asked the expert participants two specific questions related to the framework.

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[23] *Smart thermostats* are Wi-Fi enabled devices that automatically adjust heating and cooling temperature settings for optimal performance. https://www.energystar.gov/products/smart_thermostats.

Are there any high-level KPIs missing from the framework?

This question overlaps with some of the participants' initial reactions to the framework since several people provided suggestions for adding KPIs (see previous section). The following bullet points summarize suggested KPIs not already listed above. Some of the suggestions are not necessarily high-level KPIs.

- Technology: This KPI would include new, enabling technologies that might not exist yet or are emerging (e.g., IoT, cloud computing, edge computing). The new technologies may solve current problems.
- Rate of adoption: Rate of adoption of controls would be particularly important for small/medium commercial buildings.
- Readiness to adopt: This KPI would measures the organization's readiness to adopt new technologies. For example, a rating based on whether an organization has adopted or is in the process of adopting an energy management system process (EnMS) such as ISO 50001.[24]
- Reliability: Reliability itself and as it relates to resilience, load flexibility, and various dimensions might be a category that is missing.
- Interoperability: Add as a lower-level KPI, perhaps under Installation Costs.
- Operator ease: This could potentially fall under the *Operational Costs* category. It would reflect both how the operator uses the equipment and operator time requirements. A related KPI or metric could be *remote control capability*.
- Safety: In addition to fire safety and physical security, it is important to monitor the health and safety of building occupants to provide better protection. This would fall under *Occupant Impacts* and is related to the *Occupant Health* KPI. HVAC controls often protect property as well (e.g., preventing frozen pipes, expensive equipment in controlled environments such as music equipment).
- Occupant privacy: This would fall under *Occupant Impacts*.
- Building value: Value is something that could be captured somewhere as a lower-level KPI or metric. More flexible and comfortable buildings are worth more in the market.
- Data transfer: It could be captured in the *System Software* category or under a new Interoperability KPI, but the ability to transfer specific data points to a third-party controller should be included. For example, using data points from an EMCS to feed into a higher-level controller that can see key points to use in multi-building controls (like a campus) to have them work together to meet a desired goal.

Are there an appropriate number of leading indicators (e.g., technology penetration) and outcome indicators (e.g., annual energy savings)? Do we need different KPIs for different building sectors/types?

While several participants expressed concern about the data challenge with too much segmentation, many agreed that some additional segmentation would be helpful.

- Regulatory impact: Some agreed that the category of large commercial buildings may be too vague. It might be helpful to differentiate between buildings with different levels of regulatory requirements. For example, hospitals and laboratories have very different regulatory hurdles than office buildings or schools. A regulatory impact dimension in the framework may be a way to address the differences.
- Vintage: Another participant suggested that a dimension on new construction versus retrofit might be valuable.
- Sector: Some participants noted that industrial buildings can be quite different than commercial.
- Disadvantaged and historically underserved: Regarding equity and different building sectors/types, several participants agreed with the notion of considering who is able to participate in and contribute to this field (e.g., businesses owned by woman and people of color), where the benefits accrue (e.g., % penetration in disadvantaged areas is a good metric for multi-family and residential, but less material for commercial), and if there is cost parity for labor, installation, delivery, etc. across all the targeted areas. Someone else suggested adding differentiation for low- and high-income communities since this will affect the solutions and targets/metrics.

[24] International Organization for Standardization, ISO 50001: Energy Management, https://www.iso.org/iso-50001-energy-management.html.

- RECS and CBECS: There was a suggestion to consider the Residential Energy Consumption Survey (RECS) and Commercial Building Energy Consumption Survey (CBECS) segments.[25]
- Prioritization: One participant asked if there is a version of the framework where we can assign prioritization for KPIs and for different sectors. For example, sensor and hardware costs are not necessarily barriers for larger commercial buildings, but installation quality and system performance are barriers. Another person agreed that segmentation by building sectors/types may help bring a prioritization perspective to the framework. Others suggested prioritizing small and medium buildings with a quick, simple, affordable, and results-driven approach to controls.

Draft Metrics and Targets

Table 2 through Table 4, respectively, show draft metrics and targets tables for the three high-level categories of Economic Impact, Environmental Impact, and Social Impact. The moderator described the format of the draft EMCS KPI Metrics and Targets tables and discussed a few examples of the metrics and data sources. For example, the cost data in Table 2 are from NREL research (see attached NREL Technical Report). There are two additional KPI levels in each table. Level 1 indicators are in the gray shaded areas, and, in some cases, they are rolled-up values for several level 2 indicators, which are listed in the white rows.

Table 2. Draft EMCS KPI Metrics and Targets – Economic Impact

EMCS KPI Metrics and Targets – Economic Impact

ECONOMIC IMPACT			TARGETS			
	Level 1 | Level 2 Key Performance Indicators	Metric	Baseline	2035	2050	Reference
Building System Payback	***Installed System Payback***	***Payback period in years***	***4***	***3***	***2***	Rockefeller Foundation
	Total Installed Cost	***System installed cost per control point***	***$1,104***	***$900***	***$775***	NREL & calculated from payback
	Sensor and Controller Hardware	Cost per control point	$94	TBD	TBD	NREL
	Miscellaneous Hardware	Cost per control point	$117	TBD	TBD	NREL
	Installation Labor	Cost per control point	$364	TBD	TBD	NREL
	Control Application Engineering	Cost per control point	$106	TBD	TBD	NREL
	System Commissioning and Balancing	Cost per control point	$258	TBD	TBD	NREL
	Workstation/Server Configuration	Cost per control point	$164	TBD	TBD	NREL
	EMIS Installed Cost	Cost per monitoring point	$10	TBD	TBD	LBNL
	Energy Optimization Application	Cost per monitoring point	$75	TBD	TBD	LBNL
	System Data Integration	Cost per control point	$42	TBD	TBD	Aamidor Consulting
	Cybersecurity Infrastructure	Cost per control point	$30	TBD	TBD	GSA
	Operating Cost Reduction	***Annual cost savngs per square foot***	***TBD***	***TBD***	***TBD***	
	Energy Cost Reduction	Annual energy cost savings per square foot	$275.89	$300.00	$387.50	Calculated from % savings and payback
	Energy Demand Cost Reduction	Percent annual demand cost reduction	TBD	TBD	TBD	???
	Water Cost Reduction	Percentage annual water cost savings	15%	30%	50%	EPA
	Operations & Maintenance Cost Reduction	Annual O&M cost savings per square foot	TBD	TBD	TBD	???

[25] See U.S. Energy Information Administration, Residential Energy Consumption Survey (https://www.eia.gov/consumption/residential/) and Commercial Building Energy Consumption Survey (https://www.eia.gov/consumption/commercial/).

Table 3. Draft EMCS KPI Metrics and Targets – Environmental Impact

EMCS KPI Metrics and Targets – Environmental Impact

ENVIRONMENTAL IMPACT			TARGETS			
	Level 1 | Level 2 Key Performance Indicators	Metric	Baseline	2035	2050	Reference
Building Environmental Impacts	***Energy Reduction***	***Percentage annual energy savings from basic plus advanced controls***	***29%***	***33%***	***40%***	PNNL & calculated from payback
	Advanced Control Energy Reduction	Percentage annual energy savings	6%	16%	26%	PNNL
	Advanced Control Energy Installations	Percentage of systems implementing advaced control strategies	67%	TBD	TBD	EEI
	Energy EMIS Energy Reduction	Percentage annual energy savings	12%	17%	22%	LBNL
	Energy EMIS Installations	Percentage of systems implementing EMIS/FDD	35%	TBD	TBD	EEI
	Energy Optimization Energy Savings	Percentage annual energy savings	10%	12%	15%	WEF
	Energy Optimization Installations	Percentage of systems implementing advanced energy optimization	TBD	TBD	TBD	???
	Integrated Controls Energy Savings	Percentage annual energy savings	8%	13%	18%	ACEEE
	Integrated Controls Energy Installations	Percentage of systems implementing multi-system integrated control strategies	54%	TBD	TBD	EEI
	Electrical Peak Demand Reduction	***Percentage annual demand reduction (during peak periods/prices)***	***10%***	***20%***	***20%***	RMI
	Demand Management Installations	Percentage of buildings implementing demand management/demand response	50%	TBD	TBD	EEI
	Demand Flexibility Installations	Percent of buildings implementing aggregator/utilty controlled demand flexibility	TBD	TBD	TBD	???
	Carbon Emissions Reduction	***Percentage annual GHG emissions reduction***	***23%***	***80%***	***80%***	PNNL
	24x7 Carbon Emissions Reduction	Percentage of time achieving 24x7 zero carbon emissions	0%	TBD	TBD	???
	24x7 Emissions Control Installations	Percentage of operations controlled based on 24x7 GHG emissions	0%	TBD	TBD	???
	Building Operations	***Percentage time system performs to specification (device weighted)***	***TBD***	***TBD***	***TBD***	???
	Building System Reliability	Percentage of buildings with remote monitoring and control capabilities	35%	TBD	TBD	EEI - EMIS is a proxy
	Cybersecurity	Percentage of systems which have been certified for cybersecurity	TBD	10%	25%	???
	Building Systems Integration	***Percentage of buildings with multi-system data integration***	***50%***	***TBD***	***TBD***	EEI
	HVAC and Lighting Integration	Percentage buildings with HVAC and lighting system integration	54%	TBD	TBD	EEI
	HVAC, Safety & Security System Integration	Percentage buildings with HVAC, life safety and security system integration	83%	TBD	TBD	EEI
	Smart Equipment Integration	Percentage buildings with smart equipment integration	39%	TBD	TBD	EEI
	EMIS Integration	Percentage buildings with energy information management systems	35%	TBD	TBD	EEI
Grid and Other System Impacts	***Avoided Grid Capacity Investment***	***Percentage reduction in required grid capacity investment***	***TBD***	***10%***	***19%***	PNNL
	Avoided Distribution Infrastructure Investment	***Percentage reduction in energy infrastructure investment***	***TBD***	***TBD***	***TBD***	???
	Grid Connectivity	Percentage of buildings with real-time grid connectivity	TBD	TBD	TBD	???
	Solar + Storage Integration	Percentage systems with solar PV and/or storage integration	29%	TBD	TBD	EEI
	EV Charging Integration	Percentage systems with EV charging integration	TBD	TBD	TBD	???

Table 4. Draft EMCS KPI Metrics and Targets – Social Impact

EMCS KPI Metrics and Targets – Social Impact

SOCIAL IMPACT			TARGETS			
	Level 1 | Level 2 Key Performance Indicators	Metric	Baseline	2035	2050	Reference
Occupant Impacts	***Community Equity***	***Percentage of buildings with EMCS in disadvantaged communities***	***TBD***	***> 50%***	***> 75%***	???
	Thermal Comfort	***Percentage time exceeding ASHRAE 55 requirements (occupancy-weighted)***	***TBD***	***< 90%***	***< 90%***	???
	Indoor Environmental Quality	***Percentage time exceeding ASHRAE 62 requirements (occupancy-weighted)***	***TBD***	***< 95%***	***< 95%***	???
	Occupant Satisfaction	Percentage of occupants with top box IEQ satisfaction scores	80%	> 90%	> 95%	???
	Building Resilience	Percentage of buildings with automated emergency response (wildfire, power outage, pandemic	0%	>25%	> 50%	???

Initial Reactions to the Metrics and Targets

Prior to asking specific questions, the moderator asked the subject matter expert participants for their reactions to the tables of metrics and targets. The bullet points below summarize key comments organized by topic area.

Large building bias

- One participant questioned how the metrics and targets would be applied to the building portfolio universally. They felt the tables are oriented towards the large building market and would exclude a large percentage of buildings that do not yet have controls. One suggestion was to have a less ambitious set of metrics and targets for smaller, lower-budget building segments.

Need for complexity metrics

- Another participant noted that the emphasis is on energy and cost and thought there should be thinking about how to measure complexity (e.g., number of callbacks) or performance degradation (e.g., how many systems are still operating in 6-12 months).
- Others agreed with trying to measure complexity with metrics related to ease of use, convenience, operator time savings, and installation time (e.g., there could be a target of one-day installation time).
- The moderator suggested metrics for uptime of equipment, or percentage of hours the equipment is (or is not) working weighted by the number of devices.

Cost metrics

- Several participants said DOE should think very carefully about how to measure cost and may want to consider metrics other than \$/point (e.g., \$/system, \$/building, \$/ft^2, or \$/ft^2/building type, return-on-investment).
- At least one participant suggested using engineering units (e.g., kW, kWh) as an additional metric since cost drivers (although important to consider) are likely to change in 15-20 years.
- Another person suggested a total cost or total cost of ownership metric and breaking out costs into fixed and variable.
- Some participants agreed that DOE should think about how the customers pays – capital expenditure (CAPEX) versus operational expenditure (OPEX).
- Another suggestion was to conduct more cost research and add ranges in the table instead of single values.

Other suggested metrics provided by individual participants

- Percent improvement in comfort.
- Metrics around workforce training (e.g., number of college graduates majoring in HVAC and EMCS-adjacent fields, number of students in related continuing-ed programs).
- More metrics related to the ability of EMCS technologies to help integrate renewable energy; the current metric is percentage of systems with solar PV and/or storage integration, but another metric could be CO_2 emission reductions, for example.
- Time-value of electricity and carbon.

DOE's Specific Questions for the Subject Matter Expert Participants

How should 2035 and 2050 targets be established? Is a net zero carbon buildings target by 2050 a reasonable end goal?

There was general agreement in setting EMCS 2035 and 2050 targets that align with other DOE goals.

- Several participants agreed that targets for the building sector need to be more aggressive than economy wide goals to meet national net zero targets, and that it is important to define EMCS's share of national targets (e.g., in the range of 10-15%).
- At least one participant suggested setting milestones (e.g., 5% annual improvement targets) to put the targets more in front of us and ensure progress stays on track to meet the longer-term goals.

Is additional industry research needed to validate EMCS-related costs? Field studies, project data, anonymized and sent to a third-party aggregator?

The consensus is that more research and data are needed.

- One participant suggested that a great outcome of research is to inform standards related to interoperability, communication protocols, etc.
- Another person suggested that a source of data could be the General Services Administration (GSA). GSA buildings account for a huge and varied footprint, and it may be easier to mandate GSA operators to collect and share data.
- At least one participant agreed that an anonymous cost survey would be valuable.

How much energy and carbon reduction impact should be attributed to EMCS functionality (versus equipment)? How much for demand flexibility?

Some view separation of EMCS impacts from building wide impacts is important for measuring and attributing EMCS performance gains, while others feel it may not be necessary.

- One participant noted that separation of impacts needs to be considered when preparing the metrics and suggested having fewer higher-level KPIs aligned with the key challenges identified earlier (i.e., transforming small-to-medium buildings, designing successful low-cost retro-commissioning programs, transforming the grid-edge, and addressing the equity distribution). To know whether we are actually improving and achieving impacts, we need to know which of these benefits are attributable to the controls.

- Another person felt that separation of the impacts may not be necessary if the industry transitions to meter-based pay-for-performance at the whole building level.

Summary Recommendations for KPI Framework and Metrics

Many of the expert participants provided final words of advice. The bullet points below summarize the recommendations organized by topic area.[26] Some recommendations reiterate the responses provided in the sections above.

KPI Framework Structure

- There is a lot of overlap on KPIs. Reducing some and writing definitions will make it simpler.
- Disentangle the overlaps and clarify definitions in the framework (e.g., energy management information system (EMIS) energy reduction, energy optimization savings, advanced control energy savings in Table 4)
- Suggest fewer, higher-level, KPIs tied to the three areas mentioned during opening remarks, plus energy equity. Disaggregate these KPIs by building type, use, location, vintage, etc. and then define the metrics needed to calculate these KPIs; some of these metrics will be actually measured, some will be assumed values, and over time the quality of the KPI calculation will improve as more data becomes available.
- Make sure the KPI framework is not too complicated in and of itself. There is an opportunity to model simplicity.
- Whittle down the KPIs and make them more applicable to new entrants that are representative of small and underserved buildings.
- Pilot the resulting framework to see how much effort it takes to populate this.
- Develop a fresh pathway—out-of-the-box thinking and results-/user-oriented.
- Don't let perfect be the enemy of good enough.

New KPIs

- Focus on the possibility of building upon emerging technologies and develop a KPI that is future looking; otherwise, we will be stuck on some of the same challenges.
- Consider including grid resiliency as part of the economic/environmental impact.

Metrics, Targets, and Data

- Generalized targets might not be of great help for the different building segments.
- Data and field studies are needed to validate costs.
- Data is at the core of KPIs. Industry engagement on the need for a standard data layer would pave the way to reduce technology silos.
- Look for sources such as RSMeans on construction costs.[27] Also, consider industry groups such as the Air-Conditioning, Heating and Refrigeration Institute (AHRI)[28] or the Continental Automated Buildings Association (CABA)[29] for data. Unfortunately, there is fairly limited reporting in the controls world.
- Anonymous cost survey would be interesting/valuable.
- Cost data are no good without quality data.
- For the most part the data already exists, but there is a lack of understanding of that data on the part of building owners/managers/operators, in part due to skepticism.

Assessing Market Penetration

- Data on market penetration of EMCS in different sectors would be helpful and CBECS has started monitoring that.

[26] This summary compiles responses from individuals. It does not reflect consensus or resolve conflicting perspectives.
[27] RSMeans, https://www.rsmeans.com/.
[28] Air-Conditioning, Heating and Refrigeration Institute (AHRI), https://www.ahrinet.org/.
[29] Continental Automated Buildings Association (CABA), https://www.caba.org/.

- Data on market penetrations would be valuable but beware that sources such as CBECS may not be accurate.
- Need to know actual market penetration to know where to focus our efforts and investments.
- Data on market penetration can also encourage (new) businesses to pursue these opportunities.
- Need to know where the controls are not moving, then we can start asking: WHY NOT?

Building Operator Perspective

- Do not ignore the building operators and managers. Their level of understanding of a system is critical for its continued performance. If they do not understand how a complex system works, they will simplify it until it is to their level of understanding. You can build the most complex system in the world, but if you do not have somebody who understands how to operate it effectively it will end up wasting more energy than it saves.
- Focus on the dynamics between operations, owners, and occupants.
- Ongoing monitoring is crucial, in addition to operator training. An amazing EMCS can become inefficient with overrides and changes.
- Keep it simple from the operators' perspective.
- Building operators should for sure be in the loop.

Standards

- Standardization generally—and as it relates to interoperability specifically—will accelerate many things.
- For the most part, standards exist today; they just are not used or adopted. A big gap is getting controls installed in the field. Doing that can enable all the stuff we talked about today.

Disaggregation

- Disaggregation is important.
- Attribution is important for utility programs that work on "widgets." However, if we go to meter-based pay-for-performance at whole-building level, then it is not as necessary.

General

- Simulators and emulators do not really show the full complexity of the field.
- In the field, promote the potential for savings instead of the controls themselves. Achieving the savings potential is justification to install the control system. Controls ensure ongoing life cycle performance.
- Integrate controls with Services, such as Energy Management Services, etc.
- Education will be part of the key to success moving forward.
- A utility can communicate through prices and signals when they want you to consume, but the controls have to try and work within the infrastructure and thermal constraints (e.g., ideal indoor air temperature) of the actual building needs.
- Controls are vitally important! Need to see much stronger focus (and funding) from BTO to help advance controls!
- Controls are the most important element to achieving building-related goals. Heat pumps don't work by themselves, they need to be controlled. Regarding a growing DOE focus on heat pumps, remember that controls make heat pumps more useful. For big buildings, EMCSs are going in, no matter the cost. Need to find ways to make them work better—complex under the hood, but simpler on the surface. Machine learning and overlays may help with this and make electrified buildings easier to upgrade.
- Vendors respond to what they see in requests for proposals (RFPs). DOE and friends should help create best practices for RFPs and get that language into RFPs from building owners and developers.

Next Steps

DOE described the next steps as follows:

- Distribution of a report summarizing input received during this KPI Roundtable discussion. The report will support transparency and provide preliminary information about the process and substance of DOE/EERE/BTO work.
- A follow-up effort related to workforce development and training to address input received from the RFI on the importance of this topic.
- A roundtable on February 6th at the 2023 ASHRAE Winter Conference in Atlanta to discuss the KPI framework, metrics, source materials, etc.
- Preparation of an RDO publication on the finished EMCS roadmap, which will incorporate responses to the RFI and input received during the December 7th roundtable.

Appendix

Additional Questions in Slide Deck

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

- Who could/should be surveyed to estimate EMCS technology/feature penetration? How often?
- Please recommend any good data sources or research efforts to fill in missing baseline data
- Do we need different targets for new construction and retrofits? Hardware retrofits? Software only retrofits?
- Should we consider different market conditions (e.g., variations in local labor and material costs)?
- Should economic impacts be estimated from improved occupant health (e.g., healthcare costs) and comfort (e.g., productivity)?
- Please recommend potential approaches to support EMCS KPI tracking and reporting over time?

Attachments

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

Pre-meeting handout

Presentation slides

Technical report on Sensors and Controls Cost referenced during roundtable

Commercial Building Sensors and Controls Systems – Barriers, Drivers, and Costs. Prepared by Kim Trenbath, Ryan Meyer, Korbaga Woldekidan, Kristi Maisha, and Morgan Harris, National Renewable Energy Laboratory. Prepared for the U.S. Department of Energy Building Technologies Office. Technical Report NREL/TP-6A50-82117. Contract No. DE-AC36-08GO28308. August 2022. Available here: https://www.nrel.gov/docs/fy22osti/82117.pdf.

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.

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[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 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

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[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,

[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.

[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.

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.

  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.

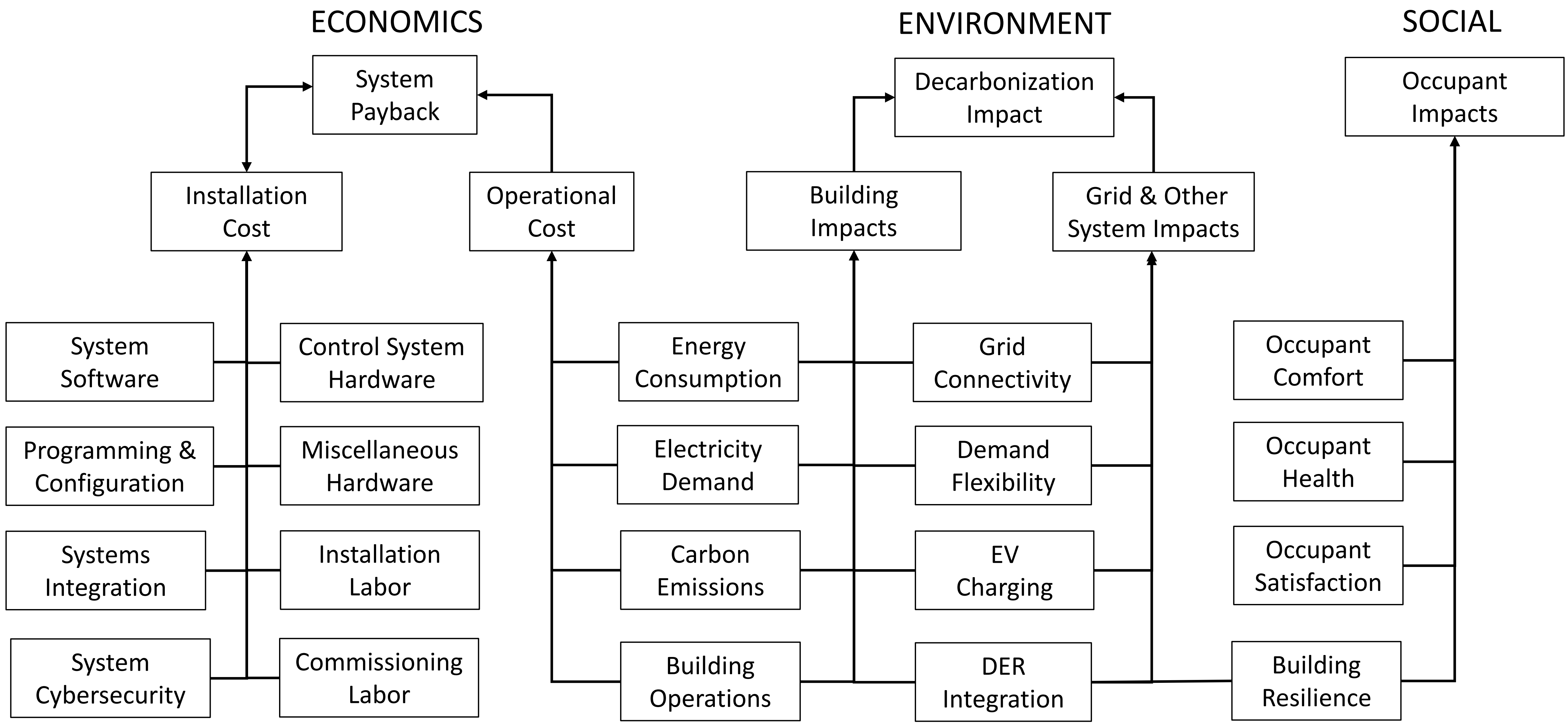
EMCS KPIs and Targets

Preliminary Framework

Version 5 - Draft for Review

15 November 2022

EMCS Key Performance Indicator Framework – DRAFT FOR REVIEW



EMCS KPI Metrics and Targets - DRAFT FOR REVIEW

ECONOMIC IMPACT			TARGETS			
Level 1 | Level 2 Key Performance Indicators		Metric	Baseline	2035	2050	Reference
Building System Payback	***Installed System Payback***	***Payback period in years***	***4***	***3***	***2***	Rockeller Foundation
	Total Installed Cost	***System installed cost per control point***	***$1,104***	***$900***	***$775***	NREL & calculated from payback
	Sensor and Controller Hardware	Cost per control point	$94	TBD	TBD	NREL
	Miscellaneous Hardware	Cost per control point	$117	TBD	TBD	NREL
	Installation Labor	Cost per control point	$364	TBD	TBD	NREL
	Control Application Engineering	Cost per control point	$106	TBD	TBD	NREL
	System Commissioning and Balancing	Cost per control point	$258	TBD	TBD	NREL
	Workstation/Server Software and Configuratio	Cost per control point	$164	TBD	TBD	NREL
	EMIS Installed Cost	Cost per monitoring point	$10	TBD	TBD	LBNL
	Energy Optimization Application	Cost per monitoring point	$75	TBD	TBD	LBNL
	System Data Integration	Cost per control point	$42	TBD	TBD	Aamidor Consulting
	Cybersecurity Infrastructure	Cost per control point	$30	TBD	TBD	GSA
	Operating Cost Reduction	***Annual cost savngs per square foot***	***TBD***	***TBD***	***TBD***	
	Energy Cost Reduction	Annual energy cost savings per square foot	$275.89	$300.00	$387.50	Calculated from % savings and payback
	Energy Demand Cost Reduction	Percent annual demand cost reduction	TBD	TBD	TBD	???
	Water Cost Reduction	Percentage annual water cost savings	15%	30%	50%	EPA
	Operations & Maintenance Cost Reduction	Annual O&M cost savings per square foot	TBD	TBD	TBD	???

SOCIAL IMPACT			TARGETS			
Level 1 | Level 2 Key Performance Indicators		Metric	Baseline	2035	2050	Reference
Occupant Impacts	***Community Equity***	***Percentage of buildings with EMCS in disadvantaged communities***	***TBD***	***> 50%***	***> 75%***	???
	Thermal Comfort	***Percentage time exceeding ASHRAE 55 requirements (occupancy-weighted)***	***TBD***	***< 90%***	***< 90%***	???
	Indoor Environmental Quality	***Percentage time exceeding ASHRAE 62 requirements (occupancy-weighted)***	***TBD***	***< 95%***	***< 95%***	???
	Occupant Satisfaction	Percentage of occupants with top box IEQ satisfaction scores	80%	> 90%	> 95%	???
	Building Resilience	Percentage of buildings with automated emergency response (wildfire, power outage, pandemic)	0%	>25%	> 50%	???

EMCS KPI Metrics and Targets - DRAFT FOR REVIEW

ENVIRONMENTAL IMPACT			TARGETS			
Level 1 | Level 2 Key Performance Indicators		**Metric**	**Baseline**	**2035**	**2050**	**Reference**
Building Environmental Impacts	***Energy Reduction***	***Percentage annual energy savings from basic plus advanced controls***	***29%***	***33%***	***40%***	PNNL & calculated from payback
	Advanced Control Energy Reduction	Percentage annual energy savings	6%	16%	26%	PNNL
	Advanced Control Energy Installations	Percentage of systems implementing advaced control strategies	67%	TBD	TBD	EEI
	Energy EMIS Energy Reduction	Percentage annual energy savings	12%	17%	22%	LBNL
	Energy EMIS Installations	Percentage of systems inplementing EMIS/FDD	35%	TBD	TBD	EEI
	Energy Optimization Energy Savings	Percentage annual energy savings	10%	12%	15%	WEF
	Energy Optimization Installations	Percentage of systems implementing advanced energy optimization	TBD	TBD	TBD	???
	Integrated Controls Energy Savings	Percentage annual energy savings	8%	13%	18%	ACEEE
	Integrated Controls Energy Installations	Percentage of systems implementing multi-system integrated control strategies	54%	TBD	TBD	EEI
	Electrical Peak Demand Reduction	***Percentage annual demand reduction (during peak periods/prices)***	***10%***	***20%***	***20%***	RMI
	Demand Management Installations	Percentage of buildings implementing demand management/demand response	50%	TBD	TBD	EEI
	Demand Flexibility Installations	Percent of buildings implementing aggregator/utilty controlled demand flexibility	TBD	TBD	TBD	???
	Carbon Emissions Reduction	***Percentage annual GHG emissions reduction***	***23%***	***80%***	***80%***	PNNL
	24x7 Carbon Emissions Reduction	Percentage of time achieving 24x7 zero carbon emissions	0%	TBD	TBD	???
	24x7 Emissions Control Installations	Percentage of operations controlled based on 24x7 GHG emissions	0%	TBD	TBD	???
	Building Operations	***Percentage time system components perform to specification (control device weighted)***	***TBD***	***TBD***	***TBD***	???
	Building System Reliability	Percentage of buildings with remote monitoring and control capabilities	35%	TBD	TBD	EEI - EMIS is a proxy
	Cybersecurity	Percentage of systems which have been certified for cybersecurity	TBD	10%	25%	???
	Building Systems Integration	***Percentage of buildings with multi-system data integration***	***50%***	***TBD***	***TBD***	EEI
	HVAC and Lighting Integration	Percentage buildings with HVAC and lighting system integration	54%	TBD	TBD	EEI
	HVAC, Safety and Security System Integration	Percentage buildings with HVAC, life safety and security system integration	83%	TBD	TBD	EEI
	Smart Equipment Integration	Percentage buildings with smart equipment integration	39%	TBD	TBD	EEI
	EMIS Integration	Percentage buildings with energy information management systems	35%	TBD	TBD	EEI
Grid and Other System Impacts	***Avoided Grid Capacity Investment***	***Percentage reduction in required grid capacity investment***	***TBD***	***10%***	***19%***	PNNL
	Avoided Distribution Infrastructure Investment	***Percentage reduction in energy infrastructure investment***	***TBD***	***TBD***	***TBD***	???
	Grid Connectivity	Percentage of buildings with real-time grid connectivity	TBD	TBD	TBD	???
	Solar + Storage Integration	Percentage systems with solar PV and/or storage integration	29%	TBD	TBD	EEI
	EV Charging Integration	Percentage systems with EV charging integration	TBD	TBD	TBD	???

EMCS KPI Roundtable

Draft Framework and Metrics

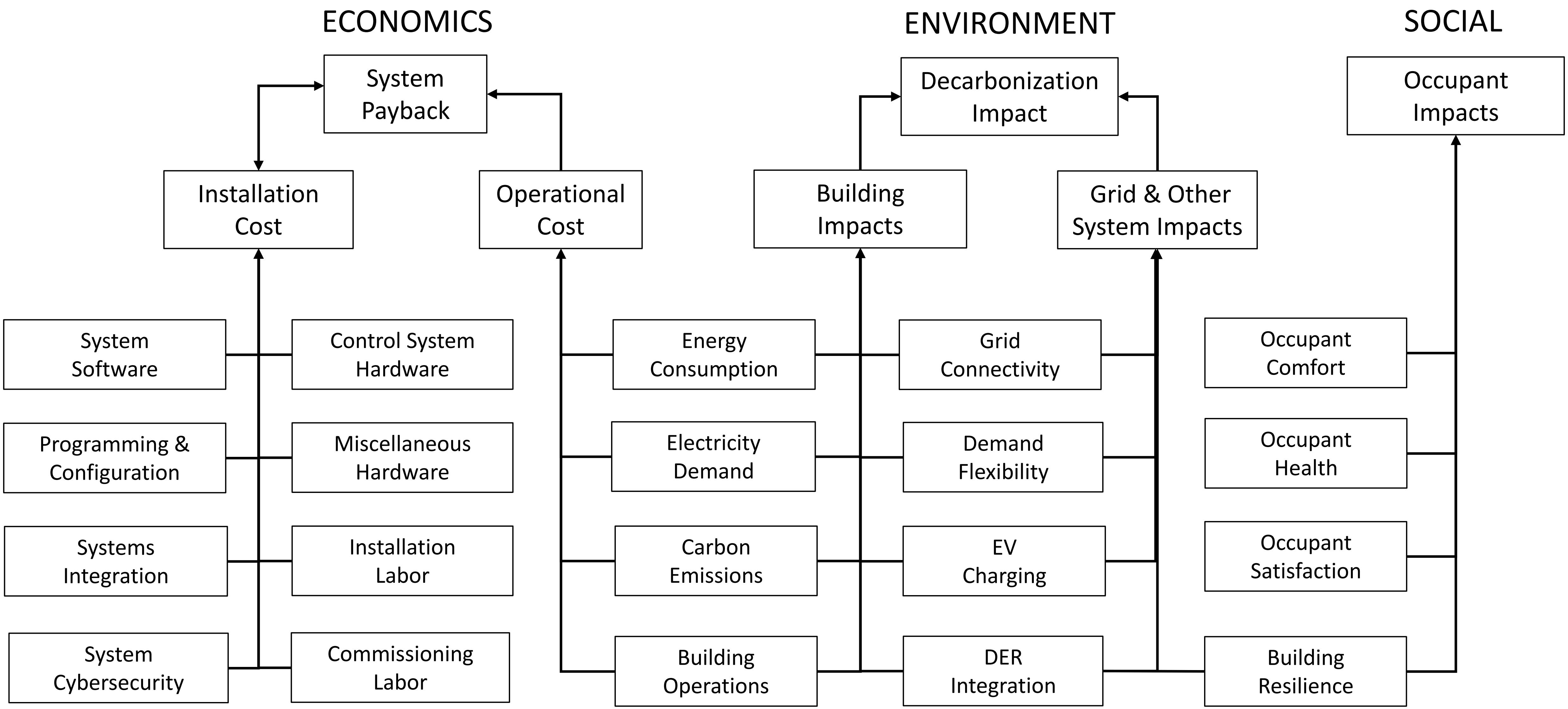
Building Energy R&D
Building Technologies Office
Department of Energy

07 December 2022

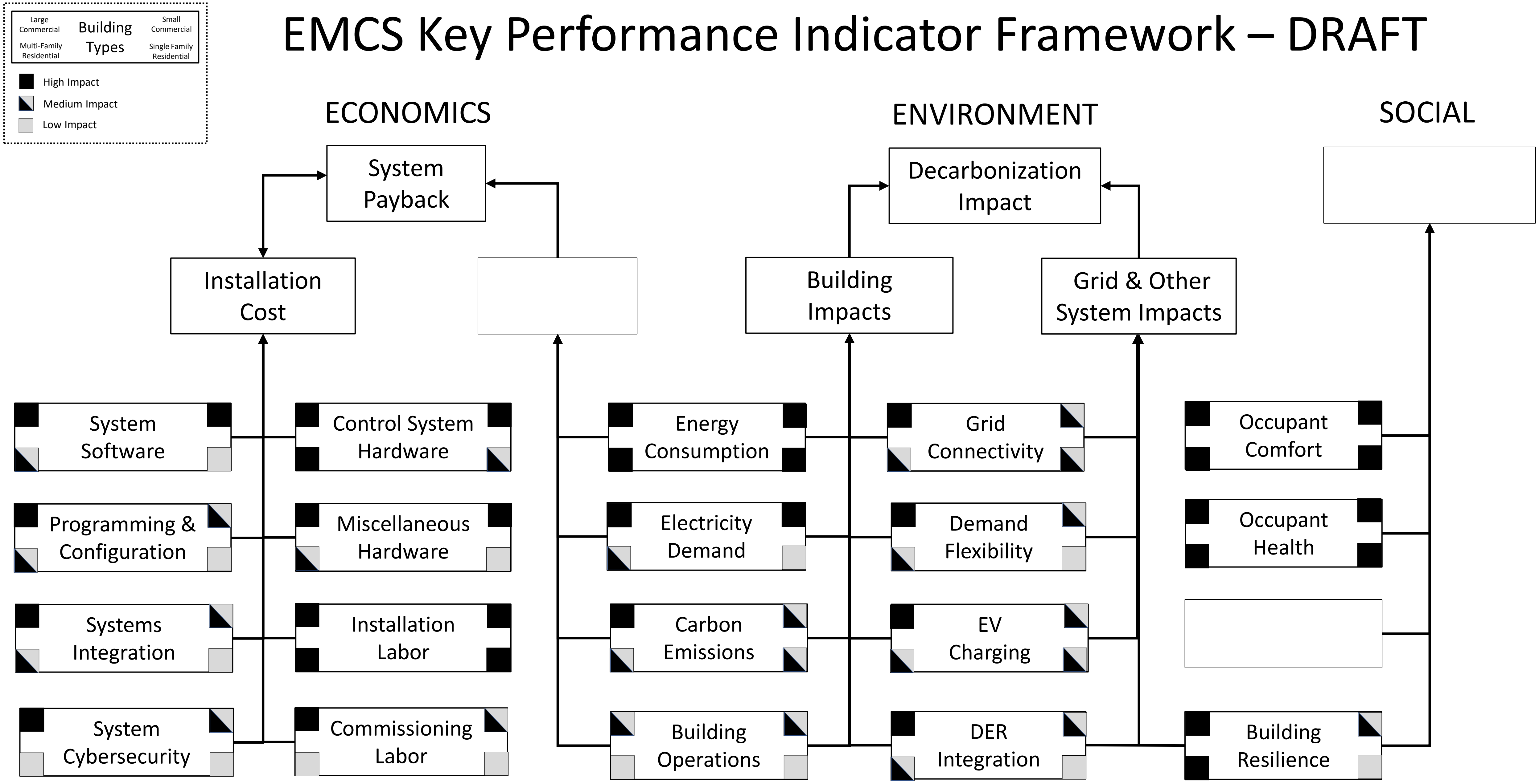
Roundtable Agenda

- Welcome and objectives – 5 min
- Agenda overview and group introductions – 10 min
- KPI framework diagram – 15 min
- Draft metrics and targets – 15 min
- Group discussion – 30 min
- Finalize recommendations for KPI framework and metrics – 10 min
- Next steps

EMCS Key Performance Indicator Framework - DRAFT



EMCS Key Performance Indicator Framework – DRAFT



EMCS Key Performance Indicator Framework – Questions

- Are there any high-level KPIs missing from the framework?
- Are there an appropriate number of leading indicators (e.g., technology penetration) and outcome indicators (e.g., annual energy savings)?
- Do we need different KPIs for different building sectors/types?

EMCS KPI Metrics and Targets – Economic Impact

ECONOMIC IMPACT			TARGETS			
Level 1 | Level 2 Key Performance Indicators		**Metric**	**Baseline**	**2035**	**2050**	**Reference**
Building System Payback	***Installed System Payback***	***Payback period in years***	***4***	***3***	***2***	Rockefeller Foundation
	Total Installed Cost	***System installed cost per control point***	***$1,104***	***$900***	***$775***	NREL & calculated from payback
	Sensor and Controller Hardware	Cost per control point	$94	TBD	TBD	NREL
	Miscellaneous Hardware	Cost per control point	$117	TBD	TBD	NREL
	Installation Labor	Cost per control point	$364	TBD	TBD	NREL
	Control Application Engineering	Cost per control point	$106	TBD	TBD	NREL
	System Commissioning and Balancing	Cost per control point	$258	TBD	TBD	NREL
	Workstation/Server Configuration	Cost per control point	$164	TBD	TBD	NREL
	EMIS Installed Cost	Cost per monitoring point	$10	TBD	TBD	LBNL
	Energy Optimization Application	Cost per monitoring point	$75	TBD	TBD	LBNL
	System Data Integration	Cost per control point	$42	TBD	TBD	Aamidor Consulting
	Cybersecurity Infrastructure	Cost per control point	$30	TBD	TBD	GSA
	Operating Cost Reduction	***Annual cost savngs per square foot***	***TBD***	***TBD***	***TBD***	
	Energy Cost Reduction	Annual energy cost savings per square foot	$275.89	$300.00	$387.50	Calculated from % savings and payback
	Energy Demand Cost Reduction	Percent annual demand cost reduction	TBD	TBD	TBD	???
	Water Cost Reduction	Percentage annual water cost savings	15%	30%	50%	EPA
	Operations & Maintenance Cost Reduction	Annual O&M cost savings per square foot	TBD	TBD	TBD	???

EMCS KPI Metrics and Targets – Environmental Impact

ENVIRONMENTAL IMPACT			TARGETS			
	Level 1 | Level 2 Key Performance Indicators	Metric	Baseline	2035	2050	Reference
Building Environmental Impacts	***Energy Reduction***	***Percentage annual energy savings from basic plus advanced controls***	***29%***	***33%***	***40%***	PNNL & calculated from payback
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	Carbon Emissions Reduction	***Percentage annual GHG emissions reduction***	***23%***	***80%***	***80%***	PNNL
	24x7 Carbon Emissions Reduction	Percentage of time achieving 24x7 zero carbon emissions	0%	TBD	TBD	???
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	Solar + Storage Integration	Percentage systems with solar PV and/or storage integration	29%	TBD	TBD	EEI
	EV Charging Integration	Percentage systems with EV charging integration	TBD	TBD	TBD	???

EMCS KPI Metrics and Targets – Social Impact

SOCIAL IMPACT			TARGETS			
Level 1 | Level 2 Key Performance Indicators		Metric	Baseline	2035	2050	Reference
Occupant Impacts	***Community Equity***	***Percentage of buildings with EMCS in disadvantaged communities***	***TBD***	***> 50%***	***> 75%***	???
	Thermal Comfort	***Percentage time exceeding ASHRAE 55 requirements (occupancy-weighted)***	***TBD***	***< 90%***	***< 90%***	???
	Indoor Environmental Quality	***Percentage time exceeding ASHRAE 62 requirements (occupancy-weighted)***	***TBD***	***< 95%***	***< 95%***	???
	Occupant Satisfaction	Percentage of occupants with top box IEQ satisfaction scores	80%	> 90%	> 95%	???
	Building Resilience	Percentage of buildings with automated emergency response (wildfire, power outage, pandemic	0%	>25%	> 50%	???

EMCS Metrics and Targets – Questions

- How should 2035 and 2050 targets be established? Is a net zero carbon buildings target by 2050 a reasonable end goal?
- Is additional industry research needed to validate costs? Field studies, project data, anonymized and sent to a third-party aggregator?
- How much energy and carbon reduction impact should be attributed to EMCS functionality (versus equipment)? How much for demand flexibility?
- Who could/should be surveyed to estimate EMCS technology/feature penetration? How often?
- Please recommend any good data sources or research efforts to fill in missing baseline data

EMCS Metrics and Targets – Additional Questions

- Do we need different targets for new construction and retrofits? Hardware retrofits? Software only retrofits?
- Should we consider different market conditions (e.g., variations in local labor and material costs)?
- Should economic impacts be estimated from improved occupant health (e.g., healthcare costs) and comfort (e.g., productivity)?
- Please recommend potential approaches to support EMCS KPI tracking and reporting over time?