# BAS Fiddling: Learning How Customers Use and Replace EMS/BAS Systems

***Christopher Dyson, Chad Telarico, DNV; Alex Abbruscato, Eversource***

## ABSTRACT

Energy Management Systems (EMS), also known as Building Automation Systems (BAS), are used widely by commercial and industrial (C&I) buildings.[1] Improving the operation of EMS systems is a promising source of future energy savings. A 2017 study from the Pacific Northwest National Laboratory (PNNL) found average energy saving of 29% across different building types by implementing a package of control-based energy efficient measures.[2]

Despite this great energy savings potential, little research has been done on how customers use their EMS systems. Not much is known as to which building systems are controlled or how often customers override the original controls or reprogram the systems to accommodate changes in building size or use. Little is known about how long these EMS systems last, a key component of lifetime energy savings calculation, or how long customers will "limp along" with poorly performing systems.

This paper presents the results of a 2020-2021 Massachusetts study designed to answer these key questions.

### Introduction

The primary objectives of this study were to identify Industry Standard Practices (ISPs) for EMS system in existing buildings and better understand the impacts of these practices. Specific research objectives which the study covered included:

1) How end use customers use their systems,
2) The level of energy savings that EMS systems and retrocommissioning (RCx) can produce,
3) The frequency and impacts of partially functional EMS systems,
4) The frequency and impacts of failed systems, and
5) The frequency of EMS upgrades and replacements and what factors drive these upgrades/replacements.

In addition to these findings about EMS standard practices, the study also assessed vendor and end user awareness of ASHRAE Guideline 36, summarized vendor recommendations for improving the Massachusetts EMS programs, reviewed Massachusetts building code requirements concerning EMS systems and reviewed recent Massachusetts EMS projects that been subject to the custom electric or gas impact evaluations.

### Methodology

The study team uses five different data collection and analysis activities to understand how EMS systems are being used and replaced:

[1] For the remainder of this paper, we will use the term EMS. Also, because when only the acronym is used it is impossible to distinguish between the singular "System" and the plural "Systems," we will often use the somewhat redundant term "EMS systems."

[2] https://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf

1. *EMS/RCx vendor interviews:* The study team completed In-depth interviews with 17 vendors who install, operate, and maintain EMS systems as well as those who commission or retro-commission (RCx) systems. These interviews were completed during the December 2020-January 2021 period.

2. *EMS customer interviews:* The team completed in-depth interviews with 26 C&I customers who operate EMS systems. These came from the sample frame of a Massachusetts C&I baseline study and included a mix of energy-efficiency program participants as well as nonparticipants. These interviews were completed during the December 2020-February 2021 period.

3. *Analysis of EMS frontend screenshots:* The team collected screenshots from the frontends of the EMS systems belonging to the C&I customers it had interviewed. It then analyzed these screenshots to determine whether these systems were operating in an optimal manner.

4. *Building code review:* The team reviewed Massachusetts state building codes to determine the minimum requirements that EMS systems in new buildings must meet.

5. *Review of EMS impact evaluations:* The team reviewed recent estimates of energy savings for EMS systems that had been produced as part of a custom program impact evaluation.

The study team then combined the findings from these five data collection and analysis activities into a report and subsequent findings memorandum (memo). The next section summarizes the findings from this report and memo.

## Findings

### How EMS Systems are Used

The study asked the C&I end users and the EMS/RCx vendors several questions about how their EMS systems are being used. Key findings included:

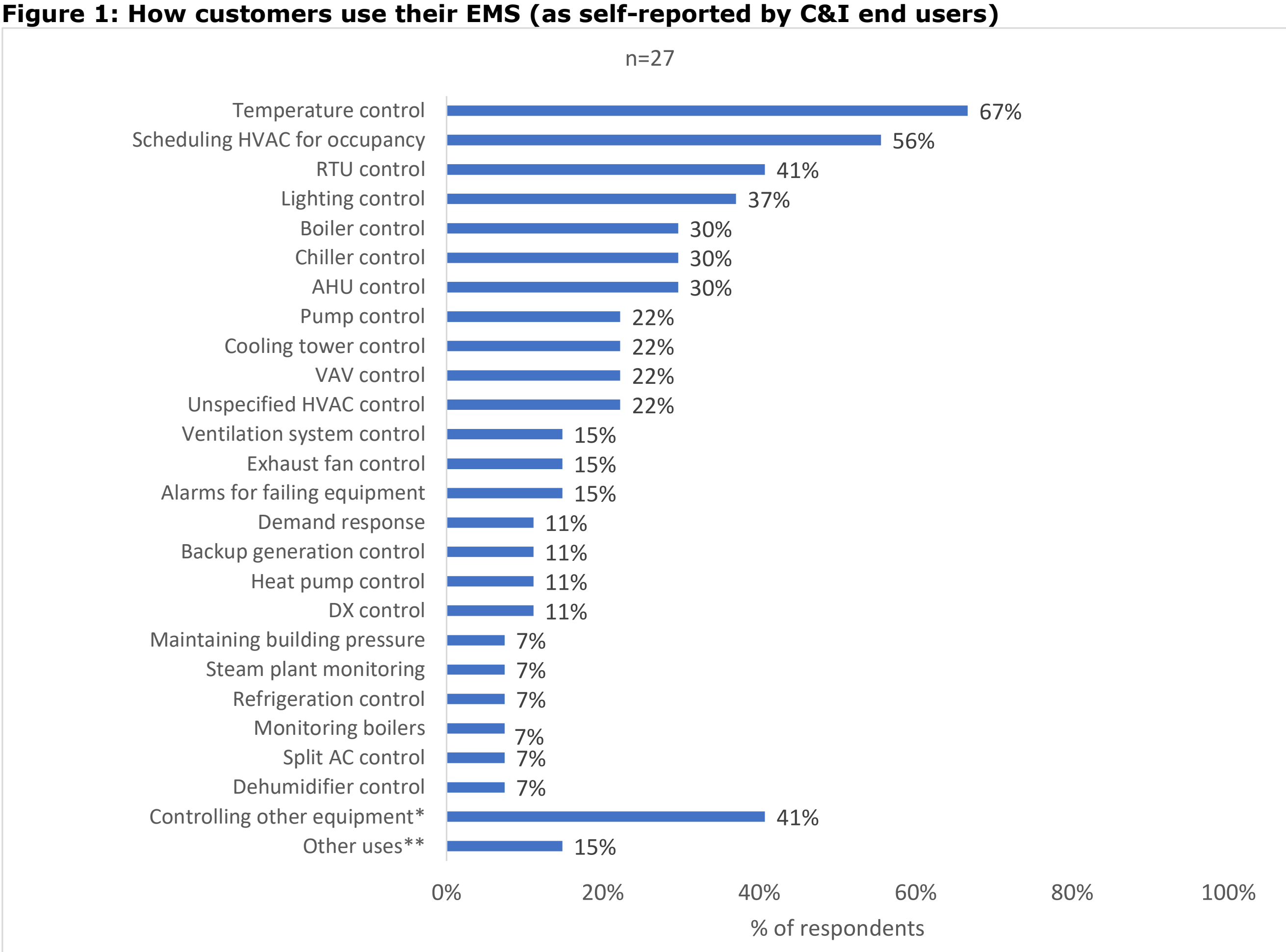
- *What systems are used to control:* When asked how they use their EMS, the end users most frequently mentioned using them for temperature control (67% of respondents), scheduling the operation of their HVAC systems based on building occupancy patterns (56%), and controlling the operations of their roof-top units (41%). Figure 1 shows the full range of responses.
- *What control sequences are typically installed:* The study team asked the EMS/RCx vendors which control sequences they typically program when installing new EMS systems in buildings which previously did not have such systems. It also asked them how frequently they install these sequences. Scheduling, temperature setback, optimal start/stop, and trim and respond were the most-cited control strategies.[3]
- *Who in the company uses the system:* Only 11% of the end users reported that they had ceded management of their EMS to an outside vendor. Forty-four percent of the companies reported having only one or two employees using the system with the remainder having more than two employees using the system. This limited access puts these companies at greater risk of loss of institutional knowledge if the companies experience employee turnover. Yet this limited access also

[3] Optimal start/stop is a control strategy where the operation of heating/cooling equipment is started early enough so that the optimal temperature is reached when the building is scheduled for occupancy. Trim and Respond is a strategy where the static pressure setpoint in a zone is trimmed slowly until the zone indicates that more static pressure is needed, in which case the controller responds by further trimming the setpoint up or down by a small increment.

likely reduces the chance that less-knowledgeable employees might override EMS functions that should not be overridden.

- *Concerns about loss of system operator expertise:* The team asked the end users: "Does your company have any concerns that the staff operating this EMS may leave/retire?" About half (48%) of the end users had such concerns.
- *EMS training:* All the vendors said they offered system training to their customers, but the length of these trainings ranged widely from one hour of remote training to two days of onsite training.
- *Frequency of system use and alteration:* Most (76%) of the end users reported accessing their EMS systems daily. However, only a small minority said they make changes to their systems daily or even weekly.

**Figure 1: How customers use their EMS (as self-reported by C&I end users)**




*Other equipment controlled included duct heaters, fan coils, water heaters, PV systems, irrigation systems, fire suppression systems, electric heating, vent dampers, furnaces, paddle fans, and motors. **Other uses included detecting water in voltage rooms, monitoring chlorine injection in pools, logging filter changes, and logging runtime. Percentages exceed 100% because interviewees could give multiple responses.

### Energy Savings from EMS Systems and Retro-Commissioning

The study team asked the EMS and RCx vendors about the energy savings that end users could expect from their EMS systems or from the recommissioning or retrocommissioning of these systems. The team also asked both vendors and end users about their awareness of the ASHRAE Guideline 36.[4] Key findings included:

- *Energy savings claims for new systems:* Seventy-nine percent of the vendors said that they do tell their customers to expect energy savings from the new EMS systems. Their average building-level energy savings estimates for the new EMS systems was 14% with a median of 11%. When asked how they they came up with their estimates of energy savings, most vendors said these estimates were based on either building energy modeling software or on custom calculations.
- *Energy savings claims for system upgrades:* Eighty-two percent of the vendors said that they do tell their customers to expect energy savings from the EMS system upgrades. Their average building-level energy savings estimates for these systems upgrades was 12% with a median value of 10%.
- *Energy savings from recommissioning:* The team asked the vendors who offered recommissioning services whether they tell their customers that they can expect energy savings from this service. Nine of the eleven vendors who offered this service said that they do tell their customers to expect energy savings with an average expected savings level of 13%.
- *Energy savings from retro-commissioning:* The team asked the vendors who offered retro-commissioning services whether they tell their customers that they can expect energy savings from this service. Seven of the ten vendors who offered this service said that they do tell their customers to expect energy savings with an average expected savings level of 9%.
- *ASHRAE Guideline 36:* The study team asked both vendors and end users whether they were familiar with ASHRAE Guideline 36. Only 4 of the 15 vendors (27%) and 2 of the 25 end users (8%) said they were familiar with this guideline. The team asked the end users: "Are you interested in implementing sequences from Guideline 36 if they can help reduce energy use?" Eighty-eight percent of the end users said they were interested with 12% saying they were unsure.

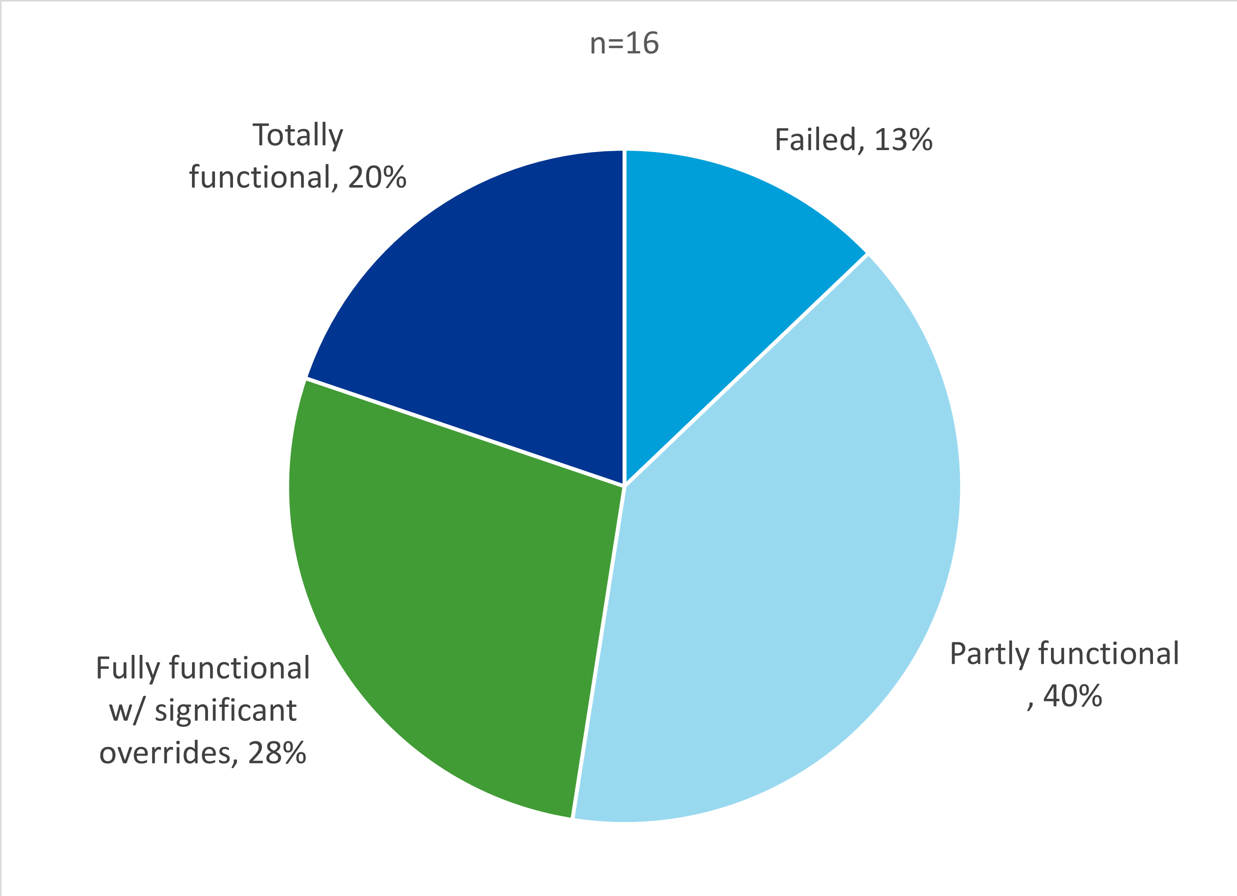
**Reductions in EMS Performance**

Another research objective of the study was to identify the prevalence of Massachusetts EMS systems that are partially functional or not performing optimally or have been subject to many overrides of their energy-saving functions. Some key findings included:

- *The range of EMS functionality:* The study team asked vendors to group the EMS systems they had encountered in Massachusetts into four categories of condition/functionality: 1) Systems that have failed, with no remaining function, 2) Systems that are only partly functional, 3) Systems that are fully functional but where there has been significant overriding of the original controls, and 4) Systems that are totally functional. Figure 2 displays the average estimated frequency for each of these four functionality categories.

[4] This new guideline: High-Performance Sequences of Operation for HVAC Systems, provides uniform sequences of operation for HVAC systems that are designed to reduce energy consumption, cost, and system downtime with more resilient systems, control sequence compliance, and diagnostic software.

**Figure 2: Vendor estimates of functionality range of MA EMS systems**




The study team also asked end users: "Is your company's EMS functioning in an optimal manner?" Most (60% of respondents) reported that their systems were functioning optimally with 12% saying that most of their system was running optimally and 28% saying that their systems were not functioning optimally.

However, when the study team examined screenshots of EMS frontends from a random sample of end users who had reported that their EMS was functioning in an optimal manner, it found that several of the systems which customers described as operating "optimally" were likely not operating optimally. Issues that the team identified from these screenshots included sensor calibration issues, systems not meeting temperature and pressure setpoints, failed actuators, and missed opportunities to reduce heating/cooling loads.

It should be noted that "optimal" is a subjective term that can take on different meanings for various customers. Customers often focus on whether their building zones are meeting setpoints and occupants are comfortable. As a result, they can sometimes overlook system and energy efficiency.

- *Non-functioning or non-calibrated points:* When asked what percentage of their installed input points were still operating, most end users (65%) said that all their input points were still operating. Those end users who reported that not all their points were operating still gave estimates of 90%-

98% functionality. The average reported functionality across all end users was 98%. The qualitative responses indicated that most end users get the equipment repaired soon after an alarm goes off.

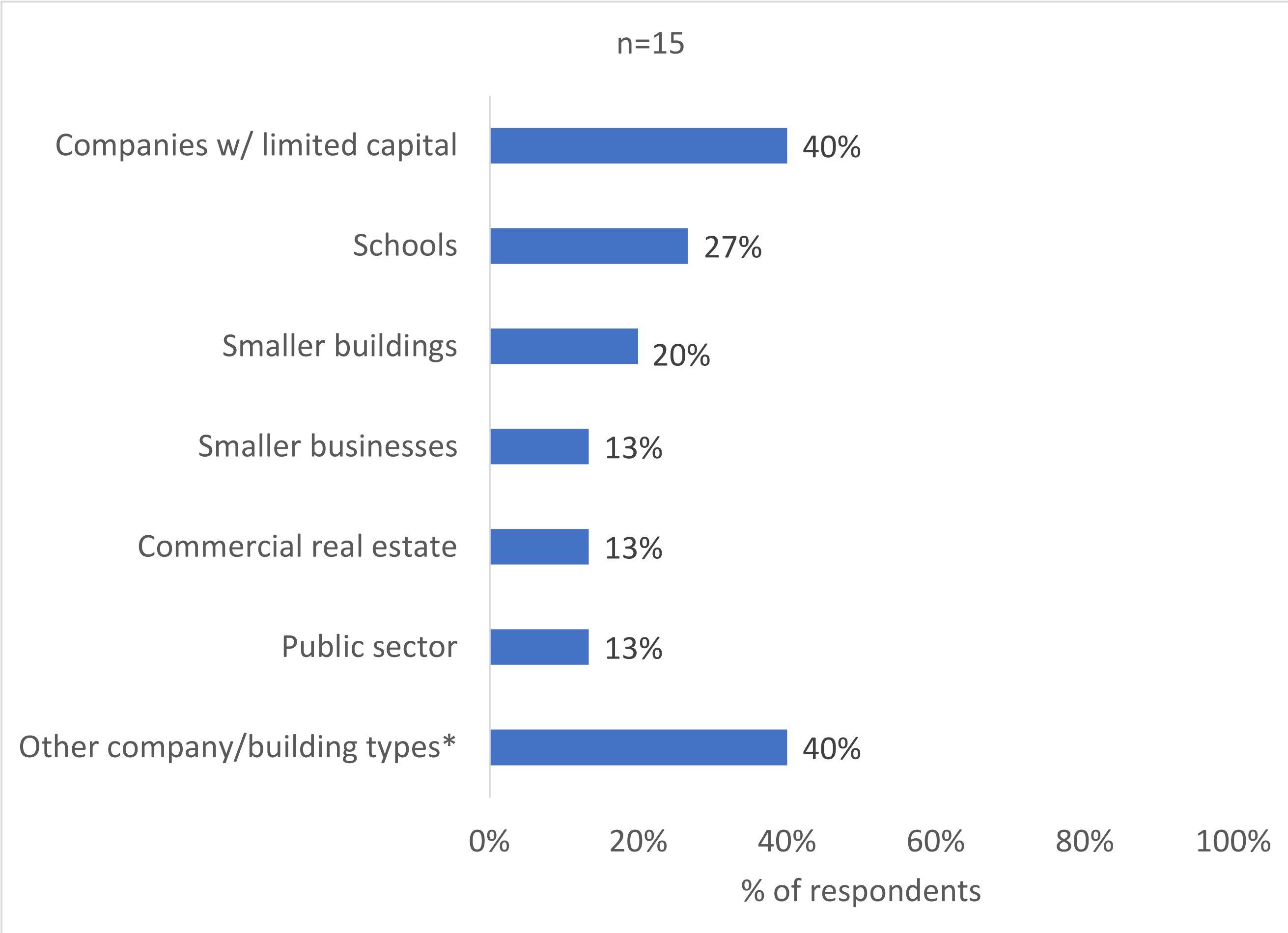
- *System overrides:* Seventy-nine percent of end users reported that some of their EMS controls were either currently overridden or had been overridden in the recent past. Several end users said that due to the COVID-19 pandemic they had overridden the controls on the outside air intake to maximize the amount of outside air coming into the building.
- *Systems in need of repair or reprogramming:* The team asked the end users: "Is your company's EMS in need of repair or reprogramming?" A third of the end users said their systems needed repair or reprogramming.
- *Abandonment of partially functioning systems:* The team asked the vendors whether they have come across situations in which customers were no longer using an EMS that was still totally or partially functional. Sixty percent said that they had encountered such situations. When asked why customers would discontinue using a workable EMS, the vendors cited a variety of reasons including lacking/losing the expertise to operate the system, tenant complaints about temperature discomfort, and simply finding that manual control was more reliable.

**EMS Failure**

Another key study objective was to identify the prevalence of failed EMS systems in Massachusetts. Some key findings included:

- *Defining system failure:* The team asked the vendors define what they meant by a failed system. Common criteria they mentioned were the loss of front-end control and monitoring and the failure of equipment.
- *The prevalence of system failure:* The vendors estimated that 13% of the EMS systems in Massachusetts had failed (Figure 2).
- *The age of failed systems:* The team asked the vendors to estimate the average age of the failed EMS systems they had encountered. Their estimates averaged 15 years. When asked for the average age of these failed systems if they had received regular maintenance, the vendors estimated 19 years. When the team asked the vendors how long end users with failed systems typically go before getting their systems replaced, the average estimate was five years.
- *Why customers allow system to fail:* The team asked the vendors why customers allow their EMS systems to fail. The top two reasons were cost barriers (65% of vendors mentioned this) and loss of trained maintenance staff (24% of vendors).
- *How buildings are controlled with failed systems:* When asked how companies with failed EMS systems typically control their buildings, the large majority of vendors (82%) mentioned manual controls or giving equipment standalone control capabilities, with overrides and the use of programmable thermostats mentioned less frequently.
- *Company/building types more likely to have failed systems:* The team asked the vendors whether they had noticed any trends in building type or size among customers with failed or inoperable systems. They named companies with limited capital, schools, and smaller buildings most frequently (Figure 3).

**Figure 3: Building/company types more likely to have failed EMS systems (from vendor interviews)**




*Other company/building types include mid-sized buildings, housing authorities, leased buildings, companies with third-party maintenance companies, retail, and hotels. Percentages exceed 100% because interviewees could give multiple responses.

**Replacing/Upgrading EMS Systems**

The study team asked the end users and vendors about standard practices concerning the replacement and upgrading of EMS systems. Some key findings included:

- *The frequency of replacing/upgrading systems:* Sixty percent of the end users reported doing a recent replacement or upgrade of their EMS system. However, when the team looked at the descriptions of the replacements/upgrades that the end users provided, it determined that only one of these projects was a true EMS replacement. In most cases (80%), the projects were expansions of the EMS systems due to new equipment or a building expansion. A significant share of the projects (40%) also involved software upgrades.

- *Reasons for replacing/upgrading systems:* Building expansions, the installation of new equipment, and the renovation or reuse of a building were the three reasons that end users mentioned most often for replacement or upgrading of their EMS systems.

- *Plans for future system replacements/upgrades:*

- Sixty-four percent of the end users said they were considering upgrades or replacements for their EMS. However, most of what they described were upgrades or expansions to their existing systems rather than wholesale replacements of their current systems.
- The team asked end users who were not considering system replacements/upgrades why their companies had no such plans. The most common responses were that their systems were working fine.
- When asked how much longer they thought they could continue using their current EMS before it would need to be replaced or upgraded, the average end user estimate was seven years. When explaining these estimates, most end users said that only obsolete software or the EMS vendor no longer supporting their product would cause them to make a wholesale change in their legacy systems.

- *Who decides to replace/upgrade systems:* End users reported that half the time the local facility manager or site engineer was involved in the decision to replace/upgrade a system. Corporate decisionmakers or school/municipal administrators were also named as project decision-makers.
- *End user concern about obsolete software:* Forty-four percent of the end users had concerns about their EMS software becoming obsolete.
- *What system components are replaced with an EMS upgrade:* The vendors said that most of the time (54% on average) when they upgraded an EMS they replaced both the components (e.g., sensors and actuators) and the system hardware. A third of the time they only replaced the system hardware and 14% of the time they only replaced components.
- *The age of replaced systems:* The team asked the vendors about the average age of the EMS systems they replaced. Their average estimate was 17 years.
- *The age of existing systems:* The team asked the end users for the age of their current EMS. The average age was 12 years with a median age of 13 years.
- *Changes to existing control settings/sequences:* Sixty-nine percent of the vendors said that they change the existing control settings/sequences when making software or hardware upgrades. Additionally, the end users who recently had an EMS replacement/upgrade said that the preexisting control sequences were either totally or partially changed in over half the projects.

**Other Findings**

In addition to these findings about EMS standard practices, the study team also reviewed Massachusetts building code requirements concerning EMS systems and reviewed recent EMS projects that been subject to the custom electric or gas impact evaluations. Some key findings included:

- *Building code review:* The study team comprehensively reviewed the current and previous versions of the Massachusetts building codes to catalogue the code-required control functions that could be implemented by an EMS. This examination showed that in new construction or major gut-rehab construction, building code spells out a comprehensive regime of control functionality across building systems, leaving limited options for better than code functions.

  Savings opportunities for new construction EMS might exist in some buildings by addressing non-building service equipment such as food service or office equipment, although these opportunities may link to unique circumstances of a particular building or building type. Reviewers of this report also cited other opportunities in new construction including incorporation of programming sequences recommended by the new ASHRAE Guideline 36, other ways to improve occupancy based control of HVAC equipment, and chiller plant optimization.

- *Impact evaluations of EMS projects in existing buildings:* The study team reviewed eleven EMS projects in the two most recent Massachusetts custom electric and custom gas impact evaluations. All eleven sites used an existing conditions baseline. Nine of the sites had existing functioning EMS systems installed at the facility (or campus). The functioning systems were acceptably controlling other HVAC equipment prior to the implementation. At these nine sites, the measures included modifying existing control strategies, adding control to new or existing equipment through the EMS, or adding a new control function with both required hardware and programming. Two of the sites had no EMS previously and were installed in a fast food service building where the primary savings were derived from control of small kitchen appliances. While the baselines of EMS projects were correctly classified, the site-specific energy savings realization rates varied widely due to operational differences that were not captured by the applicant.

## CONCLUSIONS

Key conclusions that the study reached included:

- *There are energy savings opportunities with existing EMS systems.* There had been much discussion in Massachusetts as to whether buildings with existing EMS systems could get energy savings credit for upgrading or replacing those systems. Some had contended that the baselines for existing EMS systems should be new EMS systems because the market should naturally replace systems that were aging, losing functionality, using outdated software, or facing the loss of staff trained in using the systems. Others had contended that the baseline should be the existing EMS in its current condition. This EMS ISP study concluded that energy savings opportunities exist in the replacement and upgrading of existing EMS systems and that the baseline should be the operating condition of the existing system. It based this conclusion on a range of evidence that included:
    - *The prevalence of EMS systems that were not totally functional or which had totally failed.* EMS/RCx vendors estimated that only 20% of existing Massachusetts EMS/BAS systems were totally functional and that 13% had totally failed. Twenty-eight percent of end users said that their systems were not functioning optimally and another 13% said that parts of their systems were not functioning optimally. A third of the end users also reported that their systems needed repair or reprogramming.

    - *The infrequency of EMS replacement:* While 60% of end users reported doing a recent replacement or upgrade of their EMS, when the study team looked at the descriptions of the replacements/upgrades that the end users provided, only one of these projects was a true EMS replacement. In most cases (80%), the projects were expansions of the existing EMS due to new equipment or a building expansion.

      In addition, while 64% of the end users said they were considering upgrades or replacements for their EMS/BAS systems, most of what they described were upgrades or expansions to their existing systems rather than wholesale replacements of their current systems. The end users who had no plans for future system upgrades or replacements also said that they planned to continue using their systems for another seven years, on average. Most of them said that only obsolete software or the EMS vendor no longer supporting their product would cause them to make a wholesale change in their legacy systems.

- *The aging of existing EMS systems:* Another piece of evidence that market forces were not driving end users to replace aging or suboptimal EMS systems was the age of the existing systems. The vendors said that the average age of failed EMS system was 17 years. The end users said that the average age of their systems was 12 years. With some of them planning to keep their legacy systems for another seven years, this would put these systems past the average failure age range.
- *Energy savings opportunities with existing EMS systems:* Vendor reports of the potential energy savings opportunities from replacing or upgrading an existing EMS/BAS system are other evidence that market forces are not driving end users to replace their aging or ailing systems. Seventy-nine percent of the vendors said that they do tell their customers to expect energy savings from new EMS systems. Their average building-level energy savings estimates for the new EMS systems was 14%. In addition, 82% of the vendors said that they tell their customers to expect energy savings from the EMS upgrades. Their average building-level energy savings estimates for these systems upgrades was 12%. The fact that a large majority of the vendors are finding energy savings in EMS replacements or upgrades indicates that the legacy systems were not sufficiently optimized for energy savings.

- *However, challenges remain in being able to characterize the baseline operating conditions of the existing systems to support savings claims.* While there is evidence that energy savings opportunities exist with these suboptimal EMS systems, the challenge is how to demonstrate these energy savings. Ideally, the evaluators would want evidence of the baseline condition -- how the legacy system was operating before the EMS was upgraded or replaced. And these baseline conditions are best captured by onsite metering which can be very expensive.

  The vendors indicated that they currently demonstrate energy savings to their customers for EMS system upgrades and replacements using modelling software or custom calculations. This is encouraging in the sense that developing a baseline profile of the legacy system might be something they could accommodate with their existing software without too much additional effort. However, there would still have to be some verification that the model inputs are based on actual baseline operating conditions vs. other assumptions (e.g., that equipment is running 24/7) that would exaggerate the actual energy savings. This baseline measurement requirement would also require more vendor education so that these baselines measurements could be made before the legacy system is removed. Finally, some older EMS systems with memory constraints may not be able to provide detailed trend data.

- *The difficult of defining EMS failure.* Another related challenge is being able to define an EMS as having failed. This definition is important because "replace on failure" is a widely recognized use case in energy efficiency evaluation for defining the baseline assumptions used to estimate energy savings from the installation of energy-efficient equipment. The EMS ISP study came across many definitions of failure including a system front end which was no longer controlling or communicating with the equipment, failure of the network master panel, unitary controller failure, and older computer systems with outdated software.

  However, the vendors interviewed for this study also said that when customers have failed EMS systems, most resort to manual controls. In addition, some controllers can maintain their sequences of operations even when connection with the network is cut if they have an internal clock/timestamp which allows them to operate based on last instructions from the EMS. So, failing to account for those manual interventions or autonomous controllers could overestimate the potential energy savings from replacement of a “failed” system.

- *Energy saving opportunities for EMS systems in Massachusetts new construction scenarios are limited:* As noted, this study’s examination of Massachusetts building code requirements showed that in new construction or major gut-rehab construction, these requirements contain a comprehensive regime of control functionality across building systems leaving only small energy savings opportunities for EMS systems. In addition, each recent building code iteration has further reduced these marginal opportunities by shifting sophisticated controls to smaller equipment components and requiring control parameters to be more aggressive in reducing energy consumption. However, savings opportunities for new construction EMS might exist in some buildings by addressing non-building service equipment such as food service or office equipment, although these opportunities may link to unique circumstances of a particular building or building type.
- *Increased customer and vendor education and support concerning ASHRAE Guideline 36 is needed:* This new guideline: *High-Performance Sequences of Operation for HVAC Systems*, provides uniform sequences of operation for HVAC systems that are designed to reduce energy consumption, cost, and system downtime with more resilient systems, control sequence compliance, and diagnostic software. The guideline also promotes communication between specifiers, contractors, and operators by creating a language of common terms. However, this study found that only 27% of the vendors and only 8% of the end users were familiar with this guideline.

  In addition, when the team asked the end users: “Are you interested in implementing sequences from Guideline 36 if they can help reduce energy use?”, 88% of the end users said they were interested with 12% saying they were unsure.  This indicates that there would be market support for wider adoption of ASHRAE Guideline 36.

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