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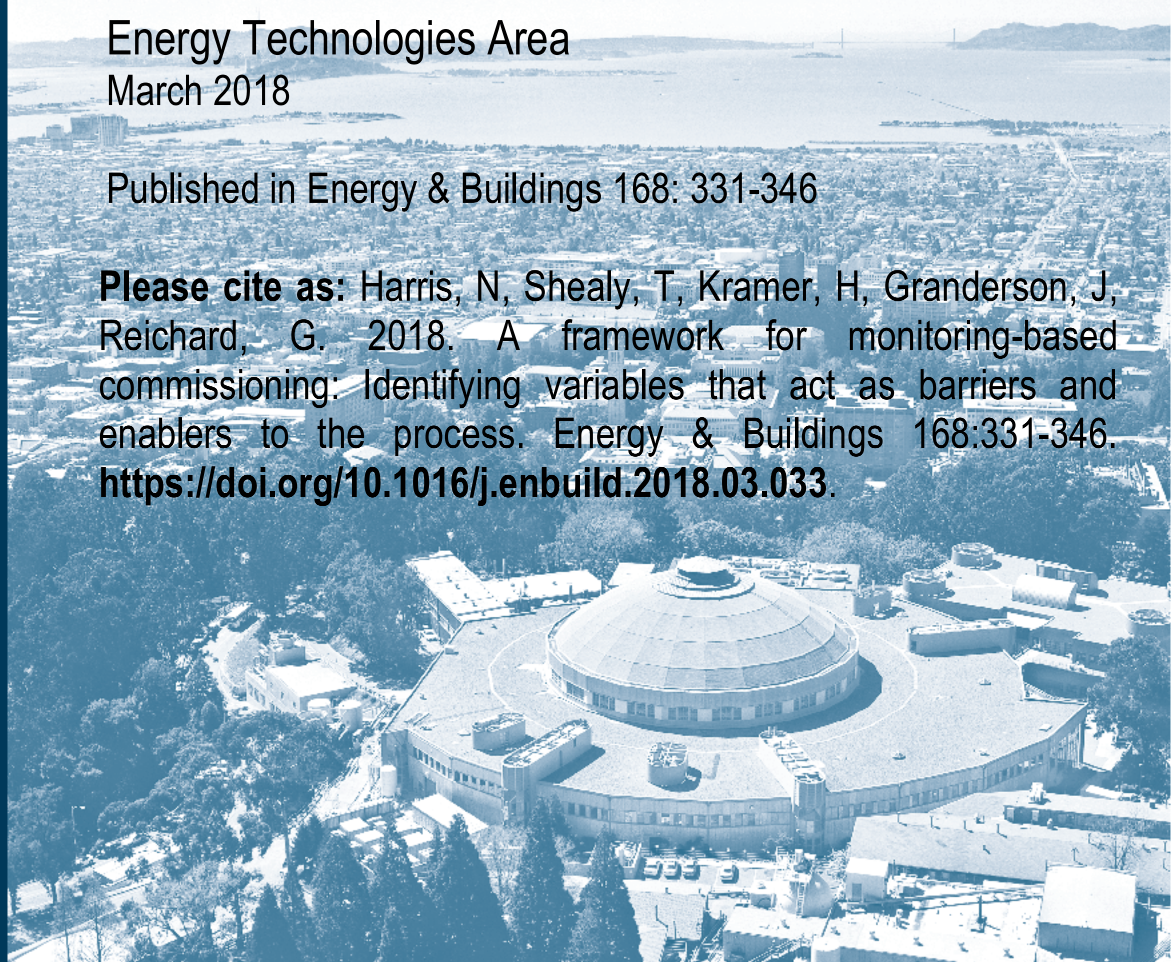

Abstract

The practice of monitoring-based commissioning (MBCx) using energy management and information systems (EMIS) has been shown to enable and help sustain up to 20% energy savings in buildings. Despite research that has quantified the costs, benefits, and energy savings of MBCx, the process remains underutilized. To understand why MBCx is not more frequently adopted and how to encourage its use, this research synthesizes qualitative data from over 40 organizations, currently engaging in MBCx. The outcome of this research is a framework containing variables that emerged from the qualitative data, marked as barriers or enablers, organized by phases of the MBCx process. The framework is comprised of 51 emergent variables that fall within 13 different categories. The variables that most frequently act as barriers are data configuration, measurement & verification (M&V), developing specifications for EMIS, and data architecture. Although some variables that act as barriers for one organization were identified as enablers for another. For example, payback/ROI was considered a barrier 7 times and an enabler 3 times. One organization had difficulty making the business case for the initial investment for MBCx due to lack of cost information, while another was able to justify large investments with documented savings of previously implemented measures identified through MBCx. The framework formally validates barriers found in previous research, and can be used by practitioners to better understand common experiences with MBCx. This research highlights the need for a similar collective data set to validate common enablers to MBCx and also the need for empirical research to determine relationships between variables.

1. Introduction

The process of monitoring-based commissioning (MBCx) can help sustain optimal energy performance in buildings, while maintaining occupant comfort [1–3]. In the building efficiency literature, MBCx entails ongoing commissioning with the goal of continuous building performance improvement by way of data monitoring and analysis [4,5]. MBCx can enable the identification of otherwise untapped energy conservation measures and also verify the energy savings from the re-commissioning of existing equipment [5].

Alongside the evolution of MBCx there is the evolution of system monitoring technologies to support the process. Specifically, energy management and information systems (EMIS) enable and help sustain up to 20% site energy savings [6]. Many technologies fall under the umbrella term EMIS (e.g. building automation systems, information monitoring and diagnostic systems, energy information systems). All of these technologies aim to efficiently manage building energy use. EMIS can report and analyze whole-building energy use (e.g. water or electricity), system-level energy use (e.g. just HVAC), or offer a combination of the two.

Despite the demonstration of benefits from MBCx in the 1990s and the beginning of a paradigm shift from retro-commissioning to MBCx in the early 2000s [7], the process remains under-utilized [6]. This could be because there are still variables acting as barriers to MBCx and supporting technologies like EMIS [8], confusion about the process, and skepticism towards its benefits [9].

This research aims to make MBCx more transparent by creating a framework of enablers and barriers to its use, based on the synthesis of experiences from organizations implementing EMIS and MBCx. Frameworks can serve as a guide for a specific outcome by organizing interlinked concepts. The framework contains variables that emerge from qualitative data, organized by phases of the MBCx process, and will point out those that are commonly experienced as barriers or enablers to the process. The framework can act as a guide to organizations implementing MBCx by making variables that impact the process more evident; it also suggests further empirical research to determine the relationship between these variables and energy saving outcomes.

The overarching goal of this research is to facilitate otherwise untapped potential for site energy savings by creating a tool for building owners practicing MBCx. This research is intended to benefit commercial building stakeholders such as building owners, facility managers, building engineers, and energy managers involved in the MBCx process, as well as researchers interested in targeting understudied areas of MBCx.

2. Background

Background information relevant to this work includes the relationship between MBCx and information systems, definition of the MBCx process, and examples of variables, or factors impacting the successful implementation of MBCx.

2.1. *MBCx relationship to information systems*

More than five decades of research in information systems have led to advances in disciplines such as management [10], healthcare [11], and manufacturing [12]. In general, information systems (IS) are defined as networks, software, and hardware that work together to acquire, store, and manage data [13]. The utilization of an EMIS, (see phase two of the MBCx process, in Section 2.2) also requires networks, software, and hardware and could be considered a subset of an IS. Petter et al. [14] defined an IS framework that contains variables that "cause" or at least influence IS success. This framework helped create a better understanding of the IS process and is a starting point for researchers to measure the interactions and outcomes of these variables. Petter et al. [14] defined IS variables based on a synthesis of over 140 studies, then assessed whether these variables, based on literature, have an impact on success outcomes like system use, system quality, user satisfaction, and net benefits. For example, the IS framework identified the variable "user involvement" defined as "the degree to which users participate and are involved in the IS development and implementation process" [14]. User involvement was then found to have conflicting impacts on the use of the IS and the authors suggested further study [14]. A similar framework to Petter, DeLone, and McLean's framework, specific to MBCx and developed in this work, can create a more holistic understanding of MBCx and lay the groundwork for comparable empirical studies.

2.2. *MBCx process*

Analogous to the traditional existing building commissioning processes, the overall MBCx process includes a planning phase, and an implementation phase [15]. However, to accommodate the use of IS, it also includes a phase for EMIS configuration. Details of the specific steps within each phase are listed in Table 1, as described in Kramer et al. [4].

The outcome of the research presented in this paper is a framework of variables that influence the MBCx process; the framework is aligned with these phases (see Table 1), and can support organizations in implementing the process. However, since, the variables within the framework may be relevant at multiple points in the MBCx process, the specific phase referenced may serve more as a general roadmap than a definitive attribution.

2.3. *Examples of variables impacting MBCx*

Previous case studies describe some variables [3,6,16–18] that act as barriers, impeding the process, or enablers, supporting the institutionalization of EMIS and/or MBCx, and energy saving goals. These variables can be inherent to the MBCx process, but cause unexpected challenges or barriers. For example, the University of California, Merced (UC Merced), adopted an MBCx process and reported that one of the biggest issues was data quality [3]. Although the performance of data quality checks is a step within the MBCx process, organizations might not know how often this actually impedes the process or that this can lead to issues like false positive alarms that cause cascading alert notifications during the implementation phase.

On the other hand, these variables may not necessarily be defined in the general MBCx process, making it difficult for organizations to anticipate their influence. Using the case of UC Merced again, network and connectivity problems led to false alarms that then required "significant resources" to validate the data [3]. Multiple case studies highlight the use of consulting and advisory services as being valuable to MBCx implementation, but this is not clearly defined within the MBCx process and organizations could benefit from learning about the experience of others. For instance, when using outside consultants to configure EMIS, a lack of documentation and training for staff responsible for continued management of the system can lead to improper ongoing use of EMIS [19,20].

In addition, there are variables described in case studies that can enable energy savings that are not defined in the MBCx process. For example, one case reports the organization leveraged their EMIS through an energy reduction campaign focused on engaging employees with the building's energy use [21]. The case highlighted the impact of empowering "energy champions" in supporting others to practice energy-saving behaviors [21]. EMIS data has also been used to design programs that create a sense of competition between occupants, retail chains, and even communities leading to energy savings [22].

Although these cases are a rich data source, organizations interested in MBCx could benefit from a framework classifying variables, such as these, that act as either barriers or enablers to the process. A framework provides a more holistic perspective than a case study, with context of other variables and their connections to each phase.

3. Research questions

By using qualitative data from over 40 organizations implementing MBCx and using EMIS for continuous data monitoring and analysis, this research aims to answer the following questions:

(1) What variables emerge from the MBCx process?
(2) At what phase do these variables occur within the MBCx process?
(3) Which of these variables are described as barriers and which are described as enablers?

The qualitative data encompasses a wide range of organizations (in size and type) and multiple EMIS types. The data was coded to determine the emergent variables impacting MBCx and then organized by MBCx process phase to create a MBCx framework. The hypothesis is that variables will emerge as barriers or enablers that are not necessarily defined in the MBCx process. Of those variables, the expectation is to find the majority to be barriers to the process due to the nature of qualitative questions (see Table 2), but we expect that some enablers will emerge as well. It is also expected that some variables will have conflicting results, being barriers to some and enablers to others. These variables are highlighted in the results. Finally, gaps in MBCx knowledge are underscored to encourage further empirical study and outlined in the discussion and conclusion.

Table 1
Three phases of the MBCx process.

MBCx planning phase
1.1. Collect building documentation and create/update current facility requirements (CFR)
1.2. Define high priority systems for performance monitoring
1.3. Create a Monitoring Action Plan (MAP)
1.4. Specify or enhance an Energy Management and Information System (EMIS)
1.5. Create Training Plan
EMIS Configuration Phase
2.1. Define data configuration requirements
2.2. Calibrate critical sensors
2.3. Perform EMIS data quality checks
2.4. Create an EMIS user interface
2.5. Configure the fault detection and diagnostics (FDD)
2.6. Configure energy savings and anomaly tracking
MBCx Implementation Phase
3.1. Identify issues and opportunities using EMIS and Monitoring Action Plan
3.2. Investigate root cause for prioritized issues
3.3. Identify and implement corrective actions, and update facility documentation
3.4. Verify performance improvement
3.5. Implement reporting, documentation, and training

Table 2
Questions from the Smart Energy Analytics Campaign used to develop the framework.

Reporting method	Specific question	# Reponses
Phone interview; researcher recorded organization's responses	What are your biggest challenges in meeting your plans?	41
Phone interview; researcher recorded organization's responses	Please give us an overview of your current data collection, any software you use, and your process for using data to support facility operation. (data source, data frequency, which type of software)	42
Organization request for technical assistance; researcher recorded organization's request	Technical Assistance Identified	90
Web survey: organization self -reports	Please describe how you used your EMIS	22
Web survey: organization self -reports	Describe your EMIS installation: Indicate the types of data points included, the automated analysis included, and any other characteristics you'd like to share	22
Web survey: organization self -reports	EMIS features were critical? How did you create the business case for funding EMIS?	9
Web survey: organization self -reports	Ongoing energy management: Describe the energy management process you used to analyze information from the EMIS, identify opportunities, and take corrective actions.	9

4. Methods

This section details the research population, the qualitative data set, and data coding methods used to identify variables and develop the MBCx framework. The coding of data was performed by multiple researchers to ensure internal validity and inter-rater reliability.

4.1. *Research population*

The population analyzed in this paper came from organizations participating in the Smart Energy Analytics Campaign (Campaign) led by the U.S. Department of Energy under the Better Buildings Alliance. The Campaign is organized by Lawrence Berkeley National Lab (LBNL) [23]. The goal of the Campaign is to encourage organizations to use EMIS technology to identify energy saving opportunities for their buildings through the practice of MBCx. Organization types involved in the Campaign include higher education (31%), office (36%), laboratory (10%), hospital (10%), retail (5%), grocery (3%), healthcare (3%), and hospitality (3%). Organizations voluntarily enrolled in the Campaign and received free technical assistance and resources in exchange for providing LBNL information about their MBCx process and energy savings.

4.2. *Qualitative data set*

Throughout participation in the Campaign, each organization was interviewed by a researcher from LBNL and completed multiple surveys about their experience. All data used in this study was stripped of identifying information prior to analysis for the purpose of developing the framework. The data used for this study is outlined in Table 2. The data was recorded either by an LBNL scientist or via self-report from the organization through online surveys, as noted in the reporting method column of Table 2. The specific questions are also detailed in Table 2. The questions chosen from the Campaign for this research were all open-ended and required the organization to reflect on their experience with MBCx. This allowed for the analysis of a rich set of information that could not be gathered from strictly numerical data or responses from closed questions. The number of responses from organizations to each question are also outlined in Table 2.

4.3. *Development of the MBCx framework*

The qualitative data analysis method is similar to a previously developed inductive coding method [24] that has been used in disciplines such as design [25] and healthcare [25,26]. There were seven steps involved in analyzing the data. The following subsections explain each of these seven steps.

4.3.1. *Qualitative data was broken into elements*

All of the qualitative data from the organizations implementing MBCx was downloaded into an excel database. The data was then divided into individual elements. The original wording of the response was maintained but the responses sometimes comprised entire paragraphs. Consequently, those responses were divided into multiple elements. Each element only contained one principal concept. After breaking down the responses, there were a total of 395 elements.

4.3.2. *Codebook was developed with two tiers of keywords*

Elements were scanned for significant words to create a preliminary codebook by Coder 1, where two tiers of keywords emerged. Tier 1 keywords contained overarching themes such as analysis & reporting. Tier 2 keywords contained detailed codes related to Tier1. For example, one Tier 2 keyword was metrics, and metrics was a subset of the Tier 1 code, analysis & reporting. Coders 2 and 3 reviewed the preliminary codebook and made suggestive edits (e.g. combining similar keywords or adding additional keywords).

4.3.3. *Elements were coded with the codebook*

All elements were then coded with the finalized codebook containing 51 sets of keywords (13 Tier 1 keywords and 51 Tier 2 keywords). Each element had the potential to be assigned up to two sets of keywords. This is because some elements fell into two different categories. For example, the following element "Doesn't know if work order connection really makes sense because of false alarms that arise from new meter configurations, or controllers that are off line, etc." would fall under the keyword sets of, system for corrective actions – false alarms (system for corrective actions being the Tier 1 keyword and false alarms being the Tier 2 keyword), but also system for corrective actions – work orders. Both sets of keywords provide insight into the organizational issue experienced during their MBCx process.

4.3.4. *Elements were classified as barrier or enabler*

Coder 1 also classified each element as "barrier", "enabler", or "neutral", depending on the connotation of the element and the particular survey or interview question. For example, the following element "*There is no structured engagement or process to manage the EIS*," was marked as a barrier because it was a response to the question "*What are your biggest challenges in meeting your plans?*" Since there was not a question that would specifically elicit enablers to the MBCx process only elements that specifically point out advantages were marked as enablers. For example, "*They do weekly meetings with each region… attended even by technicians…accountability is established,*" would be marked as an enabler.

"*Can import 15-min data into software*" was marked as neutral because although interval data is important to MBCx, it was simply an attribute of the organization's metering in response to "*Please give us an overview of your current data collection…*" and not necessarily highlighted as an extremely successful strategy.

4.3.5. *Element coding was validated by multiple coders*

Portions of the elements were dispersed between three additional coders for review. These coders are experts with graduate degrees, work experience, and numerous publications related to energy systems and engineering sustainability. There were four coders and each element was coded by at least three coders in order to create a consensus and reduce subjectivity. Any discrepancies between coders were discussed and resolved. A few additional keyword codes emerged and were added to the codebook. Coder 1 then went through a third round of coding and updated respective elements with the emergent keyword codes.

The average percent agreement between Coder 1 and Coders 2, 3 and 4 was 92%. This was determined by the sum of discrepancy with the keyword chosen by Coder 1 and the number of times an additional coder suggested another keyword for a particular element. Table 3 contains details on the specific number of discrepancies and additional keywords suggested. Since the coding for this study involved multiple sets of keywords for each element and 51 different codes, the likelihood of agreement by chance was very low. There are multiple measurements for interrater reliability with more than two raters, such as Fleiss's kappa, but a simple comparison between coders was chosen because the aforementioned ratings are intended for observational studies [27].

4.3.6. *Elements with the same keywords synthesized into variables*

Elements with the same set of keywords were then synthesized to define variables impacting the MBCx process. Essentially, Tier 1 keywords that emerged from the qualitative data coding are now the categories and Tier 2 keywords are now the names of the variables in the framework. For example, the elements *"Challenges in moving too much data, hitting the sweet spot of getting enough info for action*" and *"Dealing with massive amounts of data, but not getting value out of the data. Run out of space for storing trend data, so have to dump it*," both had the keyword set of data – overload. These elements, among others with the same keyword set, were synthesized into the variable definition for data – overload defined as: *"Too much data imported into EMIS. Can lead to challenges in determining amount of data that is useful, mining data, determining how to create value or metrics, managing volume of data, and managing storage space for volume of data."* Synthesis also involved analyzing the frequency the variable was encountered as a barrier or enabler to measure the impact of variables on the MBCx process.

4.3.7. *Variables were categorized by MBCx phase to create the framework*

Variables were then categorized by MBCx phase to create the framework. The MBCx phases used were those defined in Table 1. Similar to the original coding phase, three different coders then categorized each variable by the respective MBCx phase using the documented description of what each phase entails. Coder 1 reviewed all three coding arrangements and noted discrepancies. To reduce subjectivity, discrepancies were then discussed and the categorization of variables into the respective MBCx phase was finalized. Finally, a framework was created which contained a category for each major MBCx phase with the respective variables (with the frequency each variable was encountered as a barrier or enabler). The framework is explained in detail in the results section.

5. **Results**

The MBCx framework that emerged from the qualitative data is comprised of 51 variables that fall within 13 different categories and can be found in the Appendix, Table A1. Within the variable definitions, there are examples of strategies used in practice related to the variable and also examples from the data of how the variable can act as a barrier or lead to challenges for organizations during the MBCx process. The variables are organized by the three phases of the MBCx process: MBCx Planning Phase, EMIS Configuration Phase, and the MBCx Implementation Phase. Table A1 table also lists the frequency at which each variable occurred, whether it was classified as a barrier or enabler, and the percent of occurrences in which it was classified as a barrier. The intent of the MBCx framework is for organizations using MBCx to learn from and anticipate the barriers and enablers experienced by other organizations in practice. However, the MBCx framework does not necessarily contain all of the barriers and enablers an organization might face during the MBCx process.

Table 3
Percent agreement for data coding.

In comparison to Coder 1

Coder #	#	Discrepancies	Additional	Total	% Agreement
2	263	5	23	28	89
3	265	3	5	8	97
4	262	8	19	27	90
				Average	**92**

Variables in the framework range from overt to unexpected, based on the definition of MBCx. For example, *measurement and verification* is defined in the MBCx Implementation phase as it is a common method used to quantify savings, so, the emergence of this variable is not surprising. But *business case incentives*, defined as "financial rebates for energy savings" is a variable that organizations might not be aware of by simply understanding the general MBCx process. The category with the most variables (20%) is *analysis & reporting* (see Table 6). *Analysis & reporting* is a single category because these actions often overlap with each other; any analysis carried out is often reported in some way. Granderson et al. [4] define the *Monitoring Action Plan (MAP*) is an essential document for MBCx, which outlines the systems monitored and key analytics and metrics available through the EMIS and is the category with the second most variables (12%). The categories *RFP and occupant* both only have one variable because the variables, *occupant engagement* and *RFP developing specifications*, did not naturally fall within any of the other categories. The phases within the MBCx process had 27% (MBCx Planning Phase), 25% (EMIS Configuration Phase), and 47% (MBCx Implementation Phase) of the variables.

The following seven variables were classified as a barrier 100% of the time. That is, if the variable was encountered by the organization, it was always related to a problem:

data – naming conventions; data – overload; MAP – maintain; metering – general; staff – energy manager/champion; staff – time; and, system for corrective actions – false positives.

Organizations expressed the need for an energy manager or champion (related to the variable *staff – energy manager/champion*) devoted to overseeing the MBCx process, but many times existing staff did not have the capacity for new responsibilities and organizations experienced difficulties making the business case for a new hire.

The average frequency a variable was classified as a barrier was 5.25. There were 17 variables that were above average barriers, meaning they were common for the data set, occurring 6 times or more. Those variables are listed in Table 4, organized by MBCx phase and then in descending order by "# Times Classified as Barrier". Data – configuration was the top barrier found from the data set occurring 20 times. The high frequency of this variable underscores the difficulty when configuring or integrating data into EMIS. The discussion section offers rationale about why these barriers exist and some are so prevalent.

Table 4
Variables classified as barriers 6 times or more.

MBCx phase	Category	Variable	# Times variable occurred	# Times classified as Barrier	# Times classified as	% Variable classified
MBCx planning	EMIS	Developing specifications	20	14	2	70
	Staff	Training/Skills	15	10	0	67
	Business	Budget for investment	12	9	0	75
	RFP	Developing specifications	12	8	0	67
	Business	Management Support/Funding	9	7	2	78
	MAP	Strategies	42	6	1	14
EMIS configuration phase	Data	Configuration	22	20	0	91
	IT	Data architecture	21	14	0	67
	FDD	Strategies	12	11	1	92
	Data	Overload	9	9	0	100
	Data	Quality	10	9	0	90
	FDD	Configuration	23	8	0	35
MBCx implementation phase	Analysi s & Reporti	Measurement and verification	22	16	0	73
		Time	12	12	0	100
	Staff	Acceptance	12	9	1	75
	Analysis & Reporting	Metrics	15	7	0	47
		Payback/ROI	14	7	3	50

Very few variables were found to be enablers, with the highest occurrence being *business case – payback/ROI* classified as an enabler three times. This is not surprising, due to the nature of the questions analyzed (see Table 2), which implicitly solicit more barriers than enablers, as noted in Section 5.1 Limitations. Interestingly, there were 12 variables, including *business case – payback/ROI*, with conflicting results. Meaning, these variables were encountered as a barrier to one organization and an enabler to another. Those variables are listed in Table 5 organized by MBCx Phase. For example, *business case – payback/ROI* was considered a barrier seven times and an enabler three times. One organization had difficulty making the business case for the initial investment for MBCx due to lack of cost information, while another was able to justify large investments with documented savings of previously implemented measures.

Table 5
Variables classified as a barrier and enabler.

MBCx Phase	Category	Variable	# Times	# Times classified as Barrier	# Times classified as	% Variable classified
MBCx planning	Business case	Management Support/Funding	9	7	2	78
MBCx planning	EMIS	Developing specifications	20	14	2	70
MBCx planning	MAP	Energy management	27	5	1	19
MBCx planning	MAP	Strategies	42	6	1	14
EMIS configuration phase	FDD	Strategies	12	11	1	92
MBCx phase	Analysis & Reporting	Strategies	7	2	2	29
MBCx phase	Business case	Payback/ROI	14	7	3	50
MBCx phase	Business Case	Strategies	5	2	1	40
MBCx phase	FDD	Fault identification	18	5	1	28
MBCx phase	Staff	Acceptance	12	9	1	75
MBCx phase	System for corrective actions	Strategies	11	2	2	18
MBCx phase	Third party support	Service providers	19	5	1	26

Table 6 shows the breakdown of the percent of variables and barriers in each category. The category with the most barriers is *data*, with 16% and it only had 8% of the variables. *Staff* and *analysis & reporting* both had 14% of the barriers. The phases of the MBCx process shared the barriers almost evenly with MBCx Planning Phase having 30% of the barriers (27% of total variables), EMIS Configuration Phase with 36% (25% of total variables), and MBCx Implementation Phase with 34% (47% of total variables).

Table 6
Percent of variables and barriers in each category

Category	% Variables	% Barriers
Analysis & Reporting	20	14
MAP	12	9
Business case	10	9
Staff	10	14
System for corrective actions	10	5
Data	8	16
Metering	8	4
FDD	6	9
Third party support	6	2
EMIS	4	7
IT	4	7
Occupant	2	1
RFP	2	3

5.1. Limitations

There are several limitations to this research. First, the organizations involved in the Smart Energy Analytics Campaign were self-selected, comprising participants in a voluntary initiative. These organizations also represent relatively early adopters of MBCx within the commercial buildings sector. Therefore, this sample may be generally representative of organizations interested in practicing MBCx. Also, organizations in the study were at different phases of the MBCx process, meaning, barriers and enablers that occur during the MBCx Implementation phase might not be fully captured. Although an existing EMIS or the installation of a new EMIS was required for inclusion in this data set, some organizations were not yet at the point of the MBCx process to identify and resolve issues. It is important to note that recall bias can impact the accuracy of the self-reported data during the interviews. This is more relevant to the enablers of the MBCx process, as organizations were specifically reporting issues or barriers in order to receive technical assistance and, as mentioned, the nature of the questions implicitly solicit more barriers than enablers (see Table 2). And, since this data was reviewed post-interview, the context of some statements was difficult to determine, leading to many elements classified as neutral. Third, the qualitative data coding was initially somewhat subjective. However, this research aimed to reduce this subjectivity by using multiple subject matter experts as coders to confer on discrepancies.

6. Discussion

The EMIS Configuration Phase contained 25% of the variables, but contained 36% of the barriers. This suggests that an organization is likely to run into barriers during the EMIS Configuration Phase. The MBCx planning phase has 27% of the variables, and just 30% of the barriers. A more thorough analysis of the individual barriers themselves can lead to a better understanding of the distribution of barriers; whether organizations actually experience fewer issues during planning or if poor planning does lead to more issues later in the process

Although some of the variables had a low number of occurrences, this could be because some organizations were earlier in the process. The variables MAP – maintain energy savings and *system for corrective actions – false positives* only occurred twice, but were classified as a barrier both times. Since these variables are Likely to impact the MBCx Implementation Phase, they could be expected to occur for other organizations as they reach the later phases of the process.

Some variables experienced as barriers were unsurprising and this emphasizes the need for more research on enablers to overcome them. The highest occurring barrier was *data – configuration*, which is a crucial step during the EMIS Configuration Phase. Data configuration commonly slows the MBCx process, as supported by this research and previous case studies that described the same problem. The framework lists some of the causes of this barrier, like limited data due to legacy BAS, or issues due to different vendors or controls companies in hopes that organizations could then anticipate these issues and make sure to have the right people at the table to resolve them. Although not explicit in this data, issues with data configuration and data quality might also occur during ongoing use of EMIS due to failed sensors or the need for recalibration. Organizations that have a robust maintenance process for their EMIS infrastructure are less likely to have recurring data quality issues.

The variable *staff – acceptance*, classified as a barrier nine times, has been an issue since the advent of IS technologies such as fault detection and diagnostics tools. It is normal for organizations to experience difficulties with institutionalizing MBCx due to staff being hesitant to accept the new process and technologies. Nevertheless, organizations new to MBCx could benefit from having this pointed out in the framework. By being aware of this potential barrier, time can be set aside to do things like, point out the benefits for building operators, or give examples of problems discovered by other organizations using MBCx that may otherwise go unnoticed and could help dispel some of the staff members' hesitation. Organizations could also experiment with extrinsic incentives to encourage staff to practice MBCx. These are suggested enablers that could be studied in detail in future research.

The variable *analysis & reporting – measurement & verification* (M&V) was the second highest occurring barrier. There are many ways to satisfy the "Verify performance improvement" step of the MBCx Implementation Phase, including operational checks, energy consumption tracking, and tracking of other key performance indicators and performance metrics. Many organizations, however, desire to assess savings through a formalized M&V approach. In this research, organizations reported challenges using their EMIS embedding and automating M&V capabilities, often not knowing where to start. This illustrates that while M&V is an emerging and potentially powerful capability in many EMIS offerings, users are still acquiring the practical experience required to successfully utilize it.

Variables that were classified as barriers 100% of the time also warrant further research. *Staff – time* and *data – overload* both lead to the struggle in finding a balance for getting the most value out of MBCx. The MBCx process does not define how much data or time leads to the most impact on energy savings.

As expected, this research does not provide in-depth insight on the enablers to MBCx, yet it is worth considering variables that had conflicting results. This demonstrates that while there are variables that commonly cause barriers to the process, when anticipated proactively, organizations can leverage these to enable the process. Moreover, variables found to be barriers 100% of the time could potentially become enablers as the state of practice of MBCx evolves. For example, currently, staff – *energy manager/champion* was only found to be a barrier. This could be because the current norm is not to have a staff member solely responsible to manage energy use. If an organization is able to define this new role, it could become an enabler to the process, but when an organization was lacking this role, it was a barrier.

Variables found to be completely neutral, neither marked as an enabler or barrier, might emerge differently if studied more specifically. For example, the variable *business case – incentives* was neutral, but intuitively, an incentive to something would be expected to be an enabler.

Practitioners implementing MBCx should take away that there is no single remedy to reduce barriers. Barriers occur throughout the process and can be related to tools to support the process, and the staff, leading to interconnected issues between technology and human resources. However, focusing on variables within several key categories can help. For example, analysis & reporting, staff, and data compose 44% of reported barriers. Getting these variables correctly aligned removes about half of the reported barriers. Going further, making the business case, properly setting up the monitoring action plan (MAP), and fault detection and diagnostics (FDD) can reduce the reported barriers by over 70%.

7. Conclusion

MBCx is becoming a more common method to discover and maintain energy savings in buildings, but barriers to the process still exist, as validated by this research. By developing a MBCx framework this research has synthesized the experiences of over 40 organizations to define emergent variables and begin defining commonly experienced barriers and enablers. The framework reveals that variables impacting the MBCx process can act as barriers to one organization and enablers to another, depending on the circumstances within the organization. Although some variables in this research occurred exclusively as barriers, those with conflicting results reveal that this exclusivity is not infallible. This MBCx framework can help communicate these variables, and by simply increasing awareness, organizations will be able to better understand and plan for them.

Future research can expand this framework and add to the understanding of the MBCx process. Although best practices and guidebooks exist for MBCx, a large data set that explicitly focuses on enablers to MBCx for practicing organizations could help validate these existing resources. More empirical studies can investigate the relationships between specific variables. For example, the highest occurring barrier of *data configuration* (and associated data quality problems) could lead to the question: What changes to the data configuration process would result in more efficient and consistent EMIS implementation, with higher data quality? For variables that are expected, like *staff – acceptance*, researchers could see if there are interacting effects between variables such as: Does third party support slow or advance staff acceptance of MBCx?

There is a strong need to elicit and validate common enablers to the MBCx process. Future research can also pull from existing information systems research to help design these studies and define variables to measure the success of MBCx.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.enbuild.2018.03.033.

References

[1] K. Brown, M. Anderson, J. Harris, How monitoring-based commissioning contributes to energy efficiency for commercial buildings, in: Proceedings of the 2006 ACEEE Summer Study of Energy Efficiency in Buildings, 3, Washington, D.C., 2006, pp. 27–40.

[2] M.A. Piette, S.K. Kinney, P. Haves, Analysis of an information monitoring and diagnostic system to improve building operations, Energy Build 33 (8) (Oct. 2001) 783–791.

[3] J. Granderson, M.A. Piette, G. Ghatikar, Building energy information systems: user case studies, Energy Effic 4 (1) (2011) 17–30.

[4] H. Kramer, E. Crowe, and J. Granderson, Monitoring-based commissioning plan template, Jun-2017. [Document Online]. Available: http://eis.lbl.gov/MBCx. [Accessed: 14-July-2017].

[5] E. Mills, P.A. Mathew, Monitoring-based commissioning: benchmarking analysis of 24 university buildings in California, Energy Eng. Atlanta 111 (4) (2014) 7–24.

[6] J. Granderson, G. Lin, Building energy information systems: synthesis of costs, savings, and best-practice uses, Energy Effic 9 (6) (Dec. 2016) 1369–1384.

[7] A. Meiman, K. Brown, M. Anderson, Monitoring-based commissioning: tracking the evolution and adoption of a paradigm-shifting approach to retro-commissioning, in: Proceedings of the 2012 ACEEE Summer Study, Pacific Grove, California, 2012.

[8] J. King and C. Perry, Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings, American Council for an Energy-cient Economy, Washington, DC, Research Report A1701, Feb. 2017.

[9] M. Anderson, A. McCormick, A. Meiman, K. Brown, Quantifying monitoring-based commissioning in campus buildings: utility partnership program results, lessons learned, and future potential, 15th National Conference on Building Commissioning, Chicago, IL, 2007.

[10] D. Robey, User attitudes and management information system use, Acad. Manag. J. 22 (3) (1979) 527–538.

[11] R. Haux, Health information systems – past, present, future, Int. J. Med. Inf. 75 (3) (Mar. 2006) 268–281.

[12] A.E. Coronado M, M. Sarhadi, C. Millar, Defining a framework for information systems requirements for agile manufacturing, Int. J. Prod. Econ. 75 (1) (Jan. 2002) 57–68.

[13] T. Lucey, Management Information Systems, Thomas Learning, Ninth. London, 2005.

[14] S. Petter, W. DeLone, E.R. McLean, Information systems success: the quest for the independent variables, J. Manag. Inf. Syst. 29 (4) (Apr. 2013) 7–62.

[15] H. Friedman, E. Crowe, M. Effinger, The Building Performance Tracking Handbook, California Commissioning Collaborative, 2011.

[16] N. Motegi, M.A. Piette, S. Kinney, J. Dewey, Case studies of energy information systems and related technology: operational practices, costs, and benefits, in: Proceedings of the Third International Conference for Enhanced Building Operations, Berkeley, CA, 2003.

[17] S. Narayanan, M.G. Apte, Philip Haves, M.A. Piette, J. Elliott, Systems approach to energy efficient building operation: case studies and lessons learned in a university campus, in: 2010 Summer Study Conference Proceedings, 3, Washington, D.C., 2010, pp. 296–309.

[18] T. Webster, Trends in Energy Management Technologies Part 5: Effectiveness of Energy Management Systems: What the Experts Say and Case Studies Reveal, Lawrence Berkeley National Laboratory, 2005 Nov.

[19] P. Henderson, M. Waltner, Real-time Energy Management: A Case Study of Three Large Commercial Buildings in Washington, DC, Natural Resources Defense Council, 2013.

[20] F.J. Smothers, K.L. Kinney, Benefits of enhanced data quality and visualization in a control system retrofit, in: Proceedings of ACEEE Summer Study on Energy Effciency in Buildings, Pacific Grove, California, 2002.

[21] T. Owen, A. Pape-Salmon, B. McMurchy, Employee engagement and energy information software supporting carbon neutrality, in: Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, California, 2010.

[22] H. Kramer, Data-driven energy efficiency: how energy information systems can improve programs, Presented at the 24th National Conference & Expo: Energy Efficiency Finding the Ideal Formula, San Diego, CA USA, 2014.

[23] About the smart energy analytics campaign, Smart Energy Analytics Campaign, 2017. [Online]. Available: https://smart-energy-analytics.org/about. [Accessed: 14 July 2017].

[24] D.R. Thomas, A general inductive approach for analyzing qualitative evaluation data, Am. J. Eval 27 (2) (Jun. 2006) 237–246.

[25] J.L. Blizzard, L.E. Klotz, A framework for sustainable whole systems design, Des. Stud. (2012) 456–479.

[26] N.G. Weiskopf, C. Weng, Methods and dimensions of electronic health record data quality assessment: enabling reuse for clinical research, J. Am. Med. Inform. Assoc. 20 (1) (Jan. 2013) 144–151.

[27] K.A. Hallgren, Computing inter-rater reliability for observational data: an overview and tutorial, Tutor. Quant. Methods Psychol. 8 (1) (2012) 23–34.

Appendix

Table A1

MBCx framework.

MBC	Category	Variable	Variable description	# vari occ urred	# ba	# en	% (%
MBC Phase	Business	Budget for investment	The budget or funding for EMIS related investments such as hardware (e.g. submeters); ongoing software cost; or ECMs. **Potential challenges:** demonstrating the value of EMIS to secure budget.	12	9	0	75
MBC Phase	Business	Manageme Support/ Funding	Management support and buy-in to EMIS. Strategies include: creative ways of presenting EMIS benefits to gain management support (E.g. pitch as maintenance savings benefit); using pilot project savings to gain management support/funding. **Potential challenges:** with payback thresholds set by management; risk aversion of management; management requesting M&V of projects.	9	7	2	78
MBC Phase	EMIS	Developing specificatio	Decisions during EMIS selection and specific features needed such as the reporting method and capability of EMIS (e.g. dashboard; frequency of EMIS data update). **Potential challenges:** finding EMIS with flexibility and specific features; developing RFP; determining if it is best to own EMIS or use the software as a service model.	20	14	2	70
MBC Phase	Monitori Action	Commissio	Types of commissioning such as connected commissioning or retro commissioning. Strategies include: programs to continuously commission or MBCx; periodic retro-commissioning; using third party service providers for retro-commissioning; peer groups for continuous commissioning; connected commissioning. Organizations often interested in peer groups to learn more about strategies.	7	3	0	43
MBC Phase	Monitori Action	Energy manageme team	Energy management team/roles. Strategies include: different reports based on role in organization; necessity of collaboration between different roles. Examples of different roles: Finance person within energy group (document ROI); Field engineers (monitoring EMIS daily); Managers (receive reports); Controls engineer; Energy engineer; Data scientist (to program FDD); Property manager (receive reports); Facility team or Commissioning staff (manage system for corrective actions); Director of Operations (receive reports); Consultant team (manages EMIS). **Potential challenges:** when existing organization has staff constraints or does not have team members with the expertise to carry out monitoring action plan.	27	5	1	19
MBC x Planning	Monitoring Action Plan	Scaling	Strategies for scaling EMIS or MBCx to multiple buildings within a portfolio. Strategies include: Central database for all facilities; EMIS standardized across portfolio after a pilot run; Support from third party to support scaling EMIS to portfolio. **Potential challenges:** with deploying EMIS in multiple buildings within a portfolio.	9	4	0	4 4

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Table A1 (*continued*)

MBCx Phase	Category	Variable	Variable description	# Times variable occurred	# Times barrier	# Times enabler	% Barrier (%)
MBCx Planning Phase	Monitoring Action	Strategies	Tools or strategies defined in the Monitoring Action Plan (MAP) used to identify issues and energy conservation measures. Strategies include: BAS trending for MBCx; FDD alarms monitored consistently (daily; weekly; etc.); checking for overrides on temperature settings; eliminating off-hours energy use (e.g. equipment running overnight); using historical trends to develop strategies; re-commissioning of upgrades to old hardware and new installs implemented by controls and mechanical contractors; daily systems monitoring; improvements to set points; schedules; and sequences; development of process standards; alarms and notifications for demand thresholds; focus on major equipment due to time constraints; system for occupants to report hot/cold to buildings; real-time data to allow for proactive responses; identification and understanding of peak demand; review of interval data. **Potential challenges:** if there is not a structured process to use EMIS manual FDD or other analytics; and difficulty deciding between in-house third party commissioning.	42	6	1	14
MBCx Planning Phase	Metering	Interval	The necessary interval data from and whether it is real time vs. delayed. Interval data may be used only on specific buildings or equipment. Upgrades to smart meters may be necessary to obtain instantaneous interval data. **Potential challenges:** if there is no availability of interval data; or utility only providing day-behind interval	15	2	0	13
MBCx Planning Phase	Metering	Submetering	Submetering used for end-use (e.g. mechanical equipment; data centers); break out buildings from a main meter. **Potential challenges:** configuring submeters; determining how many submeters are necessary for without a high cost.	8	3	0	38
MBCx Planning Phase	Metering	Systems or metered	Systems metered; monitored; points; Examples of Systems Metered: Building level meters; all utilities; integration of metering data from utility bills (electrical, gas, water bill); central mechanical equipment; terminal equipment; chilled and hot water systems. **Potential challenges:** determining proper number of points to meter due meter cost; determining number of points to bring into EMIS.	27	3	0	11
MBCx Planning	RFP	Developing specifications	Development of request for proposal (RFP) for specifications such as: back-end; specific FDD rules; FDD features; EMIS features; EMIS integration with maintenance operations. **Potential challenges:** developing RFP to meet needs or understanding proposal submittals.	12	8	0	67

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Table A1 (*continued*)

MBCx Phase	Category	Variable	Variable description	# Times variable occurred	# Times barrier	# Times enabler	% Barrier (%)
MBCx Planning Phase	Staff	Energy Manager/ Champion	A staff member exclusively devoted to spearheading the MBCx and use of **Potential challenges:** for organizations without a full-time energy manager challenges making the case for a full-time energy manager.	4	4	0	100
MBCx Planning Phase	Staff	In House staff	Use of in-house staff (as opposed to third party) for management of EMIS and MBCx. Can lead to lower costs and full benefit of incentives from utility. **Potential challenges:** staff training	5	2	0	40
MBCx Planning Phase	Staff	Training/Skills	Skills/Training required to use EMIS functionality; analyze EMIS data; configure and utilize FDD; implement ECMs; develop useful EMIS dashboard and metrics **Potential challenges:** when there are staff or time constraints involving any the required skills or training above.	15	10	0	67
EMIS Configuration Phase	Data	Configuration	Configuring or integrating data from hardware into EMIS including BAS and meters. **Potential challenges:** with data integration BAS (specifically legacy limited data due to legacy BAS or other system; data integration from different vendors or controls companies systems); getting all data into a central location; determining how much data bring in; difficulty bringing in data due to IT issues.	22	20	0	91
EMIS Configuration Phase	Data	Naming conventions	Data naming conventions or tagging protocol. **Potential challenges:** developing conventions; tagging protocol strategy.	3	3	0	100
EMIS Configuration Phase	Data	Overload	Too much data imported into EMIS. **Potential challenges:** Determining amount of data that is useful; mining data; determining how to create value metrics; managing volume of data; managing storage space for volume of data.	9	9	0	100
EMIS Configuration Phase	Data	Quality	The quality of data streams being into EMIS. **Potential challenges:** getting accurate data from meters (e.g. meters o□ine; meter calibration); troubleshooting data losses and inconsistency (technical vs. human error); data errors due to communication problems (e.g. drop-data spikes); data history not being retained.	10	9	0	90
EMIS Configuration Phase	EMIS	Configuration	Setting up the interface or dashboard of EMIS/EIS or other specifics related to interface and dashboard configuration. **Potential challenges:** in configuring dashboard to support needs; creating EMIS dashboard for public; creating a real-time EMIS dashboard.	6	5	0	83

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Table A1 (*continued*)

MBCx Phase	Category	Variable	Variable description	# Times variable occurred	# Times barrier	# Times enabler	% Barrier (%)
EMIS Configuration Phase	FDD	Configuration	Methods to set up or manage fault detection and diagnostics (FDD) rules faults. Strategies include: in-house development of FDD to allow staff to better understand system; third party configuring FDD; use of FDD used to uncover faults and energy and operational savings; standard FDD rules deployed at all buildings within a portfolio; additional FDD alarms added after systems optimized; coupling FDD alarms with other strategies to maintain building energy baseline. **Potential challenges:** writing FDD testing FDD rules; vendor configuring a limited number of rules; diminishing returns of FDD after initial issues	23	8	0	35
EMIS Configuration Phase	FDD	Strategies	Need for peer support for fault and diagnostics (FDD) in hopes to learn FDD strategies from similar implementing FDD. **Potential challenges:** (see FDD – Configuration), leading many organizations to seek out peer support.	12	11	0	92
EMIS Configuration Phase	IT	Data	Data server (hosting data; on-site or cloud); database management; and the network or protocol for sending data. Connecting to external servers. **Potential challenges:** in the creation of single data warehouse; desire for open communication protocols (vs. proprietary); need for servers dedicated specifically to BAS; loss of data without data repository/backup; integration of data into EMIS (time and effort); data access; coordination with IT team.	21	14	0	67
EMIS Configuration Phase	IT	Data security	The security of data being sent from meters and systems to EMIS. **Potential challenges:** with IT lockdown of BAS servers; necessity of private networks (vs. public).	5	4	0	80
EMIS Configuration Phase	Monitorin Action	Building Automation System (BAS; BMS; BMCS; EMS; EMCS)	The integration of BAS data for use EMIS with the goal of saving energy. Strategies include: BAS data used for FDD; BAS trending for MBCx; reprogramming BAS routines for energy savings; documentation of BAS control sequences for insight on building operation. **Potential challenges:** with multiple controls companies for BAS; necessity central location to view BAS data; BAS data causing network issues; updating BAS in order to integrate data into	12	5	0	42
EMIS Configuration Phase	Metering	General	General metering concerns such as calibrating and accessing meter data. **Potential challenges:** with meters out of calibration; accessing meter data (not available through a network and must manually export on site).	3	3	0	100
EMIS Configuration Phase	Occupant	Engagement	Involvement of occupants in buildings EMIS. Strategies include: public facing EMIS dashboard with aims to change occupant behavior; dashboard for occupants to report hot and cold; to encourage energy saving behavior. **Potential challenges:** in developing public-facing dashboards.	7	3	0	43
EMIS Configuration Phase	Third Party Support	Software vendors	Use of vendors to set up EMIS; etc. Strategies include: Vendors configuring FDD rules; partnering with vendors to resolve EMIS software issues.	4	0	0	0

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Table A1 (*continued*)

MBCx Phase	Category	Variable	Variable description	# Times variable occurs	# Times barrier	# Times enabler	% Barrier (%)
MBCx Implementation Phase	Analysis & Reporting	Baseline	The use of baselining for M&V (meter-level baselines or pre- for the baseline of a key performance indicator to measure deviations over time; for regression analysis; or to understand historical trends. **Potential challenges:** developing baseline and incorporating weather normalization.	4	2	0	50
MBCx Implementation Phase	Analysis & Reporting	Benchmarking/EU	Benchmarking or EUI where energy compared to other similar buildings analysis; reporting; or to set energy saving goals. Examples include: comparison of EUI between similar buildings; calculating EUI from utility bill. **Potential challenges:** for buildings unique usage that do not have a comparison.	13	1	0	8
MBCx Implementation Phase	Analysis & Reporting	Demand	Analyzing current demand and a strategy for peak load reduction; demand response; etc. and may submeter. Examples includes: EMIS used for and informal demand; determining on network; demand testing to determine main circuits responsible load; setting alarms or notifications based on load; using EMIS to peak load; regression modeling to predict demand and make control changes; demand controlled **Potential challenges:** determining demand due to inaccurate meter automating demand response	16	3	0	19
MBCx Implementation Phase	Analysis & Reporting	Frequency	The frequency with which reports are generated using EMIS data and shared with stakeholders or building Frequency can be weekly; monthly; quarterly; etc. Strategies include: changes in frequency depending on role in organization (E.g. monthly reports to management and daily reports to technicians and energy analysts); meetings to review reports.	12	0	0	0
MBCx Implementation Phase	Analysis & Reporting	Heat map	The use of heat maps to find issues review energy use or check building schedule.	3	0	1	0
MBCx Implementation Phase	Analysis & Reporting	Manual methods	Analysis or reporting methods; such M&V; performed manually. Examples include: spreadsheet comparing nameplate data to performance; reviewing trends and comparing to actual values. **Potential challenges:** due to time constraints and generally the goal is automate.	7	3	0	43
MBCx Implementation Phase	Analysis & Reporting	Measurement and Verification	Methods of measurement and (M&V) for ECMs; quantification of savings; and proof for rebates and incentives. May require submetering. **Potential challenges:** to embed M&V into EMIS and automate M&V.	22	16	0	73

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MBCx Phase	Category	Variable	Variable description	# Times variable occurred	# Times barrier	# Times enabler	% Barrier (%)
MBCx Implementation Phase	Analysis & Reporting	Metrics	Specific metrics that are reported to track change of energy use due to the use of MBCx or RCx and to track and set goals for buildings within a portfolio. Specific examples of metrics include: energy use; cost (demand charges; taxes; fees); GHG emissions; EUI; utility bill based metrics; load ratio (high or low). **Potential challenges:** analyzing EMIS data; developing KPIs; the creation of different metrics/dashboards for different roles within an organization; transitioning from manual to automatic analysis; and difficultly comparing EUI due to variations in building use.	15	7	0	47
MBCx Implementation Phase	Analysis & Reporting	Strategies	General analysis or reporting strategies. Examples include: FDD alarms reviewed in reporting meetings; integrating bill processing with EMIS analytics; using analytics to maintain optimal performance; using analytics to investment in projects. **Potential challenges:** with the development of reporting and analytics.	7	2	2	29
MBCx Implementation Phase	Analysis & Reporting	Weather normalizatio	The integration of weather in analysis or reporting. **Potential challenges:** with integration of the weather normalization.	4	2	0	50
MBCx Implementation Phase	Business	Incentives	Financial Incentives or rebates for savings. Examples include: Energy efficiency incentives from utility company; rebates from utility company; M&V used to verify incentives and gain rebates; rebates/incentives used to fund energy manager position or third party service; payment from utility company to reduce peak load.	6	0	0	0
MBCx Implementation Phase	Business	Payback/ROI	Payback or Return on Investment (ROI) an energy conservation measure identified by using EMIS or of the EMIS itself. Strategies include: ROI used to prioritize projects; using estimated savings and annual price estimates from vendor to determine payback; pilot projects used demonstrate payback. **Potential challenges:** with a specific payback time required in order to project (e.g. client only interested in 1 year payback); difficulty obtaining cost info necessary to develop ROI numbers; diminishing ROI on FDD software.	1	7	3	50
MBCx Implementation Phase	Business	Strategies	General justification strategies for the business case of EMIS or ECMs by using EMIS. Strategies include: justify funding as part of a new construction project; using data visualization to help determine investment strategy; business case around pilot building; using benchmarking to make business case; using examples of others' success with EMIS to make business case to management. **Potential challenges:** accessing data to develop initial business case.	5	2	1	40

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MBCx Phase	Category	Variable	Variable description	# Times variable	# Times barrier	# Times enabler	% Barrier (%)
MBCx Implementation Phase	FDD	Fault identification	FDD strategies used to identify issues causing faults; and opportunities found for energy conservation measures. FDD may also be integrated with the work order system. Often needed to sustain ECM savings. Strategies include: FDD identifies wasted energy; FDD cross-checks equipment operation to operating hours; FDD identifies low airflow due to failed damper; FDD identifies failed sensors; FDD identifies reheat valves cycling improperly. **Potential challenges:** integrating FDD with system for corrective actions or work orders.	18	5	1	28
MBCx Implementation Phase	Monitoring Action Plan	Maintain	Maintaining savings achieved from **Potential challenges:** when there is no FDD to maintain savings; due to the human factor of maintaining savings needing people to regularly check systems).	2	2	0	100
MBCx Implementation Phase	Staff	Acceptance	Staff acceptance or buy-in of MBCx and institutionalizing the MBCx process. **Potential challenges:** when staff resist accepting EMIS or do not use EMIS; staff manually operating system (e.g. BAS) overriding EMIS; issues with staff maintaining savings.	12	9	1	75
MBCx Implementation Phase	Staff	Time	Anything related to staff or person-required for analysis; measure implementation; etc. **Potential challenges:** due to labor bottlenecks; time to analyze EMIS data to gain insight; time to work with EMIS service providers; time to implement ECMs; time required for root cause analysis of issues.	12	12	0	100
MBCx Implementation Phase	System for Corrective Actions	False	False alarms from smart alarms or false positives for FDD faults. **Potential challenges:** integrating alarms with system for corrective actions. Examples include: alarm when there is no issue; alarm from new meter configuration.	2	2	0	100
MBCx Implementation Phase	System for Corrective Actions	Measures	Specific issues identified and fixed and ECMs implemented. Examples of Issues Fixed (Also see FDD Fault Identification): VAV boxes open improperly; Simultaneous heating and cooling; Air handler running at maximum capacity; Overcooling; Simultaneous power-up of equipment; Single set points in BAS (as opposed to having a heating and cooling set point); Reheat valves modulating with parent AHU off; VFDs operating at constant velocity; Broken damper actuator preventing reset strategy. Examples of Measure implemented: Reduce outside air to minimum code requirements; Reduction of exterior lighting; Equipment shutdown sequencing; Schedule changes (e.g. no lighting on weekends and off hours); Zoning to reduce heating and cooling in unused areas; Lighting retrofits; Standardization of heating and cooling set points; Proper air change rates; Optimizing lead/lag control in chilled water and hot water; pump operation; Using occupancy sensors to create AHU schedules; Adding VFDs to hot water pump; Static pressure and temperature resets	22	2	0	9

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Table A1 (*continued*)

MBCx Phase	Category	Variable	Variable description	# Times variable occurs	# Times barrier	# Times enabler	% Barrier (%)
MBCx mentatio Phase	System for Corrective Actions	Prioritize	Methods used to prioritize measures; issues; or projects identified using Strategies include: Prioritizing FDD faults; prioritizing equipment based on power consumption; prioritizing FDD faults by cost impact; prioritizing buildings within portfolio by benchmarking; prioritizing projects by changes in annual energy use. **Potential challenges:** developing prioritization strategy for organization's needs.	8	2	0	25
MBCx mentatio Phase	System for Corrective Actions	Strategies	General strategies for a system for corrective actions: partnering with vendors to resolve issues; FDD alarms reviewed and assigned to technicians weekly; EMIS enabling quick detection issues; choosing vendor with ability to integrate into existing maintenance operations. **Potential challenges:** finding EMIS that integrates well with current system for corrective action; developing a process for tracking and fixing issues.	11	2	2	18
MBCx mentatio Phase	System for Corrective Actions	Work orders	Process for fixing issues or energy conservation measures. Strategies include: Integration of FDD alarms with work order system; manually creating work orders based FDD alarms; EMIS work orders tracked with general facility management work orders; commissioning agent issues and working with technicians to take corrective actions **Potential challenges:** in integrating with work orders due to false alarms; coordination with third parties; alarms from FDD with resolution.	11	4	0	36
MBCx mentatio Phase	Third Party Support	Contractors	Use of contractors to implement energy conservation measures found by other people. Strategies includes: New physical completed by controls and mechanical contractors; contractors to complete retrofits.	2	0	0	0
MBCx mentatio Phase	Third Party Support	Service	Use of service providers or consultants services such as analysis; installation of FDD; etc. Strategies include: Service provider identifying controls and capital improvements; service provider used to configure EMIS; service providers used when in-house staff does not have capacity to seek out and resolve issues. **Potential challenges:** when service providers reporting faults, but not helping prioritize or find resolutions; service providers reportedly more expensive than in-house staff.	19	5	1	26