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Guanjing Lin

Eliot Crowe

Valerie Nibler

Jessica Granderson

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Guanjing Lin[1]*, Eliot Crowe[1], Valerie Nibler[1], Jessica Granderson[1]

[1] Lawrence Berkeley National Laboratory,
Berkeley, CA, USA
Contact Information (gjlin@lbl.gov; Tel.: +01-510-486-5979)

* Corresponding Author

ABSTRACT

Energy management and information systems (EMIS) are combined hardware and software products that comprise a broad range of analytics and/or optimal control functionality to manage commercial building energy use, covering three main types of functionality: energy information system focus on interval meter data analysis, fault detection and diagnostics focus on system or equipment-level data analysis, and automated system optimization focus on optimal control. More and more researchers and building owners seek to field test and pilot EMIS. However, the studies were conducted differently with disparate design and metrics. The field validation of EMIS also facing the challenges of qualification of non-energy benefits and linkage between information analysis and energy savings.

In response, this paper presents a standardized field testing protocol for EMIS assessment based on literature review and stakeholder interviews. The protocol provides a standardized approach for assessing EMIS' energy and non-energy benefits. It balances rigor and flexibility by specifying a set of required and optional evaluation metrics that can be tailored to the needs of technology evaluators, including energy savings, demand reduction, cost effectiveness, operation and maintenance improvement, capability to enable efficiency, etc. With this protocol, consistent evaluation results can be generalized across multiple studies to support the adoption and further advancement of EMIS.

1. INTRODUCTION

Energy management and information systems（EMIS) are combined hardware and software products that comprise a broad range of analytics and/or optimal control functionalities to uncover energy savings potential and to realize cost savings through improved energy management based on building data (Granderson et al. 2021). The data integrated into EMIS primarily comes from smart meters and/or building automation systems (BAS). Other building data sources such as weather data, internet of things sensors, or occupancy data, may be integrated into EMIS. EMIS may offer one or a combination of three main functionalities:

- Energy information systems (EIS): EIS analytics focus on meter-level monitoring, is used to store, analyze, and display energy meter data. Example analytics include time-series load profiling, energy benchmarking, peak load analysis, and energy anomaly detection.
- Fault detection and diagnostics (FDD): FDD analytics automate the process of detecting faults and suboptimal performance of building systems and help to diagnose potential causes. FDD obtains data from the BAS and focuses on system or equipment-level monitoring, analysis, and charting.
- Automated system optimization (ASO): ASO analytics continuously analyze, determine and write optimal schedule or control setpoints (e.g. supply air temperature setpoint, chilled water leaving temperature setpoint) back to Heating, Ventilation and Air Conditioning (HVAC) system through building automation system (BAS) to optimize energy use while maintaining occupant comfort.

The digitalization in the building sector drives the increasing interest in EMIS. There is a growing body of EMIS field evaluation projects conducted by researchers, utility programs, and building owners to assess the performance of a specific EMIS technology in real buildings. However, there has not been a standardized protocol for EMIS assessment. Evaluation studies are often conducted differently, with disparate design and metrics, and are difficult to generalize for any stakeholder to support the adoption and further advancement of EMIS. This paper presents a standardized field evaluation protocol for assessing EMIS' energy and non-energy benefits. It illustrates the steps in the evaluation process (Section 3), the key areas covered in a field evaluation plan (Section 4), and the minimum and optional evaluation parameters and approaches that can be tailored to the needs of technology evaluators (Section 5).

2. METHODOLOGY

The authors reviewed a set of EMIS field evaluation literatures from utility emerging technologies programs, Federal emerging technology demonstration programs (e.g., the Department of Energy High Impact Technology Program, the General Services Administration Proving Ground Program, the Department of Defense Environmental Security Technology Certification Program), and other R&D organizations. There were four literatures evaluating EMIS with EIS functionality (Henderson and Waltner 2013, Mercado and Elliott 2012, Owen et al. 2010, Russell J et al. 2011), seven literatures evaluating EMIS with FDD functionality (Ferretti et al. 2017, Gorbounov et al. 2016, Katipamula et al. 2003, Lane and Epperson 2015, Summers et al. 2012, Wall and Gao 2018, Loftness et al. 2016), and five literatures evaluating EMIS with ASO functionality (Granderson et al. 2018, Hail et al. 2016, Howell et al. 2015, Parthasarathy 2016, SDG&E 2015). The common and unique elements in the areas of field test design and evaluation parameters and approaches were identified from literature review. In addition, interviews were conducted with potential users of EMIS field evaluation results, such as researchers, building owners, utility administrators, and building energy codes and standard developers, to understand the priority decision-making and data needs that could be met through a validation protocol. Development of the protocol drew upon the literature review on a wide range of EMIS assessments, interviews with key stakeholders, and past EMIS evaluation projects led by Berkeley Lab.

3. OVERVIEW OF EMIS FIELD EVALUATION

Evaluating an EMIS can take considerable time and effort, from six months to a couple of years, so it is important to take a methodical approach to maximize the value of the eventual results. Table 1 illustrates the key steps in the EMIS evaluation process, which are designed to ensure that roles are clearly understood, data and risks are managed effectively, and that final results are accurate and meet the project sponsor's ultimate objectives.

Table 1: Key steps in the EMIS evaluation process

Step	**Description**
1: Select the EMIS test site.	An information-gathering screening form is developed based on technology requirements and evaluation objectives. The form lists the required and preferred site characteristics, such as building size, type and accessibility of building automation system (BAS), HVAC system configurations, control baseline, and metering conditions. The key screening considerations include the satisfaction of the required site and system characteristics, the availability of baseline data, the changes in occupancy, and if any major energy efficiency project happened in the baseline period or will happen in the post-installation period.
2: Develop an evaluation plan.	The EMIS field evaluation plan presents the technology and site information and also defines the performance objectives, metrics, analysis approaches, and schedule.
3: Collect baseline data and information.	Baseline data and information are collected at the beginning of the evaluation and the defined baseline period. Depending on the selected performance objectives, the baseline data may include energy use, weather data, utility tariffs, space conditions, existing operation and maintenance process, and more.
4: Track the technology installation / commissioning.	To evaluate the effort needed for installation and commissioning, information is gathered to document the items like the activities implemented during the process, the responsibilities of different stakeholders for each activity, the lead time of this stage, challenges, and best practices.
5: Collect and analyze post-installation data and information.	For each EMIS performance parameter being evaluated, data will be gathered after the EMIS has been operational for the required amount of time. Performance data may be a combination of quantitative and qualitative data. In the case of quantitative data, it is recommended to review the data shortly after EMIS installation to ensure that data will be of sufficient quality.
6: Produce an evaluation report.	An evaluation report is the final deliverable in the field evaluation.

4. EMIS FIELD EVALUATION PLAN

Once an EMIS has been chosen for evaluation and a test site has been selected, the next step in the EMIS assessment process is to develop a field evaluation plan. Two key areas that should be emphasized in the EMIS field evaluation plan, including:

- **Description of the technology and the field evaluation site**: Documenting the technology and the site characteristics in the field evaluation Plan (and reproducing them when documenting assessment results) helps any reader understand that context. EMIS analytics (i.e. EIS, FDD, ASO) and data points integrated (e.g. meter data, BAS data, weather data, and other pertinent data) should be documented in the technology description. Building type, BAS model and make, building systems or equipment covered by EMIS are the essential things needs to be included in the site description. If the ASO is evaluated, the existing control sequence of the optimized control setpoints should be described, e.g., "The chilled water setpoint is reset between 42°F and 48°F based on the maximum chilled water valve position from each air handling unit."
- **Evaluation objectives and approaches**: The EMIS field evaluation plan should document the objectives of the evaluation and reference the key stakeholders targeted by the EMIS implementation (those people driving the objectives and/or expected to be affected by the EMIS). Example objectives may include energy savings, perhaps in line with organizational sustainability targets or a strategic plan; load reduction during peak periods, when electricity costs are highest; improvements to occupant comfort satisfaction (e.g., reducing hot/cold calls from occupants); and improvements in operations and maintenance (O&M) practices. Defining evaluation objectives helps when selecting the key performance parameters that will be included in the design. Analysis approaches for the selected parameters also need to be presented in the evaluation plan. The required or optional parameters and their analysis approaches are discussed in Section 5.

5. FIELD EVALUATION PARAMETERS AND APPROACHES

At the core of the EMIS validation protocol is a set of performance evaluation parameters that will allow for a consistent comparison between EMIS tools (see Table 2), along with associated methods for determining those parameters. The assessment approaches taken may be based on quantitative data analysis, surveys, or a combination of both. These evaluation parameters were chosen based on literature review and stakeholder interviews to determine the highest value core metrics, along with those that may apply in some, but not all, circumstances. At a minimum, energy savings, energy cost savings, EMIS cost, simple payback, and capability to enable energy efficiency are required for a basic EMIS assessment. Additional optional parameters fall under the following four categories:

- Energy and utility cost: In addition to annual energy savings and cost savings, stakeholders may want to assess peak demand reductions, particularly in regions where utilities apply high demand charges. Where utilities offer demand response (DR) programs, stakeholders may also want to assess the ability of EMIS to drive temporary load reductions during DR time periods.
- Non-energy benefits: Non-energy benefits can provide significant value to building owners. An occupant comfort metric allows for quantification of improvements in indoor environmental quality, and an O&M metric can verify EMIS impact on internal operational practices.
- Cost-effectiveness: While simple payback is relatively easy to calculate and understand, some organizations employ more sophisticated methods to calculate long term return on investment. Net present value (NPV) and savings-to-investment ratio (SIR) are two common examples included as optional metrics under this protocol.
- Operational capabilities: Capturing the overall impact of an EMIS is critical to most stakeholders, but for many it is also important to validate specific performance claims. It is essential to understand how effective an EMIS is at enabling energy efficient operational practices, and how the tools contribute to the energy savings. It also is necessary to provide instructions for integrating the tools into the energy management process with a "standard operating procedure." The protocol offers another two optional metrics, to address how easy an EMIS is to install and commission, and how accurately an EMIS can identify operational faults and make appropriate recommendations.

Among the optional parameters listed in Table 2, 'Occupant comfort satisfaction' is highly recommended for the evaluation of ASO, as optimizing existing controls should not adversely affect comfort. Also 'Accuracy of issues/opportunities identified by the FDD' applies only for the evaluation of FDD. As noted earlier, this EMIS validation protocol is not intended to address every possible evaluation parameter that could be applied to any situation. The key objective is to define a clear set of core parameters that will align with most stakeholders' objectives.

Table 2: EMIS field evaluation parameters summary

Performance Evaluation Parameter	Required or Optional	Approach
Energy and utility cost		
Annual energy savings (kBtu per ft^2, percent reduction)	Required	Data analysis
Annual energy cost savings ($)	Required	Data analysis
Annual greenhouse gas emission reduction (pounds of carbon dioxide equivalent, $lbCO_2e$)	Optional	Data analysis
Monthly peak demand reduction (kW)	Optional	Data analysis
Demand flexibility (W/ft^2, kW, percent)	Optional	Data analysis
Non-energy benefits		
Occupant comfort satisfaction	Optional (recommended for ASO)	Data analysis and/or survey
Operations and maintenance	Optional	Data analysis and/or survey
EMIS cost		
EMIS cost ($, $ per ft^2)	Required	Survey
Cost-effectiveness		
Simple payback (years)	Required	Data analysis
Net present value ($)	Optional	Data analysis
Savings-to-investment ratio	Optional	Data analysis
Operational capabilities		
Effort of the installation and commissioning process	Optional	Survey
Capability to enable energy efficiency	Required	Survey
Accuracy of issues/opportunities identified by the FDD	Optional (applicable to FDD only)	Data analysis

The following subsections introduce how to access energy savings, cost effectiveness, capability to enable energy efficiency in an EMIS field evaluation.

5.1 Energy savings

Defining EMIS energy savings is one of the most challenging aspects of EMIS validation, and it faces three major challenges:

- EMIS is not a widget technology. The use of EMIS leads to multiple energy efficiency measures. The energy savings should capture the impacts of all the measures.
- The building energy consumption is affected by various factors. The savings estimation needs to consider the changes in these variables, such as weather conditions and building occupancy.
- From a practical standpoint, an EMIS validation project may have time and/or budget constraints that affect the level of rigor that can be applied to an EMIS validation project.

The International Performance Measurement and Verification Protocol (IPMVP) (EVO, 2012) defines four generic M&V approaches for determining energy savings: Option A - Retrofit Isolation with Key Parameter Measurement, Option B - Retrofit Isolation with All Parameter Measurement, Option C - Whole Building Utility Data Analysis, and Option D - Calibrated Computer Simulation. Under this protocol, the recommended savings estimation method for determining annual energy savings is to follow Option C or Option B, which determines savings impacts based on actual metered data using Equation 1.

$$\text{Savings} = \text{Baseline Projected Energy} - \text{Post Installation Energy} \pm \text{Adjustments} \quad (1)$$

With Option B or C, a mathematical baseline model is created from meter data when the technology is not operating. The baseline model is then forward projected into the measure post-installation period to determine what the energy use would have been in the absence of the technology. The difference between this baseline projected energy use, and the metered post installation energy use is taken as the energy savings. The Adjustments term is used to capture the effects of variables not included in the baseline model, and not associated with the technology, such as increased internal loads, or changes to equipment or building occupancy. Linear, change-point linear, and polynomial regression models are often used to create the mathematical baseline model for IPMVP Option B or C applications. The primary independent variables used for the model include weather conditions (usually outside air temperature), building operation schedule, and building occupancy. For the regression energy model of a chiller plant or chilled water system, the cooling load is the key independent variable. If there is no Btu meter installed for measuring the cooling load, the cooling load can be estimated using outside air temperature, outside air relative humidity (or outside air wet-bulb temperature), and day of the week. The day of the week is often best included as a categorical value (e.g., Sunday, Monday, Tuesday) and not as a numerical value. The savings analysis based on the metered data provides an accurate means of verifying the impact of the multiple energy efficiency measures enabled by the EMIS. ASHRAE Guideline 14 (ASHRAE 2014), BPA Verification by Energy Modeling Protocol (BPA 2012a), and BPA Regression for M&V reference guide (BPA 2012b) provide detailed guidance on the application of meter-based Option B and Option C approaches; for example, regression energy model types, development of the energy model, and software tools to assist with energy modeling. As a general rule of thumb, IPMVP Option C using monthly data requires expected savings > 10 percent of the whole building energy savings, and > 5 percent if using hourly data.

The engineering calculation in IPMVP Option A is usually used for estimating savings of an individual efficiency measure, and therefore is only acceptable as a backup if options B or C are not possible (e.g., due to insurmountable issues with obtaining meter data or project delays resulting in lack of time to gather reporting period meter data). IPMVP Option D uses simulation software (e.g., EnergyPlus, OpenStudio) to model energy performance of a whole building. Models must be calibrated with actual hourly or monthly billing data from the facility. After the model has been calibrated, savings are determined by comparing a simulation of the baseline with either a simulation of the performance period or actual utility data. Option D is acceptable as a backup where a baseline does not exist (e.g., new construction or major building modification in the baseline period).

5.2 Cost-effectiveness

Determining the cost-effectiveness of EMIS implementation is not straightforward since EMIS with the EIS or FDD functionality is an enabling tool—installation of the software does not directly create savings. Rather, savings are achieved by acting upon the information the technology provides (i.e., the improvement opportunities that are identified). The only functionality of EMIS that achieves direct savings is ASO, since the control optimization is performed directly by the ASO functionality. Simple payback period (SPP) is the most widely used financial metric for energy efficiency projects. It is the number of years required to recover the initial investment through project savings. The simple payback period of EMIS can be established using Equation 2:

$$\text{Simple payback period} = (\text{EMIS Implementation Costs} + \text{ECM Costs})/(\text{Annual Energy Cost Savings} - \text{Annual EMIS Operating Costs}) \quad (2)$$

Where energy conservation measure (ECM) Costs are the costs incurred for implementing the ECMs found by the EMIS (e.g., adjusting system schedules, fixing leaking valves, improving setpoint reset)[1]. The elements included in EMIS implementation costs and annual EMIS operating costs are explained in Table 3. With Equation 2, SPP captures not only EMIS implementation costs, but also the costs for implementing ECMs discovered through the use of the EMIS. The denominator in Equation 2 may be considered the net annual cost savings, based on subtracting annual EMIS operating costs (EMIS software subscription, third party support, internal labor) from the annual energy cost savings.

Table 3: Key elements of EMIS costs

Cost Items			**Description**
EMIS Implementation Costs	A: Base costs for EMIS technology	A.1: Hardware costs	Costs for hardware installation and upgrade (e.g., adding meters and sensors during the project for EMIS monitoring purposes, installing gateways for communication, getting data servers for data storage)
		A.2: Software costs	Costs for the EMIS software installation and configuration to bring in all the data points, alteration of the existing BAS to expose legacy data points, and training to site staff, including EMIS vendor and service provider costs
	B: In-house labor costs for EMIS installation and commissioning		Approximate total labor costs spent by in-house staff to support installation and configuration of the EMIS
Ongoing Annual EMIS Operating Costs	C: Ongoing annual costs for EMIS technology	C.1: Annual EMIS costs	The recurring annual cost for a software license, software-as-a-service fees, or hardware (e.g. occupancy counters)
		C.2: Annual third-party consultant costs	The average annual cost paid to a third-party consultant for support in analyzing and implementing EMIS findings
	D: Ongoing annual in-house labor costs for EMIS use		Approximate labor costs spent by in-house staff reviewing EMIS reports, identifying opportunities for improvement, and implementing measures (may be based on average hours spent per month)

5.3 Capability to enable energy efficiency

Capability to enable energy efficiency can well explain the linkage between information analysis and energy savings. In this protocol, the capability to enable energy efficiency has different meanings for ASO and EIS/FDD analytics. For ASO, it means the targeted control setpoints can be successfully changed by the ASO. For EIS/FDD, it means the

[1] This cost category is not applicable for ASO, as it directly makes the efficiency changes in its system. Costs for internal staff to implement ECMs does not need to be accounted for.

ability to generate actionable information that leads to the actual efficiency measures. Evaluating the capabilities for identifying efficiency opportunities and supporting the implementation of the efficiency measures will help potential adopters understand how the tools contribute to the energy savings. It can also provide support for successful integration of an EMIS into a building's energy management process.

To evaluate the capability to enable energy efficiency of ASO, the data trends of the targeted control setpoints and measurements should be compared in the baseline and optimizer (post-installation) periods. An assessment can validate if the setpoints change and if the measurements follow the optimized setpoints via BAS data trend analysis. For example, Figure 1 shows the ASO successfully reduces the air handler unit (AHU) static pressure setpoint (SP) by 0.5 pounds per square inch (psi) compared with the baseline. The static pressure SP and static pressure in the optimizer period are shown in blue lines, and the static pressure SP and static pressure in the baseline period are shown in red lines.

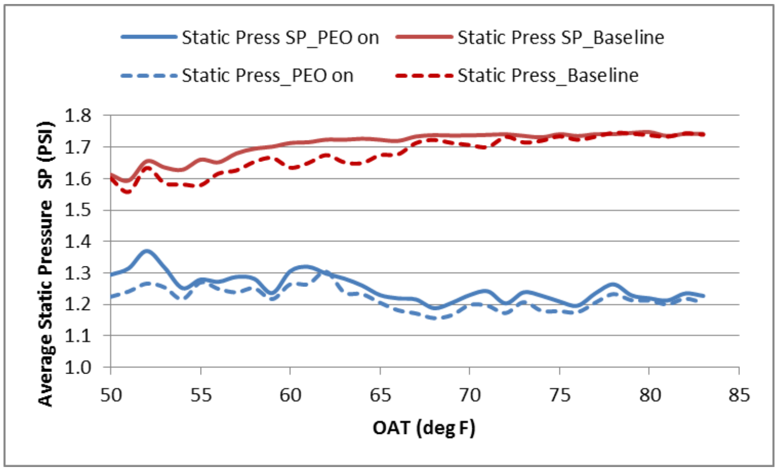

Figure 1: Example of comparison of control setpoints during the baseline and optimizer (post-installation) periods

To evaluate the capability to enable energy efficiency of EMIS with EIS and FDD analytics, the following items should be documented through building operator interviews and the results shown on the EMIS.

- *A record of the implemented efficiency measures based on EIS/FDD analytics*. An example summary is provided in Table 4.

Table 4: Summary of the identified faults in an EMIS with FDD analytics and the implemented efficiency measures

System/Equipment	Identified Faults	Implemented Efficiency Measures
AHU 1-1 AHU 1-2	AHU on all the time	Enable calendar control
VAV 1-1, VAV 1-2, VAV 1-3, VAV 1-4	Zones are outside an acceptable comfort temperature range	Reset the automatic setpoint, tune VAV supply air flow
AHU 2-1	Incorrect economizer control	Reset the minimum outside air intake ratio
AHU 2-2	Valve cycling	Change control logic proportional–integral–derivative loop
Outdoor lighting	Outdoor lighting on a fixed schedule	Introduce daylight harvesting control

- *The workflow of identifying, prioritizing, and taking actions on the issues or opportunities identified by the EIS or FDD analytics*. Faults are prioritized using criteria like impact on energy, comfort, or existence of known issues. Determine which departments or business units are involved, and who is responsible for responding to the finding. Prioritize and assign a list of faults for inspection, inspect the faults, and implement the efficiency measures. Sometimes actions such as equipment scheduling can be addressed by site-level operational staff. In other cases, further investigation may be required, and control and mechanical subcontractors need to be involved. The documentation of workflow leads to a "standard operating procedure" which is easily repeated in the future application.

6. CONCLUSIONS

This paper presents a standardized field testing protocol for EMIS assessment based on literature review, stakeholder interviews, and previous field evaluation project experience. It describes the steps in the evaluation process and the key areas covered in a field evaluation plan. It also balances rigor and flexibility by specifying a set of required and optional performance evaluation parameters that can be tailored to the needs of technology evaluators, including energy savings, demand reduction, cost effectiveness, operation and maintenance improvement, capability to enable efficiency, etc. With this protocol, consistent evaluation results can be generalized across multiple studies to support the adoption and further advancement of EMIS.

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