ENERGY MANAGEMENT

Integrating BEM & EMIS with Cx: Optimizing Building Systems' Performance

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Building commissioning services have long been an accepted practice to validate, document, and ensure compliance with design intent for mechanical, electrical, and plumbing systems. The growing development of energy management and information system (EMIS)[1] tools such as data analytics and fault detection & diagnostics (FDD), as well as the widespread application of building energy modeling (BEM) during the design phase has enabled building owners to add energy performance requirements to their owner's project requirements (OPR). Accordingly, commissioning and BEM-based design services have begun to expand to address these building performance requirements. For the purpose of this article, we will refer to the OPR performance objectives as a project's design performance intent.

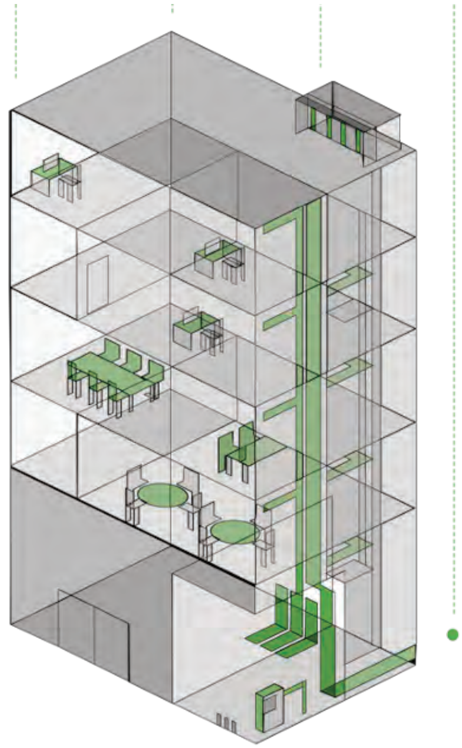
This article proposes that proper integration of BEM, EMIS, and commissioning expands the commissioning 'toolbox' to provide increased precision and reliability of pre-handoff commissioning services. More comprehensive commissioning services should extend through initial post-occupancy evaluation (warranty phase), and into ongoing retro-commissioning (retro-Cx). This integrated process helps:

1. Achieve the building's design performance intent.
2. Maintain the building's performance through ongoing operations.
3. Optimize building system operations.

Whole-Building Energy Modeling (BEM)

Whole-building energy modeling acknowledges that any building is a system of systems, and that the analysis of energy performance interaction between building systems (e.g., opaque envelope, fenestration, internal loads, heating/reheating, cooling, ventilation, domestic hot water, etc. and the controls for these) requires modeling of the whole building (all systems). The role of BEM has been largely limited to the design phase (pre-occupancy) where it has been used to accomplish up to two objectives:

1) Confirm and document compliance with building energy codes and sustainability rating systems (LEED, Green Globes). In this role, BEM is often adopted relatively late in the design process, e.g., late due date after many of the more influential energy performance design decisions have already been made (HVAC system type, building massing, fenestration amount, and opaque envelope properties). While this reduces modeling costs it also reduces the role of BEM to scoring the energy performance of the design rather than guiding the design toward a desired reference energy performance.
2) Guide design decision-making towards improved building energy performance, using metrics such as energy use intensity (EUI) in Kilo-British thermal unit per square-foot per year (kBtu/sf/yr), life-cycle costing (LCC), return on investment (ROI) and simple payback.



In either case, design-phase building energy models are frequently simplified to further reduce their cost and their run-time. Building energy codes and sustainability rating systems include provisions that limit model simplifications in order to retain the comparative value of the energy model results. These simplified design energy models are not intended to predict actual (post-occupancy) building energy use. Rather, they are intended to provide a comparative benefit similar to the EPA's gas mileage rating, e.g., "your mileage may vary."

In a similar way, simplified pre-occupancy energy models provide reference or comparative energy performance EUI. They are not intended to provide an estimate of post-occupancy building EUI. Consequently, these simplified building energy models are not well suited to serve in an expanded commissioning 'toolbox.'

Energy Management and Information System

Energy management and information system (EMIS) uses energy consumption metering, sensor/actuator-level, and system-level performance monitoring – enhanced through FDD data analytics – to guide the commissioning and retro-Cx processes. The key deliverable of EMIS is to identify – with increased confidence and accuracy – energy and energy-cost saving opportunities through improved operations by pinpointing the root cause(s) of energy performance degradation. By incorporating data analytics/FDD, EMIS significantly reduces the time, effort, and cost required to identify deviations from design intent such as:

- Failed sensors and actuators
- Inoperable mechanical equipment like dampers and linkages (economizers)
- Improperly implemented schedules
- Deviations from the sequences of operation (SOO)
- Deviations from testing, adjusting, & balancing (TAB) reporting

Accordingly, EMIS tools have become increasingly valuable for the commissioning provider to identify deviations from the design performance intent EUI both pre- and post-occupancy.

Synergy between BEM, Commissioning, and EMIS

Commissioning's greatest strength is on a component level, to answer such questions as those identified above. Commissioning/EMIS is not as strong in aggregating answers to these component-level questions to a whole-building level and extrapolating them from relatively short-term measurements to investment-grade estimates of annual or average long-term impacts.

By contrast, BEM's greatest strength is on a whole-building level by which BEM can function as an 'auditor' at the whole-building level to help better answer two key questions that would not be possible using commissioning/EMIS alone:

1) Checksum function: Have all of the deviations from design intent that are significant to energy use and energy cost been identified? BEM provides a checksum to compare with the actual sum (measured whole-building energy use and cost). This is usually accomplished as part of the post-occupancy model calibration and usually performed on a whole-building level.

2) Aggregator & extrapolator function: What will be the annual average cost, energy, and emissions savings of achieving design intent or optimal operations?

While commissioning/BMIS and BEM are certainly complementary in their strengths, integrating them greatly improves the reliability of the answers to the above questions each provides.

Combining/integrating BEM & commissioning/EMIS therefore helps accomplish the following whole-building post-occupancy objectives:

1. Achieve the building's design performance intent by fine-tuning systems.
2. Maintain the building's design performance intent through ongoing operations by providing continuous feedback on systems performance. Occasionally, system limitations are identified that were not recognized in the original design process which can yield more realistic/maintainable performance targets.
3. Optimize building system operations by identifying additional opportunities in building performance that may lead to a lower EUI than was originally identified.

BEM's Role in Post-Occupancy Commissioning: EUI Validation and Verification

During the initial post-occupancy 'warranty' phase (up to 12-months post-handoff), a detailed design-phase EUI model would be well-suited to be calibrated to actual (post-occupancy) EUI using:

- Post-occupancy, whole-building utility interval energy data
- On-site (or local airport) weather data
- Continuous EMIS collected data
- Actual (as-operated) sequence of operations data
- Sub-metered energy data (if available)
- Updated post-occupancy usage schedules such as:
  - o Actual thermostat and other control set points
  - o Updated occupancy levels and hours
  - o Actual custodial hours (and related lighting, equipment, and HVAC hours)
  - o Updated meal counts for food services, etc.

Combining BEM and commissioning/EMIS enables a much more thorough assessment of post-occupancy energy consumption that accomplishes the following:

1) Reduces and quantifies uncertainties implicit in any pre-occupancy EUI model.

2) Audits (i.e., validates and disaggregates) the drift from design EUI into an item-by-item retro-Cx action list (see Table 2 on 42).

3) Helps assign project team accountability for addressing EUI performance drift.

4) Can be used to create a feedback loop to train, inform, guide, and incentivize building facilities staff to help maintain continuous EUI performance tuning via continuous retro-Cx.

5) Is critical to project the future impact of selected corrective actions by the commissioning team, owners, facilities personnel, subcontractors, and manufacturers on whole building EUI.

To illustrate this approach, consider the following, actual example for a 71,000 ft.^{2} medical-surgery space addition to an acute-care hospital in California.

Example: Post-Occupancy BEM + Retro-Cx + EMIS Lead to Improved Post-Occupancy EUI Evaluation and Follow-Up

Background

The following are findings of an retro-Cx EUI and energy cost evaluation conducted five months – May through September – post-occupancy for a 71,000 ft.^{2} medical-surgery space addition to an acute-care hospital in California. The design-build request for proposal (RFP) for this facility targeted a not-to-exceed EUI of 166.6 kBtu/sf/year.

Post-Occupancy Data Collected

- Onsite metered energy use
- Sequence of operations and TAB data, (SAT, RAT, OAT, room temperature set points, volumetric air flow rates, etc.) from the EMIS
- On-site OAT and local airport weather data
- Revised occupancy schedules and quantity of cafeteria meals served

Methodology

1) Determine monthly EUI for the May through September period using utility interval data.

2) Using historical EMIS, weather and occupancy data for the same five month period, calibrate the EUI model to be used to:

Ultimately, the integration of pre- and post-occupancy BEM, Cx, and EMIS significantly enhances the ability to identify opportunities to improve and maintain the optimal performance of building systems.

a. Disaggregate the EUI and utility cost drift from design performance intent into identifiable and actionable corrections.

b. Estimate the impact on the EUI and utility costs for each action item.

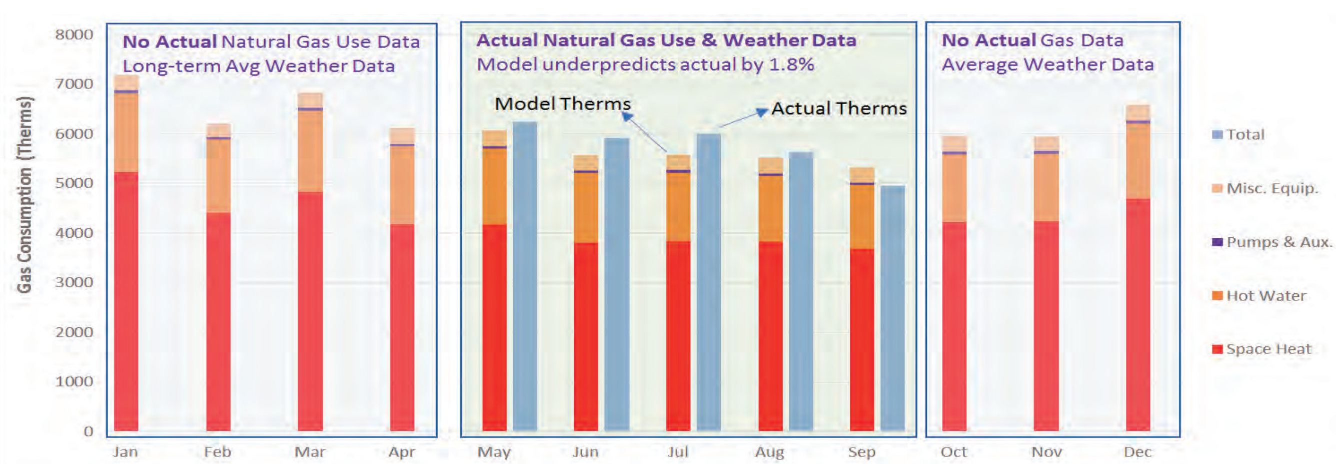
c. Extrapolate the findings for five-month data collection period to an annual estimate using local airport, long-term average weather data and assuming continuity of the commissioning-identified problems for the seven unmonitored months.

Post-Occupancy EUI Model Calibration

Figures 1a and 1b below illustrate the degree of calibration for electricity and natural gas use achieved by the design EUI model after it was updated using post-occupancy EMIS, along with weather and occupancy data for the May through September period. The predicted energy consumption for the remaining seven months was extrapolated from the available EMIS and occupancy data, assuming continuity of the identified problems. Weather for the unmonitored months used local airport long-term, average data.

Figure 1a: Actual versus Calibrated Energy Model – Monthly Electric and Natural Gas Use

Figure 1b: Natural Gas Consumption - Actual vs Model



Post-Occupancy EUI Findings

Table 1 below shows annual results from the five month monitoring period extrapolated to a full year using local airport long-term, average weather data and assuming continuity of the retro-Cx-identified problems for the seven unmonitored months. The post-occupancy model, adjusted using the historical EMIS data, matched to within ~1.4 percent for the five months of monitored EUI and utility costs.

The design-build RFP goal EUI (166.6) reflects a pre-design BEM estimate included in the original project RFP. The final design EUI represents the substantial completion design intent (aka the design performance intent). The calibrated model EUI represents the post-occupancy calibrated model's prediction, which provides the basis for extrapolating the five-month monitored EUI and costs to the twelve-month current operations estimate. These calibrated, model-based retro-Cx results were further adjusted for the model's ~1.4 percent under-predicting actual measured energy use data. The results indicate a 45 percent excess for EUI and a 19 percent (~$82,000) annual excess for energy costs.

Figure 2 below graphically quantifies and summarizes the results listed in Table 1 by reporting findings for:

- Two cases:

1. "Substantial Completion" upper
2. "As Currently Operated" lower

- Two metrics:

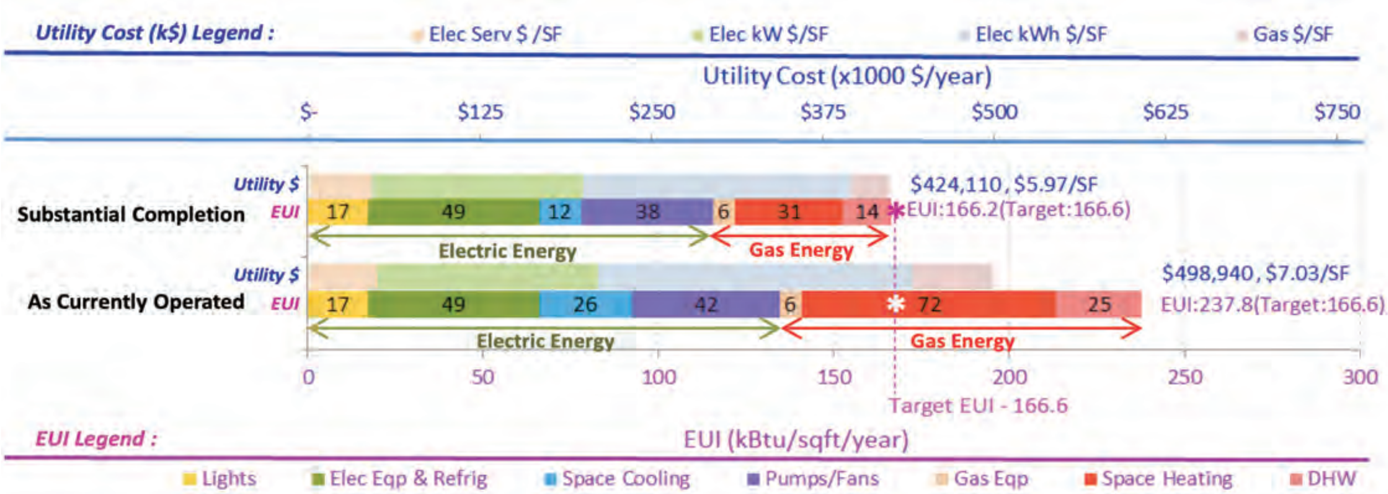
1. For annual utility $, see the upper axis and legend
2. For annual EUIs, see the lower axis and legend

Figure 2 also illustrates that natural gas consumption (space heating and domestic hot water, written as "gas energy") played a much larger role in this example's increase in EUI

Table 1: Estimated Annual Post-Occupancy EUI and Utility Cost

	RFP Goal	Final Design Intent	Calibrated Model	Current Operations	Model Calib Error	Current v Intent Increase	Current v Intent % Increase
EUI	166.6	166.2	237.8	241.1	-1.4%	74.9	+45%
Utility $	$425,000	$424,100	$498,900	$506,200	-1.4%	$82,100	+19%

Figure 2: Annual EUI and Energy Costs (Compare Table 1)



than did electric use (electric use exceeded design intent by ~16 percent, while natural gas use doubled its design intent). This was mostly due to an increase in gas-fired, hydronic reheat energy due to control problems.

Table 2 below presents more detailed findings from the post-occupancy EUI model calibrated using EMIS data. The BEM+EMIS data are then able to disaggregate and quantify the separate impact on annual EUI and annual utility costs due to each departure from design intent.

The first row in Table 2 (Case 0) represents the design performance intent EUI at handoff. Each subsequent row in Table 2 identifies a separate departure from the design performance intent. The Δ EUI and Δ Utility cost columns represent cumulative impacts. The last row (Case 6) represents the calibrated model's estimate for current operations which matches closely (-1.5 percent) the measured/extrapolated total annual departure from design performance intent EUI. In this example, Cases 4a and 4b represented SOO alternatives designed to mitigate a design problem that limited the use of economizers. Of these two alternatives, 4b was the intended, more effective SOO; however, at the time of this retro-Cx test period, SOO 4b was found to have been overlooked and not implemented. Cases 1 and 2 are identified as being the responsibility of the owner, whereas Cases 3 through 6 are identified as the responsibility of the design-build team as part of the project delivery. In this case, the owner was responsible for ~30 percent and the design-build team was responsible for ~70 percent of the excess EUI and ~15 percent and 85 percent respectively of the costs.

In this example from a healthcare facility, the excess energy cost was found to be $82,100 (Table 1) per year. Assuming a national average annual operating margin for hospitals of 6.5 percent, this energy cost excess would require an annual

Table 2: Impact on Annual EUI and Utility Cost by Drift from design performance intent – Disaggregated by Cause and Responsibility

Case	Identified RCx Issues	EUI	Δ EUI	Util $	Δ Util $	Description	Bldg Location
0	**Substantial Completion** = Handoff = Design Intent	166.2	*n/a*	$424,100	*n/a*	anticipated operations + design & control sequences from substantial completion documents	*n/a*
Owner Responsibility							
1	Revised DHW Load (# Cafeteria Meals)	177.1	+10.9	$430,300	$6,200	improved estimate for # of cafeteria meals, from cafeteria manager	Kitchen
2	Use Room Temperatures from Trends	176.2	+10	$434,700	$10,600	anticipated 72F room temps cooler by 1F to 3F, ORs at target 68F Pharmacy lower.	Throughout all levels
Design-Build Team Responsibility							
3	Disable Economizers AC 1-1A&B, 1-4, 1-5	177.9	+11.7	$438,100	$14,000	OA locked at code minimum levels due to limited return fan power	OR 1, CathLab, PACU, Pharm OR 2 & Ortho OR
4a	Disable SAT Resets AC 1-1A&B, 1-4, 1-5 (24/7/365)	191.5	+25.3	$451,300	$27,200	SAT resets appear to be permanently disabeled, 24/7/365	OR 1, CathLab, PACU, Pharm OR 2 and Ortho OR
4b	Disable SAT Resets (when OA DPT > 51.5F) ***not implemented*** *	186.8	+20.6	$446,100	$22,000	SAT resets to be disabeled only when OA dewpoint is > 51.5F ***not implemented*** *	OR 1, CathLab, PACU, Pharm OR 2 and Ortho OR
5	Eliminate Standby Setbacks for 2 of 3 ORs	206.7	+40.5	$471,900	$47,800	setback model for 2 of the 3 ORs anticipated but not currenrtly implemented	OR 2 and Ortho OR
6	Use AHU SAT from Trends **= As Currently Operated**	237.8	+71.6	$498,900	$74,800	SA temps lower than plans (51F-54F) for 1st floor systems by 1F to 4F	First floor systems

* alternative control sequence that reduces the EUI penalty resulting from disabled economizers — proposed but not implemented.

increase of $1,250,000 in patient care revenue to cover this expenditure. If this case had been for a typical large business (annual operating margin closer to 9 percent), the extra revenue to cover this expenditure would be ~$910,000. Clearly, these types of excess energy use and costs are impactful, not to mention their environmental impact.

Conclusion

Building system operations can significantly drift from their intended design phase EUI. The proper integration of BEM, commissioning, monitored data & data analytics through an EMIS in a post-occupancy retro-Cx scope of service provides synergy that can greatly improve detail, precision and confidence in results that can:

- Identify, disaggregate, and validate deviations from design performance intent
- Quantify, project, and disaggregate potential EUI and energy cost savings of post-occupancy retro-Cx services
- Assign project team accountability and/or responsibility for EUI improvement
- Create a feedback loop to inform and incentivize facilities staff to better maintain EUI performance
- Achieve, maintain, and optimize building system operations and the design performance intent

Ultimately, the integration of pre- and post-occupancy BEM, Cx, and EMIS significantly enhances the ability to identify opportunities to improve and maintain the optimal performance of building systems.

Footnote:

[1] *For a review of EMIS systems. Please refer to the following paper: Kramer, H., Curtin, C., Lin, G., Crowe, E., Granderson, J. (2020, October). Proving the Business Case for Building Analytics . Retrieved March 25, 2022, from* https://buildings.lbl.gov/publications/proving-business-case-building

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