STANDARDS RESEARCH

Quality Assurance and Quality Control of Building Energy Modelling for Program Administrators

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Contents

Executive Summary

Building energy modelling (BEM) is increasingly used to certify green buildings, establish incentives for utility programs, document compliance with energy codes, optimize the design of new buildings, and inform project retrofits. It is viewed as an essential tool for achieving carbon-neutral and net zero designs. The majority of projects that use BEM complete it as part of their participation in a BEM program, such as Leadership in Energy and Environmental Design (LEED), utility incentive programs for new and existing buildings, and energy code compliance. Thus, technical policies of these programs shape the marketplace's understanding of the applications and value of energy modelling and set the standard practice for BEM services.

Buildings are complex systems composed of numerous interacting components that are influenced by external factors such as weather and occupant behaviour. BEM tools use physics-based equations to calculate building energy use at hourly or subhourly timesteps. Using this inherently complex analysis within a BEM program framework is further complicated by the following factors:

1. There is a significant diversity of how modelling is used in a BEM program, and the program's technical requirements must be tailored to the program's context, logic, and intended outcome.
2. Building energy use depends on factors not inherent in building design, such as occupant behaviour, tenant-installed equipment, and weather.
3. The modelling rulesets often do not prescribe the impactful modelling inputs.
4. Submittal review is complicated by the use of multiple BEM tools and the lack of a standardized reporting format.
5. Energy modellers and submittal reviewers often do not have the necessary expertise and project knowledge.

Program administrators use a variety of tools and practices to mitigate these challenges. They develop the supplemental modelling requirements and standardized compliance forms, and establish methodologies for verifying achieved performance and reviewing submittals. However, these quality assurance (QA) and quality control (QC) frameworks are created for specific BEM programs, with little cross-pollination between program administrators and no consistent methodology for evaluating outcomes. A new standard that takes a holistic approach to mitigating the implementation challenges of BEM programs would improve the quality and consistency of modelling outcomes and increase the BEM programs' administration effectiveness.

In order to support a diverse range of BEM programs, the requirements of such a standard should be tailored to the BEM program's modelling methodology and intended outcome. Energy models are often classified based on their compare/comply/predict context. This may be an appropriate classification for helping building owners and managers define and procure modelling services for projects; however, it is not well suited for differentiating the BEM program's requirements. For example, program administrators increasingly expect compliance models to be predictive. Should such use cases be classified as "comply" or "predict"? An alternative classification system that is based on the simulation methodology and the intended simulation outcome of the BEM program would eliminate this ambiguity.

Comparative versus Absolute Simulation Methodology

A ***comparative*** analysis focuses on the relative performance of the modelled options, such as the difference in energy use of the proposed design relative to a virtual baseline on a new construction project, or savings from a package of energy efficiency measures on a retrofit project. An ***absolute*** analysis involves comparing a model of the proposed design to a fixed performance target that may be expressed as greenhouse gas emissions intensity (GHGI), total energy use intensity (TEUI), or as other units.

Predictive versus Standardized versus Representative Simulation Outcome

Predictive analysis strives for a close alignment between the model and the future measured energy use, with the goal of quantifying the impact of design decisions or energy conservation measures on the utility bills or GHGI. ***Standardized*** analysis involves estimating energy use based on prescribed operating conditions and weather. This is conceptually similar to emissions testing for cars, which is used for a standardized comparison between different models and is not necessarily predictive of actual performance. ***Representative*** performance is a hybrid approach that involves using the actual operating parameters where available and standardized inputs in other cases.

Below are examples of applying this classification system to several modelling rulesets used by BEM programs.

- **Comparative/Representative:** National Energy Code of Canada for Buildings (NECB) Part 8, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 rulesets
- **Absolute/Standardized:** Passive House Institute (PHI), Vancouver's Zero Emissions Building Plan GHI, and thermal energy demand intensity (TEDI) paths
- **Absolute/Predictive**: Canada Green Building Council's (CaGBC) Zero Carbon Building Standard

This report describes how the proposed classification system may be used as the basis for a new standard that would cover all aspects of a BEM program's QA/QC framework including the supplemental modelling requirements, simulation tool requirements, the methodology for verifying achieved performance, documentation requirements, submittal review process, and BEM program's quality assurance procedures. The standard would set the bar for the BEM program's quality assurance and quality control to help the program's administrators achieve a substantial improvement in the consistency and credibility of modelling outcomes.

> *"Building energy modelling is used... to document compliance with energy codes, optimize the design of new buildings, and inform project retrofits."*

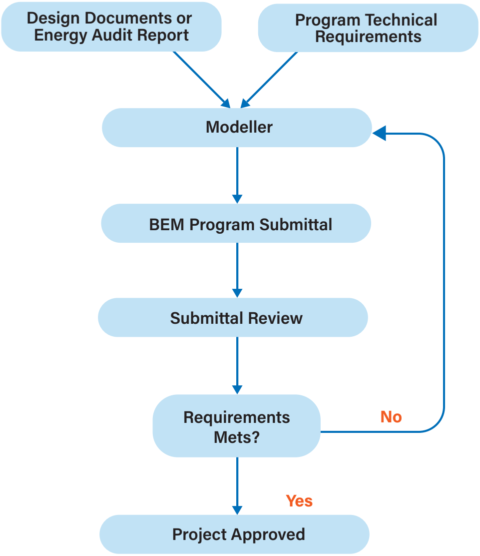
Introduction

Building energy modelling (BEM) is used in green building certification and utility incentive programs to document compliance with energy codes, optimize the design of new buildings, and inform project retrofits. The performance-based compliance options of model energy codes, including the NECB and the American Society of Heating, Ventilation and Air-Conditioning Engineers (ASHRAE) Standard 90.1, are used by a growing number of projects. Vancouver's Building Bylaws, in effect after June 2019, require energy modelling for all new office, multifamily, and retail buildings. The American Institute of Architects refers to energy modelling as essential for achieving carbon-neutral buildings by 2030 [1], and the *BC Energy Step Code Design Guide* [2] describes it as invaluable for achieving new construction design that is net zero ready by 2032.

Most projects that use BEM complete it as part of participation in a BEM program,[1] such as the Leadership in Energy and Environmental Design (LEED), utility incentive program, or municipal code enforcement programs. Thus, the technical policies of a BEM program play a critical role in shaping the marketplace's understanding of how modelling may be used on projects and sets the standard practice for BEM services.

The typical process of a BEM program is illustrated in Figure 1. It involves a modeller performing an energy analysis based on the project design documents or an energy audit report following the BEM program's technical requirements. The results of the analysis are submitted for review to the program administrator, either a rating authority (RA) or an authority having jurisdiction (AHJ), who may either approve the project or request revisions.

Figure 1: *A BEM Program's Process.*



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[1] BEM program: a modelling-based protocol administered by an authority having jurisdiction (AHJ) or a rating authority (RA), such as those administering green building rating and utility incentive programs.

The enforcement rigour varies significantly between program administrators. Some spend over 40 hours per project on submittal reviews and go through three or more review iterations before approval; others automatically accept any submittal stamped by a licensed professional [3]. Some have detailed technical requirements and reporting templates; others just reference the external standards, leaving undefined the areas subject to approval by the AHJ and RA.

There are existing industry standards that describe the modelling rulesets[2] (e.g., NECB Part 8, ASHRAE 90.1 Section 11 and Appendix G), energy estimation methodologies (Canadian Standards Association [CSA] C873 Series-15), and BEM software engine testing (ASHRAE 140-2017) [4]. The newly released ASHRAE Standard 209-2017 [5] outlines the use of energy simulation to inform design throughout the design process, from pre-schematic to construction documents and post-occupancy modelling. The International Performance Measurements and Verification Protocols (IPM&VP) describe the use of calibrated simulations for measurement and verification of savings on retrofit projects. However, there is no standard in Canada or the United States that describes the quality control (QC) and quality assurance (QA) procedures applicable to the diverse range of BEM programs, including minimum code compliance, high-performance buildings, building retrofits, and modelling to inform design development. The purpose of this report is to examine the challenges of implementing BEM programs and to explore how a new standard could serve to address these challenges.

The BEM Program's Implementation Challenges

Buildings are complex systems composed of numerous interacting components that are influenced by such external factors as weather and occupant behaviour. BEM tools[3] use physics-based equations to calculate building energy use at hourly or subhourly timesteps. Using this inherently complex analysis methodology within a BEM program's framework is further complicated by the following factors:

Diversity of BEM Use Case

Modelling may be used to compare design alternatives, to comply with code or above-code programs, or to predict future building performance. Depending on the model use case, different technical requirements may be appropriate. For example, when models are created to compare design alternatives, such as two competing heating, ventilation, and air-conditioning (HVAC) system types, many aspects of the design may still be in flux. While it is crucial to accurately characterize the HVAC system details and their differences in the model, using standard operational schedules and plug load assumptions may generate reasonable results with a relatively low modelling effort. Alternatively, models developed in support of energy performance contracts, with the goal of predicting the monetary savings associated with retrofit projects, must reflect building operational parameters, which should be determined based on onsite measurements and on interviews with building occupants.

Unknown Occupant Behaviour and Tenant-Installed Equipment

Building occupants can operate a building in a variety of ways. Temperature setpoints, hours of occupancy, and the opening and closing of windows and shades all impact energy use and can be influenced by tenant behaviour. Service hot water use can differ by a factor of four or more depending on whether an apartment is occupied by seniors or by families with children [6]. Systems and equipment installed by occupants, such as office computers, kitchen appliances, task lighting, and industrial equipment, account for an ever-growing fraction of building energy use that is difficult to predict. Heat gains from desktop computers may differ by a factor of three depending on the manufacturer, processor speed, and RAM [7]. While estimating these parameters is possible, predicting future behaviour reliably is still an area of active research.

Changing Weather Conditions

Heating, cooling, and ventilation energy use are strongly affected by weather. Different types of weather data may be appropriate depending on the model use case. Most

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[2] Modelling ruleset: core technical requirements used as the basis of a BEM program.

[3] BEM tool: software that is approved by the program administrator for performing whole building energy analysis.

models use historical climate data known as typical meteorological year (TMY). However, weather during any particular year is often significantly different from typical. As such, when model results are compared to measured performance like utility bills, the measured weather data during the same time period should be used to account for the impact of the weather. In models that evaluate long-term building performance, climate change trends may need to be considered.

Gaps and Ambiguities in Modelling Rulesets

Modelling rulesets do not cover all the inputs necessary for a complete energy model, and impactful parameters are sometimes overlooked. For example, HVAC systems operate at part load most of the time; however, ASHRAE 90.1 modelling protocols do not provide part-load performance curves. Thermal bridging is known to have a substantial impact on the performance of the building envelope. However, NECB Part 8 refers to the ASHRAE Research Project Report RP-1365, "Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings" [8], which allows the use of different methodologies across projects, while ASHRAE 90.1 does not address thermal bridging at all.

Diversity of BEM Tools

Most modelling rulesets allow multiple BEM tools. For example, over a dozen tools are approved for US commercial building tax deductions [9] and over 16 tools that are approved for by BC Hydro's New Construction Program [10]. It is well documented that simulation results can vary significantly depending on the BEM tool used. Studies by the Lawrence Berkeley National Laboratory and Texas A&M University showed that heating energy differences of over 100% and 27%, respectively, for the same building modelled in commonly used simulation tools [11],[12]. A study by Gard Analytics showed differences of 50% in the annual cooling load between two tools when running a standardized test in accordance with ASHRAE Standard 140 [13]. Furthermore, most BEM tools support multiple methods for calculating common conditions and technologies, such as infiltration or daylighting, and energy use projected by the same BEM tool for a given project may vary significantly depending on the method that the modeller chooses. The challenges are exacerbated by the diversity of commercial building designs, the rapid development of new systems and technologies, and the complexity of the underlying physics.

Vague Submittal Requirements and a Lack of Standardized Compliance Forms

Many modelling rulesets do not clearly specify the project materials that must be submitted to the program administrator and have no standardized reporting template. For example, ASHRAE Standard 90.1 does not have compliance forms that are sufficiently detailed to support a meaningful review of performance-based projects. Jurisdictions often receive a thick bundle of simulation output reports that are difficult to interpret and are not clearly related to important code requirements that need to be inspected and project information shown on drawings. Some program administrators develop reporting templates in-house, but they often lack rigour due to limited resources. Variations in reporting requirements also increase the cost of documenting compliance. For example, a project that uses modelling for LEED, for utility program participation, and to document code compliance may have to complete different reporting forms for each and respond to comments from three different reviewers.

Insufficient Modeller Expertise and Project Knowledge

The "Building Energy Modelling Innovation Summit" (2011) [14] cited the differences in the results obtained by different modellers simulating the same building with the same simulation tool as one of the top issues affecting BEM credibility. The US Department of Energy's "Research and Development Roadmap for Building Energy Modeling" [15] identified better training of energy modellers as the highest-priority task for improving BEM accuracy. Modellers are often disconnected from the design team and are not fully aware of changes made to the building design. On retrofit projects, the impactful site conditions may not be communicated to the modeller and thus may not be captured in the model.

Submittal Review Challenges

Reviewing modelling-based submittals is a challenging endeavour. Models of even simple buildings rely on thousands of inputs. Energy models are completed using different BEM tools, and each tool has different

"Cross-checks between building model inputs and design/construction parameters are often overlooked."

capabilities, nomenclature, and format and content for simulation input and output reports. Submittal reviewers often do not have the relevant experience with the tools used on projects that they are reviewing and struggle with identifying inputs and outputs of interest. The simulation reports generated by the tools can span hundreds of pages. Cross-checks between building model inputs and design/construction parameters are often overlooked, resulting in discrepancies between the building design/construction and the modelled systems and components, which may have a significant impact on performance. Program administrators have different levels of technical sophistication and different budgets for enforcing the requirements and may not be able to identify discrepancies in simulation outcomes. Some program administrators have staff specializing in model reviews, but most do not.

The BEM Program's QA/QC Framework

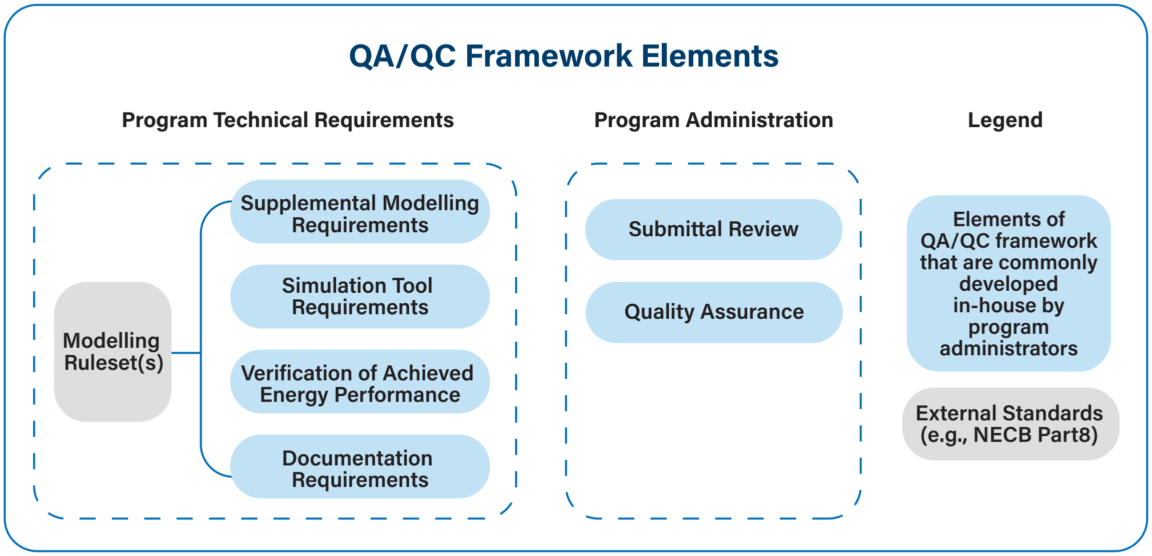
Program administrators use a variety of tools and practices to mitigate the implementation challenges of BEM programs. Many develop modelling guidelines and reporting templates to address requirement gaps in the adopted rulesets, standardize submittals, and streamline submittal reviews. The US Environmental Protection Agency's (EPA) *ENERGY STAR® Multifamily High Rise Program Simulation Guidelines* [16] (a supplement to ASHRAE Standard 90.1 Appendix G), and the City of Vancouver's *Energy Modelling Guidelines* [17] (a supplement to NECB Part 8), are two of many examples. However, these tools and resources are created for specific BEM programs, with little cross-pollination between program administrators and without any consistent methodology for evaluating outcomes.

Figure 2 shows the key elements of the QA and QC frameworks that are necessary for meaningful use of the BEM based on the experience of existing BEM programs. A new standard should take a holistic approach to mitigating the implementation challenges of BEM programs by addressing each of these elements in order to improve quality and consistency of modelling outcomes and to increase the BEM program's administration effectiveness.

Classification of BEM Use Cases

A misinterpreted or misunderstood model use case is one of the key reasons for unmet expectations on BEM projects. For example, a study of LEED-certified buildings [18] viewed deviations between modelled and measured energy use as an issue to be addressed. However, LEED models are based on ASHRAE Standard 90.1 Appendix G, which allows the use of default operating conditions and has simulation rules that limit model predictability, such as modelling all conditioned spaces as cooled regardless of whether or not cooling is specified. In addition, LEED models are based on typical weather conditions (the TMY weather file) and not on the weather during the time period covered by the utility bills to which the models were compared.

Figure 2: *Elements of a BEM Program's QA/QC Framework*



QA/QC Framework is a set of rules and procedures established by a program administrator for a BEM program.

Program Technical Requirements is the public-facing portion of the QA/QC framework that communicates the program rules to the participants.

Modelling Ruleset(s) includes the core technical requirements, such as modelling instructions and submittal requirements and the minimum capabilities of the simulation tools. Examples of modelling rulesets include NECB Part 8, Canada Green Building Council's (CaGBC) Zero Carbon Building Standard (ZCBS), and ASHRAE Standard 90.1 Section 11 and Appendix G.

Supplemental Modelling Requirements cover simulation rules and default values that expand on or modify the modelling ruleset or address requirement gaps. For example, the City of Vancouver's *Energy Modelling Guidelines* are based on NECB Part 8 with additional modelling requirements for internal gains, domestic hot water, infiltration, envelope heat loss calculations, etc.; Pacific Northwest National Laboratory (PNNL) ANSI/ASHRAE/IES Standard 90.1-2016 Performance Rating Method Reference Manual clarifies and supplements the rules of ASHRAE Standard 90.1.

Simulation Tool Requirements may range from referencing a list of approved tools published by a third party to an involved certification process that vendors must follow in order to have their BEM tool approved for use in the BEM program.

Verification of Achieved Energy Performance includes procedures to ensure that systems and components operate as modelled and a methodology for comparing performance projected by the energy models to the measured post-occupancy or post-retrofit energy use.

Documentation Requirements describe information and supporting documentation that must be submitted to the program administrator to facilitate quality control. These requirements may be part of the modelling ruleset or developed for a specific BEM program.

Program Administration portion of the framework defines the program administrator's submittal review process and quality assurance methods.

Submittal Review process determines the scope, depth, and rigour of reviews and may include a submittal review checklist to ensure review consistency across different reviewers.

Quality Assurance includes but is not limited to activities that confirm that the BEM program's technical requirements result in the expected performance outcomes and setting the minimum qualifications for professionals who develop energy models and perform project reviews.

Many key elements of the QA/QC framework, such as the supplemental modelling requirements and methods for verifying achieved energy performance, are strongly dependent on the model use case. Energy models are often classified based on their compare/comply/predict context [19]. "Compare" models involve comparing design alternatives on new construction projects or energy efficiency measures on retrofit projects; "comply" models are developed to document compliance with the energy code and above code programs; "predict" models are meant to predict future energy use. This classification system was developed to define the modelling process and help building owners and managers establish scope and procure modelling services. Due to its breadth, it does not address sublevel variations most relevant to establishing the technical requirements of BEM programs, which makes the classification not well suited for standardization of the BEM program's QA/QC framework.

For example, program administrators increasingly expect compliance models to be predictive – the CaGBC's Zero Carbon Building Standard that may be used for LEED certification is one of many examples. Should it be classified as "comply" or "predict" given that the goal is to both predict future energy use and comply with the standard? Similarly, BEM programs for existing buildings often treat modelled savings from a package of energy efficiency measures as a predictor of post-retrofit utility bills. Is it a "compare" or "predict" use case? Instead, the following alternative classification is proposed. It is based on the simulation objectives and methodology of BEM programs and can serve as a foundation for formulating the BEM program's QA/QC framework requirements.

Comparative versus Absolute Simulation Methodology

Comparative Analysis

A comparative analysis focuses on the relative performance of the modelled options. For example, the optimal envelope shape and exposure at the conceptual design stage may be established by comparing the energy use of models with different building orientations and aspect ratios. Similarly, the modelling protocols of ASHRAE Standard 90.1 and NECB Part 8 are based on comparing the proposed design model to a model of the reference design.

Comparative modelling may be further categorized depending on whether the output of interest is the difference in energy use between the two models (i.e., the delta), or percentage reduction in energy use (i.e., the ratio). Comparative delta modelling is common for utility programs that have incentives based on electricity (kWh) and fuel (MMBtu) savings of the proposed design relative to a baseline. LEED for New Construction is an example of a comparative ratio analysis, with the points determined based on the percentage improvement of the proposed design relative to the baseline.

Different QA/QC procedures may be necessary for BEM programs that are based on a comparative delta versus comparative ratio analysis. For example, savings from lighting retrofits are driven by the change in fixture wattage and modelled runtime. While baseline and proposed (or pre-retrofit and post-retrofit) fixture wattage can typically be firmly established, future runtime of the new fixtures is always an estimate. If the fixture runtime is modelled the same in the baseline and proposed design models, it cancels out (to a degree) with the comparative ratio analysis but has a strong impact on the results (kWh savings) of the comparative delta analysis. Thus, mitigating uncertainty in the fixture runtime (and modelling inputs related to the operating conditions in general) is more important for the latter.

Absolute Analysis

The absolute analysis, sometimes referred to as target modelling, requires only one model. Examples include the CaGBC's *Zero Carbon Building Energy Modelling Guidelines* [20] and passive house standards (PHI and Passive House Institute US [PHIUS]). This methodology involves comparing a model of the proposed design to fixed performance targets that may be expressed as greenhouse gas emissions intensity (GHGI), total energy use intensity (TEUI), thermal energy demand intensity (TEDI), or as other units.

The QA/QC procedures of BEM programs that are based on an absolute analysis must mitigate the impact of the BEM tools and modelling inputs not inherent in the project design on the compliance outcome. This is non-trivial. For example, California's performance-based compliance path was initially based on the fixed energy target method. The state was divided into five climate regions, and the source energy budgets were published for eight building types in each climate region, with separate budgets for heated-only buildings, cooled-only buildings, and buildings that were both heated and cooled. Projects were required to use standardized weather files and building operational assumptions, such as temperature schedules, hours of operation, outside air ventilation rates, etc. To account for differences between the BEM tools, an overall calibration factor was assigned to each approved tool. A factor greater than one was assigned if a tool consistently underpredicted energy use relative to the reference tool, which was DOE-2[4] at the time. The absolute analysis approach in California was ultimately abandoned in favour of a comparative analysis, due to challenges in achieving consistent outcomes.

The passive house protocols PHI and PHIUS use the absolute analysis. Each protocol prescribes operating conditions that must be used in the model and allow only one BEM tool (PHPP and WUFI, respectively). A BEM program based on the absolute analysis that wishes to allow the use of multiple BEM tools should establish rigorous sensitivity testing requirements to ensure close alignment in the results between different tools.

Predictive versus Standardized versus Representative Simulation Outcome

Predictive Outcome

A Predictive Outcome involves developing a model that is expected to align with future measured energy use. CaGBC's *Zero Carbon Building Energy Modelling Guidelines* [20] is an example of this approach and requires the following:

> *The expectation is that energy models used for compliance with the CaGBC's Zero Carbon Building Standard will be developed to represent the actual anticipated operation of the facility for all energy uses on site. Stipulated conditions such as schedules, occupancy, receptacle loads, and DHW loads shall be based on actual intended operational conditions for the facility in question. It is expected that the energy modelling professional will communicate with the client and facility operations staff to understand building operations as best as possible so that hours of operation and equipment run times are understood rather than relying on arbitrary defaults from software or applicable code or standards.*

Given the challenges in establishing realistic operating conditions, QA/QC procedures for predictive analysis may include site measurements in similar buildings and interviews with occupants, commissioning of installed systems, calibrating the model based on post-occupancy operation, and comparing the calibrated model to the measured post-occupancy energy use.

Standardized Outcome

A Standardized Outcome involves estimating energy use based on typical or standard operating conditions and weather. City of Vancouver's *Guidelines* [17] have the following description of the rationale:

> *The results of models created to meet these guidelines are intended for regulatory purposes only, to enable the Authority Having Jurisdiction (AHJ) to determine whether a building complies with the applicable policy or code. Much like an emissions test on a car, test results are used for standardized comparison and are not necessarily predictive of actual performance. The energy and thermal comfort performance of actual buildings will depend on many factors that can vary from these standardized assumptions, including intensity and hours of use, weather, occupant behaviour, as-built vs as-designed parameters, among many others.*

Representative Outcome

A Representative Outcome is a hybrid of the predictive and standardized approaches and involves using the actual operating parameters where available and standardized inputs in other cases. Table 1 illustrates how the classification applies to common BEM programs and modelling rulesets.

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[4] DOE-2 is an energy simulation software, originally developed with funding from the US Department of Energy (DOE) and first released in 1980. Derivative versions of DOE-2 are still in use today.

Areas That May Be Addressed by a Standard

Supplemental Modelling Requirements

Program administrators often develop modelling guidelines that supplement the adopted modelling ruleset. Peer-reviewed resources and industry best practices may be used to create a template for such guidelines and to describe the methodology for establishing simulation inputs depending on the model use case. For example, ASHRAE Standard 90.1 requires modelling lighting power that is based on the manufacturer's labelled maximum wattage of the existing or specified lighting fixtures. Following this rule, incandescent or tungsten-halogen luminaires without permanently installed ballasts that are labelled for 150 W must be modelled as 150 W even if fitted with a lower-wattage bulb, such as a 13 W screw-in CFL. This requirement ensures that compliance is established based on the worst-case scenario, e.g., if a less-efficient bulb is used as a replacement but exaggerates the modelled lighting wattage compared to what is installed. A BEM program that prioritizes predictive qualities of the model may choose to modify this requirement to have the lighting modelled based on the specified/installed bulb and ballast combination. This approach was followed by the EPA's *ENERGY STAR® Multifamily High Rise Program Simulation Guidelines*, which is based on ASHRAE Standard 90.1 Appendix G.

Simulation Tool Requirements

A standard may be used to outline BEM tool policies based on the model use case. For example, for the BEM programs that are based on the absolute analysis, procedures for mitigating the impact of BEM tools on the simulation outcomes may be necessary. For BEM programs requiring comparative analysis based on the modelling rulesets, such as NECB Part 8 or ASHRAE 90.1 Section 11 and Appendix G, adopting BEM tools that have the capability to automatically generate the reference design may be recommended.

Verification of Achieved Energy Performance

The potential of energy models to predict the performance of a new construction project or savings from an energy retrofit is one of the key reasons for using BEM. However, discrepancies between modelled and measured building performance have been widely reported [21]. For example, out of 171 projects that

Table 1: *BEM Program Model Use Case Classification Examples*

	Model Use Case	SIMULATION METHODOLOGY	
		Comparative	**Absolute**
SIMULATION OUTCOME	**Standardized**	California Title 24 Alternative Compliance Method	PHI, PHIUS, ASHRAE bEQ As-Designed, Vancouver's Zero Emissions Building Plan, GHGI and TEDI paths
	Representative	NECB Part 8, ASHRAE Standard 90.1 Section 11 and Appendix G, ASHRAE Standard 209 – Simulation Aided Design	None identified
	Predictive	International Performance Measurements & Verification Protocols Option D: Calibrated Simulation	CaGBC's Zero Carbon Building Standard

participated in a modelling-based incentive program and completed comprehensive retrofits, only 39% had projected savings within 25% of the realized savings established by comparing the annual utility bills before and after the retrofit, with the remaining projects having a greater discrepancy [22].

Factors such as the weather, occupant behaviour and demographics, and occupant-installed equipment have a strong impact on energy performance [22]. Yet the models that were developed based on expected operating conditions and typical weather are often directly compared to utility bills. The study of LEED buildings [18] is one of many examples. Specification of the necessary steps for verifying model results, such as establishing a monitoring period, determining the measured energy use during the period based on utility bills, and calibrating the model based on the measured operating conditions and weather during the monitoring period would help to mitigate discrepancies. The calibrated model could then be compared to the measured performance during the monitoring period to establish the degree of alignment.

In addition, models typically assume that building systems and controls operate as specified. However, this is rarely the case. In one study, economizers were shown to save 9% to 32% of cooling energy use depending on climate but malfunctioned in over 70% of the installations [24]. As a result, models reflecting correct economizer operations may substantially underestimate cooling energy use on many projects. To mitigate the mismatch between modelled and actual system operations, specifications on the commissioning and the development of an Operations and Maintenance (O&M) plan may be needed.

Documentation Requirements

Many administrators of BEM programs find the submittal forms included with the modelling rulesets insufficient for meaningful enforcement. They develop custom reporting templates to standardize the submittals and specify the supporting information that must be provided, such as design documents, energy audit reports, simulation input and output reports, and modelling files. A broader standardization approach may build on this experience and describe the required content of the reporting template depending on the model use case. For example, the reporting requirements for the comparative use case may involve itemizing the impactful differences between the baseline and reference design; for predictive use cases, the sources for operating condition assumptions may have to be documented; for all use cases, the impactful inputs may need to be substantiated by references to design documents, audit reports, and equipment specifications to enable the submittal review.

Submittal Review

Balancing effort and accuracy is one of the key principals of measurement and verification (M&V) [25] and is fully applicable to BEM. Models include thousands of inputs, thus it is crucial to prioritize the review checks to ensure the best use of the available review budget. A standard may provide a methodology for identifying systems and components with a significant impact on the simulation outcomes that the review should focus on. For example, if the energy savings in a comparative use case are driven by a reduction in fan energy use, the review effort should focus on verifying inputs and the modelling methodology of the baseline and proposed fan systems, and on the associated controls and loads such as the mechanical ventilation rate and schedule. A standard may also outline the effective high-level checks, such as confirming that the modelled energy use intensity (EUI) and the allocation of energy between the key end uses, including heating, cooling, lighting, fans, pumps, plug loads, and service water heating, is reasonable based on the benchmarks that would be included in the standard.

The BEM Program's Quality Assurance

The BEM program's quality assurance process may include periodic evaluation of the program's administration practices and technical requirements to ensure that they facilitate the intended performance outcomes. Some quality assurance aspects, such as the minimum qualification requirements of the submittal reviewer, may apply to all BEM programs; others may be specific to the model use case. For example, for an absolute use case, a sample of completed projects may need to be periodically reviewed to verify that the adopted performance targets (e.g., TEDI, TEUI) reflect the desired stringency and are coordinated with the allowed BEM tools and prescribed modelling inputs.

ASHRAE bEQ As-Designed (the Absolute/Standardized use case based on the proposed classification) illustrates the possible consequences of the misalignment between the prescribed inputs and the set target. For multifamily buildings, the receptacle and refrigeration loads and schedules prescribed by bEQ As-Designed account for 80% of the target EUI [26], and thus even high-performance designs exceeding passive house standards are poorly rated.

For predictive use cases, a periodic analysis of a sample of completed projects representative of the population with the best and worst alignment between measured and modelled energy use should be performed to identify patterns and inform the BEM program's rules.

Conclusions

There are existing industry standards that describe modelling rulesets (e.g., NECB Part 8, ASHRAE 90.1 Section 11 and Appendix G), energy estimation methodologies (CSA C873 Series – 15), and BEM software engine testing (ASHRAE 140) procedures; however, a standard that outlines the rules and procedures to be followed by BEM program administrators in order to mitigate the key drivers of discrepancies in BEM results does not exist.

In order to support the full range of BEM programs, including programs that target new construction and retrofit projects, minimum code compliance, and high-performance buildings, a BEM use case classification system that is based on the analysis methodology and desired performance outcomes is needed. A QA/QC standardization framework should provide a comprehensive set of default rules and procedures, tailored to the BEM program model use case, which can then be incorporated into a specific BEM program by the program administrator.

A standard that addresses these issues would improve the quality and consistency of modelling outcomes and increase the BEM program's administration effectiveness. In addition, it would have a significant spillover impact by shaping the marketplace's understanding of BEM applications and the value of energy modelling, and by setting a standard practice for BEM services.

References

1. American Institute of Architects, "*2030 by the Numbers: The 2016 Summary of the AIA 2030 Commitment*," AIA, Washington, DC, USA, 2018.

2.. J. Strebly et al., *BC Energy Step Code Design Guide, Version 1.1,* July 2019, BC Housing, Burnaby, BC, CAN.

3. M. Karpman, *"Performance-Based Code Compliance: A Roadmap to Establishing Quality Control and Quality Assurance Infrastructure",* Pacific Northwest National Library, U.S. Department of Energy, Report to be published March 2020.

4. *"Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs",* ANSI/ASHRAE Standard 140-2017, Atlanta, GA, USA, 2017.

5. *Energy Simulation-Aided Design for Buildings except Low-Rise Residential Buildings,* BSR/ASHRAE Standard 209-2017, Atlanta, GA, USA, 2017.

6. *2019 ASHRAE Handbook* – HVAC Applications, ASHRAE, Atlanta, GA, USA, 2019.

7. *2017 ASHRAE Handbook* – Fundamentals, ASHRAE, Atlanta, GA, USA, 2019.

8. M. Lawton, P. Roppel, and W. Marif, "*Thermal Performance of Buildings Envelope Details for Mid and High-Rise Buildings",* ASHRAE Research Project Report RP-1365, Atlanta, GA, 2011. [Online]. Available: http://info.morrisonhershfield.com/hubfs/blog-files/Documents/ASHRAE-D-RP-1365-20111006.pdf?t=1523558532852

9. US Department of Energy's Office of Energy Efficiency and Renewable Energy, "*Qualified Software for Calculating Commercial Building Tax Deductions,*" Energy.gov. https://www.energy.gov/eere/buildings/qualified-software-calculating-commercial-building-tax-deductions (accessed Dec. 6, 2019).

10. *New Construction Program's Energy Modelling Guidelines*, BC Hydro, Vancouver, BC, CAN, 2018.

11. J. Huang, F. Buhl, E. Erdem, R. Hitchcock, M. Yazdanian, and J. Warner, *"Evaluating the use of EnergyPlus for 2008 nonresidential standards development: Final evaluation report,"* LBNL-58841, Lawrence Berkeley National Laboratory, Berkeley, CA, USA, 2007.

12. S. Andolsun, C. Culp, and J. Haberl, *"EnergyPlus vs DOE-2: The effect of ground coupling on heating and cooling energy consumption of a slab-on-grade code house in a cold climate,"* in Fourth National IBPSA-USA Conference, New York, New York, USA, 2010, pp. 142-149. [Online]. Available: http://ibpsa-usa.org/index.php/ibpusa/article/view/282/271

13. Henninger, R. and M. Witte. *"EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2011."* Prepared for the U.S. Department of Energy Office of Building Technologies, Washington, D.C., 2013. http://apps1.eere.energy.gov/buildings/energyplus/pdfs/energyplus_ashrae_140_envelope.pdf

14. K. Tupper, et al. *"Building Energy Modeling Innovation Summit,"* Rocky Mountain Institute, Boulder, CO, USA, 2011. [Online]. Available: https://rmi.org/wp-content/uploads/2017/05/RMI_Document_Repository_Public-Reprts_2011-21_BEMPre-read.pdf

15. C.E. Barbour, R. Zogg, E. Cross, and D. Clark, *"Research & development roadmap for building energy modeling,"* US Department of Energy, Prepared by Navigant Consulting, Washington, DC, USA, 2016.

16. ENERGY STAR® Multifamily High Rise Program Simulation Guidelines – Appendix G 90.1 2016, Version 1.0, Energy Star, Washington, DC, USA, 2017.

17. Energy Modelling Guidelines, Version 2.0, City of Vancouver, Vancouver, BC, CAN, 2018.

18. Cathy Turner and Mark Frankel, *"How accurate is energy modelling in the market?"* presented at the 2008 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, Aug. 17–22, 2008. [Online]. Available: https://newbuildings.org/resource/how-accurate-energy-modeling-market/

19. E. Franconi et al., *Building Energy Modelling for Owners and Managers.* Boulder, CO: Rocky Mountain Institute, 2013.

20. Zero Carbon Building Energy Modelling Guidelines, Canada Green Building Council, Ottawa, ON, CAN, 20175. [Online]. Available: https://www.cagbc.org/cagbcdocs/zerocarbon/CaGBC_EMG_for_ZCB_v01.pdf

21. M. Karpman, *"Building system efficiency modelling—improving the accuracy of building energy modelling,"* National Electrical Manufacturers Association (NEMA BE P1-2018), Arlington, Virginia, USA, 2018. .

22. C. DeAlmagro and M. Karpman, *"Comparison of projected to realized savings for projects that participated in a modelling-based incentive program,"* presented at the ASHRAE Building Performance Analysis Conference, Atlanta, GA, USA, Sept. 27–29, 2017. [Online]. Available: https://static1.squarespace.com/static/5b9ac6e42971147e461f673f/t/5cdbfc5dec212d2d3b74dae3/1557920862795/ASHRAE+BPAC+-+2017+P4P.pdf

23. M. Karpman and M. Rosenberg, *"Building energy modelling has its place,"* NEMA Currents [Online blog], July 15, 2019. Available: https://blog.nema.org/2019/07/15/building-energy-modeling-has-its-place/

24. HVAC Economizers 101Section #3: *Why Economizers Fail and Increase Energy Use,* Battelle, Columbus, OH, USA, n.d. [Online]. Available: https://buildingretuning.pnnl.gov/training/economizers/PNWD-SA-8511%20HVAC%20Economizers%20101-Section%203.pdf

25. Core Concepts, International Performance Measurement and Verification Protocol, Efficiency Valuation Organization (EVO 10000-1:2016), Washington, DC, USA, 2016.

26. M. Karpman, C. Eley, and N. Wang, *"Comparative analysis of ASHRAE Building EQ As-Designed, Building energy asset score, and ASHRAE 90.1 performance rating method,"* presented at the Building Simulation Conference, San Francisco, CA, USA, Aug. 7-9 2017. [Online]. Available: http://karpcon.com/BS2017_Comparative_Analysis_of_Asset_Ratings_FINAL.pdf

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