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PNNL-30824

Performance-Based Code Compliance: A Roadmap to Establishing Quality Control and Quality Assurance Infrastructure

April 2021

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U.S. DEPARTMENT OF ENERGY

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Richland, Washington 99354

Summary

This report was completed as part of a research project to facilitate performance-based compliance with commercial energy codes. The report incorporates input from more than 70 stakeholders representing jurisdictions; administrators of above-code programs; members of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, 140, and 189.1 committees; the International Building Performance Simulation Association; the Commercial Energy Services Network; and others. The stakeholder engagement work was supported by Northwest Energy Efficiency Alliance.

Most energy codes in the United States include both prescriptive and whole building performance paths. The prescriptive path requires compliance with efficiency metrics for individual systems and components, such as R-value of wall insulation or maximum lighting power allowance. The performance path offers flexibility by allowing some items to be less efficient in exchange for others being more efficient, provided the whole building meets some energy target, as demonstrated through whole building energy simulation. This path currently accounts for a minority of new construction permits in most jurisdictions but is gaining momentum. Many stakeholders see it as the future of the commercial energy codes and the main pathway for achieving low energy and net zero buildings.[1]

Enforcing performance-based compliance is notoriously difficult due to the complexity of energy modeling and the lack of a clear and direct connection between the energy model and the building design. Jurisdictions and rating authorities often lack the technical expertise necessary for meaningful submittal review and the tools and resources that they can lean on are scarce. Stakeholders named modeler errors and imprecision of the simulation tools as the key reasons for incorrect compliance outcomes.

Entities that have mature acceptance procedures for performance-based submittals, including California Energy Commission (Title 24 Alternative Compliance Method), Florida Building Commission (Energy Code Commercial Performance Based Compliance), and Residential Energy Services Network (RESNET® Home Energy Rating System) share common features that help improve consistency of the compliance outcomes. They all require a multi-year commitment of an organization administering the program to establish and maintain its quality assurance (QA) and quality control (QC) infrastructure, which typically includes simulation software acceptance and standardized compliance forms. Some also require modeler and submittal reviewer accreditation and training. Many of the elements of this infrastructure are best addressed on the national level – for example, having a national testing and certification process for the simulation tools has potential for higher technical rigor and better engagement of software tool vendors.

This report identifies the following focus areas for streamlining enforcement and ensuring consistency in compliance outcomes across different modelers and simulation tools:

- Modeling standards that are comprehensive, unambiguous, and tailored to the intended use case
- A rigorous software certification process to reduce the impact of differences in physics calculations and ruleset implementation on the compliance outcomes

[1] Rosenberg MI, R Hart, J Zhang, and RA Athalye. 2015. Roadmap for the Future of Commercial Energy Codes. PNNL-24009, Pacific Northwest National Laboratory, Richland, WA. Retrieved from https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24009.pdf

- Automation of mechanical tasks involved in modeling, compliance documentation, and submittal review, to minimize subjectivity and human error and improve productivity
- An organization that will oversee the QA/QC framework; certify simulation software; create a national network of certified modelers, reviewers, and training providers; and work with rating authorities and jurisdictions to provide packaged enforcement solutions

The short-term recommendations provided in this report focus on delivering tools and resources that would immediately improve compliance with the ASHRAE 90.1 Energy Cost Budget Method (ECB) and Performance Rating Method (PRM), which are the most commonly used performance-based protocols according to the stakeholder survey. The following is recommended:

- Publish 90.1 2016/2019 ECB and PRM Compliance Forms.
- Publish 90.1 2016/2019 ECB and PRM Submittal Review Manual.
- Develop trainings for modelers and reviewers on the use of the compliance forms and review manual.
- Establish recommendations for the minimum qualification requirements for modelers and reviewers.
- Develop scope of work for third-party submittal reviewers.
- Publish technical documents to facilitate consistent interpretation of the modeling requirements and address common PRM adoption challenges.
- Update ASHRAE Standard 90.1 to clarify PRM and ECB modeling requirements and to incorporate ASHRAE Standard 140 acceptance ranges; investigate a new, simplified performance-based compliance path.
- Initiate updates to ASHRAE Standard 140 to better support impactful commercial systems and component simulation.
- Develop a new ASHRAE Standard 229P, *Protocols for Evaluating Ruleset Implementation in Building Performance Modeling Software*.

The medium-term recommendations include the following:

- Enhance PRM and ECB Compliance Forms for greater usability, to increase automation, and to incorporate updates to 90.1.
- Maintain the Submittal Review Manual to incorporate user inputs and updates to 90.1.
- Update ASHRAE Standard 140 to include physics and sensitivity testing of common commercial systems and designs, including the acceptance ranges.
- Publish ASHRAE Standard 229P and promote its adoption by authorities having jurisdiction, rating authorities, and software tool vendors.
- Update Standard 90.1 to include one detailed performance-based compliance path based on the PRM and one simplified performance-based compliance path that may be allowed for documenting minimum code compliance and/or based on project size, complexity, or other characteristics (e.g., new construction versus retrofit); add requirement for the building energy modeling (BEM) tools to comply with Standard 229P.

- Investigate pathways for establishing the certifying body(s) that will certify BEM tools and establish a national network of the certified modelers and submittal reviewers.

The long-term goal is to transfer responsibilities for modeler, reviewer, and software certification to a national certifying body(s), which will maintain and enhance the created tools and resources relying on the continuously maintained ASHRAE Standards 90.1, 140, and 229.

The recommendations for short-, medium-, and long-term activities to help facilitate the vision and address the priorities identified by the stakeholders are illustrated in the figure below.

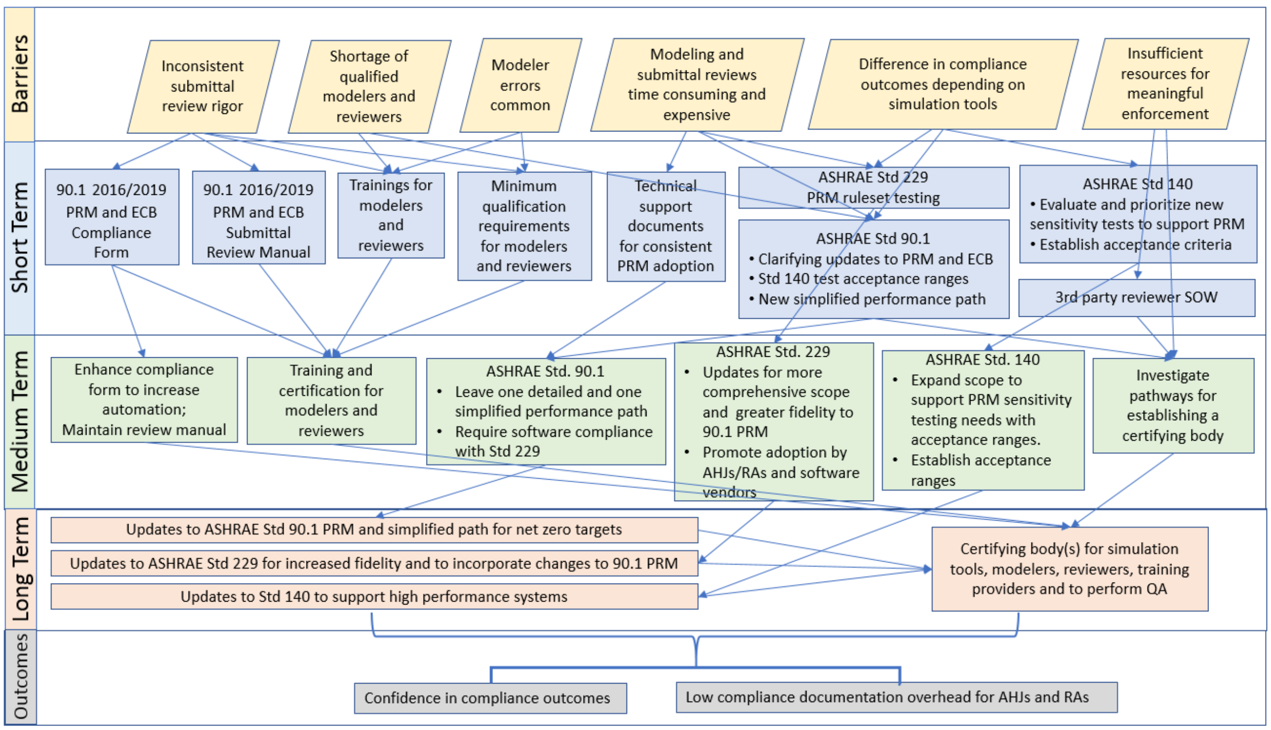

Figure S.1 Short-, Medium-, and Long-term Activities for Establishing Performance-Based Compliance QA/QC Framework

Acknowledgments

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The survey responses were processed by Christina LaPerle and Eva Spazzarini (Karpman Consulting)

Acronyms and Abbreviations

ACM	Alternative Calculation Method
AHJ	authority having jurisdiction
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEM	building energy modeling
BEMP	building energy modeling professional
bEQ	Building Energy Quotient
BIM	building information modeling
CBECC-Com	California Building Energy Code Compliance (software)
CEC	California Energy Commission
COMNET	Commercial Energy Services Network
DOE	U.S. Department of Energy
DOB	Department of Buildings
ECB	Energy Cost Budget Method
ECCCNYS	Energy Conservation Construction Code of New York State
EDAPT	Design Assistance Project Tracker
EPA	U.S. Environmental Protection Agency
FEC	Florida Energy Code
GBCI	Green Building Certification Inc.
HERS	Home Energy Rating System
HVAC	heating, ventilation, and air-conditioning
IBPSA	International Building Performance Simulation Association
IECC	International Energy Conservation Code
IES-VE	Integrated Environmental Solutions – Virtual Environment
IRS	Internal Revenue Service
LEED	Leadership in Energy and Environmental Design
MFHR	Multifamily High Rise (program)
MGP	modeling guidelines and process
MRO	Multifamily Review Organization
NA	not applicable
NEEA	Northwest Energy Efficiency Alliance
NYC	New York City
NYSERDA	New York State Energy Research and Development Authority
ODOE	Oregon Department of Energy
PNNL	Pacific Northwest National Laboratory

PRM	Performance Rating Method
PRM RM	Performance Rating Method Reference Manual
RA	rating authority
RESNET	Residential Energy Services Network
RMR	ruleset model report
SEED	State Energy Efficient Design
SOW	statement of work
TBP	Total Building Performance
QA	quality assurance
QC	quality control
WWR	window-to-wall ratio

Contents

Figures

1.0 Project Background

This report was supported by Pacific Northwest National Laboratory (PNNL) with funding from the U.S. Department of Energy (DOE) and was completed as part of a research project to facilitate performance-based compliance with commercial energy codes. The project had the following goals:

- Gather information on the current state of commercial performance-based compliance, enforcement challenges, and best practices.
- Identify the elements of quality assurance and quality control (QA/QC) infrastructure necessary for effective and efficient enforcement.
- Develop a roadmap to address the QA/QC infrastructure gaps, including implementation timeframe.
- Implement tools to aid compliance that were identified as high priority.
- Identify opportunities for maintaining the created tools and enhancing QA/QC infrastructure beyond the initial effort, to support evolving compliance needs.

The research focused on the elements that are unique to performance-based compliance – the aspects that are the same between prescriptive and performance paths, such as site inspections, were not reviewed. The work incorporated input from more than 70 stakeholders representing the key market segments involved with performance-based compliance, including jurisdictions; administrators of above-code programs; members of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, 140, and 189.1 committees; the International Building Performance Simulation Association (IBPSA); design teams; and energy consultants. In addition, stakeholders involved with the Residential Energy Services Network (RESNET®) shared their experience.

Under a parallel effort supported by the Northwest Energy Efficiency Alliance, the stakeholders were asked to complete a survey assessing performance path market penetration and trends, enforcement practices, and perceived short- and long-term priorities for improving compliance. The survey questions and summary of responses are included in Appendix A. Stakeholder feedback from the survey and from a discussion session at the 2019 DOE Energy Code Conference is referenced and quoted throughout the report.

2.0 Overview of Commercial Performance-Based Compliance

2.1 Common Performance-Based Compliance Protocols

Most energy codes in the United States include both prescriptive and whole building performance paths. The prescriptive path requires compliance with efficiency metrics for individual systems and components, such as R-value of wall insulation, combustion efficiency of heating equipment, and maximum lighting power allowance. The performance path provides flexibility by allowing some items to be less efficient in exchange for others being more efficient, provided the whole building meets some energy target, as demonstrated through building simulation using an approved building energy modeling (BEM) tool. For example, a project may show that more efficient lighting and mechanical systems offsets the performance loss due to a less efficient building envelope.

The performance-based compliance protocols include modeling rules, methodology for establishing pass/fail compliance outcomes based on the modeling results, submittal requirements, and the required capabilities of the BEM tools. These elements are referred collectively to as the **modeling ruleset** in this report.

Under most energy codes, compliance is established by comparing the energy cost of the proposed design model, which largely reflects the specified systems and components, to a model of a virtual building serving as a point of reference (Figure 2). This method, often referred to as a reference building approach, is the basis of the following rulesets:

1. ASHRAE Standard 90.1[1] Energy Cost Budget Method (ECB, Section 11)
2. ASHRAE Standard 90.1 Performance Rating Method (PRM, Appendix G),
3. International Energy Conservation Code (IECC) Section C407 Total Building Performance (TBP)
4. California Title 24 Alternative Calculation Method (ACM)

[1] ANSI/ASHRAE/IES Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, is designated U.S. legislation as the national model energy code for commercial buildings.

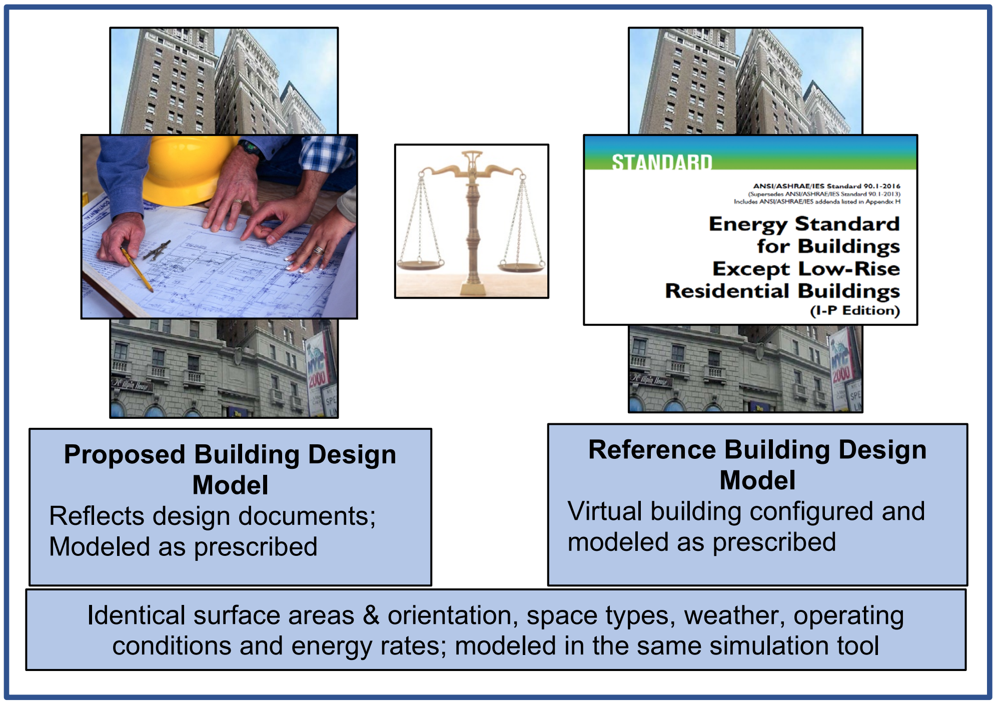


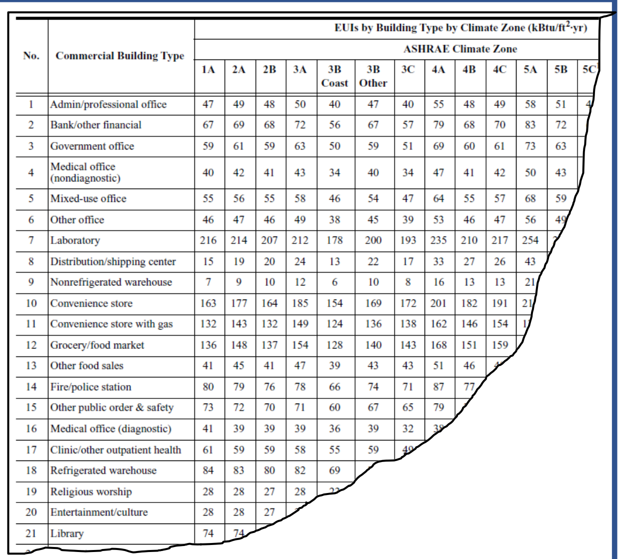
Figure 2. Performance-Based Compliance Reference Building Method

Alternatively, compliance may be established by comparing the simulated energy use of the proposed design to a predetermined performance target taken from a table of energy use values categorized by building type and climate zone instead of a parallel reference building model (Figure 3). This fixed target approach, sometimes also referred to as the fixed energy budget, is used by the following programs:

1. ASHRAE Building Energy Quotient (bEQ) As Designed
2. Seattle's Target Performance Path
3. Vancouver building bylaws
4. Passivhaus (Passive House Institute, PHI) and Passive House Institute US (PHIUS)
5. City of Boulder Energy Conservation Code (Boulder 2017)

This approach is also being considered by New York City (NYC) and several other jurisdictions.

Proposed Building Design Model
Reflects design documents;
Modeled as prescribed



No.	Commercial Building Type	EUIs by Building Type by Climate Zone (kBtu/ft²·yr) ASHRAE Climate Zone												
		1A	2A	2B	3A	3B Coast	3B Other	3C	4A	4B	4C	5A	5B	5C
1	Admin/professional office	47	49	48	50	40	47	40	55	48	49	58	51	
2	Bank/other financial	67	69	68	72	56	67	57	79	68	70	83	72	
3	Government office	59	61	59	63	50	59	51	69	60	61	73	63	
4	Medical office (nondiagnostic)	40	42	41	43	34	40	34	47	41	42	50	43	
5	Mixed-use office	55	56	55	58	46	54	47	64	55	57	68	59	
6	Other office	46	47	46	49	38	45	39	53	46	47	56	49	
7	Laboratory	216	214	207	212	178	200	193	235	210	217	254		
8	Distribution/shipping center	15	19	20	24	13	22	17	33	27	26	43		
9	Nonrefrigerated warehouse	7	9	10	12	6	10	8	16	13	13	21		
10	Convenience store	163	177	164	185	154	169	172	201	182	191	21		
11	Convenience store with gas	132	143	132	149	124	136	138	162	146	154			
12	Grocery/food market	136	148	137	154	128	140	143	168	151	159			
13	Other food sales	41	45	41	47	39	43	43	51	46				
14	Fire/police station	80	79	76	78	66	74	71	87	77				
15	Other public order & safety	73	72	70	71	60	67	65	79					
16	Medical office (diagnostic)	41	39	39	39	36	39	32						
17	Clinic/other outpatient health	61	59	59	58	55	59							
18	Refrigerated warehouse	84	83	80	82	69								
19	Religious worship	28	28	27	28									
20	Entertainment/culture	28	28	27										
21	Library	74	74											

Figure 3. Performance-Based Compliance Fixed Energy Target Method

With either the reference building or fixed target method, compliance may be established using a variety of units such as site or source energy, greenhouse gas emissions, or energy cost.

2.2 Market Penetration of Performance-Based Compliance

No objective assessment of the prevalence of performance-based projects has been compiled, as a majority of jurisdictions do not track this information. However, the following observations from the project stakeholders are informative. In most jurisdictions, the prescriptive path is still more common, often accounting for over 95% of the new construction permits. However, projects using a performance-based compliance path are typically large buildings and therefore account for an unproportionally high fraction of the floor area. For example, a Seattle stakeholder estimated that 5% of projects that use the performance path represent approximately 40%-50% of the permitted floor area. Use of the performance path for new commercial projects is the highest in Florida (90%+ of the permits), California (approximately 50% of the permits), and Washington, D.C. (30%-50%+). The California and Florida experiences are described in Appendix B of this report.

As prescriptive requirements become more stringent and are more rigorously enforced, more projects are seeking the flexibility of performance-based compliance. In Washington State, the prescriptive path requires dedicated outdoor air systems combined with cycling heating and cooling fans in schools, offices, and retail buildings – consequently, projects with all other heating, ventilation, and air-conditioning (HVAC) system designs must use the performance path. Some jurisdictions now require energy modeling for certain types of projects. For example, all new construction projects in Boulder, Colorado, must submit model results with their permit application[1] (Boulder 2017). In Connecticut (Connecticut 2011) and Oregon,[2] energy modeling is required for construction projects that receive state funding. The Federal Energy Management

[1] Section C401.2.1. The requirement applies to projects with construction valuation of $500,000 or more.
[2] Oregon State Energy Efficient Design Program. Website: https://www.oregon.gov/energy/energy-oregon/Pages/SEED.aspx.

Program requires all new buildings to exceed Standard 90.1 as demonstrated by modeling in accordance with the PRM (DOE 2015).

Based on the stakeholder survey, the 90.1 ECB is currently used more often for minimum compliance. The 90.1 PRM was originally developed specifically for evaluating high-performance designs and is an overwhelming favorite for above-code programs. Starting with the 90.1 2016 edition, PRM has become an approved path for documenting minimum compliance with Standard 90.1; however, many jurisdictions with earlier base codes have already accepted it as a compliance option. For example, New York and Connecticut energy codes allowed PRM in conjunction with 90.1 2013 base code.

The PRM is being actively developed by ASHRAE and is perceived as the future of performance-based compliance by the 90.1 committee.[1] The length of 90.1 Appendix G, where the method is described, has increased from 7 pages in the 2007 edition to 42 pages in the 2019 edition of the Standard. Conversely, TBP use is going down. It has not been consistently maintained in the recent editions of the IECC, and some jurisdictions (NYC, Rhode Island) no longer allow it.

Most jurisdictions allow multiple performance-based compliance options – e.g., many accept ECB, PRM, and TBP, sometimes with state-specific amendments. Some jurisdictions accept documented participation in approved above-code programs as a proxy for code compliance, as allowed by 2018 IECC Section 102.1.1. The City of West Palm Beach accepts submittals following Leadership in Energy and Environmental Design (LEED), the International Green Construction Code, and Green Globes requirements; in Connecticut, successful participation in the Energize CT New Construction Program is accepted. The District of Columbia allows the PRM for projects pursuing LEED or similar programs, but projects are required to demonstrate improvement over code to compensate for the perceived difference in stringency between the PRM and ECB.

The existence of three significantly different performance-based compliance options (ECB, PRM, and TBP) in the national codes complicates enforcement. Jurisdictions that allow multiple performance-based compliance options need to have submittal reviewers who are proficient with each approach and need to maintain multiple reporting templates. Permit applicants can "path shop" for a protocol that is more lenient for the project at hand, and submittals often erroneously mix and match requirements of the different protocols.

Performance-based compliance is used most often for school/university, office, hotel, and multifamily projects, according to the stakeholders, and commonly involves trading less efficient building envelope performance for more efficient lighting and HVAC performance. For example, in a live attendee poll at the 2019 DOE Energy Code Conference discussion session, over 70% of the participants indicated that projects that use energy modeling to document compliance have less efficient envelope, and over 50% indicated that such projects have more efficient lighting (Figure 4). In NYC, most performance-based projects are 50,000+ square foot high-rise multifamily buildings that trade lower performing, highly glazed building envelopes, and lack of exhaust air energy recovery for high efficiency lighting and mechanical systems.[2] A study of performance path trade-offs done in Seattle showed that over 75% of projects included a building envelope that would not have complied prescriptively (Thornton et al. 2015)

[1] Based on authors personal communication with committee members.

[2] Based on authors' personal communication with the New York City Department of Buildings.

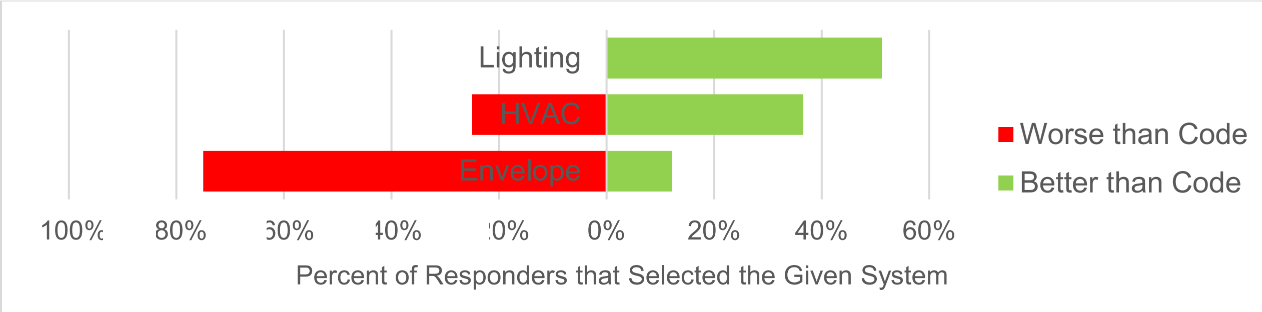


Figure 4. Common Systems Traded Off on Performance Projects

The building envelope has much longer useful life than most other building systems, and many stakeholders viewed the ability of projects with poor envelopes to demonstrate compliance with energy code via performance path as a critical flaw of the modeling rules. Addendum CR to 90.1 2019 addressed this concern by introducing an "envelope backstop" that limits the building envelope trade-offs for projects following 90.1 Section 11 and Appendix G.

3.0 Compliance Documentation Process

3.1 Overview

The compliance documentation process is illustrated in Figure 5. It involves a modeler performing an energy analysis based on the design documents, following the technical requirements of the performance-based compliance program. There may be several iterations of the analysis to capture design changes due to modeler feedback, evolving owner requirements, or updates made by the design team. Once the analysis is completed, the required compliance documentation is submitted to the submittal reviewer, who may either approve the project or request revisions.

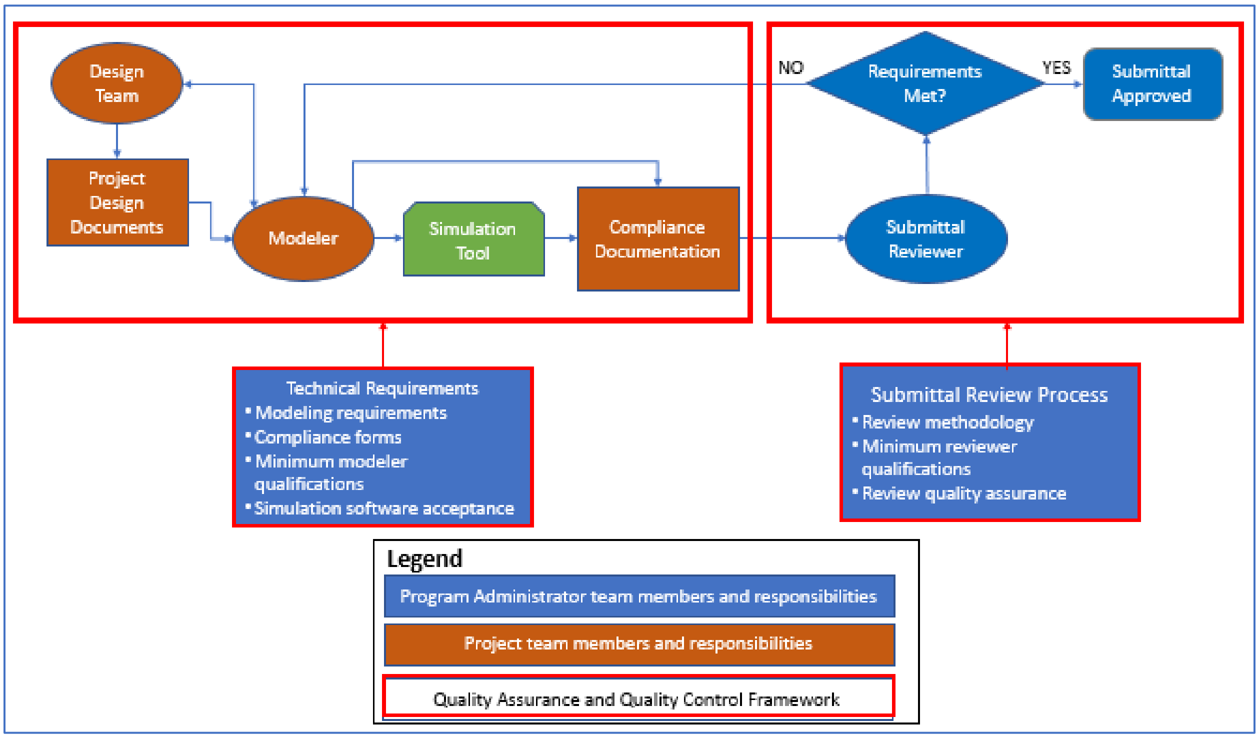


Figure 5. Compliance Documentation Process

Program administrator is an entity that administers modeling-based protocols, such as the authority having jurisdiction (AHJ) that oversees energy code compliance or the rating authority (RA) that administers above-code programs. Examples of AHJs include the local building code departments [e.g., the NYC Department of Buildings (DOB)] or state entities (e.g., New York State Division of Building Standards and Codes, Connecticut Department of Administrative Services). The U.S. Environmental Protection Agency (EPA) is the rating authority that administers the ENERGY STAR Multifamily High Rise (MFHR) program, Green Building Certification Inc. (GBCI) is the rating authority for LEED, and utility companies are the rating authorities for the utility incentive programs.

Program administrators define requirements for performing energy analysis and establish submittal review process. In this report, these rules and procedures are collectively referred to as the **Quality Assurance (QA) and Quality Control (QC) framework**. The key elements of this framework are described below.

Program Technical Requirements is the public-facing portion of the QA/QC framework that communicates program rules to the participants. It includes one or more of the following elements:

- **Modeling requirements** include simulation rules that projects must follow, which are often based on a national modeling ruleset(s) (e.g., PRM, ECB) with program-specific modifications.
- **Compliance forms** provide a standardized format in which project information must be submitted. Compliance forms may be part of the modeling ruleset or developed by the program administrator.
- **Minimum modeler qualification requirements** include work experience, education, and credentials of professionals that can develop and/or sign off on the project submittals.
- **Simulation software acceptance** is the process that the simulation tool vendors must follow in order for their tool to be approved for use in the program.

Submittal Review Process is the program's internal QA/QC framework that defines the program administrator's review policies.

- **Review methodology** determines scope, depth, and rigor of submittal reviews. It may be documented in a review checklist, review manual, or similar resources.
- **Minimum reviewer qualification requirements** include work experience, education, and credentials of professionals who review the project submittals to verify compliance with program requirements. The reviewers may be employed by the program administrator (e.g., work for DOB) or an external consultant.
- **QA** involves steps taken by the program administrator to evaluate the effectiveness of the program policies and review process.

3.2 Compliance Documentation Challenges

On a typical project, a proposed design is in flux up until the permit deadline, which does not leave time for the modeler to incorporate last-minute changes into the compliance submittal. Thus, the models often reflect intermediate design and not the final construction documents. In addition, models are typically not updated to reflect as-built conditions, as required by most energy codes, when there are any significant departures from the construction documents.

Energy modeling is often initiated late in the design process, when it is too late to make changes, and there is substantial pressure on modelers to show that the completed design complies with the energy code or demonstrates the target above-code performance, especially when these targets or LEED certification are written into contractual obligations. A modeler shared the following observations:

> "The architect doesn't want to have to redesign envelope, and the mechanical engineer doesn't want to re-size mechanical equipment or ductwork. Since the energy modeler is often a subcontractor for the architect or mechanical engineer, there is propensity for architects and mechanical engineering firms to 'shop-around' for a modeler that can get their project to qualify. This incentivizes modelers that successfully and consistently game the system, not modelers who do complete and accurate work."

On projects participating in the incentive programs, modelers are often expected to maximize the incentive for a given design. Some energy consultants work on commission, which may be as high as 22% of the incentive that they secure for the building owner (Kaysen 2012). To avoid it, some utility programs have direct modeler incentives – for example, the Energize Connecticut Energy Conscious Blueprint Whole Building Program has $15,000 to $20,000 per project funding that goes to the modeler (Karpman 2020).

3.3 Enforcement Rigor

Comments and feedback collected from the stakeholders revealed a lot about the current level of enforcement rigor. While some stakeholders noted a general improvement in submittal review rigor, it varied significantly among jurisdictions. Large cities tend to provide more thorough review than the smaller ones. In reviewing the survey data it was observed that some code officials at the local level are not even fully aware of the allowed compliance options. For example, in Rhode Island, TBP was amended out of the state code in 2013, but some projects are still being permitted under this option. In some jurisdictions, reviews may take over 40 hours and require three or more iterations before approval. Others spend less than 2 hours per project, and some automatically accept any submittal stamped by a licensed professional. Utility programs often have higher submittal review rigor, which has spill-over effect of improving the overall quality of compliance modeling.

Some stakeholders reported a positive reaction to stricter enforcement:

> "Applicants appreciate the rigor. Codes/policies that are unevenly levied on building applicants and project teams are very unpopular. The more we ensure that each and every project (to the extent we are able, given limited resources) is demonstrating compliance both at the time of permit and again throughout construction, the more credibility and support we have for our energy code."

Others have mixed experiences:

> "They know it is something they are required to comply with, so we hear complaints, but see compliance."

One stakeholder drew a dark picture of how building officials are treated and the pushback that they experience:

> "…very poor... defensive, lack truthfulness, lack of interest in compliance, try to bully the building department, and ultimately they get very political and call the city manager and city council members to push projects through without proper compliance – and this seems to work every time."

In most jurisdictions, submittal reviews are funded through permit fees that are independent of the actual review effort on a given project. For example, in NYC, the permit fee is $220 for all projects irrespective of the floor area and the compliance path followed. In a handful of jurisdictions, permit applicants cover the actual review effort – e.g., in Seattle, reviews take 10-50 hours, are done in-house, and the applicants bear the cost based on the actual time spent by reviewers at approximately $200/hr. This fee structure encourages better quality of submittals:

> "It's in their best interest …to have all their ducks in a row before they come in. We also usually have a pre-submittal meeting with applicants to discuss how they're modeling any unusual conditions - this saves a lot of time and headaches."

Based on the stakeholder survey, a pattern emerged that adopters who spent more time on the submittal reviews had less confidence in the quality of the models (Figure 6), likely due to increased awareness of the underlying complexities and frequency and severity of uncovered issues.

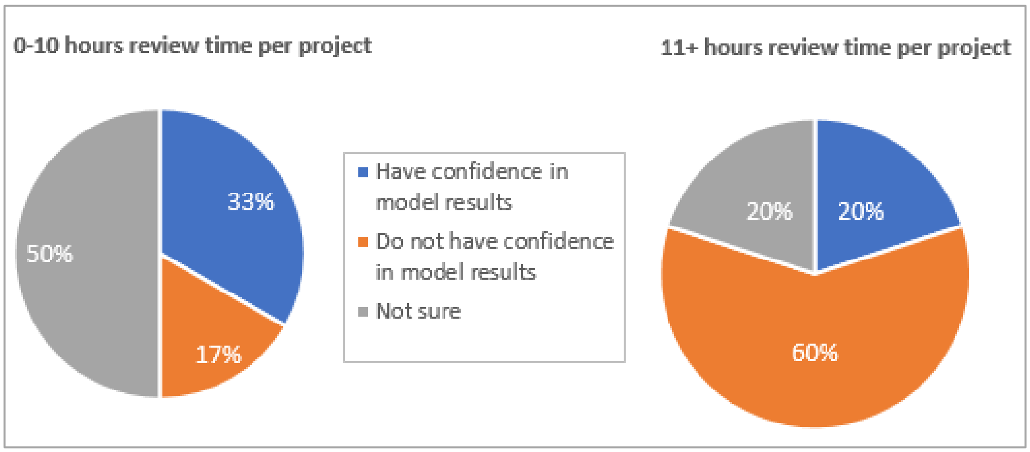


Figure 6. Time Spent on Submittal Reviews versus Confidence that the Modeling Results Are Accurate

According to the NYC DOB, lack of coordination between the energy model and design documentation is one of the most prevalent issues that has yet to show improvement. A stakeholder involved in a commercial compliance study made a similar observation and described the following experience in Florida:

> "I believe we looked at three buildings all complying using the performance path. None of the three models matched the design at all. One was like a completely different building. Different wall areas, some with no wall on certain orientations. WWR off by factor of two. Different HVAC systems. It was unreal. We all sat just shaking our heads. "

The following section describes the existing practices and challenges associated with the individual elements of the QA/QC framework of the performance-based compliance programs.

4.0 Current Quality Assurance and Quality Control Methods and Tools

4.1 Modeling Requirements

Most jurisdictions that have energy codes based on the IECC and Standard 90.1 adopt the modeling rules included in these standards as written (e.g., the 2018 Connecticut State Building Code); others have state-specific amendments. For example, the NYC 2020 Energy Conservation Code includes multiple changes to the 90.1 2016 PRM and ECB. Some jurisdictions have unique energy codes and develop custom modeling requirements that are substantially different from the model codes. Examples include California Title 24 ACM, The City of Vancouver Energy Modeling Guidelines, and the City of Seattle Total Building Performance (Vancouver 2018; Seattle 2018)

Many above-code programs have modeling requirements based on the PRM with limited modifications that are documented in the programs' guidelines – examples include the ENERGY STAR MFHR Simulation Guidelines and the section in the LEED v4 Reference Guide dedicated to modeling (EPA 2018; USGBC 2019). Some utility incentive programs have more significant deviations from PRM. These programs are funded by the ratepayers and the regulators often set constraints on the analysis methodology.

Some common changes to the modeling rules of the model codes include the following:

a. Setting performance floor for individual systems and components, to limit the allowed trade-offs. For example, NYStretch Energy Code – 2020 (NYStretch) amended ECB and PRM to add an "envelope backstop" that limits the trade-offs between envelope and other building systems (NYSERDA 2020).

b. Expressing compliance outcomes in units other than energy cost. For example, Washington State uses carbon emissions as the basis of PRM compliance; NYStretch allows the use of source energy units in addition to energy cost in conjunction with PRM.

c. Changes to the modeling rules to avoid conflicts with the program policies, such as to eliminate "fuel switching." For example, the Energize Connecticut Energy Conscious Blueprint program, which is based on 90.1 2013 Appendix G, requires modeling of electric space heating systems (typically variable refrigerant flow) in the baseline for projects that have electric space heating in the proposed design (Karpman 2020). (Based on the PRM rules, all projects in the Connecticut climate zone have gas space heating in the baseline.)

d. Accounting for local standard practices such as typical HVAC system types or better-than-code lighting or HVAC system efficiency. For example, the Mass Save incentive program requires modeling 85% efficient boilers in the baseline (Mass Save 2017).

Experience has shown that PRM, ECB, and TBP often lack the specificity necessary to support their consistent application to diverse commercial designs. A stakeholder from the NYC DOB noted difficulties with enforcement due to the lack of a manual or guidelines that clarify the ambiguities. Another stakeholder observed that there are still too many loopholes in the modeling methodologies that make it easy to get substantially different results for certain projects depending on the interpretation of the rules. The Performance Rating Method Reference Manual (PRM RM), maintained by PNNL, is a comprehensive resource for the PRM, but many modelers and program administrators are not aware of its existence (Goel and Rosenberg 2017). The PRM RM is similar to the California Nonresidential Alternative Calculation Method (CA ACM) Reference Manual, which contains the modeling requirements and procedures for approval of nonresidential Title 24 compliance software (CEC 2019). The PRM RM was developed to reflect the modeling requirements of the PRM, but largely preserved the presentation style of the CA ACM Reference Manual, which is written primarily for software developers and not energy modelers or submittal reviewers.

PRM, ECB, and TBP do not prescribe modeling inputs related to building operation (thermostat setpoints, lighting runtime hours, etc.) and energy use of systems installed by tenants (e.g., kitchen appliances in multifamily buildings, IT equipment in offices). The intent is to give modelers flexibility to capture the anticipated future building operation. However, if these operational parameters are unknown, invalid or unsupported assumptions can impact the compliance outcome. For example, the penalty associated with a less efficient building envelope may be minimized by modeling lower thermostat setpoints for heating and higher thermostat setpoints for cooling to reduce the relative impact of heating and cooling energy use on the overall building energy cost. Conversely, savings from higher efficiency lighting can be maximized by modeling longer lighting runtime hours, which increases the relative impact of lighting on performance.

ECB and PRM leave approval of some of the modeling rules up to the program administrators. For example, AHJs and RAs are expected to approve weather data, utility rates, and analysis methodologies used for the systems and components that cannot be explicitly modeled in simulation programs (exceptional calculations). However, program administrators often leave these areas unprescribed. For example, according to the survey, 65% of stakeholders do not publish approved weather files, utility rates, operating conditions, and schedules for their programs, making them more vulnerable to gaming.

4.2 Compliance Forms

Compliance documentation facilitates submittal reviews and helps ensure that:

- the proposed design model reflects design documents,
- the baseline/budget design is established and modeled correctly,
- the simulations are error-free,
- the compliance outcome is calculated correctly based on the simulation results, and
- the applicable rules of the standard are followed, such as the cap on the contribution of the renewable energy towards compliance.

IECC and 90.1 describe the documentation that must be submitted to the program administrator by performance-based projects, but do not provide the necessary compliance forms, meeting those requirements, that the program administrators can readily adopt. For example, the PRM compliance form included in the ASHRAE 90.1 2016 Users' Manual makes it appear that only the simulation results and high-level building characteristics need to be provided, while the actual 90.1 reporting requirements are substantially more comprehensive. For example, PRM also requires:

- documenting energy features that differ between the baseline and proposed design models,
- showing compliance with all the mandatory provisions, and

- providing a list identifying aspects of the proposed design that are less stringent than prescriptive requirements of the standard.[1]

To fill this gap, some jurisdictions such as the state of Oregon require performance-based projects to fill out COMCheck,[2] which is a software tool designed to document prescriptive energy code compliance. While COMCheck does not meet many of the reporting requirement applicable to the performance-based projects (e.g., does not provide means to report parameters of the baseline design), it helps code officials identify systems and components in the building design that are better or worse than prescriptive code requirements, and to ascertain that the mandatory code requirements are meant. The City of Vancouver requires projects that follow PRM and ECB to fill out the prescriptive compliance forms available in the 90.1 Users' Manual for individual building systems (envelope, lighting, etc.) with some minor modifications.

Some program administrators develop custom compliance forms. LEED® NC Version 2 introduced a fillable PDF Minimum Energy Performance Calculator that included a table with the side-by-side comparison of the key parameters of the baseline and proposed design energy models. LEED® v3 switched to a spreadsheet-based form that was easier for modelers to fill out and could accommodate supporting calculations. The spreadsheet format was retained in the LEED® v4 Energy Performance Calculator. Programs such as EPA ENERGY STAR MFHR and New Jersey Pay for Performance programs have a licensing agreement with the GBCI that allows them to use a modified version of the LEED® spreadsheet for their reporting.[3]

NYC DOB has an Excel-based EN-1 form[4] that must be included on the construction drawings (Figure 7) of projects using performance-based compliance. The form requires listing the key energy modeling inputs and outputs with references to the corresponding energy modeling reports and design document where each value can be verified (envelope insulation, capacities and efficiencies of mechanical systems, etc.). The applicant must also submit the energy model input and output reports referenced in the form.

In 2017, the New York State Energy Research and Development Authority (NYSERDA) funded enhancements to the LEED compliance spreadsheet and received permission from the GBCI to allow New York jurisdictions to use of the modified form. The form includes a detailed side-by-side comparison of the baseline and proposed design as well as the associated prescriptive requirements for the specified systems and components as required by PRM (Figure 8). There are added look-up tables that help establish the configuration of the baseline design based on a user-entered description of the proposed design and expanded QC functionality to automatically flag inputs and outputs that appear out of range (Figure 9). The template is available for download on NYSERDA's website.[5]

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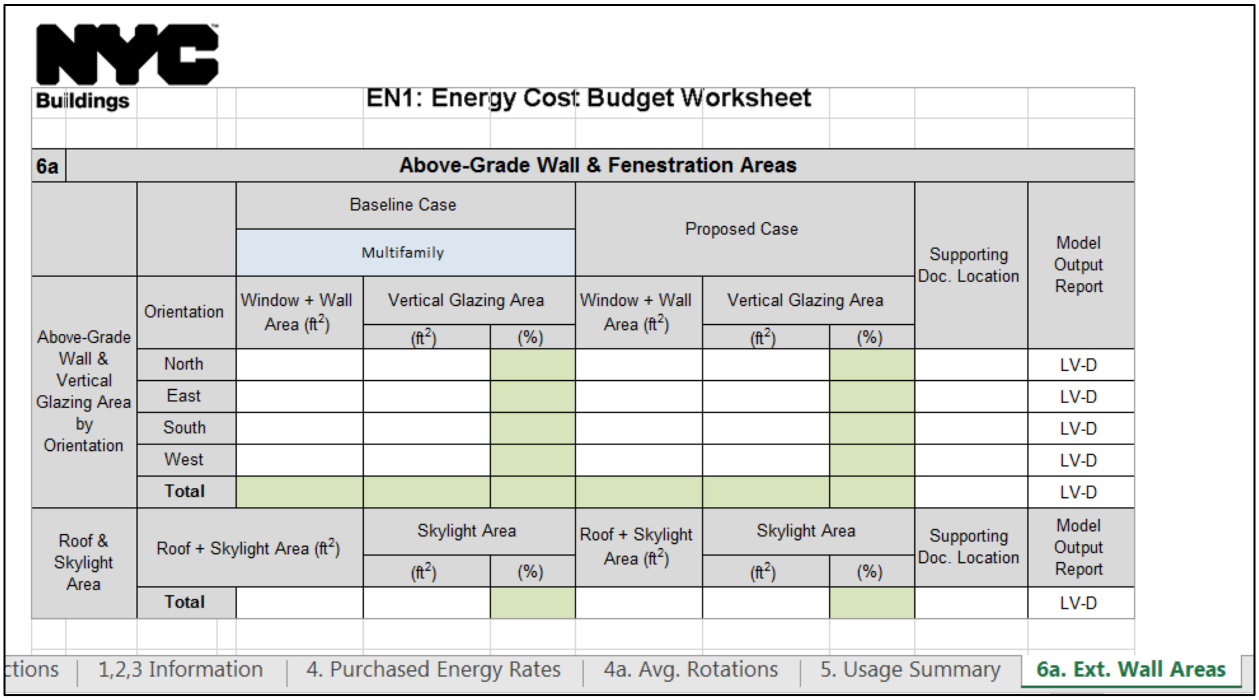
[1] ASHRAE Standard 90.1 – 2016 Section G1.3.

[2] https://www.energycodes.gov/comcheck

[3] Based on the author's firsthand knowledge and involvement in the licensing process

[4] New York City Department of Buildings. *Energy Cost Budget Worksheet*. Accessed August 2019. Retrieved from https://www1.nyc.gov/assets/buildings/excel/en1-workbook.xlsx.

[5] New York State Energy Research and Development Authority. *Performance Path Calculator*. June 2018. Retrieved from https://www.nyserda.ny.gov/-/media/Files/Programs/energy-code-training/performance-path-calculator.xlsm.



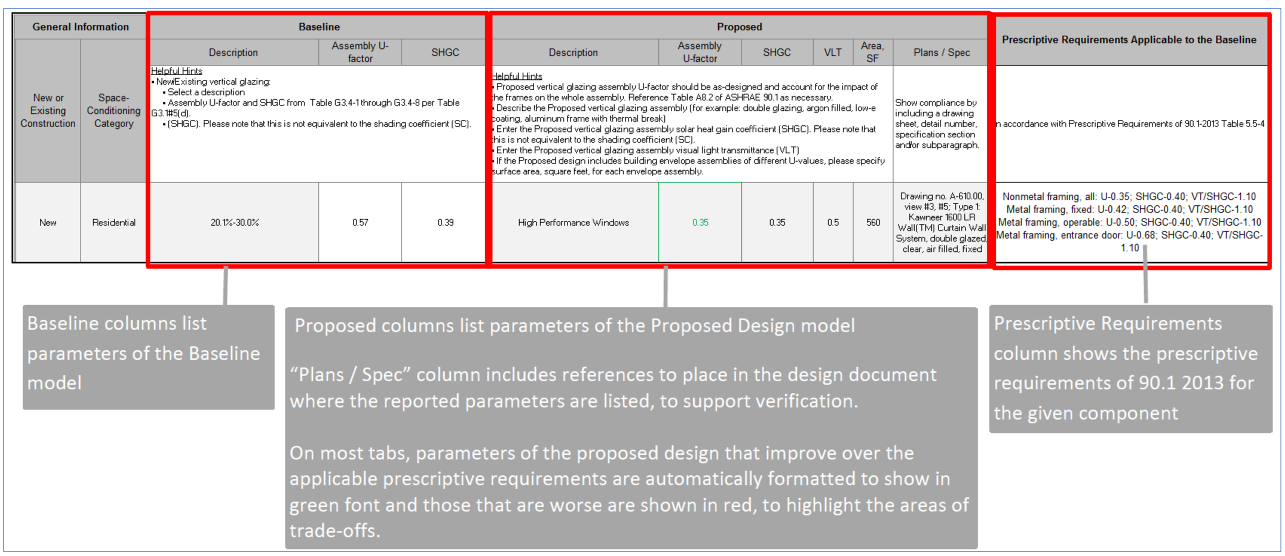
NYC Buildings

EN1: Energy Cost Budget Worksheet

6a	Above-Grade Wall & Fenestration Areas								
		Baseline Case Multifamily			Proposed Case			Supporting Doc. Location	Model Output Report
Above-Grade Wall & Vertical Glazing Area by Orientation	Orientation	Window + Wall Area (ft^2)	Vertical Glazing Area (ft^2)	Vertical Glazing Area (%)	Window + Wall Area (ft^2)	Vertical Glazing Area (ft^2)	Vertical Glazing Area (%)		
	North								LV-D
	East								LV-D
	South								LV-D
	West								LV-D
	Total								LV-D
Roof & Skylight Area	Roof + Skylight Area (ft^2)		Skylight Area (ft^2)	Skylight Area (%)	Roof + Skylight Area (ft^2)	Skylight Area (ft^2)	Skylight Area (%)	Supporting Doc. Location	Model Output Report
	Total								LV-D

ctions | 1,2,3 Information | 4. Purchased Energy Rates | 4a. Avg. Rotations | 5. Usage Summary | **6a. Ext. Wall Areas**

Figure 7. New York City ECB Compliance Form



General Information		Baseline			Proposed						Prescriptive Requirements Applicable to the Baseline
New or Existing Construction	Space-Conditioning Category	Description	Assembly U-factor	SHGC	Description	Assembly U-factor	SHGC	VLT	Area, SF	Plans / Spec	
		Helpful Hints • New/Existing vertical glazing: • Select a description • Assembly U-factor and SHGC from Table G3.4-1 through G3.4-8 per Table G3.1#5(d). • (SHGC). Please note that this is not equivalent to the shading coefficient (SC).			Helpful Hints • Proposed vertical glazing assembly U-factor should be as-designed and account for the impact of the frames on the whole assembly. Reference Table A8.2 of ASHRAE 90.1 as necessary. • Describe the Proposed vertical glazing assembly (for example: double glazing, argon filled, low-e coating, aluminum frame with thermal break) • Enter the Proposed vertical glazing assembly solar heat gain coefficient (SHGC). Please note that this is not equivalent to the shading coefficient (SC). • Enter the Proposed vertical glazing assembly visual light transmittance (VLT) • If the Proposed design includes building envelope assemblies of different U-values, please specify surface area, square feet, for each envelope assembly.					Show compliance by including a drawing sheet, detail number, specification section and/or subparagraph.	n accordance with Prescriptive Requirements of 90.1-2013 Table 5.5-4
New	Residential	20.1%-30.0%	0.57	0.39	High Performance Windows	0.35	0.35	0.5	560	Drawing no. A-610.00, view #3, #5; Type 1: Kawneer 1600 LR Wall(TM) Curtain Wall System, double glazed, clear, air filled, fixed	Nonmetal framing, all: U-0.35; SHGC-0.40; VT/SHGC-1.10 Metal framing, fixed: U-0.42; SHGC-0.40; VT/SHGC-1.10 Metal framing, operable: U-0.50; SHGC-0.40; VT/SHGC-1.10 Metal framing, entrance door: U-0.68; SHGC-0.40; VT/SHGC-1.10

Figure 8. NYSERDA 90.1 2016 Appendix G Reporting Template

Interior Lighting

	Input/Output Summary							
	Interior Lighting Power [W] (6b - General Lighting tab)	Lighting Power [W] Adjusted for OS (6b - General Lighting tab)	Non-coincident Lighting Peak Demand [W] (12 - Performance_Outputs_1 tab)	Annual Lighting Use [kWh] (12 - Performance_Outputs_1 tab)	Effective Full Load Hours	Typical EFLH (COMNET)	Diversity Factor	Effective Full Load Hours (12 - Performance_Outputs_1 tab)
	ILP	ILPwOS	NCLPD	ALU	EFLH = ALU / ILP	EFLHt	DF = NCLPD / ILP	EFLH
Baseline Design	133,020	133,020	126,120	934,375	7,024	2,884	0.95	7,409
Proposed Design	66,520	65,086	81,350	582,849	8,762	NA	1.22	7,165
Baseline / Proposed	200%	204%	155%	160%	80%	NA	78%	103%

Issue	Project Team Response
The baseline lighting non-coincident peak demand reported on the Performance Outputs tab exceeds the maximum baseline lighting power on the General Lighting tab. Please correct the lighting inputs in the baseline model, or update the inputs on the Lighting Counts tab.	
The proposed lighting non-coincident peak demand reported on the Performance Outputs tab is lower than expected, based on the Lighting Power adjusted for the Occupancy Sensors from the General Lighting tab, and the modeled lighting schedule represented by the Diversity Factor (NCPD proposed < 0.85 * MPvOS * DF). Please correct the lighting inputs in the proposed model, or update the inputs on the Lighting Counts tab.	
The difference between the proposed and baseline lighting non-coincident peak demand reported on the Performance Outputs tab is higher than expected, based on the Baseline and Proposed Lighting Power adjusted for the Occupancy Sensors from the General Lighting tab (NCPDbase / NCPD prop > 1.1 * LPwOS base / LPwOS prop). Please review and correct the lighting inputs in the proposed and / or baseline model, or update the inputs on the Lighting Counts tab.	
The effective full load hours (EFLH) exceed the typical by more than 20%. Ensure that the model reflects the mandatory lighting controls, and is based on the anticipated schedule of operation for the building. Please describe operating schedule if different than typical for the building type.	
The difference between the baseline and proposed annual lighting energy use is higher than expected (LPwOS prop / LPwOS base > 0.9*ALU prop / ALU base) based on the baseline and proposed lighting wattages and controls entered on the Lighting Counts tab. Please verify that the modeled lighting wattages and controls reflect the values reported on the Lighting Counts tab.	

Figure 9. NYSERDA Form Automated QC Flags

Some of the information that must be included in the compliance form, such as the baseline and proposed model inputs and simulation results, comes from the simulation tool. The recent versions of the LEED compliance spreadsheet allow importing simulation outputs from the standard simulation reports produced by eQUEST and Trace 700; for other tools, modelers can set up data import using standard Excel functionality or enter results manually. However, modelers must still enter some of the same information into the compliance form and simulation tool (e.g., lighting power density), which increases the modeler’s effort and may lead to discrepancies between modeled and reported parameters.

In California, all approved software tools must have a capability to generate the compliance form that meets the CA ACM requirements (Figure 10). Since the baseline design is automatically generated by the software, which is another prerequisite for the software approval, the configuration of the baseline design does not have to be verified by reviewers and thus is not shown on the form. Having the form automatically generated by the simulation tool ensures alignment between information reported in the compliance form and simulation inputs and outputs.

Project Name:	Nonresidential Sample	NRCC-PRF-01-E	Page 8 of 21
Project Address:	1234 Main St. Sacramento 95800	Calculation Date/Time:	10:38, Tue, Oct 25, 2016
Compliance Scope:	NewComplete	Input File Name:	NonRes Sample.cibd16x

J. FENESTRATION ASSEMBLY SUMMARY							**§ 110.6**		**Confirmed**	
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**		
Fenestration Assembly Name / Tag or I.D.	**Fenestration Type**	**Certification Method[1]**	**Assembly Method**	**Area ft^2**	**Overall U-factor**	**Overall SHGC**	**Overall VT**	**Status[2]**	**Pass**	**Fail**
Double Metal Tinted	VerticalFenestration	DefaultPerformance	SiteBuilt	900	0.71	0.60	0.77	N	☐	☐

[1] *Newly installed fenestration shall have a certified NFRC Label Certificate or use the CEC default tables found in Table 110.6-A and Table 110.6-B. Center of Glass (COG) values are for the glass-only, determined by the manufacturer, and are shown for ease of verification. Site-built fenestration values are calculated per Nonresidential Appendix NA6 and are used in the analysis.*

[2] *Status: N - New, A – Altered, E – Existing*

Taking compliance credit for fenestration shading devices? (if "Yes", see NRCC-PRF-ENV-DETAILS for more information)	No

K. OPAQUE SURFACE ASSEMBLY SUMMARY						**§ 120.7/ § 140.3**		**Confirmed**	
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**		
Surface Name	**Surface Type**	**Area (ft^2)**	**Framing Type**	**Cavity R-Value**	**Continuous R-Value**	**U-Factor / F-Factor / C-Factor**	**Status[1]**	**Pass**	**Fail**
R-13 Wall7	ExteriorWall	4560	Wood	13	NA	U-Factor: 0.102	N	☐	☐
Slab On Grade13	UndergroundFloor	3680	NA	0	NA	F-Factor: 0.730	N	☐	☐
R-13 Wall71	InteriorWall	200	Wood	13	NA	U-Factor: 0.095	N	☐	☐
R-30 Roof Attic19	Roof	3680	Wood	30	NA	U-Factor: 0.038	N	☐	☐

Figure 10. California Compliance Form (NRCC-PRF-01; Dodd 2016)

Some custom compliance forms developed by program administrators are very thorough, while others lack rigor due to limited resources. The lack of standardized reporting forms for the PRM, ECB, and TBP increases the cost of documenting compliance because modelers must master the reporting requirements of different programs. Projects that use the PRM for LEED, a utility incentive program and to comply with code may need to submit three different reporting forms.

Most program administrators require projects to submit supporting information in addition to the compliance forms. Many require simulation output reports that show energy use of the baseline and proposed design. Some jurisdictions (e.g., Washington State) and many above-code programs also require modeling files, to allow direct review of the models. LEED NC v4 requires simulation input and output reports but not the modeling files. Some program administrators also require the submission of equipment cutsheets and supporting calculations to justify modeling inputs.

4.3 Minimum Modeler Qualifications

The Building Energy Modeling Innovation Summit cited the difference in the simulation results obtained by different modelers simulating the same building in the same simulation tool as one of the top issues affecting BEM credibility (RMI 2011). The DOE Roadmap for Building Energy Modeling identified better training of energy modelers as the highest-priority task for improving BEM accuracy (Barbour et al. 2016). Modeler error was listed as the main reason for inconsistent simulation results by 43% of the surveyed stakeholders, more than any other factor. Yet, many program administrators have minimal or no qualification and training requirements for modelers.

Many AHJs and RAs may be hesitant to set a high bar for modeler qualification due to concerns that there will be insufficient workforce to meet the requirements. For example, as of the date of this report, there are less than 400 certified ASHRAE building energy modeling professionals (BEMPs) in the U.S. It is also feared that more rigorous qualification requirements will increase the modeling fees, as the modeler compensation would need to be comparable to other opportunities available to people with that skillset.

AHJ's typically require a licensed design professional to sign off on the compliance documentation, including on projects that follow a performance-based compliance path. The Internal Revenue Service (IRS) Section 179 D, which allows claiming tax deductions for energy efficient commercial buildings based on energy modeling that is largely aligned with the 90.1 PRM, requires that documentation be certified by a contractor or engineer licensed in the jurisdiction where the building is located.[1] This may similarly increase the modeling fees without guaranteeing improved quality of the analysis, as energy modeling is a highly specialized field.

Many utility and state incentive programs have competitively selected and/or pre-approved modeling providers (e.g., New Jersey Pay for Performance Program Partners,[2] NYSERDA Primary Energy Consultants[3]). However, based on the authors experience, the qualification requirements are often relaxed to promote program participation and due to perceived shortage of professionals meeting these requirements. For example, the requirements may apply to the company and not the individual doing the modeling – e.g., that the company must employ a licensed design professional or an ASHRAE BEMP, who has successfully completed modeling projects, etc.

The Oregon Department of Energy (ODOE) State Energy Efficient Design (SEED) Program requires that modelers have broad experience with building energy systems and operating characteristics similar to those in the building being evaluated; 3 or more years of full-time equivalent modeling experience, or 2 years of modeling experience and a certificate of completion from the ODOE modeling training course; and a demonstrated ability to perform energy studies evaluating energy-efficient designs that have been implemented and successfully operated.[4]

4.4 Simulation Software Acceptance

Based on the survey, 24% of stakeholders view simulation tools as the leading reason for inaccurate results, second only to modeler error. PRM, ECB, and TBP include requirements that the simulation tools must meet in order to be used for the compliance modeling, but program administrators often struggle to identify which tools qualify. According to the survey, only 46% of the stakeholders have a list of simulation tools approved for use in their programs, and the requirements are often vague.

For example, the 2020 Energy Conservation Construction Code of New York State (ECCCNYS) Section C101.5.1[5] requires that the compliance software be either "expressly approved in writing by New York Secretary of State" or software "developed by the United Stated Department of Energy (such as COMcheck) specifically for the ECCCNYS - Commercial Provisions or, if applicable, specifically for ASHRAE 90.1 2016 (as amended), including DOE-2 modeling software." However, COMcheck does not support whole building performance path of compliance, DOE-2 was not specifically developed for 90.1 2016, and no software was listed as approved as of the date of this report. There is also often confusion between the user interfaces and simulation engines. For example, some user interfaces to DOE-2, such as eQUEST,[6] meet

[1] IRS Notice 2006-52, retried from https://www.irs.gov/pub/irs-drop/n-06-52.pdf
[2] https://www.njcleanenergy.com/commercial-industrial/programs/pay-performance/program-partners
[3] https://www.nyserda.ny.gov/All-Programs/Programs/New-Construction-Program/Become-a-Vendor
[4] https://www.oregon.gov/energy/energy-oregon/Pages/SEED-Program-Guidelines.aspx
https://www.oregon.gov/energy/energy-oregon/Documents/SEED%20Guidelines%20Appendix%20C.pdf
[5] https://codes.iccsafe.org/content/NYSECC2020P1/chapter-1-ce-scope-and-administration
[6] http://www.doe2.com/equest/

ECB and PRM simulation requirements (90.1 Sections 11.4.1 and G2.2) while others, such as NEO,[1] do not.

Some program administrators use the software approved for IRS Section 179D commercial tax deductions as a proxy.[2] However, the IRS Section 179D modeling requirements are based on ASHRAE Standard 90.1-2007 with the addenda supplement package; thus, the IRS determination of the compliant software does not apply to programs that are based on more recent editions of Standard 90.1.

The California Energy Commission (CEC), Florida Building Commission, and RESNET® established software certification requirements for their performance-based compliance programs and administer the certifications. They all require software to have **compliance shell** modules that automatically generate the baseline building model based on the user model of the proposed design, determine pass/fail compliance outcome based on the simulation results, and generate the compliance report in the prescribed format. The software certification process includes prescribed ruleset tests to verify that the baseline models are correctly generated, and sensitivity tests to confirm that simulation results are in general alignment with other tools.

Compliance shells are not required by any non-residential program administrators except for the CEC and the Florida Building Commission, which are in the two states with the highest volume of performance-based projects. It is unclear whether performance-based compliance became prominent in these states because of the automation, or whether the high volume of modeling projects made it worthwhile for the software vendors to implement compliance shells, but the scale of the program is clearly a principal factor. Stakeholders from Washington State and the City of Seattle indicated that their jurisdictions

> "…are small markets, have a history of significant code changes every 3 years, and have a unique modeling rule set. Getting any custom shell developed has been a non-starter unless the region paid for it, and so far, that has not happened. There have been a few discussions over the years, but no one has stepped up with money."

Coordinating with the software vendors was noted to be an

> "…. impossible task …given that we get submittals in four different software packages, each of which has multiple versions in use."

Through the 2012 edition, the IECC required that the simulation tools used for TBP have a compliance shell with a capability to automatically generate the standard reference design using only the input for the proposed design, but the requirement was later removed due to a very limited number of software tools implementing such capability[3]. The requirement remains for residential performance-based compliance. ECB includes an informative note recommending that the simulation programs implement the rules of Section 11 to "control simulation inputs and outputs for the purposes of easier use and simpler compliance," and a similar note is being considered for the 2022 version of the PRM.

[1] https://netenergyoptimizer.com/why-neo/
[2] Qualified Software for Calculating Commercial Tax Deductions https://www.energy.gov/eere/buildings/qualified-software-calculating-commercial-building-tax-deductions
[3] Authors are only aware of one software tool, IES-VE, that supported it. https://www.iesve.com/software/virtual-environment/modules/iecc-2012-navigator

Several software tools, including but not limited to Bentley Systems, Design Builder, eQuest, EnergyGauge, HAP, IESVE, Trace 700, Trace 3D Plus, and OpenStudio, have implemented at least some level of PRM or ECB automation. However, without third-party certification, there is no way to ascertain fidelity of the compliance shells to the requirements of the rulesets. The Standard 90.1 subcommittee charged with the development of the ECB and PRM often receives interpretation requests from modelers and program administrators to clarify application of the rules to various real-life scenarios. The correct interpretation is sometimes not obvious. The availability of an automated compliance shell implies that a software tool can generate the baseline model for any possible commercial building design. However, as members of the ASHRAE 90.1 ECB subcommittee, the authors are not aware of any ECB or PRM interpretation request having been submitted by a software vendor in at least in the last 5 years.

4.5 Submittal Review Methodology

Review of the modeling-based submittals is a challenging endeavor. Models for even simple projects include thousands of inputs. Mistakes may involve deviations between the proposed design model and systems and components specified on design documents, not following the rules of the modeling protocol for the baseline or proposed design, and incorrect use of the simulation tool. The modeling protocols often lack specificity, do not cover all scenarios that may occur on actual projects, or have vague rules that allow multiple interpretations. A stakeholder made the following observation:

> “The review process is difficult because there is so much that must be known for certain building types. For complicated projects the best outcomes are the ones where there can be back and forth during the review process that allows for consensus to be developed on addressing ‘loopholes’ or ‘gray areas’ in the modeling methodologies. Much more education is needed around how to model and what the intent of modeling for code compliance is really about.”

Review of modeling-based submittals is complicated by the use of different simulation tools (there are over a dozen tools on the IRS Section 179D software list). Each tool has different capabilities, nomenclature, format, and content of simulation input and output reports. Submittal reviewers often do not have experience with the tools used on projects that they have to review, and struggle with identifying inputs and outputs of interest – simulation reports generated by the tools may span hundreds of pages. 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 must be verified. Some programs mandate the use of a single modeling tool to alleviate the review burden.[1] However, forcing modelers to use simulation tools that they are not comfortable with increases human error, which many consider the leading reason for poor submittals.[2]

Mismatches between design documents and user models is one of the most impactful problems reported by the stakeholders. Unless the software used to generate the design documents is integrated seamlessly with the energy modeling software used for compliance, there is no way to ensure that the model reflects the building as designed. Therefore, this verification requires manually comparing model inputs to design drawings, which is time-intensive, tedious, and error

[1] Xcel Energy EDA Consultant Scope of Work (May 2015) Retrieved from https://www.xcelenergy.com/staticfiles/xe-responsive/Admin/Managed%20Documents%20&%20PDFs/CO-Bus-EDA-Scope-of-Work.pdf

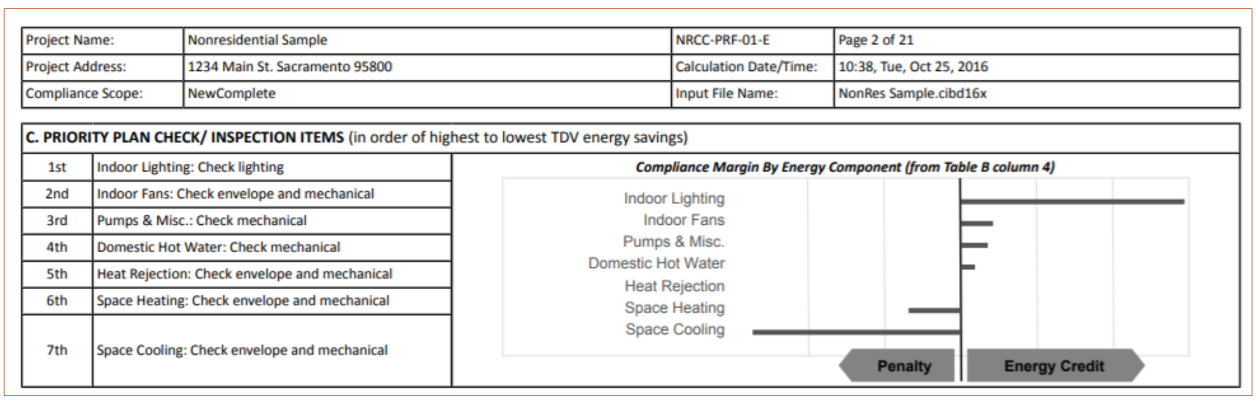
[2] Based on stakeholder survey responses.

prone. In addition, many modeling inputs, such as material properties and part load performance of HVAC systems, are not part of or difficult to locate within construction documents and specifications.

Another challenge is that jurisdictions often have different staff members reviewing submittals, and design teams “find the inconsistency across reviewers frustrating.” Some program administrators have a designated person who performs the final QC of the review comments on all projects to ensure consistency across multiple reviewers; however, this approach cannot be scaled up. Some program administrators use review checklists to help standardize the reviews. For example, a stakeholder from Vancouver, Canada noted that they use the same review checklists for performance-based projects as on prescriptive projects[1] and include some additional checks:

> “We review ratios such as % glazing, EUIs, regulated vs non-regulated loads and totals. First 2 years, 19/20 failed basic metrics reviews.”

NYC DOB has a standard checklist that examiners follow when reviewing energy models, but additional items often have to be reviewed “based on the nuances of the modeling and building designs.” In California, the compliance forms list the key modeling inputs that can be checked against drawings and specifications. In addition, end uses driving the trade-offs are highlighted and may guide the review (Figure 11). For example, if, based on the simulation results, lighting accounts for a substantial fraction of building energy use and drives savings of the proposed design relative to the baseline, a reviewer may focus on verifying that the modeled lighting reflects the actual lighting design.



Project Name:	Nonresidential Sample	NRCC-PRF-01-E	Page 2 of 21
Project Address:	1234 Main St. Sacramento 95800	Calculation Date/Time:	10:38, Tue, Oct 25, 2016
Compliance Scope:	NewComplete	Input File Name:	NonRes Sample.cibd16x

C. PRIORITY PLAN CHECK/ INSPECTION ITEMS (in order of highest to lowest TDV energy savings)

1st	Indoor Lighting: Check lighting
2nd	Indoor Fans: Check envelope and mechanical
3rd	Pumps & Misc.: Check mechanical
4th	Domestic Hot Water: Check mechanical
5th	Heat Rejection: Check envelope and mechanical
6th	Space Heating: Check envelope and mechanical
7th	Space Cooling: Check envelope and mechanical

Figure 11. CA Priority Plan Checks in the NRCC-PRF-01 Compliance Form

NYSERDA has funded the development of a comprehensive Submittal Review Manual[2] and Review Checklist[3] for use by New York code officials (Figure 12). The Manual includes several hundred checks for verifying different aspects of the baseline and proposed design models. Since it’s impractical to perform all checks for each project, the Manual recommends strategies

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[1] City of Vancouver. *Energy requirements, forms, and checklists for all buildings*. Accessed August 2019. Retrieved from https://vancouver.ca/home-property-development/large-building-energy-requirements-forms-checklists.aspx.

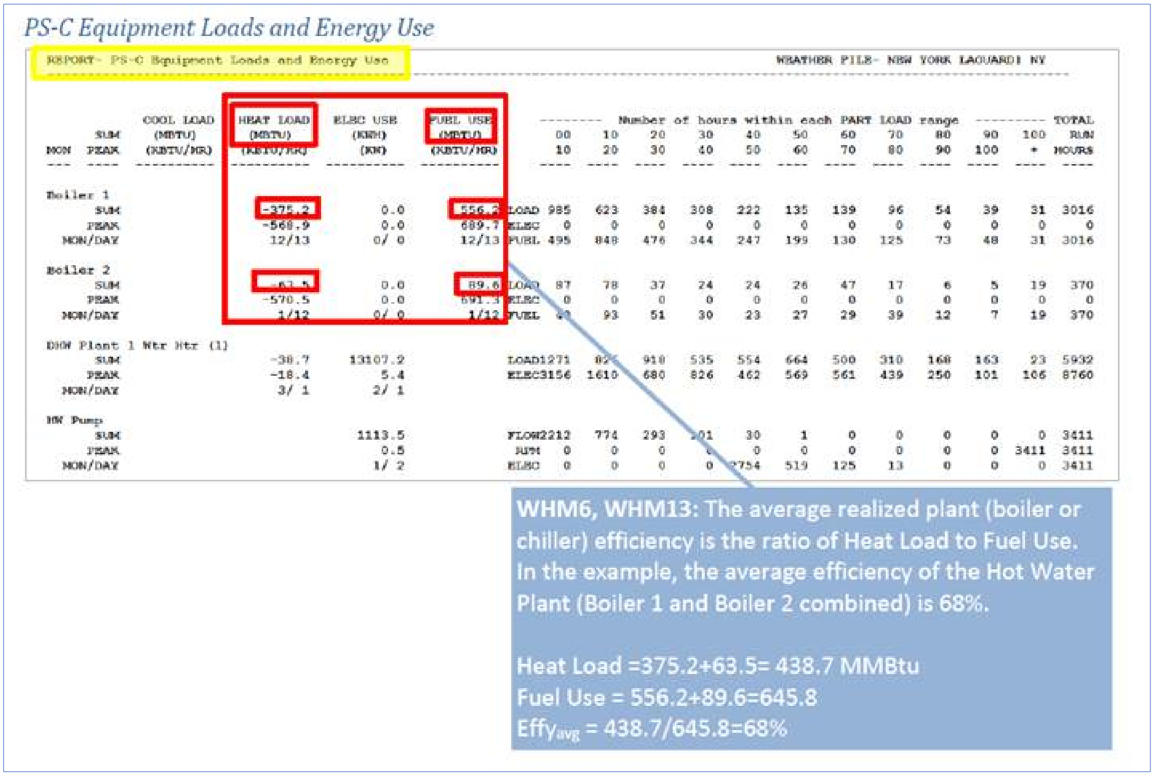
[2] https://www.nyserda.ny.gov/-/media/Files/Programs/energy-code-training/performance-path-review-manual.pdf

[3] https://www.nyserda.ny.gov/-/media/Files/Programs/energy-code-training/performance-path-review-manual.pdf

for prioritizing reviews to identify and focus on the most impactful systems and components. Each check is first formulated in a software-neutral fashion (e.g., check that modeled cooling efficiency reflects efficiency of the specified equipment), and is also covered in the software-specific sections of the Manual that describe how to perform the checks using simulation reports generated by the supported tools (Figure 13). The Manual includes eQUEST and TRACE 700 sections with the annotated reports.

Step 1: Check submittal for completeness
○ Use Submittal Checklist tab of the Review Checklist to verify that all required documentation is provided. ○ Request additional information if submittal is incomplete.
Step 2: Review description of the proposed design in the reporting template and perform high-level proposed design simulation review
○ Complete the Code Requirements (CR) checks in the Proposed Design tab of the Review Checklist, to verify that description of the energy features of the proposed design reported in the submittal is complete and reflects design documents. ○ Perform Modeling Output (MO) checks to verify that simulation outputs are generally consistent with the reported proposed systems and components
Step 3: Review description of the baseline (budget) design in the reporting template and perform high-level baseline (budget) design simulation review
○ Complete CR review checks in the Review Checklist, ECB Budget & PRM Baseline tab to verify that the baseline (budget) design is established correctly following PRM (ECB) requirements. ○ Perform Modeling Output (MO) checks to verify that simulation outputs are generally consistent with the reported baseline (budget) systems and components
Step 4: Prioritize the remaining review to verify that the key differences between the baseline (budget) and proposed design based on Steps 2 and 3 are properly reflected in the simulations.
○ Based on the checks completed in Steps 2 and 3, identify the key systems and components of the proposed design that differ from the corresponding systems and components in the baseline (budget) design. These differences represent trade-off areas. ○ In the Review Checklist, mark the checks that verify that these systems and components are properly modeled, to be included in the review. ○ Complete MO checks to establish the end uses that changed the most between the baseline (budget) and proposed design based on the simulation outputs ○ In the Review Checklist, select the checks that verify the relevant systems and components, to be included in the review.
Step 5: Complete the remaining review checks
○ Complete the check identified in Step 4. ○ Perform additional checks as review budget / schedule allows
Step 6: Communicate review outcome to the Permit Applicant
○ Provide written comments to PA to require corrective actions or approve the submittal.

Figure 12. NYSERDA Submittal Review Manual – Process Description



PS-C Equipment Loads and Energy Use

REPORT- PS-C Equipment Loads and Energy Use — WEATHER FILE- NEW YORK LAGUARDI NY

MON	SUM PEAK	COOL LOAD (MBTU) (KBTU/HR)	HEAT LOAD (MBTU) (KBTU/HR)	ELEC USE (KWH) (KW)	FUEL USE (MBTU) (KBTU/HR)		00 10	10 20	20 30	30 40	40 50	50 60	60 70	70 80	80 90	90 100	100 +	TOTAL RUN HOURS
Boiler 1																		
	SUM		-375.2	0.0	556.2	LOAD	985	623	384	308	222	135	139	96	54	39	31	3016
	PEAK		-568.9	0.0	689.7	ELEC	0	0	0	0	0	0	0	0	0	0	0	0
	MON/DAY		12/13	0/ 0	12/13	FUEL	495	848	476	344	247	199	130	125	73	48	31	3016
Boiler 2																		
	SUM		-63.5	0.0	89.6	LOAD	87	78	37	24	24	26	47	17	6	5	19	370
	PEAK		-570.5	0.0	691.3	ELEC	0	0	0	0	0	0	0	0	0	0	0	0
	MON/DAY		1/12	0/ 0	1/12	FUEL	[illegible]	93	51	30	23	27	29	39	12	7	19	370
DHW Plant 1 Wtr Htr (1)																		
	SUM		-38.7	13107.2		LOAD	1271	[illegible]	918	535	554	664	500	310	168	163	23	5932
	PEAK		-18.4	5.4		ELEC	3156	1610	680	826	462	569	561	439	250	101	106	8760
	MON/DAY		3/ 1	2/ 1														
HW Pump																		
	SUM			1113.5		FLOW	2212	774	293	[illegible]	30	1	0	0	0	0	0	3411
	PEAK			0.5		RUN	0	0	0	[illegible]	0	0	0	0	0	0	3411	3411
	MON/DAY			1/ 2		ELEC	0	0	0	0	[illegible]	519	125	13	0	0	0	3411

Figure 13. NYSERDA Submittal Review Manual – Annotated Software Report

4.6 Minimum Reviewer Qualifications

Many jurisdictions do not have staff with the qualifications necessary for reviewing performance-based projects. Stakeholders shared the following observations:

> "The more complicated the model, the less it gets enforced."
>
> "In my experience, energy code officials are not trained or experienced enough to know how to probe the inputs and outputs of an energy model. Beyond-code programs are another matter though and city officials often prefer a third party such as GBCI to complete energy model reviews."

The NYC DOB does not have formal qualification requirements for reviewers; however, reviewers assigned to performance projects have backgrounds in energy modeling, and several staff members are trained to review energy models and have attended energy modeling trainings. Some program administrators assign reviewers to projects based on the project complexity. For example, the submittal review process followed by the New Jersey Pay for Performance program includes experienced reviewers with the direct modeling experience peer-reviewing comments on all projects that claim high incentives.

Some program administrators perform reviews in-house, while others use external "third-party" reviewers for some or for all the reviews. Third-party reviewers were used for many years in Oregon. The reviewer qualification requirements were the same as for the modeler, and the permit applicants bore the review cost.

> "It worked great … the third-party review process took away the burden from the building official."

One stakeholder expressed the following concern about engaging third-party reviewers:

> "The expert modelers in Seattle know each other personally and, in many cases, have worked together at the same firms, so they might be reluctant to give each other a hard time about modeling discrepancies. On the other hand, firms outside of Seattle may not have an expert-level understanding of …our peculiar code."

The EPA ENERGY STAR® Multifamily High-rise Program and Multifamily New Construction Program rely on a network of competitively selected pre-approved Multifamily Review Organizations (MROs). Modelers must pick an MRO for each project and pay the MRO an agreed-upon, market-based fee for the review. EPA oversees the MROs and maintains a review checklist to ensure that the scope and rigor of reviews meet program requirements and are consistent among the MROs. The approach is getting traction – the NYSERDA Multifamily New Construction Program, which previously performed submittal reviews in-house, now requires participating projects to use an EPA-approved MRO. Since the NYSERDA program has some additional requirements compared to the EPA program, the MROs approved to perform NYSERDA reviews are trained to check for the additional items.

4.7 Quality Assurance

Quality assurance processes include manual and automated verification. Examples of manual QA include periodic third-party evaluations performed by state and utility incentive programs that assess past performance and inform program policies going forward. DOE funds periodic code compliance evaluations; however, those evaluations have not focused on projects following performance-based compliance as they account for a relatively small number of new commercial permits nationwide.

The RESNET® HERS protocol involves having market-based QA designees perform third-party reviews of a sample of approved projects to confirm that they adhered to the program rules. Additional QA is performed by RESNET® staff. EPA similarly conducts QA reviews on a sample of projects approved by each MRO.

Examples of automated QC include the RESNET® HERS requirement for the approved software tools to flag user inputs that appear erroneous based on the specified criteria. Parameters that are subject to verification include but are not limited to the number of bedrooms for a home of a given size, ceiling height (the values less than 7 ft or over 15 ft are flagged), floor area not equal to ceiling area, exhaust or supply fan power exceeding 0.12 W/CFM, and home appliance energy use outside of the expected range. The software tools must also be capable of saving project information, including the input flags, to an XML file in the prescribed format. The files are then uploaded to the central project registry to facilitate QA reviews.

The Energy Design Assistance[1] program, administered by XcelEnergy, and the Austin Energy Integrated Modeling Incentive[2] program use Design Assistance Project Tracker (EDAPT) platform, which facilitates automated model input and output checks and centralized online

[1] Energy Design Assistance: Program Manual, Colorado, prepared by ExcelEnergy May 2018, retrieved from https://www.eda-pt.org/system/files/EDA%20Program%20Manual_2018.pdf
[2] https://savings.austinenergy.com/rebates/multifamily/offerings/new-construction/integrated-modeling

project tracking[1] as part of normal program operation. The automated QA/QC checks include unmet hours, suspicious energy use intensity, and many others recommended as best practices (Elling et al. 2014). Both programs require participating projects to use OpenStudio, which is not among the tools that modelers preferer based on experience of the programs that do not restrict software use. Only 6% of stakeholders who participated in the survey picked OpenStudio as the most commonly used tool. OpenStudio was also not reported as one of the top three most popular energy modeling tools used by either architects, engineers, or energy consultants based on the AIA 2030 Commitment Progress Report (AIA 2018). Plans to extend EDAPT web service to multiple utilities did not get traction (DOE 2014).

Based on the stakeholder survey, the majority of program administrators do not have processes or tools to automatically extract project information from submittals into a central database. When project information is tracked, it is typically entered manually. For example, a stakeholder indicated that Rhode Island has a statewide electronic permit tool, but most plan review approvals are done via direct contact with owners or through email communication, and even some basic functionality is missing – e.g., there are no checkboxes included in the online permit software to approve inspections.

[1] https://www.eda-pt.org/

5.0 Path Forward

5.1 Focus Areas

Compliance modeling includes two main use cases:

1. Documenting minimum compliance of the proposed design with the energy code.
2. Documenting above-code performance, which typically involves establishing the margin of improvement of the proposed design over a minimally code compliant design. Depending on the project context, this margin may determine rewards such as the number of LEED points, utility incentive, or tax deduction that the project qualifies for.

For either use case, the PRM, ECB, or TBP compliance outcome is determined by the energy use of the proposed design relative to the reference design.

There is also a growing interest in the compliance models being more predictive of the measured post-occupancy energy use. This is a distinctly different use case that may require site measurements in similar buildings and interviews with occupants to establish operating schedules that should be modeled, commissioning of installed systems, calibrating the proposed design model based on post-occupancy operation, and comparison of the calibrated model to the measured post-occupancy energy use. It may also necessitate changes to the modeling protocols that include rules that serve a useful compliance purpose but practically guarantee deviation from post-construction utility bills, such as modeling cooling in conditioned spaces irrespective of whether it is specified (Karpman and Rosenberg 2019, 2020). The QA/QC framework described below does not specifically focus on this use case.

A fundamental premise of performance-based compliance is that the compliance outcome is driven by the merits of the building design and is largely independent of the modeler who performed the analysis and the simulation tool that was used (Figure 14).

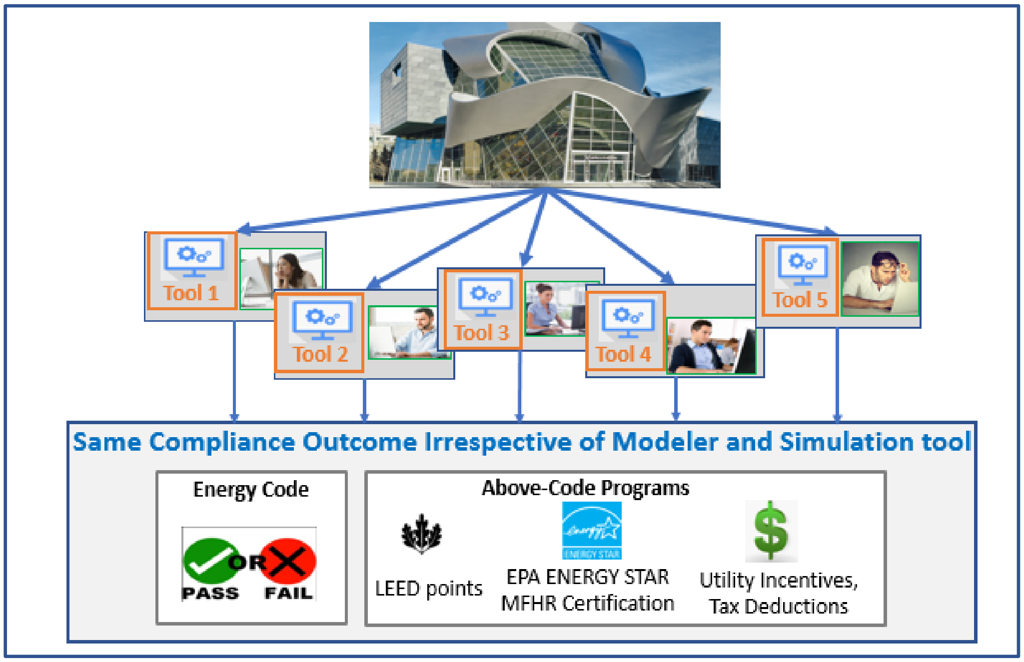


Figure 14. QA/QC Framework Objective

The following are necessary to achieve this objective:

- Modeling standards that are comprehensive, unambiguous, and tailored to the intended use case
- A rigorous software certification process to reduce the impact of differences in physics calculations and ruleset implementation on the compliance outcomes
- Automation of mechanical tasks involved in modeling, compliance documentation, and submittal review, to minimize subjectivity and human error and improve productivity
- An organization that will maintain and oversee the QA/QC framework

The following sections describe opportunities for improvement in each of these focus areas.

5.2 Modeling Protocols

1. **Reduce the number of detailed whole building performance-based compliance options**

There are currently three performance-based whole building compliance protocols (ECB, PRM, and TBP) available in the commercial model energy codes for designs that cannot meet prescriptive provisions of the respective standards. Each option requires detailed energy simulations but has different simulation rules, trade-off opportunities, and methodologies for establishing compliance.

Maintaining each protocol requires substantial effort from standard developers – for example, ASHRAE 90.1 committee members spend over 700 person-hours annually on maintaining PRM and ECB requirements. Variations in simulation requirements also complicate compliance documentation – modelers and submittal reviewers must be proficient with the multiple rulesets, and program administrators need to develop compliance forms for each. It also fragments the market for the software tool vendors, making them less likely to implement compliance shells.

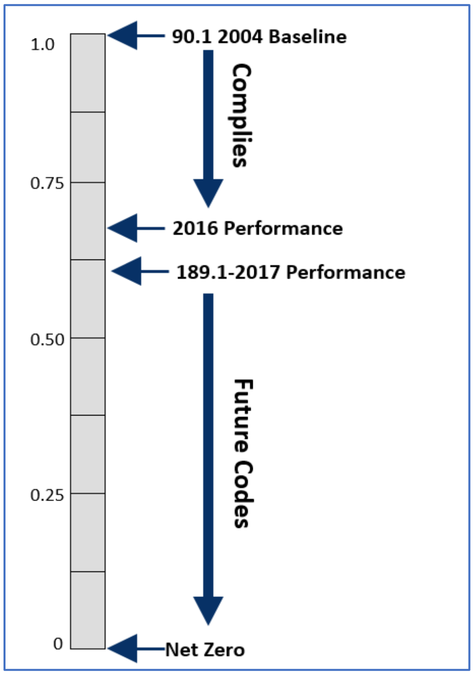


Figure 15. PRM Stable Baseline Concept

Reducing the number of whole building performance-based compliance options that may be used for documenting the minimum code compliance will streamline compliance modeling for all stakeholders. The PRM is already used more than the other protocols for above-code programs, and its popularity is expected to further increase due to its versatility, as it is the only method that can be used for documenting minimum compliance and in above-code programs. The PRM "stable baseline" approach incorporated into the 90.1 2016 edition minimizes changes to the baseline building design from edition to edition, which simplifies automation in the simulation tools. It is also better suited for evaluating changes in building performance across different editions of 90.1, as illustrated in Figure 15, compared to the ECB and TBP, which have a baseline based on the current editions of the standards.

The PRM has the well vetted modeling requirements within Standard 90.1 and in the supplemental documents such as the PNNL Performance Rating Method Reference Manual and Developing Performance Cost Index Targets for ASHRAE Standard 90.1 Appendix G – Performance Rating Method (Goel and Rosenberg 2017; Rosenberg and Hart 2016). The first edition of ASHRAE Standard 229P, which aims to facilitate consistent automation of the compliance modeling in the simulation tools, will support the PRM but not the ECB or TBP.

Thus, developing a QA/QC framework for the PRM will have the greatest immediate impact and may encourage program administrators to adopt it in their programs and make it the only allowed protocol.

2. **Introduce a simplified whole building performance-based compliance path**

PRM, ECB, and TBP involve developing a detailed model of the proposed design that is consistent with the design documents. This task is non-trivial due to variety and complexity of commercial designs. Thus, the existing compliance modeling protocols will require involvement of experienced modelers and submittal reviewers, even if the reference design model is automatically created by the simulation tools. Increased stringency of prescriptive requirements and local laws that require whole building simulation is creating an increased demand for performance-based compliance modeling. This has the potential to create a shortage of qualified professionals, increase the cost of documenting compliance and further complicate the submittal review process.

While detailed whole building simulation may be necessary for complex projects striving to substantially exceed code, smaller and simpler buildings often do not have the budgets to support a typical ECB or PRM model, and the level of detail required by those protocols may be unnecessary. Over 80% of buildings in the U.S. are smaller than 25,000 ft^2. This subsector usually ends up complying with energy codes and qualifying for incentives using prescriptive measures or generalized design guides. A simplified whole-building trade-off approach designed for buildings with less complex systems has the potential to encourage greater use of simulation to achieve more efficient designs. The key to success with such a path is careful definition of the simplifications and consideration of projects that are permitted to use this approach.

3. **Minimize changes to the modeling rules of the model codes by jurisdictions and rating authorities**

Some jurisdictions and rating authorities modify simulation rules of the adopted protocols to better support program-specific policies, goals, or reporting. Some develop custom protocols that differ substantially from the national standards (e.g., CA ACM). The variability in modeling requirements creates challenges similar to those caused by the existence of multiple detailed performance-based rulesets discussed above.

Changes to the modeling requirements may be minimized by identifying the reasons that drive the modifications and either developing solutions to address them without changing the modeling rules or updating modeling rules of the model codes to address the common barriers. For example, PRM methodology leads to unfavorable compliance outcomes on projects with efficient electric space heating systems in locations where electricity is expensive relative to natural gas. Some program administrators address this by changing the modeling rules for the baseline heating system type. However, the issue may be resolved by determining PRM compliance using metrics other than energy cost, such as source energy or greenhouse gas emissions (Rosenberg et al. 2020).

Some changes made by jurisdictions and rating authorities address omissions or ambiguities in the modeling requirements of the model codes and should be incorporated into the base codes. For example, simulation guidelines of the EPA ENERGY STAR MFHR program included the baseline lighting power density for the dwelling units, which was not addressed in 90.1 2016 but has since been added. The envelope back-stop methodology to limit the envelope trade-offs was first introduced in NYStretch and has since been published and will be included in the 2022 edition of Standard 90.1. The process of enhancing modeling requirements based on input from adopters should continue and be expanded.

4. **Coordinate development of the modeling protocols with the simulation tools physics and sensitivity testing**

The compliance modeling protocols largely focus on keeping up with the evolving prescriptive requirements of the energy code, to ensure that they can be "traded off." Consideration of simulation tool capabilities is often limited to confirming that the system or component is "supported" in the common tools.

For example, envelope air leakage tests in ASHRAE Standard 140 are based on the fixed annual infiltration rate independent of wind speed, indoor/outdoor temperature difference, and other factors, while the PRM requires that infiltration be modeled with adjustments for weather and building operation (ASHRAE 2014). There is no evidence that the energy use predicted by these more complex methods is in general alignment among different simulation tools. Similarly, an overwhelming majority of projects modeled following PRM have daylighting in the proposed design, which is a mandatory code requirement for most spaces that have windows or skylights.

However, there are no daylighting tests in Standard 140 to ensure consistency in results with different simulation tools.

When a new system or component is considered for addition to the PRM or ECB trade-offs by 90.1 committee, it should trigger consideration of development of a corresponding sensitivity test case in an appropriate external standard such as ASHRAE 140. This would help ensure that the simulation results of new modeling requirements produced by different tools are generally consistent. Systems, components, or controls that are not supported by sensitivity testing may be allowed for projects demonstrating above-code performance but not for minimum code compliance.

5. **Develop pathways for using compliance modeling in conjunction with the building energy performance standards**

Jurisdictions across the country are moving toward Zero Net Energy performance codes and are adopting ordinances that require buildings to meet strict targets based on measured performance. These requirements are often referred to as building energy performance standards or building performance standards. For example, NYC Local Law 97[1] has established carbon emissions intensity limits for buildings over 25,000 gross square feet with annual fines of $268 per metric ton if the building's carbon footprint exceeds the allowance. Studies have shown that some new buildings use more energy than their older peers – e.g., based on NYC 2018 Energy and Water Data disclosure,[2] college/university buildings constructed before 1968 have lower median site energy use intensities than buildings constructed on or after 2000. To help identify and mitigate risk of post-occupancy liability for poor building performance, design teams and developers are increasingly turning to energy modeling.

To help make compliance models more predictive of future energy use, protocols like ECB and PRM should evaluate eliminating or modifying rules that almost guarantee that the proposed design model will not be predictive, such as those requiring ventilation fans to run continuously when a building is occupied, that all conditioned spaces be both heated and cooled, and that piping and ductwork heat loss be ignored. In addition, the QA/QC framework for these methods should mitigate the impact of simulation tools and simulation assumptions (occupancy schedules, equipment schedules, weather files, etc.) on results, and include guidance on post-occupancy model calibration to measured energy use. As design and operation become more closely related in the project delivery process, solutions should be developed to help program administrators meaningfully integrate compliance modeling with the building energy performance standards.

5.3 Simulation Tools

PRM, ECB, and TBP list the minimum simulation tool requirements, which include but are not limited to the capability to perform the analysis at an hourly or more granular timestep, capturing hourly variations in building operation, and explicit support of certain building systems and components. In addition, testing following ASHRAE Standard 140 is required. The software requirements of RESNET® HERS, CA ACM, Florida Energy Code, and the Commercial Energy Services Network (COMNET) are more comprehensive – for example, these programs all

[1] Local Laws of the City of New York for the Year 2019 (Int. No. 1253-C) https://www1.nyc.gov/assets/buildings/local_laws/ll97of2019.pdf

[2] https://www1.nyc.gov/html/gbee/html/plan/ll84_scores.shtml

require the approved simulation tools to have a compliance shell to automatically generate the reference design model.

The scope of the simulation tool testing required by different programs is illustrated in Figure 16. Green color in the figure indicates high requirements rigor, yellow indicates average rigor, and orange indicates low rigor. The New York column reflects requirements of ECCCNYS and is representative of the programs that use PRM, ECB, or TBP and do not require or oversee and testing beyond the minimum required in 90.1 and the IECC. These requirements are limited to testing following Standard 140 and have no pass/fail criteria – testing alone is required. Furthermore, Standard 140 covers only a small subset of systems found in commercial buildings.

	RESNET HERS	COMNET	CA ACM	Florida	New York
PHYSICS and SENSITIVITY TESTING					
Required?	Yes	Yes	Yes	Yes	Yes
Acceptance criteria provided?	Yes	Yes	Yes	No	No
Coverage of common systems and designs addressed by the ruleset	Broad	Average	Average	Limited	Limited
RULESET IMPLEMENTATION TESTING					
Required?	Yes	Yes	Yes	Yes	No
Coverage of common designs & rules	Broad	Limited	Limited	Limited	NA

Figure 16. Software Testing Requirements of Compliance-Based Programs

RESNET® HERS has the most rigorous software requirements. The program addresses single family homes and low-rise multifamily buildings that are much simpler and more homogeneous than commercial buildings in the scope of ASHRAE 90.1. Yet, the RESNET® HERS variability study suggested that further increase in testing rigor and narrower acceptance ranges may be necessary for achieving desired consistency in compliance outcomes (DOE 2018). This implies that greater testing rigor is necessary for simulation tools used for commercial performance-based compliance. Opportunities for improvement relevant to the simulation tools include the following.

1. **Expand the scope of sensitivity and physics testing included in Standard 140**

Physics and sensitivity tests verify that BEM tools produce consistent simulation results for common systems and components when simulation inputs are reasonably aligned. The scope of Standard 140 should be expanded to include physics and sensitivity tests for systems and components that can participate in the compliance modeling trade-offs.

2. **Develop a standard for verifying ruleset implementation**

Qualitative ruleset tests verify that the reference design model is configured as required by the ruleset for the given project design. Traditionally, such testing only applied to the BEM tools that implemented compliance shells. However, the newly initiated ASHRAE Standard 229P uses an innovative per-project verification approach that may also be applied to manually generated models. Ruleset implementation testing helps ensure consistent implementation of the rulesets to streamline model reviews.

3. **Facilitate implementation of the compliance shells in BEM tools**

Creating a model of the reference design is a mechanical task that may be automated in the simulation tools to improve productivity and reduce subjectivity and modeling mistakes. However, the automation is hindered by the existence of several different compliance rulesets, the ambiguities and complexities of the different ruleset requirements, and the lack of a national standard for verifying fidelity of automation to the modeling rules. Addressing these barriers will help improve the productivity of both modelers and submittal reviewers and improve the quality and consistency of compliance modeling.

5.4 Automating Compliance Documentation

Aside from automatically generating the reference design model as described above, there are significant automation opportunities related to compliance documentation, which currently involves many manual steps. Energy modelers typically start by transferring some of the information from the design documents into custom spreadsheets or other tools to determine simulation inputs. For example, lighting power to be modeled for each thermal block is calculated based on the type and number of fixtures specified for the corresponding spaces and the manufacturer's maximum rated wattage of these fixtures. The results of these supporting calculations are then manually entered into the modeling tool.

Once the analysis is completed, simulation results and other required information, including the description of systems shown in the design documents and corresponding baseline and proposed model inputs, is manually entered into compliance forms. The process is illustrated in Figure 17.

Figure 17. Current Manual Compliance Documentation Process

A significant increase in productivity may be achieved by automating these manual steps. For example, envelope geometry and lighting loads in individual spaces may be transferred from design documents into simulation tools using a common schema. Compliance shells may generate the baseline and proposed design models and create compliance documentation based on the information transferred from the building information modeling (BIM) tool, freeing the modelers from tedious data-entry tasks and allowing them to shift their focus to optimizing building design. Automation will also reduce submittal review burden by eliminating errors associated with the mismatch between the model and design documents and flagging simulation inputs and outputs that are inconsistent or outside of the expected ranges. The fully automated compliance documentation process is illustrated in Figure 18.

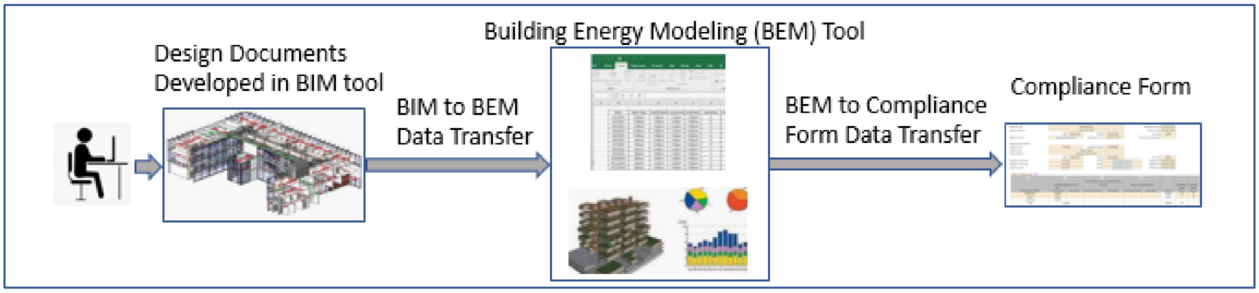


Figure 18. Fully Automated Compliance Documentation

Full automation requires a schema that supports data interoperability between building information models and building energy models and is integrated into both the BIM software used to create design documents and the BEM tools. While several data formats have been developed to facilitate such data transfer, seamless integration between BIM and BEM is still a research domain, as the time and effort required to troubleshoot the data transfer often exceeds the effort of creating an energy model from scratch (Fernald et al. 2018)

As an intermediate solution, a compliance form may be developed that would help organize information and perform supporting calculations necessary for input into simulation tools and facilitate the required reporting. Limited automation may be achieved by importing simulation results from standard reports produced by the BEM tools into the compliance form. This process is illustrated in Figure 19.

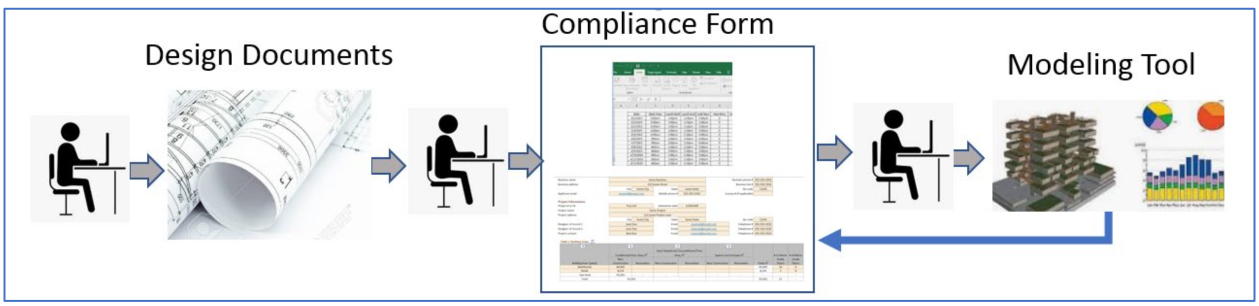


Figure 19. Partial Automation Using a Compliance Form

Transferring information from the BEM tool into the compliance form is another opportunity for the partial automation. It requires development of a ruleset model report (RMR) schema that will cover building details that are included in the model and are also part of the ruleset reporting requirements. To support it, BEM tools will need to express some of the detailed model information using energy code nomenclature – for example, three-dimensional window coordinates will need to be translated into window area and orientation or window to wall ratio. The RMR schema may be used to populate the compliance form or import information into program administrator's databases to track projects and facilitated QA, similar to that performed by RESNET®.

Some information that must be reported by performance-based projects based on the documentation requirements of ECB, PRM, and TBP is not entered into the BEM tool. For example, PRM requires listing prescriptive requirements applicable to the specified building systems and components and documenting that the design meets the applicable 90.1 mandatory provisions. These reporting requirements are the same as for projects that follow a prescriptive path of compliance with the energy code and are implemented in COMcheck, which is a DOE-funded tool widely used by projects documenting prescriptive compliance with 90.1 and IECC. The stand-alone performance-based compliance form may be integrated into COMcheck to take advantage of synergies in the reporting requirements between performance and prescriptive paths and leverage the ongoing maintenance of COMcheck to align with evolving codes.

5.5 Certifying Body

Reviews of mature performance-based programs reveal several important patterns. They all require a multi-year commitment of an organization administering the program, such as the states of California and Florida, and RESNET®. Furthermore, the program administrators identified similar elements necessary for a meaningful enforcement, such as simulation software testing and certification procedures and standardized reporting, and have developed solutions to address them.

For example, the Florida Building Commission, which provides ongoing state code development and implementation oversight, has a $400,000 annual research budget, some of which goes toward support of performance-based compliance, including development and maintenance of the 158-page Energy Simulation Tool Approval Technical Assistance Manual.[1]

Similarly, the CEC funds continuous development of the software California Building Energy Code Compliance (CBECC-Com),[2] which is used to benchmark and certify third-party software tools with the goal of providing two CBECC-Com releases per year. In addition, CEC maintains the comprehensive CA ACM Reference Manual, which contains the requirements needed for the approval of compliance software, develops and maintains the reference test suite for each version of CBECC-Com, and oversees third-party software certification (CEC 2019). Similar work is done on the residential side with CBECC-Res compliance software.

Many states and above-code programs do not have the financial and technical resources necessary to create such frameworks in-house. Furthermore, many of the key elements of this framework are best addressed on the national level. For example, having a national testing and certification process for the simulation software will provide potential for higher technical rigor and better engagement of software tool vendors. Thus, the proposed long-term solution is to facilitate creation of a national certifying body(s) that will develop, coordinate, and maintain the adoption framework based on national standards such as ASHRAE Standards 90.1 and 140. The certifying body will perform the following functions:

- Certify simulation software.
- Maintain a national network of certified modelers, reviewers, and training providers.
- Work with the rating authorities and jurisdictions to provide packaged enforcement solutions that they can oversee independently or through the certifying body.
- Provide ongoing QA and update the processes and tools.

Some of the elements for QA/QC framework may apply to multiple modeling rulesets (PRM, ECB, TBD), while others, such as software testing and certification and standardized compliance forms, may be different for each ruleset. The program administrators may rely on

[1] "All Hands on Deck: Raising the Bar on Whole Building Performance-Based Code Compliance and Above-Code Programs," M Karpman, M Rosenberg, B Liu, J Williams, ACEEE 2020.
[2] http://bees.archenergy.com/

the certifying body with all aspects of the program or just the individual elements. For example, they may reference the list of the approved simulation tools maintained by the certifying body (similar to how the IRS Section 179D list is currently used) or require the use of certified third-party submittal reviewers (similar to how incentive programs rely on the EPA's MROs).

6.0 Recommendations

6.1 Priorities Identified by Stakeholders

Tools and resources identified by stakeholders as short-term and long-term priorities for facilitating performance-based compliance are illustrated in Figure 20 and Figure 21.

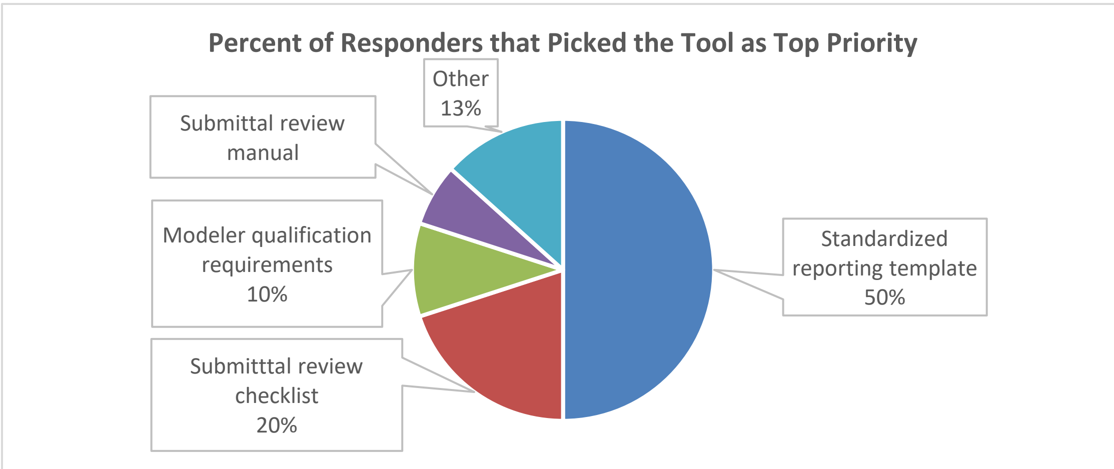


Figure 20. Tools and Resources Identified by Stakeholders as the Top Short-Term Priority

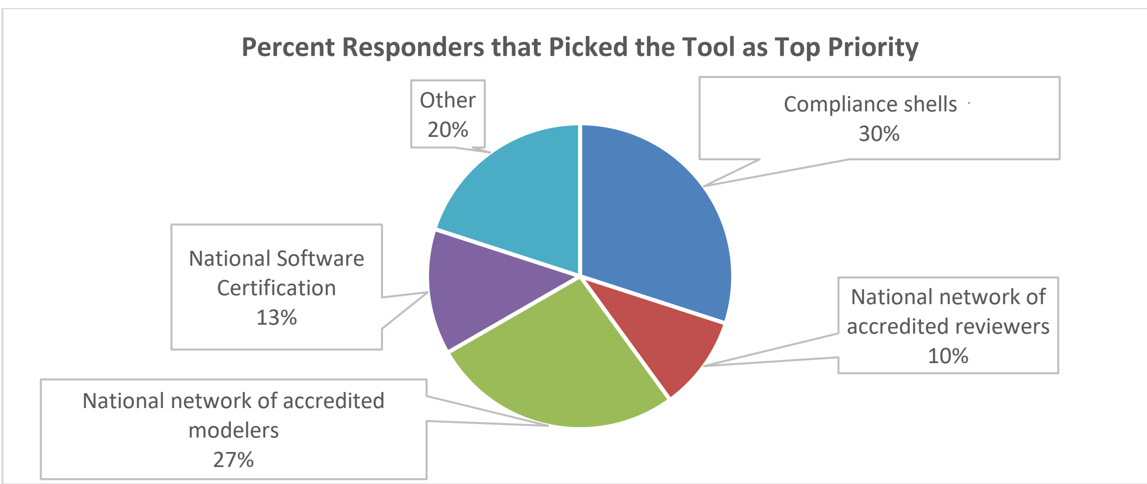


Figure 21. Tools and Resources Identified by Stakeholders as the Top Long-Term Priority

The recommendations for short-, medium-, and long-term activities to help facilitate the vision and address the priorities identified by the stakeholders are illustrated in Figure 22 and further described in the following sections.

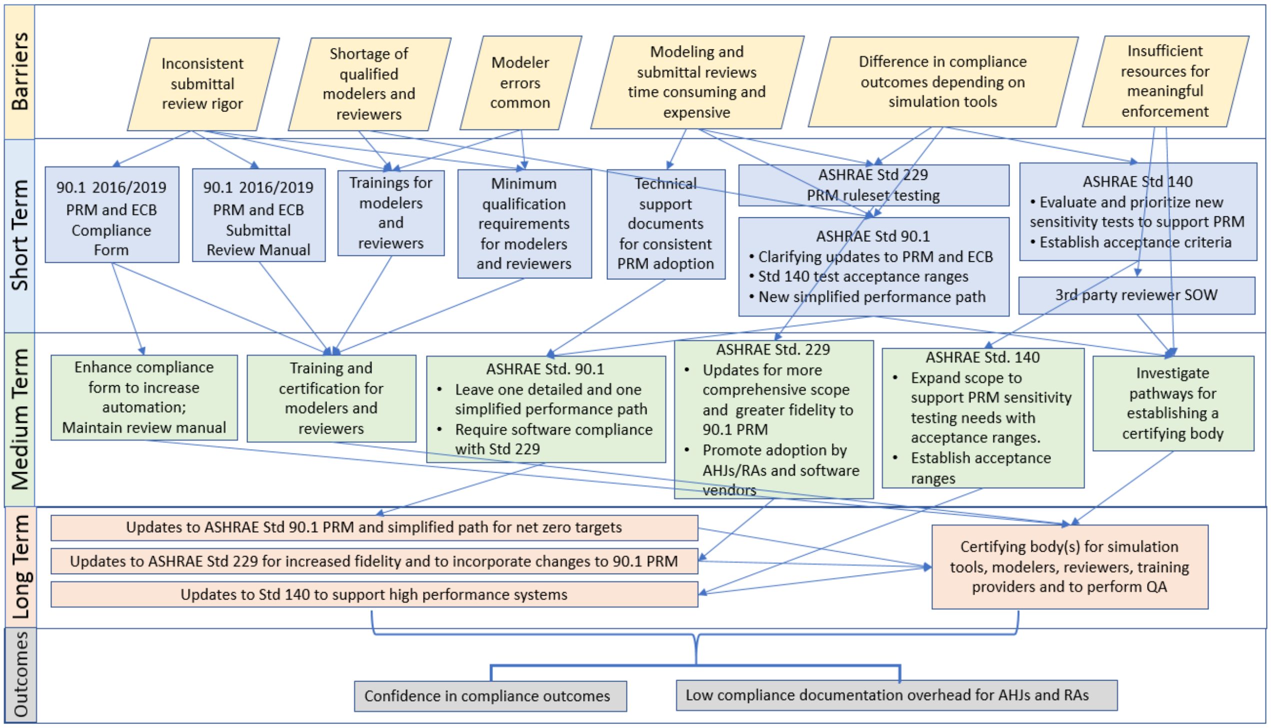


Figure 22. Short-, Medium-, and Long-term Activities for Establishing Performance-Based Compliance QA/QC Framework

6.2 Short Term (2020-2022)

1. Develop 90.1 2016 / 2019 PRM and ECB Compliance Form

A detailed compliance form will help ensure consistency of modeling submittals and create a foundation for standardizing submittal reviews across different modelers and reviewers. It will include the following:

- A detailed side-by-side list of inputs for the baseline and the proposed design
- Code look-up tables and built-in calculators to facilitate the development of the baseline and proposed design models based on the information in the design documents for the specified systems and components
- Specific references to design documents, connecting simulation inputs to the project drawings and specifications, to mitigate poor coordination between the design and the model
- A list of simulation reports that must be submitted to facilitate reviews, depending on the simulation tool used
- Automated QC checks to flag potential inconsistencies in the submittal to facilitate submittal reviews and enable internal QC before the project is submitted to AHJs/RAs.

The compliance form will support both code and above-code applications, to reduce compliance overhead for projects that submit results to several rating authorities and jurisdictions. It will be based on the NYSERDA/LEED template and will support the 90.1 2016 and 2019 PRM and ECB. While it is hoped that PRM will become the dominant modeling ruleset, in the short term it is necessary to also support the ECB as it is still widely used by jurisdictions. Having a rigorous compliance form for PRM but not ECB will make ECB the path of the least resistance for permit applicants, inadvertently encouraging its wider use.

The compliance form will be developed with input from the ASHRAE Standard 90.1 committee, code officials, the energy modeling community, and software vendors. It will be Excel-based and will include limited data import and export capabilities to facilitate automation, such as importing simulation results from BEM tools into the compliance form and exporting project summary information in a schema format to facilitate data exchange with external tools such as program administrators' tracking databases. While the Excel format is not conducive to a fully automated workflow, it will facilitate rapid delivery to ensure that the compliance form is readily available to the program administrators while the automation framework is being developed.

2. **Publish 90.1 2016 / 2019 PRM and ECB Submittal Review Manual**

The Review Manual will be a companion to the compliance form and will support 90.1 2016/2019 PRM and ECB. It will include the review checks to confirm:

- that the proposed design reported in the compliance form reflects design documents,
- that configuration of the baseline and proposed design models is established correctly
- that the baseline and proposed models are modeled as reported, and
- that the compliance outcome is established correctly based on the simulation results.

Each project typically has only a handful of high-impact areas, and the review effort may be reduced by focusing on these aspects (Rosenberg et al. 2016). The Review Manual will include a comprehensive list of software-neutral checks and prioritization strategies based on the project characteristics, such as the contribution of different end uses (heating, cooling, lighting, etc.) toward trade-offs, to focus efforts on the areas where mistakes are often made. The software vendors will be engaged to develop software-specific sections of the manual that will contain simulation reports annotated with tips on how to perform the review checks in the given tool. To facilitate submittal reviews, the checks described in the Review Manual will be included in the Quality Control Checks tab of the compliance form, and outcomes for some of the checks will be established automatically based on project information reported in the compliance form.

The review checks identified as universally impactful in the Review Manual may be performed on all projects; additional checks may be performed on a rotating or randomized basis, encouraging modelers to focus on the most impactful requirements, while ignoring none. Alternatively, more comprehensive reviews may be performed on larger, more energy intensive projects. The Review Manual may also be used by AHJs/RAs to communicate the required review scope and rigor to third-party reviewers.

The NYSERDA Review Manual will be used as a starting point for the work. The modeling community and organizations such as IBPSA will be engaged to provide input and peer review of the checks, rules of thumb, and prioritization methodology described in the manual.

3. **Develop training for modelers and reviewers focused on performance-based compliance.**

This training will cover the general concepts of performance-based compliance following the 90.1-2016 and 90.1-2019 versions of PRM and ECB and focusing on submittal QC. It will be based on the submittal review process described in the Review Manual and will train attendees on the use of the manual and compliance form.

4. **Establish minimum qualification requirements for modelers and reviewers**

The Review Manual will include recommendations for the minimum qualification requirements for the modelers and submittal reviewers. It may also include description of the required work experience, relevant certifications such as ASHRAE BEMP or AEE BESA, the completion of training on performance-based compliance, and experience with the specific building modeling tool and energy studies evaluating similar energy-efficient designs.

5. **Develop scope of work (SOW) for third-party reviewers**

It may be impractical for small jurisdictions that see a low volume of performance-based projects to have reviewers on staff who have the necessary expertise with review of modeling-based submittals. SOWs for third-party reviewers will describe the submittal review tasks and deliverables to facilitate soliciting help from external consultants.

6. **Develop ASHRAE Standard 229P, a ruleset testing protocol to facilitate consistent implementation of the PRM**

The ruleset testing standard will provide procedures for verifying ruleset implementations by the compliance shells or on individual projects. It will incorporate the best practices and lessons learned from similar efforts undertaken by California, Florida, RESNET®, and others, and manual submittal reviews. Developing the ruleset testing procedures in the framework of an ASHRAE standard, with committee members representing program administrators, developers of the relevant standards (e.g., ASHRAE 90.1 and 140), modelers and software tool vendors would require more time to establish consensus, but would improve technical rigor, increase awareness, and encourage adoption. This work has already begun with the new ASHRAE Standard 229P, *Protocols for Evaluating Ruleset Implementation in Building Performance Modeling Software*.

7. **Propose additional sensitivity and physics tests for inclusion into ASHRAE Standard 140**

This work will include cataloging systems and components that are included in the baseline design, found in typical designs of projects minimally compliant with the energy code, and common on high-performance projects. This list will be compared to the current scope of Standard 140 to identify gaps. The additional tests will be prioritized based on the impact of relevant systems on the compliance outcomes and how frequently these systems participate in performance trade-offs.

The proposed new tests will be discussed with Standard 140 committee to gauge opportunities for including the new tests in the standard, and whether the new tests should be included in Standard 140 or another standard or guideline.

8. **Include acceptance criteria in ASHRAE Standard 140**

ASHRAE Standard 140 does not currently include acceptance ranges or pass/fail criteria. Thus, references to Standard 140 included in the compliance modeling protocols such as ECB and PRM only require software vendors to perform the testing and publish the results, which does not in itself guarantee consistency in results among different tools. Work is underway to establish pass/fail methodology that may be incorporated into Standard 140 and/or standards that reference it.

9. **Update ASHRAE Standard 90.1 to eliminate ambiguities in PRM and ECB language, introduce a simplified performance path, and coordinate with Standard 140**

The tasks will cover the following general areas:

   a. Review the PRM and ECB rules to identify and eliminate ambiguities as well as those requirements that conflict with the use of the models to predict future energy use.
   b. Use a more structured format where feasible – for example, formulate the rules for establishing HVAC baseline system type as a flow chart instead of a table with multiple exceptions.
   c. Review changes made to PRM by program administrators and update the requirements to address common needs. This may include limiting allowed trade-offs for individual systems and component (e.g., envelope) and methodologies for expressing compliance outcomes in units other than energy cost (e.g., source energy, greenhouse gas emissions).
   d. Identify and add details not covered in the standard that are necessary for consistent interpretation and implementation of the PRM.
   e. Address the known shortcomings of the PRM, e.g., with respect to renovation projects and projects using purchased heat and chilled water.
   f. Investigate adding a simplified performance path that may be used by projects of certain size, type, and complexity for documenting minimum code compliance.
   g. Maintain deliberate coordination between the scope of Standard 140 and the trade-offs allowed by the PRM.
   h. Incorporate sensitivity testing acceptance criteria, if not addressed within Standard 140.

10. **Develop technical support documents to facilitate consistent adoptions of PRM and inform the use of compliance modeling in conjunction with building energy performance standards**

This work may include a review of changes made to the PRM by various program administrators to address, for example, fuel switching, differences between the PRM baseline and local standard practice, methodologies to calculate savings by fuel (e.g., electricity kWh) relative to code, and so forth. The documents will also explore opportunities and develop pathways to help program administrators meaningfully integrate compliance modeling with building energy performance standards. The technical documents will be maintained and updated to support the evolving needs of program administrators. In addition, the Performance Rating Method Reference Manual should continue to be maintained to incorporate changes to 90.1 PRM and address gaps.

6.3 Medium Term (2022-2025)

1. **Maintain and enhance the compliance form**

This work should focus on improvements to usability and increased automation through expanding data exchange with the BEM tools and opportunities and updates for new editions of 90.1. In addition, changing the compliance form format should be investigated, such as integrating it with web-based COMcheck to leverage its reporting features that overlap between performance and prescriptive compliance options.

2. **Maintain and enhance the Review Manual**

This work should focus on enhancing review prioritization strategies, adding review checks for special situations that are currently not addressed in detail (e.g., designs with purchase heat or chilled water, retrofit projects), and incorporating input from modelers and reviewers. The manual should also be updated for new editions of 90.1.

A subset of impactful QC checks included in the Review Manual may be recommended for inclusion into the software tools to automatically flag potential errors similar to the QA flags required by RESNET®. Some of the checks (e.g., unrealistic energy use intensities, excessive simultaneous heating and cooling) may be applicable to both compliance and design support modeling, and thus valuable for a wider audience. Figure 23 illustrates a similar functionality available in eQUEST. The requirement for automated QC may be added to Standard 229P or 90.1 software requirements, similar to the existing check for unmet load hours.

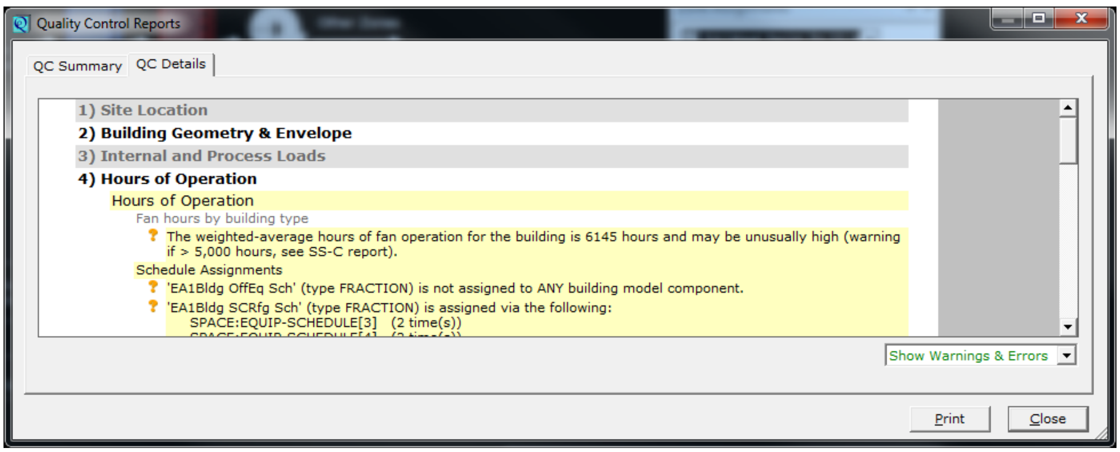


Figure 23. eQUEST Quality Control Report

3. **Enhance training opportunities for modelers and reviewers**

Comprehensive training programs for modelers and submittal reviewers with the focus on compliance modeling should be developed and made widely available.

4. **Continued updates to ASHRAE Standard 90.1**

The work will include the following focus areas:

- Leave a single, detailed, whole-building performance path based on the PRM.
- Transform ECB into a simplified performance path available to projects that meet certain criteria.
- Add requirements for the software tools to comply with Standard 229P.
- Continue work to ensure deliberate coordination between the modeling requirements and scope of Standard 140 and the acceptance ranges.

5. **Updates to Standard 140 to better support commercial compliance modeling**

This work should include the following focus areas:

- Continue development of the sensitivity tests in support of the PRM and work on incorporating them into Standard 140 or an alternative standard or guideline.
- Engage with software tool vendors to help refine test case descriptions and establish acceptance ranges.

6. **Publish ASHRAE Standard 229P and promote its adoption**

This work should include publishing Standard 229P, educating jurisdictions and rating authorities about its values, and ensuring its adoption by vendors of the popular simulation tools.

7. **Investigate pathways for establishing the certifying body(s).**

This activity may involve the following:

a. Review prior efforts in the commercial sector such as COMNET and other relevant precedents in the U.S. and abroad, including the technical aspects and business models, which may be market based (COMNET, RESNET®) or publicly funded (CEC).

b. Evaluate the pathways for certifying software tools, including the following:
   - Identify the key elements of the compliance software certification process based on the experiences of California, Florida, and RESNET® and lessons learned.
   - Develop and publish a software self-certification process, which may include ruleset testing, sensitivity testing, and demonstrating the capability to generate compliance forms, with the relevant materials posted on the vendor's website.
   - Engage with vendors of commercial software tools to encourage their participation in the software certification process; provide public funding to the commercial tool vendors to speed up implementation of the compliance shells.

c. Establish a national certification program to create a pool of qualified modelers and reviewers.

d. Identify candidate organizations that may fill the role of the certifying body.

6.4 Long Term (2025-2030)

The long-term activities will focus on delegating the maintenance of the QA/QC framework to the certifying body(s) which will perform the following functions:

1. Certify simulation tools.
2. Maintain a national network of certified modelers, reviewers, and training providers. Other than certification, there is no way to gauge modeler expertise, or even for modelers to gauge their own expertise (Roth 2019).

3. Work with the rating authorities and jurisdictions to provide packaged enforcement solutions that they can oversee independently or through the certifying body.

4. Provide ongoing QA and update the QA/QC infrastructure as necessary to maintain consistent compliance outcomes.

In addition, the continued development of the national standards that form the basis of the QA/QC infrastructure, including but not limited to ASHRAE Standards 90.1, 140, and 229P, will be necessary to support the evolving industry needs.

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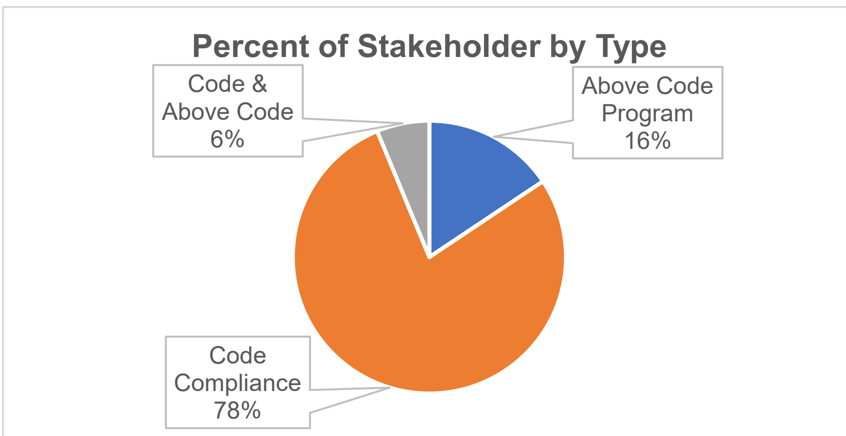
Appendix A – Stakeholder Survey Summary

A.1 Background

This report was informed by a stakeholder group that included more than 70 building officials, administrators of above-code programs, modelers, and members of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) committees for Standards 90.1, 140, 189, and 229P. The stakeholder engagement work was supported by the Northwest Energy Efficiency Alliance (NEEA) and included six 2-hour stakeholder webinars and two 4-hour in-person meetings – one in Portland, hosted by NEEA, and another in New York City, hosted by New York City Department of Buildings.

In addition, a comprehensive survey was developed that included 33 questions on performance path market penetration and trends, enforcement practices, and short- and long-term priorities for improving compliance. Respondents demographics is shown in the figure and table below. Detailed follow-up discussions were held with many stakeholders to better understand their perspective. The questions and responses are summarized in this appendix and referenced throughout the report.



Number of Stakeholders by Location and Type

Location:	MA	CA	DC	AL	CO	IA	IL	WA	NY	USA*	CT	YVR*	GA	FL	OR	RI	Total
Above Code Program	1	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	5
Code Compliance	1	4	2	1	3	1	1	1	2	0	1	1	1	4	1	1	25
Code & Above Code	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
Total	2	4	2	1	3	1	1	1	2	4	3	1	1	4	1	1	**32**

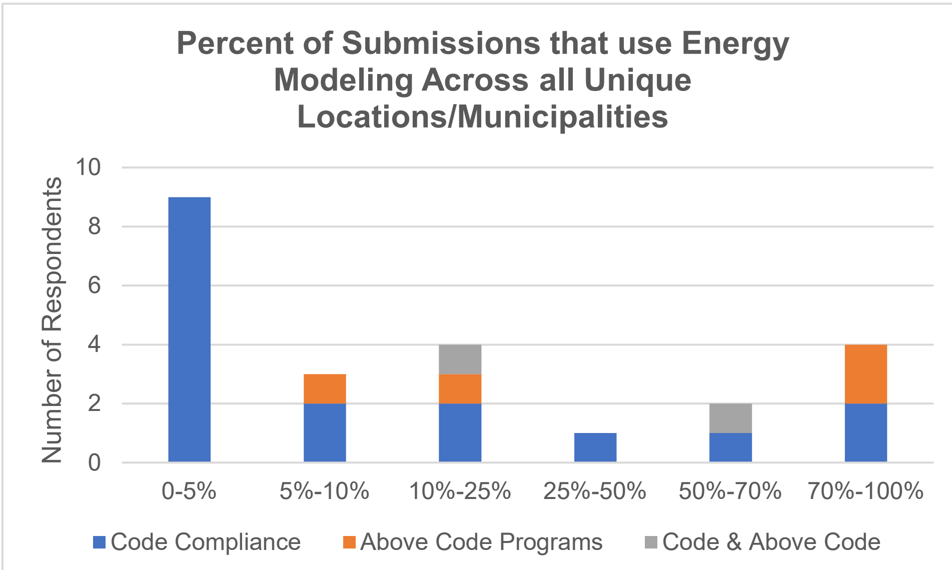
USA = Nationwide and YVR = Vancouver, Canada

A.2 Performance Path Market Penetration and Trends

1. **In your experience, what percentage of projects use energy modeling to document code compliance?**

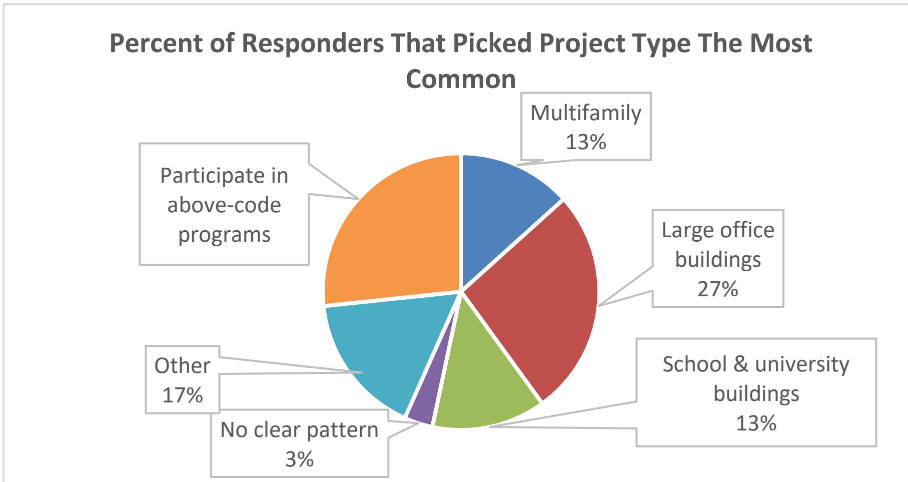
   Number of unique responses: 23

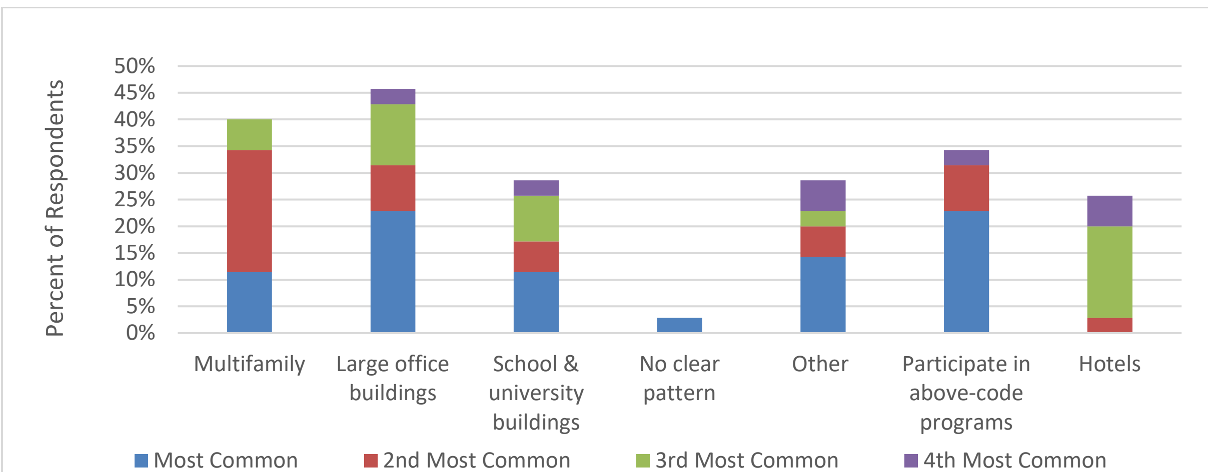
   Multiple responses were grouped together and counted as one unique response to this question if several stakeholders provided information for the same program.



2. **In your experience, which types of projects use performance path most often? Please list in order of occurrence, starting with the most frequent.**

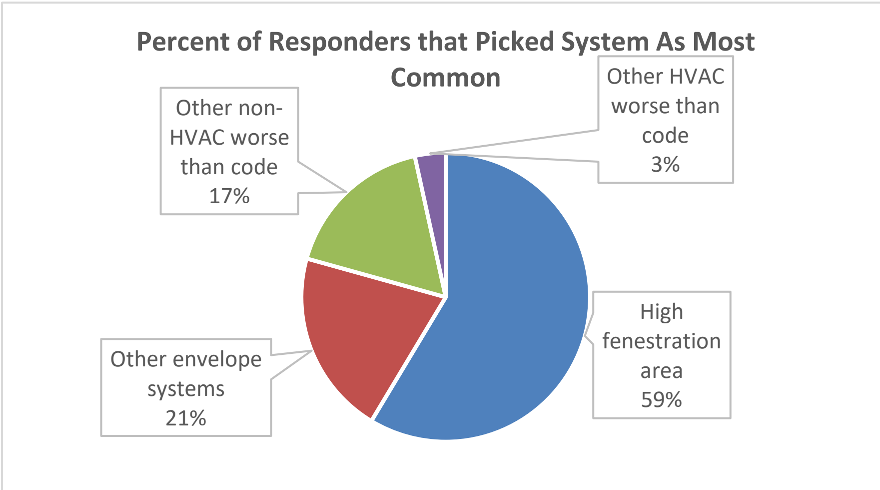
Number of responses: 30

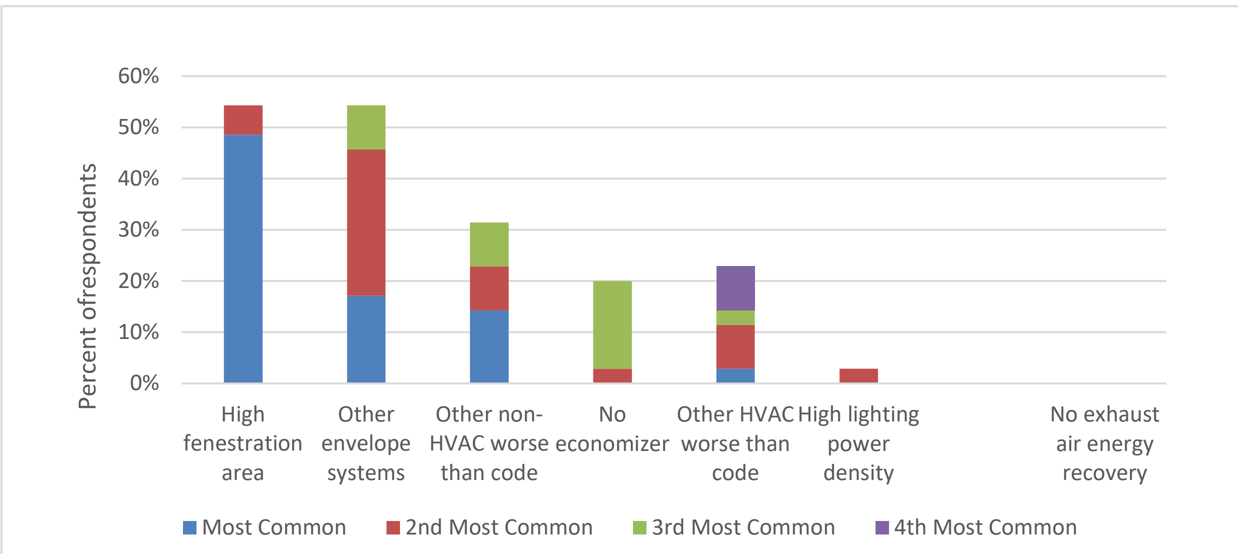




3. **Projects that choose performance path typically do so because they don't meet some of the prescriptive requirements. In your experience, what prescriptive requirements are most commonly not met? Please list in order of occurrence, starting with the most frequent.**

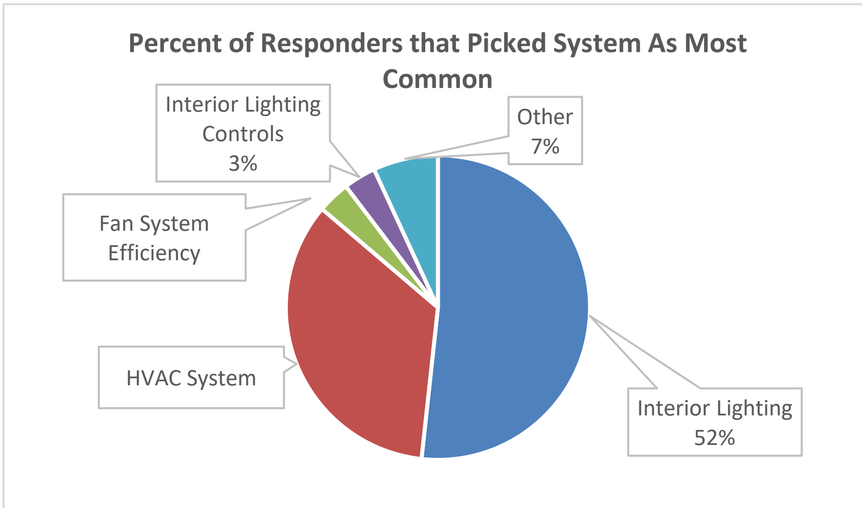
Number of responses to this question: 29

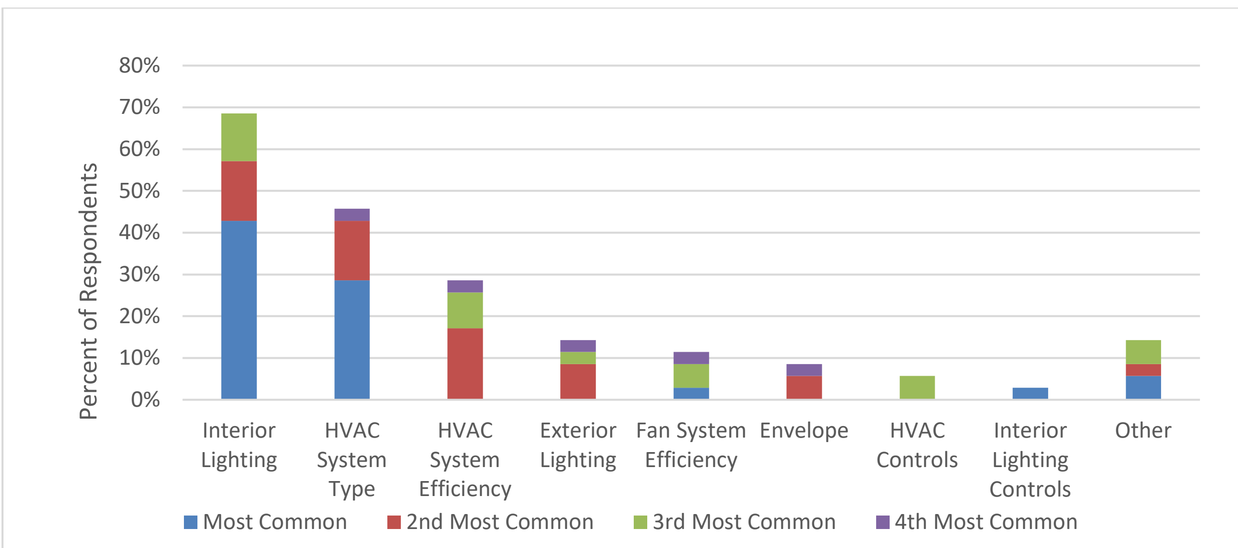




4. **What systems and components commonly make up for the penalty? Please list in order of occurrence, starting with the most frequent.**

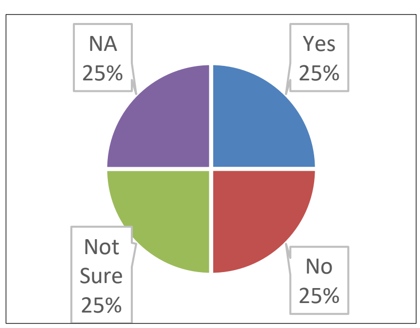
   Number of responses to this question: 29





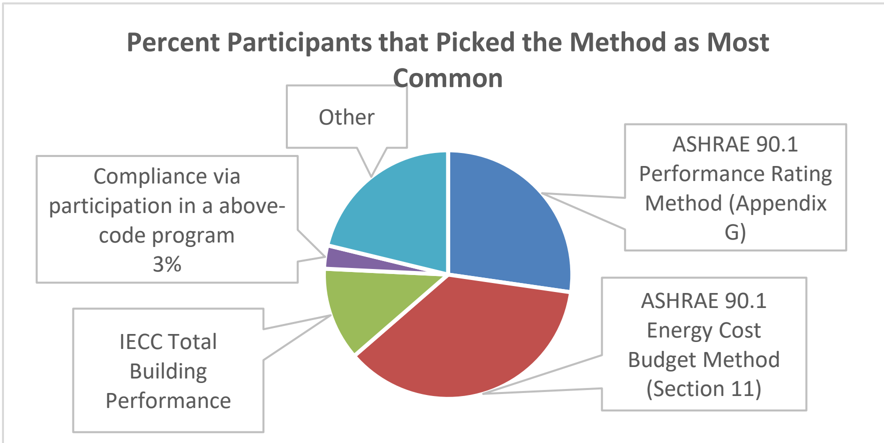
5. **Did you notice an increase in the number of performance-based submittals over the last few years?**

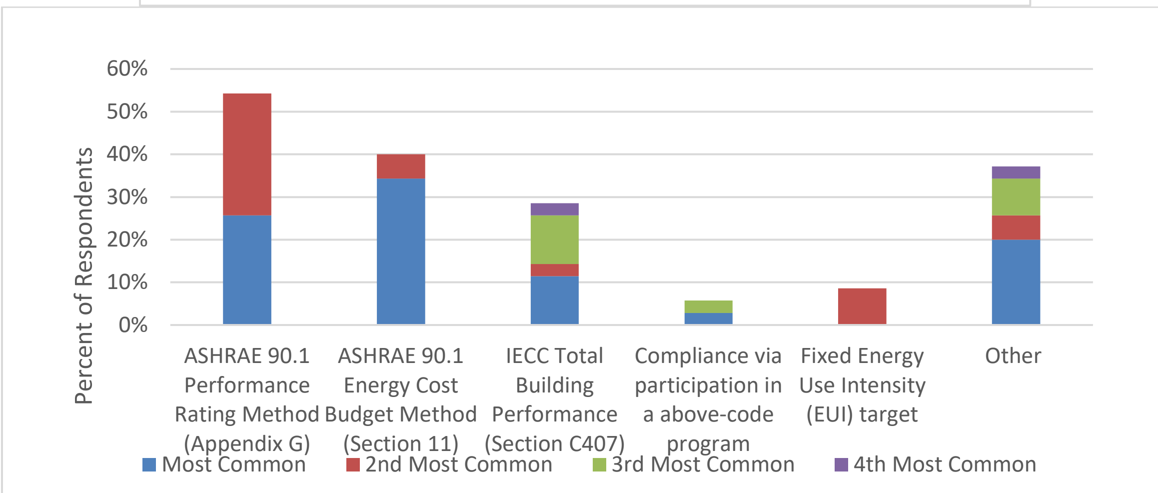
   Number of responses to this question: 28



6. **What performance-based compliance options are allowed in your jurisdiction or above-code program? If several options are allowed, select all that apply in the "Performance-based Compliance Option" column. In the "Year" column, indicate the edition used. For example, if 90.1 2016 Appendix G is allowed, enter "2016". For each option, enter approximate percentage of projects that use it.**

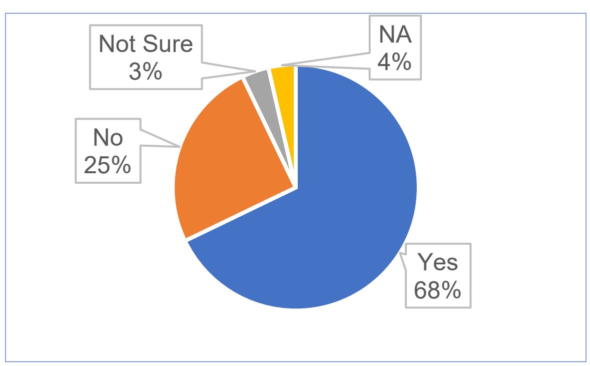
   Number of responses: 33





7. **Does your jurisdiction or above-code program require submitting the modeling files and/or simulation reports for review?**

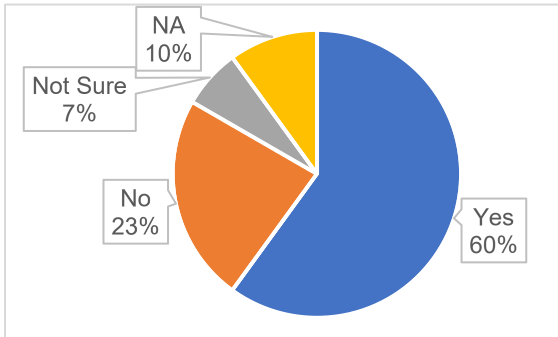
   Number of responses to this question: 28



8. **If options other than ASHRAE 90.1 or IECC are allowed, please briefly describe the rules (for example, programs that uses Fixed EUI Target may be based on ASHRAE bEQ As Designed) and/or provide a link to the relevant documents.**

9. **If your jurisdiction or above-code program uses 90.1 Section 11 or Appendix G, are there additional requirements (e.g. Simulation Guidelines) that projects must follow?**

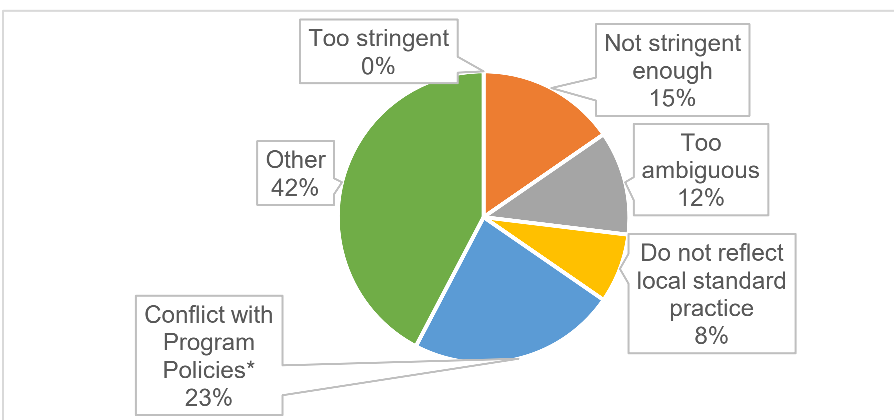
   Number of responses to this question: 30



   a. **If so, can you share them? Please provide a link to the documents or include the documents as attachments.**

   b. **If so, why were these supplemental requirements adopted? Was it because some of the requirements of 90.1 Section 11 or Appendix G are…. (Select all that applies in the order of importance, starting with the most important reason).**

   Number of responses to this question: 17

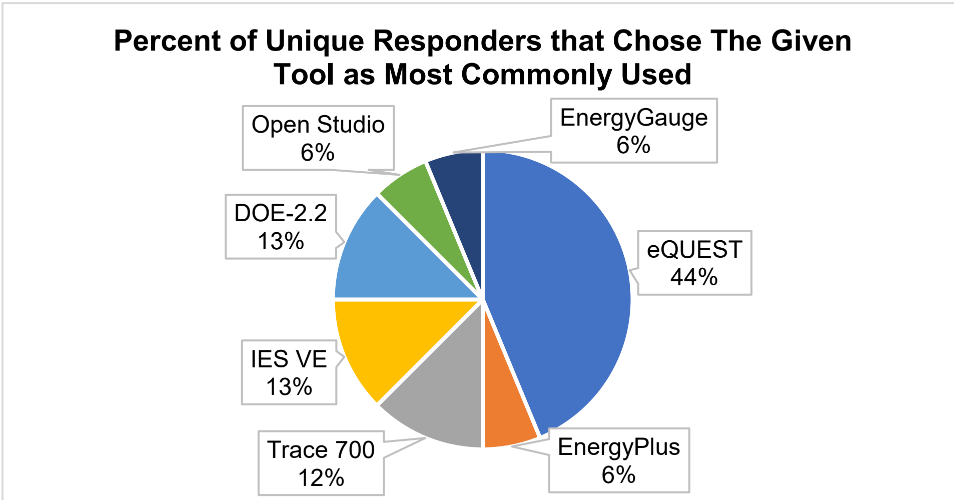


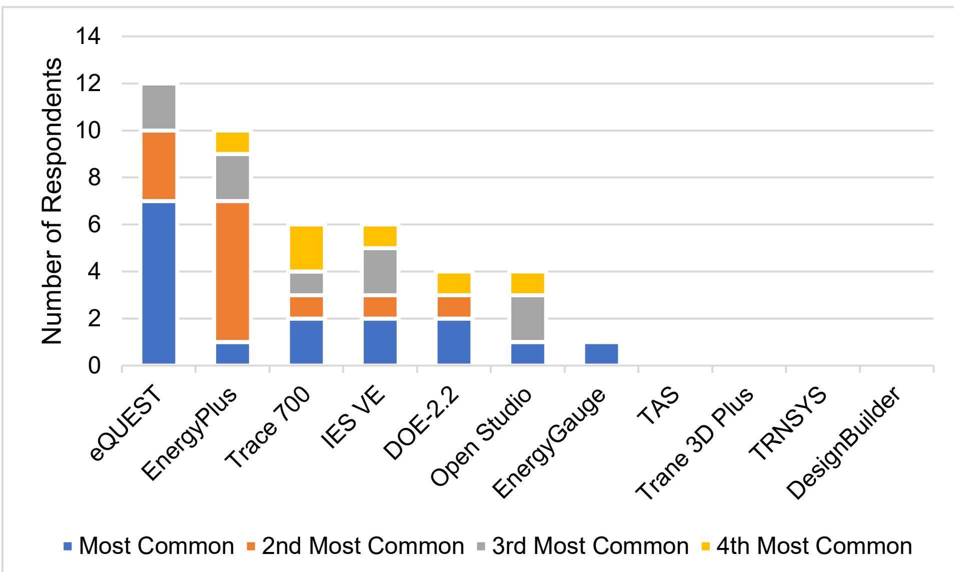
* Conflict with program policies, such as fuel switching or difficulty with reporting savings relative to code

10. **Which simulation tools are most commonly used in your jurisdiction or above-code program?**

Number of unique responses to this question: 16

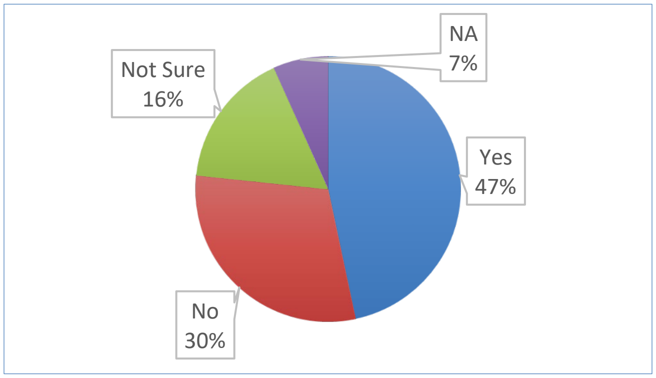
Multiple responses were grouped together and counted as one unique response to this question if several stakeholders provided information for the same program.





11. **Based on your experience, is review of modeling-based submittals becoming more structured and rigorous?**

    Number of responses to this question: 30



12. **If so, how do modelers, design teams and/or building owners react to more rigorous enforcement?**

    "Applicants appreciate the rigor. Codes/policies that are unevenly levied on building applicants and project teams are very unpopular. The more we ensure each and every project (to the extent we're able, given limited resources) is demonstrating compliance both at the time of permit and again throughout construction, the more credibility and support we have for our energy code."

    "… mad at first, but then they learn and comply"

    "they know it is something they are required to comply with so we hear complaints, but see compliance".

    "…very poor... defensive, lack truthfulness, lack of interest in compliance, try to bully the building department, and ultimately they get very political and call the city manager and city council members to push projects through without proper compliance - and this seems to work every time."

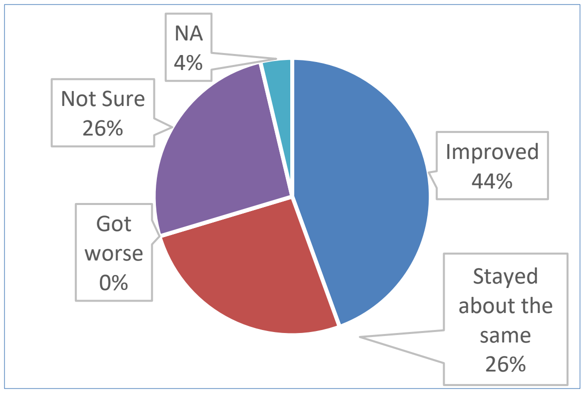
    "The first year was the most difficult when we were establishing the enforcement program and modelers were not used to getting any comments on their models. It took them time and money and typically several revisions to … provide enough documentation to prove compliance, along with much pushback…. Now, we don't get as much pushback from the modeling firms, but more from owners who are frustrated that they are not receiving approval due to energy code. Submittals got much better than when we first started enforcement 5yrs ago, and we saw dramatic improvement over the first two years, but since then it's about the same."

    "Submittals are getting exponentially better over time due to many factors. Firstly, it is worth their while to improve as … industry knows energy and energy enforcement is here to stay. Local firms become the best in the country and help the offices in other provinces. Everybody wins."

    "… some modelers are better than others, we have seen 'new' firms submit energy models, and those submissions are very poor – lack of understanding of the modeling protocol, lack of understanding of the modeling software, very poor correlation between the model and the design."

13. **Did you notice changes in quality of modeling-based submittals? Is there trend to improvement (e.g. better this year than last year), do they stay about the same, or are getting worse? Include additional noted in the column to the right.**

    Number of responses to this question: 27

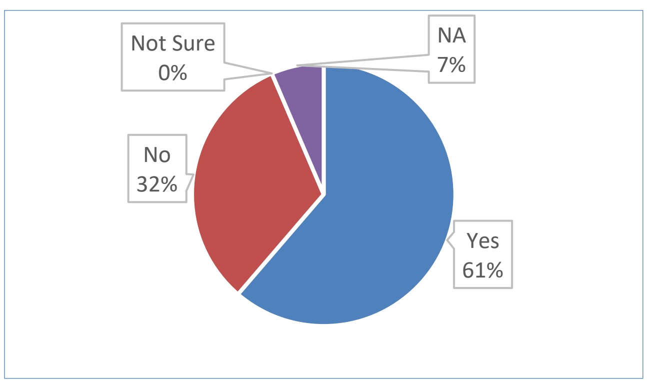


14. **Do you want to share other observations or thoughts about recent trends in the performance-based compliance?**

A.3 Enforcement Practices used by Jurisdictions and Above-code Programs for Performance-Based Projects

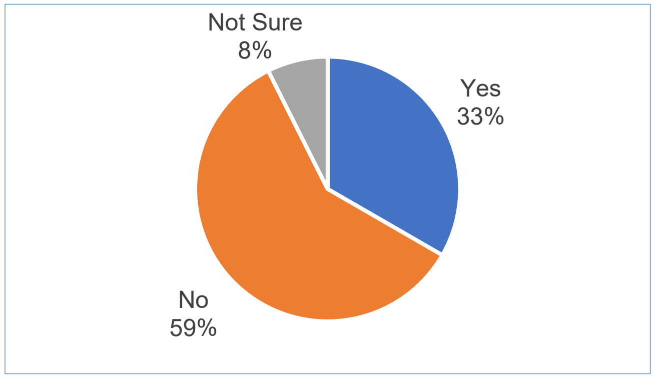
1. **Is there a standard reporting template that projects are required to use? If so, can you share it?**

   Number of responses to this question: 31



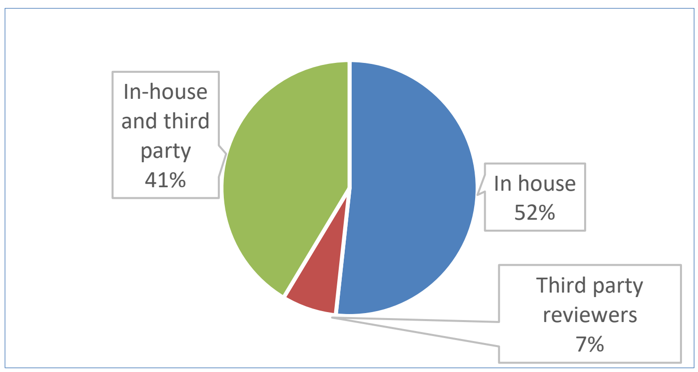
2. **Is there a standard review checklist that all reviewers must follows? If so, can you share it?**

   Number of responses to this question: 27



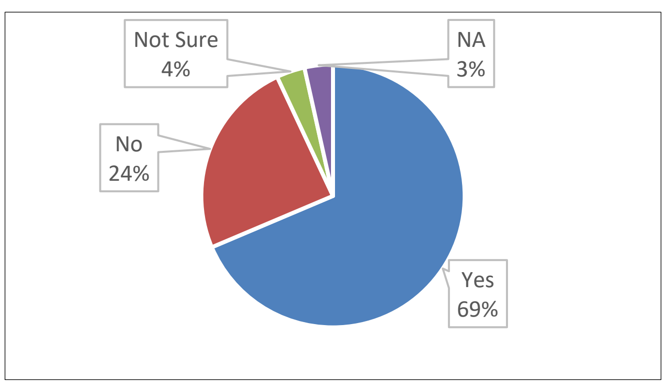
3. **Are reviews done in-house or by external consultants (third party reviewers)?**

   Number of responses to this question: 29



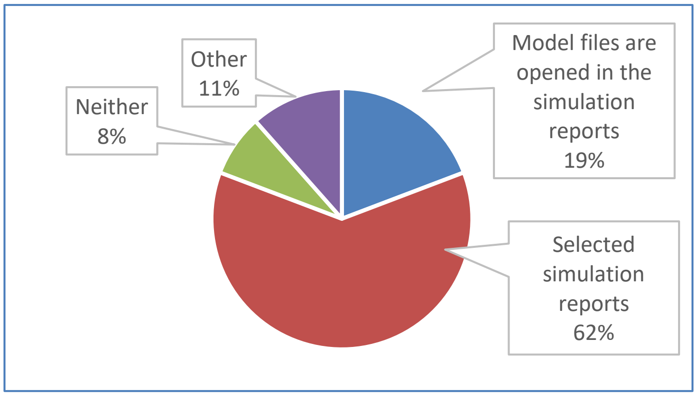
4. **Does your jurisdiction or above-code program require submitting the modeling files and/or simulation reports for review?**

   Number of responses to this question: 28



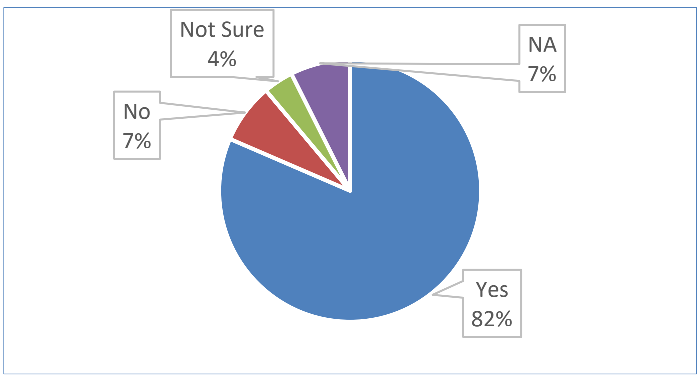
5. **What is the standard scope of the model review?**

   Number of responses to this question: 26



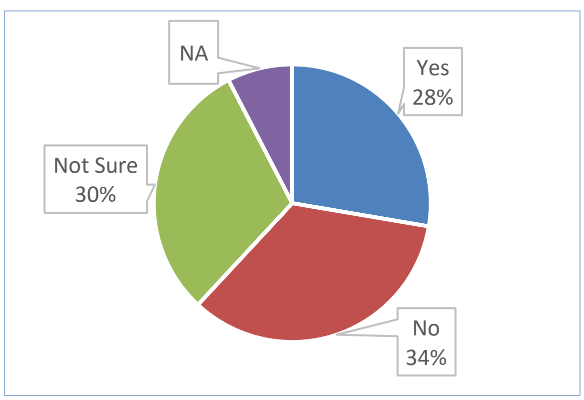
6. **As part of the model review, is it verified that building design documents or as-built construction or both match model inputs?**

   Number of responses to this question: 27



7. **Do you have confidence that the modeling results you receive are accurate?**

   Number of responses to this question: 26

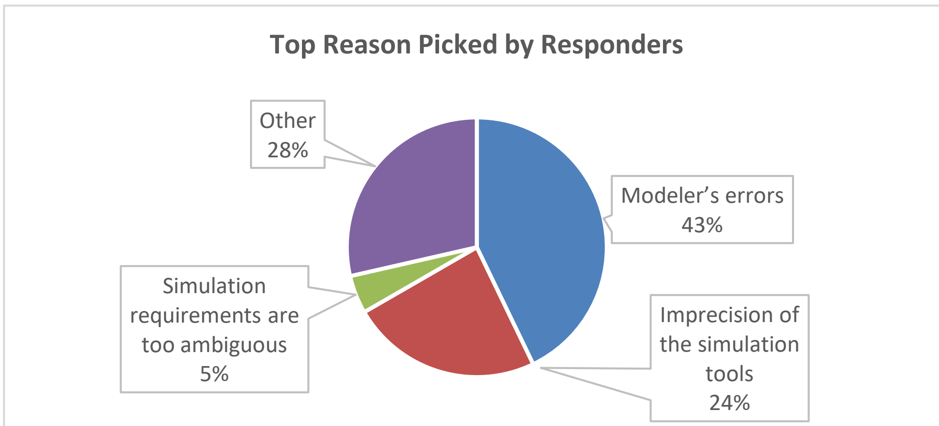


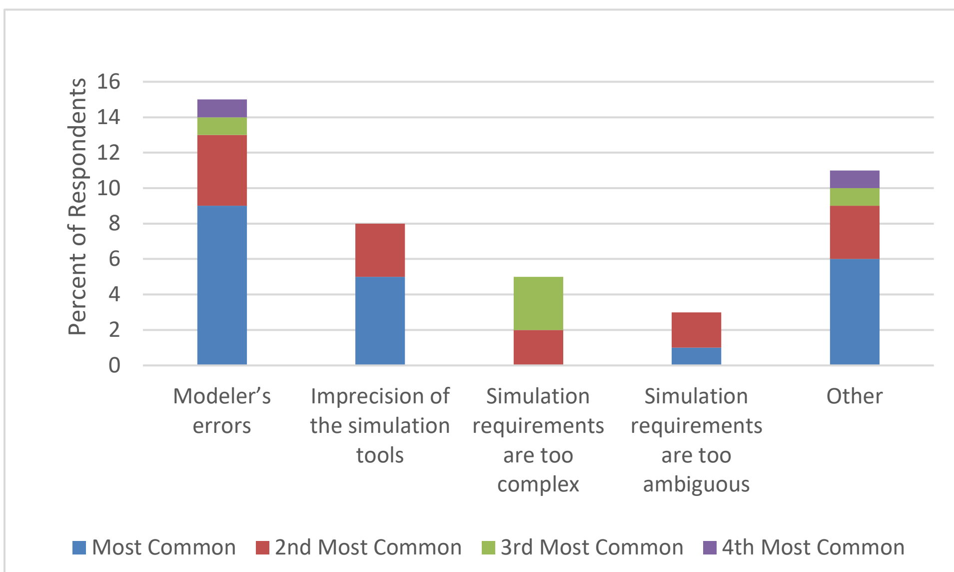
"The modeling tools and the modeling protocols underpredict energy consumption considerably. Boulder is collecting data through our rating and reporting program for commercial buildings, specifically EUIs. As we compare this data to the models that were provided for these buildings (at time of permit), it's clear that models are not accurately predicting energy consumption."

"What is "accurate"? Reasonable - yes, accurate is a never-ending issue. Basic items - yes, but more complicated issues such as accurately accounting for thermal bridging is our next layer of the onion. In the end we want reasonable models that can be achieved while not creating undue hardship on the industry, so they can continue to improve rather than give up."

8. **If not, what do you think is the main reason for inaccuracy? (Select reasons in the order of importance, starting from the most important, and add notes to the right.)**

   Number of responses to this question: 21



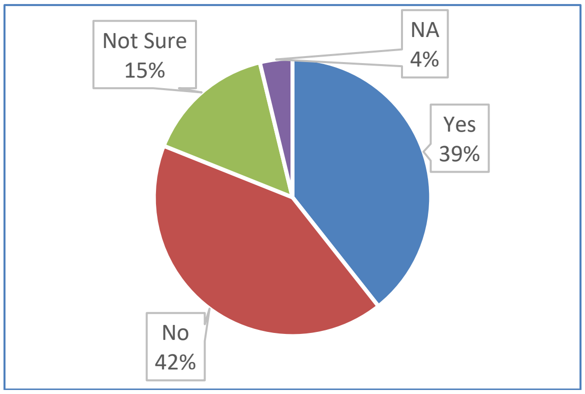


"Communication between modeler and design team, especially MEP firm is important. Sometimes there is a disconnect between the modeler and mechanical firm as to equipment types, size, efficiencies, etc."

"I think it's primarily user error but typically unintentional. In addition to model input mistakes there are often problems with modeler knowledge of the software and systems they are modeling. Building energy models are often pushed down to the least expensive engineering professionals who are often not experienced enough to know what they're doing wrong."

9. **Are you concerned that, due to inherent technical complexity and enforcement challenges, some projects use the performance path as a loophole to circumvent code? (Please add notes to the right.)**

Number of responses to this question: 26



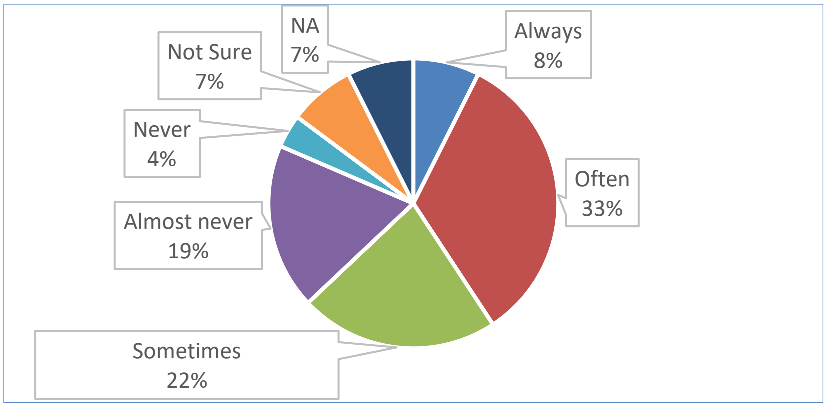
"I think DC has made gains in this area, and this is less the case than it used to be. Broadly I think this continues to be an issue."

"I have heard of large projects that use the performance path to help obtain the least costly building allowed to meet code."

"They follow the rules (mostly) so it's not circumventing the code, but modeling is used to circumvent the energy-saving intent of the code. The idea of an even exchange relies on three serious fallacies, the phantom baseline, the measure life discrepancy, and perfect functioning. The measures that modelers make worse are real and result in measurable and permanent increases in energy use over the life of the building. The measures that modelers make "better" are most frequently what they'd be doing anyway, even without modeling: almost nobody uses 82% efficiency boilers, nobody uses their entire lighting power allowance, nobody uses their entire fan power allowance, but the baseline model always assumes this most extreme case rather than a typical or average case. Thus, modeled buildings inevitably perform worse than if they had been prescriptively designed, sometimes dramatically worse. The measures that modelers make worse are long-lasting and in general will never be upgraded over the entire life of the building. Fenestration area, slab edge insulation and economizer function, to name the three most popular ones, are permanent features of the building."

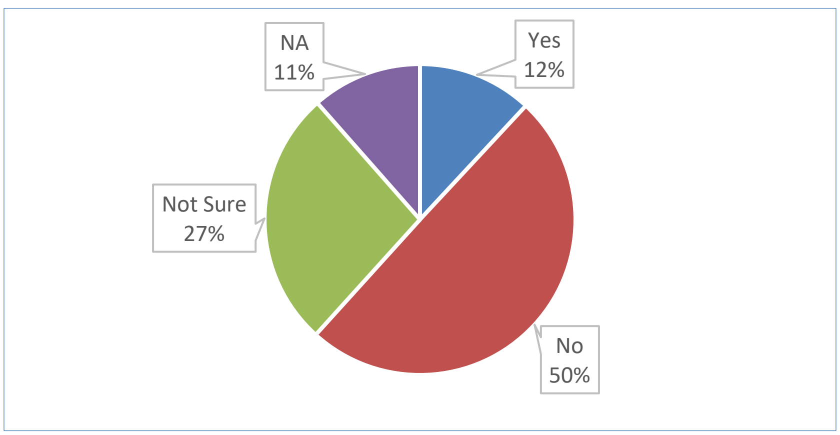
10. **In your experience, how often do review comments lead to design changes?**

Number of responses to this question: 27



11. **Is there a time budget for review of performance-based submittals? If so, please indicate the number of hours in the column to the right.**

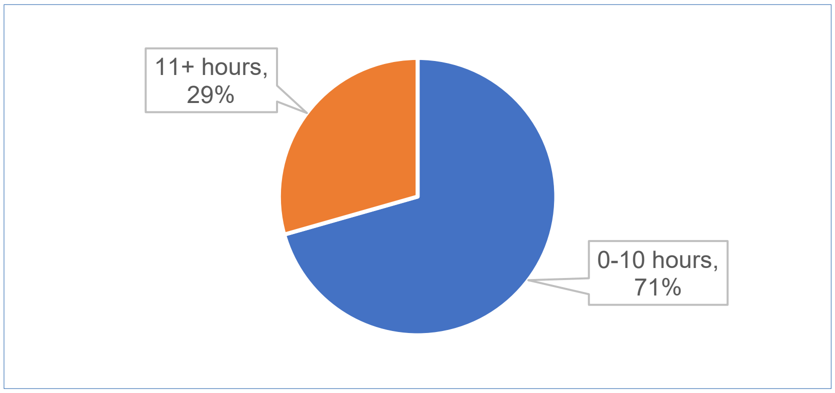
Number of responses to this question: 26



12. **How many hours per project do reviews of performance-based projects typically take?**

    Number of responses to this question: 17

    Maximum: 40 hours, minimum: 30 minutes, average: 10 hours. Many comments reflected that there is a large variability in review times based upon the complexity of the submission, for example, one of the stakeholders stated, “varies extremely - 10 - 50 hours” and another stated, “entirely dependent on project complexity and scope”.



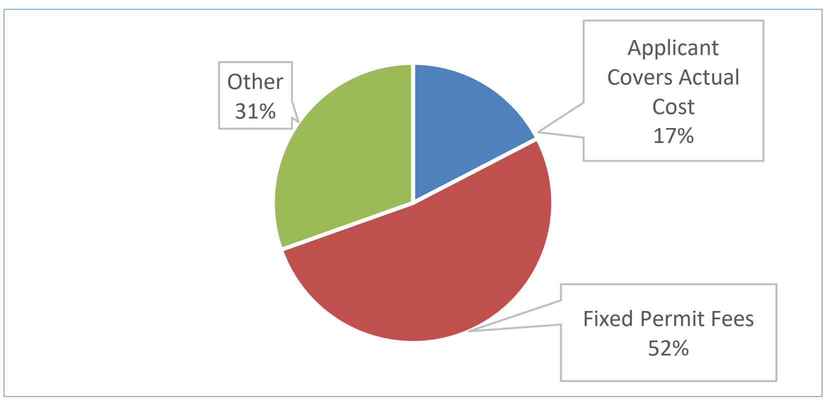
13. **How many review iterations are typically required before projects are approved?**

    Number of responses to this question: 20

    Maximum: 4, minimum: 1, average: 2.3 iterations. Similar to question 12, some stakeholders indicated that complexity and quality were factors in determining the number of iterations. For example, a stakeholder stated that, “[It is] dependent on quality of submittal and complexity of project,” in response to this question.

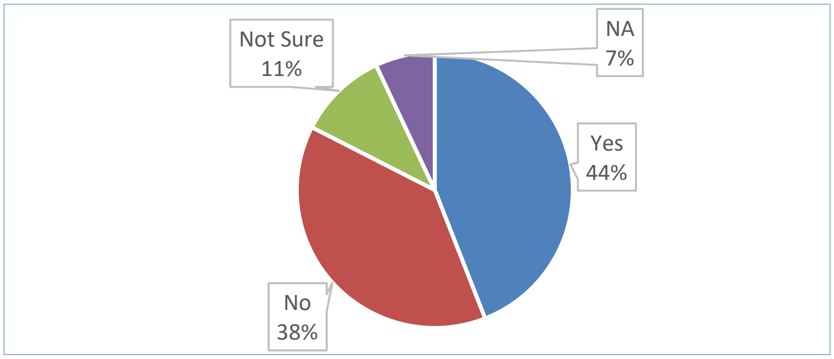
14. **How are reviews funded?**

    Number of responses to this question: 23



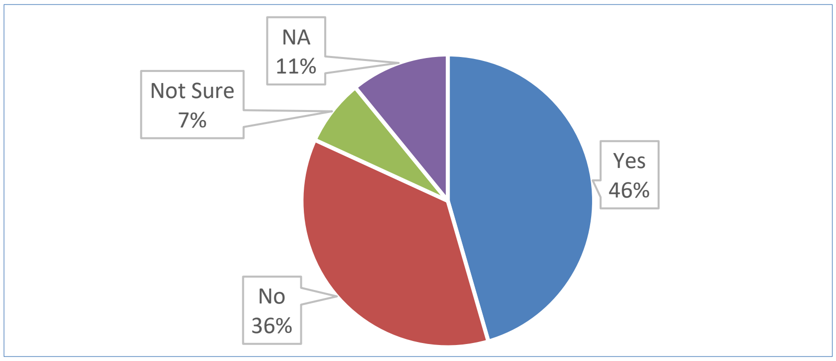
15. **Does your jurisdiction or above-code program have staff that specializes in review of modeling-based submittals?**

Number of responses to this question: 30



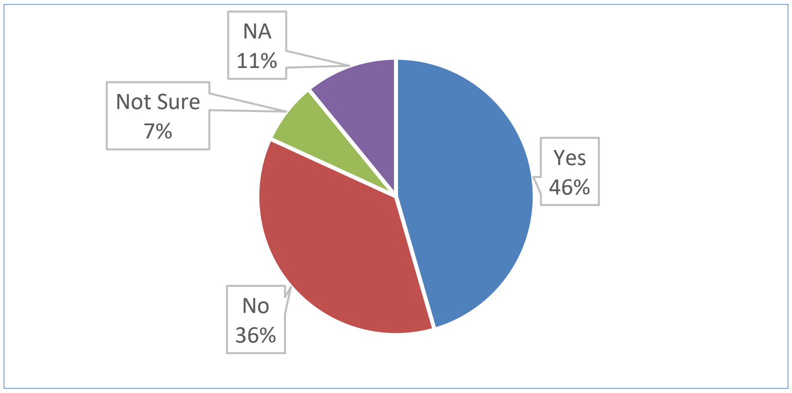
16. **Does your jurisdiction or above-code program have qualification requirements for reviewers? If so, can you share them?**

Number of responses to this question: 28



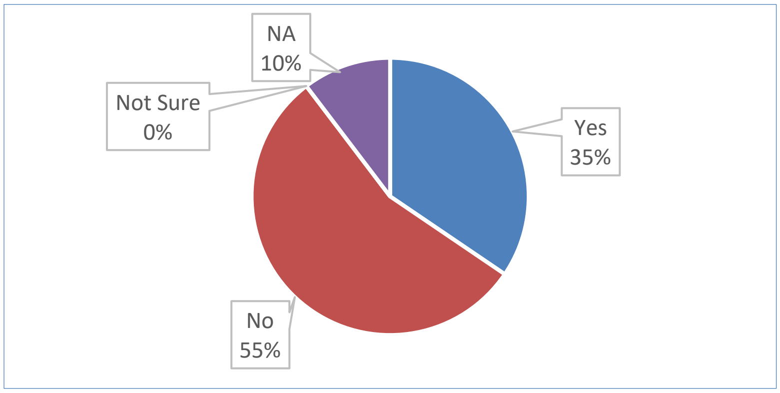
17. **Does your jurisdiction or above-code program have a published list of approved simulation tools? If so, can you share it?**

Number of responses to this question: 29



18. **Does your jurisdiction or above-code program have a published list of approved weather files, utility rates, operating conditions assumptions or schedules? If so, can you share these?**

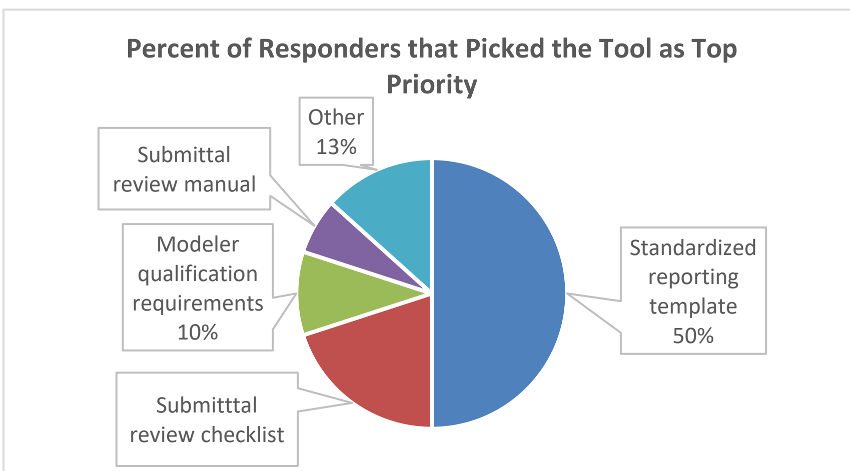
    Number of responses to this question: 29

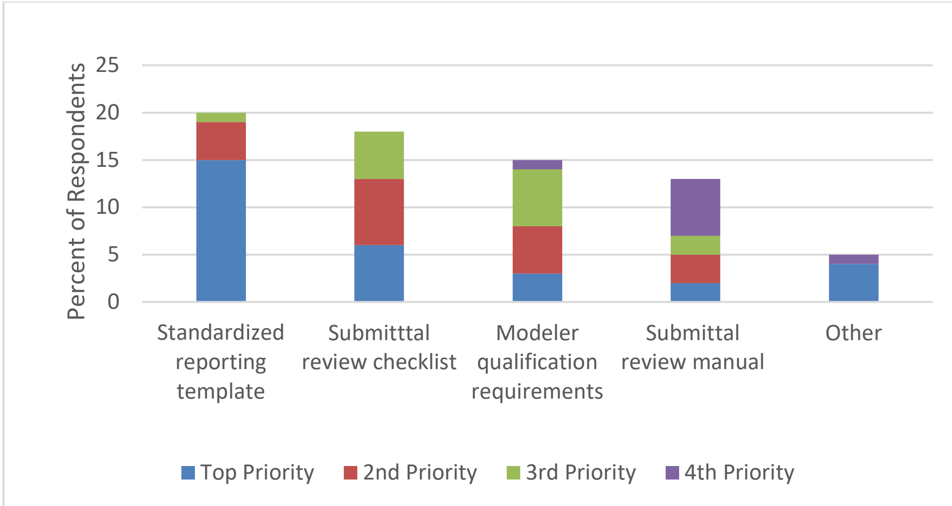


A.4 Short- and Long-Term Goals for Improving Performance-Based Compliance

1. **What tools and resources would you like to see developed in the near future to improve performance-based compliance? (Please list in order of priority.)**

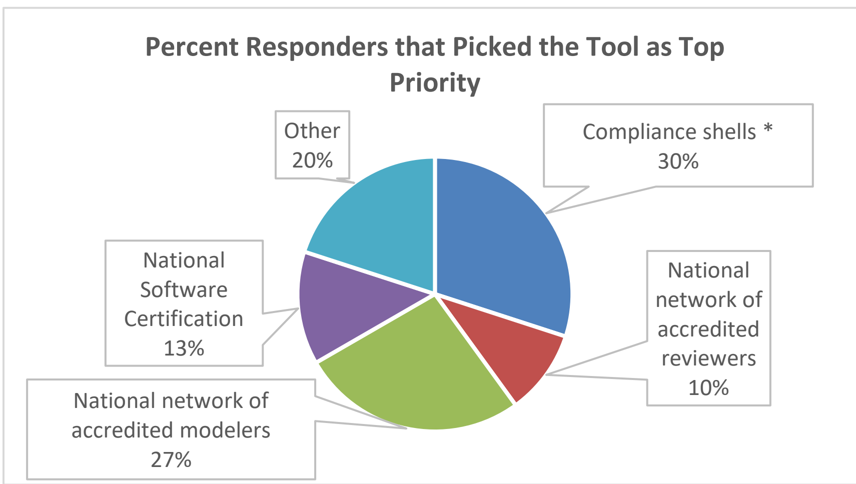
    Number of responses to this question: 30

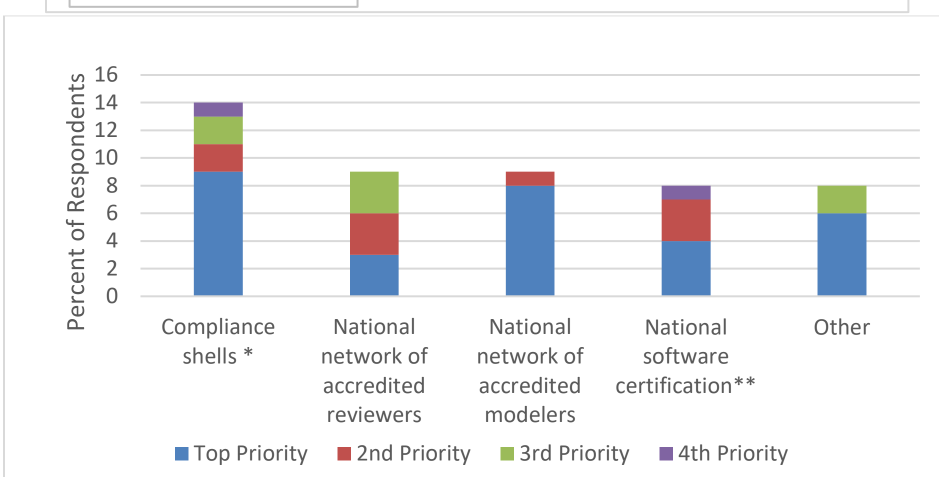




2. **What do you see as the long-term goals for streamlining performance-based compliance? (Please list in order of priority).**

Number of responses to this question: 30





Appendix B – Examples of Modeling-Based Compliance Programs

B.1 California Title 24

California performance-based compliance dates back to 1978, and 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. To mitigate variability in the compliance outcomes, projects were required to use standardized weather files and building operational assumptions such as temperature schedules, hours of operation, and outside air ventilation rates, among others. To account for differences among simulation tools, an overall calibration factor was later assigned to each approved tool. A factor greater than 1 was assigned if a tool was perceived to consistently under-predict energy use relative to the reference tool, which was DOE-2 at the time.

In 1992, the fixed energy target method was replaced by a reference building method that was inherently less prone to outcome variability because the same simulation tool, climate data, and building operational assumptions were used for both the proposed and reference building models and thus the impact of these factors canceled out to a large degree. Simultaneously, the California Energy Commission (CEC) instituted a requirement that all software approved for compliance calculations be able to automatically generate the reference building using the prescribed weather data and building operating assumptions, produce standard reports, and meet accuracy tests relative to the reference program. This automation led to a significant increase in the use of performance-based compliance in the state.

The simulation requirements and software certification procedures were documented in the California Nonresidential Alternative Calculation Method (CA ACM) Reference Manual, which was updated every 3 years and included detailed modeling rules and approximately 160 tests designed to demonstrate that the applicant software tool was consistent with the benchmark. Initially, EnergyPro was the only certified commercial software program, and the CEC's Perform software, which had a rudimentary interface, served as a benchmark. Both tools used the DOE2.1E engine. Several years later, eQUEST (based on DOE 2.2) was certified.

However, Perform software became increasingly outdated and lacked support for new and emerging technologies, which interfered with the state's strategic energy goals. There were also concerns about variability of compliance outcomes for a given project modeled in different tools, and the general lack of transparency in compliance modeling. To address these concerns, the CEC replaced Perform with the California Building Energy Code Compliance (CBECC-Com) software in 2013. CBECC-Com uses the EnergyPlus simulation engine and includes a graphical user interface, report generator, and compliance manager that performs compliance analysis including creating the EnergyPlus input files configured as required by California energy code and determines compliance based on the simulation results. In addition, the CA ACM Reference Manual became a living document that could be changed during the code cycle as opposed to once every3 years, to allow for ongoing maintenance (Liu et al. 2019).

Initially, CBECC-Com was the only approved compliance engine and other commercial interfaces had to connect through the CBECC-Com API.[1]

The new approach reduced variability in compliance outcomes due to differences among the software tools, but some variability still remained. For example, CBECC-Com allows the use of simplified or detailed (3D) geometry input, which affects daylighting calculations, among others. CBECC-Com was also not well received by the industry due to initial issues with the interface and slow runtime, the limitations that it imposed on the simulation tools that could be used, and inability to model certain designs.

In 2019, CEC has removed the requirement to use the CBECC-Com Compliance Manager. The new software certification process involves completing the ACM tests and submitting documentation to demonstrate that the CBECC-Comm Compliance Manager is successfully integrated into the vendor software or that the vendor software achieves the substantially similar simulation results as the CEC software.

The current software certification approach gives CEC better control over the entire analysis process from user inputs to reporting, reduces variability in compliance outcomes, and allows for ongoing bug fixes and enhancements to CBECC-Com. However, it is complicated and time consuming both for the CEC, which must maintain CBECC-Com, develop software certification requirements and administer certifications, and for the third-party software vendors that want to certify their software for use in California. The certification test suite covers only a small subset of systems that may be present in commercial buildings. In addition, it complicates compliance documentation for projects that use systems and designs that are not supported by CBECC-Com.

Commercial software tools currently approved for compliance include EnergyPro and the Integrated Environmental Solutions – Virtual Environment (IES-VE), in addition to the state sponsored CBECC-Com. The stakeholders estimated that about 50% of commercial new construction projects in California use the performance path.

B.2 Florida Energy Code

Florida has principally used performance-based compliance for over 40 years. The original approach involved a standard HVAC sizing methodology modified to calculate annual energy use values rather than peak loads. Sets of summer and winter multipliers were developed for all building envelope components and cooling, heating, and hot water systems. Compliance was documented in a six-page paper and pencil form that was used for many years before the advent of personal computers. In the 1980s, the multiplier method was implemented in a DOS software that was converted to Windows in the mid-1990s. The reference building method and hourly simulation based on DOE2 were adopted in the early 2000s. Performance-based compliance remains dominant in Florida and is used for over 90% of commercial new construction permits.[2]

The whole building performance options in the 2017 Florida Energy Code (FEC) include ECB and Total Building Performance (TBP). The Florida Building Commission's approval process for compliance software programs and the related procedures, guidelines, and assumptions is

[1] Energy Design Resources e-News Issue 93 June 2014. Retrieved from https://energydesignresources.com/media/19649858/edr_enews_093.pdf?tracked=true

[2] Based on stakeholder surveys

outlined in a 160+ page Technical Assistance Manual (the Manual; Florida DPOR 2018), which covers residential and commercial compliance. The software tool requirements include the following:

1. The compliance software must have the simulation capabilities identified in the FEC.
2. The software vendor must perform the certification tests described in the Manual, certify in writing that the software program passed, and submit the modeling files used to generate results with the compliance evaluation application.
3. The software must include a user's manual or help system describing how to use the software for compliance with the FEC, including input instructions, explanations on how to generate the compliance reports, and a sample of compliance documentation. The user's manual must support both the modelers and the enforcement agency's ease of verifying compliance.
4. The vendor must provide ongoing user and enforcement agency support.
5. The software must be re-certified if there are changes to the energy calculations, modeling capabilities applicable to compliance, and/or changes to the format or content of the compliance forms. The currently approved tools include EnergyGauge and IESVE 2019.

B.3 RESNET® HERS

The Residential Energy Services Network (RESNET®) Home Energy Rating System (HERS) Standard is a modeling-based protocol widely used to evaluate the performance of single-family homes and low-rise multifamily buildings. It has been recognized by major rating authorities and agencies, including ENERGY STAR, the U.S. Green Building Council, utility energy efficiency programs, and by the Internal Revenue Service and the U.S. Department of Energy as a basis for tax credits for residential energy efficiency. In 2015, the RESNET® Standard became the foundation of the Energy Rating Index, which is an energy code compliance option in over a dozen states and is included in the 2015, 2018, and soon to be published 2021 versions of International Energy Conservation Code.

The program was conceived in the early 1980s, when a group of mortgage industry stakeholders sought to establish the financial merit of the energy efficiency of a home in a mortgage loan. The RESNET® HERS Index is determined following ANSI/RESNET/ICC Standard 301, Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index, and is a variation of the reference building approach conceptually similar to the Performance Rating Method (PRM), ECB, and TBP, making HERS experience relevant to commercial performance-based compliance.

HERS is governed by the RESNET® Mortgage Industry National Home Energy Rating System Standards,[1] which cover a broad range of quality assurance and quality control topics including the following:

1. HERS rater training and certification

   Prospective raters must complete a training course from a RESNET® Accredited Training Provider and pass the national HERS Rater Tests, Combustion Appliance

[1] *RESNET Standards - Continuous Maintenance Version.* Residential Energy Services Network. Accessed August 2019. Retrieved from https://standards.resnet.us/index.htm#t=minhers_adv%2FHome%2FHome.htm.

Simulation Tests, and Rater Simulation Practical Test. In addition, the candidate must complete five probationary ratings with a Rating Quality Assurance Provider overseen by a RESNET® certified Candidate Field Assessor.

2. Simulation tool testing and accreditation

   The RESNET® software accreditation requirements are covered in the Procedures for Verification of RESNET® Accredited HERS Software Tools and include testing following ANSI/ASHRAE Standard 140, HERS Reference Home auto-generation tests, HERS method test (to confirm that the modeling results are correctly used for calculating the HERS Index), and HVAC, duct distribution system efficiency, and hot water system performance tests (RESNET 2020). All tests have prescribed acceptance ranges (Fairey 2017). The currently accredited tools include REM/Rate, Ekotrope, and EnergyGauge.

3. Quality assurance infrastructure

   RESNET® certified Quality Assurance Designees perform file review of a minimum of 10% of all HERS rater modeling files and conduct in-person field review of 1% of all rated homes. In addition, RESNET® staff conducts an annual review of all quality assurance reports and inspects a minimum of 25% of accredited Rating Quality Assurance Providers' files. In 2015, over 20,000 HERS rated homes received quality assurance oversight.

Improving the consistency of HERS index scores across different simulation tools and raters is one of the key RESNET® focus areas. For example, the requirement has been recently added for all accredited software tools to have the integrated bounds checks to limit or warn users when inputs are beyond reasonable limits, and the RESNET® registry XML schema was expanded to include flags that alert RESNET® quality assurance staff of potential issues (Baden 2014). In addition, all accredited tools are required to use hourly calculations by January 2021.

Yet, a recent study uncovered significant variations in HERS index scores of the same home depending on the rater and simulation tool used (DOE 2018). The variability was linked to ambiguities in the modeling requirements, differences between the accredited simulation tools, and modeler error. For example, for a three-bedroom house in Denver, three of the five raters counted five bedrooms, one rater counted four bedrooms, and the other rater counted the correct number. RESNET® expressed concerns over the methodologies used in the study, such as allowing the use of different version of RESNET® software and not following RESNET's standards for confirmed rating. However, RESNET® admitted that work needs to be completed to improve the consistency of calculating HERS index scores. It has formed a HERS Software Consistency Committee and hired an energy modeling director to enhance the consistency among the RESNET® accredited HERS software programs. RESNET® has also modified its rater quality assurance standards and protocols to create greater consistency among HERS raters.[1]

[1] Based on written input from Steve Baden, RESNET executive director.

B.4 COMNET

COMNET (the Commercial Energy Services Network) was formed in 2010 as a commercial-sector equivalent of the RESNET®. The goal of COMNET was to become the industry standard for providing technically credible and reliable procedures for evaluating the energy performance of nonresidential and high-rise residential buildings (Baker et al. 2014). The procedures were to be used for documenting compliance with building energy codes, in green building ratings such as ENERGY STAR's Target Finder™ tool and ASHRAE Building Energy Quotient (bEQ) As Designed, and in government and utility programs. COMNET aimed to build consensus among software developers, rating authorities, and energy modelers, and through this process, develop and maintain a quality assurance program consisting of the following elements:

- Modeling guidelines and process (MGP) for accreditation of energy modeling software including a detailed specification for energy analysis and requirements for automated generation of baseline building and standard output reports.
- Ongoing review and quality assurance of accredited energy modeling software.
- Updates and enhancements to the accreditation requirements and software re-accreditation.
- A portal through which all the accredited energy analysis would pass, to facilitate the basic automated quality assurance checks of every project and allow selecting a subset of projects for detailed quality assurance.
- Official interpretations on how the MGP specification applies to specific projects.
- Periodic internal quality audits to evaluate compliance with the COMNET procedures and the effectiveness of current processes, per ISO 9000.
- Credentialing and/or training of energy modelers.

The MPG was published in 2010 and was based on the ASHRAE Standard 90.1 2007 PRM. In 2012, the COMNET Energy Modeling Portal was launched to allow design teams to directly upload building energy modeling information to Leadership in Energy and Environmental Design (LEED) Online. The portal supported importing from eQUEST output reports (.sim files) and the COMNET XML schema that was implemented by Trane TRACE™ 700 and EnergyPro v5.1. The goal was for the portal to streamline LEED documentation for design teams, provide basic quality assurance features to reduce errors in LEED submittals to GBCI, and generate revenue to support continued COMNET development.

However, the initiative did not generate enough industry support and the funding dwindled. The COMNET Portal was discontinued, with the MPG forming the basis of PNNL's Performance Rating Method Reference Manual (Goel and Rosenberg 2017).

B.5 References

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