Modeling Energy Use of Green Buildings: Metric-Driven Quality Control

Shelley Beaulieu and Tom Rooney, TRC
Maria Karpman, Karpman Consulting LLC

ABSTRACT

In the past few years, there has been a huge surge of both government funding and market interest for green buildings. This has resulted in the establishment of many new programs with a heavy emphasis on energy efficiency. Many of these programs, whether government-funded or market-driven, depend on the use of energy models for predicting the energy use in buildings. However, by tying financial incentives or certifications to energy models, it becomes vital for a successful program to ensure that those models are accurate and complete. This paper presents one approach to performing quality control on these models. This approach focuses on the use of metric-driven quality control, which concentrates on analyzing the model outputs to help identify significant errors in the model. That paper details a step-by-step process to perform this type of review, describes the tools that would be needed, lists the types of information that the modelers need to provide to facilitate this process, and provides insight on the amount of effort required to perform this level of quality control on a program administration level. In addition, this paper discusses how this approach is being applied in one of the largest modeling-based incentive programs in the country.

Modeled Savings-Based Energy-Efficiency Programs

The energy efficiency sector is in the midst of unprecedented growth due to several issues, including national interest in energy independence, rising fuel costs, and public concern about global warming. This growth is being fueled by a significant increase in federal and state government funding of energy efficiency programs (Hardcastle and Waterman-Hoey 2009, iii). In addition, the U.S. Green Building Council's LEED green building certification has significantly raised public awareness of green buildings, with more than 50,000 registered buildings and over 160,000 LEED Accredited Professionals (U.S. Green Building Council).

The recent trend over the past few years has been a growing popularity and market penetration of building energy models as a tool for predicting energy efficiency in both government-funded and market-based programs. Many local and national factors have contributed to this trend, including the endorsement of technical and professional associations (e.g. ASHRAE, AIA), the increasing number of states with energy codes that require energy models to verify compliance, the popularity of the LEED rating system, and the desire to align with federal programs such as EPAct Tax Deductions for Commercial Buildings.

One such Program is the New York State Energy Research and Development Authority's (NYSERDA) Multifamily Performance Program (MPP). There are currently over 160 active projects totaling over 10,300 apartments enrolled in the New Construction component of the Program (MPP NC), and more than 80% of these projects qualify as affordable housing projects. MPP NC is part of a national EPA pilot to develop an ENERGY STAR High-Rise Multifamily label, which is expected to be launched as a standard national program in mid-2010. To date, seven of the participating projects have earned the ENERGY STAR label, with dozens more expected in 2010.

In addition to potentially earning the ENERGY STAR label for their building, developers of the qualified projects are eligible to receive financial incentives from NYSERDA, with the total incentive pool of over $23M. A portion of the incentive, between $15,000 and $20,000 per building, is intended to offset the added green building design and analysis cost. The rest of the funding available to the projects, between $1.50 and $2.50 per square foot of heated residential space, is meant to contribute toward the incremental cost of installing energy efficient measures.

To qualify for the program incentives, buildings participating in MPP NC must achieve a *performance rating* of 20%, as evidenced by ASHRAE 90.1 Appendix G - compliant energy models. *Performance rating* is defined in ASHRAE 90.1 as “a calculation procedure that generates an index of merit for the performance of building designs that substantially exceeds the energy efficiency levels required by this standard.” To calculate the performance rating, a proposed design model is developed that incorporates the energy efficiency measures that reduce that project’s energy consumption relative to a baseline model that adheres to the ASHRAE 90.1-2004 Appendix G protocol, supplemented by NYSERDA’s Simulation Guidelines. The Simulation Guidelines offer energy modelers guidance on modeling assumptions that ASHRAE 90.1 explicitly leaves open to the Rating Authority, as well as guidance for handling components not covered in the standard. In addition to achieving a 20% performance target, participating buildings must comply with the Minimum Performance Standard, which sets the efficiency trade-off limits in certain areas. For example, Minimum Performance Standard requires that all major appliances are Energy Star labeled.

To ensure that the model reflects the actual design, a number of site inspections are performed at the various stages of construction. However, since significant portion of the incentives are paid before the construction is completed, quality control and review of the submitted models becomes critical for the program success.

Model Quality Control Challenges

The rapid rise in the number of modeled savings-based programs has resulted in a huge demand for energy modelers. Due to the otherwise slow economy, this demand for modelers has attracted professionals from related fields, many with little or no prior modeling experience or training, and some entirely new to the building industry. This problem has been exacerbated by a lack of educational resources (Goldman et al. 2010, 38) and insufficient attention to quality control (Lynch and Ivanovich, 2009, 10).

The review of energy models is a challenging endeavor, as the accuracy of the predicted energy savings is directly related to the accuracy and detail of the inputs. As stated by Mark Frankel, “modeling programs are sophisticated enough to accurately predict performance outcome, given the right inputs” (Lynch and Ivanovich, 2009, 10). Given the large increase in the number of inexperienced and undertrained modelers, robust quality control is imperative to ensure that these programs actually result in high performance buildings. In order to fully verify all these details, both the model files and the project design documents must be reviewed. Such an extensive review, however, may lead to unacceptable program administration overhead.

The following factors complicate the model quality control process:

- Technical complexity of energy modeling, which requires that both the modelers and the reviewers possess in-depth expertise in many adjacent areas including building science, existing and emerging building technologies, ASHRAE Standard 90.1, and simulation techniques.
- Use of many different simulation tools in the program that are all compliant with ASHRAE 90.1 Appendix G, which potentially requires reviewers to understand multiple tools intimately enough to perform accurate quality control.
- Poor quality models and insufficient level of expertise of the energy modelers. For example, in MPP NC, early submittals from some modelers that had little modeling experience resulted in reviewers shifting their focus from performing quality control on a specific project to training the energy modelers on the fundamental use of the simulation tools.
- Some energy analysts are accustomed to the lack of accountability for the modeling results. Aside from research projects, building modeling was traditionally used to size mechanical equipment. In this setting, mistakes were highly visible, leading to compromised occupant comfort and potential lawsuits. On the other hand, models put together to evaluate energy performance were often neither adequately reviewed by the organizations administering the programs, nor validated through post-construction utility bills or measurements, leaving the analysts in an information vacuum with no feedback on the quality of their work.
- There are unique challenges associated with using a sophisticated technical protocol in the framework of an incentive program where incentives are linked to modeled energy savings. In this setting the modeler may find him/herself under pressure to manipulate the results to maximize the payoff, creating the danger of gaming. For example, NYSERDA’s Multifamily Performance Program requires projects to achieve a 20% performance target in order to access sizable incentives. If the proposed design does not achieve this 20% target, the Partner may be pressured by the developer to tweak the model so that it appears to have reached the target.

To improve efficiency of the quality control, review options must be carefully prioritized to find the optimal balance between review effort and the potential to filter errors. The selected process must be documented to ensure consistency of the reviews and transparency of the review process to the rating authority and program evaluators. In addition, the project submittal requirements must be thoroughly thought through to ensure that they support the selected review protocol.

Metric-Driven Quality Control Protocol

One approach to the model review would focus on verifying model inputs to ensure that they match the building description and demonstrate understanding of the modeling protocol. This was attempted initially for MPP NC, however, this approach soon proved to be cost prohibitive, as models of even a simple building involve hundreds of inputs. The resulting review comments were often many pages long, listing all the discrepancies, big or small, noticed in the model, and prompting numerous iterative submittals of revised models. Clearly, this approach is not optimal and a different approach should be used, one that allows some acceptable level of uncertainty.

Another approach to model review would be to focus on the model outputs instead of the inputs. The proposed Metric-Driven Quality Control Protocol involves the following steps:

Step 1 – Review the Project Description Included in the Report

Ensure that baseline and proposed components are described fully and correctly, and that reasonable and sufficient details are provided on how each energy savings measure is modeled. In addition, special attention should be paid to known problem areas. For example, in MPP NC, common errors were omission of electric heating in common spaces, excessive ventilation, and uninsulated rim joists. Explicit questions were often included in the review comments addressing these areas, e.g. "Is there electric heating in the building?"

Step 2 – Evaluate General Quality of Simulation

Review all error and warning messages produced by the simulation and look for apparent inconsistencies and concerns in the output simulation files. In MPP NC, this included looking for problems such as a significant number of unmet load hours in the model (when the building is under-heated or under-cooled) and unexplained high hours of simultaneous heating and cooling load.

Step 3 – Verify that Simulation Outputs are Consistent with Results of Previously Approved Projects

Compare the key outputs produced by the simulation to the similar metrics for other projects using a metric database, as discussed in the next section of this paper. These key outputs include annual Btu/ft^2 consumption by end use for heating, cooling, lighting, DHW, appliances, and other (fans, pumps, etc,) for the both the baseline and proposed models, and the improvement in consumption achieved in each end use; the total Btu/ ft^2 of the baseline and proposed design models; a benchmarking score; and the performance rating. If the simulation outputs do not display any anomalies when compared to the metric database, then there is no need to look further into those related model inputs. For example, if the lighting Btu/ft^2 looks normal, then there is no need to investigate accuracy of lighting any further.

Step 4 – Verify that the Magnitude of Projected Savings is Consistent with the Features of the Design

Qualitatively compare the simulated energy savings by end use to the building design to ensure that results are reasonable. For example, a significant projected reduction in lighting energy of the proposed design compared to the baseline should be questioned if the proposed design did not include significant improvements to the lighting fixtures or controls.

Step 5 –Review of Model Files (Optional)

This is an optional step that is not recommended for projects that successfully pass the other verification steps. Even if the project fails one of the previous checks, the reviewer could ask the modeler to clarify or correct the discrepancy and place the responsibility of addressing the concern on the energy modelers. For example, the review comment may say: "The heating usage Btu/ft^2 in your model exceeds by 90% the average heating usage of the projects previously approved in the program. Please correct or clarify."

However, if the program implementers feel strongly that reviewers should open the models and investigate the identified problems, then it is only at this step that such a detailed review should occur.

Output Metric Database

A key step in the process outlined above is determining whether or not the building's energy use is "reasonable" for both the baseline and proposed models. While theoretically this can be done qualitatively using general building science knowledge and experience, a more direct approach is to create a database of output metrics from previous models and use that database to quantitatively compare new models as they are created.

To develop such a database, every participating project should be required to report the following key data points: the floor area of conditioned space by general space type (e.g. residential space, common space), the utility rates, and the baseline and proposed annual energy consumption separated by both end use and fuel type. Note that the end uses listed in the step-by-step process above are based on guidance from ASHRAE 90.1-2004 Section G1.4 and the ASHRAE 90.1-2004 User's Guide Compliance Form. Using this key data, the database can then calculate the baseline and proposed annual energy use per square foot for each end use.

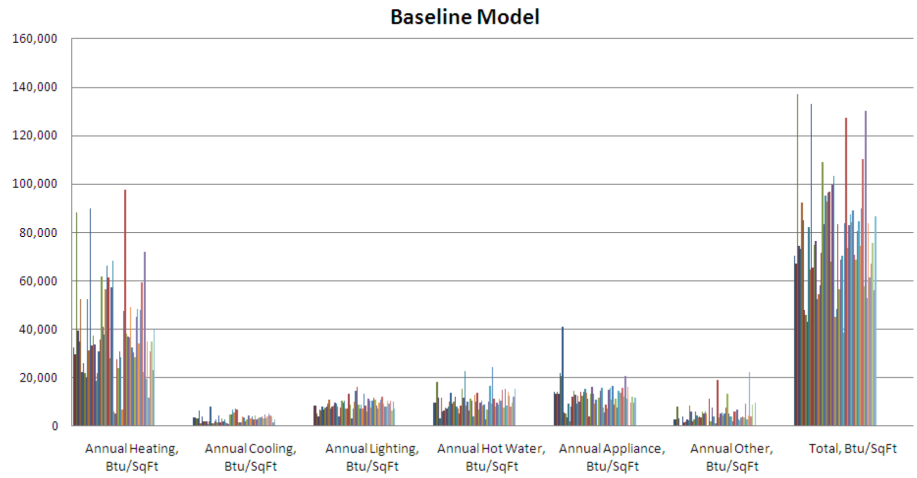
In MPP NC, such a database has been developed to track the output metrics of all participating projects. This database performs simple statistical analysis to remove any outliers from this dataset and calculates the mean energy use intensity (BTU/ft^2) for the baseline and proposed models and the percent savings, all separated by end use. It also calculates the standard deviation for each metric. The ranges of energy use intensity by end use for the currently approved projects are shown in Table 1.

Table 1. Typical Energy Use Intensity by End Use within MPP NC Pipeline. This Range Represents the Calculated Mean Value +/- One Standard Deviation, Excluding Outliers.

Baseline Model	Range
Annual Heating, Btu/SqFt	22415 - 43037
Annual Cooling, Btu/SqFt	1527 - 3272
Annual Lighting, Btu/SqFt	6477 - 9601
Annual Hot Water, Btu/SqFt	7932 - 12223
Annual Appliance, Btu/SqFt	10305 - 15158
Annual Other, Btu/SqFt	2019 - 6501
Total, Btu/SqFt	56917 - 88005
Proposed Model	**Range**
Annual Heating, Btu/SqFt	14423 - 25691
Annual Cooling, Btu/SqFt	1015 - 4130
Annual Lighting, Btu/SqFt	4937 - 7966
Annual Hot Water, Btu/SqFt	4625 - 10859
Annual Appliance, Btu/SqFt	9118 - 15039
Annual Other, Btu/SqFt	1492 - 5246
Total, Btu/SqFt	41511 - 66547

The resulting information is then used in two ways. The database should be set up to show the data for all the projects in three separate graphs – the baseline model (Figure 1), the proposed model, and the predicted energy savings. This offers a quick visual way to tell how the project compares to other models in the dataset.

Figure 1. Output Verification Screenshot: Baseline Model Energy Use by End Use for MPP NC Pipeline



This data can also used to quantitatively compare the current model to the energy use of other models in the database. The database can then calculate the number of standard deviations and the percentage that the model in question differs from the average building in the database. Figure 2 illustrates how the MPP NC database presents this information. In this database, if the results are off by more than one standard deviation for that end use, the cell turns red to indicate a potential concern. All of the projects that passed the model quality control process are included in the data set used to calculate the program-wide averages and standard deviations.

Figure 2. Output Verification Screenshot: Comparison of Project Energy Use to Average Project in Pipeline

Comparison of Current DOE2 Project to Averages with No Outliers

	Current Project Baseline	Avg Baseline	Std. Dev.'s from Avg	Diff. from Avg.
Annual Heating, Btu/SqFt	96,082	32,727	6.14	193.59%
Annual Cooling, Btu/SqFt	1,751	2,400	0.74	-27.05%
Annual Lighting, Btu/SqFt	8,220	8,040	0.12	2.25%
Annual Hot Water, Btu/SqFt	2,849	10,078	3.37	-71.73%
Annual Appliance, Btu/SqFt	8,767	12,732	1.63	-31.14%
Annual Vent. Fans, Btu/SqFt				
Annual Pumps & Aux., Btu/SqFt				
Annual Exterior Usage, Btu/SqFt				
Annual Other, Btu/SqFt	7,682	4,260	1.53	80.31%
Total, Btu/SqFt	125,351	72,462	3.40	72.99%

	Current Project Proposed	Avg Proposed	Std. Dev.'s from Avg	Diff. from Avg.
Annual Heating, Btu/SqFt	27,582	20,057	1.34	37.52%
Annual Cooling, Btu/SqFt	879	2,573	1.09	-65.83%
Annual Lighting, Btu/SqFt	4,249	6,452	1.46	-34.16%
Annual Hot Water, Btu/SqFt	1,919	7,743	1.87	-75.21%
Annual Appliance, Btu/SqFt	7,955	12,079	1.39	-34.14%
Annual Vent. Fans, Btu/SqFt				
Annual Pumps & Aux., Btu/SqFt				
Annual Exterior Usage, Btu/SqFt				
Annual Other, Btu/SqFt	5,615	3,369	1.20	66.65%
Total, Btu/SqFt	48,200	54,029	0.47	-10.79%

	Current Project Baseline	Avg % Better	Std. Dev.'s from Avg	Diff. from Avg.
Annual Heating, Btu/SqFt	71.29%	38.96%	2.61	82.98%
Annual Cooling, Btu/SqFt	49.77%	11.02%	2.22	351.62%
Annual Lighting, Btu/SqFt	48.32%	24.19%	2.66	99.71%
Annual Hot Water, Btu/SqFt	32.63%	34.02%	0.13	-4.08%
Annual Appliance, Btu/SqFt	9.26%	9.32%	0.01	-0.70%
Annual Vent. Fans, Btu/SqFt				
Annual Pumps & Aux., Btu/SqFt				
Annual Exterior Usage, Btu/SqFt				
Annual Other, Btu/SqFt	26.90%	20.03%	0.24	34.28%
Total, Btu/SqFt	61.55%	31.52%	5.44	95.26%

It is important not to run this analysis blindly, because some buildings may have justified reasons for having significantly different end-use profiles. For example, a building with a significantly higher fraction of ventilated common spaces would be expected to have higher than average heating usage. Or, if the building has a large commercial kitchen and the typical building does not, then it would be expected that the appliance energy use would be much higher.

As the number of projects in the database increases, a more focused comparison of models may be performed, such as by climate zone or building sector. However, until the data set of that specific group gets large enough to support statistical analysis, a comparison to the larger data set can still be useful as long as the reviewer keeps in mind the differentiating characteristic of the building. For example, the projects in the MPP NC database comprise both ground-up new construction, as well as gut rehab projects. As can be seen in Figure 1, there are several projects with significantly higher heating uses; these projects are all gut rehabs, which, per Appendix G, use the existing envelope as their baseline. Because of this, it seems reasonable that the heating energy use of these projects is significantly higher than the heating energy use of a building that was modeled with an envelope meeting ASHRAE 90.1 standards.

Model Submittal Requirements

Another key aspect of this metric-driven quality control approach is a requirement that the energy modelers submit certain documentation along with their model to ensure that the information required for the review is readily available.

It is highly recommended that a report template is used to establish a single, standard format for reporting all aspects of the project. Given the number and variety of the ways information can be presented, the template is a necessity to ensure efficient reviews.

A building description section of the template should include fields for the building's location, number of apartments, size of building spaces separated by the use of space (e.g. mechanical rooms, hallways, apartments), information on whether these spaces are heated, cooled or have mechanical ventilation, utility rates used in analysis, and a table with detailed component-by-component description of the characteristics of the baseline and proposed design (Figure 3).

Figure 3. Screenshot of MPP NC Report: Proposed and Baseline Components Used in Energy Simulation

Building Component	Proposed Design	Baseline Design
Wall (above and below grade wall construction and U-value)	Stucco exterior, 6" Metal Stud 24" OC, Wall R-21 Batt insulation (R-9 effective per A3.3), 2" polystyrene (R-8) exterior insulation, 5/8" GYP board. Assembly: U-0.049	Walls of apartment units: steel-frame 16"OC, R-13+R-7.5ci, U-0.064 Non-residential spaces: Steel-frame, R-13, U-0.124 U-value includes R-0.08 for stucco, R-0.56 for 0.625 gyp board on exterior and interior, per A3.3.1
Doors	U-0.70, swinging, ENERGY STAR doors not available.	U-0.70, swinging
Windows (window-to-wall-ratio, frame material, U-Value and SHGC)	U-0.35, SHGC-0.28 Window-to-wall ratio 29% residential, 33% non-residential , low-e aluminum frame windows.	U-0.57, SHGC -0.39 for non-residential windows, U-0.67, SHGC-0.39 for residential windows, same window-to-wall ratio as in proposed. Double pane, air space, tinted, fixed wood/vinyl frame.

An energy reduction measures section of the report should include a table with energy consumption by end use (Figure 4), energy reduction measures with measure-by-measure energy savings and cost information, and a list of energy reduction measures with the details on the proposed and baseline components.

Figure 4. Screenshot of MPP NC Report: Energy Summary by End Use

End use	Energy Type	Baseline Electricity (kWh/yr)	Baseline Fuel (MMBtu/yr)	Proposed Electricity (kWh/yr)	Proposed Fuel (MMBtu/yr)	Percent Improvement
Apartment Lighting	electric	162,350	0	119,010	0	27%
Building or Common Area Lighting	electric	0	0	0	0	0%
Space Heating	gas	0	2,527	0	1,754	31%

In order to effectively review the submittals, descriptions of all measures included in the report need to be specific and contain performance characteristics of the proposed measure including R-values, U-factors, SHGC, efficiencies, and brief descriptions of the measure. Descriptions such as "Above Code," "High Efficiency," and "Energy Efficient" are ambiguous and could have a variety of meanings. For example, "high efficiency boilers" does not sufficiently describe the proposed measure; instead a good description would be "Install two Natural Gas Space Heating Condensing Boilers, 420,000 Btu/hr each, 87% E_t." For any lighting measures, information on the proposed lighting, including fixture types by space, similar to the lighting schedule that is included in the building's drawings, should be required. Assumptions used to calculate energy cost savings that are outside of the scope of program guidance, as well as any energy cost saving calculations for measures that cannot be modeled explicitly using the simulation software, should also be included in the report.

It is recommended that an appropriate benchmarking tool, such as the ENERGY STAR Portfolio Manager, be incorporated into the submittal requirements. The benchmarking scores for both the baseline and proposed models can be used to compare the building to a national database of similar projects and provide a quick reference point to evaluate whether the model outputs and savings are realistic.

In addition, the modelers should be required to submit the model files to allow in-depth review of the simulation as needed. Included in these files should be simulation output reports that are produced by the building simulation tool, which include detailed output information and error/warning messages.

Lastly, the program may want to consider requiring submittal of project mechanical and lighting schedules. Historically, MPP NC did not require these documents, however, based on the model reviews and site inspections of the participating buildings, it was discovered that lighting and mechanical systems that may have significant impact on the energy consumption are routinely overlooked and misrepresented in both the model and the report. Two specific examples are over-lighting of common areas and the use of electric resistance heaters in utility spaces. Modelers often assume that the lighting in the common areas is equivalent to the lighting in the ASHRAE baseline building. However, the ASHRAE baseline is fairly strict and often the actual lighting installed in the buildings have higher lighting power densities, especially for senior housing projects. Also, many of the projects have electric resistance heaters in the stairwells, mechanical rooms, laundry rooms, or corridors. The modelers often overlook this and either leave these spaces unconditioned or model them as being heated by the central system. However, if modeled correctly, these electric heaters result in a significant energy penalty for these projects.

Model Quality Control Effort

A key decision that needs to be made by the program administrators regarding this, or any, quality control process is what level of inaccuracy in the projects is acceptable. While in an ideal world all models would have no inaccuracies, this is neither a reasonable nor cost-effective expectation. A major variable that must guide this decision is the amount of time budgeted for quality control of each project.

For MPP NC, the main goal of the quality control process is to ensure that the modeled savings were reasonable given the proposed scope of work and building design, and that the proposed building would, given all this information, reasonably meet the performance target of 20% energy savings required by the Program. The metric-driven quality control process described above is used to determine whether or not these goals are met. A secondary goal of the MPP NC review is to increase the modeling skills of the companies working in this Program, as MPP was designed to promote market transformation of the multifamily building sector. So, if a reviewer notices an error in the model that would not likely cause a significant change to the output of the model, then this error is noted. However, insignificant errors such as these would not prevent a project from being approved for incentives; instead, they would be returned as "approved with comments."

In MPP NC, there are three submittal milestones for each project that would trigger this quality control review: at 75% design completion (draft proposed), at 100% design completion (final proposed), and post-construction (as-built). The intent of these different milestone submittals is to ensure the projects are on the right track early on, while changes can still be made, and to provide financial incentives to the developer throughout the life of the project.

The intent of the draft proposed submittal is to ensure that the energy modeler is on the right track with their modeling (i.e. following ASHRAE and the Simulation Guidelines correctly). For this submittal, as long as the project scope shows reasonable promise to hit the required performance target of 20%, the project is allowed to move forward in the pipeline. Any discrepancies identified by the model review are included in the Review Comments document, and the review outcome is typically listed as "approved with comments," which qualifies the project for the first level of incentives.

The final proposed and as-built submittals, however, almost always require resubmittals prior to being approvable: 2% required no revisions, 45% required one revision, 38% required two revisions, 9% required three revisions, and 6% required four or more revisions. Similar to the draft submittals, those projects that require excessive revisions tend to be the first projects a given energy modeling firm has submitted to the program.

As shown above, the MPP NC reviewers see any given project, on average, five times throughout its life, in order to approve it for the three incentive payments. Typically, the review of the draft proposed submittal takes the longest, as it requires that the reviewer gets familiar with the project. The subsequent reviews require diminishing effort. Another key factor driving the review effort is the experience level of the energy modeler. For example, the first projects submitted by a modeler may take twice as much time to review compared to the projects submitted by someone with more experience.

On average for MPP NC, the review of the first draft of the submittal takes four to six hours; however a difficult project (e.g. a modeler's first attempt) can take up to 12 hours to review. The review of subsequent submittals average between two to three hours; however, especially for projects that had significant issues with the draft proposed submittals, these reviews can occasionally take as long as the review of the draft submittals.

Conclusion

Designing an energy efficient building is only the first step in actually achieving an energy-efficient building (e.g. a creative building operator can overcome the efficiency of even the best designed building). However, the design of the building will still have a huge impact on achieving an energy efficient building. A high-quality energy model, when used correctly, can provide essential assistance in improving the design of a building.

Therefore, when designing the quality control process for modeled savings-based programs, it is imperative to find a middle ground between overly strict – which will limit the amount of resources that can be used on other aspects of achieving a high performing building, such as good construction management, commissioning, or training building operators – and overly passive – which could result in a model riddled with errors that will misguide the design. This paper presents one option to assist in finding that middle ground. The metric-driven quality control process described here allows for some error in the energy model, but seeks to ensure reasonable results that make sense. This process has been used successfully in NYSERDA's MPP NC, which has resulted in seven ENERGY STAR buildings over the past three years, with dozens more expected in the coming years.

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