Chapter 15: Commercial New Construction Protocol

The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures

Created as part of subcontract with period of performance
September 2011 – December 2014

Steven Keates,
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Subcontract Report
NREL/SR-7A40-62432
September 2014

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Acronyms

ANSI	American National Standards Institute
CV	coefficient of variation
CVRMSE	coefficient of variation of the root mean square error
DOE	U.S. Department of Energy
DSM	demand-side management
ECM	energy conservation measure
EM&V	Evaluation, measurement, and verification
HVAC	heating, ventilation, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
LEED	Leadership in Energy & Environmental Design
M&V	measurement and verification
NMBE	normalized mean bias error
TMY	typical meteorological year

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1 Measure Description

This protocol is intended to describe the recommended method when evaluating the whole-building performance of new construction projects in the commercial sector. The protocol focuses on energy conservation measures (ECMs) or packages of measures where evaluators can analyze impacts using building simulation. These ECMs typically require the use of calibrated building simulations under Option D of the International Performance Measurement and Verification Protocol (IPMVP).[1]

Examples of such measures include Leadership in Energy & Environmental Design (LEED) building certification, novel and/or efficient heating, ventilation, and air conditioning (HVAC) system designs, and extensive building controls systems. In general, it is best to evaluate any ECM expected to significantly interact with other systems within the building and with savings sensitive to seasonal variations in weather.[2] The protocol classifies commercial new construction projects as:

- **Newly constructed buildings:** The design and construction of an entirely new structure on a greenfield site or wholesale replacement of a structure torn down to the ground.
- **Addition (expansion) to existing buildings:** Significant extensions to an existing structure that requires building permits and triggers compliance with current codes.
- **Major renovations or tenant improvements of existing buildings:** Significant reconstruction or "gut rehab" of an existing structure that requires building permits and triggers compliance with current codes.

Evaluators may need to apply the evaluation methods described here for new construction projects for some projects in the retrofit programs. While some retrofit projects have much in common with new construction projects, their scope does not uniformly fall under the new construction categories previously described. Evaluators should assess these projects according to the guidelines described for retrofit equipment (described in separate protocols).

Evaluation, measurement, and verification (EM&V) of new construction programs involves unique challenges, particularly when defining baseline energy performance. An agreed-upon building energy code or industry standard defines the baseline equipment evaluators use to measure energy impacts for new construction measures. As the baseline equipment for new construction measures does not physically exist and cannot be measured or monitored, evaluators typically employ a simulation approach. Due to the nuances involved in appropriately determining baseline equipment/performance evaluations, experienced professionals with a good understanding of building construction practices, simulation code limitations, and the relevant building codes should oversee these types of projects.

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[1] As discussed in the section "Considering Resource Constraints" of the Introduction chapter to this report, small utilities (as defined under U.S. Small Business Administration regulations) may face additional constraints in undertaking this protocol. Therefore, alternative methodologies should be considered for such utilities.

[2] Note the term whole-building modeling does not necessitate use of sophisticated stand-alone simulation software (e.g., eQUEST, EnergyPlus). It is acceptable to employ engineering models using spreadsheet calculations, provided they meet the guidelines set forth in Section 4.

Further, evaluators typically assess new construction measures within the first few years of construction. During this period, there is often considerable change in building occupancy and operation before the measures design intent becomes realized. This results in additional challenges for evaluators using monitored data and/or facility utility billing or energy consumption history to define as-built building performance.

2 Application Conditions of Protocol

Use the algorithms and protocols described here to evaluate new construction whole-building performance ECMs installed in commercial facilities. When new construction ECMs do not directly impact HVAC energy use, it is often possible to use spot measurements and engineering calculations to evaluate savings with sufficient rigor (ASHRAE 2002). This is usually the case, for example, with lighting and domestic hot water retrofits.[3] This protocol does not cover the guidelines for selecting the appropriate monitoring and verification (M&V) rigor for such measures. Consult the IPMVP or measure-specific protocols within the Uniform Methods Project protocols to review evaluation guidelines for measures that do not require calibrated building simulation.

2.1 Incentive Types

Program administrators typically classify new construction demand-side management (DSM) program incentives as being either component-based or performance-based and design the program to offer one or both types of incentives.

2.1.1 Component-Based Incentives

Component-based (or "prescriptive") incentives tend to involve individual technologies and equipment. Examples of prescriptive incentives may include lighting fixtures, occupancy sensors, motors, and small packaged (unitary) HVAC units. Evaluators often determine rebate amounts and claimed savings estimates based on stipulated per-unit estimates.[4] Evaluators will sometimes assess component-based rebates according to measure-specific protocols using partial or complete retrofit isolation evaluation strategies (IPMVP Option A or Option B).

2.1.2 Performance-Based Incentives

Performance-based incentives tend to target more complex projects involving improvements to the overall building energy performance.

Whole-building performance incentives can:

- Encompass various specific (above-code) upgrades
- Fund design, analysis, equipment, and/or installation (labor) costs.[5]

An example of a performance-based project is LEED certification. Buildings that are LEED certified often encompass ECMs that range from envelope improvements to high-efficiency equipment installations (often going beyond just HVAC) and complicated controls algorithms.

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[3] While the general magnitude of the secondary impacts imparted by lighting measures on HVAC equipment are well-established for various building types, take care to estimate these impacts appropriately in new construction building stock. New buildings typically have more efficient HVAC equipment, which reduces the magnitude of heating and cooling interactive effects. Secondary impacts can be estimated using prototypical building models, representative of the physical facility. See the Uniform Method Project's *Commercial and Industrial Lighting Evaluation Protocol* or CPUC 2004 for guidelines regarding HVAC interactive factors.

[4] Units used do not necessarily represent quantity. Frequently applied units include: installed horsepower, tons of refrigeration, and square footage.

[5] Some new construction programs have been successfully implemented without direct financial incentives (design assistance, financing, etc.).

The complex interactions between these ECMs can only be reliably determined through the use of calibrated building simulation models.

Performance-based incentive amounts are typically determined by the expected annual energy and/or demand impacts (e.g., per kilowatt-hour, therm, kilowatt).[6] Annual energy-savings estimates for performance-based projects (and programs) require evaluators to use custom calculations via whole-building simulation modeling tools. Therefore, highly skilled technical labor is required to successfully implement and evaluate these programs.[7]

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[6] Depending on program design, the "expected" energy impacts can be either *ex ante* or *ex post*.

[7] See Johnson & Nadel 2000 for more information.

3 Savings Calculations

Use the following algorithm to calculate energy savings for new construction measures. Note that evaluators can calculate demand savings using the same algorithms by simply substituting "demand" for "energy use."[8]

Equation 1

Energy Savings = Projected Baseline Energy Use – Post-construction Energy Use

Where,

Projected Baseline Energy Use = Projected energy use of baseline systems at full design occupancy and typical building operating conditions

Postconstruction Energy Use = Energy use of measure systems at full design occupancy and typical building operating conditions

As described in Section 4, *Measurement and Verification Plan*, calculate projected baseline energy use and postconstruction energy use using a whole-building simulation model that is calibrated to monthly (or hourly) utility energy consumption histories. Evaluators can use four components to report savings for new construction ECMs:

- Expected (planned) measure savings
- Rebated measure savings
- Non-rebated measure savings
- Total achieved savings

Section 4 discusses each component.

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[8] When calculating the coincident peak demand savings, average the hourly demand savings over the "peak demand window" period, as defined by the utility.

4 Measurement and Verification Plan

4.1 International Performance Measurement and Verification Protocol Option

The preferred approach to calculate savings for whole-building performance new construction projects is calibrated building simulation models according to IPMVP Option D (IPMVP 2006). The recommended approach requires sufficient resources be allocated to the project to allow for detailed onsite data collection, preparation of the simulation models, and careful calibration. The method is less costly when a functioning *ex-ante* model is available to the evaluator, though obtaining the *ex-ante* model is not a prerequisite to its application.

Determine the appropriate modeling software by the specifics of the evaluated buildings (e.g., HVAC system and zoning complexity, building constructions, complexity of the ECMs); there is no single software (currently available) that can simulate all variations of HVAC system types, building constructions, and ECMs. Thus, it may be necessary to use multiple tools to evaluate building performance accurately.

In general, the appropriate software for modeling building systems and energy performance must:

- Create outputs that comply with American National Standards Institute (ANSI)/ASHRAE Standard 140-2011[9]
- Accurately simulate the building's systems and controls
- Use an hourly or sub-hourly time step to perform simulation[10]
- Simulate building performance using user-defined weather data at hourly intervals

For more information on specific requirements for simulation software, see pp. 133 in *The California Evaluation Framework* (CPUC 2004) and pp. 26-27 in *Appendix J – Quality Assurance for Statistical, Engineering, and Self-Report for Estimating DSM Program Impacts* (CADMAC 1998).[11]

The U.S. Department of Energy's (DOE) Energy Efficiency and Renewable Energy website[12] contains a list of building energy simulation software. Although some tools listed are proprietary, the website also lists public-domain DOE-sponsored tools. Summary comparisons and descriptions of commonly used software can be found in Crawley (2005).

The preferred full Option D approach will in some cases be intractable due to limited data availability or evaluation budgetary limitations. In such cases, alternate methodologies are acceptable but the following guidelines should be followed:

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[9] ANSI/ASHRAE Standard 140-2011 establishes test procedures validating software used to evaluate thermal performance of buildings (and applicable HVAC equipment).

[10] It is preferable the software use unique time steps for each interval (e.g., 8,760 hours).

[11] For further commentary on simulation software requirements, see ASHRAE 2002, IPMVP 2001, and IPMVP 2006.

[12] The DOE's Energy Efficiency and Renewable Energy website can be found at: http://apps1.eere.energy.gov/buildings/tools_directory/.

- Onsite verification and review of as-built drawings and commissioning reports (as available) should be performed to verify which energy saving features were actually installed and are functioning

- Ex-ante savings calculations should be based in a whole building simulation model of the building or of a building that is representative of the actual facility

- Results should be compared with billing data (when available), engineering rules of thumb, and/or secondary literature to review reasonability.

4.1.1 Verification Process

Figure 1 depicts the overall process to verify savings under Option D, from *The California Evaluation Framework* (CPUC 2004). The process starts by specifying which site data collection and equipment monitoring requirements are in an M&V plan. Additionally, the M&V plan should specify:

- The applicable version of the building codes and equipment standards that determine the baseline (or applicable 'practice' that may determine baseline). This is discussed in more detail in Section 4.3.
- The above-code technologies present in the building (claimed as ECMs)
- The software for modeling building performance
- Appropriate data for calibrating the simulations
- How to address modeling uncertainties
- Against what statistical indices calibration will be measured.

While reviewing the energy consumption data can be useful in developing data collection needs, it is not a prerequisite to creating and implementing the M&V plan. However, when developing the M&V plan, evaluators should consider how long a building has been occupied because that will determine amount and granularity of energy consumption data available. Fewer months of consumption data, or the availability of only monthly data, usually means there will be a greater emphasis on metering specific pieces of equipment. Conversely, the presence of a building automation system, energy monitoring system, lighting control panels, (collectively referred to here as building automation system) or other devices to control and/or store data about the operational characteristics of the building will allow for a lesser dependence upon utility usage data.

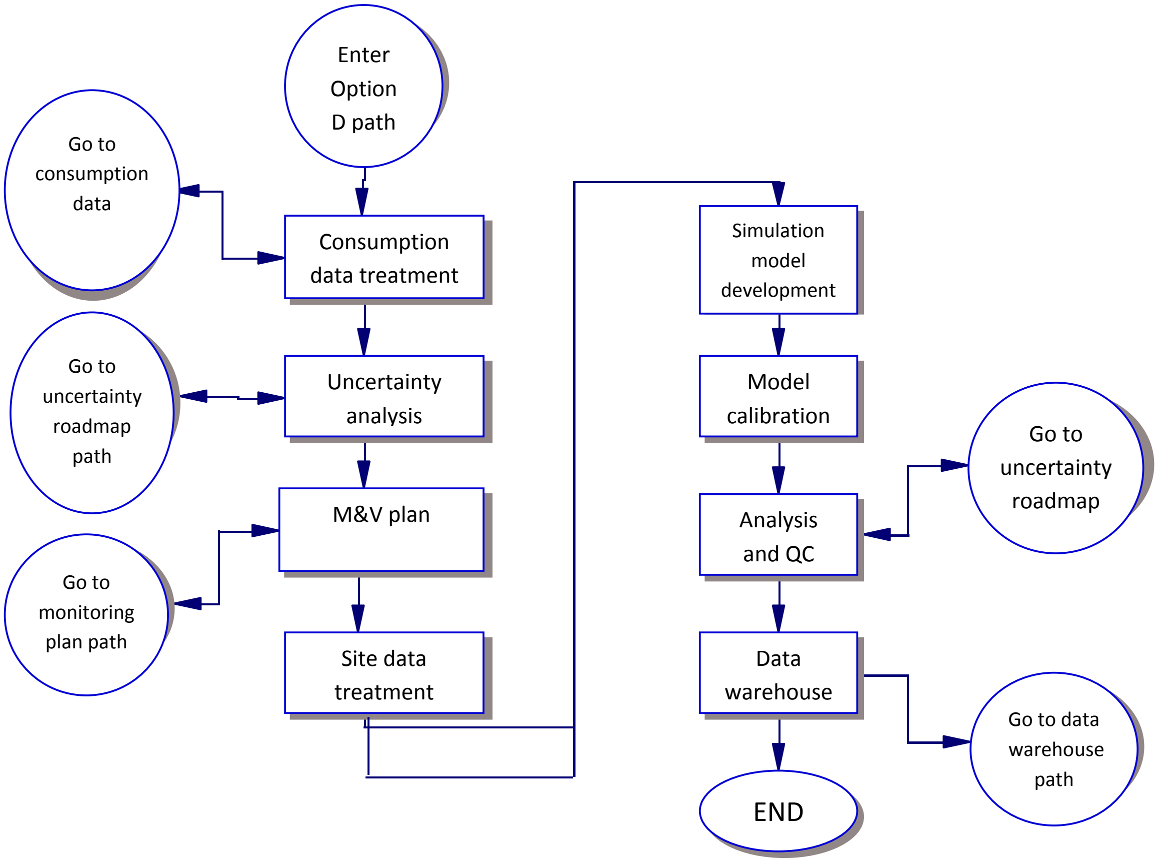

Figure 1. Roadmap for IPMVP Option D

4.1.2 Data Requirements and Collection Methods

Data collected during this step includes all of the information required to define and calibrate the building simulation model. Due to the unique nature of each new construction project, it is impractical to prescribe a comprehensive list of specific parameters evaluators should collect on site. Instead, use the following guidelines to identify key data points and minimize the uncertainty in the final calibrated simulations. After identifying specific parameters, refer to the Uniform Methods Project's *Metering Cross-Cutting Protocols* for instructions regarding the methods to submeter the physical parameters.

The data used to define building simulation models come from stipulated and physical sources. Furthermore, these data can be static or dynamic in nature, as described here:

- *Static data points.* These are essentially constant values that describe physical properties of the equipment and the building surfaces or the set point and operational range controlling the building equipment. [13] Examples of static data points are window glazing, motor efficiencies, and thermostat set points.

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[13] Set points can refer to a control zone, thermostat, control valve, flow rate, voltage, photocell, or other parameter that is designed to maintain optimal environmental conditions within the building. Some set points are "dynamic" in that they may change according to the time of day.

- *Dynamic data.* These are time-dependent variables that describe building and equipment operations. These data capture the behavioral and operational details (e.g., weather, motor loading, and building occupancy) needed to establish a building's energy-use characteristics. Dynamic data, which are often the most difficult to collect, represent the greatest source of uncertainty in a building simulation.

IPMVP Option D (IPMVP 2006) allows use of stipulated data, although it is important to minimize the number of these inputs, as they represent degrees of freedom (and, therefore, additional uncertainty) in the model. Sources for such data include peer-reviewed research, engineering references, simulation program defaults, manufacturers' specifications, and/or survey information from on-site visits (e.g., mechanical and architectural drawings and visual inspection of nameplate information).

The following are convenient categories of important physical data to collect on site (ASHRAE 2002):

- Lighting systems
- Plug loads
- HVAC systems
- Building envelope and thermal mass
- Building occupants
- Other major energy-using loads.[14]

Another important element of the data collection process entails the use of submetering to define behavioral and dynamic aspects of a building and its subsystems. In this protocol, the term submetering encompasses both direct placement of monitoring equipment by evaluation personnel and collecting data from the building automation systems (also known as trend data) when available. Even when the absolute accuracy of the collected data is unknown, submetered data is useful for informing operational schedules (e.g., lighting and ventilation) and calibrating the model.

The degree of submetering required is largely dependent upon the quality and resolution of the facility's energy consumption history. The following descriptions of submetering represent the minimum amount of data collected for calibrating simulation models. Additional submetering may be necessary to verify complex control schemes and/or set points. Perform additional submetering as budget and time permit.[15] Use such data to inform model inputs rather than to function as a calibration target.

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[14] This category is particularly important in buildings such as grocery stores, refrigerated warehouses, and some retail.

[15] For example, verifying functionality of chilled water reset controls or condensing water relief set points.

4.1.2.1 Submetering With Monthly Bills

When only a monthly utility billing history is available for a facility, it is important to submeter both HVAC fan schedules[16] and interior lighting fixtures. Also, if the facility has unique or considerable equipment loads (e.g., data centers), meter these as well.

When monitoring unitary HVAC equipment, isolate the power used by fans from that used by compressors. This ensures evaluators can use the resulting data when calibrating time-of-use and magnitude of fan power.

If, due to site or budget limitations, the electrical monitoring must comprise the unitary system as a whole, use motor nameplate information and fan curves in conjunction with local weather data to disaggregate the fan and compressor power.[17]

Alternatively, use one-time power measurements to establish a unit's demand for each operation mode. Combine these measurements with time-series data to identify time spent in each operation mode and, thereby, determine the fan schedules.

4.1.2.2 Submetering With Hourly Bills

Hourly (or subhourly) energy consumption histories contain much more information for model calibration than monthly usage alone. While this additional information reduces submetering requirements, it does not eliminate the need to submeter HVAC fan schedules as they are important for disaggregating base loads from ventilation. As described for monthly billing data, consider submetering other large energy-using features (e.g., pool-heating and space-cooling equipment, atria lighting, and internet technology loads) if possible given evaluation budgets.

4.2 Simulation Model Development

It is important to model several iterations of the simulated building so as to fully capture the various aspects of the savings for new construction ECMs. Table 1 lists this iterative process, which entails three versions of the as-built building and two versions of the baseline building, including:

- As-built physical
- As-built design
- As-built expected design
- Whole-building reference
- Measure building reference.

Table 1 does not include intermediate modeling of individual ECMs. Intermediate modeling can be used to disaggregate individual measure impacts and interactive effects. If measure-level

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[16] It is important to capture a building's ventilation schedule when HVAC systems are used to supply outside air to maintain required fresh requirements. If performing submetering on a sample of HVAC fans, place priority on accurately capturing when (and how much) outside air is introduced into the building.

[17] To employ this method, the modeler must have the requisite expertise to apply appropriate statistical and engineering modeling techniques to perform this analysis. For further information on energy consumption analysis, see the *Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol*.

savings estimates (and therefore, intermediate modeling of measures) is required, work with the governing jurisdiction for the evaluation process to establish an appropriate hierarchy to govern the order in which measures are stacked and individual measure savings assessed.

Table 1. List of Models Used To Simulate Savings for New Construction ECMs

Model	Model Name and Purpose	Model Description
1	As-Built Physical *To calibrate simulations and assess uncertainty*	Model and simulate, as found during site visit. Use the occupancy and building operation, as reflected in billed energy history and submetered data. Simulate using actual local weather observations matching the consumption history period.
2	As-Built Design *To estimate typical usage at full occupancy*	Base on as-built physical model. Use full design occupancy and expected typical building schedules. Use construction and equipment efficiencies, as found during site visits. Simulate using normalized weather data (e.g., typical meteorological year [TMY] datasets).[a]
3	As-Built Expected Design *To estimate difference between original and as-built models*	Base on as-built design model. Use full design occupancy and expected typical building schedules. Use assumed constructions and equipment efficiencies. Simulate using normalized weather data (e.g., TMY datasets).
4	Whole-Building Reference *To estimate savings of the ECMs*	Base on as-built design model. Use full design occupancy and expected typical building schedules. Apply baseline requirements defined by reference codes or standards. Simulate using normalized weather data (e.g., TMY).
5	Measure Building Reference *To isolate savings claimed by the participant*	Base on whole-building reference model. Use full design occupancy and expected typical building schedules. Apply baseline requirements defined by reference codes or standards. Include ECMs not incentivized by DSM program. Simulate using normalized weather data (e.g., TMY).

[a] Note the TMY are referenced here as an example series of normalized weather data. When incorporating TMY weather data, use TMY3 weather data when available. While TMY weather represents a common standard, review the reporting needs of the project, as other normalized weather datasets may be more appropriate (e.g. Weather year for Energy Calculations [WYEC] or California Thermal Zones [CTZ]).

Begin the development of the model by generating a model of the building as it was built and is operating during the site visit—and as reflected by utility energy consumption data. Use this initial model, the as-built physical model, to calibrate the modeled building to available physical data. This ensures evaluators can use successive iterations in a predictive capacity. A detailed discussion of the calibration process falls outside the scope of this protocol; however, for detailed calibration procedures and guidelines see Section 6.3.3.4 in ASHRAE Guideline 14-2002 (ASHRAE 2002).

Once calibrated, use the as-built physical model to generate the as-built design model, which should reflect the building at full-design occupancy and operation according to expected typical schedules. The only differences between these models are building occupancy, operational schedules, and any modeling guidelines incorporated from codes or standards used to define baseline performance. For buildings currently operating at full occupancy, there may be very little difference between these models. Refer to Tables 11.3.1 and G3.1 in ASHRAE Standard 90.1-2007 (ASHRAE 2007) for examples of modeling requirements specified by codes and standards.

Then, use the as-built design model to generate the as-built expected design model. While this model simulates the building's operation according to its design intent, it also includes claimed assumptions regarding envelope constructions and equipment efficiencies. Review the model for discrepancies between claimed assumptions and the physical building; if no discrepancies exist, this model will be identical to the as-built design.

After developing as-built models, evaluators can model baseline building performance, which results in the whole-building reference model; to generate this model, apply the appropriate codes and standards used to define baseline building performance to the as-built design model. The M&V plan should identify such standards before modeling begins. The following section, *Baseline Considerations*, discusses additional considerations for baseline selection. Similar to the as-built design model, the whole-building reference model should reflect the building's operation according to its expected long-term patterns while using equipment and construction that minimally complies with the reference code or standard.

Finally, start with the whole-building reference model to generate the measure building reference model—this model will include ECMs not incentivized by the DSM program. It is likely all the implemented ECMs are included in the whole-building performance incentives; therefore, both the baseline models may be identical. However, as incentives often are applied for during the building's design and construction process, additional above-code equipment or construction may be implemented that were not included in the final incentive.

4.3 Baseline Considerations

Defining baseline building physical characteristics and equipment performance is one of the most important (and difficult) tasks in evaluating savings for new construction ECMs. This is for several reasons. As noted, new construction ECMs do not have a physical baseline to observe, measure, or document. Rather, evaluators must define the baseline "hypothetically" through an appropriate interpretation of the applicable energy codes and standards. It is typically complicated to establish an *appropriate* interpretation due to the overlapping scope of federal, state, and local codes. Conversely, some states do not have a building energy-efficiency standard separate from the federal standards. Typically, evaluators determine baseline building characteristics and equipment performance requirements by locally adopted building energy codes. In some cases, however, applying a more rigorous, above-code baseline may better reflect standard local construction or industry-standard practices. Thus, in addition to a good understanding of the relationship between federal, state, and local standards, evaluators may need to consult with program guidelines (which often specify greater than code stringency or other technical specifications) or statewide evaluation frameworks.

Enforcement of the state codes is the responsibility of the local building officials. The EM&V effort of energy-efficiency programs is usually carried out by utility or other program administrators or by a public utilities commission. Whereas the public utilities commission usually has no enforcement responsibility for the codes and standards, they often point to the official state standards as the governing document regardless of the degree of enforcement of those codes at the local level.

In general, the baseline must satisfy the following criteria (IPMVP 2006):

- It must appropriately reflect how a contemporary, nonparticipant building would be built in the program's absence.[18]
- Evaluators must rigorously define it with sufficient detail to prescribe baseline conditions for each individual ECM and for the building components simulated.
- Evaluators must develop it with sufficient clarity and documentation to be repeatable.

The BCAP-OCEAN website (http://energycodesocean.org) can be a useful resource in identifying locally adopted energy codes and standards when starting the evaluation of a whole-building or commercial new construction project.

4.4 Calculating Savings

To calculate savings, apply simulation outputs (from models 2 through 5 in Table 2) to the formulas described in Section 3. In all cases except as-built physical, simulate the postconstruction energy use and the projected baseline energy use using normalized weather data (TMY).

As discussed in Section 3, there are four components that comprise calculated energy savings (defined in Table 2 and shown in Figure 2). Determine the final reported (verified) savings values in the context of M&V objectives.

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[18] Locally adopted building codes will define gross savings of new construction programs. Only consider standard construction practices of nonparticipant buildings when performing a net-to-gross analysis. One notable exception is when the evaluated program defines its own baseline, according to an above-code standard (for example, ASHRAE Standard 189.1-2011).

Table 2. Comparison of Savings Components for New Construction ECMs

Savings Component	Model Subtraction	Description
Expected Measure Savings	N/A	Energy savings expected by the building designers and/or the DSM program application (also known as the project's planned energy savings).
Rebated Measure Savings	5 – 2	Evaluated (or realized) energy savings for incentivized ECMs, often determined by an independent third-party evaluator. Calculate these savings by subtracting the difference in simulated energy use of the as-built design from the measure building reference (the result is also known as the project's *ex post* savings).
Nonrebated Measure Savings	4 – 5	Energy savings resulting from ECMs implemented in the final building design, but not rebated by the DSM program. Calculate these savings by subtracting the difference in simulated energy use of the measure building reference from the whole-building reference (the result is also known as the spillover savings).
Total Achieved Savings	4 – 2	Evaluated (or realized) energy savings for all implemented ECMs, whether rebated or not. These are often determined using an independent third-party evaluator, and calculated by subtracting the difference in simulated energy use of the as-built design from the whole-building reference. Some DSM programs report this (rather than rebated measure savings) as the project's *ex post* savings.

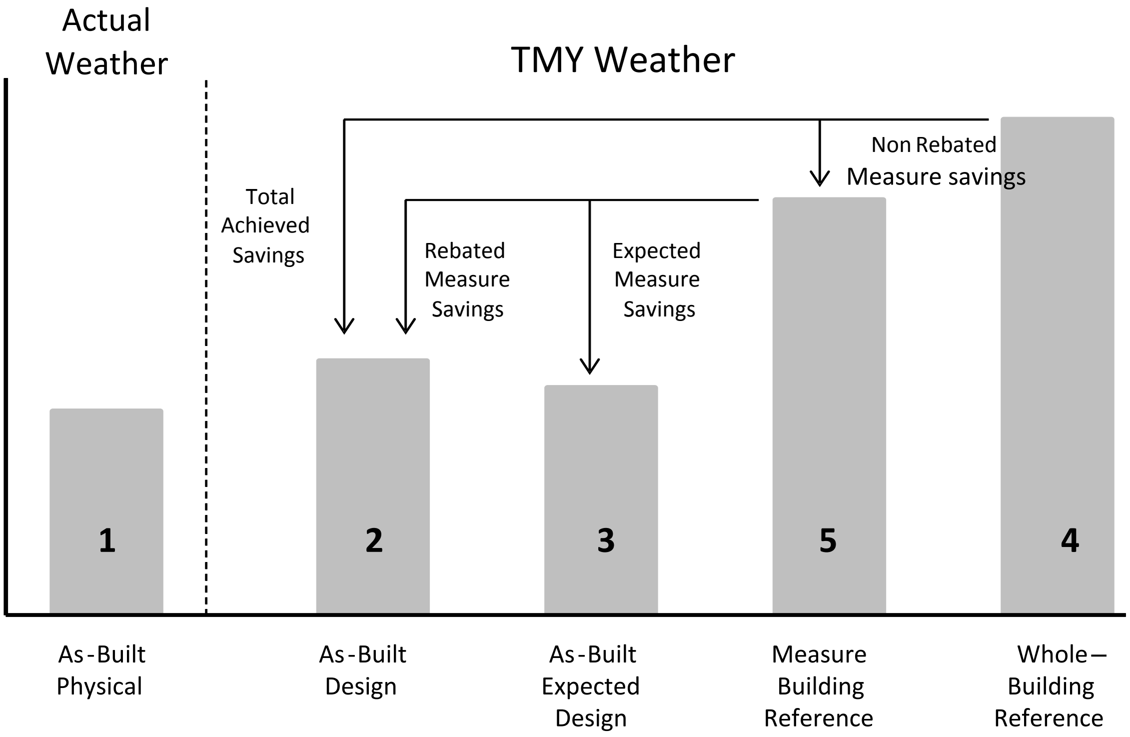

Figure 2. Illustration of savings components for new construction ECMs

4.5 Quantify and Locate Modeling Uncertainty

Due to the complex set of physical, thermodynamic, and behavioral processes simulated, it is difficult to fully characterize the uncertainty in modeled outputs without multiple statistical and analytical tools. Additionally, practical limitations on budgets and time allotted for M&V activities frequently result in qualifying uncertainty in final simulated savings by reporting uncertainty in the model's calibration to energy consumption history. Quantify calibration uncertainty using the normalized mean bias error (NMBE) and coefficient of variation of the root mean square error (CVRMSE).[19] Pages 13-16 of ASHRAE Guideline 14-2002 (ASHAE 2002), provides detailed descriptions of these calculations and their applications.

Determine calibration uncertainty by comparing outputs from the calibrated as-built physical model with the facility's consumption history. Table 3 shows calibration uncertainty targets for monthly and hourly consumption history resolutions (ASHRAE 2002).

Table 3. Acceptable Tolerances for Uncertainty in Calibrated Building Simulations

Resolution of Energy Consumption History	NMBE Tolerance	CVRSME Tolerance
Monthly	±5%	±15%
Hourly	±10%	±30%

As newly constructed buildings have a short energy consumption history, it is important to consider how many monthly observations are required to attain a suitably calibrated model. The amount of consumption history required for calibration depends on building type and occupancy. Buildings with little seasonal variations in energy use[20] and short ramp-up periods may need as little as three or four months of consumption history, assuming building occupancy and usage are well-defined and stable. Typically, buildings in this category include grocery stores, restaurants, and data centers.

Conversely, buildings that experience significant seasonal variation, or that are not fully occupied for extended periods, may require a complete year (or more) of consumption history before modelers can determine a reliable calibration. For these buildings, occupancy and usage must be well-defined and stable during all observations used for calibration. Typical buildings of this type include offices, schools, and malls (both strip and enclosed).

Mandating definitive requirements for the minimum number of observations required to sufficiently calibrate a simulation would unduly constrain modelers and could place impractical limitations on EM&V efforts. However, this protocol recommends the following as guidelines:

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[19] These two statistical measurements provide an assessment of the variance between the simulated and measured (by the utility meter) energy use and electric demand. This protocol considers modeling uncertainty acceptable when this variance is below the thresholds suggested in Table 3.

[20] Although energy used by HVAC systems can vary seasonally, such usage generally correlates well with outside weather. Thus, the energy simulation model can sufficiently extrapolate such seasonality (when simulated using the appropriate weather data), reducing the number of billed observations required to calibrate buildings having HVAC use that is dominated by weather.

- Observations should sufficiently characterize a building's energy use, so modelers can extrapolate reliable annual energy-use values.
- Observations should sufficiently describe expected seasonal variations in building operations.
- Building occupancy and operating conditions must be known for the set of observations.
- Building occupancy and operating conditions must remain stable for the duration of observations used for calibration.

While NMBE and CVRSME may prove useful in describing uncertainty in final savings, it is important to minimize the uncertainty in the simulation inputs. These metrics will not completely capture uncertainty in the inputs.

All software packages acceptable for use in Option D require modelers specify a significant number of physical parameters before simulating a building. Often, many of these parameters have default settings in the software package; however, evaluators can base the parameter inputs on experience or standard practices.

Any parameter not directly based on a physical building or its equipment represents a degree of freedom for calibrating the model against a facility's consumption data.[21] By varying these parameters, the modeler can calibrate the same model to meet uncertainty targets in multiple ways, although for very different reasons.

Lack of a unique calibration point can cause misleading results for NMBE and CVRSME. Furthermore, the resultant calibrations respond differently to changes in other parameters, which can lead to significantly divergent savings estimates. Therefore, it is very important modelers minimize calibration uncertainty *and* they accomplish the calibration for the correct reasons. Modelers should not unreasonably alter inputs simply to reduce NMBE or CVRSME.

The following guidelines minimize uncertainty in the calibration process:

- Experienced simulators (or modelers directly supervised by an experienced simulator must perform the modeling.
- Modelers must document each simulation process step, so reviewers can audit the model, its outputs, and its assumptions.
- Simulators and auditors should determine the most influential default model parameters and confirm their appropriateness.
- Simulated equipment (e.g., HVAC coils, chillers, pumps) should not "auto size" in final simulations.[22]

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[21] Each parameter must be constrained by a physically realistic range of values.

[22] When specific data are unavailable, auto-sizing can be helpful in determining appropriate coil capacities, fan speeds, etc. However, only use it for initial equipment sizing. Once equipment sizes have been determined, input them directly. Often, modelers must use auto-sizing to define baseline equipment, as the measures impact building loads. In such cases, calculate an *oversize ratio* for as-built equipment and apply it to the baseline simulation.

- Simulators should identify the parameters to which the simulation outputs are most sensitive.[23]

In addition to quantifying NMBE and CVRSME errors, modelers should analyze the sensitivity of final savings to variations in key model inputs. Modelers should also report such parameters (including their effects on simulated energy savings and the uncertainty in their values) with calibration uncertainty.

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[23] Further discussion regarding sensitivity analysis of simulation parameters falls outside this chapter's scope. For additional material on this topic, see Spitler, Fisher, & Zietlow 1989.

5 Sample Design

Use sampling under the following conditions:

- When performing submetering on building equipment
- When performing a detailed survey of an entire building proves impractical.

Evaluators determine the specific targets for sampling certainty and relative precision in the context of the evaluation. For detailed information regarding sample design and for calculating certainty and precision, see the Uniform Method Project's *Sample Design Cross-Cutting Protocols*.

5.1 Sampling for Submetering

Perform submetering to collect information regarding a building's operational schedules. Monitored systems include lighting, ventilation, large equipment (e.g., data centers), and HVAC zone temperatures. Generally, it is acceptable to assume a coefficient of variation (CV) of 0.5 for most submetering; however, while many of these schedules are a function of the overall building type, significant variation in schedules can occur from space to space within a facility. Therefore, interview site personnel to identify any operational differences (and the magnitude of such differences) within the facility before creating a sample design. Account for variations in operating schedules and usage patterns by using a larger CV or by stratifying unique usage groups. See the Uniform Method Project's *Metering Cross-Cutting Protocols* for additional considerations for commonly monitored equipment.

5.1.1 Example: Monitoring the Lighting Schedule in a Two-Story Office Building

A two-story commercial office building receives a whole-building performance rebate for LEED certification. For the certification process, a DOE2.2 model is built, for which evaluators develop lighting loads and schedules. During the on-site visit, evaluators note the same tenant occupies both floors, and the building remains open from 6:30 a.m. to 10:00 p.m. The evaluators also identify two unique lighting usage patterns:

- Enclosed offices are located on the building's perimeter
- Open office space is located in the building's core.

As the evaluators identified two distinct usage patterns, they should design the sampling to capture the variability within the schedules for both space types.

- As the open office space is located in the building's core, lighting fixtures likely operate continuously during the building's open hours. Additionally, lighting is commonly shared by all workspaces in the building's core. Therefore, a CV of 0.5 is justified and may prove conservative in determining how many fixtures to monitor.
- Lighting fixtures located in enclosed office spaces typically experience significantly more usage variation due to exaggerated behavioral and external influences. Also, the enclosed office space fixtures receive additional light from perimeter windows, thereby reducing the need for interior lighting during daytime hours. These impacts can be exaggerated (or

diminished), depending on fixture control types, building aspects, weather, and times of year. Such additional variability would necessitate a higher assumed CV and additional monitoring points.

5.2 Sampling for Building Surveys

The on-site data collection encompasses a detailed survey of building systems, such as:

- Lighting fixtures
- Plug loads
- HVAC equipment and controls
- Elevator and auxiliary equipment
- Fenestration
- Envelope constructions.

For many buildings, surveyors can perform a complete walk-through and can install monitoring equipment within a single day. However, larger buildings (such as high-rise office buildings, hotel casinos, and hospitals) present logistical and budgetary complexities that make it impractical (and often impossible) to perform a complete facility walk-through. In these cases, it is permissible to perform a walkthrough of a representative sample of building areas and extrapolate the findings to the rest of the building. Evaluators can apply the findings to individual spaces or to entire floors (the exact sample design depends on the facility design, including any considerations, such as access to space).

5.2.1 Example: On-Site Audit of a High-Rise Office Building

A 34-story high-rise commercial building located in a major city's downtown region receives a whole-building performance rebate. Various retail businesses rent the first floor, and various tenants use the remaining floors as office space, including a United States Department of Agriculture office. Evaluators collect data during the on-site visit to build a DOE2.2 model; however, the building owner will only provide evaluation personnel access to the building for a single day.

The building is too large to conduct a thorough walk-through in one day. Additionally, it is expected at least one tenant will have areas within its occupied space that evaluators will not be allowed to access. Therefore, evaluators will have to perform sampling for both floors and space types. Evaluators should audit enough floor space to sufficiently characterize internal loads and usage patterns for each tenant and for the building as a whole. The exact number of floors visited will depend on the number of tenants and on the homogeneity between spaces/floors. The evaluators should:

- Identify unique operating conditions, such as occupancy schedules, lighting power density (and schedules), and equipment power density (and schedules).
- Identify currently vacant areas (or floors).
- Interview facility staff to:

    - Identify differences in space temperatures or ventilation requirements for each tenant
    - Determine variations in building occupancy (by month or as appropriate) since its opening.
- Audit all central plant equipment.
- Sample air distribution system equipment using sampling criteria described in the Uniform Method Project’s *Sample Design Cross-Cutting Protocols*.

6 Program Evaluation Elements

These elements differentiate evaluations of new construction programs from those of other programs:

- Evaluators need significantly more resources to define and justify a hypothetical baseline.
- Evaluators have a limited selection of methods for determining site-level savings.
- Buildings rarely operate at a "steady state" at the time of evaluation.

While this is not a comprehensive list, it specifies critical factors that evaluators must consider in developing an evaluation plan—particularly with regard to budget resources for defining and justifying the baselines used to determine energy savings.

Commonly applied codes (such as ASHRAE 90.1) provide multiple compliance pathways, but leave room for local jurisdictions to maintain their own interpretations. Therefore, evaluators should work with local jurisdictions, program implementers, and evaluation managers and oversight agencies to identify the most appropriate baseline for a building. Further, local jurisdictions may adopt an updated building code during implementation of a program, so the evaluator may have to develop baselines from multiple building codes for a given program year.

Given the limited information available to assess new construction ECMs, using calibrated building simulations is often the only option for determining energy savings. Significant planning ensures:

- Evaluators develop detailed M&V plans each project site
- The evaluation allows sufficient time to perform the analyses.

Evaluators often collect additional information using submetering and/or consumption data analysis. As this information is important for model calibration, the M&V plan should allot sufficient time for a thorough analysis of all submetered data and consumption data.

For programs offering incentives, evaluators usually assess energy efficiency measure performance during the first few years of their operation. During this period, building systems and controls typically require troubleshooting,[24] and buildings have low, but growing, occupancy rates.

Evaluators should also keep in mind that owners (or tenants) may use building spaces differently than as originally designed. Thus, the specific codes or standards governing the originally permitted building drawings may not be appropriate for assessing actual energy use or energy savings. This protocol strongly recommends evaluators consider these and other such factors when calibrating models and simulating annual energy savings.

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[24] Troubleshooting is formally done through a commissioning process; however, not all buildings are professionally commissioned. In many facilities, facility management must dial in building controls.

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