Commercial New Construction

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1 Measure Description

This protocol is intended to describe best practices when evaluating "whole building performance" new construction projects in the commercial sector. The focus is on measures (or packages of measures) whose impacts are best evaluated using building simulation. Examples of such measures include LEED building certification, novel and/or efficient HVAC system designs, extensive building controls systems, etc. In general, any measure (or set of measures) expected to significantly "interact" with other systems within the building, or whose savings are sensitive to seasonal variations in weather are best evaluated using whole building modeling.[1] Commercial New construction projects can be classified as follows:

- ***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 requiring building permits and triggering compliance with current codes.
- ***Major renovations or Tenant Improvements of existing buildings.*** Significant reconstruction or "gut rehab" of an existing structure, requiring building permits and triggering compliance with current codes.

Evaluators may find some projects in retrofit programs that must be assessed in a manner similar to that described here for new construction projects.[2] While such projects have much in common with new construction projects, their scope does not uniformly fall under the new construction categories described above. These projects should be evaluated 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. The baseline equipment against which energy impacts for new construction measures are evaluated is defined by an agreed-upon building energy code or industry standard. Since the baseline equipment for new construction measures has never physically existed it cannot be measured or monitored and a simulation approach is usually required. Due to the nuances involved in appropriately determining baseline equipment/performance evaluations of such projects should be overseen by experienced professionals with a good understanding of building construction practices, simulation code limitations, and the relevant building codes.

Further, new construction measures are typically evaluated in the first years after a building's construction. During this period, there is often considerable flux in building occupancy and operation before their design intent becomes realized. This results in additional challenges when using monitored

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[1] Note that term whole building modeling here does not necessitate use of sophisticated "stand-alone" simulation software (eQuest, EnergyPlus, etc.). Engineering models using spreadsheet calculations can be acceptable provided they meet the guidelines set forth in section 4.

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

data and/or facility utility billing or energy consumption history to define as-built building performance.[3]

2 Application Conditions of Protocol

The algorithms and protocols described here pertain to evaluating new construction "whole building performance" energy-conservation measures (ECMs) installed in commercial facilities. When new construction ECMs are installed that 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, 34). This is usually the case, for example, with lighting and domestic hot water retrofits.[4] The guidelines for selecting the appropriate monitoring and verification (M&V) rigor for such measures are not covered in this chapter. Evaluation guidelines for measures that do not require calibrated building simulation can be found in the International Performance Measurement and Verification Protocol (IPMVP), 11-24, or elsewhere within the Uniform Methods Project protocols.

2.1 Incentive Types

New construction demand-side management (DSM) program incentives are typically classified as being either component-based or performance-based and can be designed 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 such incentives may include, but are not limited to, lighting fixtures, occupancy sensors, motors, and small packaged (unitary) HVAC units. Rebate amounts and claimed savings estimates (*ex-ante*) are often determined using stipulated "per unit" estimates.[5] Component-based rebates are sometimes evaluated according to measure-specific protocols using partial or complete retrofit isolation evaluation strategies (IPMVP Option A or Option B).

Evaluation of these ECMs is not covered in this protocol, as they typically do not require use of calibrated building simulations (IPMVP Option D).

2.1.2 Performance-Based Incentives

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

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

[4] 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 reduce the magnitude of heating and cooling interactive effects. Secondary impacts can be estimated using prototypical building models, representative of the physical facility. See the Commercial and Industrial Lighting Evaluation Protocol or (CPUC 2004, 128) for guidelines regarding HVAC interactive factors.

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

Whole-building performance incentives can:

- Encompass various specific (above code) upgrades; and
- Fund design, analysis, equipment, and/or installation (labor) costs.[6]

An example of a performance based project is LEED certification. LEED certified buildings often encompass ECMs that range from envelope improvements to high-efficiency equipment installations (often going beyond just HVAC) and complicated controls algorithms. 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 (per kWh, therm, kW, etc.).[7] Annual energy savings estimates for performance-based projects (and therefore programs) are custom calculations involving the use of whole building simulation modeling tools. Therefore these programs require highly skilled technical labor to implement and evaluate successfully.[8]

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

7 Depending on program design the "expected" energy impacts can be either ex-ante or ex-post.

8 See (Johnson and Nadel 2000) for more information.

3 Savings Calculations

Energy savings for new construction measures are calculated using the following algorithm. (Note that demand savings can be calculated using the same algorithms by simply substituting "demand" for "energy use.")[9]

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
>
> *Post-Construction Energy Use* = Energy use of measure systems at full design occupancy and "typical" building operating conditions

As described in Section 4, Projected-Baseline Energy Use and Post-Construction Energy Use are calculated using a whole-building simulation model that is calibrated to monthly (or hourly) utility energy consumption histories. Four components are used to report savings for new construction ECMs. Each is discussed further in Section 4.

- Expected Measure Savings (*ex-ante*)
- Rebated Measure Savings
- Non-Rebated Measure Savings
- Total Achieved Savings

4 Measurement and Verification Plan

4.1 IPMVP Option

Savings for whole-building performance new construction projects are calculated using calibrated building simulation models according to IPMVP Option D. The appropriate modeling software is determined by the specifics of buildings being evaluated (e.g. HVAC system and zoning complexity, building constructions, complexity of the ECMs) and 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 have the following capabilities:

- Creates outputs that comply with ANSI/ASHRAE Standard 140-2011;[10]
- Accurately simulate the building's systems and controls;

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

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

- Uses an hourly or sub-hourly time step to perform simulation;[11] and
- Simulates building performance using user-defined weather data at hourly intervals.

For more information on specific requirements for simulation software, see CPUC 2004, 133, and CADMAC 1998, 26-27.[12]

The U.S. Department of Energy's (DOE) EERE Website[13] 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).

4.1.1 Verification Process

The overall process by which savings are verified under Option D is illustrated in Figure 1, from the *California Evaluation Framework* (CPUC 2004, 177). The process starts by developing an M&V plan in which site data collection and equipment monitoring requirements are specified. Additionally, the M&V plan should specify the following:

- The applicable version of the codes and standards which determination the baseline;
- The above-code technologies present in the building which are claimed as EEMs;
- The software that will be used to model building performance;
- The data that will be used to calibrate the simulations;
- How modeling uncertainties will be addressed; and
- Against what statistical indices calibration will be measured.

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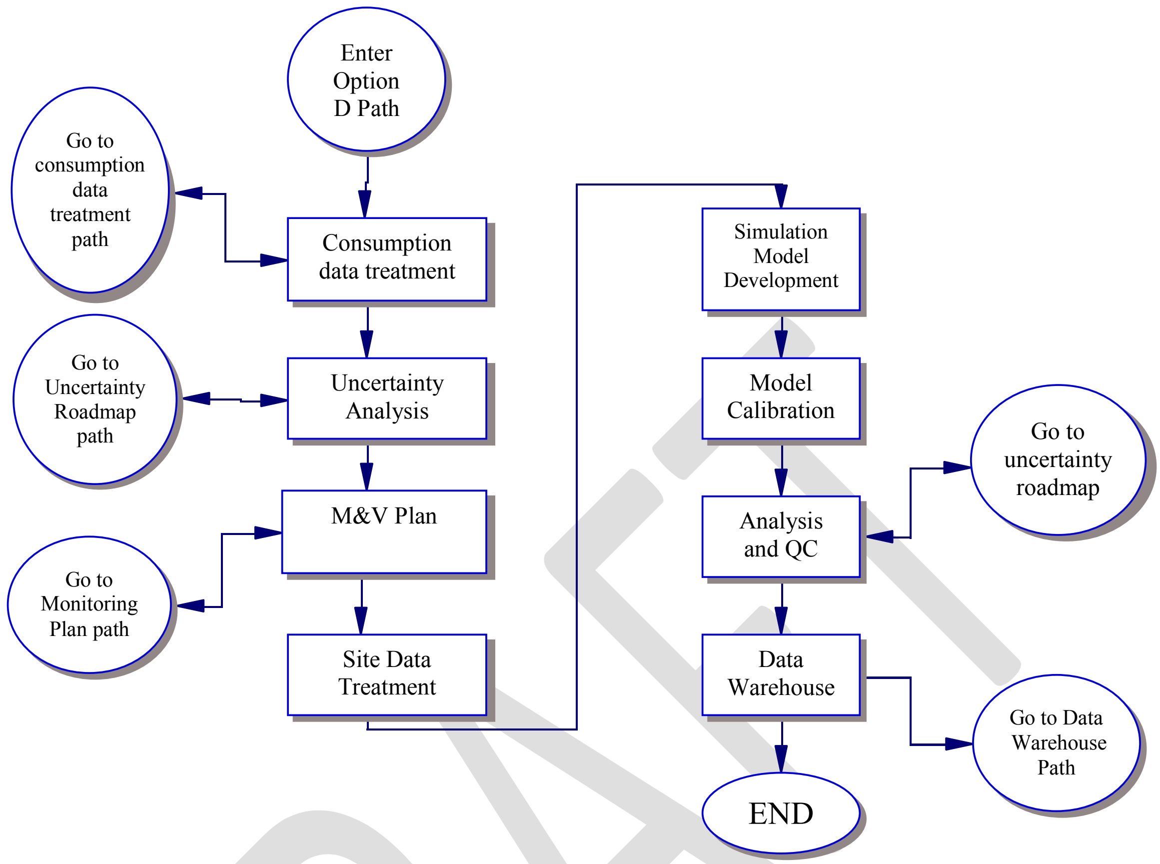
11 It is preferable the software use unique time steps for each interval (8760 hours, for example).

12 Further commentary on simulation software requirements can be found in (ASHRAE 2002, 18 & 32), (IPMVP 2001, 33), and (IPMVP 2006, 19).

13 http://apps1.eere.energy.gov/buildings/tools_directory/

Figure 1. Roadmap for IPMVP Option D



While reviewing the energy consumption data can be useful in developing data collection needs, it is not pre-requisite to creating and implementing the M&V plan. However, the length of time that the building has been occupied and therefore the amount and granularity of energy consumption data available should be considered when developing the M&V plan. The fewer months of consumption data or the availability of only monthly data usually means 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 BAS) or other devices to control and/or store data about the operational characteristics of the building would allow for a lesser dependence upon utility usage data. The remainder of this section describes each of the steps shown in the roadmap.

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 to be collected on-site. Instead, use the following guidelines to identify key data points and minimize the uncertainty in the final calibrated simulations. Once specific parameters are identified, refer to Chapter [*Chapter on Metering]* for instructions regarding the methods by which the physical parameters are sub-metered.

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

- *Static data points* are essentially constant values that describe physical properties of the equipment and the building surfaces or the set points and operational range to which the building equipment is controlled.[14] Examples of these are window glazing, motor efficiencies, and thermostat set points.

- *Dynamic data* are time-dependent variables that describe building and equipment operations. These data capture the behavioral and operational details (such as 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.

Use of stipulated data is allowed under IPMVP Option D (IPMVP 2006, 19-20), 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 (such as mechanical and architectural drawings).

The following are convenient categories of important physical data to collect on site (ASHRAE 2002, 35-36):

- Lighting Systems
- Plug Loads
- HVAC Systems
- Building Envelope and Thermal Mass
- Building Occupants
- Other Major Energy-Using Loads[15]

Another important element of the data collection process entails the use of sub-metering to define behavioral and dynamic aspects of a building and its sub-systems. In this protocol, the term "sub-metering" encompasses both direct placement of monitoring equipment by evaluation personnel and collecting data from the building automation systems (BAS) ("trend" data) when available. Even when the absolute accuracy of the collected data is unknown, sub-metered data is useful for informing operational schedules (lighting, ventilation, etc.) and calibrating the model.

The degree of sub-metering required is largely dependent upon the quality and resolution of the facility's energy consumption history. Note that the following descriptions of sub-metering represent the minimum amount of data collected for calibrating simulation models. Additional sub-metering may be necessary to verify complex control schemes and/or set points. Perform additional sub-metering as budget and time permit.[16] Such data would be used to inform model inputs rather than to function as a calibration target.

[14] Set points can refer to a control zone, thermostat, control valve, flow rate, voltage, photocell or other parameter which 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.

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

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

4.1.2.1 Sub-Metering with Monthly Bills

When only a monthly utility billing history is available for a facility, it is important to sub-meter both HVAC fan schedules[17] and interior lighting fixtures. Also, if the facility has unique or considerable equipment loads (for example, data centers), meter these, as well.

When monitoring unitary HVAC equipment, isolate the power used by fans from that used by compressors. This ensures that the resulting data can be used in 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.[18]

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

4.1.2.2 Sub-Metering with Hourly Bills

Hourly (or sub-hourly) energy consumption histories contain much more information for model calibration than monthly usage alone. While this additional information reduces sub-metering requirements, it does not eliminate the need to sub-meter HVAC fan schedules, as they are important for disaggregating base loads from ventilation. As described for monthly billing data, sub-metering other large energy using features (e.g., pools, atria, and decorative lighting features) should be considered 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 from for new construction ECMs. This iteration process, which is shown in Table 1, entails three versions of the as-built building and two versions of the baseline building:

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

This list does not include intermediate modeling of individual ECMs. Intermediate modeling can be used to disaggregate individual measure impacts and interactive effects. If measure level savings estimates (and therefor 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.

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17 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 sub-metering is performed on a sample of HVAC fans, the priority should be placed on accurately capturing when (and how much) outside air is introduced into the building.

18 This method has been written with the expectation the modeler has the requisite expertise to apply appropriate statistical and engineering modeling techniques to perform this analysis. For further information on energy consumption analysis, see Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol.

Table 1. List of Models Used to Simulated 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 sub-metered 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 constructions and equipment efficiencies as found during site visits. Simulate using normalized weather data (e.g., TMY datasets).
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 (*ex-ante*) constructions and equipment efficiencies. Simulate using normalized weather data (e.g., TMY datasets).
4	**Whole-Building** Reference *To estimate savings of the EEMs*	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).

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. This initial model, the As-Built Physical model, is used to calibrate the modeled building to available physical data. This ensures that successive iterations can be used 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 2002, 37-41.

Once calibrated, the As-Built Physical model is used 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. Examples of modeling requirements specified by codes and standards can be found in Tables 11.3.1 and G3.1 in ASHRAE Standard 90.1-2007 (ASHRAE 2007).

The As-Built Design model is then used 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. If no discrepancies are found between claimed assumptions and the physical building, this model will be identical to the As-Built Design.

Once As-Built Models have been developed, baseline building performance can be modeled, resulting in the Whole-Building Reference model. This is generated from the As-Built Design model by applying appropriate codes and standards used to define baseline building performance. Such standards should be identified in the M&V plan before modeling begins. Additional considerations for baseline selection are discussed in the following section, “Baseline Considerations.” 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, the Measure Building Reference model is generated from the Whole-Building Reference model, and it includes ECMs not incentivized by the DSM program. It is likely all 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 has not been 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 at this document’s beginning, new construction ECMs do not have a physical baseline to observe, measure, or document. Rather, the baseline must be defined “hypothetically” through an appropriate interpretation of the applicable energy codes and standards. Establishing an *appropriate* interpretation is typically complicated by 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, baseline building characteristics and equipment performance requirements are determined 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.

It should also be noted that while the 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 PUC 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;[19]

[19] For gross savings of new construction programs, this is defined by locally adopted building codes. Standard construction practices of nonparticipant buildings are only considered 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).

- It must be rigorously defined, with sufficient detail to prescribe baseline conditions for each individual ECM and for the building components simulated; and
- It must be developed 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

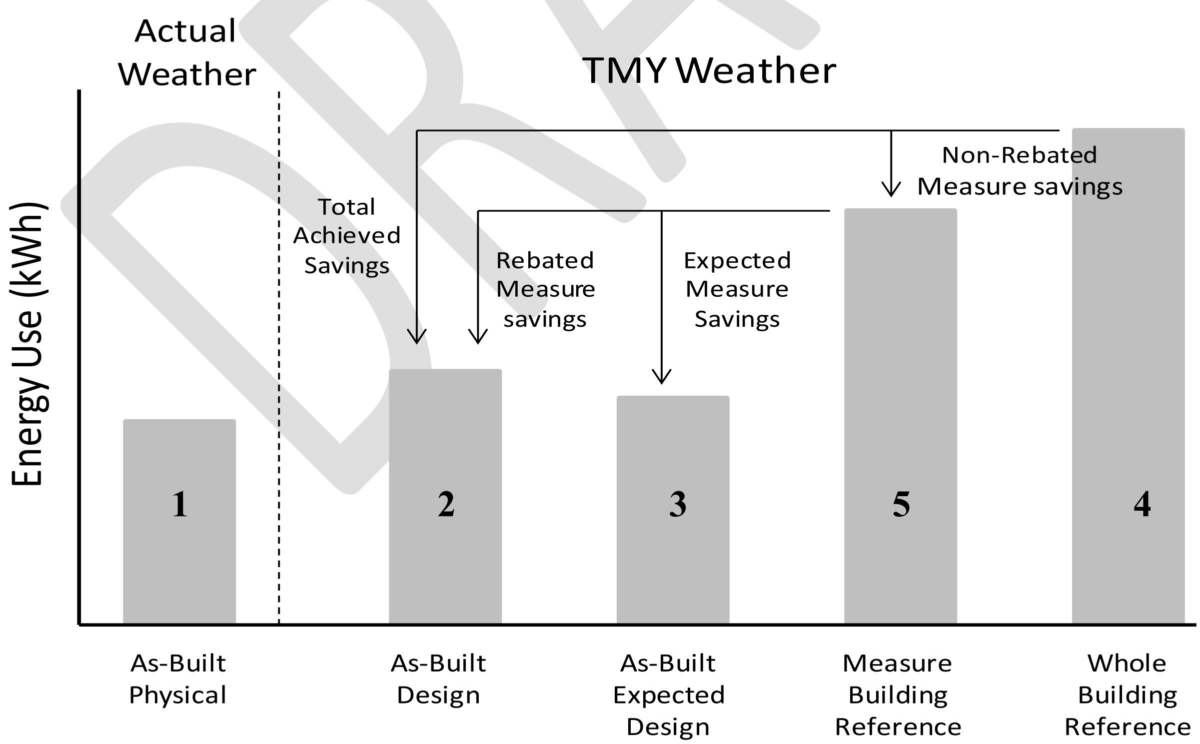
Savings are calculated by applying simulation outputs (from models 2 through 5 in Table 1) to the formulas described in Section 3. In all cases except As-Built Physical, the Post-Construction Energy Use and the Projected Baseline Energy Use should be simulated using normalized weather data (TMY).

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

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 *ex-ante* 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.)
Non-Rebated 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 that are being 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. Calibration uncertainty is quantified using Normalized Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Square Error (CVRMSE).[20] ASHRAE 2002, 13-16, provides detailed descriptions of these calculations and their applications.

Calibration uncertainty is determined 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	±10	± 30
Hourly	± 5	± 15

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[21] 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. Buildings typically included in this category are 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 a reliable calibration can be determined. 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).

Providing prescriptive 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:

- Observations should sufficiently characterize a building's energy use, so reliable annual energy-use values can be extrapolated.
- Observations should sufficiently describe expected seasonal variations in building operations.

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

[21] 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.

- 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. Uncertainty in the inputs will not be completely captured by these metrics.

All software packages acceptable for use in Option D require that a significant number of physical parameters be specified before a building can be simulated. Often, many of these parameters have default settings in the software package; however, the parameter inputs can be based 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.[22] By varying these parameters, the same model can be calibrated 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 that the modeler minimize calibration uncertainty *and* that such calibration is accomplished for the correct reasons. Model inputs should not be unreasonably altered simply to reduce NMBE or CVRSME.

The following guidelines minimize uncertainty in the calibration process:

- Modeling should be performed by (or be directly supervised by) an experienced simulator.
- Each the simulation process step should be documented so that 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 (HVAC coils, chillers, pumps, etc.) should not be allowed to "auto-size" in final simulations.[23.]
- Simulators should identify the parameters to which the simulation outputs are most sensitive.[24]

In addition to quantifying NMBE and CVRSME errors, simulators should analyze the sensitivity of final savings to variations in key model inputs. Such parameters, their effects on simulated energy savings, and the uncertainty in their values should be reported with calibration uncertainty.

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

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

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

5 Sample Design

Sampling can be used under the following conditions:

- Sub-metering is performed on building equipment; or
- 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 Sample Design Cross-Cutting Protocol.

5.1 Sampling for Sub-metering

Perform sub-metering 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 sub-metering; 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 […cross reference to monitoring chapter…] 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 lighting loads and schedules are developed. During the on-site visit, evaluators note that 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, and
- Open office space is located in the building's core.

As two distinct usage patterns have been identified, the sampling should be designed to capture the variability within the schedules for both space types.

- As 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 = 0.5 is justified, and may prove conservative in determining how many fixtures should be monitored.
- Lighting fixtures located in enclosed office space typically experience significantly more usage variation due to exaggerated behavioral and external influences. Also, 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:

- Lighting fixtures,

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

For many buildings, surveyors can perform a complete walkthrough 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 walkthrough. 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. This can be applied 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 walkthrough in one day. Additionally, it is expected at least one tenant will have areas within its occupied space which will not allow evaluators to access. Therefore, sampling will have to be performed 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 [Sampling Chapter].

6 Program Evaluation Elements

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

- Significantly more resources are required to define and justify a hypothetical baseline;
- Evaluators have a limited selection of methods for determining site-level savings; and
- 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 often offers the only option for determining energy savings. Significant planning is required to ensure:

- Detailed M&V plans are developed for each site evaluated; and
- Sufficient time is allotted to perform the analyses.

Additional information is often collected using sub-metering and/or consumption data analysis. As this information is important for model calibration (rather than generating savings estimates directly) sufficient time should be allotted for a thorough analysis of all sub-metered data and consumption data.

Traditionally, incentivized buildings are evaluated during their first few years of operation. During this period, building systems and controls typically require troubleshooting[25] and have low-but-growing building occupancy.

As a final consideration, owners (or tenants) may use building spaces differently than was intended in the original design. Thus, specific codes or standards to which the original permitted building drawings were intended to comply may prove inappropriate for evaluation of energy savings. Such factors must be considered during calibration and when simulating annual energy savings.

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[25] 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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