Retrocommissioning Evaluation Protocol

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1 Measure Description

Retrocommissioning (RCx) is a systematic process for optimizing energy performance in existing buildings. It specifically focuses on improving the control of energy-using equipment, such as heating, ventilation and air conditioning (HVAC) equipment and lighting, and typically does not involve equipment replacement. Field results have shown proper RCx can achieve energy savings ranging from 5% to 20%, with a typical payback of two years' time or less (Thorne 2003).

A study conducted on behalf of Lawrence Berkeley National Laboratory analyzed data from 11 utilities operating RCx programs across the United States; a data set that included 122 RCx projects and over 950 RCx measures (PECI, 2009). Figure 1 provides a summary of the most common RCx measures, by highlighting the nine measures that represent the majority of the analyzed project savings.

Figure 1. Common RCx Measures

RCx Measure	% of Total Savings
Revise control sequence	21%
Reduce equipment runtime	15%
Optimize airside economizer	12%
Add / optimize supply air temperature reset	8%
Add variable frequency drive to pump	6%
Reduce coil leakage	4%
Reduce / reset duct static pressure setpoint	4%
Add / optimize optimum start/stop	3%
Add / optimize condenser water supply temperature reset	2%

As shown in Figure 2 (PECI 2010), RCx measures vary, depending on types of equipment and control mechanisms introduced or optimized. For example, some RCx measures control HVAC equipment according to a predefined schedule, while some measures introduce outdoor air temperature (OAT)-dependent controls.

Figure 2. Categorization of RCx Measures

Control Mechanism	Equipment Type		
	HVAC Airside	***HVAC Waterside***	***Lighting***
Scheduled	Matching supply fan schedule to occupancy schedule	Adding/optimizing space setback temperatures	Matching lighting schedule to occupancy schedule
Variable	Optimizing airside economizer	Adding chilled water supply temperature set point reset strategy	Optimizing daylighting control

The method presented in this protocol provides direction regarding: (1) how to account for each measure's specific characteristics, and (2) how to choose the most appropriate savings verification approach.[1]

[1] 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.

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In a classic RCx process, improvements to building systems and operations are identified, implemented, and maintained via the following five phases (BPA 2011).

1. *Planning.* This phase involves screening buildings to determine whether they provide a good fit for RCx by assessing indicators such as equipment age and condition, building energy performance and size, and type of control system. Ideally, facilities should have an existing building automation system (BAS) in good working order, as well as HVAC equipment that is in relatively good condition. If a facility does not have a BAS, one could be installed; however, this would be considered an HVAC controls and commissioning project rather than an RCx project. When a facility's HVAC equipment nears the end of its useful life, undertaking RCx may not be appropriate, since control measures could become obsolete when the equipment is replaced.
2. *Investigation.* The investigation phase involves: analyzing facility performance by reviewing building documentation, performing diagnostic monitoring and functional tests, and interviewing staff; identifying a list of recommended improvements; and estimating savings and costs.
3. *Implementation.* The implementation phase involves: prioritizing recommended measures and developing an implementation plan; implementing the measures; and testing to ensure they operate as intended. Implementation often entails an iterative approach, since final control set points may need to be determined through several stages of modification and assessment. These stages ensure that building equipment continues to operate properly and that occupant comfort can be maintained. Typically, a facility's BAS is used to assess how effectively RCx measures operate.
4. *Turnover.* The turnover phase involves: updating building documentation (e.g., system operation manuals); developing and presenting a final report; and training building operators on proper operations and maintenance (O&M).
5. *Persistence.* The persistence phase involves: monitoring and tracking energy use over time; continually implementing persistence strategies, such as refining control measures or enhancing O&M procedures, to ensure that savings are sustained; and documenting ongoing changes. Depending on the availability of program resources and the program timeline, this phase is not always actively supported by energy-efficiency programs.

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2 Application Conditions of Protocol

RCx program activities are designed to overcome a number of market barriers, as shown in Figure 3.

Figure 3. RCx Market Barriers

Market Segment	Barrier	Opportunities
Supply-Side Actors, End Users	Lack of tangible examples of RCx performance *in situ*	Undertaking pilot projects
Supply-Side Actors	Lack of service provider capacity for undertaking the RCx investigation and implementation phases	Training for service providers
End Users	Lack of awareness and understanding of the RCx benefits	Education to increase building owner and operator awareness
End Users	Cost of undertaking RCx	Incentives

Energy-efficiency programs are designed to overcome these barriers through activities addressing available opportunities. RCx programs may include some or all of the following activities.

- *Pilot projects.* Program administrators sometimes fund pilot projects to demonstrate the benefits of RCx to end users in their target markets. Savings for these pilot projects would be verified using the methods presented later in this protocol and, ideally, these savings would attract participants to the program.
- *Training.* Program administrators sometimes fund or develop training for service providers. In some jurisdictions, service providers do not routinely provide RCx services to their customer base. Thus, to develop RCx capacity in the market, program administrators might offer training to service providers on how to provide best practice RCx investigation and implementation services. Service providers may also require training on how to sell these services to their clients.
- *Education.* Program administrators sometimes develop educational materials and hold events or workshops for end users. Prior to making a decision to undertake RCx activities in their facilities, building management and building operators need to understand the business case for RCx. Detailed cases studies showcasing project savings are an example of education tools that can be used to facilitate this decision making process.
- *Incentives.* Program administrators often provide incentives to undertake the RCx investigation, implementation, and persistence phases. Even though the payback for RCx measures is typically low, end users often require incentives to encourage them to move forward with projects[2]. Incentives may also encourage end users to undertake projects sooner—or with a greater scope—than they would have without market intervention.

This protocol provides structured methods for determining energy savings resulting from the implementation of RCx measures. The approaches described here provide direction on how to verify savings consistently from pilot projects as well as from projects implemented by program participants. It does not address savings achieved through training or through market transformation activities.

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[2] Some programs may impose a penalty, rather than an incentive. For example, if participants fail to implement measures identified during the investigation phase that fall below a certain payback threshold, they may not be eligible for the full investigation phase incentive.

3 Savings Calculations

Specific savings calculations[3] for RCx measures inherently vary, due to the breadth of possible RCx measures, which can differ by type of equipment or control mechanism. This section presents a high-level gross energy savings equation that is applicable to all RCx measures. Detailed directions for specific measure categories are presented under Section 4, Measurement and Verification Plan.

Energy savings for all measures will be determined using the following general equation (EVO 2012):

Equation 1

Energy Savings = (Baseline Energy – Reporting Period Energy) ± Routine Adjustments ± Non-Routine Adjustments

Where,

Energy Savings	= First-year energy consumption savings.
Baseline Energy	= Pre-implementation consumption.
Reporting Period Energy	= Post-implementation consumption.
Routine Adjustments	= Adjustments made to account for routinely changing independent variables (variables that drive energy consumption). Savings should be normalized to typical meteorological year (TMY) weather data as well as other significant independent variables (e.g., occupancy, production data), if applicable.
Non-Routine Adjustments	= Adjustments made to account for parameters typically not expected to change during the implementation period. If these parameters change *and* this change influences the reporting period energy use, they should be accounted for (e.g., changes to a facility's building envelope during implementation of an RCx HVAC measure). This would only have to be considered if savings were verified using Option C of the International Performance Measurement and Verification Protocol (IPMVP).[4]

Determining RCx demand savings is not a straightforward extension of verified consumption savings (unlike lighting retrofits, for example, where established load savings profiles can easily be applied to consumption savings data). For RCx projects, load savings profiles vary, depending on the distribution of the measure types implemented. If applicable, evaluators should produce load savings profiles on a measure-by-measure basis,[5] aggregate these profiles, and then apply regional coincidence factors to determine coincident peak demand savings at the project level.

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3 As presented in the Introduction, the protocols focus on gross energy savings and do not include other parameter assessments, such as net-to-gross, peak coincidence factors, or cost-effectiveness.

4 Whole facility consumption analysis

5 Alternatively, if savings are verified using Option C or D of the IPMVP, the aggregate project level load savings profile could be measured or computed, negating the requirement to build up the profile on a measure-by-measure basis. If Option C is being used, evaluators should investigate whether data from advanced metering infrastructure (e.g. interval meters) is available in order to increase the accuracy of billing data analyses.

4 Measurement and Verification Plan

This section contains both recommended approaches to determining RCx energy savings and the directions on how to use the approaches. The information is presented under the following headings:

- M&V Method
- Data Collection
- Interactive Effects
- Specific Savings Equations
- Regression Model Direction
- Deemed Spreadsheet Tool Functionality Requirements

4.1 M&V Method

There is a structured method for determining the most appropriate approach to verifying RCx energy savings. This method balances the need for accurate energy-savings estimates with the need to keep M&V costs in check, relative to project costs and anticipated energy savings. Depending on what measures are implemented, different approaches to estimating the savings are appropriate. Following IPMVP protocols, the following options are:

Option A: Retrofit Isolation: Key Parameter Measurement

Option B: Retrofit Isolation: All Parameter Measurement

Option C: Whole Facility

Option D: Calibrated Simulation

Measurement is inherent with most RCx projects since RCx measures typically involve modifications made through a facility's BAS. As mentioned, the implementation process, which often is iterative, leverages metered data to evaluate and optimize changes being made. Therefore, in many cases, a retrofit isolation approach adhering to Option A or Option B of the IPMVP proves most logical. That said, scenarios exist where Option C, Option D, or even a deemed approach may be more appropriate. Figure 4 presents a decision flow chart for determining the approaches to follow.

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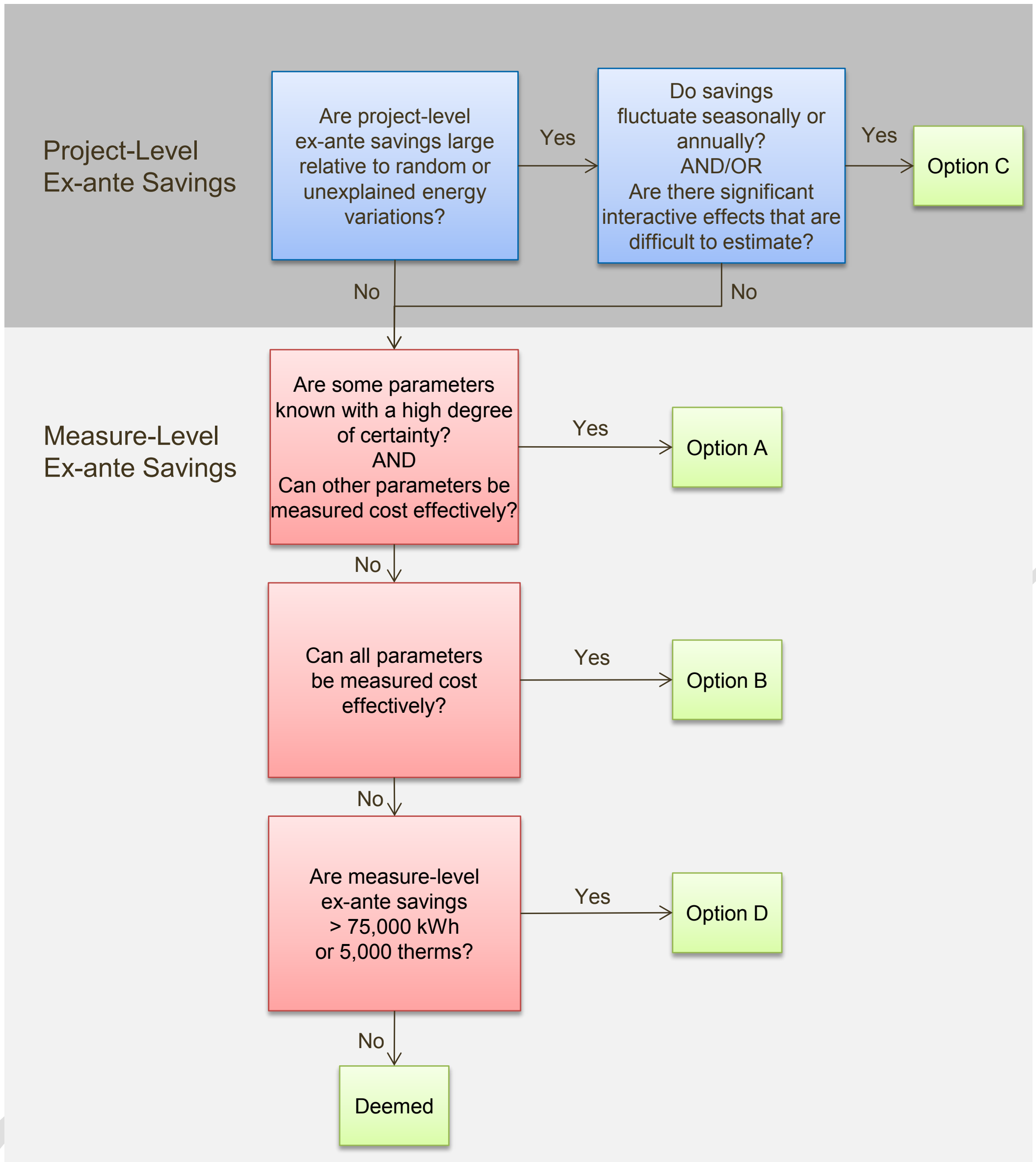
Figure 4. RCx Approach—Decision Flow Chart



The decision-making process shown in Figure 4 accounts for factors such as the magnitude of estimated savings and the measurement's cost-effectiveness. The process begins by considering project-level savings.

- *Option C*. If estimated project-level savings are large compared to the random or unexplained energy variations that occur at the whole facility level[6], and if savings fluctuate over a seasonal or annual cycle (e.g. savings that fluctuate depending on OAT), a whole facility approach—adhering with Option C of the IPMVP—likely is the most cost-effective approach for verifying savings. This approach proves relatively inexpensive, as it involves analysis of utility bill data. It has a downside, however, in that verification cannot be undertaken until a full season or year of reporting period data has been collected. Even if savings remain

[6] Typically savings should exceed 10% of the baseline energy for a particular meter (e.g. electricity meter) in order to confidently discriminate the savings from the baseline data when the reporting period is shorter than two years (EVO 2012).

consistent month to month, Option C may provide the best approach if project measures cause complex, significant interactive effects. Such interactive effects are, by nature, difficult to estimate accurately. Also, if the effects are significant (large, relative to direct-measure savings), a whole-facility approach might be required to measure impacts accurately. The reduced heating and cooling energy resulting from schedule changes to an air handling unit, when control modifications have also been undertaken for both the heating and cooling systems, is an example of a complex significant interactive effect warranting Option C.

If Option C is ruled out, verification should be considered on a measure-by-measure basis.

- *Option A.* If measures involve some parameters known with a high degree of certainty *and* other parameters can be measured cost-effectively, then a retrofit isolation approach adhering to Option A of the IPMVP likely presents the most cost-effective approach for verifying savings. In many cases, metered data can be collected directly from the facility's BAS. If required, additional control points can be added to the BAS, either as part of the implementation process or specifically for M&V purposes. Where the BAS cannot provide the information, temporary meters may be used to collect data, provided that costs are not prohibitive.
- *Option B.* If a given measure's parameters are uncertain, but can be measured cost-effectively, a retrofit isolation approach adhering to Option B of the IPMVP likely offers the most cost-effective approach for verifying savings. Metered data could be collected (similar to Option A) either through the BAS or by using temporary meters.
- *Option D.* A calibrated simulation approach adhering to Option D of the IPMVP will have to be followed with measures for which it is prohibitive to meter all required parameters. Calibration should be undertaken in two forms: (1) the simulation should be calibrated to the actual baseline or reporting consumption data; and (2) the reporting period inputs should be confirmed via the BAS front-end system, wherever possible.[7] [8]
- *Deemed.* Finally, if a measure is relatively common[9] and its estimated savings are small, its savings may be deemed rather than simulated. Savings estimates can be considered "small" if they are less than 75,000 kWh or 5,000 therms[10] (PECI 2010). A spreadsheet tool should be used to calculate savings, adhering to functionality requirements presented later in the protocol.

4.2 Data Collection

Depending on the approach followed, these M&V elements will require particular consideration:

- The measurement boundary;
- The measurement period and frequency;
- The functionality of measurement equipment being used; and
- The savings uncertainty.

[7] In many cases, the simulation should represent the entire facility; however, in some cases, depending on the facility's wiring structure, a similar approach could be applied to building sub-meters, such as distribution panels that include the affected systems.

[8] See chapter on Commercial New Construction for more information on using Option D

[9] If regulators are involved, going through the effort of deeming savings for a rare measure can be burdensome.

[10] Program administrators and evaluators may wish to customize these thresholds for particular programs and/or jurisdictions.

4.2.1 Measurement Boundary

For measures that are assessed with an Option A or Option B approach and that require metering external to the BAS, it will be important to define the measurement boundary. When determining boundaries—the location and number of measurement points required—the project's complexity and expected savings should be considered:

- A narrow boundary simplifies data measurement (e.g. a single piece of equipment), but the variables driving energy use outside the boundary (interactive effects) will need to be accounted for;
- A wide boundary will minimize interactive effects and increase accuracy (e.g. systems of equipment like chilled water plants and air handling units). However, as M&V costs may also increase, it is important to ensure that the expected project savings justify the increased M&V costs.

4.2.2 Measurement Period and Frequency

For all measures assessed with an Option A or Option B approach, two important timing metrics should be considered:

- The measurement period (the length of the baseline and reporting periods); and
- The measurement frequency (how regularly measurements are taken during the measurement period).

As a general rule, the measurement period should be chosen to capture a full cycle of each operating mode. For example, if a control modification has been made to heating equipment, data should be collected over the winter and shoulder seasons.

The measurement frequency should be chosen by assessing the type of load measured:

- *Spot Measurement:* For constant loads, power can be measured briefly, preferably over two or more intervals.
- *Short-Term Measurement:* For loads predictably influenced by independent variables (e.g., HVAC equipment influenced by OAT), short-term consumption measurements should be taken over the fullest range of possible independent variable conditions, given M&V project cost and time limitations. [11] For systems expected to have non-linear dependence (such air handling units with outside air economizers), measurements should incorporate sufficient range to characterize the full breadth of conditions.
- *Continuous Measurement:* For variable loads, consumption data should be measured continuously, or at appropriate discrete intervals, over the entire measurement period.

Direction regarding measurement periods and frequency for specific measure types are provided under the "Specific Saving Equations" subheading.

4.2.3 Measurement Equipment

When meters external to the BAS are required, the meter selection process should follow these guidelines:[12]

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[11] For example, if control modifications have been made to a chiller plant, the measurement frequency should be long enough to capture the full OAT operating range. In a temperate climate zone, this could be accomplished by taking measurements over a four-week period in the shoulder season, and another four-week period during the summer season.

[12] For more information on selecting measurement equipment, see the cross-cutting chapter on Metering

- Size the meter for the range of values expected most of the time.
- Select the meter repeatability and accuracy that fits the budget and intended use of the data.
- Install the meter as recommended by the manufacturer.
- Calibrate the meter the meter before it goes into the field, and maintain calibration, as recommended by the manufacturer. If possible, select a meter with a recommended calibration interval that is longer than the anticipated measurement period.

4.2.4 Savings Uncertainty
Accuracy of measured data[13] should be quantified, if possible, and an error propagation analyses should be undertaken to determine overall impacts on the savings estimate.

4.3 Interactive Effects
For projects following Option A, Option B, or deemed approaches, interactive effects should be considered and estimated, if they are significant. For example, if an air handling unit supply fan schedule is reduced, not only will direct fan savings will be achieved, but significant cooling and heating energy savings may be realized due to decreases in conditioned ventilation air supplied to the space.

Interactive effects should be estimated using equations that apply the appropriate engineering principles. Ideally, these analyses would be undertaken using a spreadsheet tool adhering to the same functionality requirements discussed for the Deemed Spreadsheet Tool. When interactive effects are expected to be large, it may be possible to measure them rather than applying engineering estimates. In the example above, the chilled water plant could be metered to determine the cooling load reduction.

Interactive effects for projects being verified using Option C or Option D are typically included in facility-level savings estimates.

4.4 Specific Savings Equations
If Option A or Option B is followed, savings will need to be verified using equations matching a given measure's characteristics: specifically, whether savings are dependent on independent variables (such as OAT) and how the affected equipment is controlled.

Figure 5 presents the three categories of savings equations, with further explanations following the flow chart:

[13] Metering accuracy is only one element of savings uncertainty. Inaccuracies also result from modeling, sampling, interactive effects, estimated parameters, data loss, and measurements being taken outside of a meter's intended range.

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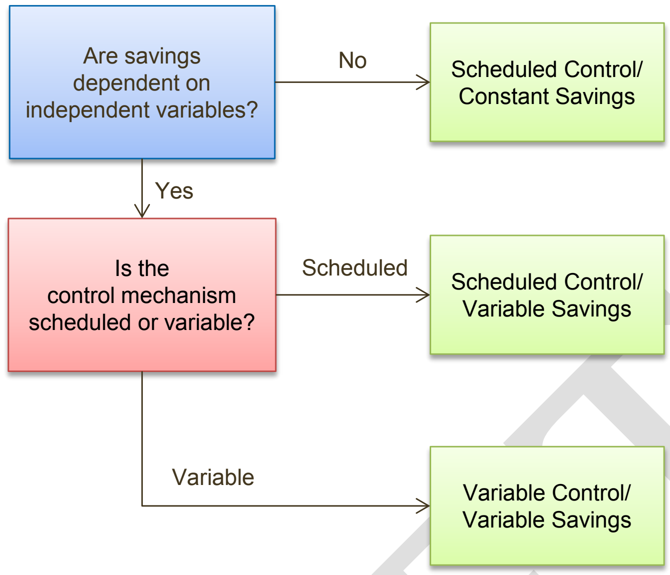
Figure 5. Savings Equation Categories



4.4.1 Scheduled Control/Constant Savings

This savings equation category encompasses scheduled control measures on equipment not influenced by independent variables (such as OAT); therefore, this is the most straightforward equation category.

Lighting schedule optimization presents an example of a measure verified using this savings equation category. In this example, lighting would be turned off according to a schedule (scheduled control), and constant savings would be achieved while it is off (constant savings)[14].

Equation 2

Scheduled Control/Constant Savings = Baseline Energy – Reporting Period Energy

Where,

Scheduled Control/Constant Savings = First-year energy consumption savings resulting from a scheduled control measure with constant savings.

Baseline Energy = $HRS_{baseline}$ x $kW_{controlled}$

Reporting Period Energy = $HRS_{reporting}$ x $kW_{controlled}$

And,

$HRS_{baseline}$ = Annual operating hours during the baseline: If this parameter is not known with a high degree of certainty, it should be measured. Short-term measurements should be taken for the duration of each existing schedule type.

[14] While a single piece of equipment (one lighting fixture) may have a constant load, the system (lighting throughout a building) may have some variability. In a lighting system that includes a degree of occupant control (such as switches in private offices) nearly one hundred percent of fixtures may operate midday, but substantially fewer may be on at the beginning or end of the day when the savings due to scheduling would likely occur.

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$HRS_{reporting}$ = Annual operating hours during the reporting period: Short-term measurements should be taken for the duration of each new schedule type.

$kW_{controlled}$ = Electric demand controlled by scheduling measure: If this parameter is not known with a high degree of certainty, it should be measured. Spot measurements should be taken during the baseline or reporting period.

4.4.2 Scheduled Control/Variable Savings

This savings equation category encompasses scheduled control measures on equipment influenced by independent variables (such as OAT). Space setback temperature optimization provides an example of a measure verified using this savings equation category. In this example, the heating space temperature set point would be lowered according to a schedule during unoccupied hours (scheduled control), and the savings achieved would vary, depending on OAT (variable savings).

Following Equation 3, Figure 6 presents the five-step process for determining adjusted baseline and reporting period energy consumption.

Equation 3

Scheduled Control/Variable Savings = Adjusted Baseline Energy – Adjusted Reporting Period Energy

Where,

Scheduled Control/Variable Savings = First-year energy consumption savings resulting from a scheduled control measure with variable savings.

Adjusted Baseline Energy = $\sum_{All\ Schedule\ Types} Adj\ Baseline\ Consumption_{Schedule\ Type}$ and determined through the five-step process presented below.

Adjusted Reporting Period Energy = $\sum_{All\ Schedule\ Types} Adj\ Reporting\ Period\ Consumption_{Schedule\ Type}$ determined through the five-step process presented below.

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Figure 6. Adjusted Consumption for Scheduled Control/Variable Savings Measures

<table>
<tr><th>Step</th><th>Details</th></tr>
<tr><td>1. Develop baseline/ reporting regression model(s) by measuring equipment operation and independent variables.</td><td>Take short-term measurements at representative load levels for the affected equipment for each schedule type.
Take coincident measurements of the independent variable(s).
Do a regression analysis to determine the relationship between independent variables and equipment load. This relationship should be expressed in terms of an equation (baseline/reporting period model). Note: if there are schedules for occupied and unoccupied times during the reporting period, two regression models are required, one for each set of data.</td></tr>
<tr><td>2. Develop a bin operating profile[15] by normalized independent variable data.</td><td>Develop bin data tables presenting the following data (one table for each schedule type):
<table>
<tr><th>Independent Variable</th><th>Load</th><th>Annual Hours</th></tr>
<tr><td>Create approx. 10 bins over the normalized independent variable data range. (e.g., if the equipment's energy consumption varies depending on weather, use normalized TMY.)</td><td>Calculate the normalized load by applying the baseline/reporting period regression model to the midpoint of each bin.</td><td>Use short-term measured data to estimate hours of operation within in each bin, or base this on TMY data and the equipment operating schedule.</td></tr>
</table></td></tr>
</table>

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[15] Alternatively, if the independent variable is OAT, an hourly profile could be developed over the full operating schedule of the affected equipment.

Step	Details
3. Calculate the baseline/reporting period consumption at each load bin for each schedule type.	Adj $\text{Consumption}_{\text{Load,Shedule Type}}$ = $\text{Load}_{\text{Schedule Type}}$ x Annual $\text{Hrs}_{\text{Schedule Type}}$
4. Sum the consumption savings across bins for each schedule type.	$\sum_{All\ Load\ Bins_{Schedule\ Type}} Adj\ Consumption_{Load,Schedule\ Type}$
5. Sum the consumption savings across schedule types.	$\sum_{All\ Schedule\ Types} Adj\ Consumption_{Schedule\ Type}$

4.4.3 Variable Control/Variable Savings

This savings equation category encompasses variable control measures on equipment influenced by independent variables, such as OAT. Introducing a chilled water supply temperature set point reset strategy serves as an example of a measure that would be verified through this savings equation category. In this example, the chilled water supply temperature set point would be determined depending on OAT (variable control), and the savings achieved would vary depending on OAT (variable savings).

Following Equation 4, Figure 7presents the four-step process for determining the adjusted baseline and reporting period energy consumption.

Equation 4

Variable Control/Variable Savings = Adjusted Baseline Energy – Adjusted Reporting Period Energy

Where,

Variable Control/Variable Savings = First-year energy consumption savings resulting from a variable control measure with variable savings.

Adjusted Baseline Energy = $\sum_{All\ Load\ Bins} Adj\ Baseline\ Consumption_{Load}$ determined through the four-step process presented below.

Adjusted Reporting Period Energy = $\sum_{All\ Load\ Bins} Adj\ Reporting\ Period\ Consumption_{Load}$ determined through the four-step process presented below.

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Figure 7. Adjusted Consumption for Variable Control/Variable Savings Measures

<table>
<tr><th>Step</th><th colspan="3">Details</th></tr>
<tr><td>1. Develop baseline/reporting regression model(s) by measuring equipment operation and independent variables.</td><td colspan="3">• Take short-term measurements at representative load levels for the affected equipment.
• Take coincident measurements of the independent variable(s).
• Do a regression analysis to determine the relationship between independent variables and equipment load. This relationship should be expressed in terms of an equation (baseline/reporting period model).</td></tr>
<tr><td rowspan="3">2. Develop a bin operating profile[16] by normalized independent variable data.</td><td colspan="3">• Develop bin data tables that present the following data:</td></tr>
<tr><td>Independent Variable</td><td>Load</td><td>Annual Hours</td></tr>
<tr><td>Create approx. 10 bins over the normalized independent variable data range. (e.g., if the equipment's energy consumption varies depending on weather, use normalized TMY.)</td><td>Calculate the normalized load by applying the baseline/reporting period model to the midpoint of each bin.</td><td>Use short-term measured data to estimate hours of operation within in each bin, or base this on TMY data and the equipment operating schedule.</td></tr>
<tr><td>3. Calculate the baseline/ reporting period consumption at each load bin.</td><td colspan="3">$\text{Adj Consumption}_{\text{Load}} = \text{Load} \times \text{Annual Hrs}$</td></tr>
<tr><td>4. Sum the consumption savings across all load bins.</td><td colspan="3">$\sum_{All\ Load\ Bins} Adj\ Consumption_{Load}$</td></tr>
</table>

4.5 Regression Modeling Direction

To calculate normalized savings, whether following the IPMVP's Option A, Option B, or Option C, a baseline and reporting period regression model[17] will need to be developed for the majority of projects. There are three types of analysis methods can be used to create a model:

- *Linear Regression:* For one routinely varying significant parameter (e.g., OAT)[18].
- *Multivariable Linear Regression:* For more than one routinely varying significant parameter (e.g., OAT, occupancy).
- *Advanced Regression:* Such as polynomial or exponential[19].

When required, these models should be developed in accordance with best practices, and they should only be used when they are statistically valid (see subsection 4.5.2, *Testing Model Validity*). If no significant independent variables arise (as with a lighting schedule measure), a model is not required, because calculated savings will be inherently normalized.

4.5.1 Best Practice Model Development

Energy and independent variable data should be representative of a full cycle of operation. Thus, for a heating space temperature setback measure, collect energy data across the full range of OATs for each

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[16] Alternatively, if the independent variable is OAT, an hourly profile could be developed over the full operating schedule of the affected equipment.
[17] This could either be a single regression model that uses a dummy variable to differentiate the baseline/reporting period data, or two independent models for the baseline and reporting period respectively.
[18] One of the most common linear regression models is the three-parameter change point model. For example, a model that represents cooling electricity consumption would have one regression coefficient that describes non-weather dependent electricity use, a second regression coefficient that describes the rate of increase of electricity use with increasing temperature, and a third parameter that describes the change point temperature, also known as the balance point temperature, where weather-dependent electricity use begins.
[19] Advanced regression methods might be required if RCx activities impact manufacturing or industrial process equipment.

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of the operating schedules (occupied and unoccupied) for each season, as shown in Figure 8.

Figure 8. Example of Data Required for Model Development

	Shoulder Season	Winter Season
Occupied Hrs	Short-term energy measurements during occupied hours. Measurements should be representative of the full range of shoulder-season OAT (approximately 10 OAT bins).	Short-term energy measurements during occupied hours. Measurements should be representative of the full range of winter-season OAT (approximately 10 OAT bins).
Unoccupied Hrs	Short-term energy measurements during unoccupied hours. Measurements should be representative of the full range of shoulder-season OAT (approximately 10 OAT bins).	Short-term energy measurements during unoccupied hours. Measurements should be representative of the full range of winter-season OAT (approximately 10 OAT bins).

The data collected should be analyzed to identify outliers. This involves employing approaches such as the cumulative sum (CUSUM)[20] of differences technique or by visually inspecting a plot of the energy consumption data versus the independent variable data. Only remove outliers when a tangible explanation can be provided to support the erratic data points.

4.5.2 Testing Model Validity

To assess the model's accuracy, review the parameters listed in Figure 9 (EVO 2012).

Figure 9. Model Statistical Validity Guide

Parameter Evaluated	Description	Suggested Acceptable Values
Coefficient of Determination (R^2)	A measure of the extent that variations in the dependent variable from its mean value are explained by the regression model.	> 0.75
T-statistic	An indication of whether regression model coefficients are statistically significant.	> 2
Mean bias error	An indication of whether the regression model overstates or understates actual energy consumption.	Will depend on the measure, but generally: < +/- 5%

If any of these parameters fall outside their acceptable ranges, the regression model is not considered statistically valid, and should not be used to normalize data. When possible, attempts should be made to enhance the regression model by increasing or shifting the measurement period; by incorporating more data points; by including independent variables that were previously unidentified; or by eliminating statistically insignificant independent variables.

4.6 Deemed Spreadsheet Tool Functionality Requirements

When collecting measured energy data is not cost-effective and claimed (*ex ante)* savings estimates for a given measure are sufficiently small (75,000 kWh or 5,000 therms), a deemed approach can be used to calculate savings. In this scenario, a spreadsheet tool should be used to calculate savings, and this tool should meet these general requirements.

- *The model should be transparent.* A third party should be able to review the spreadsheet tool and clearly understand how all savings outputs have been derived. To this end, all inputs and

[20] The CUSUM technique involves running independent variable data through the model and comparing energy consumption outputs to actual energy consumption data. Differences are summed over the range of independent variable inputs. If no significant outliers arise, the plotted sum of differences should be a horizontal line, intersecting zero on the y-axis (i.e., the differences should be insignificant).

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calculation algorithms should be clearly explained and referenced within the spreadsheet, cells or sheets should not be locked or hidden, and links should not be broken.

- *Relevant secondary data should be used.* When secondary data are used as inputs to savings algorithms, they should be relevant to the project's region or jurisdiction. This relevancy should be substantiated within the spreadsheet. For example, if hours of operation for heating equipment are assumed, these secondary data should be taken from a regional resource (e.g., a technical resource manual from the most applicable demand-side management authority).
- *Input elements should be verified, either on-site or through the BAS front-end system.* Even when using a deemed approach, verify and update some inputs with actual site observations, rather than by solely relying on secondary data. For example, a new lighting schedule should be confirmed through the BAS front-end system and noted in the spreadsheet tool.
- *Default values for unverifiable parameters should be established*. For certain parameters that cannot be verified, default values should be used. For example, assumed values for motor efficiencies and load factors should be clearly stated.

The Building Optimization Analysis Tool[21], developed by Portland Energy Conservation, Inc., (PECI 2010) provides an example of a best-practice benchmark for RCx spreadsheet tools. Although the following rigor level is not required, ideally, a best practice spreadsheet tool should:

- Incorporate regional TMY data;
- Incorporate regional building archetype templates; and
- Undergo a calibration process, testing algorithms using measured data from previous regional projects.

[21] Download for free at: http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html

5 Sample Design

Chapter 11: *Sample Design* describes general sampling procedures that should be consulted if the RCx program project population is sufficiently large, or if the evaluation budget is constrained. Ideally, stratified sampling should be undertaken by partitioning RCx projects by measure type, facility type, and/or project size. This stratification ensures that sample findings can be extrapolated confidently to the remaining project population. The confidence and precision-level targets that influence sample size are typically governed by regulatory or program administrator specifications.

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6 Other Evaluation Issues

When claiming lifetime and net program RCx impacts, persistence and net-to-gross (NTG) should be considered in addition to first-year gross impact findings.

6.1 Persistence

Persistence of savings encompasses both the retention and the performance degradation of measures. Evaluators should consider persistence on a program-by-program basis because the persistence of RCx projects can vary widely depending on the distribution of measure types implemented and, perhaps more significantly, on how well modifications are maintained. Chapter 13: *Assessing Persistence and Other Evaluation Issues* can be consulted for more information.

6.2 Net-to-Gross

The cross-cutting net-to-gross chapter discusses an approach for determining net program impacts at a general level, including direction on how to assess free-ridership. Supplementary to this general section, however, evaluators may consider assessing participant spillover if evidence emerges of participants implementing no-cost measures. This would specifically apply to no-cost measures identified during the investigation phase, but not explicitly included under the scope of program-funded RCx implementation activities.

If no-cost measures exist, but no savings claims have been made, the attribution evaluation may involve interviews with building operators and their service providers to obtain estimates of the savings magnitude resulting from these measures. Participant spillover would positively influence on the program's overall NTG factor.

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