Deep Energy Retrofit
Energy Modelling Guide – 2021
Version 1.0

Prepared by
Sustainable Buildings Canada

Acknowledgements

Sustainable Buildings Canada (SBC) has prepared this Guide as a resource for energy modellers to aid in the modeling of Deep Energy Retrofit projects. SBC wishes to thank all modellers participating in the Savings by Design program for their continuing support and their active involvement in improving the program and the critical energy modelling science that supports it.

SBC would like to thank Ryan Evans and the team from EVNA Engineering for their significant contributions to the development of this Guide. Any errors or omissions are purely the responsibility of SBC.

SBC welcomes users of this Guide to provide commentary regarding content and potential areas for improvement. Please email: msingleton@sbcanada.org.

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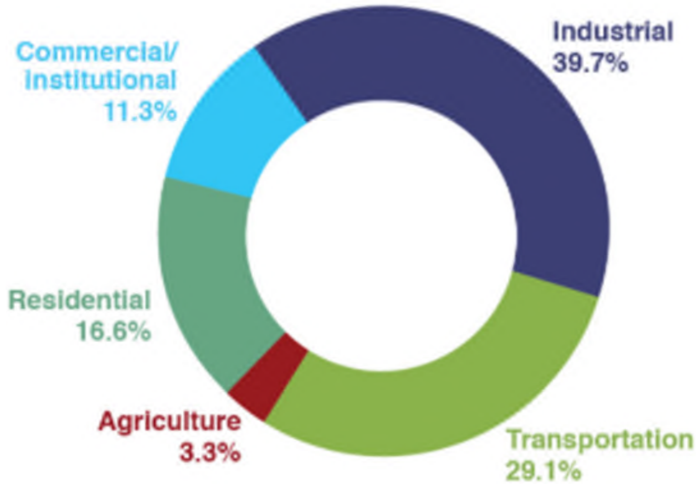
1.0 INTRODUCTION

In 2017, Natural Resources Canada (NRCan) reported that the Commercial/Institutional and Residential sectors accounted for a combined 28% of Canada's total 9,089 PJ of secondary energy use[1] (Figure 1).

Figure 1: Secondary Energy Use by Sector (2017)



As all levels of government continue to impose more stringent targets to lower energy consumption and greenhouse gas emissions, the focus of these targets must include existing buildings of all types and notably in the commercial/institutional and multi-unit residential sectors (CIMs). Deep Energy Retrofits (DER) are expected to become an industry standard for achieving high reductions in both energy use and GHG emissions in the existing building sectors.

While there currently is no standardized definition for what constitutes a DER, one definition that appears to be gaining industry acceptance is as follows:

A Deep Energy Retrofit (DER) consists of an extensive whole-building analysis and construction process aimed at reducing a building's energy use by at least 50% compared to a historical baseline[2]. Successful implementation of a DER can additionally result in an overall performance improvement of a building's indoor air quality, durability, and thermal comfort.

Sustainable Buildings Canada (SBC) notes that there may be challenges with using a single threshold to establish what constitutes a DER due to building specific conditions. SBC thus prefers to use an "activity-based" definition which combines both a threshold metric of 50% reduction and an activity metric that requires the consideration of envelope upgrades along with mechanical/active systems upgrades where the 50% reduction is a target but envelope upgrades are a requirement. In particular, SBC notes that envelope upgrades will result in a reduction in heating loads which is important for achieving GHG reductions in jurisdictions where natural gas or fuel oil are the predominant energy sources for space heating. It is understood that not all projects will achieve the 50% reduction, however including the envelope retrofit expectation ensures a holistic perspective on the project.

[1] **Secondary energy** is energy that has been transformed to more convenient forms of energy that can be used directly by society, such as electricity, refined fuels, or synthetic fuels such as hydrogen fuel. Secondary energy is also referred to as energy carrier. (https://oee.nrcan.gc.ca/publications/statistics/trends/2017/totalsectors.cfm#L1)

[2] This is consistent with the Federal Government's target and with a number of municipal governments.

1.1 Category of Building Retrofits

There are three typical categories of retrofitting an existing building; Minor Retrofits, Major Retrofits, and DER. Some of the key differences between the three are outlined in the following table.

	Minor Retrofit	Major Retrofit	DER
Approach	Typically consists of low-cost system upgrades with short payback period. For example: lighting retrofits or operational improvements.	Typically consists of more complex system upgrades, with higher costs and longer payback period. For example: heating & cooling systems. *Please note that building additions can sometimes be considered as a major retrofit.*	A whole building system upgrade, including building enclosure, mechanical, and electrical systems, resulting in significant overall energy use reduction.
NBC Code Parts	Part 10 or 11	Part 3, 9, 10, or 11	Part 3, 9, 10, or 11
Energy Performance	Offers small energy savings relative to the historical Baseline (<10%).	Offers higher energy savings relative to the Baseline (10-30%).	Offers at least 50% energy savings relative to the historical Baseline.
Implementation Cost	Low	Low – Medium *(Depends on project scope)*	High
Occupant disruption during construction	Minimal	Minimal – Moderate *(Depends on project scope)*	Significant
Improvement to indoor environment quality?	Depends on measure being implemented	Depends on measure being implemented	Yes

1.2 Purpose of this Energy Modelling Guide

This Guide aims to establish a best practice methodology for conducting whole building energy simulations on existing CIMs buildings in the context of implementing DER. While the focus is primarily on DERs, the modeling methodology can be used to model both Minor and Major building retrofit projects.

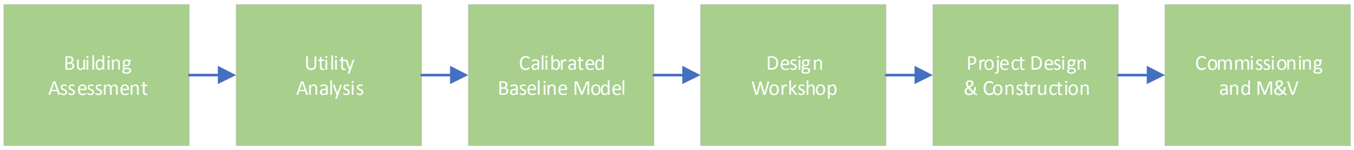
This Guide outlines the energy modelling process and supporting documentation required to clearly demonstrate the anticipated energy performance improvements achievable by undergoing a DER on an existing CIMs building.

Note that the recommended approach includes the use of integrated design, coupled with detailed energy modelling as a way to fast-track the potential savings estimates and identify key issues that might affect the outcome. Having delivered over 600 design workshops for both new construction and DER, SBC has first-hand experience with the power of integrated design and as such, is a strong proponent of this approach.

1.3 SBC's Approach to DER

SBC recommends the following approach to successfully implement a DER.

Figure 2: SBC DER Approach



1.3.1 Building Assessment

The first step is to complete a thorough assessment of the existing building's systems and operations; whether by on-site assessments, review of building design drawings and schematics, or a combination of the two. The objective of the assessment is to gather enough information on the existing condition of the building to identify opportunities for improvement.

1.3.2 Utility Bill Analysis

This is one of the key differentiators with modelling existing buildings versus new buildings, there are real data to illustrate the building's historical energy use.

The utility bill analysis establishes a representative historical baseline which is used to calibrate the Baseline Building model. Details on conducting a typical utility analysis are outlined in Section 3.1.2 below.

1.3.3 Calibrated Baseline Model

The calibrated Baseline Model is a representative energy model of the existing building systems and operations, calibrated to the historical baseline defined from the utility analysis.

The Calibrated Baseline Model is used to determine the potential energy savings associated with DER.

1.3.4 Integrated Design Workshop as Applied to DER

SBC promotes the use of an Integrated Design Workshop as a way of establishing recommendations for building upgrades that can be considered as part of a holistic assessment which includes individual measure savings estimates and a combined measure solution that represents the potential DER outcome. The workshop includes project stakeholders, design team members, and subject matter experts, for the purpose of engaging in a tailored discussion on the various building system measures that can be considered based on the existing building's current condition. Energy modelling is used to quantify the performance improvements of proposed energy conservation measures associated with the DER.

The building systems typically reviewed/discussed during the workshop include:

- Building Enclosure (e.g. walls, roof, slabs, windows, doors, airtightness)
- Loads Reduction (e.g. lighting, elevators, plug load equipment etc.)
- Water-side HVAC (e.g. boilers, chillers, cooling towers, pumps)
- Air-side HVAC (e.g. Make Up Air Units, rooftop units, terminal units, fan coils, heat pumps)
- Domestic hot water

1.3.5 Project Design & DER Construction

The phase of DER where the design is finalized, and construction is started/completed.

It is strongly recommended to retain a third party commissioning agent to ensure the energy performance targets are achieved following retrofit completion.

1.3.6 Commissioning and Measurement & Verification

Following completion of the construction phase, the final items of building commissioning are executed to ensure that the building systems installed during construction comply with the design requirements, and that the building operations comply with the new sequence of operations defined by the design team.

Measurement & Verification (M&V) is conducted according to the M&V Plan defined prior to the retrofit, and details the process to be followed to confirm the energy savings estimate was achieved.

1.4 Simulation Program

Whole-building energy simulation programs are computer-based software programs for the analysis of energy use in building. These programs are commonly used in new building construction to ensure compliance with Building Code energy performance requirements, achieving green building certifications and designations, and applying for project incentive funding. These same programs can be used for DER projects.

Recommended energy modelling software includes any of the following 8,760-hour whole-building simulation software (tested to ASHRAE 140 Standard), which are all capable of producing the necessary hourly reports of energy use to establish the annual energy consumption for the Baseline and Proposed Building design models:

- ☐ CAN-QUEST version 1.1 rev 3268 or higher,
- ☐ EnergyPlus version 8.6 or higher,
- ☐ eQUEST version 3.65 build 7173 or higher, or
- ☐ IES Virtual Environment version VE 2016 or higher.

For reference, ASHRAE Standard 140 specifies a standard method of test for evaluating the technical capabilities and applicability of software used in calculating the thermal performance of buildings and their HVAC systems. These test procedures can then be used to identify/diagnose predictive differences from whole-building energy simulation software that may be caused by algorithmic differences, modelling limitations, faulty coding, inadequate documentation, or input errors.

1.5 Definitions and Abbreviations

Applicable Building Code : means (a) the "building code" as defined in the Building Code Act, 1992 (Ontario), as may be amended; and (b) any other applicable building code imposed by a municipality, if any, to the extent that it supplements the building code referred to in (a) or any part thereof.

Baseline Building: a representative energy model of the existing building systems and operations, calibrated to a historical baseline (i.e. – the current energy use of the building).

Building: A wholly enclosed structure used or intended for supporting or sheltering any use or occupancy. Buildings that are subject to the practices outlined in this modelling guide include buildings under Part 3, Part 9 and Part10/11of the Building Code.

Building Permit Application: means the initial construction building permit application submitted to the municipality to obtain a building permit – for DER, some provinces require a Building Permit Application.

Clear Field Assembly: An opaque wall or roof assembly with uniformly distributed thermal bridges, which are not practical to account for on an individual basis for U-value calculations. Examples of thermal bridging included in the Clear Field are brick ties, girts supporting cladding, and structural studs. The heat loss associated with a Clear Field assembly is represented by a U- value (heat loss per unit area).

CWEC (2016): normalized Canadian weather data for energy calculations, which includes up to 30 years of data through 2014, available for download here: climate.onebuilding.org

Design Workshop: typically a full day session wherein project stakeholders and their design team participate with team of subject matter experts who focus on specific design solutions tailored to the Proponent's project, with the aim of achieving the DER performance target.

Design Workshop Report: a summary of the workshop discussion topics, including the energy performance improvements of the proposed Energy Conservation Measures discussed during the workshop, and demonstrates the potential of achieving the DER performance target.

Dormitory: consists of individual bedrooms with individual or common/shared bathrooms, common areas, and either a shared common kitchen or no kitchen at all. When modelling multi-residential buildings, the Dormitory space type shall not be used in place of a Dwelling Unit space type (see Residential Dwelling Unit).

Deep Energy Retrofit (DER): consists of an extensive whole-building analysis and construction process aimed at reducing a building's energy use by at least 50% (targeted) compared to a historical baseline and includes envelope upgrades as part of the retrofit. Successful implementation of a DER can additionally result in an overall performance improvement of a building's indoor air quality, durability, and thermal comfort.

Energy Conservation Measure (ECM): is any type of design change or technology recommendation that improves a building's energy performance. ECMs are implemented to reduce the building's energy consumption relative to the Baseline Building.

Energy Modelling Report: means a report prepared by the energy modeller summarizing the methodology and assumptions used with the Approved Modelling Software, in accordance with the required reporting methodology.

Energy-Recovery Ventilator (ERV): A ventilation system designed to recover heat (i.e. sensible and latent) from the exhaust air steam, in order to pre-heat the outdoor air supplied to the downstream system or space.

Energy Savings : means the aggregate of all energy savings expressed in consistent units of ekWh/yr AND GJ/yr and as a percentage of the total annual energy consumption for the Project (calculated as the aggregate of all energy consumption in the calibrated Baseline Building, minus all energy consumption in the Proposed Building, divided by the energy consumption in the calibrated Baseline Building).

Note that for the purposes of ensuring consistent reporting, SBC will provide the conversion factors to be used for the various energy calculations to be used in the design workshop.

Heat-recovery ventilator (HRV): A ventilation system designed to recover heat (i.e. sensible) from the exhaust air steam, in order to pre-heat the outdoor air supplied to the downstream system or space.

Heating Ventilating Air Conditioning (HVAC): Mechanical systems used to condition air by heating or cooling and used to distribute air throughout a building.

Interface Details: Thermal bridging related to the details at the intersection of building envelope assemblies and/or structural components. Interface details interrupt the uniformity of a *clear field assembly* and the additional heat loss associated with interface details can be accounted for by linear and point thermal transmittances (heat loss per unit length or heat loss per occurrence, respectively). Examples of linear interface details include intermediate floor junctions, balconies, wall to roof transitions, and window to wall transitions. Examples of point interface details include structural columns and beams that protrude from the building envelope.

Lighting Power Density (LPD): the amount of lighting power in Watts per unit area.

Measurement and Verification (M&V): the post-construction review process conducted by a qualified measurement and verification professional, to verify whether or not the DER project was successful in achieving the target reduction in energy use relative to the historical baseline.

Modelled Floor Area: is the total modelled area of the building including appropriate conditioned spaces as identified in the drawings. Modelled floor area excludes parking areas.

Proponent: the project stakeholders.

Proposed Building: a representative energy model of the calibrated Baseline Building including the Energy Conservation Measures (ECMs) proposed for the project during the design workshop by the Subject Matter Experts (SMEs). For the purpose of DER, the Proposed Building should target an energy reduction of at least 50% relative to the calibrated Baseline Building and include envelope upgrades.

Reference Building: a representative energy model of the calibrated Baseline Building if it were required to comply with the applicable building code (e.g. OBC-SB-10) requirements in force at the time of the analysis. For the purpose of a DER analysis, the Reference Building is typically used as a benchmark for illustration purposes, highlighting to the project team how the Baseline Building's performance fairs against current code requirements.

Residential Dwelling Unit: also referred to as residential suites in a multifamily building, contains a separate full kitchen and bathroom. A 'full kitchen' consists of a refrigerator, stove/oven, plumbed sink and range hood. A mini fridge with a microwave and hot plate do not constitute a full kitchen.

Retirement Home/Residence: a building or part of a building that is a retirement home as defined in subsection 2 (1) of the Retirement Homes Act, 2010.

Retrofit: A construction process that aims to modify an existing building. A retrofit could be performed to obtain energy savings or to upgrade equipment that has reached its end of life.

Secondary System: means a system that provides air for the purposes of ventilating, heating and cooling a zone or group of zones.

Sensible heat-recovery efficiency (SRE): The apparent effectiveness adjusted per clause 9.3.3 of CSA C439–09 equation 12 to take into account fan energy, leakage (exhaust air transfer), mass and flow imbalance, frost control, and certain other external and internal energy gains and losses.

Site: The building(s) and all associated area where energy is used or generated. A site may include one or more buildings, either as independent structures or interconnected.

Site Energy Use: All energy used on site including all end-uses, such as heating, cooling, domestic hot water, fans, pumps, elevators, parkade lighting and fans, plug and process energy, interior and exterior lighting, among others. It incorporates all site efficiencies, including the use of heat pumps or re-use of waste heat, but does not include energy generated on site.

Subject Matter Expert (SME): An individual engaged for the purposes of the design workshop who has specific expertise related to the key operating characteristics of the building, including opaque and fenestration and related building science, mechanical systems, interior loads, interior environmental quality, costing and estimating etc.

Total energy-recovery efficiency (TRE): The apparent total (enthalpy) effectiveness adjusted per clause 9.3.3 of CSA C439–09 equation 13 to account for fan energy, leakage (exhaust air transfer), mass and flow imbalance and certain other external and internal gains and losses.

2.0 DER DESIGN WORKSHOP

The design workshop consists of project stakeholders, the project design team members, an energy modeller and the subject matter expert team who review the current building systems and make recommendations regarding potential improvements through the implementation of ECMs. Energy modelling is undertaken to estimate their individual and combined energy/GHG emissions reduction potential using the calibrated Baseline Building as the starting point.

For existing buildings, building code requirements are not relevant as older buildings typically demonstrate higher energy consumption when benchmarked against newer buildings in the same operating sector. Additionally, existing buildings tend to fall under Parts 10 and 11 of the Building Code (Ontario), which at the time of this writing, does not contain any energy performance requirements. Note however that some programs (notably the Enbridge Savings by Design Program) requires that the building be treated as if were new which necessitates the creation of a code compliant Reference Building energy model.

2.1 DER Design Workshop Process – What to Expect

The process commences with a planning meeting with the proponent and key design team members. The objective of this meeting is to establish the DER performance expectations and identify the existing building conditions.

With the appropriate commitments in place, a team is assembled which includes cross-disciplinary SMEs and an energy modeller. Recommended SMEs include envelope (opaque and fenestration), actives systems, indoor environment etc. Building assessment data (including as collected by a site visit) and historical utility data are collected and the energy modeller prepares an energy model for the Baseline Building (Refer to Section 3.0 for details) while the SME team reviews the building assessment data, and prepares a list of ECMs for discussion during the workshop.

The workshop starts with a review of the existing conditions and Baseline energy model. With this as a starting point, the SME team facilitates a discussion focusing on the proposed ECMs, and the potential Proposed Building energy performance. The subsequent ECM-specific energy model results are then considered as part a holistic assessment wherein individual measures are selected for inclusion in the final combined DER solution. This process may be iterated a number of times to optimize the final selection of measures and typically includes and understanding of up-front and life-cycle costs, market conditions etc.

The DER measures considered in a design workshop must address all of the existing building systems to some degree; including building envelope, mechanical systems, electrical systems, passive design etc.

Some preliminary analysis tools like the Parametric Analysis can be used to evaluate a variety of DER measure combinations that could achieve significant energy savings relative to the calibrated Baseline Building. Figures 3 and 4 below summarize the typical value-add of various building system retrofit measures, their energy reduction potential, and capital cost ranges.

Figure 3: DER Measure Value Add Examples

1) DEEP ENERGY RETROFIT MEASURES		2) BUILDING PERFORMANCE	3) VALUE	
ENVELOPE	Insulation Windows Air tightness Green/white roof Etc.	THERMAL COMFORT ACTIVE OCCUPANT ENVIRONMENTAL CONTROL INDOOR AIR QUALITY VISUAL ACUITY AND COMFORT GREEN BUILDING RATING OR SCORE VIEWS TO THE OUTDOORS SPACE EFFICIENCY SPACE FLEXIBILITY	REDUCTION IN COST	Lower maintenance cost Lower health cost (absenteeism, health care) Lower employee recruiting and churn costs
PASSIVE DESIGN	Natural ventilation Daylighting Landscaping Etc.		REVENUE GROWTH	Higher occupancy rates Higher rents Increased employee productivity Improved marketing & sales
ELECTRIC LIGHTING	Fixtures upgrade Controls Redesign Etc.		IMPROVED REPUTATION AND LEADERSHIP	Recruiting best employees or tenants Employee or tenant satisfaction and retention Public relations/brand management Retain "social license" to operate
PLUG LOADS & MISC.	Efficient equipment Controls Etc.		COMPLIANCE WITH INTERNAL AND EXTERNAL POLICIES/ INITIATIVES	Meet needs of Global Reporting Initiative, Corporate Social Responsibility, Carbon Disclosure Project Meet responsible investment fund requirements Meet growing Securities and Exchange Commission regulations
HEATING, COOLING, & VENTILATING	Demand control ventilation Digital controls Balance air & water flows Chiller upgrade Etc.		REDUCED RISK TO FUTURE EARNINGS	Reduced risk from energy disclosure mandates Limit exposure to energy/water price volatility Overall reduced potential loss of value due to functional obsolescence Reduced legal risks—sick building syndrome and mold claims, etc.

Figure 4: Typical ECM Energy Reduction & Cost

ENERGY USE	ENERGY REDUCTION (KBTU/SF/YR)	CAPITAL COST ($/SF)
PLUG LOAD	6–15	0
LIGHTING	6–8	3–5
VENTILATION	4–5	2–5
COOLING	10–25	10–75
HEATING	3–10	10–75
TOTAL	30–50	25–150+

3.0 DER MODELLING METHODOLOGY

SBC uses the following approach for conducting a DER energy modelling analysis for the purpose of the design workshop.

a. Energy modeller is retained by SBC and joins the project's design workshop SME team.

b. The energy modeller creates the calibrated Baseline Building model, refer to section 3.1 below for details.

c. The design workshop SME team identifies the various ECMs applicable to the project, based on the existing building conditions.

d. With the list of curated ECMs, the energy modeller creates the Proposed Building model.

e. The energy modeller carries out the necessary simulation runs and conducts the energy performance analysis.

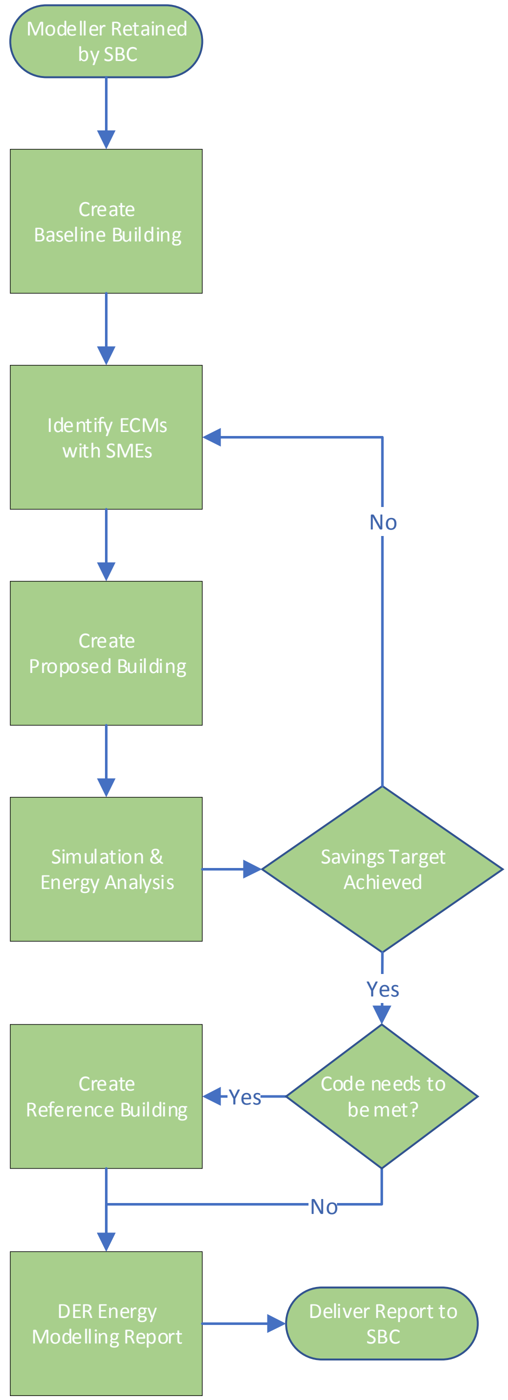
f. The energy modeller verifies the Proposed Building's estimated energy reduction relative to the calibrated Baseline Building meets or exceeds the savings target (i.e. 50%).

   i. If no, the energy modeller works with rest of the SME team to define additional ECMs (step c).

g. The proponent team confirms whether or not the project is subject to building code performance requirements.

   i. If yes, a Reference Building is created.

h. Once the DER energy savings are achieved, the energy modeller prepares the design workshop modelling report.



3.1 Baseline Building

Unlike an energy modelling analysis for a new construction project, DER seeks to significantly improve the energy performance of an existing building. This implies that the history of the existing building (i.e. the Baseline Building), as well as current operating conditions, will influence the methodology used by the energy modeller to conduct their analysis.

To account for the existing building's energy use history, the DER energy analysis is based on a properly calibrated Baseline Building model. The calibration process of the Baseline Building is one of the fundamental differences that separates a DER analysis from other energy modeling analyses.

The purpose of this section is to outline the process for modelling and calibrating the Baseline Building for a DER design workshop. The following flow chart illustrates the key milestones for creating a Baseline Building model.

Figure 5: Baseline Building Modelling

3.1.1 Building Assessment

There are multiple ways to conduct a building assessment, each with varying degrees of detail. ASHRAE standard 211-2018 defines three levels of building assessments.

For the purpose of a DER design workshop, the building assessment conducted by the SME team should target a level of detail consistent with ASHRAE's 211-2018 Level 2 assessment. The data collected from the facility site survey will be used to generate the Baseline Building.

If building design drawings are available and still relevant, they can be used to support any systems that cannot be confirmed during a facility site survey.

If the building has recently undergone a building assessment from a third party, and the content is consistent with an ASHRAE level 2 Assessment, the third assessment can be used to gather the necessary building system information for the purpose of the design workshop.

3.1.2 Utility Data Analysis

To establish a reliable and accurate Baseline Building for the purpose of a DER design workshop, it is strongly recommended to utilize at least 4 years worth of historical utility data. This affords the energy modeller the opportunity to identify any anomalies in the data when determining the historical baselines to be used for model calibration. A historical baseline should be established for each fuel source supplied to the building.

Utility billing periods typically do not fall on the first day of the month, nor do they start and end on the same days for every building. To conduct a meaningful utility data analysis, whether it be comparing or trending facility energy use or calibrating an energy model, a first step is to calendarize the building's utility data. This eliminates the arbitrary billing periods determined by the utility, and produces a consistent year-to-year month-by-month calendarized baseline.

The following equation can be used to calendarize the utility data month-by-month:

$$\begin{aligned} &Average\ Monthly\ consumption \\ &\quad = \text{Daily consumption from billing period A x Number of days in billing period A} \\ &\quad + \text{ Daily consumption from billing period B x Number of days in billing period B} \end{aligned}$$

For example, assume the following utility data:

Monthly Utility Bill	Billing Period Start Date	Billing Period End Date	Number of Days	Metered Energy Use	Daily Energy Use
January	December 17	January 16	31	465 kWh	15 kWh/day
February	January 17	February 15	30	360 kWh	12 kWh/day

To calendarize the average energy consumption for the month of January, sum the product of the daily energy use and the respective days in January from each utility bill. The calendarized energy consumption for January would equal 420 kWh as illustrated by the following formula:

$$Average\ January\ Consumption = 15\frac{kWh}{day}x\ 16\ days\ +\ 12\frac{kWh}{day}x\ 15\ days = 420\ kWh$$

Once the historical utility data has be calendarized, it was now ready to be used for determining the historical baseline and calibrating the Baseline Building model.

3.1.3 Weather Analysis

For the purpose of the SBC DER, the CWEC 2016 weather file that best reflects the projects location and weather conditions shall be used in the energy modelling analysis.

CWEC 2016 weather files many Canadian locations can be downloaded from climate.onebuilding.org.

As an additional resource, please refer to Environment Canada's Map of Active Weather Stations. This will assist with choosing the most appropriate weather file for the project. The energy modeller is required to identify the weather file used in the energy analysis.

3.1.4 Baseline Building Modelling

Upon completion of the building assessment and the utility data analysis, there is enough information about the building systems and operations to create the Baseline Building model.

3.1.4.1 Building Dimensions

The Baseline Building dimensions should be representative of the actual building. Dimensions can be taken from relevant design drawings, or in the absence of drawings, on-site measurements. It is important for the modeller to capture the building dimensions as accurately as possible as this will influence the thermal loads on the mechanical systems and the building's overall energy use.

For the additional clarity, building dimensions include the following:

- Number of floors: above and below grade,
- Floor area(s) and height(s),
- Roof area(s),
- Wall area(s),
- Window area(s) and Window to Wall Ratio (WWR),
- Space area by space type.

3.1.4.2 Building Envelope

When relevant design drawings are available, the thermal performance of the building envelope assembly can be estimated from the drawing details. The envelope assemblies can be further evaluated during facility site surveys; whether conducted by a member of the SME team, or from a previously completed third party building assessment.

In the likely event of missing or unavailable envelope assembly data, the energy modeller can work with the envelope SME to estimate the thermal performance of the various envelope assemblies based on their age and wall thickness. These estimates should be conservative, as to not over inflate the potential energy savings associated with the retrofit measure. Any building performance estimate used in the Baseline Building should be flagged by the modeller in the workshop report, as these uncertain model inputs may be adjusted during the model calibration (refer to Section 3.1.5).

3.1.4.3 Infiltration

Energy modellers experienced in new construction compliance modelling are familiar with the building code's prescriptive building infiltration requirements. Code compliance modelling typically ignores the impact of infiltration, requiring the Reference Building's infiltration to be set equal to the Proposed Building.

For existing buildings however, infiltration has a significant impact on the overall energy use that must be accommodated. The most accepted measurement approach for determining building infiltration is a blower door test. If the building has recently undergone a whole building infiltration test by a qualified blower door professional, the energy modeller can use the blower test results when creating the Baseline Building. When using single-point envelope leakage test results or multipoint envelope leakage test results, the modeller should have a sound understanding how the software program calculates infiltration before using these infiltration values.

In the likely event that no blower test data is available, the energy modeller can work with the envelope SME to estimate the building's infiltration. This infiltration estimate should be conservative, as to not over inflate the potential energy savings associated with the retrofit measure and should be flagged by the modeller in the workshop report. As an uncertain model input, infiltration may also be adjusted during the model calibration (refer to Section 3.1.5).

Cautionary Notice: the energy performance improvement associated with reducing building infiltration is a simple measure to simulate in an energy model however, it proves to be much more challenging to achieve during the construction or retrofit process and verify during the post-construction M&V. Modellers should use professional judgement and remain conservative when including infiltration reduction as a DER Measure, especially if the energy savings target threshold cannot be met without it.

3.1.4.4 Building Internal Loads

With the exception of lighting, internal building electrical loads and occupancy are variable in nature and often difficult to accurately assess during a site survey without historical sub-metered data.

In the likely absence of sub-metered load data, it is recommended that the modeller use the representative NECB[3] load values when creating the Baseline Building as a starting point. Given that

[3] NECB: The NECB version implied is the most current NECB version publish at the time of the Deep Energy Retrofit energy analysis. At the time of writing, the most current NECB version is NECB 2017.

these internal loads are considered uncertain model inputs, they may also be adjusted during the model calibration (refer to Section 3.1.5).

3.1.4.5 Building HVAC Systems

When relevant mechanical design drawings are available, the equipment details for the various mechanical systems can be estimated from the drawings. With regards to system operations, discussions with members of the proponent team would be required to get a proper understanding the current sequence of operations and control schedules.

In the likely event of missing or unavailable mechanical drawings, the mechanical systems can be evaluated during facility site surveys; whether conducted by a member of the SME team, or from a previously completed third party building assessment. The assessment would need to identify the inventory of mechanical equipment, the performance specifications, the current sequence of operations, and equipment operating schedules.

The preferred data source for the mechanical equipment details is a proper building assessment including facility site surveys. Given that the building HVAC equipment typically accounts for the large majority of energy use in a building, ensuring that the most accurate mechanical system and operations details are used in the Baseline Building model will increase the quality of the analysis.

While uncertain model inputs may be adjusted during the model calibration (refer to Section 3.1.5), it is strongly recommended to limit the amount of mechanical system estimates in the Baseline Model to ensure a higher degree of accuracy.

3.1.5 Baseline Building Calibration

Calibrating the Baseline Building model is an iterative process that involves evaluating the building information collected during the building assessments or design drawing takeoffs and adjusting the values of uncertain model inputs[4].

Depending on the number assumptions used by the modeller for the unknown model input, it is very likely that the Baseline Building model output will not align with the historical utility baseline. Many different model input combinations can end up producing similar energy use projections, therefore professional judgement is an important factor during the calibration process.

The following energy model calibration methodologies are suggested:

- Manual calibration based on an iterative approach,
- Graphical-based calibration methods, or
- Mathematical and Statistical calibration methods.

[4] Uncertain Model Input: Building system details that can not be accurately assessed during a building assessment nor verified in the building design drawings. Such input can include infiltration, occupancy loads, internal electrical loads, service water loads, vintage mechanical system performance specifications.

For modellers using a statistical calibration method, which may be used to quantify the calibration error – which is the error that exists between the Baseline Building model energy use and the historical utility baseline energy use, ASHRAE Guideline 14-2014 recommends two metrics for validating calibration accuracy of model fit:

1. The coefficient of variation of the root-mean-square error (CVRMSE), and
2. The normalized-mean-bias error (NMBE).

The CVRMSE describes the variation in data patterns, while NMBE describes the variation between predicted model values and the mean historical values.

A calibrated Baseline Building model in compliance with ASHRAE Guideline 14 is required to have a maximum CVRMSE of ±15% and a maximum NMBE of ±5% when using monthly data.

The equations for the CV(RMSE) and NMBE are shown below.

$$CV(RMSE) = \frac{1}{\bar{y}}\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-p}} \quad , \quad NMBE = \frac{1}{\bar{y}}\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n-p}$$

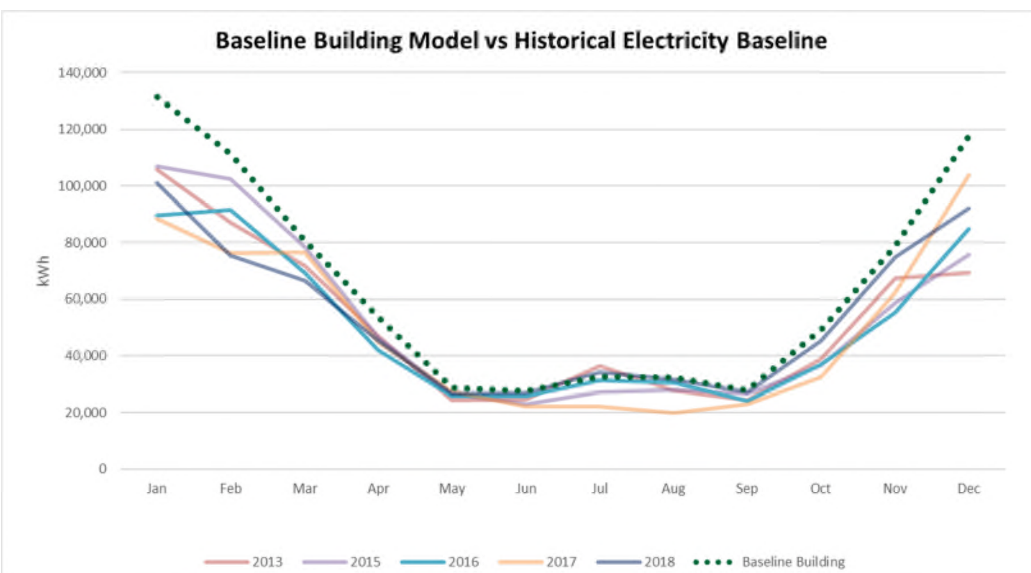
Where:

y = Historical utility value | ŷ = Baseline Building predicted value | ȳ = Mean of the annual historical data (i.e. the average) | n = Number of data points in the sample (i.e. monthly data, therefore n = 12) | p = P-value; for this purpose, p = 1

Example 1 – Initial assumptions showing overestimation of energy use:

The model uses the NECB 2015 default loads for an 8-storey electrically heated multi-unit residential building (5W/m² for both lighting and plug loads, 500W/occupant for service water) and an infiltration rate of 3.5 ACH50 on the basis that the building is over 50 years old.

The following graph illustrates the Baseline Building model versus five years (5) of historical electricity baseline data.

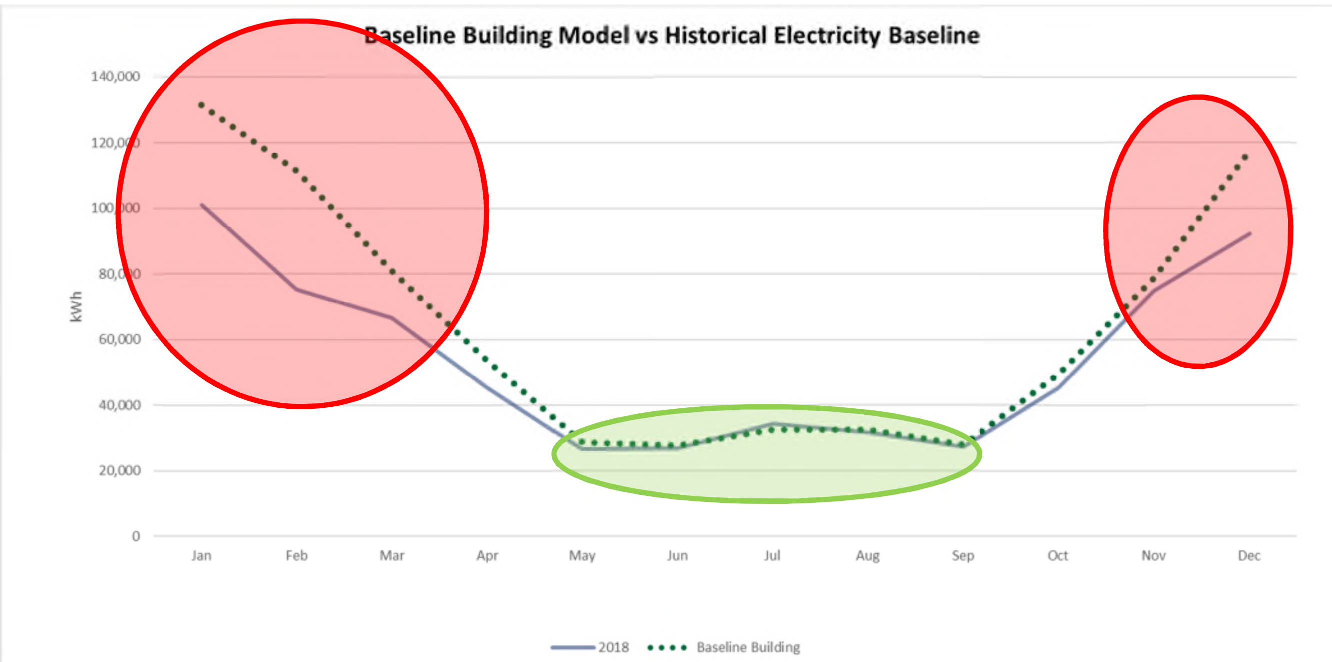


Visually from the above graph the modeller should be able to identify an overestimate in the predicted Baseline Building energy use. However, to double check the modeller can validate using the CVRMSE (±15%) and NMBE (±5%) metrics:

Historical Baseline Year	CV(RMSE)	NMBE
2013	30%	-26%
2015	27%	-23%
2016	36%	-30%
2017	39%	-32%
2018	31%	-21%

From the metrics summarized above, the Baseline Building model does not meet the minimum calibration criteria.

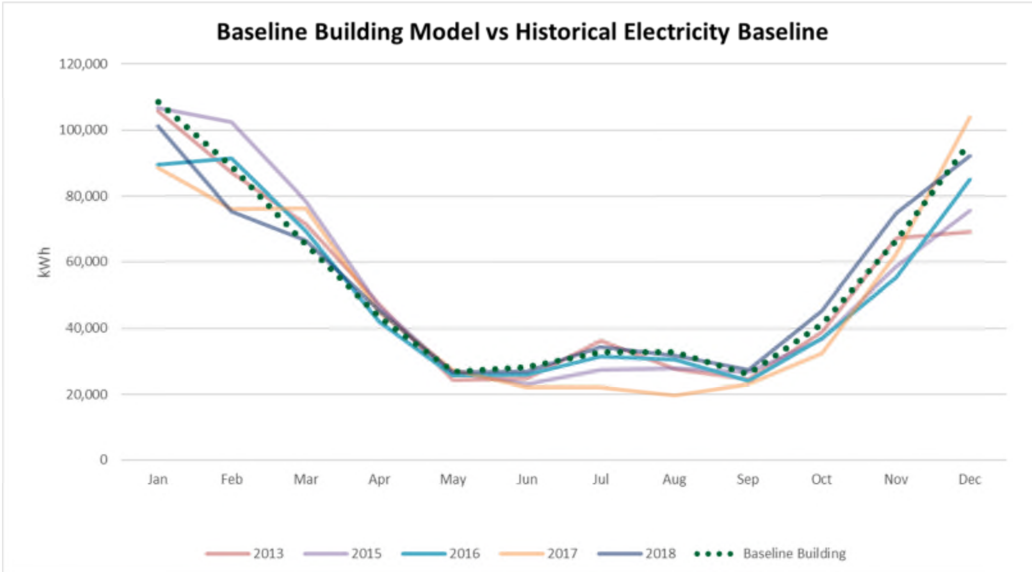
The modeller would also have the choice to examine the most recent year, which in this case would be 2018:



As shown, the Baseline Building model is overestimating the energy use during the heating season. During the cooling season highlighted in green, the Baseline Building model is representative of the historical energy use.

<u>First calibration iteration:</u>

The modeller makes an adjustment to the infiltration rate, as this input would have a larger influence on space heating, compared to lighting and plug loads and reduces the infiltration estimate by 50%, assuming a rate of 1.75 ACH50.



As shown, the Baseline Building energy use appears to be more representative. Again, the next step would be to validate using the CVRMSE (±15%) and NMBE (±5%) metrics:

Historical Baseline Year	CV(RMSE)	NMBE
2013	16%	-6%
2015	15%	-3%
2016	14%	-9%
2017	21%	-11%
2018	11%	-2%

From the above metrics, the Baseline Building model meets the minimum calibration criteria for the 2018 and 2015 historical baseline years.

At this point, the modeller could continue with additional iterations to adjust the 2013 and 2016 historical years and further improve the model fit.

The Baseline Building model is considered 'calibrated' if the output meets the recommend minimum ASHRAE 14 calibration criteria for at least two anomaly free historical baseline years.

3.2 Proposed Building Modelling

For modellers experienced with new construction, the Proposed Building model is a representation of the project that is being designed for construction. An energy analysis for a new construction project consists of comparing the Proposed Building's predicted energy performance relative to a Code compliant Reference Building, to ensure the design meets/exceeds the minimum performance requirements prescribed by the Code.

For DER projects, the Proposed Building model is a representation of what the existing building could be if the combination of ECMs were implemented. The Proposed Building's energy performance is now compared against the calibrated Baseline Building to demonstrate the predicted energy use reduction.

The following section highlights the general approach for energy modellers to create the Proposed Building model for the purpose of an SBC DER workshop.

3.2.1 Creating the Proposed Building

In new construction, the Proposed Building is created from the project's design documentation (design drawings, mechanical specifications, control schemes, manufacturer specifications and shop drawings, etc.) with the intent of predicting the project's energy performance relative to a defined target: a Code requirement, a certification requirement, a funding requirement, etc.

For DERs, the Proposed Building serves to predict the potential energy performance of the existing building by implementing a combination of ECMs relative to the calibrated Baseline Building.

As such, the Proposed Building is created from the calibrated Baseline Building, changing only the necessary model input associated with the proposed ECMs, and leaving all the remaining model inputs equal to the calibrated Baseline Building.

3.2.2 Modeling ECMs

As discussed, the Proposed Building is created from the calibrated Baseline Building, changing only the necessary model inputs associated with the proposed ECMs.

> Enclosure assembly measure example:
>
> The calibrated Baseline Building, a 1-storey 60 year school, consists of brick & block walls above grade and 5 year old double pane glazing units. According to observations noted during the site assessment, the enclosure assembly is assumed to be un-insulated with an assembly USI-2.47 (R-2.3).
>
> The SME team identifies an enclosure measure consisting of insulating the exterior wall with a continuous layer of exterior insulation (Assembly USI-0.227 | R-21). The window units were excluded from the list of potential ECMs.
>
> The energy modeller creates the Proposed Building from the Baseline Building model and updates the exterior wall input per the recommended ECM. The windows are excluded from the measure and remain equal to the Baseline Building.

Each ECM is modelled separately against the Baseline Building. The modeller examines the ECM's simulations results and if reasonable, records the energy consumption and performance targets.

3.2.3 Results Analysis

The ECM simulation results are shared with the proponent team during the design workshop, and also serve to identify the DER pathway to achieving the project's high performance targets.

Once all the ECMs are individually modelled and evaluated, the SMEs, proponent team and modeller identify a selection of measures that represent the combined DER solutions and the modeller prepares a final Proposed Building model to predict the DER performance improvement relative to the Baseline Building. This may be an iterative process as the team considers the inclusion of measures (or not) vis a vis the performance target.

The Proposed Building model includes all the ECMs that would make up the DER, accounting for the secondary effects between the various building systems.

Cautionary Notice: The DER energy performance improvement is not the aggregate of each individual ECM. When evaluating ECMs individually, the secondary interactive effects (i.e. the influence that one building system has on another) are not accounted for. Depending on the combination of measures, the ECM aggregate energy use reduction can be greater than the Proposed Building's energy use reduction relative to the Baseline Building. The modeller needs to be aware of this and address it as part of the reporting.

3.2.4 Confirmation of Targets

As noted in Section 1.0 above, SBC uses an "activity-based" DER definition which combines both a threshold metric of 50% reduction and an activity metric that requires the consideration of both enclosure upgrades along with mechanical/active systems upgrades.

In the event the project's savings target is not achieved, the team is encouraged to consider more aggressive combinations of ECMS that meet the target. Ultimately the proponent team is responsible for the final decision regarding which measures are included in the project. In cases where performance incentives are available, it is expected that the selection of measures will meet the target consistent with the incentive program[5].

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[5] The Enbridge Gas Savings by Design Program requires that the DER workshop outcome demonstrated 15% Better than Code Performance as compared to a REFERENCE building.

3.3 Reference Building Modelling

As illustrated in the flow diagram in Section 3.0 above, if the proponent team identifies that the project is subject to building code performance requirements, then a Reference Building model is required.

Alternatively, if the proponent wishes to pursue incentive funding for their DER project, depending on the specific program requirements, a Reference Building may be required to complete a relative performance analysis.

The purpose of this section is to provide the modeller with a general methodology for creating a Code compliant Reference Building to be used as a benchmark in the DER workshop.

This Guide does not aim to provide detailed modelling direction for creating a Code compliant Reference Building.

3.3.1 Creating the Reference Building

In new construction, the Reference Building is created from the Proposed Building; the Proposed Building is being evaluated for compliance relative to the minimum Code requirements.

For DER, it is the new portions of buildings and their systems, as well as the new systems and equipment in existing buildings that are being evaluated for compliance relative to the minimum Code requirements.

Therefore, the Reference Building is also created from the DER Proposed Building, changing only the necessary model inputs associated with the proposed ECMs to their minimum Code requirements, and leaving all the remaining model inputs equal to the calibrated Baseline Building.

It is noteworthy that existing buildings, in whole or in part, may or may not be included in the Code scope enforceable at the time of the project’s construction. It is strongly recommended to check with the local authorities. For example:

- ASHRAE 90.1 Scope applies to new portions of buildings and their systems (i.e. an addition to an existing building), as well as new systems and equipment in existing buildings.
- NECB Scope applies to additions to existing buildings including the associated systems, components and assemblies. For clarity, an addition can be thought of as a new building that happens to be built contiguous to an existing building or as a new portion of an existing building.

4.0 RESOURCES

The following are a list of resources that can be used in the Baseline calibration process.

- ASHRAE Guideline 14-2014
- IPMVP
- Path Finder Parametric Analysis tool to analyse the effect of ECMs.

The following Site Assessment Checklist can be used to ensure all the necessary information required for building the Baseline model is collected (also available in spreadsheet format).

DER Site Assessment Checklist	
Site and Building Information	
	Site and Building desccription (orientation, nearby objects, shading)
	Building Type
	Building Area
	Floor to Floor Height
	Owner/leasing structure
Operation	
	Automated controls present?
	O&M logs
Occupancy and Zoning	
	Occupancy Density per zone
	Occupancy Schedule
	Thermal zoning
	Zone thermostat setpoints
Building Envelope	
	Wall R-values
	Roof R-values
	Floor R-values
	Window R-values
	Door R-values
	Window areas and locations
	Infiltration Controls
	Blower door test results
Loads	
	Lighting fixture counts per zone
	Lighting wattage
	Lighting controls
	Lighting schedules
	Miscellaneous equipment wattages
	Miscalleneous equipment controls
Systems	
	System type
	Age
	Capacity
	Efficiency
	Operating Schedules
	Operating setpoints
	Rated fan powers
	Fraction of outside air (OA)
	Supply air temperature