

# Leveraging ASHRAE 14 Guidelines for Robust Building Energy Modeling/Computer Simulation and Decarbonization Strategies\*

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## ABSTRACT

Building energy models are critical for understanding the performance of a building and the impact of implementing multiple energy efficiency measures (EEMs) and their interactions. Energy models provide means for replicating known systems and assessing several EEM combinations. However, the reliability of the results depends on the modeler's experience, the quality of the input, the computer simulation methodology, and the soundness of the baseline considerations. For baseline scenarios, ASHRAE 14 guidelines offer valuable advice.

ASHRAE 14 outlines a strategy for creating a calibrated baseline model that closely matches the actual energy consumption of a building. These guidelines include recommendations about data collection procedures, model debugging strategies, and for selecting computer simulation modeling software. ASHRAE 14 also introduces a statistical comparison technique for assessing the reliability of calibrated models.

Modelers can duplicate and modify reliable calibrated models to simulate various EEM packages and compare results to reveal insights into energy savings and carbon emissions reductions. These are fundamental in defining decarbonization pathways grounded in technical and financial assessments.

This article discusses ASHRAE 14 and explores best practices in building energy modeling using computer simulation software. The discussion will include examples to explain the critical role of these guidelines in creating effective decarbonization strategies for buildings.

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## INTRODUCTION

Building energy models are essential tools for evaluating and understanding the energy performance of buildings. They play a critical role in identifying opportunities for energy efficiency improvements and assessing the impact of multiple energy efficiency measures (EEMs) and their interactions. By simulating the behavior of known systems, energy models allow engineers to test various EEM combinations and understand how each affects a building's overall performance. However, the accuracy and reliability of these models are contingent on several factors, including the quality of input data, the experience of the modeler, the methodologies employed, and the robustness of the baseline assumptions.

To address these complexities and ensure accuracy, ASHRAE Guideline 14: Measurement of Energy, Demand, and Water Savings was introduced in 2002. The guideline was created to meet the industry's need for a standardized methodology to calculate energy and power savings in buildings. As energy consumption and demand fluctuate due to changes in occupancy, usage patterns, and external factors like weather, measuring and evaluating savings is more intricate than many assume. The buildings sector accounts for nearly 40% of global greenhouse gas emissions, making accurate evaluations of energy savings crucial to climate action and decarbonization efforts.

This article explores the application of ASHRAE 14 guidelines in building energy modeling (computer simulation), discussing best practices, challenges, and their role in supporting decarbonization strategies. Examples are included to demonstrate the importance of these guidelines in developing effective pathways toward decarbonization.

## THE IMPORTANCE OF BUILDING ENERGY MODELS

Building energy models serve several important functions in the management and improvement of building energy performance. They provide the means to create a baseline energy model—often referred to as a calibrated model—which is a tool used for assessing the energy efficiency measures (EEMs) or energy conservation measures (ECMs) of a building. A calibrated model is key to understanding how energy is consumed in a

building and enables engineers to simulate the performance of different retrofit measures.

Energy models provide valuable insights into how energy is consumed in buildings, especially when sub-metered data is unavailable. By generating a breakdown of energy usage by system or end-use, these models help identify the most energy-intensive areas. This information enables energy managers to pinpoint high-consumption systems and target them for efficiency improvements, leading to potential energy savings.

In practice, energy models help future-proof buildings by providing a roadmap for maintenance, equipment upgrades, and new technology installations. They allow building operators to simulate future energy usage, helping them to proactively plan maintenance schedules and invest in energy efficiency upgrades. These models also support data-driven decision-making, by providing reliable technical analyses, which enables building operators to evaluate the technical and financial impact of implementing multiple retrofit measures and their interactions.

Moreover, building energy models support the calculation of energy savings and greenhouse gas (GHG) emissions reductions. This is vital for organizations looking to meet decarbonization targets. However, achieving these goals depends on the quality of the input data, the modeling/simulation methodology, and the calibration of the model itself, all of which are addressed in ASHRAE 14 guidelines.

## CHALLENGES IN BUILDING ENERGY MODELING/ COMPUTER SIMULATION

Despite the benefits, building energy modeling or simulation comes with several challenges. The first challenge is the availability and quality of input data. We all have heard the expression “garbage in, garbage out,” especially when dealing with simulation software. Accurate energy modeling/simulation requires high-quality input, including utility data, weather data, occupancy patterns, sub-metered data, and as-built drawings of the building. Unfortunately, this data is not always readily available, or it may be outdated or incomplete. Therefore, gaps must be filled with information collected during the site visit and from interviewing the building’s manager and occupants.

The second challenge lies in the experience of the modeler. As it happens with any other activity, the more experience one has, the better. But sometimes we do not have a 10-year expert in the team that can lead us to expedite the completion of an energy model. Building energy modeling with computer simulation software is a highly technical field, requiring in-depth knowledge of energy systems, software tools, and data analysis techniques. Modelers must be skilled in creating dependable models that accurately reflect the actual energy consumption of the building.

Creating energy models can be a time-consuming process, posing a significant barrier. Collecting data, selecting the right software, and troubleshooting the model demand a substantial investment of time and resources. Several factors influence the time required to develop an energy model, including building size, HVAC (heating, ventilating and air conditioning) system complexity, data availability, the modeler's expertise, and the software's capability to accurately represent the spaces and systems. Also, modeling/simulating non-conventional spaces, such as those with irregular shapes or unique energy loads, presents further challenges in accurately simulating energy performance. For example, a multi-purpose room that is used to teach hot yoga during the day and host bingo during the night. Additionally, modeling/simulating non-conventional and innovative HVAC systems might require creative workarounds within the computer simulating software to properly simulate their performance.

Finally, the variability in building use, occupancy rates, and fluctuating weather conditions further complicates energy savings evaluation. Buildings evolve, and their energy consumption changes due to seasonal variations, behavioral shifts, and technology updates. Accurately measuring and accounting for these variations is critical to producing valid results.

## ASHRAE 14 GUIDELINES: OVERVIEW AND BEST PRACTICES

ASHRAE Guideline 14 provides a comprehensive framework for calculating utility savings from building retrofits and for creating accurate and reliable energy models. These models are essential for evaluating the overall performance of buildings and assessing the impact of energy

efficiency measures. The guideline outlines three main approaches for computing savings, each suited to different project types and conditions. To ensure the validity of the savings estimates, compliance with each approach requires that the overall uncertainty remains within prescribed thresholds.

The three approaches are:

- **Retrofit Isolation Approach:** This approach measures the energy use, and relevant independent variables of the individual systems or equipment affected by the retrofit. Baseline and post-installation measurements are taken for a specific duration to illustrate the full range of the retrofit's impact on energy consumption.
- **Whole Facility Approach:** In this method, savings are determined using the measured energy use of the entire building or facility. It requires the collection of utility meter data or sub-metered data, as well as independent variables such as weather conditions, to accurately assess energy savings.
- **Whole Building Calibrated Simulation Approach:** This approach uses a computer simulation tool to model the building's energy use and demand. It is typically applied in pre-retrofit analyses and leverages actual measurements of energy usage and demand to project post-retrofit performance. This technique is particularly effective for accounting for multiple energy end uses, especially where interactions occur between different energy-saving measures. This approach outlines best practices for calibrating energy models and provides a statistical comparison technique for assessing the reliability of calibrated models.

Each approach offers flexibility based on the project's requirements, providing a standardized method to ensure accurate and reliable savings estimates.

A central focus of the "Whole Building Calibrated Simulation Approach" is the development of a calibrated simulation that accurately reflects real-world conditions. The process involves collecting high-quality input data, such as hourly weather records, detailed energy use data, and comprehensive information on the building's physical characteristics, including its envelope, HVAC performance, and lighting

schedules. Without this level of detail, energy models may fail to capture the true energy dynamics of a building, leading to inaccurate results. ASHRAE 14 also stresses the importance of selecting the right software for energy modeling or energy simulation.

Calibration is an iterative process that involves comparing simulated energy use with actual measured data to refine the model until it closely matches the real-world performance of the building. Statistical metrics such as Mean Bias Error (MBE) and the Coefficient of Variation of the Root Mean Squared Error (CVRMSE) are used to gauge the accuracy of the calibration. ASHRAE 14 recommends that the MBE be within  $\pm 5\%$  and the CVRMSE within  $\pm 15\%$  for monthly data. For hourly data, the tolerances are  $\pm 10\%$  for MBE and  $\pm 30\%$  for CVRMSE. These benchmarks ensure that the energy model is reliable for assessing energy efficiency upgrades.

### **Best Practices**

The following includes recommendations based on experience and best practices from ASHRAE 14 when it comes to creating calibrated building energy models:

- The software should be capable of performing hourly calculations and managing complex datasets. This capability allows for a more precise simulation of energy use, particularly when accounting for fluctuations in weather or occupancy patterns. Several software solutions on the market meet these requirements, such as eQuest, IES, EnergyPlus, and HAP.
- Hourly weather data should be used, and it must correspond to the same period as the energy use data to which the model is being calibrated. If metered weather data is not available, using standardized weather datasets, such as those available from ASHRAE or the National Renewable Energy Laboratory (NREL), helps normalize energy savings across different climate conditions.
- Develop a calibrated simulation plan. This includes defining the software to be used, identifying missing data, requesting additional information, reviewing available materials before site visits, and meeting with building managers. Clearly defining the scope of work and the level of detail required will help expedite the analysis and

reduce the margin of error.

- Effective data collection is critical to building a robust energy model. ASHRAE 14 recommends gathering detailed information about the building's equipment, operating schedules, and physical conditions. This includes equipment nameplate data, indoor temperature and humidity levels, operating hours, temperature set points, and specific details on plug loads, lighting fixtures, and HVAC zones. On-site surveys or audits are often necessary to verify this data.
- In most cases, plug loads for devices such as computers, printers, and refrigerators are not measured or collected during site visits due to time constraints. In such cases, plug load power densities from ASHRAE 90.1 for specific building types or spaces can be used. Similarly, if lighting data is unavailable, lighting power densities from ASHRAE 90.1 can be applied. These values can then be adjusted during the calibration process.
- Thermal zones should be defined as accurately as possible. This information can be obtained from as-built drawings or collected during the site visit.
- Gather envelope data, such as the characteristics of windows, doors, walls, and the roof. This information can typically be found in as-built or shop drawings. For wall thermal values, it is recommended to use effective thermal values derived from thermal bridging calculations. The Building Envelope Thermal Bridging Guide provides a methodology for completing these calculations (9).
- If infiltration rate measurements are not available, typical infiltration rates from the local energy code or infiltration rates based on the modeler's experience can be used. These rates can then be modified during the calibration process.
- Determine whether the calibration will be based on monthly or hourly data, depending on the project requirements.

After the steps described above are completed, the energy model can be created, and run, and its output compared against baseline energy records. ASHRAE 14 provides clear guidelines for validating energy models using statistical analysis. Both graphical and statistical

comparisons are employed to evaluate the alignment between simulated and actual energy use. The primary objective is to refine the model until it meets the acceptable calibration criteria, ensuring that future predictions are based on a model that accurately reflects the building's performance. Common adjustments during calibration include infiltration rates, occupancy patterns, and HVAC system performance. Calibration not only improves model accuracy but also allows energy managers to predict how different energy efficiency measures will interact and affect overall building performance.

Debugging is a critical step in the energy modeling/simulating process. ASHRAE 14 outlines several best practices for identifying and correcting errors within the model. Modelers should confirm that HVAC systems are meeting heating and cooling loads, equipment schedules are accurate, and fan and ventilation air loads are appropriate. This often requires running multiple simulation iterations and adjusting parameters until the simulated results align with measured data. Debugging can also reveal assumptions—such as default infiltration rates—that may need refinement to improve model accuracy.

Additionally, it is recommended to compare the model's end-use energy breakdown with actual installed equipment loads and operational hours or to reference typical end-use energy breakdowns for similar buildings in the same region. Sources such as the U.S. Energy Information Administration and Natural Resources Canada provide typical energy breakdowns for a variety of building types. This comparison can highlight areas needing further adjustment. For instance, if lighting energy use appears higher than expected assumptions about lighting schedules or power densities may need to be revisited.

It is highly advisable to document all changes made during the debugging, calibration, and fine-tuning processes. This record will help track modifications and their impact on calibration efforts, ensuring an organized approach.

After several iterations and once the MBE and CVRMSE tolerances are satisfied, the modeler will have a calibrated model—a solid baseline to assess the effects of Energy Efficiency Measures (EEMs) in a building. Figure 1 illustrates the energy model calibration process in a simplified flow diagram.

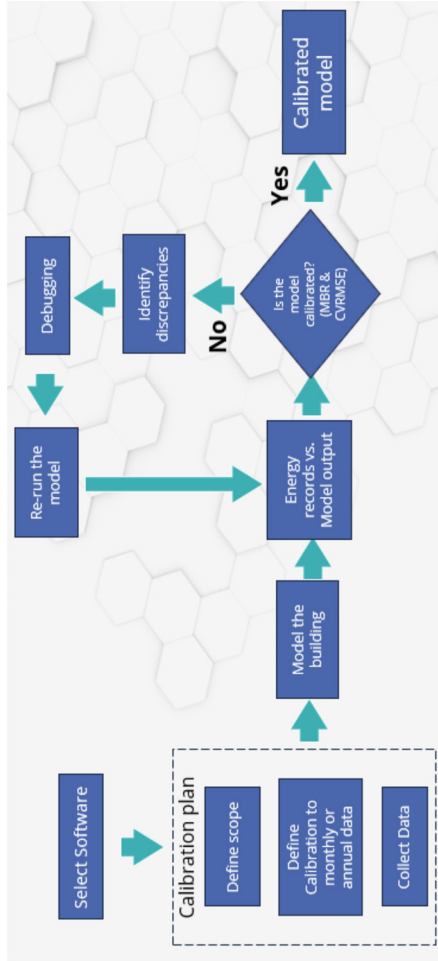


Figure 1. Flow Diagram—Building Energy Model Calibration Process

## ASHRAE 14 ROLE IN DECARBONIZATION STRATEGIES

ASHRAE 14 plays a critical role in the development of decarbonization strategies for buildings. By creating a dependable baseline energy model, engineers can evaluate different combinations of energy conservation measures (ECMs) and assess their potential for reducing energy consumption and greenhouse gas (GHG) emissions, as well as identifying which combinations are most effective in achieving decarbonization targets. This is particularly important for organizations with long-term decarbonization goals, such as reducing emissions, for example, by 50% by 2030 or achieving net zero by 2050.

The calibrated energy model serves as a valuable tool for supporting data-driven decisions. Its reliable energy consumption estimates can be incorporated into financial models to identify the most cost-effective solutions. Additionally, building managers can use the technical analysis derived from the energy model's output to complete a financial analysis and plan the implementation of energy efficiency measures (EEMs). This planning can be aligned with decarbonization targets, capital costs, equipment life span, the cost-effectiveness of EEMs, and greenhouse gas (GHG) reduction ratios, among other key performance indicators.

Moreover, ASHRAE 14 guidelines help in future-proofing buildings by allowing for the adjustment of decarbonization pathways over time. As innovative technologies emerge and equipment reaches the end of its life, the energy model can be updated to reflect these changes. This ensures that the decarbonization strategy remains aligned with current energy goals and that the most cost-effective measures are implemented at the right time.

### CASE STUDY: MULTI-PURPOSE BUILDING

A practical application of ASHRAE 14 guidelines can be seen in a case study of a multi-purpose building.

#### **Assumptions**

- Baseline energy consumption: 2023
- Calibrated to monthly consumption
- Decarbonization pathways to reach 50% reduction by 2030 and 80% reduction by 2050

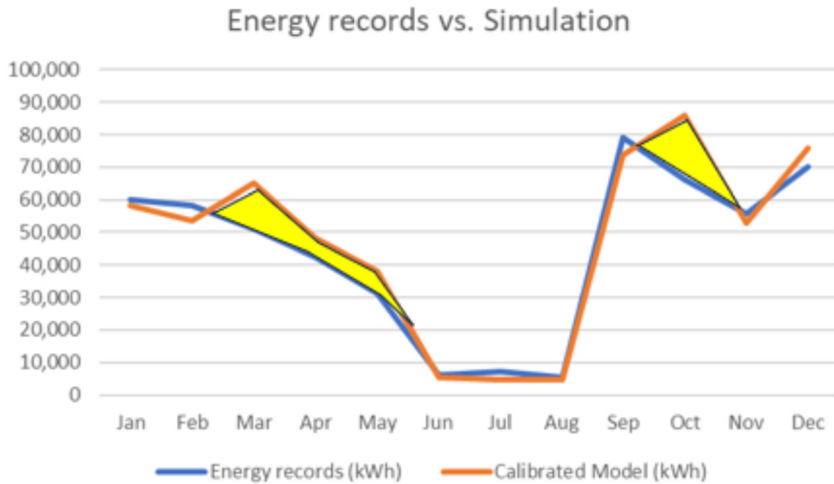
- To achieve these goals, an energy audit was conducted to identify potential EEMs:
  1. Lighting upgrade
  2. Replace chiller with heat recovery chiller
  3. Programmable thermostats
  4. Replace the oil boiler with an electric boiler
  5. Lighting controls optimization
  6. Windows upgrade
  7. Solar photovoltaic (PV)
  8. Solar domestic hot water heaters
  9. Replace propane radiant heaters with electric unit heaters
  10. Enable the use of the economizer for free cooling.

### **Energy Modeling/Simulation and Calibration**

The energy model was completed considering the best practices in this article. The output from the first iteration was compared against the 2023 energy records. It showed that the model requires some adjustments to be calibrated. For example, the energy consumption in March and

**Table 1. Energy Records vs. Energy Model First Iteration**

<b>Months</b>	<b>Energy Records (kWh)</b>	<b>Energy Model (kWh)</b>	<b>Calibrated vs Metered (%)</b>
Jan	60,038	58,327	-3%
Feb	58,162	53,671	-8%
Mar	51,000	65,236	28%
Apr	42,600	48,089	13%
May	31,200	38,110	22%
Jun	6,000	5,469	-9%
Jul	7,200	4,783	-34%
Aug	5,400	4,833	-11%
Sep	79,200	73,629	-7%
Oct	66,000	85,987	30%
Nov	55,800	52,995	-5%



**Figure 2. Energy Records vs. Energy Model First Iteration**

October is too high compared to the metered data. Table 1 and Figure 2 show this comparison. The MBE and CV(RMSE) tolerances were calculated, and it was revealed that the model was not calibrated (MBE: -7% and CV(RMSE): 19%).

Then, after applying the debugging and “fine-tuning” strategies, the model was calibrated after 10 iterations. Table 2 and Figure 3 show this comparison. The MBE and CV(RMSE) tolerances were calculated and showed that the model is calibrated (MBE: 1.5% and CV(RMSE): 6.3%).

Using a calibrated energy model based on ASHRAE 14 guidelines, the engineering team simulated various combinations of EEMs to determine the most effective pathway to meet the building’s decarbonization targets.

The model revealed that implementing 6 out of 10 EEMs was sufficient to achieve the 2030 target, while four additional EEMs would be required to meet the 2050 target. Then, the implementation of the EEMs can be planned based on parameters agreed with the building owner, such as emission targets, implementation cost, end-of-life of equipment to be replaced, funds availability, and cost-benefit analysis, among others.

Table 3 shows how the implementation of EEMs can be scheduled based on funds availability estimated by the building owner, for example. It is worth mentioning that if charges to the pathway are needed in 10 or 15 years, the model can be adjusted to redefine the decarbonization pathway.

Table 2. Energy Records vs. Energy Model Tenth Iteration

Months	Energy Records (kWh)	Energy Model (kWh)	Calibrated vs Metered (%)
Jan	60,038	58,327	-3%
Feb	58,162	53,671	-8%
Mar	51,000	52,097	2%
Apr	42,600	45,512	7%
May	31,200	30,215	-3%
Jun	6,000	5,469	-9%
Jul	7,200	6,548	-9%
Aug	5,400	4,833	-11%
Sep	79,200	76,686	-3%
Oct	66,000	63,326	-4%
Nov	55,800	52,995	-5%
Dec	70,200	75,759	8%
Annual	532,800	525,438	-1%

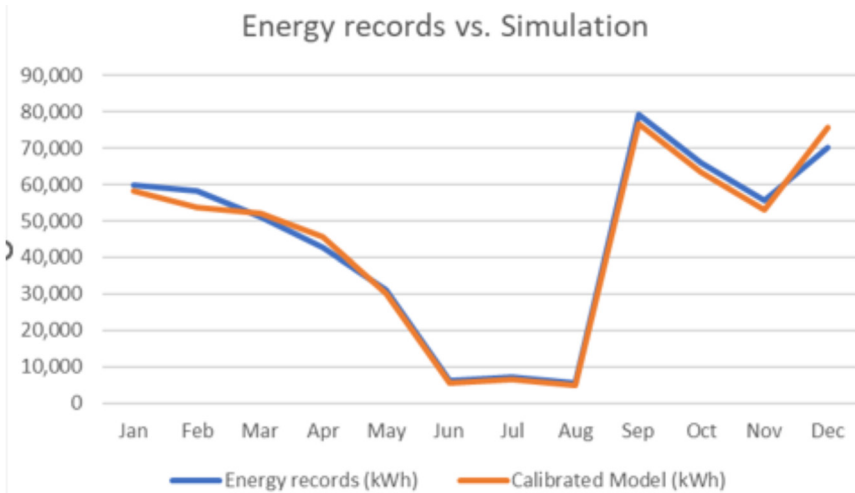


Figure 3. Energy Records vs. Energy Model tenth Iteration

**Table 3. EEM Implementation Schedule**

<b>Number of Years</b>	<b>Year</b>	<b>EEM</b>
0	2023 Baseline	N/A
1	2024	EEM5
2	2025	EEM1
4	2027	EEM2/7
5	2028	EEM10
6	2029	EEM6
<b>9</b>	<b>2030</b>	<b>GOAL</b>
14	2037	EEM9
16	2039	EEM4
18	2041	EEM3
21	2044	EEM8
<b>27</b>	<b>2050</b>	<b>GOAL</b>

By using the ASHRAE 14 framework, the team was able to create a flexible and adaptive decarbonization strategy that not only met emission reduction targets but also optimized the building's operational efficiency and cost-effectiveness.

## SUMMARY

ASHRAE 14 guidelines provide a robust framework for creating calibrated energy models, which are essential for assessing the impact of energy efficiency measures and developing effective decarbonization strategies. By following best practices for data collection, model debugging, and statistical analysis, engineers can create reliable models that accurately reflect a building's energy performance. These models are invaluable tools for future-proofing buildings, meeting GHG reduction targets, and making informed decisions about energy efficiency upgrades.

Additionally, calibrated energy models as per ASHRAE 14 provide a solid and reliable foundation for dependable decarbonization pathways. The combination of this technical assessment along with a financial analysis, allows for the use of science-based methods to analyze different scenarios and make decisions.

As the world moves towards more sustainable energy practices, the use of ASHRAE 14 guidelines will continue to play a pivotal role in

the transition to low-carbon and net-zero buildings. Through careful simulating and strategic planning, building operators can not only reduce their energy consumption and carbon footprint but also enhance the long-term value and sustainability of their assets.

## Bibliography

1. ASHRAE. (2014). ASHRAE Guideline 14-2014: Measurement of Energy, Demand, and Water Savings. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
2. HFA Architecture & Engineering. (n.d.). ASHRAE Guideline 14: Measurement of Energy Demand and Water Savings. HFA. Retrieved from <https://www.hfa-ae.com/blog/ashrae>.
3. Accuris Tech. (2023). ASHRAE Guideline 14-2023: Measurement of Energy Demand and Water Savings. Accuris Tech. Retrieved from [https://store.accuristech.com/standards/ashrae-guideline-14-2023-measurement-of-energy-demand-and-water-savings?product\\_id=2569793](https://store.accuristech.com/standards/ashrae-guideline-14-2023-measurement-of-energy-demand-and-water-savings?product_id=2569793).
4. WatchWire. (2023). ASHRAE Guideline 14: A Critical Framework for Energy Efficiency Projects. WatchWire. Retrieved from <https://watchwire.ai/ashrae-guideline-14/>.
5. West, S. (2023). ASHRAE Guideline 14-2023 Update: What's New? LinkedIn. Retrieved from <https://www.linkedin.com/pulse/ashrae-guideline-14-2023-update-scott-west-ly7mc/>.
6. International Building Performance Simulation Association (IBPSA). (2020). Energy Modeling Best Practices and Applications: Orlando Workshop. IBPSA-USA. Retrieved from [https://www.ibpsa.us/wp-content/uploads/2021/11/Energy-Modeling\\_Orlando\\_2.4.20\\_2.pdf](https://www.ibpsa.us/wp-content/uploads/2021/11/Energy-Modeling_Orlando_2.4.20_2.pdf).
7. Chiu, Y. K. (2018). Calibrating the Energy Simulation Model of an Aquatic Centre Using EnergyPlus and DesignBuilder. In Proceedings of the 2018 Building Performance Analysis Conference and SimBuild (pp. C074). International Building Performance Simulation Association. Retrieved from [https://publications.ibpsa.org/conference/paper/?id=simbuild2018\\_C074](https://publications.ibpsa.org/conference/paper/?id=simbuild2018_C074).
8. Lam, J. C. (2018). Whole Building Calibrated Simulation Performance Path Using ASHRAE Guideline 14. In Proceedings of the 2018 Building Performance Analysis Conference and SimBuild (pp. C075). International Building Performance Simulation Association. Retrieved from [https://publications.ibpsa.org/conference/paper/?id=simbuild2018\\_C075](https://publications.ibpsa.org/conference/paper/?id=simbuild2018_C075).
9. BC Hydro. (2016). Building envelope thermal bridging guide: Analysis, applications, and insights (Version 1.6). BC Hydro. <https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/builders-developers/building-envelope-thermal-bridging-guide-v1-6.pdf>.



## AUTHOR BIOGRAPHY

**Marcos Casimirri, PEng, CEM**, is a senior mechanical engineer, energy specialist at CBCL. With over 17 years of professional experience, Marcos has cultivated expertise in the analysis and implementation of energy efficiency measures, decarbonization pathways for building portfolios and renewable energy projects. He holds a Master of Engineering from Dalhousie University and a Bachelor of Science in Mechanical Engineering from UNEXPO University in Venezuela.

Marcos has led and managed a wide variety of projects related to deep energy retrofits and decarbonization pathways for the private sector and multiple level of governments in Canada, Latin America, and the Caribbean. He has successfully completed and managed multiple building energy simulating studies, energy audits, energy management programs, and renewable energy projects for a broad range of facilities. He has also played an instrumental role in supporting multilateral development banks in advancing energy projects to shape a greener future.

As an active member of AEE and Engineers Nova Scotia, Marcos is deeply committed to the advancement of sustainability and energy efficiency. In addition, Marcos is dedicated to mentoring emerging engineers either by serving as a judge at Dalhousie University's Capstone Project Event, guiding young professionals in his team or providing guidance to mentees through CBCL's Mentorship program. Beyond his professional activities, Marcos values quality time with his family and enjoys leisure activities such as exploring new destinations and languages, reading about world history, and playing baseball. Marcos Casimirri may be contacted at [mcasimirri@cbcl.ca](mailto:mcasimirri@cbcl.ca).