Methodology of Energy Conservation Calculation for Buildings

This document serves as a methodology for calculating energy conservation from retrofitted and in-operation buildings.

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Contents

Executive Summary

This white paper outlines a comprehensive methodology for calculating energy conservation in buildings, developed collaboratively by Singapore's Building and Construction Authority (BCA) SLEB Smart Hub and the Monetary Authority of Singapore's Project NovA!. The methodology aims to quantify energy savings in retrofitted and operational buildings, supporting Singapore's sustainability goals and green building initiatives.

Key components of the methodology include:

1. Energy Conservation Calculation (ECC): A standardized approach to measure energy savings by comparing actual energy consumption against a baseline, typically set at 50-60% improvement over 2005 Green Mark levels.
2. AI-Driven Modelling: An innovative tool that streamlines energy performance assessment, reducing input requirements and computation time while maintaining accuracy.
3. Data Collection Framework: A structured process for gathering building attributes, energy consumption data, and system specifications to ensure consistent and reliable assessments.
4. Baseline Establishment: A method to create a customized baseline for each building, accounting for its unique characteristics and operational dynamics.
5. Energy Saving Calculations: Detailed procedures for quantifying energy savings and carbon emission reductions based on implemented Energy Conservation Measures (ECMs).

The methodology supports various applications, including:

- Issuance of Energy Conservation Certificates
- Generation of Emission Reduction Units
- Facilitation of Green Loans
- Facilitation of Sustainability-Linked Loans
- Potential linkage to financial incentives

The paper also presents a case study demonstrating the practical application of the methodology to a hotel building, showcasing significant energy savings and carbon emission reductions.

This methodology provides a robust framework for evaluating building energy performance, supporting Singapore's transition to a low-carbon built environment, and aligning with global sustainability efforts. It offers a standardized approach for stakeholders in the building sector to measure, verify, and monetize energy conservation efforts.

1. Background

1.1 Singapore Sustainability Goals

Singapore is steadfast in its commitment to fulfilling its obligations under the Paris Agreement, with a comprehensive strategy outlined in the **Singapore Green Plan 2030**. This ambitious plan sets Singapore on a clear pathway to achieving net-zero emissions by 2050. Key intermediate targets include a 36% reduction in emissions intensity from 2005 levels by 2030 and a firm commitment to peak greenhouse gas emissions by that year.

The Green Plan 2030 encompasses various initiatives across multiple sectors—such as energy, transportation, and urban development—to drive sustainable growth while reducing carbon dependency. Efforts include expanding solar energy capacity, greening public transportation, enhancing waste reduction, and encouraging sustainable lifestyles, all of which support Singapore's transition to a low-carbon economy. These initiatives highlight Singapore's proactive approach to tackling climate change and fostering a sustainable, resilient future.

1.2 Singapore's Buildings Sustainability Goals

Buildings account for nearly half of Singapore's electricity consumption and approximately 20% of its carbon emissions. In response, the **Building and Construction Authority** (BCA) and the **Singapore Green Building Council** (SGBC) have introduced the **Singapore Green Building Masterplan** (SGBMP), with ambitious targets aimed at transforming the built environment:

- Achieving **"Green"** status for 80% of buildings by 2030.
- Ensuring 80% of new buildings attain **Super Low Energy Building (SLEB)** standards by 2030.
- Enhancing energy efficiency in top-performing buildings to achieve an **80% improvement** from 2005 levels.

1.3 Green Mark Certification Scheme

The Building and Construction Authority (BCA) **Green Mark Certification Scheme** is an internationally recognized program designed to assess and promote sustainable building practices. As a cornerstone of the Singapore Green Building Masterplan (SGBMP), the scheme plays a pivotal role in advancing Singapore's environmental sustainability objectives.

The Green Mark scheme rigorously evaluates buildings based on their environmental impact and performance, with a strong emphasis on energy efficiency, water conservation, indoor environmental quality, and sustainable construction practices. By setting high standards, the scheme encourages the integration of advanced energy-efficient technologies and innovative design solutions, pushing the boundaries of sustainable development in Singapore's built environment. Through the adoption of the Green Mark certification, building owners and developers are motivated to achieve higher levels of environmental performance, contributing to a greener, more resilient cityscape.

1.4 Super Low Energy Building (SLEB) Smart Hub

Launched in 2019, the SLEB Smart Hub (www.sleb.sg) is a cutting-edge digital platform that leverages data analytics and artificial intelligence to advance Singapore's energy conservation and decarbonization objectives in the built environment.

Aligned with the Green Mark certification scheme and Singapore Green Building Masterplan, the SLEB Smart Hub serves as a pivotal enabler for the nationwide adoption of Super Low Energy Buildings (SLEBs), driving sustainable development across the sector.

The platform provides powerful analytical tools to deeply analyse building energy consumption patterns, fostering innovation in energy efficiency and enabling stakeholders to make data-driven decisions. Additionally, it facilitates green financing solutions, simplifying access to funding for sustainable building projects. By offering these capabilities, the SLEB Smart Hub empowers building owners, developers and policymakers to advance energy efficiency initiatives, contributing meaningfully to Singapore’s green building targets.

1.5 Monetary Authority of Singapore's Project NovA!

Project NovA![1], launched by the Monetary Authority of Singapore (MAS), is a groundbreaking initiative aimed at fostering innovation in the financial sector through the use of artificial intelligence (AI) and machine learning. The project focuses on enhancing risk management, compliance, and financial inclusion by promoting the development and implementation of ethical AI standards, ensuring transparency, fairness, and accountability across financial services. Core Functions include but not limited with the below functions:

- **Risk Management & Compliance:** Enhance the financial sector's capabilities in risk assessment and regulatory compliance through advanced AI-driven solutions.
- **Financial Inclusion:** Utilize AI and machine learning to create more accessible and inclusive financial services, ensuring broader access to financial tools and resources.
- **Ethical AI Standards:** Promote the development of transparent, fair, and accountable AI standards, fostering responsible AI usage within the sector.

Beyond its core focus, Project NovA! also supports green finance initiatives, including sustainability-linked loans, by forging partnerships that utilize AI to amplify the environmental and social impact of financial activities. By integrating advanced technology with responsible practices, Project NovA! is paving the way for a more resilient, inclusive, and sustainable financial ecosystem:

- **Sustainability-Linked Loans:** Facilitate the growth of green finance initiatives by supporting loans tied to environmental and social performance metrics.
- **Partnerships for Impact:** Collaborate with industry partners to leverage AI for enhancing the environmental and social impact of financial activities, aligning financial practices with sustainability goals.

[1] Details about Project NovA! is available at https://www.mas.gov.sg/news/media-releases/2023/ai-powered-system-to-support-sustainable-finance-in-real-estate-sector

1.6 AI-Driven Building Energy Model

Through a collaborative effort, the BCA SLEB Smart Hub and MAS Project NovA! teams have developed an advanced AI-driven energy model to simulate building energy performance (see Annex A for further details). This model leverages data from the BCA Green Mark Online (GMO) and Building Energy Submission System (BESS) platforms.

Key Features of the AI Model:

- **Streamlined Data Input:** Requires fewer data points, enhancing both efficiency and ease of use.
- **Accelerated Computation:** Provides rapid results while upholding industry-standard accuracy, facilitating faster decision-making.
- **Innovative Application:** Serves as an alternative to tools like EnergyPlus, TRNSYS, and ESP-r, simulating notional building energy performance to establish a normalized baseline.
- **Seamless Integration:** Aligns with BCA Green Mark standards, ensuring consistent and reliable energy efficiency assessments throughout the building lifecycle, from planning and design to construction and operation.

This model is calibrated to simulate the typical energy performance of buildings similar to the existing one, providing a notional baseline at the Green Mark 2005 level. This approach offers a fair and standardized reference point for evaluating the actual energy performance of the existing building under a business-as-usual scenario.

2. Building Energy Conservation Calculation

2.1 What is a Building Energy Conservation Calculation (ECC)?

The building **Energy Conservation Calculation** (ECC) is a standardized methodology designed to quantify the energy savings achieved by retrofitted and operational buildings, with a focus on performance that surpasses baseline requirements, such as those established by Green Mark ratings. The ECC measures energy savings by comparing the building's actual energy consumption with the designated ECC baseline over a defined reporting period. This approach provides an objective benchmark to evaluate improvements in energy efficiency. For specific ECC baseline settings, please refer to Table 1 below:

Table 1 The ECC Baseline Settings

<table>
<tr><th>Green Mark Rating</th><th>ECC baseline</th><th>Applicable Building Types</th></tr>
<tr><td>Green Mark SLE</td><td>60% savings over Green Mark 2005 level</td><td rowspan="4">Office, Retail, Hotel, Mixed Development (Combinations of Office, Retail, And Hotel), Healthcare, Institutional Buildings.</td></tr>
<tr><td>Green Mark Platinum</td><td>55% savings over Green Mark 2005 level</td></tr>
<tr><td>Green Mark Gold^{PLUS}</td><td>50% savings over Green Mark 2005 level</td></tr>
<tr><td>Existing Building Not Certified Under Green Mark Scheme</td><td>50% savings over Green Mark 2005 level</td></tr>
</table>

2.2 Why is ECC Important?

The ECC plays a critical role in providing a fair and consistent method for evaluating a building's energy performance against a customized baseline that accounts for the building's unique characteristics and operational dynamics, including operational hours, tenant composition, and occupancy rates. By offering a nuanced assessment, the ECC not only verifies energy savings but also transforms these achievements into potential revenue streams. Energy savings calculated through ECC can be converted into tradable digital assets or transition credits, creating new financial opportunities for building owners.

Additionally, the ECC serves as a standardized framework for sustainability-linked loans, embedding energy efficiency directly into financing mechanisms. This integration allows building owners to leverage their energy performance improvements in financial instruments, supporting both economic and environmental goals.

3. Methodology for Building Energy Conservation Calculation

3.1 Scope and Applicability

The methodology for the Energy Conservation Calculation (ECC) applies to retrofitted and operational buildings that incorporate Energy Conservation Measures (ECMs). These measures focus on reducing energy consumption through enhanced systems and operational practices while integrating renewable energy solutions. Typical examples include the implementation of high-efficiency HVAC systems, improved lighting solutions such as LED technologies, and building façade enhancements to minimize heat transfer and improve insulation.

Furthermore, this methodology covers the integration of advanced energy monitoring and optimization tools, such as Building Energy Management Systems (BEMS), which provide real-time data to guide energy-efficient operations. The utilization of renewable energy sources, particularly rooftop solar photovoltaic (PV) systems, is also an essential component of this framework. These systems are designed to offset grid electricity usage and contribute to the overall energy conservation objectives.

The methodology aligns closely with Green Mark standards, providing a structured approach to evaluate energy efficiency improvements against a defined baseline. Annex A outlines the AI-driven modeling tools that are used to predict baseline energy consumption and evaluate the effectiveness of ECMs. Additionally, a practical case study in Annex C illustrates the methodology's application to a retrofitted hotel building, demonstrating measurable improvements in energy performance and carbon emission reductions.

3.2 Project Boundary and Reporting Period Boundary

To provide further clarity, Table 2 summarizes the key components of the project and reporting period boundaries:

The **project boundary** defines the physical and geographical scope of the energy conservation measures being evaluated. This boundary typically includes all energy-consuming systems and spaces directly associated with the building's operation. For instance, it encompasses HVAC systems, lighting installations, and mechanical ventilation systems, as well as any renewable energy sources deployed on-site, such as rooftop solar panels. These systems must fall within the physical confines of the building or its ancillary infrastructure, ensuring a clear demarcation of responsibility and impact.

The **reporting period boundary** establishes the timeframe during which the building's energy performance is measured and assessed. This period begins after the completion of retrofitting or construction and once the building has achieved a stable operational state. Stability in operation is crucial to ensure that data collected is representative of typical energy usage patterns. The reporting period is typically aligned with crediting periods used for energy savings verification, which is often a multi-year duration to provide a robust basis for cumulative energy performance assessment.

A clear example of these boundaries can be observed in Annex C, which details a case study of a hotel building. The project boundary in this case included HVAC systems, common area lighting, and renewable energy installations, while the reporting period spanned from January 1, 2020, to

December 31, 2023. The consistent application of these boundaries ensured that energy savings could be accurately quantified and benchmarked against the ECC baseline.

Table 2 Description and Examples of Project Boundary and Reporting Period Boundary

Boundary Type	Description	Examples
Project Boundary	Physical limits encompassing all energy-consuming systems and renewable energy installations.	HVAC systems, lighting installations, solar PV systems.
Reporting Period Boundary	Timeframe for energy performance evaluation post-completion of retrofitting or construction.	Multi-year crediting periods, such as 2020–2023 for the case study detailed in Annex C.

3.3 Overall Process

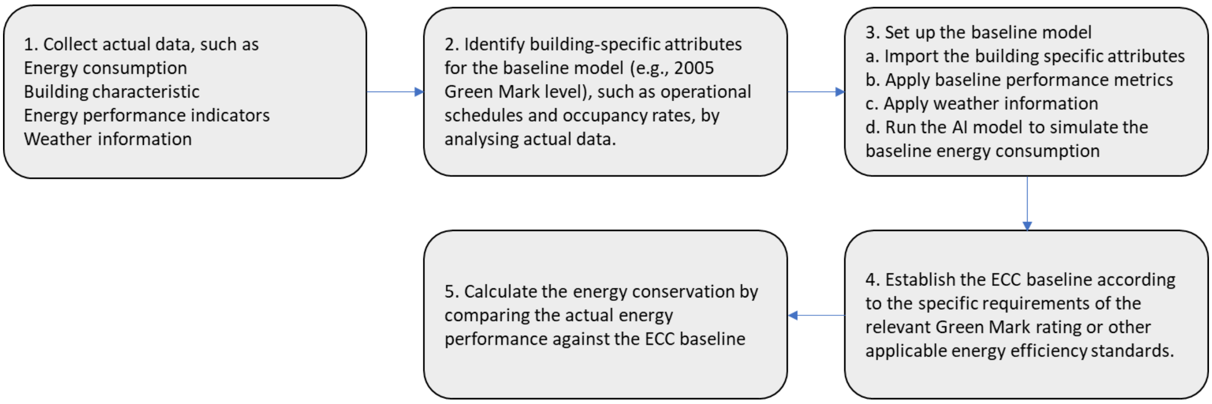

Figure 1 Process of Energy Conservation Calculation

The energy conservation calculation process, outlined in **Figure 1**, consists of a structured sequence of steps to accurately assess and quantify energy savings. This process ensures a comprehensive evaluation by incorporating key data and simulation models:

1. **Data Collection**: The first step involves gathering factual data on various aspects of the building, such as:
   - **Energy Consumption:** Record actual energy usage data over a defined period.
   - **Building Characteristics**: Document structural and operational features of the building.
   - **Energy Performance Indicators:** Identify metrics that reflect energy efficiency.
   - **Weather Information:** Capture weather data, which can significantly influence energy consumption patterns.
2. **Identification of Building-Specific Attributes**: Define the attributes necessary for creating a baseline model, such as:
   - Operational schedules and occupancy rates, which directly affect energy demand.

- Specific baseline models, like the 2005 Green Mark level, that provide reference standards for comparison.

3. **Setting Up the Baseline Model**:

    - **Import Attributes:** Load building-specific attributes into the model to establish a representative baseline.
    - **Apply Baseline Performance Metrics: Use** standard performance metrics to ensure consistency with the chosen baseline level.
    - **Incorporate Weather Information:** Adjust the model for weather variations to accurately simulate conditions.
    - **Run AI Simulation:** Employ AI-driven models to simulate the building's baseline energy consumption, providing a reliable reference for future comparisons.

4. **Establishing the ECC Baseline**: Based on the results from the baseline model, establish the Energy Conservation Calculation (ECC) baseline. This baseline aligns with the specifications of the relevant Green Mark rating or other applicable energy efficiency standards, serving as a benchmark for evaluating improvements.

5. **Energy Conservation Calculation**: Calculate energy conservation by comparing the actual energy consumption data with the ECC baseline model. The difference reflects the energy savings achieved through conservation measures and efficiency improvements.

3.4 Collection of Actual Data

Accurate and comprehensive data collection is a cornerstone of the Energy Conservation Calculation (ECC) methodology. This chapter outlines the process for gathering the necessary data to evaluate energy performance and measure improvements achieved through energy conservation measures (ECMs). The data collection framework ensures consistency, reliability, and alignment with established energy performance benchmarks, such as the Green Mark standards. The overall data collection process is summarized in Figure 1, illustrating the seamless integration of data preparation, recording, verification, and baseline modelling.

3.4.1 Data Requirements and Standardization

The ECC methodology relies on a standardized data collection approach to ensure uniformity across diverse projects. This involves gathering data from utility bills, energy meters, and building management systems, as well as supplementary sources such as tenant agreements. Annex B provides templates and detailed guidelines for the collection and recording of key data parameters, including building attributes, energy consumption, and building system specifications . Table 3 summarizes the examples of core data requirements:

Table 3 The Example Metric of Core Data Requirement

Data Parameter	Unit	Source	Frequency	Description
Average Monthly Energy Consumption	kWh	Utility bills, energy meters	Annually	Monthly average electricity consumption is based on at least 6 month's data.
Gross Floor Area (GFA)	m²	Building plans, building survey	Initially and triennially	Gross floor area excluding car park area
Operational Schedule	Hours/week	Building survey, recorded energy use	Annually	Total building operation hours per week
Building Type		Building plan, building survey	Initially	The category or classification of the building based on its purpose, including Office Building, Retail Building, Hotel, Healthcare Facility, Educational Institution, Industrial Building, Residential Building, Mixed Development, and Others
Percentage of Air-Conditioned Area		Building plan, building survey	Initially and triennially	The proportion of the building's total floor area that is served by air-conditioning, expressed as a percentage.

This standardized approach, detailed in Annex B, minimizes errors and enhances comparability across projects by establishing consistent measurement units, data sources, and monitoring frequencies.

3.4.2 Data Collection Process

The data collection process is structured into three distinct phases:

1. **Preparation Phase** During this phase, building managers or project teams gather preliminary information about the project building, including its type, gross floor area, and baseline energy performance data. This phase also involves setting up monitoring systems, such as Building Energy Management Systems (BEMS) or IoT sensors, to automate data collection. Annex C highlights how a hotel building retrofit project used high-accuracy measurement systems to monitor HVAC and lighting systems effectively.

2. **Data Recording Phase** In this phase, energy consumption data is recorded over the defined reporting period. This involves:
    - Capturing real-time data through energy meters and BEMS, which are calibrated to ensure accuracy.
    - Cross-verifying recorded data with utility bills to prevent discrepancies.

- Monitoring occupancy density and operational schedules, which directly influence energy demand. Annex A describes how AI-driven models integrate these datasets for accurate simulation and baseline establishment.

3. **Data Verification Phase** Collected data undergoes rigorous verification to ensure accuracy and integrity. Verification measures include:
    - Comparing energy meter readings with historical records and utility bills.
    - Conducting spot audits to validate operational schedules and occupancy rates.
    - Implementing audit trails to trace data changes and maintain transparency. Annex B provides additional details on verification protocols, highlighting best practices for maintaining data integrity.

3.4.3 Integration into ECC Baseline

Once collected and verified, the data is integrated into the AI-driven model described in Annex A to simulate the building's baseline energy performance. This model uses key parameters such as EUI, gross floor area, and weather data to establish the ECC baseline. For example, in the hotel retrofit case study (Annex C), the AI model calculated a baseline EUI representing a 50% improvement over the 2005 Green Mark level, serving as a benchmark for energy savings evaluation.

3.5 Derivation of Building-Specific Attributes

Generating baseline energy consumption requires building-specific attributes such as gross floor area, operation schedule, and occupancy density. Some attributes, like gross floor area, can be directly obtained from user input. However, others, such as occupancy density, may be more challenging to determine and may require a calibration process to match the actual operational condition of the target building.

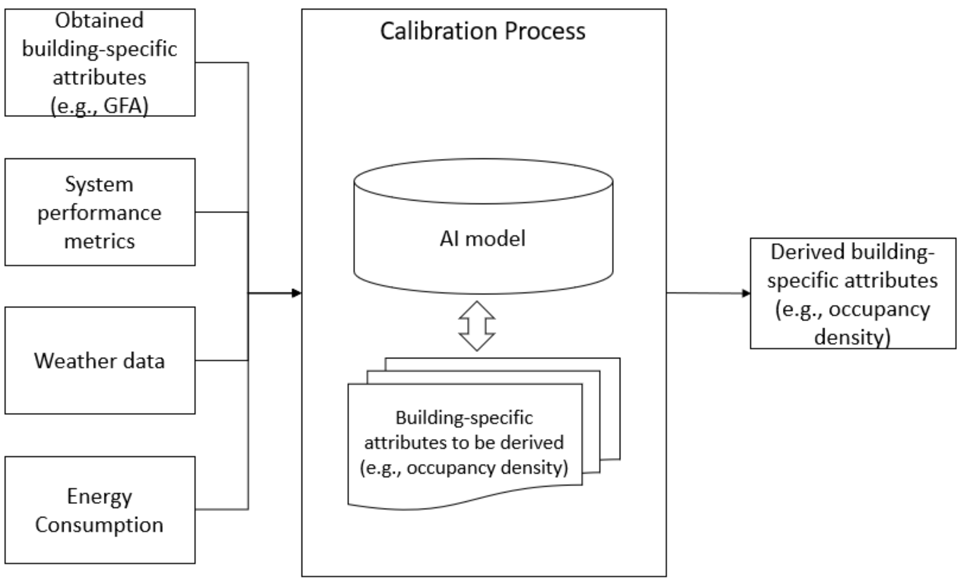

Figure 2 Building-Specific Attributes Derivation Process

Figure 2 illustrates how these building-specific attributes are derived. Available data, including building-specific attributes, system performance metrics, and weather data, are fed into an AI model. The model iteratively tests different values for the attributes that need to be derived. It selects the values that produce energy consumption estimates most closely matching the actual data, which are then used to derive the required attributes for the baseline model.

3.6 Baseline Model Set-Up

Establishing a robust and accurate baseline is a critical step in the Energy Conservation Calculation (ECC) methodology. The baseline serves as the benchmark for assessing energy savings achieved through implemented Energy Conservation Measures (ECMs). The typical process for setting up the baseline model, including the selection of input parameters, calibration, and verification procedures, as well as its integration into the ECC framework.

3.6.1 Baseline Model Configuration

The baseline energy consumption represents the theoretical performance of the building under business-as-usual conditions, such as compliance with the 2005 Green Mark standards. The model setup involves two primary steps:

Step 1: Calculation of Notional Energy Consumption Using historical data and energy simulation tools, the notional energy consumption is calculated based on the Green Mark 2005 baseline standards. This includes factors such as HVAC system efficiency, façade thermal performance, and operational characteristics. Annex A provides a detailed description of the Green Mark 2005 baseline assumptions, as summarized in Table A1.

Step 2: ECC Baseline Calibration The ECC baseline is further refined to align with current Green Mark standards or other applicable benchmarks. This ensures the baseline reflects the target energy performance levels required by certification frameworks. For example, in the hotel retrofit case study (Annex C), the baseline EUI was set to represent a 50% energy savings over the 2005 level, providing a dynamic and fair benchmark.

3.6.2 Input Parameters for the Baseline Model

The accuracy of the baseline model depends on the quality and comprehensiveness of input parameters, which are grouped into three categories (Table 4):

Table 4 Input Parameters for the Baseline Model

Category	**Examples**	**Source**
Building-Specific Attributes	Gross floor area, occupancy density, operational schedule	Building plans, energy management systems
Energy Performance Metrics	HVAC efficiency, façade thermal properties	Manufacturer specifications, historical data
External Environmental Factors	Weather conditions, urban heat island effects	Local meteorological stations, IoT sensors

The AI-driven model described in Annex A integrates these inputs to simulate baseline performance accurately. For instance, the Envelope Thermal Transfer Value (ETTV) is used to estimate cooling loads, while weather data accounts for seasonal variability.

3.6.3 Baseline Setup Process

The baseline setup involves the following key steps:

1. **Data Input and Model Initialization** All relevant building-specific attributes and energy performance metrics are collected and entered into the AI model. Weather data, such as temperature and humidity levels, is also integrated to reflect real-world conditions. Annex B outlines the templates and tools for collecting these inputs.
2. **Simulation and Calibration** The AI model performs an initial simulation to estimate the notional baseline energy consumption. It then undergoes iterative calibration, comparing simulated results with historical performance data to ensure alignment with actual building conditions. This process minimizes deviations and enhances model accuracy.
3. **Verification and Validation** The baseline model is verified through cross-referencing with third-party data sources, such as utility bills or Green Mark certification reports. The process also involves sensitivity analyses to test the model's robustness against variations in key parameters.

3.7 Inputs for the AI Model:

The AI model used to calculate baseline energy consumption relies on a comprehensive set of input variables to ensure accuracy and reliability. These inputs are grouped into three main categories, as shown in Figure 3:

- **Energy Performance Metrics:** This category includes metrics that impact the building's overall energy efficiency, such as the Envelope Thermal Transfer Value (ETTV), air-conditioning system efficiency, and performance indicators of additional energy conservation measures. These metrics provide essential insights into the building's thermal and mechanical energy demands.
- **Building-Specific Attributes:** To accurately reflect the project building's conditions, the model incorporates attributes such as gross floor area, operational schedule, and occupancy density. These attributes, either directly measured or derived from collected data, allow the model to

align closely with the building's unique characteristics. For example, occupancy behavior patterns, including peak usage times, are quantitatively assessed to enhance model precision.

- **Weather Data:** External weather conditions, such as temperature, humidity, and solar radiation, significantly influence a building's energy requirements, particularly for heating, cooling, and ventilation. Incorporating real-time and historical weather data enables the model to simulate realistic.

To further improve model accuracy, additional input variables may be considered, such as specific occupancy behaviour patterns and localized environmental impacts, which can be quantified through sensor data and historical analyses.

Using these inputs, the AI model applies advanced building energy simulation techniques and machine learning algorithms to generate a baseline energy consumption estimate. This approach leverages extensive datasets, ensuring that the baseline model is both robust and adaptable to complex building scenarios.

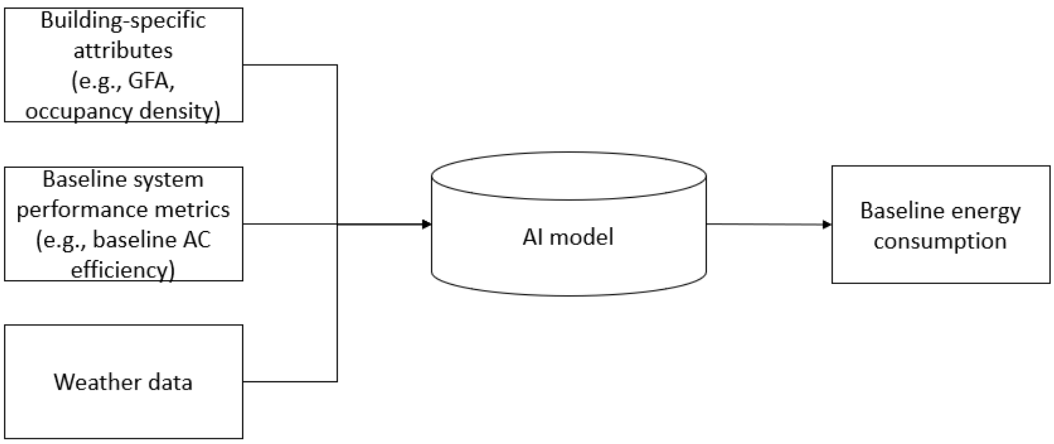

Figure 3 Baseline Energy Consumption Calculation Process

By combining precise data inputs and rigorous calibration processes, the baseline model provides a reliable benchmark for evaluating the energy savings achieved through ECMs. The integration of AI-driven tools, as described in Annex A, ensures efficiency and consistency in model development, enabling accurate and meaningful assessments within the ECC framework.

3.8 Energy Conservation Calculation

The energy consumption difference (ECD) is determined by comparing the building's actual energy consumption with the ECC baseline, as shown in Equation (1):

$$ECD_i = BEC_i - AEC_i \quad (1)$$

Where:

ECD_i: Energy consumption difference of the building for a given year i (MWh)

BEC_i: Baseline energy consumption of the building for a given year i (MWh)

AEC_i: Actual energy consumption of the building for a given year i (MWh)

This difference indicates the amount of energy saved relative to the ECC baseline. A positive ECD value shows that the building's energy use is below the ECC baseline, reflecting energy savings. A negative ECD value indicates that the building's energy use exceeds the baseline.

To calculate the cumulative energy difference over the crediting period, use Equation (2):

$$\sum_{i=1}^{j} ECD_i = \sum_{i=1}^{j} BEC_i - \sum_{i=1}^{j} AEC_i \qquad (2)$$

The cumulative carbon emission reduction due to energy savings during the crediting period can be calculated using Equation (3):

$$\sum_{i=1}^{j} ERD_i = \sum_{i=1}^{j} ECD_i \times GEF_i \qquad (3)$$

Where:

ERD_i: Carbon equivalent emission reduction in year i (tCO_{2e})

GEF_i: Grid emission factor in year i (tCO_{2e}/MWh)

The annual baseline energy consumption can be calculated using energy use intensity (EUI) when EUI is used as the evaluation metric, as shown in Equation (4):

$$BEC_i = BEUI_i \times GFA_i \qquad (4)$$

Where:

$BEUI_i$: Baseline energy use intensity of the building in year i (kWh/m²/year)

GFA_i: Gross floor area of the building (excluding carpark) in year i (m²)

Similarly, the annual actual energy consumption can be calculated as:

$$AEC_i = AEUI_i \times GFA_i \qquad (5)$$

Where:

$AEUI_i$: Actual energy use intensity of the building in year i (kWh/m²/year)

3.9 Applications

The Energy Conservation Calculation (ECC) offers four potential applications:

1. **Issuance of Energy Conservation Certificates:** The amount of energy conserved, as determined by the difference in consumption, can be converted into energy conservation certificates. Each certificate represents 1,000 kWh of energy saved.

2. **Issuance of Emission Reduction Units:** These energy conservation certificates can be further converted into CO2 equivalent emission reduction units, based on the grid emission factor. This allows for the quantification of the environmental impact in terms of reduced greenhouse gas emissions. Figure 4 illustrate the concept.

3. **Facilitation of Sustainability-Linked Loans for Buildings**: The ECC plays a pivotal role in enabling sustainability-linked loans for buildings, a cutting-edge financial instrument that ties borrowing terms to sustainability performance. In this application, borrowers and financial institutions utilise the Energy Use Intensity (EUI) as a key metric to set and track sustainability performance targets against an agreed baseline, such as 60% of savings over the 2005 level. Crucially, this baseline is dynamic and adaptive, adjusting to the building's 'business-as-usual' scenario and accounting for weather changes, ensuring that sustainability targets remain relevant and challenging. By providing a standardised yet flexible method of quantifying energy conservation, the ECC facilitates the integration of sustainability goals into financial agreements. This innovative approach not only encourages building owners to invest in energy-efficient technologies and practices but also allows financial institutions to align their lending practices with broader sustainability goals, driving the transition towards more energy-efficient buildings through economic incentives and creating a win-win scenario for both parties and the environment.

4. **Link to Financial Incentives:** Calculated energy savings can be potentially linked to the financial incentives such as tax rebates, energy efficiency incentive grant, energy credits, or enhanced loan terms, providing a direct benefit to building owners for energy conservation efforts.

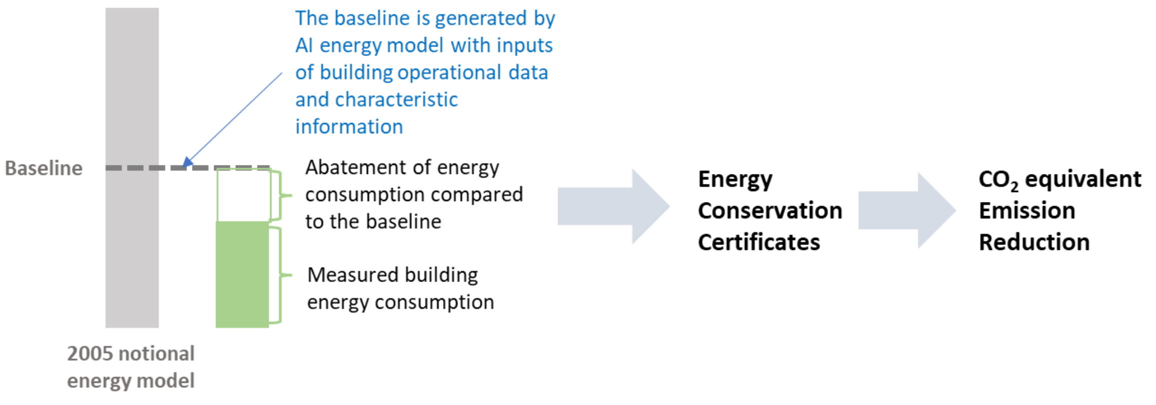

Figure 4 Building Energy Conservation Calculation and Applications

3.10 Tools for Energy Conservation Calculation and Verification

The SLEB Smart Hub (www.sleb.sg) provides two tools for energy conservation calculation and verification:

1. Building Energy Efficiency Assessment (BEEA): This tool calculates the notional energy consumption for project building based on 2005 level and assesses its energy efficiency against this baseline consumption figure.
2. My Building: This centralized digital Monitoring, Reporting, and Verification (dMRV) portal digitises and automates MRV processes, ensuring transparency, accuracy and efficiency.

How the My Building Tool Works:

1. Registration and Data Sharing: The applicant registers on SLEB.sg as the building owner and grants permission for data sharing.
2. Data Submission: The applicant uses the 'My Building' feature to submit building data. This data can be automatically populated if available on the SLEB platform. Alternatively, the building's energy management system can connect to SLEB via APIs to provide the necessary information.
3. Energy Savings Calculation and Verification: The AI model then calculates the energy savings above the established baseline and tracks the building's energy performance against this baseline.

The process of using BEEA and My Building are shown in Figure 5.

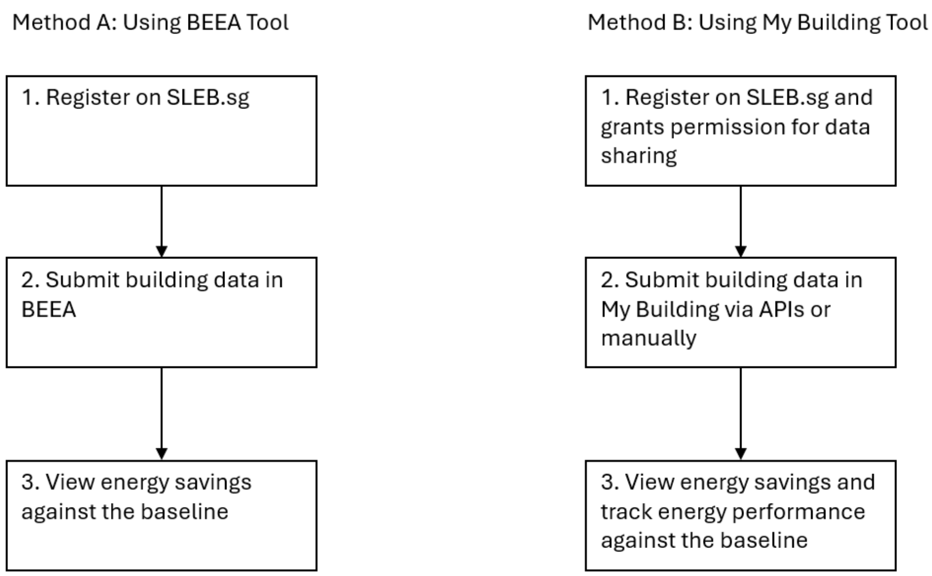

Figure 5 Process of using BEEA and My Building

The Section 4 presents a case study utilizing the ECC methodology and the SLEB Smart Hub Building Energy Efficiency Assessment (BEEA) tool to quantify energy savings and carbon emission reductions achieved through a retrofitting project.

4. Case Study

Table 5 provides details of a Singapore hotel building used for this case study. Energy conservation upgrades were completed in 2019, and the crediting period for calculating energy savings runs from January 1, 2020, to December 31, 2023.

Table 5 Case Study Hotel Building Information

Parameter Description	Value
Gross Floor Area (m^2)	26188
Number of Buildings in Project	1
Building Type	Hotel
Number of Storeys	8
Year of Construction	1985
F&B Area (m^2)	150
Data Centre/Server Room Area (m^2)	35
Operation Schedule (hr/week)	168
Percentage of Air-Conditioned Area (%)	74.84
Air Conditioning System Type	Water-cooled Chilled Water Plant
Air Distribution System Type	AHU-VAV
Total Mechanically Ventilated Area (m^2)	6000

Table 6 lists the technical descriptions of the Energy Conservation Measures (ECMs) implemented in this building.

Table 6 Technical Description of Energy Conservation Measures (ECMs) Implemented In The Case Study Building

Energy Conservation Measures	**Technical Description**
ECM 1	The installation of a more efficient Screw VSD chiller, along with the replacement of ancillary chiller plant equipment, has improved the efficiency of the chilled water system from 1.22 kW/RT to 0.646 kW/RT.
ECM 2	Renovation of the existing 4 Pre-cooling Air Handling Units (AHUs) to be more energy efficient.
ECM 3	Installation of the high-accuracy permanent measurement and verification system to monitor and control the chiller plant.
ECM 4	Replacement of traditional light source to 100% LED lights at the hotel common areas.
ECM 5	Replacement of all lifts equipped with ACVVVF drives with sleep mode features.
ECM 6	Installation of CO sensor at the basement car park to modulate Mechanical Ventilation fan for fresh air demand.

Figure 6 shows the building's Energy Use Intensity (EUI) from 2018 to 2023. During the crediting period (2020–2023), the EUIs were recorded as follows: 194, 205, 216, and 221 kWh/m²/year.

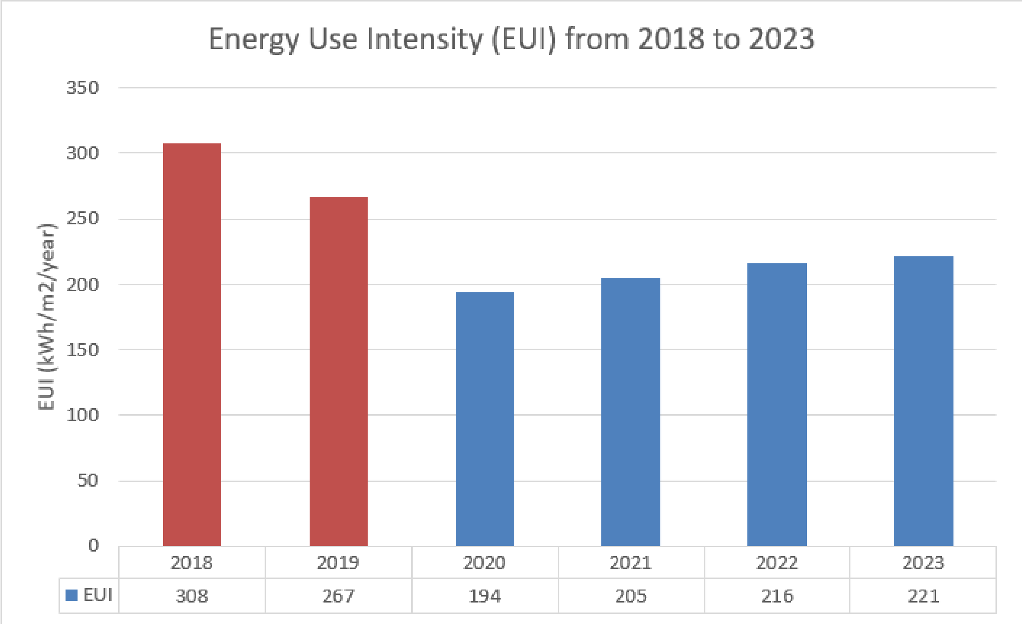

Figure 6 Case Study Building's EUI from 2018 to 2023

The baseline EUI values were calculated using the Building Energy Efficiency Assessment (BEEA) tool from the SLEB Smart Hub. In this case study, the ECC baseline is set to represent a 50% energy savings over the 2005 level. Table 7 presents the detailed calculations.

Table 7 Baseline EUI Calculation

Crediting Period	Benchmark EUI at 2005 level (kWh/m^2/year)	ECC baseline, e.g. 50% improvement over 2005 level	Baseline EUI (kWh/m^2/year)
	A	B	BEUI =A*B
Year 2023	498.8	50 %	249.4
Year 2022	487.5	50 %	243.75
Year 2021	462.7	50 %	231.35
Year 2020	437.9	50 %	218.95

Using Equation (4), Table 8 calculates the ECC baseline energy consumption for each year of the crediting period.

Table 8 Calculation of The Baseline Energy Consumption of Each Year during the Crediting Period

Crediting Period	Baseline EUI, 50% savings over 2005 level (kWh/m^2/year)	Gross Floor Area (m^2)	Baseline energy consumption (MWh)
	BEUI	GFA	BEC=BEUI*GFA/1000
Year 2023	249.4	26188	6531
Year 2022	243.75	26188	6383
Year 2021	231.35	26188	6059
Year 2020	218.95	26188	5734

Table 9 shows the actual energy consumption for each year, calculated using Equation (5).

Table 9 Calculation of the Actual Energy Consumption of Each Year during the Crediting Period

Crediting Period	Actual EUI (kWh/m^2/year)	Gross Floor Area (m^2)	Actual energy consumption (MWh)
	AEUI	GFA	AEC=AEUI*GFA/1000
Year 2023	221	26188	5788
Year 2022	216	26188	5657
Year 2021	205	26188	5369
Year 2020	194	26188	5080

Using Equations (1) and (2), Table 10 calculates the energy consumption difference for each year and the cumulative energy savings over the crediting period.

Table 10 Calculation of the energy consumption difference for each year and accumulative energy consumption savings

Crediting Period	Baseline energy consumption in year *i*	Actual energy consumption in year *i*	Energy consumption difference (MWh)
	BEC	AEC	ECD= BEC-AEC
Year 2023	6531	5788	743
Year 2022	6383	5657	726
Year 2021	6059	5369	690
Year 2020	5734	5080	654
Accumulative energy consumption difference during the crediting period			2813

Based on Equation (3), Table 11 calculates the cumulative carbon emission reductions during the crediting period.

Table 11 Calculation of the Accumulative Carbon Emission Reductions

Crediting period	Difference of energy consumption (MWh)	Grid emission factor (tCO_{2e}/MWh)	Carbon emission reduction (tCO_{2e})
	ECD	GEF	ERD = ECD*GEF
Year 2023	743	0.417	310
Year 2022	726	0.417	303
Year 2021	690	0.409	282
Year 2020	654	0.407	266
Accumulative carbon emission reduction during the crediting period			1161

In this case study, the building achieved the Green Mark Gold^{PLUS} energy efficiency standard following its renovation, qualifying it for a green loan application. Additionally, the project verified the issuance of 2,813 Energy Conservation Certificates and a reduction of 1,161 tons of CO_2 emissions.

5. Mutual Acceptance

For building projects situated in temperate climate zones, this methodology aligns with and accepts the calculation approach outlined in the Technical Specification for Identification of Carbon Emission Reduction Verification of Comprehensive Renovation Projects of Public Buildings (hereafter referred to as the "Technical Specification"). This Technical Specification, endorsed by the Chinese Society for Environmental Sciences, establishes recognized standards in carbon emission reduction verification for public building renovations. Additional information on the Technical Specification can be accessed via link.

Furthermore, this methodology supports a comprehensive suite of tools for assessment, monitoring, reporting, and verification, all developed in accordance with the Technical Specification. The methodology, along with these associated software tools, has achieved mutual acceptance with the Technical Specification, ensuring consistency and reliability in carbon emission assessments across relevant projects.

6. Acknowledgements

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Annex A – AI-Driven Modelling for Analysing Buildings Energy Performance

A1. Introduction

In Singapore, Green Mark certification requires calculating a building's energy savings percentage over a baseline through energy modeling (EM). While EM is an internationally recognized methodology for integrated green building design, it is often a time and resource intensive process. Depending on the complexity of the building design, EM can take over two weeks to complete.

To address this, an innovative AI-driven building performance assessment tool (referred to as the "AI-driven Model") has been developed to streamline the process. This tool reduces the number of user inputs and computation time required for calculating energy savings, all while maintaining high accuracy. The solution is achieved by combining machine learning with rule-based modeling techniques.

The AI-driven model can be applied to generate the baseline and calculate energy conservation based on building characteristics.

A2. Process and Framework of AI-driven Model

The process of the AI-driven model is shown in Figure A1. The AI-driven model first receives user input, which includes building attributes, operational information, system efficiency, and actual building performance data. Next, system variables are determined based on user input. The system variables include baseline system efficiency and other assumed defaults as shown in Annex B. Using user input and system variables, the model predicts building system performance by applying predefined machine learning and rule-based models. The model is then calibrated to align the predicted results with actual building performance by adjusting load information. Once calibrated, baseline performance is generated using the adjusted load data, and energy savings are calculated. Finally, the system outputs the building's performance, baseline performance, and energy savings.

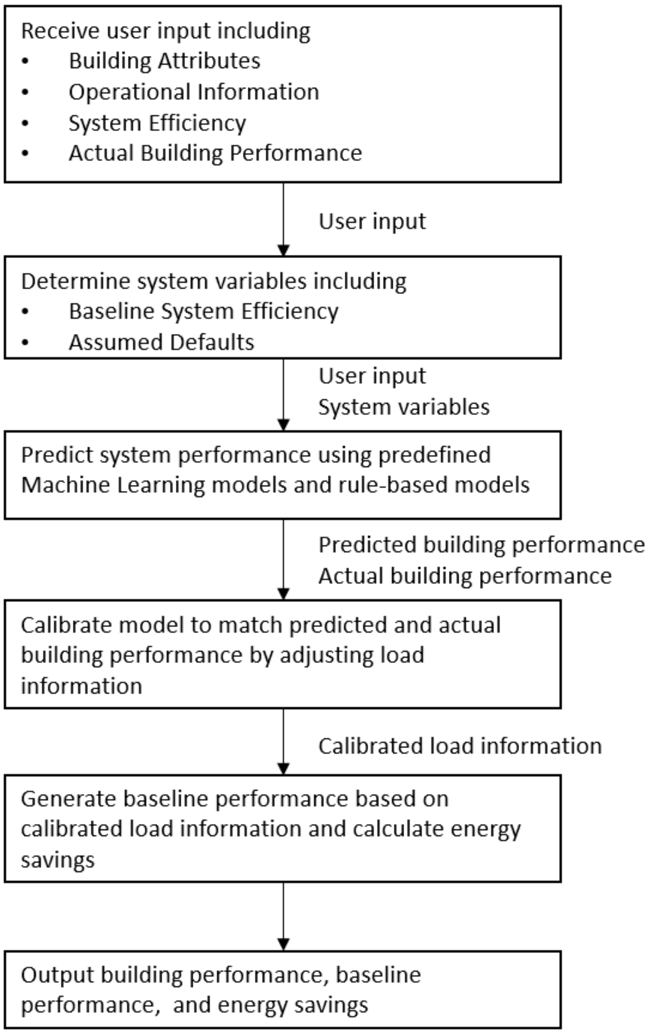

Figure A1 Process of the AI-driven Model

The system architecture of the AI-driven model is shown in Figure A2. The AI-driven model consists of a prediction module, a calibration module and system variables. System variables include baseline system efficiency and assumed defaults as shown in Annex B, which are used in the prediction module to predict building performance and baseline performance.

The prediction module predicts building performance and baseline performance based on user input building attributes, operational information and system efficiency, as well as system variables.

The prediction module includes multiple machine learning models for prediction of cooling load, HVAC system efficiencies and energy consumption. The prediction module also includes multiple rule-based models to calculate the energy consumption of other systems. The reason why machine learning model is built only for HVAC system is that other systems can be accurately predicted using simpler rule-based models, whereas the HVAC system is the most complex and cannot be accurately predicted using simple rule-based method. Focusing solely on HVAC system also enhances the overall accuracy of the machine learning models, as it allows for a targeted approach without the added variability of other systems.

The calibration module is designed to fine-tune the model by aligning the input load with the actual load, thereby improving prediction accuracy. This module iteratively receives the predicted building performance, compares it with the actual building performance, and adjusts load information. The process continues until the difference between predicted and actual performance is minimized, ensuring the model's accuracy.

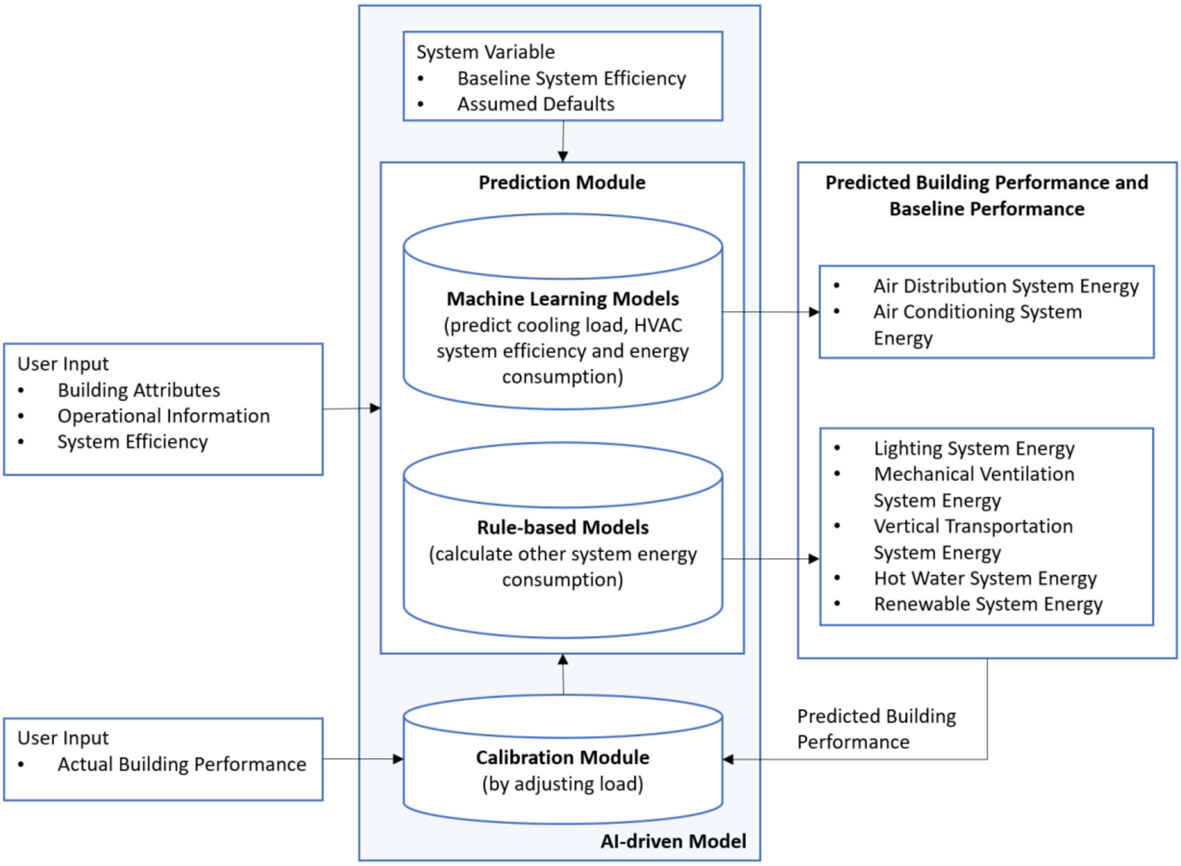

Figure A2 System Architecture of AI-driven Model

A3. Baseline Establishment and Energy Saving Calculation

Table A1 shows the baseline requirement and assumptions which are used to calculate the Green Mark 2005 baseline.

Table A1 Green Mark 2005 Baseline Standard and Assumptions

S/N	Component	Baseline Standard and Assumptions
1	**Building Description**	
1.1	Building Envelop Design	• Window to Wall Ratio (WWR): 0.4 • Glass U-Value ($W/m^2 \cdot K$): 2.8 • Glass SHGC: 0.36 • Window Frame U-Value ($W/m^2 \cdot K$): 1.5

		• Solar Window Film U-Value ($W/m^2 \cdot K$): NA (No Solar Window Film) • Solar Window Film SHGC: NA (No Solar Window Film) • Wall U-Value ($W/m^2 \cdot K$): 1.6 • Solar Reflectivity of Wall Paint: 0.2 • Shading Coefficient: 1 (No Shading Devices) • Roof U-Value ($W/m^2 \cdot K$): 1.6
1.2	Building Size and Configuration	• Building GFA: Reference Model to be the same as Proposed Model • Percentage of Air-Conditioned Area (%): Reference Model to be the same as Proposed Model • Percentage of naturally ventilated area converted from air-conditioned area (%): 0 • Total Mechanically Ventilated Area Including Carpark (m^2): Reference Model to be the same as Proposed Model • Building Storey: Reference Model to be the same as Proposed Model
2	**System Description**	
2.1	Air-conditioning System and Air-distribution System	• Air Conditioning System Type: Reference Model to be the same as Proposed Model • Air Conditioning System Efficiency (kW/RT): Based on air-conditioning system components' efficiency below • Chiller Efficiency (kW/RT): 0.91 (water-cooled chiller),1.52 (air-cooled chiller) • Chilled Water Pump Efficiency ($kW/m^3/s$): 470 • Condensing Water Pump Efficiency ($kW/m^3/s$): 400 • Cooling Tower Efficiency (L/s/kW): 1.3 • Unitary Air-Conditioning System Efficiency (kW/RT): 1.44 • Air Distribution System Type: AHU-CAV (if proposed model uses AHU), FCU-CAV (if proposed model uses FCU) • Air Distribution System Efficiency (kW/RT): Based on air-distribution system components' efficiency below • Air Conditioning System Optimisation: Not Applied • Use of Variable Speed Drive (VSD) in AHU/FCU: Not Applied • Use of Alternative Cooling Technologies: Not Applied • Air Distribution Fan Efficiency (W/CMH): 0.56 (AHU-CAV), 0.23 (FCU-CAV) • Demand-Controlled Ventilation of AC Area: Not Applied • Use of Energy Recovery Ventilation System: Not Applied • Use of Fans to Offset Cooling Load: Not Applied

		• Fresh Air Intake Rate (L/s/m^2): 0.94 (Office Building, Hotel, Healthcare Facility, Industrial Building, Residential Building), 1.89 (Retail Building), 3.15 (Educational Institution), 1.18 (Others)
2.2	Mechanical Ventilation Fan Systems	• Mechanical Ventilation Fan Efficiency (W/CMH): 0.31 • Demand-Controlled Ventilation of MV Area: Not Applied • Average Floor Height of Ventilated Area (m): 3.5 • Average Ventilation Rate (ACH): 6
2.3	Lighting Systems	• Use of Energy Efficient LED Lights: Not Applied • Light Efficacy (lm/W): 31 • Lux Level: 500 (Office Building, Healthcare Facility, Industrial Building, Others), 600 (Retail Building), 300 (Educational Institution, Hotel, Residential Building) • Use of Smart Lighting Control: Not Applied • Use of Daylighting: Not Applied
2.4	Hot Water System	• Hot Water System COP: 2.215 • Use of Solar Hot Water Collectors: Not Applied • Hot Water Usage (L/person/day): 0 (Office Building, Industrial Building, Retail Building, Educational Institution, Others), 80 (Residential Building), 125 (Hotel), 160 (Healthcare Facility)
2.5	Lift & Escalator	• Use of Energy Efficient Lift: Not Applied • Use of Energy Efficient Escalator: Not Applied • Lift Power Density (W/m^2): 2 (Office Building), 1 (Retail Building), 1.5 (Hotel), 0.9 (Educational Institution), 1.5 (Healthcare Facility), 0.6 (Industrial Building), 0.5 (Others), 0.2 (Residential Building) • Escalator Power Density (W/m^2): 0.3 (Office Building), 2.5 (Retail Building), 0.5 (Hotel), 0.1 (Educational Institution), 2 (Healthcare Facility), 0.1 (Industrial Building), 0.5 (Others), 0 (Residential Building)
3	**Others**	
3.1	Receptacle Loads	• Use of Smart Plug Load Control: Not Applied • Use of Energy Efficient Appliance: Not Applied • Receptacle Load Density (W/m^2): 6 (Retail Building), 8 (Industrial Building, Residential Building, Others), 10 (Office Building, Educational Institution), 12 (Hotel), 21 (Healthcare Facility)
3.2	Building Energy Management System (BEMS)	• Implementation of Building Energy Management System: Not Applied
3.3	Renewable Energy System	• Installation of Rooftop Photovoltaic (PV) : Not Applied • Installation of Building Integrated Photovoltaic (BIPV): Not Applied

		• Full-sun Hour for Rooftop PV (hour): 3.5
3.4	Operation Schedules	• Operation Schedule (hr/week): Reference Model to be the same as Proposed Model
3.5	Occupancy Load	• Occupancy Density (m^2/person): 10 (Office Building, Hotel, Healthcare Facility, Industrial Building), 5 (Retail Building), 3 (Educational Institution), 29 (Residential Building), 8 (Others)

Table A2 outlines the energy-saving calculation methods for the Energy Efficiency Measures (EEMs) applied to the affected systems.

Table A2 Energy Saving Calculation Method for the Energy Efficiency Measures

Energy Efficiency Measure	Affected System	Energy Saving Calculation Method for the Impacted System
Design of Natural Ventilation	Air-conditioning and Air-distribution System	Eliminated all air-conditioning and air-distribution energy consumption for areas converted from air-conditioned to naturally ventilated spaces.
Reduced Window to Wall Ratio	Air-conditioning and Air-distribution System	Resulted in a reduced ETTV (Envelope Thermal Transfer Value) based on the ETTV formula, leading to a decreased cooling load as predicted by the Machine Learning model.
Insulation of Roof		
Insulation of External Walls		
Use of High Performance Glass		
Use of Solar Window Film		
Use of Thermally Broken Window Frames		
Use of Reflective Paint/Cool Paint		
Installation of External Shading Devices		
Energy-Efficient Unitary Air-Conditioning System	Air-conditioning and Air-distribution System	The reduced air-conditioning system energy consumption is calculated based on improved unitary air-conditioning system efficiency over baseline and cooling loads of proposed model and baseline, respectively.
Energy-Efficient Chiller	Air-conditioning System	Resulted in improved air-conditioning system efficiency over baseline which is predicted by Machine Learning model.
Energy-Efficient Chilled Water Pump		
Energy Efficient Condensing Water Pump		

Energy-Efficient Cooling Tower		
Air Conditioning System Optimisation	Air-conditioning System	The reduction in air-conditioning system energy consumption is estimated based on an assumption of 15% energy savings compared to the scenario without the application of this EEM.
Use of Variable Speed Drive (VSD) in AHU/FCU	Air-distribution System	Resulted in improved air-distribution system efficiency compared to the scenario without the application of this EEM, which is predicted by Machine Learning model.
Use of Alternative Cooling Technologies	Air-conditioning and Air-distribution System	The reduction in air-conditioning and air-distribution system energy consumption is estimated based on an assumption of 30% energy savings compared to the scenario without the application of this EEM.
Energy Efficient Air Distribution Fan	Air-distribution System	Resulted in improved air-distribution system efficiency over baseline which is predicted by Machine Learning model.
Demand-Controlled Ventilation of AC Area	Air-conditioning and Air-distribution System	The reduction in air-conditioning and air-distribution system energy consumption is estimated based on an assumption of 15% energy savings compared to the scenario without the application of this EEM.
Use of Energy Recovery Ventilation System	Air-conditioning System	Resulted in reduced cooling load which is calculated based on estimated Fresh Air Cooling Load Ratio according to building type and proposed Energy Recovery System Efficiency
Use of Fans to Offset Cooling Load	Air-conditioning System	The reduction in air-conditioning system energy consumption is estimated based on an assumption of 10% energy savings on the applied space compared to the scenario without the application of this EEM.
Use of Energy Efficient LED Lights	Lighting System	Resulted in reduced light power density in the applied space, which is calculated based on the assumed lux level according to building type and efficacy of light.

Use of Smart Lighting Control	Lighting System	The reduction in lighting system energy consumption is estimated based on an assumption of 30% energy savings on the applied space compared to the scenario without the application of this EEM.
Use of Daylighting	Lighting System	The reduction in lighting system energy consumption is estimated based on an assumption of 30% energy savings on the applied space compared to the scenario without the application of this EEM.
Energy-Efficient Mechanical Ventilation Fan	Mechanical Ventilation System	The reduction in mechanical ventilation system energy consumption is calculated based on the improved fan efficiency and estimated mechanical ventilation rate.
Demand-Controlled Ventilation of MV Area	Mechanical Ventilation System	The reduction in mechanical ventilation system energy consumption is estimated based on an assumption of 20% energy savings on the applied space compared to the scenario without the application of this EEM.
Use of Smart Plug Load Control	Receptacle Loads	The reduction in receptacle load energy consumption is estimated based on an assumption of 15% energy savings compared to the scenario without the application of this EEM.
Use of Energy Efficient Appliance	Receptacle Loads	The reduction in receptacle load energy consumption is estimated based on an assumption of 20% energy savings compared to the scenario without the application of this EEM.
Use of Energy Efficient Hot Water System	Hot Water System	The reduction in hot water system energy consumption is calculated based on the improved hot water system efficiency, hot water heating temperature and estimated hot water consumption according to building type.
Use of Solar Hot Water Collectors	Hot Water System	Eliminated hot water energy consumption for the proportion of hot water supplied by solar hot water collectors.

Use of Energy Efficient Lift	Lift & Escalator	The reduction in lift energy consumption is estimated based on an assumption of 18% energy savings compared to the scenario without the application of this EEM.
Use of Energy Efficient Escalator	Lift & Escalator	The reduction in escalator energy consumption is estimated based on an assumption of 30% energy savings compared to the scenario without the application of this EEM.
Implementation of Building Energy Management System	All Building Systems	The reduction in the overall building energy consumption is estimated based on an assumption of 10% energy savings compared to the scenario without the application of this EEM.
Installation of Rooftop Photovoltaic (PV)	Renewable Energy System	The rooftop renewable energy generation is estimated based on rooftop solar panel area, rooftop solar panel efficiency and the assumed full-sun hour per day according to the building location.
Installation of Building Integrated Photovoltaic (BIPV)	Renewable Energy System	The BIPV renewable energy generation is estimated based on BIPV solar panel area, BIPV solar panel efficiency and the assumed full-sun hour per day according to the building location.

A4. Machine Learning Model

A4.1 Dataset Generation

The purpose of the Machine Learning model is to produce predictions that are close to the predictions of traditional EM software, e.g., EnergyPlus. Therefore, simulation data using EnergyPlus is used to create the machine leaning models.

To generate the required dataset, parametric simulations are conducted to calculate building performances under different building configurations. As shown in Figure A3, a large amount of simulation runs is set up to simulate different building configurations. Each building configuration is represented by an IDF file, which is processed by EnergyPlus to output respective building performance data, including cooling load, HVAC system efficiencies and HVAC energy consumption. The input data together with the respective output data forms a complete dataset, which is used to train and test machine learning models.

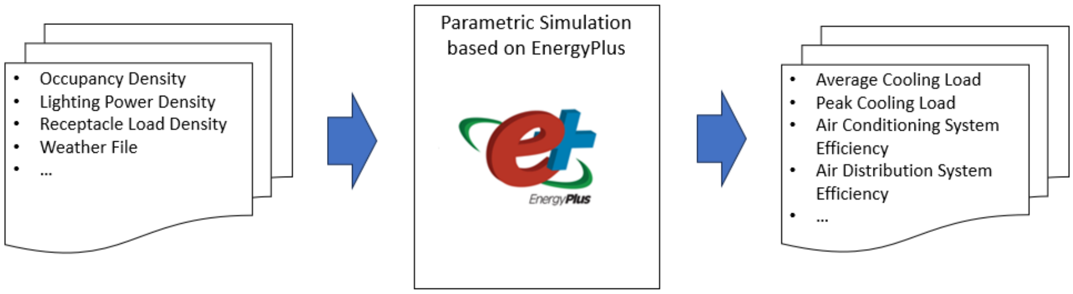

Figure A3 Illustration of Parametric Simulation using EnergyPlus

A4.2 Machine Learning Model Creation Process

As the dataset is generated from simulation, the data cleaning process has been omitted, assuming that the data is already clean and free of errors. Feature selection is carried out based on domain expertise and is aligned with the key input variables used in building simulation models. This ensures that the selected features are directly relevant to the targets.

The dataset is then split into training and testing subsets with a 70-30 split ratio (train-test ratio of 7:3). Multiple machine learning algorithms, including Random Forest, Support Vector Machine (SVM), and XGBoost, are evaluated. These algorithms are trained using hyperparameter tuning to optimize their performance. A grid of potential hyperparameter ranges is defined, and hyperparameters are randomly sampled from this grid. During each iteration, K-fold cross-validation (CV) is used to assess model performance for every combination of hyperparameters. This ensures that the hyperparameters selected provide the best generalization ability for the models, preventing overfitting and ensuring robustness.

A4.3 Model Performance

Table A3 shows the performance comparison between different algorithms, for the task of predicting average building cooling load. The baseline approach is to predict the mean of the target variable for all samples.

Table A3 Model Performance

	Baseline (No Model)	Random Forest	Support Vector Machine	XGBoost
Mean Squared Error (Training)	6917.5419	6.4175	7.1246	8.5852
R^2 (Training)	0.0000	0.9991	0.9990	0.9988
Mean Squared Error (Test)	6815.3353	11.0929	116.0639	12.4785
R^2 (Test)	0.0000	0.9984	0.9830	0.9982

Random Forest was selected as the final model due to its superior performance across both the training and test datasets. The minimal difference in performance between the training and test sets suggests a low risk of overfitting, indicating that the model generalizes well to unseen data. Furthermore, the significant improvement over the baseline model underscores the effectiveness of the Random Forest model in capturing the underlying patterns within the data. The high R-squared value further reinforces the model's ability to explain a large proportion of the variance in the target variable. This indicates that the model is not only accurate in its predictions but also provides a robust fit to the data, making it a reliable choice for predicting the outcomes in this context. The reason why the model achieves such high R-squared value is because the dataset being used is generated by large number of parametric simulations with minimum noise.

Annex B – Tables for Data Terms

Table B1 and B2 shows the data that is required to assess the building performance and calculate the ECC.

Table B1 Building Attributes and Energy Consumption

Data Term	Data Unit	Description	Source of data	Monitoring frequency
Building Name or Project Name		The official name or identifier of a building or project for reference and documentation.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Address		The physical location of the building or project, including street details.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Postal Code		A numerical code used to identify the specific area of the building or project location	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Project Status		The current stage or progress of the building or project, including New Development, Retrofitting Project, and In Operation	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Building Type		The category or classification of the building based on its purpose, including Office Building, Retail Building, Hotel, Healthcare Facility, Educational Institution, Industrial Building, Residential Building, Mixed Development, and Others	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Number of Storeys		The total number of levels or floors in the building, including above-ground and, if applicable, basement levels.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Year of TOP/CSC		The year the building received its Temporary Occupation Permit (TOP) or Certificate of Statutory	The following data sources or other relevant sources may be used:	For the first year of the project implementation

		Completion (CSC), indicating readiness for occupancy.	(a) Temporary Occupation Permit (b) Certificate of Statutory Completion	
Gross Floor Area of Building	m^2	Gross floor area excluding car park area	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation, and every third year thereafter
F&B Area	m^2	The total floor space allocated for food and beverage establishments, such as restaurants, cafes, or food courts.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation, and every third year thereafter
Supermarket Area	m^2	The total floor space designated for supermarket or grocery store operations within the building or project.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation, and every third year thereafter
Data Centre/Server Room Area	m^2	The total floor space dedicated to housing data center facilities or server rooms, including equipment and support infrastructure.	The following data sources or other relevant sources may be used: (a) Building operation records (b) Tenant agreements	For the first year of the project implementation, and every third year thereafter
Percentage of Air-Conditioned Area	%	The proportion of the building's total floor area that is served by air-conditioning, expressed as a percentage. If the design of natural ventilation is applied, the Percentage of Air-Conditioned Area remains the same as the value before natural ventilation was implemented, as it represents the originally planned air-conditioned portion of the building.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation, and every third year thereafter
Total Mechanically Ventilated Area	m^2	The area which is non-air-conditioned but served by commercial or	The following data sources or other relevant sources may be used:	For the first year of the project implementation,

		industrial ventilators, such as jet fans for basement carpark and ducted fans and blowers (exclude the household models such as ceiling fan and stand fan).	(a) Building Plan (b) Building Survey	and every third year thereafter
Operation Schedule	hr/week	Total building operation hours per week	The following data sources may be used: (a) Building Survey (b) Recorded Energy Use	Annually
Average Monthly Energy Consumption	kWh	Monthly average electricity consumption is based on at least 6 month's data.	The following data sources may be used: (a) Utility bill (b) Energy meters installed in the building	Annually

Table B2 Building System Specifications

Data Term	Data Unit	Description	Source of data	Monitoring frequency
Percentage of NV area converted from AC area	%	Required for the EEM: Design of Natural Ventilation This equals the Naturally Ventilated (NV) area converted from Air-Conditioned (AC) area over the building's gross floor area (GFA). Hence, its value cannot be larger than the percentage of AC area.	A written justification detailing the design strategies with due consideration for ventilation requirements and thermal comfort of the designated non-air-conditioned spaces	For the first year of the project implementation
Window to Wall Ratio (WWR)		Required for the EEM: Reduced Window to Wall Ratio The Window-to-Wall Ratio (WWR) is the fraction of the exterior wall area that is covered by windows, calculated as the ratio of the windows' area to the gross exterior wall area. Lowering WWR can reduce the amount of cooling energy required.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation
Roof U-Value	$W/m^2{\cdot}K$	Required for the EEM: Insulation of Roof	The following data sources or other relevant sources may be used: (a) Building Plan	For the first year of the project implementation

		Insulating the roof prevents excess heat from entering the building during hot weather. U-value is used to indicate the effectiveness of the insulation of roof.	(b) Building Survey (c) Manufacturer Specifications	
Wall U-Value	W/m²·K	Required for the EEM: Insulation of External Walls Insulating the wall prevents excess heat from entering the building during hot weather. U-value is used to indicate the effectiveness of the insulation of wall.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Glass U-Value	W/m²·K	Required for the EEM: Use of High Performance Glass The use of high-performance glass can reduce cooling load by minimizing solar heat gain and improving thermal insulation. The Glass U-Value measures heat transfer through glass, with lower values indicating better insulation.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Glass SHGC		Required for the EEM: Use of High Performance Glass The use of high-performance glass can reduce cooling load by minimizing solar heat gain and improving thermal insulation. The Glass SHGC (Solar Heat Gain Coefficient) measures the fraction of solar radiation that enters a building, with lower SHGC values reducing cooling demand.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Solar Window Film U-Value	W/m²·K	Required for the EEM: Use of Solar Window Film The use of solar window film reduces cooling load by blocking solar heat gain and improving insulation. The U-value of solar window film measures its	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation

		effectiveness at reducing heat transfer.		
Solar Window Film SHGC		Required for the EEM: Use of Solar Window Film The use of solar window film reduces cooling load by blocking solar heat gain and improving insulation. The Solar Window Film SHGC (Solar Heat Gain Coefficient) measures the fraction of solar radiation that enters a building, with lower SHGC values reducing cooling demand.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Window Frame U-Value	W/m²·K	Required for the EEM: Use of Thermally Broken Window Frames A thermally broken window frame is designed to reduce heat transfer by incorporating an insulating material (often plastic or foam) between the interior and exterior frame sections. The U-value of a window frame indicates how well it resists heat transfer.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Solar Reflectivity		Required for the EEM: Use of Reflective Paint/Cool Paint Solar reflectivity of reflective or cool paint measures its ability to reflect solar radiation. This reduces cooling loads, and air-conditioning energy use.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Shading Coefficient of External Shading Devices		Required for the EEM: Installation of External Shading Devices The Shading Coefficient (SC) of external shading devices measures their effectiveness in reducing solar heat gain through windows. It is the ratio of solar heat gain with the shading device compared to clear, unshaded glass.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation

Air Conditioning System Type		Air Conditioning System Type refers to the design used for cooling, including Water-cooled Chilled Water Plant, Air-cooled Chilled Water Plant, Unitary Air-conditioning System, and District Cooling System	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Air Conditioning System Efficiency	kW/RT	Required for the EEM: Energy-Efficient Unitary Air-Conditioning System Air Conditioning System Efficiency measures how effectively an air conditioning system converts energy into cooling output	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Chiller Efficiency	kW/RT	Required for the EEM: Energy-Efficient Chiller Chiller Efficiency measures how effectively a chiller converts energy into cooling	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Chilled Water Pump Efficiency	$kW/m^3/s$	Required for the EEM: Energy-Efficient Chilled Water Pump Chilled Water Pump Efficiency measures how effectively a pump circulates chilled water in a cooling system	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Condensing Water Pump Efficiency	$kW/m^3/s$	Required for the EEM: Energy Efficient Condensing Water Pump Condenser Water Pump Efficiency measures how effectively a pump circulates water between the condenser and cooling tower in a chiller system	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Cooling Tower Efficiency	L/s/kW	Required for the EEM: Energy-Efficient Cooling Tower Cooling Tower Efficiency measures the effectiveness of a cooling tower in rejecting heat from the condenser water to the atmosphere	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually

Air Distribution System Type		Air Distribution System Type refers to the method used to deliver conditioned air within a building, including AHU-CAV, AHU-VAV, FCU-CAV, and FCU-VAV	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Air Distribution System Efficiency	kW/RT	Air Distribution System Efficiency measures how effectively an air distribution system delivers conditioned air to spaces with minimal energy loss.	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Air Distribution Fan Efficiency	W/CMH	Required for the EEM: Energy Efficient Air Distribution Fan Air Distribution Fan Efficiency measures the energy performance of fans in distributing conditioned air	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Air Conditioning System Optimisation		Air Conditioning System Optimization improves efficiency and reduces costs by fine-tuning controls, regular maintenance, upgrading components, and integrating smart systems. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Use of Variable Speed Drive (VSD) in AHU/FCU		The use of Variable Speed Drive (VSD) in Air Handling Units (AHUs) and Fan Coil Units (FCUs) allows fans to adjust their speed based on cooling or ventilation demand, reducing energy consumption, improving efficiency, and maintaining comfort. Indicate the existence of this EEM with: • AHU-VAV: Implemented in AHU • FCU-VAV: Implemented in FCU • No: Not implemented	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Demand-Controlled		Demand-Controlled Ventilation (DCV) in an air-conditioned area adjusts	The following data sources or other relevant sources may be used:	For the first year of the project implementation

Ventilation of AC Area		ventilation rates based on occupancy or air quality, optimizing energy use. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	(a) Building Plan (b) Building Survey (c) Manufacturer Specifications	
Energy Recovery Ventilation System Efficiency	%	Required for the EEM: Use of Energy Recovery Ventilation System Energy Recovery Ventilation (ERV) System Efficiency measures the system's ability to transfer heat and humidity between incoming and outgoing air streams, reducing the need for heating or cooling. Higher efficiency means more energy is recovered.	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Percentage of Application for Use of Fans to Offset Cooling Load	%	Required for the EEM: Use of Fans to Offset Cooling Load This EEM applies when ceiling fans are installed in air-conditioned spaces to maintain equivalent thermal comfort while allowing for a higher set-point temperature, thereby reducing cooling energy consumption. Percentage of Application refers to the proportion of the total area where this EEM has been implemented.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
LED Lights Efficacy	lm/W	Required for the EEM: Use of Energy Efficient LED Lights LED Lights Efficacy measures the efficiency of LED lighting, indicating how much visible light is produced for each watt of electrical power consumed.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Percentage of Use of LED Lights	%	Required for the EEM: Use of Energy Efficient LED Lights The Percentage of Use refers to the proportion of	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey	For the first year of the project implementation

		the total area where LED lights have been implemented.	(c) Manufacturer Specifications	
Percentage of Application for Use of Smart Lighting Control	%	Required for the EEM: Use of Smart Lighting Control The use of smart lighting control involves automated systems to adjust lighting based on occupancy, daylight levels, or schedules. Percentage of Application refers to the proportion of the total area where this EEM has been implemented.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Percentage of Application for Use of Daylighting	%	Required for the EEM: Use of Daylighting The use of daylighting involves designing buildings to maximize natural light, reducing the need for artificial lighting. Percentage of Application refers to the proportion of the total area where this EEM has been implemented.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Mechanical Ventilation Fan Efficiency	W/CMH	Required for the EEM: Energy-Efficient Mechanical Ventilation Fan Mechanical Ventilation Fan Efficiency measures the energy performance of fans used in mechanical ventilation systems.	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Percentage of Application for Demand-Controlled Ventilation of MV Area	%	Required for the EEM: Demand-Controlled Ventilation of MV Area Demand-Controlled Ventilation of Mechanically Ventilated (MV) Areas adjusts ventilation rates based on occupancy or air quality. Percentage of Application refers to the proportion of the total area where this EEM has been implemented.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Use of Smart Plug Load Control		The use of smart plug load control involves managing and reducing energy	The following data sources or other relevant sources may be used:	For the first year of the project implementation

		consumption of devices connected to electrical outlets. Through automation, scheduling, or real-time monitoring, it identifies idle devices and cuts power supply when not in use. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	(a) Building Plan (b) Building Survey (c) Manufacturer Specifications	
Use of Energy Efficient Appliance		The use of energy-efficient appliances involves selecting and using appliances designed to consume less energy while maintaining performance. These appliances typically have higher energy ratings. For example, in Singapore, this EEM is valid if appliances with energy efficiency rating of 3 ticks and above are used where applicable. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
COP of Hot Water System		Required for the EEM: Use of Energy Efficient Hot Water System The COP (Coefficient of Performance) of a Hot Water System measures the system's efficiency in converting energy into hot water.	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually
Percentage of Hot Water Supplied by Solar Hot Water Collectors	%	Required for the EEM: Use of Solar Hot Water Collectors Percentage of Hot Water Supplied by Solar Hot Water Collectors refers to the proportion of the total hot water demand met by solar energy through solar thermal systems.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Use of Energy Efficient Lift		The use of energy-efficient lifts involves installing lifts or elevators designed to	The following data sources or other relevant sources may be used:	For the first year of the project implementation

		consume less energy while maintaining performance. This EEM is valid for lifts with regenerative features. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	(a) Building Plan (b) Building Survey (c) Manufacturer Specifications	
Use of Energy Efficient Escalator		The use of energy-efficient escalators involves installing escalators designed to reduce energy consumption while maintaining performance. This EEM is valid for escalator with sleep mode or 2 speed function. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Implementation of Building Energy Management System		The implementation of a Building Energy Management System (BEMS) involves installing a centralized system to monitor, control, and optimize energy use within a building. Indicate the existence of this EEM with: • Yes: Implemented • No: Not implemented	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Rooftop Solar Panel Area	m^2	Required for the EEM: Installation of Rooftop Photovoltaic (PV) Rooftop Solar Panel Area refers to the total surface area of a building's roof that is covered with solar panels.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
Rooftop Solar Panel Efficiency	%	Required for the EEM: Installation of Rooftop Photovoltaic (PV) Rooftop Solar Panel Efficiency measures the ability of solar panels to convert sunlight into electricity.	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually

BIPV Solar Panel Area	m²	Required for the EEM: Installation of Building Integrated Photovoltaic (BIPV) BIPV Solar Panel Area refers to the surface area of a building's structure, such as walls, windows, or roofs, that is integrated with solar panels to generate electricity.	The following data sources or other relevant sources may be used: (a) Building Plan (b) Building Survey (c) Manufacturer Specifications	For the first year of the project implementation
BIPV Solar Panel Efficiency	%	Required for the EEM: Installation of Building Integrated Photovoltaic (BIPV) BIPV Solar Panel Efficiency refers to the ability of solar panels integrated into building materials (such as windows, roofs, or facades) to convert sunlight into electricity.	The following data sources or other relevant sources may be used: (a) Manufacturer Specifications (b) Onsite Measurement	Annually

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