U.S. & Canada CRREM Pathways: A More Granular Approach for North American Real Estate

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About the Carbon Risk Real Estate Monitor

The Carbon Risk Real Estate Monitor (CRREM) is the leading global initiative for establishing targets for operational carbon emissions for standing real estate investments consistent with the ambitions of the Paris agreement. CRREM publicly released decarbonization pathways that translate the ambitions of limiting global warming to 1.5°C by the end of the century into regionally- and property-type-specific trajectories against which real estate assets and portfolios can benchmark themselves. The pathways and other resources provided, like the CRREM tool, assess asset alignment with relevant pathways, help the market price risks related to carbon emissions from buildings. CRREM is aligned with the leading international accounting and reporting frameworks, disclosure guidelines and recommendations published by initiatives working within the field of decarbonization and real estate. The initiative was initially an EU project and is now being funded by the Laudes Foundation and supported by major industry bodies.

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Contents

Executive Summary

The Carbon Risk Real Estate Monitor (CRREM) framework has emerged as one of the main methods for investors to assess, price, and mitigate carbon performance and risk in their real estate investments. As governance practices solidify and investors continue to pursue portfolio-level decarbonization, real estate industry stakeholders that use or plan to use CRREM in their transition risk analysis, governance, and reporting protocols have called for a technical analysis and more granular pathways that more accurately reflect the grid and building stock in the United States (U.S.) and Canada. To this end, CRREM, Urban Land Institute (ULI), and Lawrence Berkeley National Lab (LBNL) partnered to combine the existing CRREM methodology with current, detailed data sources to create more granular pathways for the U.S. and Canada. These pathways show a building's target energy use and carbon footprint each year from now until 2050.

LBNL is the author of this report, which outlines the analysis methodologies along with CRREM recommendations. LBNL's analysis began with investigating the existing CRREM downscaling methodology, which translates global and national data into real estate subsectors to enable target setting and risk assessment for specific assets in real estate portfolios. LBNL also engaged with working group stakeholders and coordinated with CRREM to understand the nuances of how data sources should be selected to align with CRREM's global methodology. LBNL provided updated data input to CRREM, which were then processed by CRREM and used to create draft granular pathways that were passed back to LBNL for quality checks.

The updated results, once approved and integrated into the CRREM tool and other CRREM offerings, can be used by building owners and real estate stakeholders to assess transition risk more accurately at both the asset and portfolio levels in the U.S. and Canada. CRREM users will have increased geographical granularity, and the data sources informing CRREM pathways will more accurately depict the realities and nuances of the U.S. and Canadian markets.

Summary of Major Recommendations

The following list contains the main recommendations to CRREM from the project team's analysis. All recommendations are based on extensive scientific research by Berkeley Lab alongside intensive stakeholder consultation, and include supporting calculations and derivations as needed for ease of integration into the CRREM tool and other CRREM offerings.

National Downscaling

Previously, CRREM rounded down energy use intensity (EUI) targets in an effort to stay conservative when establishing pathways. After discussions with the project team, CRREM agreed that rounding down leads to overly conservative and inequitable targets. Consequently, CRREM will adjust their EUI targets to unrounded values going forward.

United States

- Subdivide the U.S. geography into the intersections of climate zones, as defined by the Commercial Buildings Energy Consumption Survey (CBECS)/ Residential Energy Consumption Survey (RECS); and Emissions and Generation Resource Integrated Database (eGRID) regions.

- Simplify the building stock data sources used to calculate aggregate sector energy intensity to focus on CBECS/RECS and maintain use of existing data sources for stock projections.
- Use new data sources and two methodologies to derive new starting median EUIs.
- Derive new weighted emission factors using updated electric grid factors, present and future, utilizing updated data sources. Use linear interpolation to align data sources.
- Use Retail Store as the primary retail type classification outside of shopping centers.
- Split the CRREM property type Health Care into two property types, Inpatient Care and Outpatient Care, to align with the energy profiles of these asset types.
- Split the CRREM property type Multifamily into three types, Multifamily High-Rise (greater than or equal to 20 units), Multifamily Low-Rise (greater than or equal to 20 units), and Small Multifamily (less than 20 units), to align with best available EUI data.

Canada

- Subdivide the Canadian geography into provinces (plus territories aggregated into a single subregion) and align with available data sources.
- Use SCIEU 2019 and SHEU 2019 data sources to calculate aggregate sector energy intensity and maintain use of existing data sources for stock projections.
- Use new data sources and two methodologies to derive new starting median EUIs.
- Derive new weighted emission factors using updated electric grid factors, present and future, utilizing updated data sources.
- Split the CRREM property type Health Care into two property types, Inpatient Care and Outpatient Care, to align with the energy profiles of these asset types.
- Split the CRREM property type Multifamily into two types, Multifamily High-Rise and Multifamily Low-Rise, to align with best available EUI data.

1. Introduction

The importance of building decarbonization and energy reduction cannot be overstated, as the built environment is a critical sector for achieving the climate goals outlined in the Paris Agreement. The Carbon Risk Real Estate Monitor (CRREM) is an important benchmark for measuring transition risk for real estate assets. The CRREM framework sets out decarbonization pathways (or "CRREM curves"), which show a building's target energy use and carbon "budget" each year from now until 2050. The framework considers the amount of renewable energy anticipated to be available on the grid and the amount of energy that different building sectors should be allocated to achieve net zero emissions, based primarily on climate zone and property type.

The CRREM framework is emerging as one of the main methods for investors to assess, price, and mitigate carbon performance and risk in their real estate investments. In addition to being used by international investors, CRREM carbon pathways are being adopted by international reporting frameworks like Global Real Estate Sustainability Benchmark (GRESB) and are slated for integration into the annual GRESB Real Estate Benchmark Assessment. In addition, CRREM has partnered with the Science Based Targets initiative, a multi-organization collaboration that defines and promotes best practice in science-based target setting.

As governance practices solidify and investors continue to call for portfolio-level decarbonization, real estate industry stakeholders have called for more accurate representations within CRREM of the electric grid and building stock in the United States and Canada to support their transition risk analysis, governance, and reporting protocols. To this end, the project team of CRREM, Urban Land Institute (ULI), and Lawrence Berkeley National Lab (LBNL) partnered to conduct a technical analysis and combine the existing CRREM methodology with current, detailed data sources to create more granular decarbonization pathways for the U.S. and Canada. Specifically, the project aimed to create pathways that are scientifically robust and reflective of the varying conditions across different regions in the U.S. and Canada.

The project team launched an industry working group chaired by Elena Alschuler, LaSalle Investment Management's Head of Sustainability for the Americas. From May to October 2023, CRREM, ULI, and LBNL (or "the project team") hosted four virtual working group sessions with more than 300 participants to engage a broad set of real estate industry stakeholders to help inform the analysis topics and priorities.

This project scope focuses on the data inputs and methodologies associated with the development of pathways and therefore does not include recommendations for changes to the CRREM Risk Assessment Tool (or "CRREM tool"), which helps building owners evaluate their performance relative to the developed pathways. Modified pathways reflecting this report's recommendations will be available, however, through new versions of the CRREM tool.

To assist CRREM in deriving the decarbonization and energy reduction pathways for the U.S. and Canada, LBNL evaluated CRREM's existing data sources and assumptions and recommended new ones with more granular, up-to-date, and/or accurate data. This work resulted in updated inputs that CRREM used to derive updated regional pathways.

This work did not include changes to CRREM's existing downscaling methodology for CO_2 and EUI pathways, or to the CRREM global EUI target setting methodology. Rather, the scope focused on the data sources and geographic divisions associated with U.S. and Canada regional and sub-regional breakdowns.

This memo seeks to increase understanding of the described analysis effort and support future updates to the CRREM pathways. The updated results, once approved and integrated into the CRREM tool, can be used by building owners and real estate stakeholders to assess performance and risk more accurately at both the asset and portfolio levels in the U.S. and Canada. CRREM users will have both increased geographical granularity and more accurate data sources depicting the realities and nuances of those markets. In turn, these improvements will drive further participation in transition risk evaluation for portfolios and more robust evaluation criteria to drive investment in buildings with strong environmental performance.

The following sections contain LBNL's documentation of the analysis methodology and process.

2. Investigation Topics

Table 1 lists the 12 investigation topics that were determined and validated through stakeholder/working group feedback and discussions with CRREM. Eight potential investigation topics determined by the project team were disseminated at the start of the project and presented to stakeholders at Working Group 1. Four additional topics were added based on feedback from Working Group 1.

In Working Groups 2 and 3, attendees were split into two breakout groups to discuss investigation topics. Working Group 2 addressed topics 1–6 in detail and Working Group 3 addressed topics 7–12 in detail.

Several topics were determined to be out of scope for this project because they related either to the CRREM Risk Assessment Tool or to guidance for applying pathways to specific portfolios. These topics were addressed through reference guidance and ULI's Frequently Asked Questions document, the latter of which was updated throughout this process.

Table 1 denotes each topic's scope within the project and where related findings can be found.

Table 1: List of Investigation Topics

	Topic	**Scope of Topic**	**Reference to Findings**
1.	Current & future projections for grid carbon intensity	Pathways	**Modeling Electric Grid Factors: Present and Future** **United States Recommended Data Sources** **Canada Recommended Data Sources**
2.	Assumptions for median building site energy use intensity (site EUI) today	Pathways	**United States: Derivations for Starting Energy Intensities** **Canada: Derivations for Starting Energy Intensities**
3.	EUI target setting refinement (technical limit such as HDD and CDD vs. downscaled carbon budget)	Pathways	**Final EUI Targets**
4.	How markets/geographies should be divided	Pathways	**United States: Dividing Markets/Geographies** **Canada: Dividing Markets/Geographies**
5.	How to add/rename asset classes	Pathways	**United States: Assessing Property Type Classifications** **Canada: Assessing Property Type Classifications**
6.	Assumptions about building stock growth in the future (regional level)	Pathways	**United States Recommended Data Sources** **Canada Recommended Data Sources**

7.	Comparison of methodology to Building Performance Standards	Reference to Pathways	**Comparison of CRREM v2 Pathways to Building Performance Standards**
8.	Handling district systems – assumptions for pathway calculations and guidance for tool use	Tool Use / Guidance	CRREM Risk Assessment Reference Guide PCAF Accounting and Reporting of GHG Emissions from Real Estate Operations Assumptions for pathway calculations addressed in respective U.S. and Canada Energy Mix & Projected Energy Mix sections.
9.	Identify integration/interoperability needs with ESPM and GRESB	Tool Use / Guidance	CRREM North America Working Group FAQs
10.	Normalization methodology – vacancy, weather, data estimation guidance (sq ft and time gaps) – compared to ENERGY STAR™	Tool Use / Guidance	CRREM Risk Assessment Reference Guide CRREM North America Working Group FAQs PCAF Accounting and Reporting of GHG Emissions from Real Estate Operations
11.	Methodology for how to track and show market-based vs. location-based energy procurement	Tool Use / Guidance	CRREM Risk Assessment Reference Guide CRREM North America Working Group FAQs PCAF Accounting and Reporting of GHG Emissions from Real Estate Operations
12.	EUI leveling year investigation/analysis (i.e., year at which final target EUI is achieved in the pathway)	Pathways	**Final EUI Targets: Leveling Year**

Note: HDD = heating degree days, CDD = cooling degree days, EPA = U.S. Environmental Protection Agency, ESPM = ENERGY STAR™ Portfolio Manager, EUI = energy use intensity, IMT = Institute for Market Transformation, PCAF = Partnership for Carbon Accounting Financials.

3. LBNL Analysis Overview

LBNL's analysis began with investigating the existing CRREM downscaling methodology (see the **CRREM Methodology Overview** in this document), engaging with working group stakeholders, and coordinating with CRREM to understand the nuances of how data sources should be selected to align with CRREM's global methodology. Each investigation topic (see Table 1) resulted in updated data source considerations, feedback/recommendations to CRREM, or no change if none was deemed needed.

The proposed data sources used and processed by LBNL for building-level energy use, emission factors, energy mix, and heating/cooling degree days are summarized in the following sections on **United States Recommended Data Sources** and **Canada Recommended Data Sources**. To integrate these data into CRREM, LBNL proposed a method for aggregating data by more refined geographic units. The details of this method are explained in subsequent country-specific sections in this document.

The result of updating the data sources can be found in the updated input sheets provided by LBNL to CRREM. These input sheets were then processed by CRREM and used to create new decarbonization pathways. LBNL provided these input sheets to CRREM in the same file format as CRREM had used previously to facilitate seamless transfer into CRREM's proprietary calculation sheets. CRREM provided the resulting pathways to LBNL to perform quality checks.

A Note on Energy Use Intensity Units

Existing regional differences in units can lead to confusion and misinterpretation of results. Acknowledging these differences is particularly important in working with the energy use intensity (EUI) metric, which has been commonly used in building environmental performance for decades. In an effort to balance respect for regional unit standards with the desire to compare results across regions, the project team established the following guidelines for this report:

- Visuals/results specific to the U.S. are presented in kBtu/square foot (kBtu/sq ft)
- Visuals/results specific to Canada are presented in kWh/square meter (kWh/m^2)
- Visuals/results across both countries are presented in CRREM's default unit of kWh/square meter (kWh/m^2).

4. CRREM Methodology Overview

This section details elements of the CRREM methodology that are of interest to the project scope and stakeholders, along with any associated recommendations from the project team on how it can continue to evolve.

Downscaling Process

The downscaling process used by CRREM is well outlined in its publicly available methodology document. Broadly speaking, CRREM was developed to take cumulative global carbon allotments through 2050 in accordance with the Paris Agreement and apportion that carbon to the global real estate sector, then to individual countries, and subsequently to individual property types and subregions (i.e., regions within a country) when appropriate. The initial carbon budget is determined by referencing several 2050 net zero scenarios, as itemized on pg. 49 of the CRREM methodology document. The apportionment process depends on many factors, including the existing energy intensity of assets, energy mix, expected growth, and projected changes in energy mix through 2050—all of which are specific to each region.

Figures 1 and 2 illustrate the inputs that determine the starting point, rate of reduction, and final targets for CRREM carbon (kg CO_2/m^2) and energy (kWh/m^2) pathways using U.S. office buildings as an example. Note that energy pathways are representative of total consumption as of CRREM v2, in contrast to older CRREM versions of CRREM that reflected site energy use net of on-site renewable energy consumption; see page 36 of the CRREM methodology document for more details.

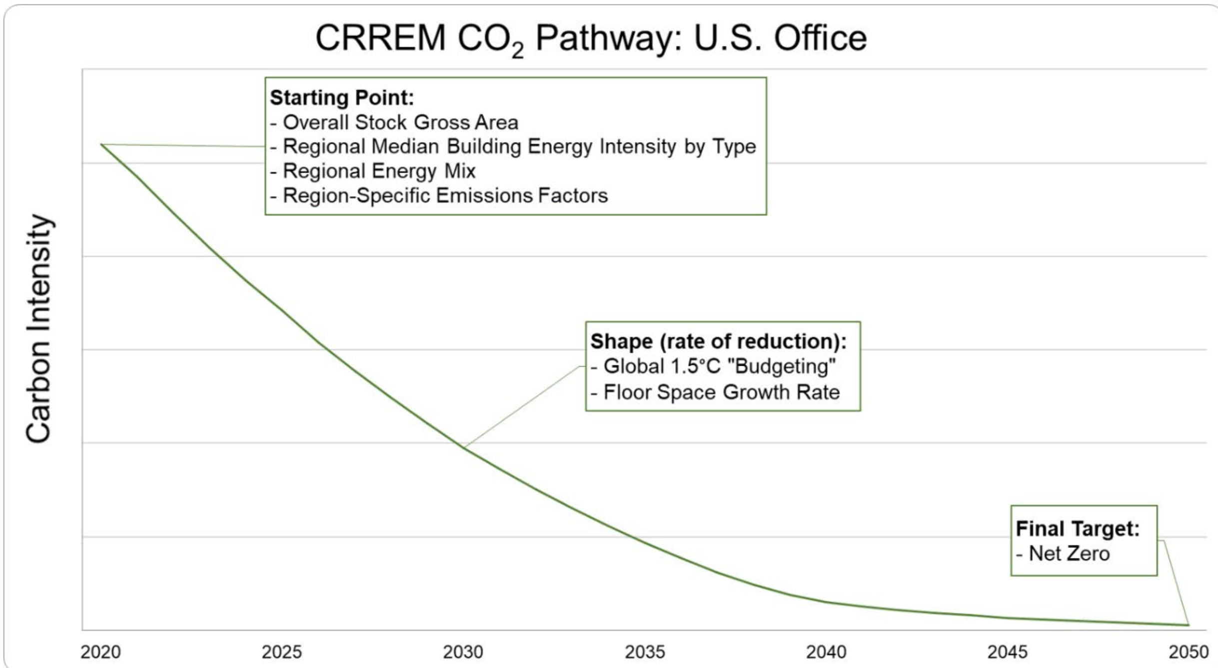

Figure 1: Inputs that determine CRREM CO_2 pathway (example: U.S. office buildings).

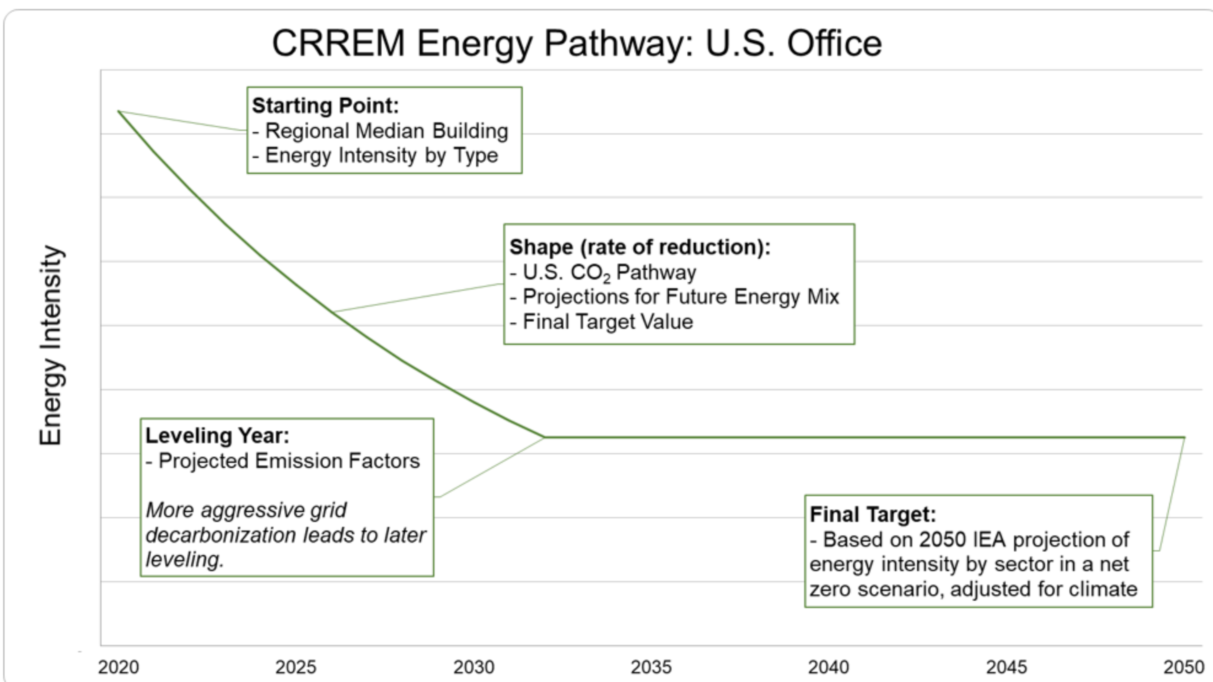

Figure 2: Inputs that determine CRREM energy pathway (example: U.S. office buildings).

Final EUI Targets

CRREM's energy pathways were changed significantly in CRREM v2, with the introduction of final EUI targets. Previously, energy pathways would trend toward net zero in alignment with CO_2 pathways. With the v2 release, a new methodology was introduced to align with a fully decarbonized power sector by 2050. These final target values are based on available carbon-free energy in 2050 according to an International Energy Agency (IEA) Net Zero Emissions (NZE) global scenario for full decarbonization by 2050 (IEA NZE 2020) and apportioned based on climate zone. The calculation weights the degree days of a particular sub-region proportional to IEA's projection of the end-use breakdown of heating and cooling energy consumption (16.5 percent + 10.6 percent, respectively, across all climate zones), and therefore provides less aggressive targets for colder climates. Figure 3 depicts how global targets are calculated and downscaled nationally.

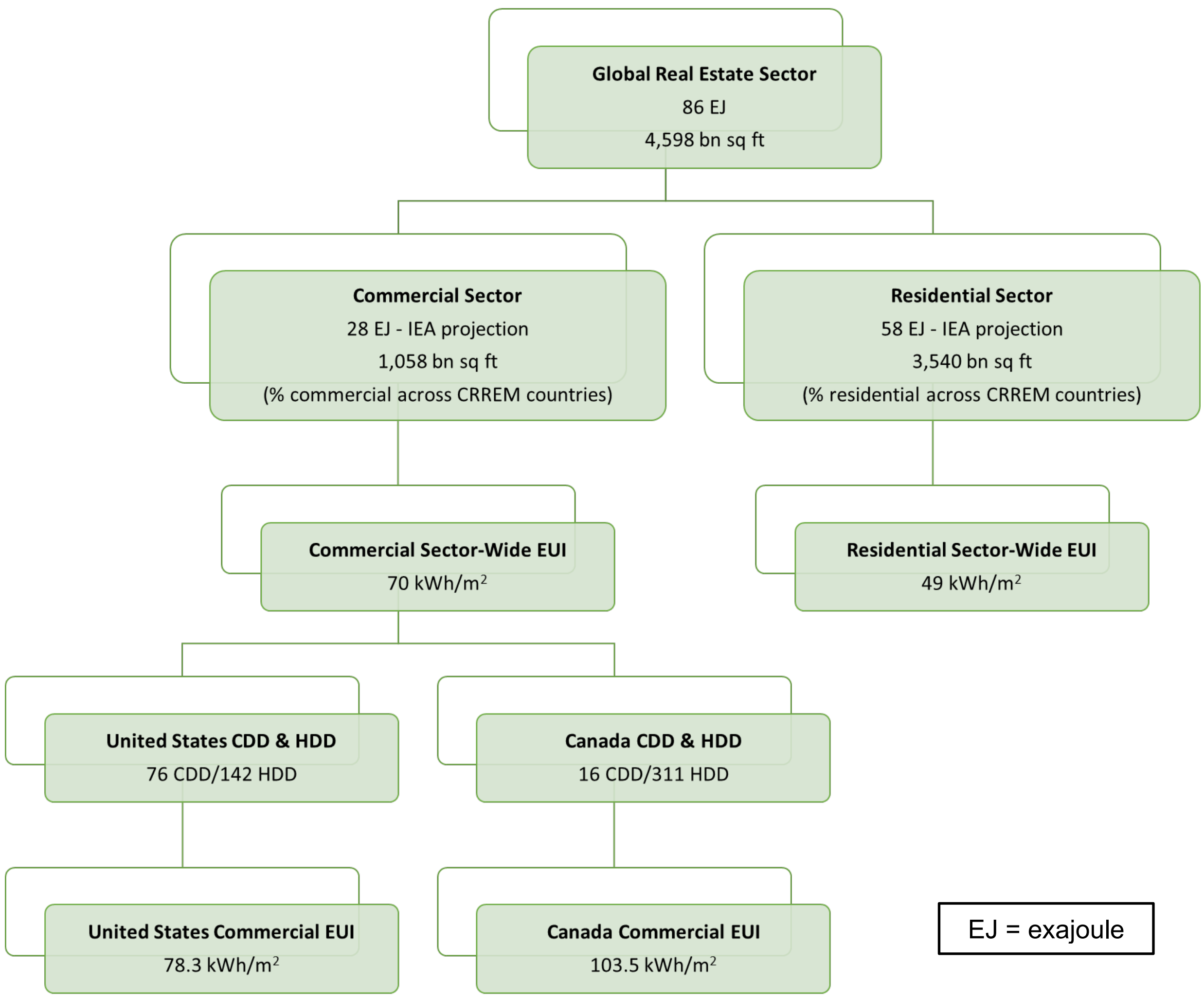

Figure 3: How CRREM calculates country-level EUI targets.

Final EUI Targets: Leveling Year

A key point of discussion within the working groups related to how quickly any particular pathway reaches its respective final EUI. For the purposes of this discussion, the term "leveling year" was coined to describe the year in which the final EUI target must be achieved to maintain alignment with CRREM pathways.

Leveling year was discussed in detail with the CRREM team, and it was confirmed that this value is dependent on both the final EUI target and the original EUI pathways as derived from CO_2 budgeting/downscaling, as shown in Figure 4. The energy pathway is derived from the CO_2 pathway (utilizing aggregated, region-specific weighted emission factors), up until the point where the energy intensity value is equivalent to the final target value. So although the final EUI target as a scalar value is independent of grid carbon intensity, areas with more carbon-intensive energy mixes have proportionally more aggressive rates of reduction of their EUI pathways, and therefore more urgency around reaching a final site EUI target (i.e., an earlier leveling year).

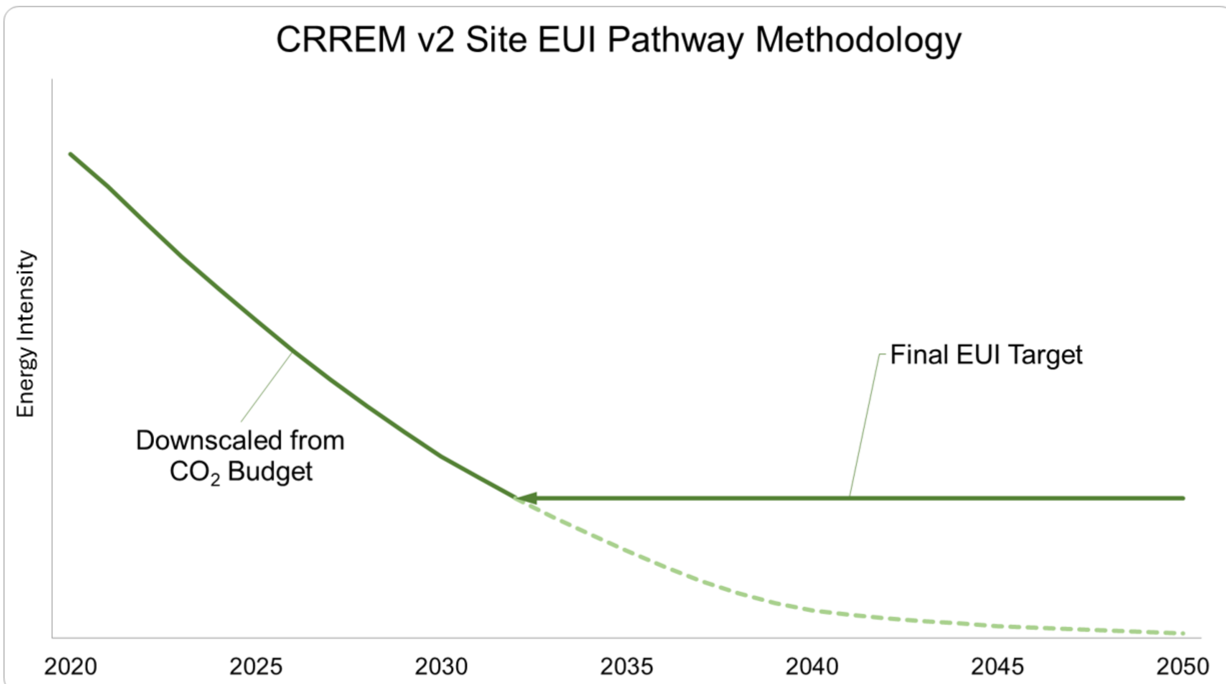

Figure 4: CRREM v2 energy pathway intersecting final EUI target.

Final EUI Targets: Discussed Revisions and Reference Points

Through discussions among the project team, it was decided that the conservative rounding down of EUI targets (e.g., U.S. Commercial EUI of 78.3 kWh/m^2 rounded down to 70 kWh/m^2) leads to overly aggressive and inequitable targets when EUI targets happen to have a high “ones digit”. The CRREM team plans to use unrounded values moving forward.

Because of the wide variety of climate zones across the U.S. and Canada, subregional degree days were derived to support better apportionment of energy intensity targets. These subregional degree days were used to create subregion-specific multipliers utilizing the same methodology as apportionment at the country level. More details on sub-regional breakdowns and degree-day derivations, which are aligned with the IEA degree-day calculation methodologies that are used by CRREM globally, are available in each country’s respective analysis section.

Because the CRREM approach to setting final targets is based on a global scenario of full decarbonization by 2050[1] across the aggregate commercial and residential sectors, it does not directly consider the technical limits on energy efficiency for specific property types. To provide additional context at the property-type level, the project team used other standards to develop comparison points for the CRREM final targets. These comparisons were developed using the revised EUI targets for the U.S., as the geographic divisions by climate zones (discussed later in this report) aligned well with the referenced alternative standards.

The two alternative standards referenced by the project team are: (1) the Zero Energy Commercial Building Targets report by the New Building Institute (NBI); and (2) the Energy and Emissions Building Performance Standard for Existing Buildings report by ASHRAE. NBI's report uses both measured and modeled data to establish energy targets that are net zero carbon-aligned but cover only certain specific property types. ASHRAE Standard 100, while not net zero-aligned, provides granularity in both property type and climate zones needed for accurate comparisons.

The project team used NBI's values for property types that overlapped with ASHRAE Standard 100 to derive "more aggressive" targets by climate zone for other property types not represented by the NBI report. Broadly speaking, the targets are in the same general range, with shopping malls and retail stores as the only two major outliers. There is also a general trend of CRREM having more aggressive targets in hot climates; this aligns with the degree-day method CRREM employs, which weighs heating degree days more than cooling degree days. Note that these reference results should be taken as a rough estimate, given the assumptions used to produce the complete set of reference data. The comparison results are shown in Figures C.1 and C.2 in Appendix C: .

Working group participants voiced a desire to have alternative reference points when defining an asset's final EUI that is representative of best-in-class efficiency and performance. To this end, the project team derived EUI equivalents from EPA ENERGY STAR™ Portfolio Manager (ESPM) scores as they are derived from real building data and comparisons to a national peer group; consequently, high ENERGY STAR™ scores are representative of top-performing buildings. The resulting memo prepared by the project team contains EUI equivalents for ESPM scores ranging from 75 to 100 in five-point increments for the following property types:

- Office
- Non-Refrigerated Warehouse
- Refrigerated Warehouse
- Retail
- Hospital
- Multifamily High-Rise
- Multifamily Low-Rise

The project team then developed ESPM Site EUI equivalents by expanding the ESPM reverse scoring methodology, as detailed in the section **Derivations for Starting Energy Intensities**. The methodology was originally built to derive the median energy intensity for an asset (i.e., with an ENERGY STAR™ score of 50). The same methodology for deriving the predicted source EUIs for all climates and then adjusting them to site EUIs is applied. Instead of using only a score of 50 to estimate the median of an asset, scores ranging from 75 to 100, in increments of 5, were used to provide reference points for all levels of

[1] IEA NZE: International Energy Agency Net Zero Emissions. "Net Zero Emissions by 2050 Scenario (NZE)," Table 03_28, 2020.

distribution. The lower boundaries in the energy efficiency ratio lookup tables (“Energy Efficiency Ratio >=”) were used to determine the source EUIs for each level.

The equivalent EUI values are provided for an empirically based reference point for the energy performance of buildings. Reference points are derived for several property types, but not comprehensively across all CRREM property types. Similar methodologies could be applied to derive tables for any property type that currently has an ENERGY STAR™ score methodology. Note that the project team makes no proclamations or determinations of a particular ENERGY STAR™ score threshold whereby a building is aligned to broader climate goals.

5. Comparison of CRREM v2 Pathways to Building Performance Standards

One of the major transition risks manifesting in North America is the proliferation of Building Performance Standards (BPS) policies across the U.S. and Canada. Since CRREM is fundamentally focused on transition risk, the project team and working group participants requested a comparison of CRREM v2 pathways to existing BPS policies across the U.S. and Canada. LBNL performed this comparison for New York City's Local Law 97, Boston's BERDO, and Vancouver's Annual Greenhouse Gas and Energy Limits Bylaw.

The comparison showed that most current regulatory targets related to BPS policies are less aggressive than the associated CRREM pathways, suggesting that CRREM-aligned assets will generally perform well in regions with upcoming or existing BPS policies. The same cannot be said for BPS-aligned assets which may be in compliance with local BPS policies but may not necessarily align with CRREM. Notably, the gap between CRREM ambition levels and local requirements is, on average, narrowing over time. The results underpin CRREM's general observation that alignment with their pathways positions investors to meet current and future regulatory decarbonization frameworks.

An exception is Vancouver, whose BPS targets are more aggressive than CRREM pathways starting in 2040. Exceptions like these may become more typical given the wide variety of BPS policies, property type designations, and associated targets. Vancouver's case is somewhat unusual in that it has both a very low carbon intensity electrical grid and a policy that focuses on total elimination of on-site emissions by 2040. Further study is needed across a broader sampling of BPS policies to form more universal conclusions about how CRREM compares to the BPS policy landscape across the U.S. and Canada.

Figures 5 and 6 compare two U.S. BPS standards, New York City and Boston, with CRREM pathways for office buildings and multifamily buildings, respectively, while Figures 7 and 8 compare Vancouver's BPS standard with CRREM pathways for office buildings and retail buildings. The unit for these comparisons is kg CO_2/m^2, to stay aligned with the BPS policies' carbon intensity metrics.

U.S. Comparison (New York City and Boston): Office and Multifamily

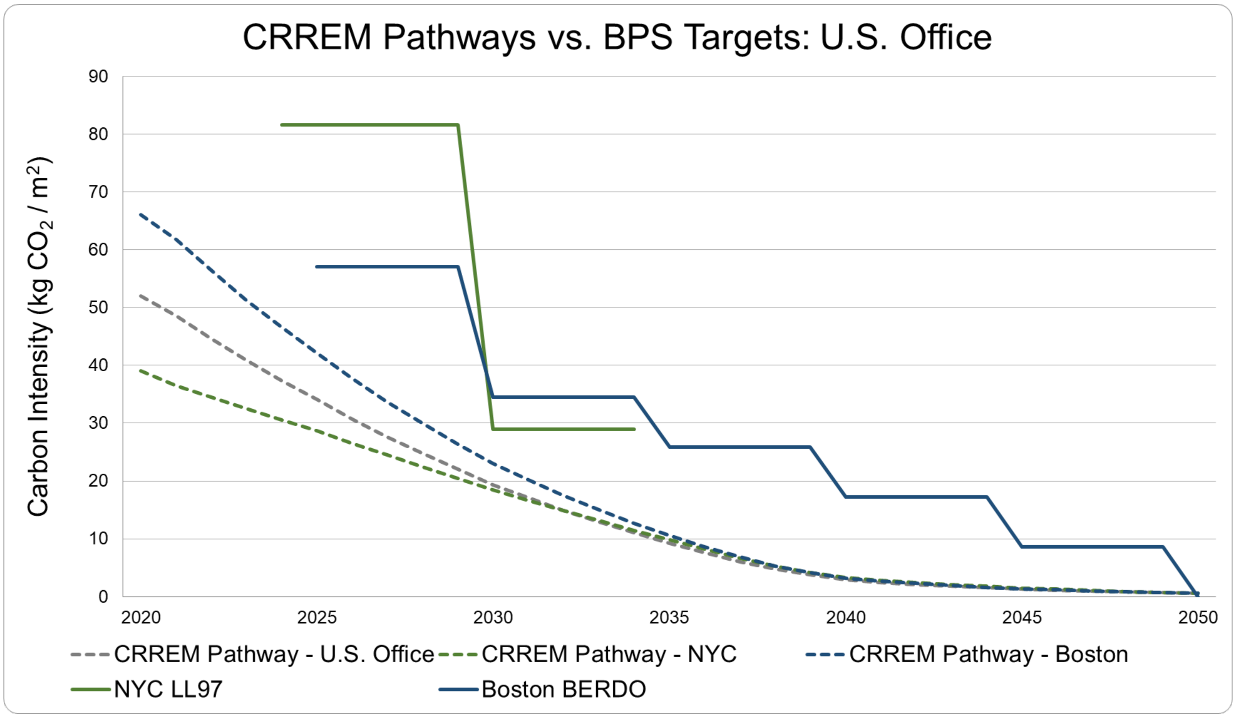

Figure 5: Comparison between CRREM pathways and U.S. BPS for office buildings.

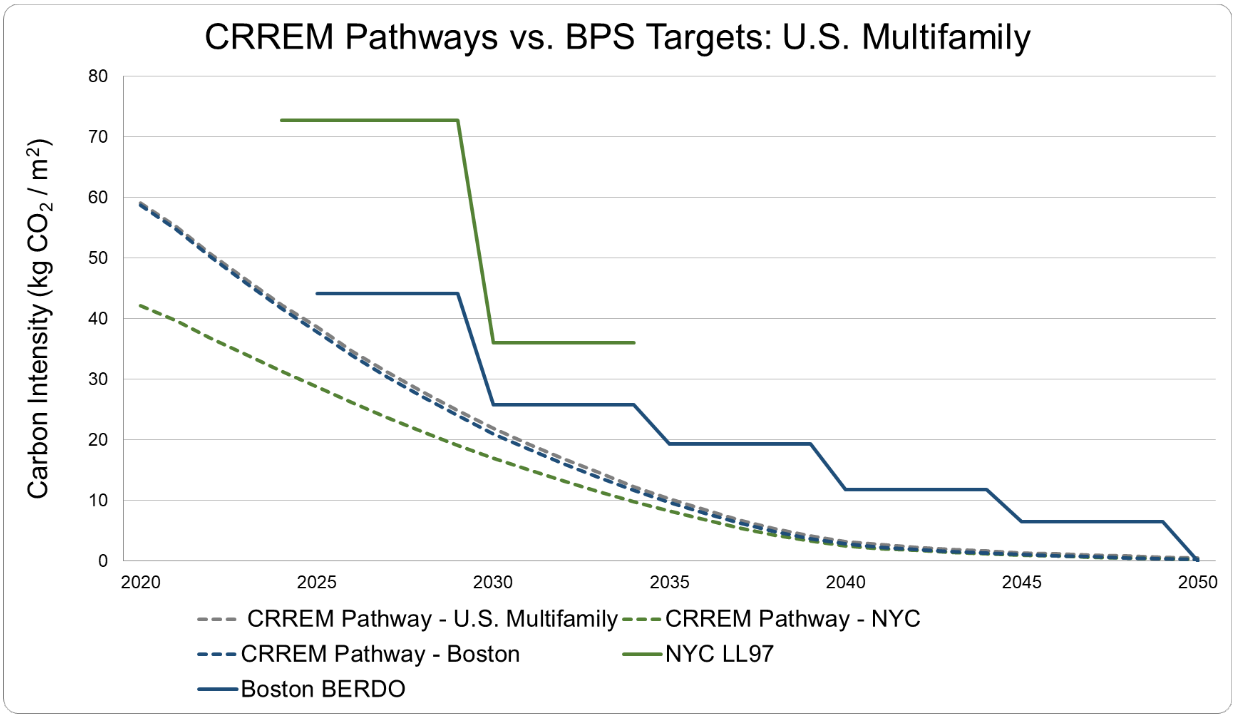

Figure 6: Comparison between CRREM pathways and U.S. BPS for multifamily buildings.

Canada Comparison (Vancouver): Office and Retail

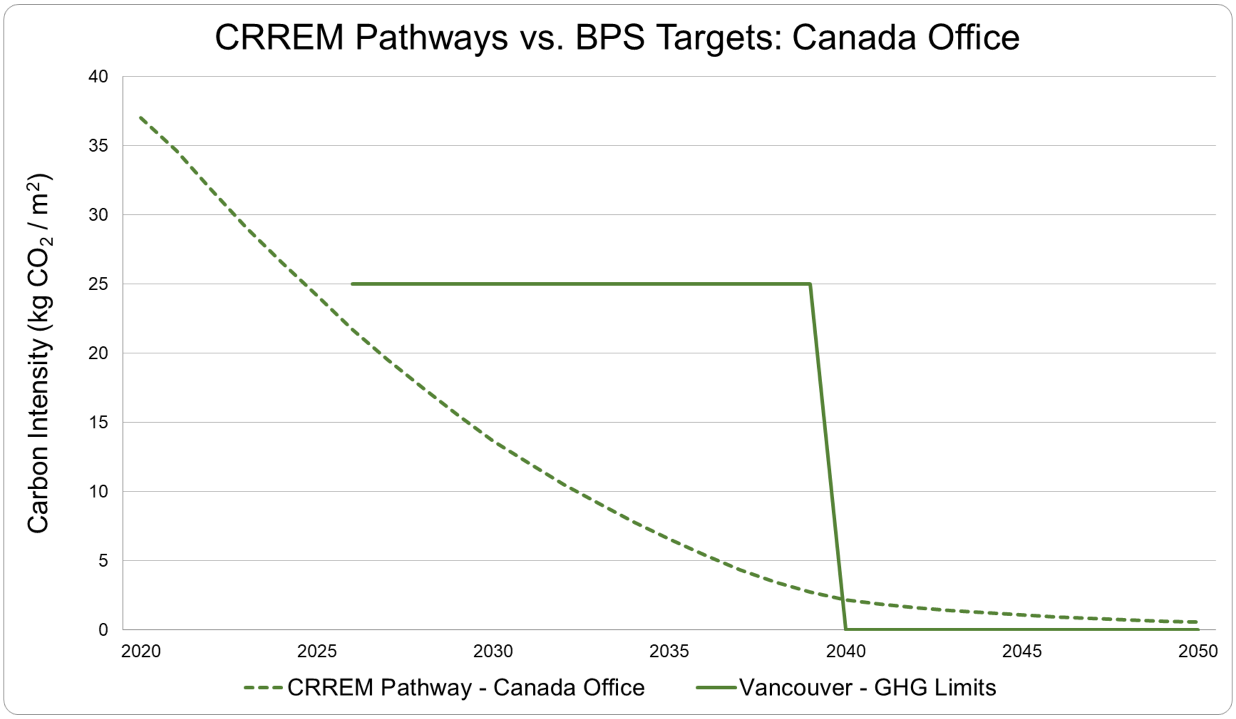

Figure 7: Comparison between CRREM pathways and Canada BPS for office buildings.

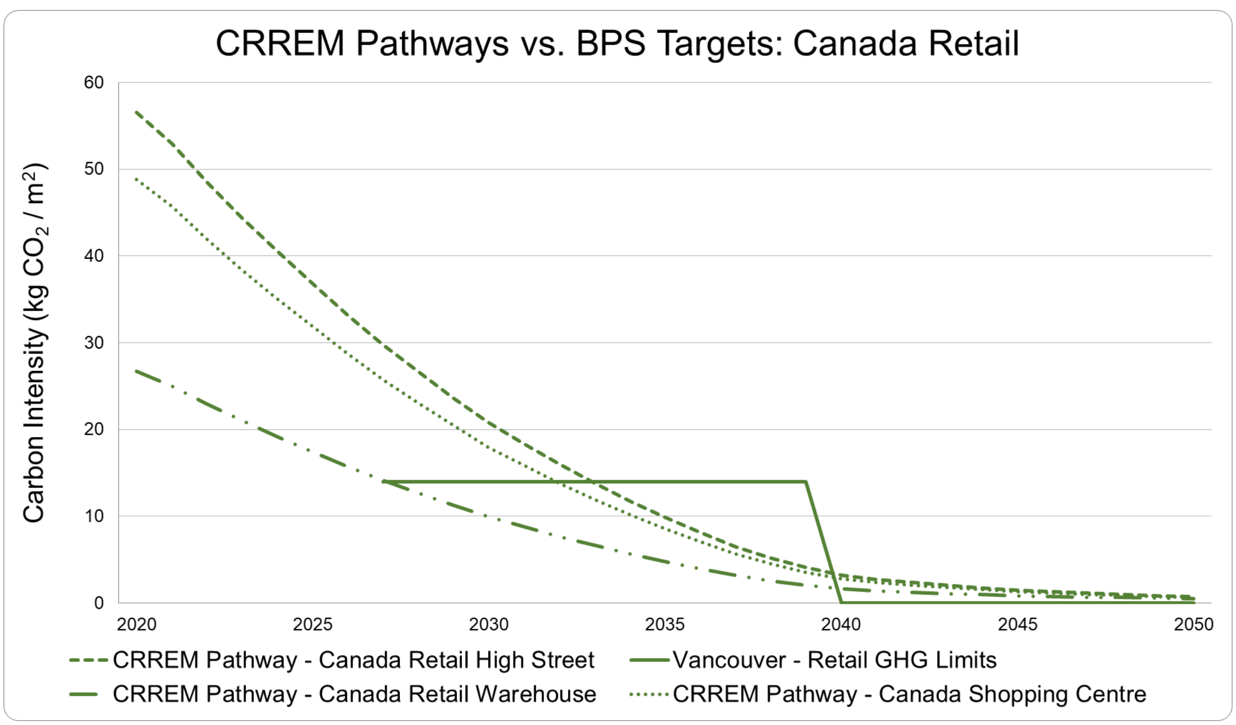

Figure 8: Comparison between CRREM pathways and Canada BPS for retail buildings.

6. United States Analysis

This section details the components of LBNL's analysis that were specific to the United States.

Dividing Markets/Geographies

One of the highest priorities for stakeholders and thus the analysis was determining the appropriate division of markets/geographies. This decision dictates the number of CRREM pathways and the accuracy of regional aggregations. CRREM pathways result from several input parameters, but the primary geographic elements most material to the pathways themselves are climate zone (U.S. climate zones, as defined by 2018 CBECS) and electric grid region (as defined by the Emissions and Generation Resource Integrated Database, or "eGRID"). Climate zones are a key driver of energy consumption, whereas eGRID affects the emissions resulting from energy consumption. Because of the importance of CBECS to the derivation of starting energy intensities, CBECS climate zones were chosen as the primary geographic delimiter for climate.

Before this analysis, the CRREM pathways for the U.S. had 15 major cities established as subregions, which was limiting for CRREM users with assets beyond those 15 cities. For assets outside those cities, CRREM users had to use national values, which could not accurately characterize ground conditions or buildings in other climate zones.

Working group participants overwhelmingly requested higher granularity and coverage in the U.S. At the start of this analysis, dividing the geography by state was considered, because it would include all U.S. buildings, but state boundaries often span multiple climate zones and grid regions. To balance the working group's wishes with data availability, the unique combination of eGRID region and CBECS climate zone resulted in 57 subregions.

These 57 subregions correspond to each unique combination of eGRID region and CBECS climate zone and have a resulting CRREM pathway. For ease of use, LBNL mapped each U.S. ZIP code to its respective combination of climate zone and eGRID region. This mapping allows CRREM users, who may not know their asset's climate zone and eGRID region, to retrieve the appropriate CRREM pathway by simply entering their asset's ZIP code.

Assessing Property Type Classifications

CRREM establishes several property type classifications, most of which are well aligned to U.S. standards. However, some of CRREM's property types are defined differently from U.S. property types, which can lead to user confusion and misalignment of data sources. This section outlines the property types that were misaligned and how the project team addressed them.

Retail – High Street is defined by CRREM as retail buildings located on the high street in a particular area, usually terraced buildings located in the city center or other high-traffic pedestrian zones. This definition did not fully align with U.S. standard classifications for retail. To address this matter, two methods were applied. First, a new property type of Retail Store was included and derived in alignment with U.S. data sources. Second, an alternative methodology was applied (see **Method 2: ENERGY STAR™ Reverse Scoring**) to calculate the best possible approximation of a Retail – High Street asset. Both are included in the output materials of this project. The project team recommends that CRREM consider using Retail Store as the primary retail type classification outside of shopping centers.

Health Care includes hospitals, clinics, and therapy centers. Inpatient care facilities (e.gl, hospitals, rehab centers, etc.) have significantly different energy use profiles than outpatient care facilities (e.g., clinics, therapy centers, etc.). When combined, the output median values are driven by the total existing counts of these asset types across the U.S. and yield targets that are too aggressive for inpatient care and too lenient for outpatient care. The project team recommends that CRREM split Health Care into two property types, Inpatient Care and Outpatient Care, to align with the distinct energy profiles of these asset types. These split types are included in the final outputs of this project.

Multifamily properties were evaluated on the basis of available data sources and associated scoring methodologies and were shown to have significant variation in energy intensity, depending on the size and height of the building. Because of this variation, the project team recommends that multifamily properties be split into three types: Multifamily High-Rise (greater than 20 units), Multifamily Low-Rise (greater than 20 units), and Small Multifamily (less than 20 units). The following section provides more detail on why these types were chosen, along with the associated data sources for each type.

Derivations for Starting Energy Intensities

Site energy use intensity (site EUI) values represent the annual energy consumption of an asset per floor area, typically in units of kBtu/sq ft in the United States and kWh/m^2 globally.

The U.S. Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS) is widely accepted as the most robust and trusted source for nationally representative building energy consumption in the U.S. These surveys have been performed since 1979 and have a well-documented process, methodology, and quality assurance. All other sources considered for this analysis fundamentally rely on user-entered data with limited verification and limited validation and are not guaranteed to be statistically representative of the existing building stock.

For example, the U.S. EIA's Residential Energy Consumption Survey (RECS) was evaluated for residential property types but has the inherent limitation of excluding common area energy and square footage from the scope of the survey, leading to problems with characterizing whole-building consumption of larger multifamily buildings with central heating and/or cooling plants.

Because of these limitations on the scope of RECS, the Fannie Mae Multifamily Energy and Water Use Survey was evaluated as another primary source because of its focus on whole-building energy data. Fannie Mae partnered with industry leaders on a national survey effort to collect multifamily property energy and water consumption and costs in the United States.[2] Bright Power, a firm with expertise in multifamily energy and water efficiency, assisted Fannie Mae in data collection and analysis. This analysis uses Fannie Mae's 2014 Green Initiative and ENERGY STAR™ for Multifamily for larger multifamily assets.

For ease of reference, derivations for median EUI values with multifamily buildings with fewer than 20 units are described in the section **Method 1: CBECS/RECS Filtered Microdata** in this document, and larger multifamily buildings (greater than or equal to 20 units) are described in the section **Method 2: ENERGY STARTM Reverse Scoring** in this document.

[2] Industry partners who participated included the Commercial Real Estate Finance Council (CREFC), Enterprise Community Partners, Mortgage Bankers Association (MBA), National Apartment Association (NAA), National Council of State Housing Agencies (NCSHA), National Multifamily Housing Council (NMHC), NeighborWorks America, Stewards of Affordable Housing for the Future (SAHF), and Urban Land Institute (ULI).

Two methodologies were used for establishing starting site EUIs. The first method (CBECS/RECS Filtered Microdata method) is purely statistical, using CBECS/RECS microdata to derive weighted median site EUI values. This method is preferred but cannot always be used in cases of low sample sizes or type mismatches. The second method (ENERGY STAR™ Reverse Scoring Method) was used in cases where the primary method was inapplicable or insufficient. Each method is detailed in the following sections.

Method 1: CBECS/RECS Filtered Microdata

This method uses CBECS/RECS microdata to derive weighted median site EUI values. To develop pathways for different property types, survey teams must first align the CBECS/RECS microdata with the property types specified by CRREM. Table 2 provides a comprehensive mapping between CRREM property types and CBECS/RECS building types.

Table 2: Mapping Between CRREM Property Types and CBECS/RECS Building Types

CRREM Property Type	**CBECS/RECS Building Type**
Outpatient Health Care	Outpatient Health Care
Hotel	Lodging
Office	Office
Retail and Warehouse	Strip Shopping Center
Shipping/Distribution Warehouse	Non-refrigerated Warehouse - Shipping/distribution centers
Self-Storage	Self-Storage
Lodging, Leisure, and Recreation	Public Assembly
Small Multifamily (< 20 units)	Apartment in a building with two to four units

The CBECS/RECS energy usage data are then categorized by building types and 2018 CBECS climate zones. The median value obtained from this grouping is selected as the representative number for CRREM use. Note that the median value referenced here is a weighted median, using the sample weights (CBECS User's Guide 2023) in CBECS microdata that allow the selected cases to represent all buildings.

- **Blank data processing:** In CBECS/RECS, certain data samples contain blank cells for energy use and the official user guide does not explicitly explain them. To handle these unidentified blanks, the surveys provide flag columns for fuel usage, which can show whether the columns represent zero values or missing data. For example, FKUSED, which indicates whether fuel oil is used, helps identify that blanks actually represent "not applicable."
- **Electricity- and natural gas-only buildings:** CRREM focuses mainly on electricity and natural gas usage. To develop uniform site EUI median values representative of typical buildings and align with CRREM's scope and methodology, the analysis excludes buildings that primarily use fuels other than electricity and natural gas. In CBECS/RECS, the major fuels include electricity, natural gas, fuel oil (i.e., fuel oil, diesel, kerosene), and district heating (thermal). Thus, only building samples where electricity and natural gas use account for more than 90 percent of total

use are kept in the analysis. When later processing those retained building samples, analysts assume that the natural gas equals the total use minus electricity use (Natural gas percentage = 100 – Electricity percentage).

Special considerations and exclusions to this methodology are as follows:

Retail – Shopping Center posed a challenge because of small sample sizes and CBECS-cited difficulties in data collection for enclosed malls. Although these cited challenges were part of an earlier version of CBECS, the output data of CBECS 2018 maintained similarly lower-than-expected values for enclosed malls that ran counter to CRREM global values and other empirical data sources such as the Building Performance Database and EPA Data Explorer. Other data sources were considered for comparison and determination of the most accurate approach. A study by the International Council of Shopping Centers (ICSC) was used to set baseline values for enclosed malls as its methodology was deemed sufficiently robust for inclusion, particularly its careful data collection and emphasis on accurately characterizing tenant loads. The ICSC study provided only national values, which needed to be scaled appropriately across U.S. climate zones. Ratios of EUI for building samples categorized within each climate zone are calculated using the ENERGY STAR™ reverse scoring methodology (see below). These calculated ratios are then applied to the ICSC national values.

Retail – Warehouse is defined by CRREM as buildings in an unenclosed retail space, otherwise known in the U.S. as a strip center or strip mall. These data were mapped to the CBECS category of "Strip Shopping Mall." Although strip malls were cited within CBECS data collection challenges, EIA used a new data collection methodology for Strip Shopping Malls in the 2018 CBECS release, adding confidence in the supplied values and leading the project team to recommend CBECS as the best data source for this property type.

Inpatient Care properties (that is, Hospitals) within CBECS had all climate data withheld and relatively low sample sizes. Because of this, the ENERGY STAR™ reverse scoring methodology was applied specifically to hospitals to provide accurate and climate-specific results (see below).

Multifamily properties, particularly larger buildings, face challenges with the quantification of whole-building energy, in particular common area energy and square footage. Because larger multifamily assets often have central plants serving all housing units, in-unit energy intensity can often be lower than whole-building energy intensity. For this reason, for larger multifamily assets, Fannie Mae data were utilized by way of the ENERGY STAR™ reverse scoring methodology (see below). The threshold was set at 20 or more units, in alignment with EPA guidance. As buildings trend smaller, the discrepancy between in-unit energy intensity and central plant intensity diminishes because the central plant serves fewer units. For this reason, RECS data were considered the best available source for smaller multifamily assets.

Method 2: ENERGY STAR™ Reverse Scoring

For property types where the CBECS/RECS Filtered Microdata method was inapplicable or insufficient, this methodology was applied. The U.S. EPA's ENERGY STAR™ Portfolio Manager (ESPM) is a free-to-use platform for managing building energy data and used ubiquitously across the U.S. and Canada. In addition to storing and tracking energy building performance, the platform also employs a robust and transparent scoring mechanism to evaluate the energy efficiency of various property types, with both climate and operational normalization. This scoring methodology uses CBECS/RECS microdata to develop regression models to predict the median energy intensity of an asset on the basis of building operating parameters and characteristics. Input variables are aligned with the characteristics of each

CRREM property type considered, and a score of 50 is used as a proxy for median energy intensity of an asset. (For more information about the ESPM regression models used in our analysis, see **Appendix E**.)

Heating Degree Days (HDD)/Cooling Degree Days (CDD) Considerations: Heating and cooling degree days are used by almost all ESPM score models to scale expected EUI on the basis of climate zones. HDD/CDD values were calculated using ESPM's methodology and household-weighted (as a proxy for total building square footage) to aggregate from ASHRAE climate zones to CBECS climate zones. Note that these HDD/CDD values vary from IEA's HDD/CDD, because a different methodology is used by IEA to calculate degree days generally.

Site/Source EUI Considerations: ESPM score models are built around the metric of Source EUI, which differs from the Site EUI requirements of this project. Because of this difference, whole-building source-to-site factors were developed, tailored to climate zone and property types as appropriate, based on relevant CBECS microdata for energy mix. ESPM site-to-source multipliers for each fuel type are then applied to this energy mix to derive whole-building site-to-source multipliers by climate zone and property type.

The four ESPM score models used in this analysis are:

Inpatient Care (that is, Hospitals): The method ENERGY STAR™ Score for Hospitals in the United States was used, with all default inputs for non-climatic variables. Because Hospitals do not have climate zone information within CBECS, outpatient care was used to develop the distribution of source-to-site factors by climate zone, and then scaled to national differences between outpatient and inpatient care. This process produced output EUIs for a prototypical hospital, scaled appropriately to each climate zone.

Retail – High Street: The method ENERGY STAR™ Score for Retail Stores and Supermarkets in the United States was used to represent Retail – High Street assets. Input variables aligned with CRREM's expectations of this asset, with no supermarket or commercial refrigeration units included. Source-to-site factors were derived from the CBECS property type Retail Other Than Mall.

Distribution Warehouse – Cooled: Because of the low sample sizes within CBECS, the project team opted to use the ENERGY STAR™ Score for Warehouses in the United States to represent refrigerated warehouses. This score includes both refrigerated and non-refrigerated warehouse buildings, but the input variables were adjusted in kind to represent a prototypical refrigerated warehouse. The percentage of cold storage was set at 81, in line with the average reported by CBECS survey respondents. The remaining 19 percent of space was considered standard conditioned space (i.e., both heated and cooled). All other non-climatic variables were defaults. Source-to-site factors were also derived from the CBECS property type Refrigerated Warehouse.

Multifamily: Because of concerns noted earlier regarding the limitations of RECS in quantifying whole-building consumption for larger assets, ENERGY STAR™ Score for Multifamily Housing in the United States was used to characterize assets with more than 20 units. This score was derived from the Fannie Mae Multifamily Energy and Water Use Survey and a follow-on effort between EPA and Fannie Mae to derive appropriate statistical weightings. The score distinguishes between low-rise and high-rise assets, because the data showed material differences in energy consumption between these two classes of large multifamily buildings. To this end, large multifamily assets are split into two property types: Multifamily High-Rise (greater than or equal to 20 units) and Multifamily Low-Rise (greater than or equal to 20 units).

Geographic Mapping

This section explains how the project team mapped the emission factor data source and the building energy use data source to a common geographic unit. The energy use data sources, CBECS and RECS, are categorized by U.S. census region or climate zones, which are adapted from ANSI/ASHRAE Standard 169-2021. The Cambium dataset, described in the section **Modeling Electric Grid Factors: Present and Future** in this document, has several levels of granularity: balancing areas (BAs),[3] generation emission assessment (GEA) regions, and states. Cambium's 20 GEA regions cover the contiguous United States. They are based on the EPA's eGRID regions, however they are not identical because of the geographic models of the Cambium workflow and slight but material differences in balancing areas. Generally speaking, GEA regions are considered close approximations of eGRID regions.

By delving into these geographic units and their definitions, LBNL identified opportunities to further disaggregate some of them into smaller units to create an accurate alignment for full national coverage. The CBECS/RECS climate zones are aggregated on the basis of Building America and IECC climate zones, which can be mapped to ASHRAE-defined counties. Cambium's GEA regions are groupings of balancing areas. And the balancing areas are also county aggregates. Thus, the county is used as the minimal unit to map between the geo units of building energy use data source and the emission factor data source. The process of geo-mapping is depicted in Figure 9.

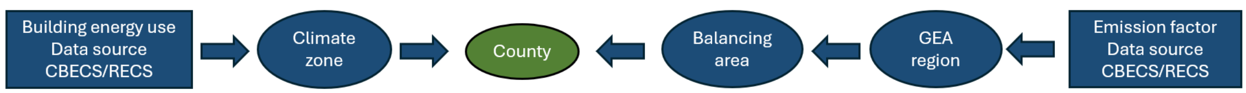

Figure 9: Geographic mapping for energy use and emission data sources.

Deriving Degree Days from TMY Models for EUI Target Adjustments

The existing CRREM methodology uses climatic data to apportion energy from the 2050 target scenario to various regions, with more extreme climates getting more allowances in proportion to typical heating and cooling energy use. For the U.S., national, population-weighted aggregates of degree days are used and applied equally across the country, independent of climate zones. The project team's investigation led to the development of degree days broken down by the new geographic divisions. This result allows for more accurate climate adjustments to final targets, which are proportionate to the total number of heating and cooling degree days by climate zone. Note that the current methodology does not account for future changes in degree days associated with climate change.

Because the IEA degree day calculation methodology used by CRREM differs from typical U.S. degree day calculation methods employed by NOAA, EPA, and others, the project team derived the degree–day data using typical meteorological year (TMY) data. The third and latest TMY collection (TMY3) was based on data for 1,020 locations in the U.S. and derived from a 1976–2005 period of record where available. The U.S. Department of Energy (DOE) has defined one representative city for each climate zone in the U.S.; in this analysis, annual heating degree day and cooling degree day data are calculated using the hourly weather files of these representative cities.

[3] Cambium's balancing areas were originally proposed by ReEDS, which was developed by NREL. They are county aggregates intended to represent model nodes where electricity supply and demand is balanced.

Hourly data was required to appropriately align the resulting degree days. Following IEA's methodology, the degree-day data are defined as the sum of the difference between daily average temperatures (calculated as the average of the daily minimum and maximum temperatures) and the base temperatures (16°C/18°C for a heating degree day, 18°C/21°C for a cooling degree day). To align with CRREM's existing degree-day sources and calculation methodology (IEA's Weather, Climate and Energy Data Tracker), annual HDD and CDD values were calculated and averaged on monthly basis, as shown in Table 3 below.

Table 3. Heating Degree Days and Cooling Degree Days for U.S. ASHRAE Climate Zones

ASHRAE Climate Zone	ASHRAE Moisture Regime	HDD 16°C	HDD 18°C	CDD 18°C	CDD 21°C
1	A	2.1	5.9	207.9	129.0
2	A	24.8	38.9	171.2	107.3
2	B	27.8	49.1	161.9	110.5
3	A	94.6	123.2	88.8	48.9
3	B	82.3	110.6	105.5	63.1
3	C	35.0	69.2	22.2	3.7
4	A	181.5	219.5	55.9	28.7
4	B	151.2	186.3	62.7	31.9
4	C	156.3	205.9	7.1	1.4
5	A	253.5	298.2	23.9	7.8
5	B	233.5	274.9	40.9	16.8
5	C	206.8	265.2	0.7	0.0
6	A	336.0	380.5	25.0	8.2
6	B	306.5	355.1	17.4	6.9
7	N/A	422.0	471.9	13.4	3.8
8	N/A	539.0	595.4	1.8	0.1

Deriving Energy Mix for Building Type and Climate Zones

Given that the typical energy mix of a building is not uniform across different property types and U.S. climate zones, a more nuanced approach is proposed to estimate the energy mix for each combination of property types and climate zones. CBECS and RECS are utilized again to analyze energy consumption patterns by property type and climate zone to determine the starting energy mix by property type.

National projections from IEA are then used to project future energy mix, aligned with CRREM's existing approach. The added granularity of this approach is expected to allow for a more accurate assessment of pathways tailored to diverse real estate portfolios.

It is important to note that this study focuses exclusively on buildings that utilize electricity and natural gas as their primary energy sources. When processing the micro data of CBECS and RECS, buildings are included only if the combined consumption of electricity and natural gas accounts for at least 90% of their total energy use. The weighted averages of electricity to gas ratios are derived from these buildings.

To keep consistency in utilizing the same data resources for different components of this project, the same property mapping method used to derive the starting EUI (see Table 2) is applied here. However, in instances where sample sizes are insufficient or where discrepancies exist between CBECS/RECS classifications and CRREM proposed property types, alternative strategies are applied. These exceptions and their corresponding approaches are detailed below.

Inpatient Health Care data samples do not include climate information for confidentiality reasons. With the limited data available for this specific property type, the values derived for outpatient health care are applied instead.

Retail – High Street and ***Retail – Store*** do not match up with property types defined in CBECS. The closest CBECS property type, Retail Other than Mall, is used to derive the energy mix data for these types.

Large Multifamily – High Rise (>20 units) and ***Large Multifamily – Low Rise (>20 units).*** Deriving starting EUIs for these property types was based on ENERGY STAR™ Multifamily Housing, due to the limitation of RECS in quantifying whole-building consumption for larger assets. For the same reason, RECS is not representative and therefore not used for estimating electricity and gas ratios. Instead, the Fannie Mae Multifamily Energy and Water Use Survey was used because of its focus on whole-building energy data.

Modeling Electric Grid Factors: Present and Future

To update the previous pathway which used 2020 as the starting baseline, the project team combined several data sources including eGRID, Cambium 2020, and Cambium 2022. eGRID's historical data are most commonly used in the United States for greenhouse gas registries and inventories, carbon footprints, consumer information disclosure, emission inventories and standards, and power market changes. eGRID has published data through 2021 and was used as a data source for 2020 and 2021. Cambium, developed by the National Renewable Energy Laboratory (NREL), contains modeled emission, cost, and operational data of the U.S. electricity sector through 2050. Cambium 22, the latest version, contains data starting 2023, so it was combined with Cambium 20 to account for 2021 and 2022.

Because of the specifics of how power plants are modeled and assigned to different grid regions in Cambium versus eGRID, there are sometimes large discrepancies between near-term values from Cambium for average emission rates and historical eGRID values. The Cambium team has advised caution when using Cambium 2020 and 2022 datasets for years prior to 2030 in combination with historical eGRID values.

Due to this limitation, the project team sourced eGRID data for 2020–2021 and Cambium data for 2035–2050 directly. For the interim period of 2022–2034, the data was interpolated using the following method.

The table in Figure 10 uses the Arizona/New Mexico subregion (AZNMc) as an example to illustrate the procedure. In the "Final Value" column, which expresses emission rates in kg/MWh, green values are sourced from eGRID, while dark blue values are sourced from Cambium. Using the data trend from Cambium for 2021–2035, the yearly change rate during this period is identified. Finally, using eGRID 2021 data as the starting point and Cambium 2035 data as the endpoint, intermediate data points for 2022–2034 are computed linearly by applying the yearly change rate.[4]

Year	eGRID - 2021	eGRID - 2020	Cambium20	Cambium22	Cambium Shape	Cambium Change Rate	Final Value
2020		385.6					385.6
2021	373.3		303.79		1.00		373.3
2022			283.16		0.93	8.8%	346.6
2023			262.52		0.86	8.8%	319.9
2024				241.89	0.80	8.8%	293.2
2025				221.26	0.73	8.8%	266.4
2026				200.63	0.66	8.8%	239.7
2027				166.21	0.55	14.6%	195.1
2028				131.79	0.43	14.6%	150.5
2029				119.60	0.39	5.2%	134.7
2030				107.40	0.35	5.2%	118.9
2031				99.61	0.33	3.3%	108.8
2032				91.82	0.30	3.3%	98.7
2033				84.03	0.28	3.3%	88.6
2034				76.24	0.25	3.3%	78.5
2035				68.45	0.23	3.3%	68.5
2036				63.42			63.4
2037				58.39			58.4
2038				53.35			53.4
2039				48.32			48.3
2040				43.29			43.3
2041				41.13			41.1
2042				38.97			39.0
2043				36.81			36.8
2044				34.65			34.6
2045				32.49			32.5
2046				32.90			32.9
2047				33.30			33.3
2048				33.70			33.7
2049				34.11			34.1
2050				34.51			34.5

eGRID Value
Interpolation
Cambium Value

Figure 10: Example of eGRID historical values and Cambium projected values (for AZNMc).

As a modeled comprehensive dataset, Cambium comprises 10 scenarios reflecting various technology, market, and policy assumptions. It also encompasses a multitude of metrics serving different purposes.

[4] Note that Cambium specifically covers the contiguous U.S., which excludes Alaska and Hawaii. To complement these data, eGRID's historical data are used as starting values. The national shape of emission changes over years was calculated using Cambium data and applied to the starting values to get projections for Alaska and Hawaii.

Following are notes used in selecting scenarios along with some intermediate calculations taken in the project team's work:

- The "Mid-case" scenario is selected to convey a conservative projection of the pathway. This scenario represents central estimates for inputs such as technology cost, fuel prices, and demand growth. No nascent technologies are included. It also assumes the continuation of existing policies in the electricity sector as they stand at present, inclusive of the Inflation Reduction Act of 2022.
- The average emission rates (AER) are end-use values at the point of consumption. To be consistent with the previous pathway methodology, LBNL needed to estimate the change in emissions from a change in load or generation at the busbar level, which refers to the point where generators connect to the bulk grid. Busbar level metrics were obtained by applying the average distribution loss rate (α) (Gagnon, Cowiestoll, and Schwarz 2023, Section 5.1: Busbar and End-Use Values):

$$X_{busbar} = X_{end-use} \times (1 - \alpha)$$

The distribution loss rate is the percentage of electrical energy that is lost as it travels from power plants to end-users through the distribution network. Cambium provides an average distribution loss rate applicable to this conversion for AERs.

The CRREM downscaling process uses weighted emission factors, by property type and year, to convert between energy and CO_2 pathways. These factors represent the carbon intensity of the whole building's energy consumption, inclusive of electricity and fossil fuels. In the following equation, the variables for each fuel percentage (Elec%, Gas%) show projected percentages of that fuel type for each property type by climate zone. All fossil fuel consumption is assumed to be natural gas as a simplifying assumption, aligning with CRREM's global methodology. The natural gas emission rate is sourced from the U.S. Energy Information Administration. Energy mix data from CBECS/RECS and Fannie Mae are applied to the above-mentioned emission rates to get weighted emission factors (EF) as follows:

$$Weighted\ EF = Electricity\ EF * Elec\%_{+}\ Natural\ Gas\ EF * Gas\%$$

Table 4 shows the calculation procedure using the Office building type in Warm climate in the AZNMc subregion as an example. Note that percentages denoted in Table 4 are not expected to sum to 100 percent, as renewable/carbon-neutral energy is assumed to make up the remainder of the energy mix at the asset with an assumed emissions factor of zero in alignment with CRREM's global methodology.

Table 4: Emission Factors Calculation (AZNMc Example)

Year	Electricity Emission Rate (kg/MWh)	Natural Gas Emission Rate (kg/kWh)	Elec %	Gas %	Weighted Emission Factor (kg/kWh)
2020	385.62	0.181	0.808	0.192	0.346
2021	373.34	0.181	0.814	0.186	0.338
2022	346.62	0.181	0.820	0.180	0.317

Note: EF = emission factor.

2023	319.89	0.181	0.825	0.175	0.296
2024	293.16	0.181	0.829	0.171	0.274
2025	266.43	0.181	0.834	0.166	0.252
2026	239.70	0.181	0.838	0.162	0.230
2027	195.11	0.181	0.841	0.159	0.193
2028	150.51	0.181	0.844	0.156	0.155
2029	134.71	0.181	0.847	0.153	0.142
2030	118.91	0.181	0.850	0.150	0.128
2031	108.82	0.181	0.853	0.147	0.119
2032	98.73	0.181	0.857	0.143	0.111
2033	88.64	0.181	0.860	0.140	0.102
2034	78.54	0.181	0.864	0.136	0.092
2035	68.45	0.181	0.868	0.132	0.083
2036	63.42	0.181	0.872	0.128	0.078
2037	58.39	0.181	0.877	0.123	0.073
2038	53.35	0.181	0.882	0.118	0.068
2039	48.32	0.181	0.887	0.113	0.063
2040	43.29	0.181	0.893	0.107	0.058
2041	41.13	0.181	0.898	0.102	0.055
2042	38.97	0.181	0.903	0.097	0.053
2043	36.81	0.181	0.909	0.091	0.050
2044	34.65	0.181	0.915	0.085	0.047
2045	32.49	0.181	0.919	0.081	0.044
2046	32.90	0.181	0.925	0.075	0.044
2047	33.30	0.181	0.929	0.071	0.044
2048	33.70	0.181	0.934	0.066	0.043
2049	34.11	0.181	0.938	0.062	0.043
2050	34.51	0.181	0.942	0.058	0.043

Note: EF = emission factor.

7. Canada Analysis

This section details the components of LBNL's analysis that were specific to Canada. Special thanks go to Daniela Agnoletto (Real Property Association of Canada), Brent Gilmour (Canada Green Building Council), Mark Hutchinson (Canada Green Building Council), and Darryl Neate (Real Property Association of Canada) for volunteering their time and insights to support the development of CRREM pathways for Canada.

Dividing Markets/Geographies

The geographic unit used for Canada aligns with its political geography, comprising 10 provinces (Alberta, Manitoba, New Brunswick, Nova Scotia, British Columbia, Ontario, Newfoundland and Labrador, Prince Edward Island, Quebec, and Saskatchewan) and three territories (Northwest Territories, Yukon, and Nunavut). The geographic unit was decided because both the energy data sources and emission data sources used in this analysis exist at the province level. The three territories were aggregated into a single subregion on the basis of data availability.

Assessing Property Type Classifications

CRREM establishes a number of property type classifications, most of which align well with Canadian standards. However, some of CRREM's property types are defined differently from Canadian property types, which can lead to user confusion and misalignment of data sources. This section outlines the misaligned property types and how the project team addressed them. Canadian property types were aligned with the newly proposed U.S. property types wherever possible, data permitting.

Health Care includes hospitals, clinics, and therapy centers. Similar to the U.S., inpatient care facilities (i.e., hospitals and rehab centers) in Canada have significantly different energy use profiles compared with outpatient care facilities (e.g., clinics, therapy centers, etc.). When combined, the output median values result in targets that are too aggressive for inpatient care and too lenient for outpatient care. The project team recommends that CRREM split Health Care into two property types, Inpatient Care and Outpatient Care, to align with the distinct energy profiles of these asset types. These split types are included in the final outputs of this project.

Multifamily properties were evaluated on the basis of available data sources and associated scoring methodologies. Similar to the U.S., they were shown to have significant variation in energy intensity depending on the height of the building. In contrast to the U.S., however, the available data sources in Canada showed less variation based on the number of units in the building. Because of this, the project team recommends that multifamily properties are split into two types: Multifamily High-Rise and Multifamily Low-Rise.

Derivations for Starting Energy Intensities

Similar to the methodology for deriving starting site energy use intensities in the U.S., two methods were used for Canada. The first is statistical, using the Survey of Commercial and Institutional Energy Use (SCIEU) 2019 for commercial building types and the Survey of Household Energy Use (SHEU) 2019 for multifamily buildings. These surveys are used by Natural Resources Canada (NRCan) in support of energy efficiency policy and program development, and by building owners/managers and energy specialists to learn about building energy consumption patterns.

SCIEU 2019 does not contain province-level data, as data collection was limited by COVID. As an alternative approach to getting province-level data, province-to-nation ratios were obtained from the National Energy Use Database (NEUD) 2020 and applied to the nation-level values in SCIEU by building type.[5] The property categories and definitions vary between NEUD and SCIEU, with Table 5 illustrating the method used to match them. As with the U.S.-specific analysis, the ENERGY STAR™ Reverse Scoring Method was used for Canada in cases where the primary method was inapplicable or insufficient.

Method 1: SCIEU/SHEU Coupled with NEUD
This method uses the nation-level energy use intensities from SCIEU 2019 and derived province-level data by applying the province-to-nation ratios from NEUD 2020. The property type mapping from these two data sources to the types in CRREM is depicted in Table 5.

Table 5: Property Type Mapping Across Canadian Data Sources (CRREM, SCIEU 2019/SHEU 2019, and NEUD 2020)

CRREM	SCIEU 2019/SHEU 2019	NEUD 2020
Inpatient Health Care	Hospital Buildings	Health Care and Social Assistance
Outpatient Health Care	Office Space – Medical	Health Care and Social Assistance
Hotel	Hotel, Motel, Hostel, or Lodge	Accommodation and Food Services
Office	Office Space – Excluding Medical	Offices
Retail – High Street	Retail – Non-food	Retail Trade
Retail – Shopping Center		
Retail – Warehouse		
Shipping/Distribution Warehouse	Warehouse	Transportation and Warehousing
Lodging, Leisure, and Recreation	Recreation Center, Ice Rink, Museum or Gallery, Library or Archives	Arts, Entertainment, and Recreation

Retail Subtypes. Special considerations and exclusions to this methodology involve subtypes in retail, as neither SCIEU nor NEUD have subcategories for retail buildings. Therefore, the ratios of these subcategories to the whole retail category from the most recent update of CRREM are applied to SCIEU values. This method is depicted in Table 6.

[5] Although SHEU 2019 has granular data by provinces, some province-level data were marked as “too unreliable to be published.”

Table 6: Deriving EUIs for Retail Subcategories

Category	EUI Ratio (Relative to "Retail – All")	EUI (kWh/m^2)
Retail – High Street	1.29	361.3
Retail – Shopping Center	1.11	311.7
Retail – Warehouse	0.61	170.0
Retail – All	1.00	281.0

Method 2: ENERGY STAR™ Reverse Scoring
The ENERGY STAR™ reverse scoring methodology was applied to property types where SCIEU/NEUD data was insufficient, as described by each property type at the end of this section. As described in the U.S. analysis section, the U.S. EPA's ENERGY STAR™ Portfolio Manager (ESPM) is a free-to-use platform for the management of energy data in buildings and is used ubiquitously across the U.S. and Canada. In addition to storing and tracking energy building performance, the platform also employs a robust and transparent scoring mechanism to evaluate the energy efficiency of various property types, with both climate and operational normalization. For our Canada-specific analysis, this scoring methodology uses SCIEU microdata to develop regression models to predict the median energy intensity of an asset based on building operating parameters and characteristics. Input variables are aligned with the characteristics of each CRREM property type considered, and a score of 50 is used as a proxy for the median energy intensity of an asset. (For more information, see **Appendix E**.)

HDD/CDD Considerations: Heating and cooling degree days are used by almost all ESPM score models to scale expected EUI on the basis of climate. For each province in Canada, the Canadian Weather Year for Energy Calculation (CWEC) weather file of the most populated city is used to calculate the HDD and CDD and represent the province (Table 7). Note that these HDD/CDD values vary from IEA's HDD/CDD, as a different methodology is used by IEA to calculate degree days in terms of base temperature, monthly versus annual value, and definition of the daily average temperature. Here, the HDDs are in units of Celsius, the base temperature is 65°F (18.3°C), and annual values are used.

Table 7: HDD Calculated Based on CWEC for the Most Populated Cities in Canada Provinces

Province	Most Populated City and CWEC Weather Station #	HDD 18.3°C
AB	Calgary 718770	5316.2
BC	Vancouver 718920	3166.9
MB	Winnipeg 718520	5950.4

NB	Saint John 716090	4838.9
NF	St. Johns 718010	4996.8
NS	Halifax 716010	4291.7
ON	Toronto 716240	4259.3
PE	Charlottetown 717060	4774.6
PQ	Montreal Intl. Airport 716270	4647.7
SK	Saskatoon 718660	5964.0
YT	Whitehorse 719640	7164.4

Note: AB = Alberta; BC = British Columbia; MB = Manitoba; NB = New Brunswick; NF = Newfoundland; NS = Nova Scotia; ON = Ontario; PE = Prince Edward Island; PQ = Quebec; SK = Saskatchewan; YT = Yukon Territory; CWEC = Canadian Weather Year Energy Calculation; HDD = heating degree days.

Site/Source EUI Considerations: ESPM score models are built around the metric of source EUI, which differs from the site EUI requirements of this project. Because of this, whole-building source-to-site factors were developed based on ENERGY STAR™ published national median EUI values for Canada. ENERGY STAR™ publishes both site and source EUI values, and the associated ratio was used to convert from predicted source EUI to site EUI for each property type.

Refrigerated Warehouse: This property type is not specified in SCIEU/NEUD, so the project team opted to use the ENERGY STAR™ Score for Warehouses in Canada to represent refrigerated warehouses. This score includes both refrigerated and non-refrigerated warehouse buildings, but the input variables were adjusted to represent a prototypical refrigerated warehouse. The percent of cold storage was set to 81 percent, in line with the average percent of cold storage reported through U.S. CBECS survey respondents. The remaining 19 percent of space was considered standard conditioned space (i.e., the "Percent That Can Be Heated" variable in this regression model). All other non-climatic variables were defaults. Source-to-site factors were derived from the U.S. CBECS property type Refrigerated Warehouse.

Multifamily Housing: Several data sources were evaluated for use with multifamily housing, including SHEU 2019 and the Survey of Energy Consumption of Multi-Unit Residential Buildings (SECMURBs), two key national data sources representing multifamily buildings. To obtain the necessary granularity by climate, province, and low-rise versus high-rise buildings, the team opted to use the ENERGY STAR™ Score for Multifamily Buildings in Canada to represent multifamily buildings. This scoring method is based on SECMURBs microdata. This score includes both low-rise and high-rise multifamily buildings and includes both heating and cooling degree-day variables for adjustment by location. The buildings are assumed to be 100 percent heated and 100 percent cooled. All other non-climatic variables were defaults.

Modeling Electric Grid Factors: Present and Future

Emission factors are utilized to convert baseline and projected future energy values to carbon emissions for pathway development. LBNL recommends that CRREM switches to Canada's Official Greenhouse Gas Inventory and Greenhouse Gas Emissions Projections developed by Environment and Climate Change Canada (ECCC). This source provides both historical and projected emission data until 2050 for Canadian provinces which aligns with the project team's needs.

For Canada, the CRREM downscaling process uses weighted emission factors, by sector and year, to convert between energy and CO_2 pathways. These factors represent the carbon intensity of a building's entire energy consumption, including both electricity and fossil fuels. All fossil fuel consumption is assumed to be natural gas, in line with CRREM's global methodology.

Energy mix ratios are sourced from "Canada's Energy Future 2023," developed by the Canada Energy Regulator (CER), and applied to emission rates using the following equations to generate weighted emission factors:

$$Weighted\ EF_{Res} = Electricity\ EF \cdot Elec\%_{Res} + Natural\ Gas\ EF \cdot Gas\%_{Res}$$

$$Weighted\ EF_{Com} = Electricity\ EF \cdot Elec\%_{Com} + Natural\ Gas\ EF \cdot Gas\%_{Com}$$

Appendix A: United States Recommended Data Sources

Building Stock and Building Stock Projection Residential/Commercial

Brief Description

Current building stock data are used by CRREM to derive the baseline carbon intensity for each country's building sector. Projections of that building stock growth to 2050 are used when calculating the downscaled CO_2 pathways. Countries with projected growth greater than average face more aggressive pathways, aligned with the Sectoral Decarbonization Approach developed by the Science Based Targets initiative.

Current Data Source + Feedback

Building Stock:

- U.S. Energy Information Administration (EIA). 2020. Residential Energy Consumption Survey (RECS), Table HC10.1: Total Square Footage of U.S. Homes, 2020.
- U.S. Energy Information Administration (EIA). 2018. Commercial Buildings Energy Consumption Survey (CBECS), Table B7: Building Size, Floorspace, 2018.
- U.S. Census Bureau. 2019. Quarterly Starts and Completions by Purpose and Design.
- CoStar. 2020. Floor Area.
- Center for Sustainable Systems, University of Michigan. 2019. Residential Buildings Factsheet.

Building Stock Projection:

- MCP Moura, SJ Smith, and DB Belzer. 2015. 120 Years of U.S. Residential Housing Stock and Floor Space. PLOS ONE 10(8): e0134135. https://doi.org/10.1371/journal.pone.0134135.
- NREL. 2020. U.S. Building Stock Characterization Study. https://resstock.nrel.gov/page/typology.
- UN Environment Programme, Global Status Report. 2022. Building Stock Development for North America.

Current data sources are somewhat disparate. LBNL recommends the use of CBECS and RECS as the exclusive data sources wherever possible for existing stock. Since pathways are only affected when country-level stock projections are greater than the global average, the data sources for future building stock projections are deemed sufficient as-is since there is no material impact to the U.S. pathways.

Recommended New Data Source, If Applicable

Building Stock:

- CBECS 2018
- RECS 2020

Energy Intensities – Starting Values

Brief Description

Median site energy intensity values by property type are used by CRREM to establish the starting point of both CO_2 and energy pathways. Current CRREM pathways are established both nationally and across 15 subregions corresponding to major cities.

Current Data Source + Feedback

- CBECS. 2012. Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/.
- ENERGY STAR. 2020. U.S. Energy Use Intensity by Property Type, Portfolio Manager. www.energystar.gov.
- BPD. 2022. Building Performance Database. https://bpd.lbl.gov/explore (Site EUI).

Recommended New Data Source, If Applicable

The following references were used for the CBECS/RECS Filtered Microdata Method:

- CBECS 2018.
- RECS 2020.
- Fannie Mae Multifamily Energy and Water Use Survey

The following references were used for the ENERGY STAR™ Reverse Scoring method for the United States:

- ENERGY STAR™ Score for Hospitals (General Medical and Surgical) – Updated 02-19-2021. https://www.energystar.gov/buildings/tools-and-resources/energy-star-score-hospitals-general-medical-and-surgical.
- ENERGY STAR™ Score for Retail Stores and Supermarkets – Updated 08-24-2018. https://www.energystar.gov/buildings/tools-and-resources/energy-star-score-retail-stores.
- ENERGY STAR™ Score for Warehouses – Updated 08-24-2018. https://www.energystar.gov/buildings/tools-and-resources/energy-star-score-warehouses.
- ICSC Shopping Center Energy Intensity Benchmarking Study. 2016. https://www.icsc.com/uploads/about/ICSC-Industry-Benchmarking-Report-For-Distribution.pdf.

Emission Factors (Present and Projected)

Brief Description

Emission factors are used to convert baseline and projected future values from energy to carbon for pathway development. In combination with the Energy Mix data source (next section), these factors define the shape of the CO_2 and energy pathways, and the aggressiveness of interim target values.

Current Data Source + Feedback

- Carbon Footprint. 2022. Country Specific Electricity Grid Greenhouse Gas Emission Factors. www.carbonfootprint.com.
- International Energy Agency (IEA). 2017. Energy Technology Perspective 2017. Scenario data for United States.

Current data sources were deemed insufficient in terms of the required granularity (for proposed grid regions) and recency (for future projections). The proposed data sources below provide sufficient granularity and take into account recently passed legislation (Inflation Reduction Act of 2022) that had a significant impact on future grid projections.

Recommended New Data Sources, If Applicable

- Cambium 22, Cambium 20.
- eGRID.

Note that while Cambium 22 was used as the primary data source for electric emission factors through 2050, Cambium 20 was needed to fill the gap between most recent eGrid data and Cambium 22 data.

Energy Mix and Projected Energy Mix

Brief Description

Current and future energy mix aligned to a 1.5°C scenario is used by CRREM to establish baseline and future weighted emission factors. In combination with the Emission Factors data source above, this information defines the shape of the CO_2 and energy pathways, and the aggressiveness of interim target values.

Current Data Source + Feedback

- IEA International Energy Agency (2017): Energy Technology Perspective 2017. Scenario data for USA.

Considering that energy situations are not uniform across different property types and regional contexts vary significantly, a more nuanced approach is needed to better estimate the energy mix by property type and climate zone.

Recommended New Data Source, If Applicable

- IEA International Energy Agency (2017): Energy Technology Perspective 2017. Scenario data for USA.
- CBECS 2018
- RECS 2020
- Fannie Mae Multifamily Energy and Water Use Survey

CBECS/RECS and Fannie Mae are utilized to analyze energy consumption patterns by property type and climate zone and establish starting energy mix. The rate of change in the 2017 IEA report is still utilized to project future energy mix of assets.

Energy Target 2050

Brief Description

This data source is used within the CRREM framework to establish the final energy targets by property type. The final target values are based on projections of the aggregate, available carbon-free energy in 2050. This is then apportioned to building types/climates through the CRREM global EUI final target setting process. More detail on this process can be found in the section **Final EUI Targets** in this document.

Current Data Source + Feedback

- IEA NZE. 2020. Net Zero Emissions by 2050 Scenario (NZE), Table 03_28.

The current data source was determined to be robust and best available for the methodology employed by CRREM to establish final energy targets for buildings.

Recommended New Data Source, If Applicable

No change recommended.

Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Brief Description
The existing CRREM methodology uses climatic data to apportion energy from the 2050 target scenario to various regions, with more extreme climates getting more allowances in proportion to typical heating and cooling energy use.

Current Data Source + Feedback

- IEA Weather, Climate and Energy Tracker, National Population-Weighted Averages, 2007–2021.

For the United States, national, population-weighted aggregates of degree days are used and applied equally across the country independent of climate zones. Given the variety of U.S. climate zones, a more granular data source is highly recommended.

Recommended New Data Source, If Applicable

- TMY3 data from U.S. Department of Energy Prototype Building Models, adjusted to IEA calculation method for degree days.
- IEA calculation method for degree days: Weather for Energy Trackers: Users Guide.

Typical meteorological year (TMY) data is created by selecting and synthesizing hourly meteorological data from different years to represent a typical year's weather patterns for a specific location. The latest set TMY3 was derived from a 1976–2005 period of record where available. Note: These degree-day calculations are different from those employed in the ENERGY STAR™ Reverse Scoring Method, because of differences in the way each platform calculates degree days.

Summary of Recommended Data Sources for the United States

Table A-1: Summary of Recommended Data Sources for United States

Input Parameter	Source 2020	Proposed Sources
Building Stock	U.S. Energy Information Administration (EIA). 2020. Residential Energy Consumption Survey (RECS), Table HC10.1 Total Square Footage of U.S. Homes, 2020. U.S. Energy Information Administration (EIA). 2015. Commercial Buildings Energy Consumption Survey (CBECS), Table B7. Building size, Floorspace, 2015. U.S. Census Bureau. 2019. Quarterly Starts and Completions by Purpose and Design. CoStar. 2020. Floor Area. Center for Sustainable Systems, University of Michigan. 2019. Residential Buildings Factsheet.	U.S. Energy Information Administration (EIA). 2018. Commercial Buildings Energy Consumption Survey (CBECS). U.S. Energy Information Administration (EIA). 2020. Residential Energy Consumption Survey (RECS), Table HC10.1: Total Square Footage of U.S. Homes, 2020.
Building Stock Projection Residential/ Commercial	MCP Moura, SJ Smith, DB Belzer. 2015. 120 Years of U.S. Residential Housing Stock and Floor Space. PLOS ONE 10(8): e0134135. https://doi.org/10.1371/journal.pone.0134135 NREL. 2020. U.S. Building Stock Characterization Study. Online: https://resstock.nrel.gov/page/typology Global Status Report. 2022. Building Stock Development for North America.	No change recommended.
Energy Intensities – Starting Values	CBECS. 2018. Commercial Buildings Energy Consumption Survey. Online: https://www.eia.gov/consumption/commercial/ ENERGY STAR. 2020. U.S. Energy Use Intensity by Property Type, Portfolio Manager. Online: www.energystar.gov	CBECS 2018 and RECS 2020 Fannie Mae Multifamily Energy and Water Use Survey ENERGY STAR™ Score for Hospitals (General Medical and Surgical) - Updated 02-19-2021 ENERGY STAR™ Score for Retail Stores and Supermarkets - Updated 08-24-2018 ENERGY STAR™ Score for Warehouses - Updated 08-24-2018

		ICSC Shopping Center Energy Intensity Benchmarking Study (2016)
Emission Factors (Present and Projected)	Carbon Footprint. 2022. Country Specific Electricity Grid Greenhouse Gas Emission Factors. Online: www.carbonfootprint.com International Energy Agency (IEA). 2017. Energy Technology Perspective 2017. Scenario data for United States.	Cambium 22 Cambium 20 eGRID.
Energy Mix and Projected Energy Mix	International Energy Agency (IEA). 2017. Energy Technology Perspective 2017. Scenario data for United States.	CBECS 2018 and RECS 2020 Fannie Mae Multifamily Energy and Water Use Survey
Energy Target 2050	IEA NZE. 2020 Net Zero Emissions by 2050 Scenario (NZE), Table 03_28.	No change recommended.
Heating Degree Days (HDD) and Cooling Degree Days (CDD)	IEA Weather, Climate and Energy Tracker, National Population-Weighted Averages, 2007–2021.	TMY3 data from U.S. Department of Energy Prototype Building Models, adjusted to IEA calculation method for degree days. IEA calculation method for degree days: Weather for Energy Trackers: Users Guide.

Appendix B: Canada Recommended Data Sources

Building Stock and Building Stock Projection Residential/Commercial

Brief Description

Current building stock data are used by CRREM to derive the baseline carbon intensity for each country's building sector. Projections of that building stock growth to 2050 are used when calculating the downscaled CO_2 pathways. Countries with projected growth greater than average face more aggressive pathways, aligned with the Sectoral Decarbonization Approach developed by the Science Based Targets initiative.

Current Data Source + Feedback

Building Stock:

- Point2 Homes. 2017. Canadians Enjoy Second-Most Living Space per Person: Global Survey.
- Statistics Canada. 2017. Census in Brief: Dwellings in Canada.

Building Stock Projection:

- The Global Status Report. 2017. Global Status Report of the International Energy Agency (IEA) for the Global Alliance for Buildings and Construction (GABC).

Existing data sources were deemed sufficient for stock growth projections. Similar to the United States, the project team recommends using SHEU 2019 and SCIEU 2019 for the purposes of aggregate sector intensity calculations.

Recommended New Data Source, If Applicable

No change recommended.

Energy Intensities – Starting Values

Brief Description

Median site energy intensity values by property type are used by CRREM to establish the starting point of both CO_2 and energy pathways. Current CRREM pathways are established both nationally and across 15 subregions corresponding to major cities.

Current Data Source + Feedback

- ENERGY STAR. 2019. Canadian Energy Use Intensity by Property Type, Portfolio Manager. Online: www.energystar.gov.
- NRCAN. 2020. Commercial and Institutional Building Energy Use Survey. Median Values (Score 50).

Canadian stakeholders recommended different data sources to align with province-level granularity and the most up-to-date, publicly available information.

Recommended New Data Source, If Applicable

- Survey of Commercial and Institutional Energy Use (SCIEU) 2019 for commercial building types.
- Survey of Household Energy Use (SHEU) 2019 for residential sector and multifamily buildings specifically.
- National Energy Use Database (NEUD) 2020 as a supplemental source for deriving province-level EUIs.

Emission Factors (Present and Projected)

Brief Description

Emission factors are used to convert baseline and projected future values from energy to carbon for pathway development. In combination with the Energy Mix data source (next section), these factors define the shape of the CO_2 and energy pathways, and the aggressiveness of interim target values.

Current Data Source + Feedback

- Carbon Footprint. 2022. Country Specific Electricity Grid Greenhouse Gas Emission Factors. Online: www.carbonfootprint.com.

This data source refers to Canada's Official Greenhouse Gas Inventory for present emission factors, so LBNL recommends switching to refer to the original source. Emissions projections are not available through www.carbonfootprint.com, and are added to the team's recommendations below.

Recommended New Data Source, If Applicable

- Canada's Official Greenhouse Gas Inventory and Greenhouse Gas Emissions Projections.

These projections are developed by Environment and Climate Change Canada (ECCC) and have both historical and projected emission data for electricity and fossil fuels to 2050 for Canada provinces, which meet the project team's needs.

Energy Mix and Projected Energy Mix

Brief Description
Current and future energy mix aligned to a 1.5°C scenario is used by CRREM to establish baseline and future weighted emission factors. In combination with the Emission Factors data source above, this information defines the shape of the CO_2 and energy pathways, and the aggressiveness of interim target values.

Current Data Source + Feedback

- CERI Canadian Energy Research Institute. 2017. Greenhouse Gas Emissions Reductions in Canada Through Electrification of Energy Services.

Recommended New Data Source, If Applicable

- Canada's Energy Future. 2023.

Canada's Energy Future is developed by the Canada Energy Regulator (CER). The Energy Future explores how possible energy futures might unfold for Canadians over the long term with comprehensive economic and energy models. The current data source predicted that natural gas use will increase in the future years, which conflicts with the policy and market trends.

Energy Target 2050

Brief Description

This data source is used within the CRREM framework to establish the final energy targets by property type. The final target values are based on projections of available carbon-free energy in 2050. More detail on this process can be found in the section **Final EUI Targets** in this document.

Current Data Source + Feedback

- IEA NZE. 2020. Net Zero Emissions by 2050 Scenario (NZE), Table 03_28.

The current data source was determined to be robust and best available for the need for the methodology employed by CRREM to establish final energy targets for buildings.

Recommended New Data Source, If Applicable

No change recommended.

Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Brief Description
The existing CRREM methodology uses climatic data to apportion energy from the 2050 target scenario to various regions, with more extreme climates getting more allowances in proportion to typical heating and cooling energy use.

Current Data Source + Feedback

- IEA Weather, Climate, and Energy Tracker (National).

Recommended New Data Source, If Applicable

- IEA Weather, Climate, and Energy Tracker (Subnational).

The IEA Weather, Climate, and Energy Tracker has recently published subnational data. The monthly HDD and CDD values for provinces in Canada can be obtained from the new "Subnational" feature in this data tool. For consistency with previous work, the averages for 2007–2021 are computed.

Summary of Recommended Data Sources for Canada

Table B-1: Summary of Recommended Data Sources for Canada

Input Parameter	Source 2020	Proposed Sources
Building Stock	Point2 Homes. 2017. Canadians Enjoy Second-Most Living Space per Person: Global Survey. Statistics Canada. 2017. Census in Brief – Dwellings in Canada.	No change recommended.
Building Stock Projection Residential/ Commercial	The Global Status Report. 2017. Global Status Report of the International Energy Agency (IEA) for the Global Alliance for Buildings and Construction (GABC).	No change recommended.
Energy Intensities – Starting Values	ENERGY STAR. 2019. Canadian Energy Use Intensity by Property Type, Portfolio Manager. Online: www.energystar.gov. NRCAN. 2020. Commercial and Institutional Building Energy Use Survey. Median Values (Score 50).	Survey of Commercial and Institutional Energy Use (SCIEU) 2019 Survey of Household Energy Use (SHEU) 2019 National Energy Use Database (NEUD) 2020
Emission Factors (Present and Projected)	Carbon Footprint. 2022. Country Specific Electricity Grid Greenhouse Gas Emission Factors. Online: www.carbonfootprint.com	The Environment and Climate Change Canada (ECCC) Canada's Greenhouse Gas Emissions Projections: Reference Scenario Provincial and Territorial Energy Profiles – Canada
Energy Mix and Projected Energy Mix	CERI Canadian Energy Research Institute. 2017. Greenhouse Gas Emissions Reductions in Canada Through Electrification of Energy Services.	Energy Future 2023
Energy Target 2050	IEA NZE. 2020. Net Zero Emissions by 2050 Scenario (NZE), Table 03_28.	No change recommended.
Heating Degree Days (HDD) and Cooling Degree Days (CDD)	IEA Weather, Climate, and Energy Tracker (National).	IEA Weather, Climate, and Energy Tracker (Subnational).

Appendix C: Comparison of CRREM Final EUI Targets to Other Technical Standards

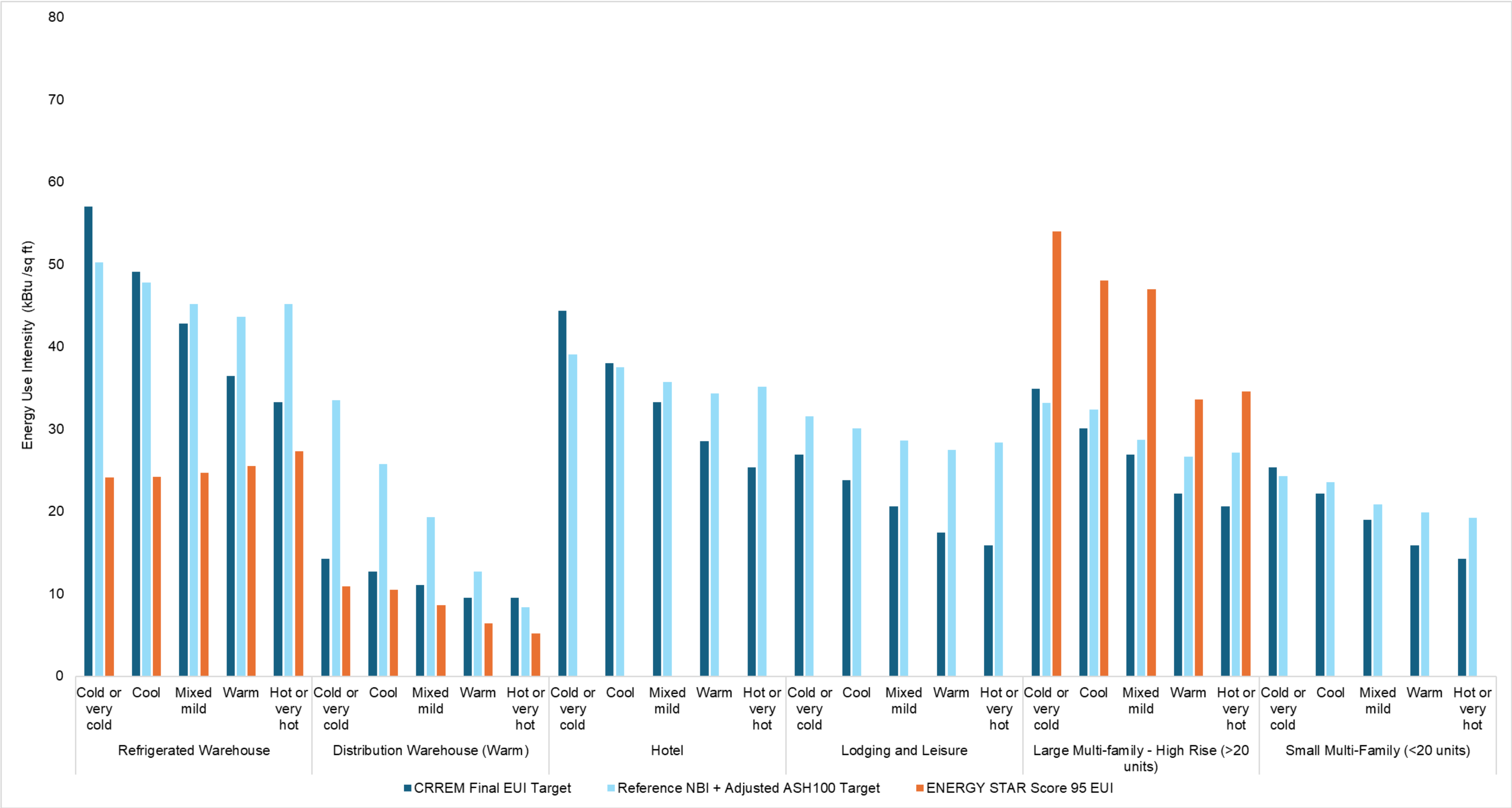

Figure C.1: Comparison between CRREM final EUI targets and Reference NBI + Adjusted ASH100 targets for warehouses, hotel, lodging & leisure, large multifamily properties high-rise, and small multifamily

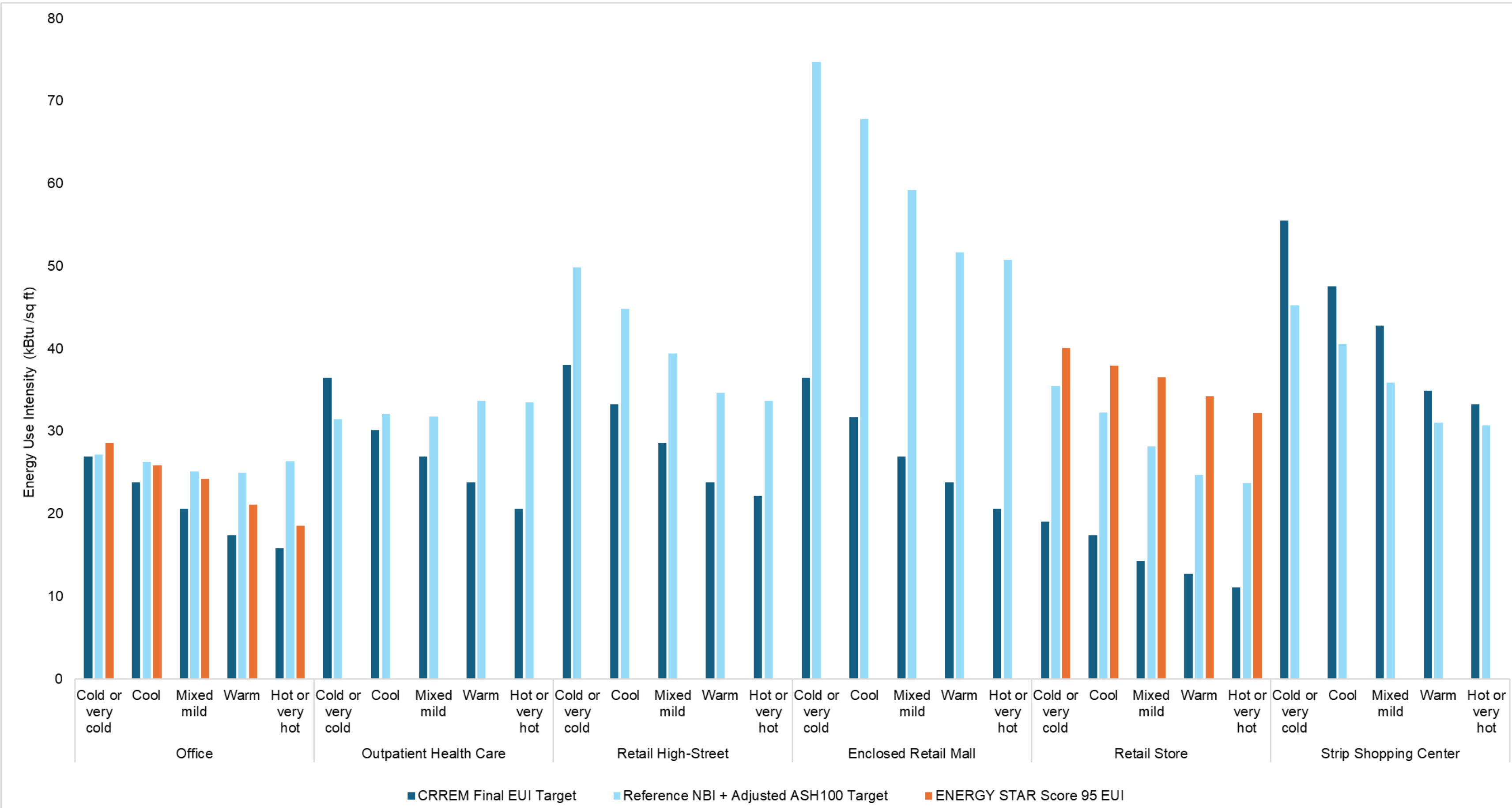

Figure C.2: Comparison between CRREM final EUI targets and Reference NBI + Adjusted ASH100 targets for office, outpatient health care, retail high-street, enclosed retail mall, retail store, and strip shopping center

Appendix D: CBECS Survey Sample Sizes for Median EUIs

Building Type	Climate Zone	Row Count	Total Weights
Health Care	Cold or very cold	14	7208.7
	Cool	47	24612.3
	Mixed mild	63	29159.7
	Warm	57	46391.7
	Hot or very hot	21	18957.7
Hotel	Cold or very cold	3	3092.1
	Cool	22	33627.9
	Mixed mild	30	22020.3
	Warm	40	26786.8
	Hot or very hot	14	6707.6
Industrial-Distribution Warehouse Cooled	Cold or very cold	N/A	N/A
	Cool	N/A	N/A
	Mixed mild	N/A	N/A
	Warm	N/A	N/A
	Hot or very hot	N/A	N/A
Industrial-Distribution Warehouse Warm	Cold or very cold	45	93615.3
	Cool	155	222780.1
	Mixed mild	177	174805.3
	Warm	224	168789.3
	Hot or very hot	87	112334.7
Lodging, Leisure, and Recreation	Cold or very cold	21	16013.9
	Cool	116	145180.0
	Mixed mild	84	112168.3

	Warm	100	118503.5
	Hot or very hot	63	63309.7
Office	Cold or very cold	78	75832.8
	Cool	255	228326.7
	Mixed mild	339	189869.3
	Warm	313	283001.9
	Hot or very hot	182	147974.1
Retail – High Street	Cold or very cold	23	23164.4
	Cool	81	90934.7
	Mixed mild	69	72654.5
	Warm	92	98624.1
	Hot or very hot	65	46548.0
Retail-Shopping Center	Cold or very cold	N/A	N/A
	Cool	N/A	N/A
	Mixed mild	N/A	N/A
	Warm	N/A	N/A
	Hot or very hot	N/A	N/A
Retail-Warehouse	Cold or very cold	9	6999.1
	Cool	53	45309.2
	Mixed mild	34	24868.5
	Warm	73	55721.6
	Hot or very hot	39	32760.0
Multifamily (RECS)	Cold or very cold	370	11896064.5
	Cool	840	8454474.2
	Mixed mild	1015	8550950.4
	Warm	603	7469180.5
	Hot or very hot	421	4742643.5

Appendix E: ENERGY STAR™ Score Models

United States

Inpatient Care (Hospitals) in the United States

Summary				
Dependent Variable	Source Energy Intensity (kBtu/ft²)			
Number of Observations in Analysis	135			
R^2 value	0.2240			
Adjusted R^2 value	0.2062			
F Statistic	12.60			
Significance (p-level)	<0.0001			
	Unstandardized Coefficients	Standard Error	T value	Significance (p-level)
Constant	433.6	7.395	58.64	<0.0001
C_Number of FTE Workers per 1000 ft²	21.55	7.228	2.980	0.003400
C_Number of Staffed Beds per 1000 ft²	106.1	47.23	2.250	0.02630
C_Number of MRI Machines per 1000 ft²	7,673	2,815	2.730	0.007300
C_Cooling Degree Days *(restricted, see notes)*	0.01825	0	Infty	<0.0001
C_Heating Degree Days *(restricted, see notes)*	0.001752	0	Infty	<0.0001

Retail Stores and Supermarkets in the United States

Summary				
Dependent Variable	Source Energy Intensity (kBtu/ft²)			
Number of Observations in Analysis	189			
R^2 value	0.7766			
Adjusted R^2 value	0.7679			
F Statistic	89.88			
Significance (p-level)	<0.0001			
	Unstandardized Coefficients	Standard Error	T value	Significance (p-level)
Constant	162.0	6.684	24.24	<0.0001
C_Weekly Operating Hours	1.222	0.2167	5.639	<0.0001
C_Number of Workers per 1,000 ft²	39.28	8.478	4.633	<0.0001
C_Number of Commercial Refrigeration/Freezer Units per 1,000 ft²	56.88	16.13	3.526	0.0005
C_Percent Heated x Ln (Heating Degree Days)	6.493	2.399	2.707	0.0074
C_Percent Cooled x Ln (Cooling Degree Days)	5.698	2.607	2.186	0.0301
Supermarket	252.6	25.12	10.05	<0.0001
Supermarket x C_Number of Workers per 1,000 ft²	81.23	32.36	2.510	0.013

Warehouses in the United States

Summary				
Dependent Variable	Source Energy Intensity (kBtu/ft²)			
Number of Observations in Analysis	472			
R^2 value	0.4015			
Adjusted R^2 value	0.3950			
F Statistic	62.51			
Significance (p-level)	< 0.0001			
	Unstandardized Coefficients	Standard Error	T value	Significance (p-level)
Constant	69.62	1.978	35.19	<0.0001
C_Weekly Operating Hours	0.1943	0.06284	3.092	0.0021
C_Number of Workers per 1,000 ft²	25.83	3.205	8.059	<0.0001
C_Percent Cold Storage	239.3	27.56	8.683	<0.0001
C_Percent Heated x Heating Degree Days	0.009370	0.0009534	9.829	<0.0001
C_(Percent Cooled + Percent Cold Storage) x Cooling Degree Days	0.01209	0.002710	4.464	<0.0001

Multifamily Housing in the United States

Summary				
Dependent Variable	Source Energy Intensity (kBtu/ft²)			
Number of Observations in Analysis	322			
R^2 Value	0.2298			
Adjusted R^2 value	0.2176			
F Statistic	18.85			
Significance (p-level)	<0.0001			
	Unstandardized Coefficients	Standard Error	T value	Significance (p-level)
Constant	130.7	2.705	48.3	<0.0001
C_Unit Density	48.01	6.416	7.483	<0.0001
C_Bedrooms per Unit	22.64	5.700	3.972	<0.0001
Low Rise	- 19.00	3.976	- 4.777	<0.0001
C_HDD	0.008989	0.001502	5.983	<0.0001
C_CDD	0.01406	0.002494	5.638	<0.0001

Canada

[Warehouses in Canada](#)

Summary				
Dependent variable	Source energy use intensity (GJ/m²)			
Number of observations in analysis	221			
R^2 value	0.426			
Adjusted R^2 value	0.413			
F statistic	31.91			
Significance (p-level)	< 0.0001			
	Unstandardized Coefficients	Standard Error	T Value	Significance (p level)
Constant	1.0995	0.03042	36.14	<.0001
Clear Height	0.0424	0.01838	2.31	0.0220
PercHeat x HDD	8.97E-05	1.876E-05	4.78	<.0001
Worker Density	0.2112	0.04759	4.44	<.0001
IsRfgHDD20	1.15E-04	3.762E-05	3.07	0.0025
Percent Cold Storage	0.8719	0.3134	2.78	0.0059

[Multifamily Housing in Canada](#)

Summary				
Dependent variable	Source energy use intensity (GJ/m²)			
Number of observations in analysis	219			
R^2 value	0.1700			
Adjusted R^2 value	0.1545			
F statistic	10.96			
Significance (p-level)	< 0.0001			
	Unstandardized Coefficients	Standard Error	T Value	Significance (p-level)
Constant	1.115	2.462E-02	45.29	<.0001
Bedroom Density*	0.1235	7.924E-02	1.56	0.1205
Unit Density	0.2363	7.576E-02	3.12	0.0021
Percent Units in Mid-Rise or High-Rise	0.2138	5.879E-02	3.64	0.0003
Percent Cooled x CDD**	0.0002	n/a	n/a	n/a
Percent Heated x HDD	5.950E-05	2.939E-05	2.02	0.0441

Appendix F: Summary of Public Comment Period Revisions

On April 17, 2024, the project team hosted the final working group session to present the draft pathways and open a public comment period that closed on May 31, 2024. Sixteen responses were collected, and the feedback was distilled into potential action items. Due to budget constraints and lack of data availability, not all comments could be addressed comprehensively. Action items were evaluated, scoped, and subsequently prioritized by the project team based on their projected impact to the revised CRREM pathways.

The project team chose to incorporate the following action items in the final deliverable:

1. Correct emissions factors

The calculations had incorrectly classified on-site fuel use (other than natural gas) with a zero-carbon emission factor for residential property types. This led to an approximately 9% increase in starting weighted emission factors for the affected property types.

2. Disclose weighted EF calculations and clarify why Cambium alone does not suffice

Public feedback had posed questions around the use of Cambium for forward-looking electric grid emission factor projections. More detail was added to the weighted EF calculation methods section, with further detail on eGRID-to-Cambium transition (present to future) for emission factors.

3. Show pathways in both kWh and kBtu

A minor point of feedback, pathways/visuals are now shown in both kWh and kBtu where relevant in the CRREM pathway input files.

4. Clarify HDD/CDD calculations

More detail was added to the relevant sections on how HDD/CDD values were derived. Degree day calculation methods can vary based on available data and standards utilized. Because IEA utilizes a method that is different than is typically used in North America, it was important to recalculate degree days from TMY data and other sources to align with the international degree day calculations employed by CRREM through the IEA weather tracker.

5. Add ASHRAE climate zone numbers

A minor point of feedback, ASHRAE climate zone numbers were included as reference where possible in the CRREM pathway input files.

6.+ 7. Use more granular subregion and property types for energy mix (as data availability allows)

The original draft methodology utilized a similar assumption to the CRREM v2 methodology, using a constant energy mix by sector. Public feedback flagged an interest in more granular energy mix calculations based on property type and climate zone. The CRREM team was amenable to this change, and the project team went through additional efforts to calculate more granular weighted emission factors on those dimensions.

Finally, the project team used the ENERGY STAR^{TM} reverse scoring methodology to determine additional reference EUIs for select property types. The project already required this methodology for four property types for the U.S. (Inpatient Care, Retail Stores and Supermarkets, Refrigerated Warehouses, and Multifamily) and two property types for Canada (Warehouses and Multifamily). The methodology was used to develop EUI equivalents by ENERGY STAR^{TM} score for the following U.S. property types: Office and Non-Refrigerated Warehouse.

The result of this effort is a separate memo that details EUI equivalents for the U.S. properties from ENERGY STAR™ scores 75 to 95, in increments of 5. Once available, this memo can be found on the ULI CRREM North America Project website.

Appendix G: CRREM EUI Changes by Country, Property Type, and Sub-Region

U.S. EUI Comparisons (kBtu/sq ft)

Original Property Type	CRREM v2		New Types / Values																	
			New Property Types	Code	Cold or very cold			Cool			Mixed mild			Warm			Hot or very hot		
	Start EUI	Target EUI			Start	Target	Year Range	Start	Target	Year Range	Start	Target	Year Range	Start	Target	Year Range	Start	Target	Year Range
Resi Multi-family	60	16	Large Multi-family - High Rise (>20 units)	MFH	84	43	2031 - 2038	75	38	2031 - 2037	73	33	2032 - 2037	52	29	2032 - 2037	54	25	2035 - 2039
			Large Multi-family - Low Rise (>20 Units)	MFL	74	38	2030 - 2038	65	32	2031 - 2037	63	29	2032 - 2037	44	24	2032 - 2037	46	22	2035 - 2039
			Small Multi-Family (<20 units)	MFS	49	29	2029 - 2037	63	25	2033 - 2038	51	22	2032 - 2037	37	19	2032 - 2038	43	17	2036 - 2040
Office	53	21	Office	OFF	53	27	2030 - 2037	54	24	2032 - 2037	56	21	2033 - 2040	50	17	2035 - 2041	49	16	2037 - 2046
Retail High-Street	85	33	Retail High-Street	RHS	82	38	2031 - 2037	78	33	2032 - 2038	75	29	2033 - 2040	70	24	2035 - 2041	66	22	2037 - 2050
			Retail Store	RST	43	21	2030 - 2037	40	17	2032 - 2038	39	16	2033 - 2040	36	13	2035 - 2041	34	11	2037 - 2050
Shopping Centre	91	29	Enclosed Retail Mall	ERM	101	41	2032 - 2038	83	35	2032 - 2038	72	32	2032 - 2039	59	25	2034 - 2040	57	24	2036 - 2045
Retail Warehouse	52	14	Open-Air Shopping Center	SSC	175	60	2033 - 2038	144	52	2033 - 2037	75	46	2029 - 2036	108	40	2034 - 2038	92	35	2036 - 2039
Hotel	79	30	Hotel	HOT	89	44	2030 - 2037	116	38	2034 - 2038	76	33	2032 - 2038	66	29	2033 - 2039	94	25	2038 - 2042
Distribution Warehouse (Warm)	23	11	Shipping/Distribution Warehouse	SDW	51	17	2033 - 2039	27	14	2030 - 2036	42	13	2035 - 2040	15	11	2025 - 2030	23	10	2036 - 2040
			Self Storage	SST	9	5	2030 - 2039	5	3	2026 - 2033	7	3	2033 - 2044	3	3	2020 - 2020	4	3	2025 - 2028
Healthcare	82	35	Inpatient Health Care	IHC	212	116	2029 - 2037	229	100	2031 - 2037	212	89	2032 - 2039	207	74	2035 - 2042	202	67	2037 - 2050
			Outpatient Health Care	OHC	72	32	2031 - 2038	67	27	2032 - 2037	72	24	2034 - 2040	74	21	2037 - 2043	75	19	2038 - 2050
Lodging and Leisure	98	38	Leisure	LEI	62	29	2031 - 2037	42	24	2028 - 2035	54	22	2032 - 2038	55	19	2035 - 2040	69	17	2038 - 2042
Refrigerated Warehouse	84	27	Refrigerated Warehouse	RFW	93	57	2029 - 2037	93	49	2031 - 2040	95	43	2033 - 2046	98	36	2035 - 2045	105	33	2038 - 2050

Canada EUI Comparisons (kWh /m^2)

Original Property Type	CRREM v2		New Types / Values																					
			New Property Types	Code	Alberta			Manitoba			Quebec			Ontario			Saskatchewan			Newfoundland		
	Start EUI	Target EUI			Start	Target	Year	Start	Target	Year	Start	Target	Year	Start	Target	Year	Start	Target	Year	Start	Target	Year
Resi Multi-family	142	50	Multi-family - High Rise	MFH	235	120	2034	247	125	2028	233	115	2029	231	105	2027	246	130	2034	238	120	2032
			Multi-family - Low Rise	MFL	194	100	2034	206	105	2028	192	95	2029	190	85	2027	205	105	2035	197	95	2032
Office	275	65	Office	OFF	353	95	2036	328	95	2032	258	85	2032	317	80	2033	485	95	2039	186	90	2031
Retail High-Street	420	105	Retail High-Street	RHS	509	115	2037	422	115	2033	307	105	2031	368	95	2033	565	120	2038	279	110	2032
Shopping Centre	363	90	Enclosed Retail Mall	ERM	439	100	2037	364	100	2033	265	90	2031	318	85	2032	488	100	2038	241	95	2032
Retail Warehouse	198	45	Open-Air Shopping Center	SSC	240	55	2037	199	55	2033	145	50	2031	173	45	2033	266	55	2038	131	50	2032
Hotel	244	95	Hotel	HOT	497	110	2037	437	115	2033	321	105	2032	359	95	2032	434	115	2037	255	105	2032
Distribution Warehouse (Warm)	175	35	Shipping/Distribution Warehouse	SDW	370	90	2037	309	95	2032	236	85	2031	329	80	2033	348	95	2037	175	85	2031
Healthcare	288	110	Inpatient Health Care	IHC	899	235	2037	835	245	2032	727	220	2032	809	200	2033	822	245	2037	564	225	2032
			Outpatient Health Care	OHC	307	80	2037	285	85	2032	248	75	2032	276	70	2033	280	85	2037	192	80	2032
Lodging and Leisure	244	120	Leisure	LEI	372	90	2037	282	95	2031	280	85	2032	306	80	2032	349	95	2037	195	90	2031
Refrigerated Warehouse	369	85	Refrigerated Warehouse	RFW	342	105	2036	352	110	2032	331	95	2032	325	90	2032	352	110	2037	337	100	2034

Canada EUI Comparisons (kWh /m^2)

Original Property Type	CRREM v2		New Types / Values																		
			New Property Types	Code	Prince Edward Island			Nova Scotia			New Brunswick			British Columbia			Territories		
	Start EUI	Target EUI			Start	Target	Year	Start	Target	Year	Start	Target	Year	Start	Target	Year	Start	Target	Year
Resi Multi-family	142	50	Multi-family - High Rise	MFH	232	110	2029	227	105	2037	233	110	2028	215	95	2030	262	160	2024
			Multi-family - Low Rise	MFL	191	90	2029	186	85	2037	192	95	2027	175	80	2029	221	130	2025
Office	275	65	Office	OFF	186	80	2029	186	80	2036	186	85	2028	217	75	2031	217	120	2027
Retail High-Street	420	105	Retail High-Street	RHS	279	100	2031	279	95	2037	279	105	2032	251	90	2031	251	145	2026
Shopping Centre	363	90	Enclosed Retail Mall	ERM	241	85	2031	241	85	2037	241	90	2032	217	80	2031	217	125	2026
Retail Warehouse	198	45	Open-Air Shopping Center	SSC	131	50	2030	131	45	2037	131	50	2032	118	45	2030	118	70	2025
Hotel	244	95	Hotel	HOT	255	100	2030	255	95	2037	255	100	2031	268	90	2032	268	145	2027
Distribution Warehouse (Warm)	175	35	Shipping/Distribution Warehouse	SDW	175	80	2029	175	80	2036	175	85	2027	199	70	2031	199	115	2026
Healthcare	288	110	Inpatient Health Care	IHC	564	210	2031	564	200	2037	564	215	2032	529	185	2031	529	305	2026
			Outpatient Health Care	OHC	192	70	2031	192	70	2037	192	75	2031	180	65	2031	180	105	2026
Lodging and Leisure	244	120	Leisure	LEI	195	80	2030	195	80	2036	195	85	2028	227	75	2032	227	120	2028
Refrigerated Warehouse	369	85	Refrigerated Warehouse	RFW	333	90	2033	325	90	2038	334	95	2035	307	85	2033	372	135	2033

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