SimBuild
2024

Eleventh National Conference of IBPSA-USA
Denver, Colorado
May 21 – 23, 2024

Integration of Hourly Energy Usage And Emission Rates through Mapping Between Climate Zones And eGRID Region

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Abstract

Building energy codes are among the most cost-effective strategies for reducing carbon emissions. In this study, we have enhanced the U.S. DOE's commercial and residential prototype model frameworks. These were originally designed to support the development of building energy codes based on energy use and cost metrics. Now, we have augmented these frameworks to quantify carbon emissions. This is achieved by simulating hourly building energy usage and utilizing the Cambium hourly emission rates. To integrate these two different geographic scales – the eGRID regions from which the Cambium emission rates are derived, and the ASHRAE climate zones where energy simulations are conducted – we have established quantitative mappings between climate zones and eGRID regions. These mappings are created for both commercial and residential prototype buildings, using commercial construction volumes and residential construction permits, respectively. This approach allows our analysis framework to account for emission rate disparities across various eGRID regions within a particular climate zone, as well as for energy consumption variations in buildings with different functionalities.

Introduction

The building industry accounts for approximately 40% of global greenhouse gas emissions (GHGs). It is projected that the global building stock will double by 2060 (ASHRAE 2022), leading to a substantial increase in GHG emissions. Enhancing building energy efficiency is recognized as one of the most cost-effective strategies for reducing GHG emissions, with building energy codes and standards playing a pivotal role in this effort.

Historically, building energy codes emphasized energy impact, typically using energy use and energy cost as the primary metrics for measurement. However, recent years have seen a shift towards carbon emission-oriented metrics. This change requires the inclusion of emission factors for each fuel type to formulate these carbon emission-based metrics. ASHRAE 90.1-2022 and ASHRAE 189.1-2020 have incorporated a carbon emission metric based on annual GHG emission factors.

Electricity is one of the primary energy sources, and its emission factors are critical for the evaluation of building emissions. This is especially true considering the growing trend of electrification, which will increase electricity's contribution among fuel types.

Electricity emission factors are dynamic and can change over time. For instance, in areas with prevalent solar power generation, CO2 emission factors for electricity are likely to be low during the daytime and high at night. Similarly, regions with extensive hydropower generation may have lower emission factors during rainy seasons compared to dry seasons. Therefore, relying on constant annual emission factors is overly simplistic. It can result in either overestimating or underestimating carbon emission reduction of energy measures, depending on climate zones (Lou et al., 2021).

Based on modeled scenarios for the future of the United States (US) electricity sector, Cambium compiles structured datasets of energy-related metrics, such as carbon emissions, to aid long-term decision-making (Gagnon, Hale and Cole, 2022; Gagnon, Cowiestoll, and Schwarz, 2023). These Cambium datasets feature modelled hourly emission, cost, and operational data for various potential futures of the U.S. electricity sector up to 2050. Furthermore, the Cambium datasets provide estimates of the Long-Run Marginal Emission Rates (LRMER) for the contiguous U.S.

In this study, we propose using the hourly LRMER as a substitute for the annual electricity carbon emission rate. Incorporating an hourly emission rate alongside hourly energy consumption provides a more precise representation since both energy usage and the emission intensity of the electricity utility grid vary based on the time of day and season.

The U.S. Department of Energy (DOE) has supported the development of commercial prototype building models (Hart and Liu, 2015; DOE, 2023a) and residential prototype building models (Taylor, Mendon, and Fernandez, 2015; DOE, 2023b) to aid formulating ASHRAE Standards and IECC codes. These models assess the energy impact stemming from changes in the energy code. They achieve this through building simulations that consider the diverse code requirements across different climate zones and moisture regions. To augment the code evaluation with additional carbon emission-based metrics, the prototype modelling frameworks need to be enhanced.

To accurately gauge the carbon emission impact using the hourly LRMER rate alongside the simulated energy consumption from prototype building models, it is imperative to perform energy simulations on an hourly basis. Furthermore, it is vital to determine a correlation between the climate zone where the building energy simulation takes place and the eGRID region from which the hourly LRMER rates originate. While such a correlation might not be necessary for building energy efficiency case studies focused on selected locations, it is essential for studies supporting building energy code development. This is because the evaluation of the energy or emission impact of energy measures in code development needs to be conducted at the climate zone levels of the U.S., state, and/or the entire country. This involves aggregating results simulated on a finer scale.

The aim of this study is to enhance the existing prototype modeling framework, augmenting from an annual energy use and energy cost focus to a framework that offers carbon emission metrics based on hourly energy consumption data, sourced from building energy simulations. This enhancement necessitates the integration of hourly electricity emission rates. The crux of this enhancement is the creation of quantitative mappings between climate zones and eGRID regions, drawing upon data like commercial construction volume and residential construction permits. Without explicit mappings, one must resort to implicit methods such as using the arithmetic mean or selecting one option from multiple possibilities for consolidation when dealing with data from two different geographic scales, such as eGRID regions and climate zones. Given the geographic variation in emission rates, the differences in energy consumption among various building types, and the geographical variation in the prevalence of these building types, meaningful mappings between these two geographic scales are necessary. These mappings enable the accurate application of specific emission rates from various eGRID regions to the corresponding climate zones where energy results are simulated. Consequently, accurate carbon emissions at the climate zone level can be deduced by applying weighted averaging to these designated rates. This carbon emission metric complements other metrics, such as energy use and energy cost, and is crucial in evaluating different code editions and in proposing modifications to code provisions.

Table 1 Commercial Prototype Buildings

Principal Building Activity	Prototype	Abbreviation used in the Figure
Office	Small Office	SO
	Medium Office	MO
	Large Office	LO
Mercantile	Standalone Retail	SR
	Strip Mall	SM
Education	Primary School	PS
	Secondary School	SS
Healthcare	Outpatient Healthcare	OH
	Hospital	HO
Lodging	Small Hotel	SH
	Large Hotel	LH
Warehouse	Warehouse (non-refrigerated)	WA
Food Service	Quick-service Restaurant	QR
	Full-service Restaurant	FR
Apartment	Mid-rise Apartment	MA
	High-rise Apartment	HA

This paper is organized as follows: We start with an overview of the commercial and residential prototype modeling framework in the 'Prototype Modeling Framework' section. The 'Methodology' section then outlines the geographic scale of climate zones, where building energy simulations occur, and eGRID regions, from which electricity emission rates are derived, respectively. Additionally, this section delves into the hourly Cambium emission rates, commercial construction volume data, residential construction permit data, and the approach used to create mappings between climate zones and eGRID regions. Subsequently, the 'Results' section showcases the established quantitative mappings established between climate zones and eGRID regions. We conclude by discussing the applications of these climate zone-to-eGRID region mappings in diverse research scenarios in the ‘Conclusion’ section.

Prototype Modeling Framework

Commercial Prototype Building Models

To facilitate the advancement of building energy codes and standards, and to aid states in adopting, implementing, and enforcing these evolving codes and standards, the DOE's Building Energy Codes Program (BECP) has devised a set of 16 commercial prototype building models. Collectively. these prototypes represent approximately 80% of the U.S. commercial building floor area, which encompasses both mid-rise and high-rise residential buildings. Furthermore, they account for over 70% of the energy consumed in U.S. commercial buildings [Let et al, 2020]. Table 1 lists these 16 commercial prototype building models. The prototypes capture the majority of building characteristics consistent across different energy code editions and climate zones, such as building dimensions, activities and occupancy types, and types of mechanical systems. In-depth descriptions of these prototype building models can be found from (Thorton et al., 2011), and commercial energy code determinations. When using these prototype building models to assess the impacts of varying energy code editions or proposed code change proposals, prototypes sharing similar features are tailored to align with the provisions of the respective code editions or proposed code change proposals (Maddox et al., 2023).

Residential Prototype Building Models

The two prototypes supporting the development of residential building energy codes are designed to represent a typical new single-family home or townhouse and a low-rise multifamily building, such as an apartment, cooperative, or condominium. These prototypes are termed the Single-Family and Multifamily prototypes. Four foundation types are considered for all buildings: vented crawlspace, slab-on-grade, heated basement with wall insulation, and unheated basement with insulation in the floor above the basement. All buildings come equipped with central air conditioning and one of four heating system types: gas furnace, oil furnace, heat pump, and electric furnace. Mirroring the commercial prototype, residential prototypes possess features consistent across various energy code editions and climate zones. For a comprehensive description of these prototype building models, refer to (Taylor, Mendon, and Fernandez, 2015). Each prototype is tailored to adhere to the primary prescriptive requirements of the corresponding energy code (Salcido et al., 2021).

Methodology

This section begins by detailing the characteristics of climate zones and eGRID regions. It then introduces the data sources and methods employed to establish the mappings between the climate zones and the eGRID regions,

Climate Zone

Climate plays a significant role in the energy consumption of both commercial and residential buildings. As a result, current energy codes and standards incorporate many climate-dependent requirements. In the prototype modeling framework, we use the standardized climate zones outlined in ASHRAE Standard 169-2013 (ASHRAE 2013), as depicted in Figure 1. These climate zones range from 0 to 8, with heating degree days (HDDs) increasing and cooling degree days (CDDs) decreasing. Moreover, these climate zones are further segmented into three moisture regimes: moist (A), dry (B), and marine regions (C). Furthermore, for the residential building energy code, a warm-humid (WH) region in the southeastern United States is defined based on humidity levels. This affects only the moist regime of climate zone 3 in determining the need for basement insulation.

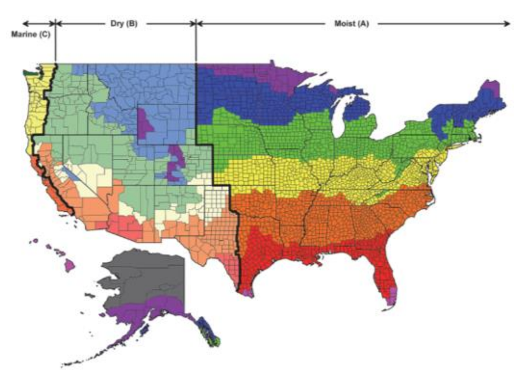

Figure 1. ASHRAE 169 Climate Zone

When using prototype building models to assess the energy impact of codes or code change proposals, simulation results are typically conducted and presented at the national climate zone level or at the climate zone level of individual U.S. states.

eGRID Region

The Emissions & Generation Resource Integrated Database (eGRID) is a comprehensive source of data from the EPA's Clean Air Markets Division. It offers information on the environmental attributes of almost all electricity produced in the United States (EPA, 2021). Subregions are delineated to restrict the import and export of electricity. This setup forms aggregated areas where the determined emission rates align most closely with the generation and emissions from the plants within that subregion. The United States comprises 26 eGRID regions. Drawn from the U.S. EPA's eGRID regions, Cambium has established 20 eGRID regions covering the contiguous United States, as shown in Figure 2.

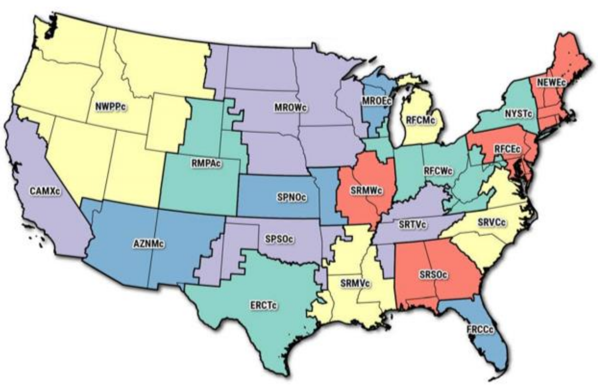

Figure 2. Cambium eGRID regions

From Figures 1 and 2, it is evident that the ASHRAE climate zones and the Cambium eGRID regions represent two separate geographic groupings of U.S. states and counties. As a result, there aren't unique emission rates that can be directly utilized to compute carbon emissions from energy consumption simulations at the climate zone level. To rectify this, we need to create mappings between the eGRID regions and climate zones. This will enable accurate carbon emissions calculations based on building energy consumption simulations specific to each climate zone.

Mappings between climate zones and eGRID regions

Approach

To create a mapping between two different scales, a finer common scale, upon which both scales are based, is essential. Additionally, to develop a meaningful quantitative mapping between the two scales, pertinent quantities are necessary.

In the current prototype modeling framework, commercial construction volumes [Doug et al., 2023, Lei et al, 2020] and residential construction permits [Taylor et al., 2015] serve as weighting factors. These weighting factors assist in evaluating the energy use and energy cost impact at the national and/or state level using detailed simulation models. For example, energy consumption is simulated for the Single-Family and Multifamily prototypes. These simulations account for variations in combinations of four different heating system types and four foundation types across different climate zones. Construction permits act as a weighting factor to consolidate these detailed simulation results to the climate zone levels of the states and/or the nation as a whole. Consequently, weighting factors grounded on commercial construction volumes and residential construction permits were established (Hart and Liu, 2015; Taylor, Mendon, and Fernandez, 2015). A similar rationale can be employed in creating quantitative mappings between eGRID regions and climate zones.

The common element between ASHRAE climate zones and Cambium eGRID regions is the counties within U.S. states. In the diagram shown in Figure 3, Nevada and New Mexico serve as examples to showcase the ASHRAE climate zones and eGRID regions for counties in those two states. When commercial construction volumes and residential construction permits are accessible for each U.S. County, determining the proportion of eGRID regions contributing to the ASHRAE climate zones based on construction activity becomes direct. Since building construction patterns differ geographically, these mappings will be tailored for various prototype building types.

Data

- Cambium hourly emission rates:

The Cambium datasets include modeled hourly emissions, costs, and operational data, forecasting various potential futures for the U.S. electricity sector up to 2050 (Gagnon, Cowiestoll, Schwarz, 2023). In this study, we utilized the long-run marginal emission rates from the 20 eGRID regions as the electricity emission rates. This data was sourced from (Gagnon, Hale and Cole, 2022).

- eGRID region designation by county of the states:

The Cambium datasets offer a table detailing county, state and eGRID region. This information was used to create a mapping table between the residential permit data and commercial construction volume data, as elaborated in the subsequent bullet points. This data originates from (Cambium Data 2022).

- Commercial construction volumes by county of the states:

In a recent initiative to update the weight factors utilized in commercial prototype modeling analyses, Lei et al. sourced commercial construction permit data from the Dodge Data & Analytics Construction Projects Starts Database (hereafter referred to as Dodge Data). This data spans from 2003 to 2018 (Dodge Database 2018) and comprises about one million individual samples of commercial building construction across the U.S. Each sample from Dodge Data represents a distinct construction project, providing numerous data fields such as the county, state, and primary building activity. After data cleansing, about half of samples remained. These samples were categorized by prototype building type and assigned an ASHRAE 169 climate zone. The weight factors, both national and state-level, used in the commercial prototype modeling by climate zone and by prototype, were derived by aggregating this comprehensive construction project dataset (Lei et al. 2020). This same dataset was employed in our analysis. It was consolidated to represent the 3,245 U.S. counties across the 51 U.S. states and the District of Columbia, capturing the available ASHRAE climate zone label and the construction volumes for the 16 prototype buildings within those counties.

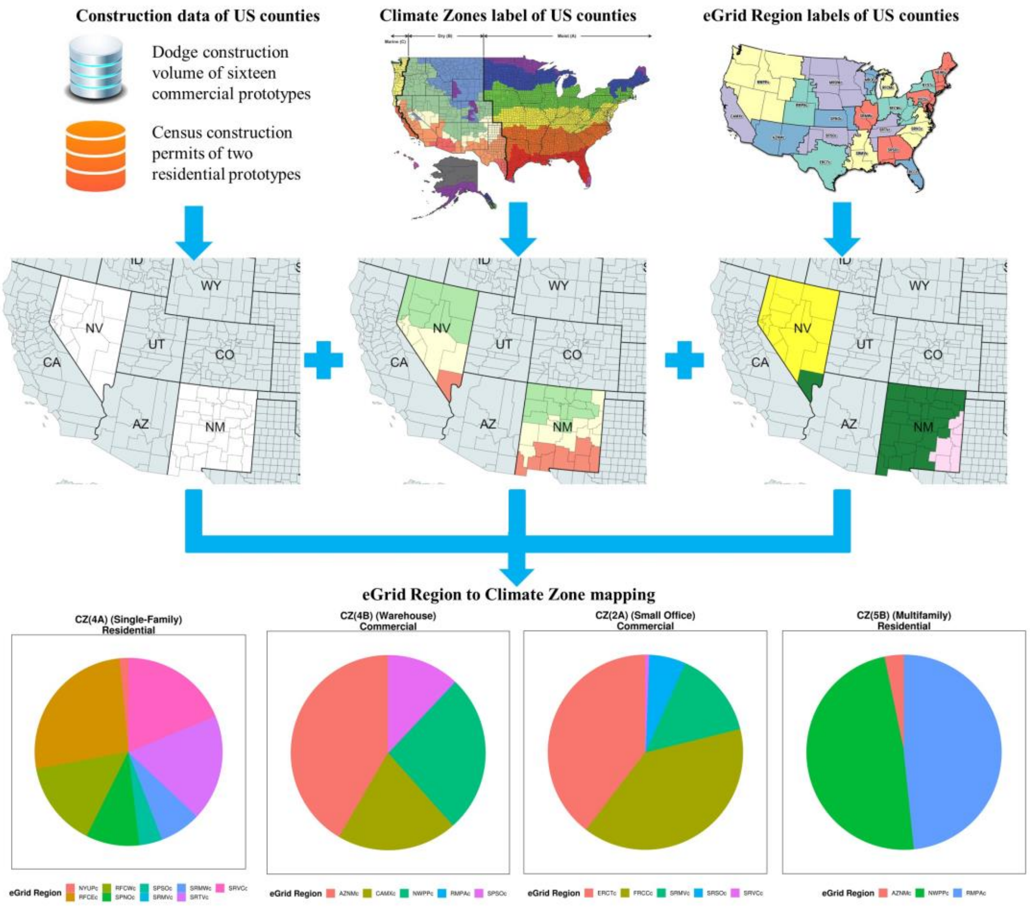

Figure 3. Data sources and Mapping between eGRID Regions and Climate Zones

- Residential construction permits by county of the states:

The 2021 state new residential construction permit data was sourced from the U.S. Census Bureau website (U.S. Census Bureau, 2021). This data set comprises new construction permits of buildings with varying numbers of units across counties in U.S. states. By integrating the ASHRAE 169 climate zone label, this dataset is primed for the creation of eGRID regions to Climate zone mapping for the residential prototypes.

Data Cleaning

Data from different sources often necessitates cleaning and synchronization for effective combined use. The data cleaning process in this study encompassed the following steps:

- **Addressing County Data:** Some data sources lacked county names for a few states. For these states, we filled in the missing county data to construct the mapping table that includes county, state, and climate zone.
- **Synchronizing County Names:** County names can differ across data sources. For instance, some names might have unexpected spaces at the beginning, middle, or end. Moreover, the capitalization of county names isn't consistent across different sources. To ensure uniformity, we established and employed a standardized set of county names.
- **Handling Residential Construction Permit Data:** The Census Bureau's website occasionally reports residential construction permit data under categories like "Balance of State" or "Unorganized Territory." These aren't recognized counties within a state. To ensure the sum of permits for counties aligns with state permits, the permits from these categories were proportionally distributed across all the counties in the state, based on each county's permit count.

Mapping Between eGRID Regions and ASHRAE Climate Zones

Figure 3 presents a diagram outlining the data requirements and steps involved in developing the quantitative mapping between eGRID regions and ASHRAE climate zones for both commercial and residential prototypes. For each county in the U.S. states, construction volume data is available for each of the 16 commercial prototype buildings, sourced from the Dodge dataset, as well as there are records of new residential construction start permits for the two residential prototype buildings, sourced from the Census Bureau's permit data. Every county is assigned an ASHRAE climate zone designation and an eGRID region label, based on county specific ASHRAE climate zone data and eGRID region data.

To establish a quantitative mapping between eGRID regions and the climate zone for a particular prototype building, we compile the construction volumes (for commercial prototypes) or construction permits (for residential prototypes) from all counties within a specific climate zone in the U.S. or within an individual state. This compiled data is labeled as either the total construction volume or total construction permit for the climate zone. We then aggregate the data from the eGRID region(s) situated within this climate zone. The ratio of the eGRID region's total to the comprehensive total of the climate zone provides the quantitative mapping between eGRID regions and the climate zone for the prototype building, applicable nationally or for a designated U.S. state. This procedure is reiterated for all commercial and residential prototype buildings.

Following the methodology depicted in Figure 3, we've derived mappings between eGRID regions and ASHRAE climate zones both nationally and for each state. This encompasses all combinations of climate zones and moisture regimes for the 16 commercial and 2 residential prototypes. Notably, for the residential prototypes, the climate zone and moisture regime combination CZ3 is divided into two: one for warm-humid and another for non-warm-humid designations.

Calculation of Carbon Emission Based on Cambium Hourly Emission Rates

To leverage the Cambium hourly emission rates, the prototype modeling framework has been enhanced to deliver hourly energy consumption data, complementing the annual energy consumption data from simulations.

Once the hourly energy consumption by fuel type is obtained from the energy simulation, the emission rates for the pertinent eGRID regions are extracted, aligned with the specified climate zones of the prototypes. The alignment is based on the mapping from eGRID region to climate zone. The hourly emission rates and hourly energy consumption data are then multiplied for the calculation of emissions on an hourly basis. Carbon emissions are computed distinctly for each fuel type. While Cambium emission rates are applied to electricity consumption, constant gas and oil emission rates are attributed to their specific energy consumptions.

The hourly emission calculated can be examined to discern temporal or seasonal emission patterns and can also be aggregated to derive annual emissions.

Results

Mappings have been created for both commercial and residential prototype building models at both national and state levels. Tables 1 and 2 showcase the national mapping results for the commercial and residential prototypes, respectively. These mappings will be utilized to calculate carbon emission based on simulated energy consumption.

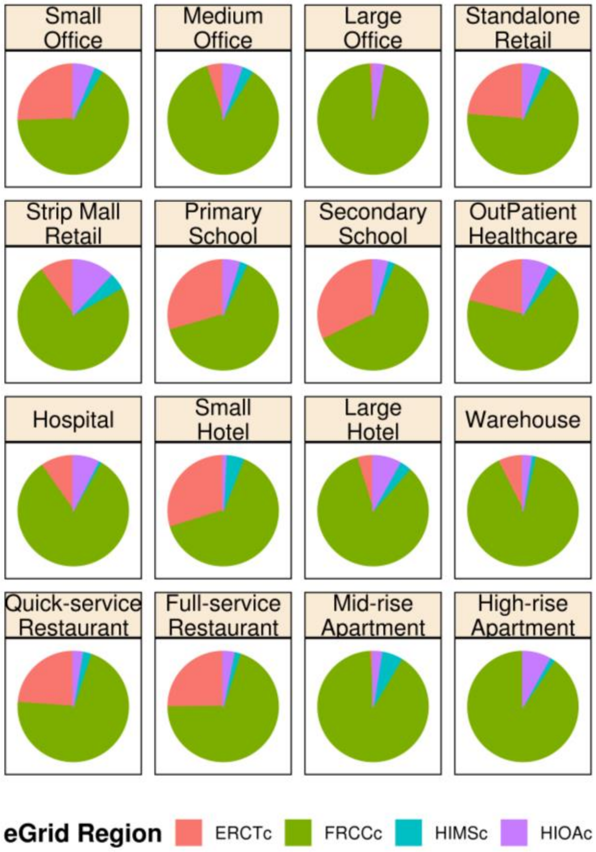

Figure 4. eGRID Region Mapping at CZ1A for Commercial Prototypes

For illustrative purpose, the national-level mappings for CZ1A (commercial) and CZ1AWH (residential) are depicted in Figures 4 and 5, respectively.

The state mappings follow the same format as the national ones but include an additional identifier: the state. Due to space constraints, the state mappings are not showcased in this paper.

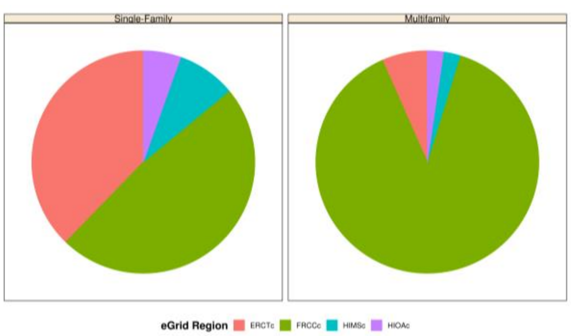

Figure 5. eGRID Region Mapping at CZ1AWH for Residential Prototypes.

Conclusion

This paper extends the US DOE's BECP prototype modeling framework beyond energy use and energy cost metrics to incorporate carbon emission metric. This is achieved by generating hourly energy consumption data and integrating hourly emission rates. Mappings between climate zones and eGRID regions are necessary when assimilating emission rates from eGRID regions with energy consumption simulated in climate zones, as they represent two distinct geographic scales. Relying on an implicit arithmetic mean or arbitrarily selecting one from multiple options is inadequate, considering the variation in emission rates across eGRID regions, the differences in energy consumption among various building types, and the geographic distribution of these building types. In this study, meaningful quantitative mappings have been established for both commercial and residential prototype building models using data from commercial construction volumes and residential construction permits specific to each prototype building. Such mappings let us account for emission rate disparities across various eGRID regions within a particular climate zone, where the building energy simulations occur. As a result, emissions computed at the eGRID region level can be consolidated at the climate zone level, mirroring the energy use and energy cost metrics traditionally produced by the prototype modeling framework.

These mappings streamline the use of the Long-Run Marginal Emission Rate for carbon emission estimations and aid in analyzing demand response and building electrification measures. This extended prototype modeling framework will be employed in future research endeavors.

State and national model energy codes are incorporating decarbonization measures like EV charging, electric readiness, solar readiness, mandatory PV, energy storage, and demand response. By simulating these and other decarbonization measures within an hourly carbon emission framework, we can bolster analyses for emission reduction and validate concepts. The developed hourly carbon emission framework lays the groundwork for future carbon analysis capabilities, such as computing the Residential Energy Services Network's (RESNET) CO2 Index, as outlined in RESNET Standard 301-2022 Addendum B.

Acknowledgment

This research was funded by the Building Energy Codes Program (BECP) of U.S. DOE. The Pacific Northwest National Laboratory is operated for U.S. DOE by Battelle Memorial Institute under contract DE-AC05-76RL01830.

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Table 2: Fractions of eGRID regions in climate zones in terms of construction volumes of commercial prototypes

Climate Zone	Prototype	SO	MO	LO	SR	SM	PS	SS	OH	HO	SH	LH	WA	QR	FR	MA	HA
1A	ERCTc	0.255	0.049	0.012	0.238	0.100	0.295	0.323	0.209	0.097	0.298	0.048	0.074	0.239	0.252	0.011	0.004
	FRCCc	0.659	0.863	0.957	0.682	0.731	0.635	0.615	0.685	0.821	0.642	0.837	0.890	0.710	0.699	0.904	0.901
	HIMSc	0.025	0.032		0.027	0.048	0.023	0.020	0.032	0.008	0.051	0.034	0.011	0.024	0.018	0.061	0.015
	HIOAc	0.061	0.055	0.031	0.054	0.120	0.047	0.042	0.074	0.074	0.008	0.081	0.024	0.026	0.031	0.025	0.080
2A	ERCTc	0.396	0.536	0.784	0.462	0.368	0.529	0.576	0.475	0.478	0.463	0.458	0.592	0.458	0.472	0.571	0.422
	FRCCc	0.392	0.317	0.142	0.344	0.452	0.265	0.233	0.349	0.336	0.250	0.362	0.288	0.363	0.316	0.356	0.401
	SRMVc	0.145	0.097	0.060	0.121	0.083	0.116	0.118	0.125	0.136	0.152	0.106	0.049	0.116	0.132	0.037	0.040
	SRSOc	0.061	0.043	0.014	0.067	0.083	0.086	0.067	0.043	0.048	0.126	0.070	0.069	0.059	0.071	0.034	0.136
	SRVCc	0.006	0.006		0.005	0.014	0.004	0.007	0.007	0.003	0.009	0.004	0.002	0.004	0.009	0.002	
2B	AZNMc	0.974	0.982	1.000	0.916	0.919	0.834	0.806	0.963	0.962	0.752	0.959	0.968	0.933	0.914	0.998	1.000
	CAMXc	0.006	0.003		0.033	0.051	0.011	0.021	0.009	0.010	0.039	0.004	0.005	0.010	0.022		
	ERCTc	0.020	0.015		0.050	0.030	0.155	0.173	0.028	0.029	0.210	0.037	0.027	0.057	0.064	0.002	
3A	ERCTc	0.083	0.125	0.141	0.100	0.076	0.138	0.115	0.120	0.104	0.096	0.090	0.086	0.118	0.079	0.105	0.027
	RFCWc	0.001	0.000		0.001	0.000	0.000	0.000	0.001	0.000			0.000	0.001	0.001	0.000	
	SPSOc	0.100	0.068	0.050	0.089	0.050	0.108	0.090	0.122	0.103	0.138	0.105	0.064	0.094	0.124	0.029	0.015
	SRMVc	0.078	0.050	0.021	0.095	0.078	0.076	0.099	0.098	0.086	0.132	0.068	0.079	0.070	0.071	0.013	0.008
	SRMWc	0.000			0.000		0.000	0.001	0.000	0.000			0.000		0.000		
	SRSOc	0.291	0.233	0.291	0.286	0.370	0.304	0.330	0.223	0.281	0.273	0.249	0.374	0.308	0.295	0.317	0.430
	SRTVc	0.104	0.105	0.153	0.097	0.085	0.070	0.069	0.109	0.111	0.109	0.160	0.101	0.110	0.115	0.113	0.104
	SRVCc	0.342	0.418	0.344	0.333	0.341	0.305	0.296	0.327	0.314	0.252	0.328	0.297	0.298	0.315	0.422	0.416
3B	AZNMc	0.267	0.146	0.090	0.222	0.167	0.211	0.151	0.204	0.207	0.156	0.451	0.106	0.289	0.310	0.076	0.268
	CAMXc	0.651	0.807	0.892	0.708	0.806	0.677	0.747	0.693	0.718	0.564	0.511	0.880	0.603	0.617	0.906	0.732
	ERCTc	0.036	0.021	0.019	0.037	0.013	0.050	0.045	0.048	0.044	0.144	0.017	0.004	0.048	0.034	0.000	
	NWPPc	0.011	0.010		0.006	0.008	0.016	0.023	0.021	0.011	0.037	0.007	0.006	0.016	0.006	0.004	
	SPSOc	0.035	0.015		0.028	0.007	0.045	0.034	0.034	0.020	0.099	0.014	0.004	0.043	0.033	0.014	
3C	CAMXc	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4A	NYUPc	0.038	0.051	0.264	0.073	0.111	0.062	0.076	0.061	0.086	0.177	0.230	0.039	0.019	0.050	0.171	0.560
	RFCEc	0.221	0.343	0.376	0.227	0.366	0.307	0.309	0.220	0.289	0.155	0.312	0.348	0.198	0.262	0.421	0.268
	RFCWc	0.223	0.167	0.043	0.195	0.109	0.181	0.159	0.237	0.197	0.171	0.120	0.219	0.269	0.198	0.088	0.019
	SPNOc	0.123	0.078	0.037	0.123	0.075	0.109	0.105	0.103	0.086	0.140	0.057	0.084	0.129	0.102	0.058	0.011
	SPSOc	0.026	0.023	0.004	0.021	0.009	0.026	0.026	0.021	0.015	0.029	0.020	0.012	0.026	0.021	0.006	0.000
	SRMVc	0.000	0.000		0.002		0.001	0.001	0.001	0.001	0.001		0.000	0.001	0.000	0.000	
	SRMWc	0.058	0.068	0.042	0.110	0.070	0.068	0.090	0.115	0.123	0.075	0.072	0.075	0.075	0.092	0.052	0.024
	SRTVc	0.153	0.112	0.014	0.139	0.097	0.129	0.110	0.153	0.090	0.160	0.070	0.156	0.203	0.163	0.038	0.008
	SRVCc	0.157	0.158	0.219	0.110	0.163	0.117	0.124	0.089	0.114	0.092	0.119	0.067	0.080	0.112	0.167	0.109

Table 2: Fractions of eGRID regions in climate zones in terms of construction volumes of commercial prototypes (continued)

Climate Zone	Prototype	SO	MO	LO	SR	SM	PS	SS	OH	HO	SH	LH	WA	QR	FR	MA	HA
4B	AZNMc	0.480	0.732		0.504	0.791	0.646	0.509	0.470	0.433	0.384	0.554	0.416	0.676	0.637	0.609	
	CAMXc	0.178	0.104		0.123	0.155	0.050	0.042	0.086	0.202	0.069	0.146	0.200	0.033	0.073	0.238	
	ERCTc				0.001			0.001									
	NWPPc	0.171	0.085	1.000	0.111	0.016	0.045	0.046	0.050	0.150	0.063	0.065	0.263	0.053	0.066	0.007	
	RMPAc	0.006			0.005	0.004	0.012	0.013	0.024	0.014	0.025	0.027	0.001		0.004	0.001	
	SPSOc	0.164	0.079		0.256	0.034	0.247	0.390	0.370	0.202	0.459	0.208	0.120	0.239	0.220	0.145	
4C	CAMXc	0.000	0.001		0.008		0.002	0.017	0.009	0.006	0.019	0.008	0.001	0.001	0.004	0.000	
	NWPPc	1.000	0.999	1.000	0.992	1.000	0.998	0.983	0.991	0.994	0.981	0.992	0.999	0.999	0.996	1.000	1.000
5A	MROEc	0.032	0.053	0.042	0.026	0.011	0.022	0.025	0.035	0.027	0.029	0.026	0.015	0.019	0.024	0.037	0.027
	MROWc	0.143	0.135	0.061	0.094	0.101	0.140	0.113	0.121	0.109	0.142	0.106	0.063	0.093	0.088	0.077	0.026
	NEWEc	0.104	0.204	0.257	0.150	0.180	0.149	0.185	0.130	0.118	0.120	0.204	0.113	0.117	0.178	0.322	0.225
	NYUPc	0.081	0.076	0.047	0.083	0.083	0.030	0.062	0.084	0.066	0.128	0.101	0.050	0.081	0.087	0.089	0.048
	RFCEc	0.039	0.063	0.050	0.065	0.112	0.099	0.080	0.058	0.053	0.080	0.097	0.129	0.046	0.063	0.070	0.029
	RFCMc	0.116	0.128	0.051	0.116	0.074	0.082	0.093	0.133	0.112	0.089	0.100	0.062	0.143	0.157	0.060	0.046
	RFCWc	0.453	0.323	0.490	0.430	0.426	0.442	0.408	0.399	0.482	0.358	0.343	0.555	0.469	0.367	0.334	0.592
	RMPAc	0.002	0.003		0.002		0.002	0.002	0.001	0.003	0.004	0.001	0.000		0.000		
	SPNOc	0.001			0.001		0.002	0.002	0.001	0.003	0.007		0.000	0.000	0.000	0.000	
	SRMWc	0.029	0.015	0.002	0.031	0.013	0.030	0.026	0.037	0.027	0.040	0.020	0.013	0.028	0.030	0.010	0.008
	SRVCc	0.001	0.000		0.002		0.002	0.004	0.001	0.000	0.003	0.001	0.000	0.003	0.004	0.001	
5B	AZNMc	0.055	0.028	0.012	0.053	0.027	0.094	0.081	0.064	0.064	0.117	0.058	0.016	0.051	0.040	0.018	0.008
	CAMXc	0.005	0.002		0.003	0.001	0.001	0.003	0.003	0.002	0.006	0.008	0.003		0.001	0.005	
	NWPPc	0.546	0.500	0.397	0.498	0.484	0.595	0.564	0.501	0.372	0.441	0.361	0.546	0.437	0.433	0.352	0.185
	RMPAc	0.394	0.470	0.592	0.447	0.488	0.310	0.352	0.432	0.562	0.436	0.574	0.435	0.512	0.526	0.625	0.807
5C	AKMSc	0.020	0.099				0.232	0.040	0.072	0.092	0.099		0.058			0.008	
	NWPPc	0.980	0.901	1.000	1.000	1.000	0.768	0.960	0.928	0.908	0.901	1.000	0.942	1.000	1.000	0.992	
6A	AKMSc	0.000			0.001		0.000	0.007	0.004	0.002	0.000		0.003			0.000	
	MROEc	0.068	0.064	0.050	0.075	0.068	0.064	0.040	0.116	0.085	0.051	0.065	0.053	0.068	0.068	0.018	0.011
	MROWc	0.673	0.616	0.902	0.550	0.664	0.704	0.664	0.598	0.656	0.484	0.571	0.662	0.584	0.569	0.825	0.967
	NEWEc	0.124	0.167	0.047	0.162	0.174	0.157	0.163	0.149	0.123	0.234	0.137	0.153	0.149	0.206	0.100	0.012
	NYUPc	0.036	0.047	0.000	0.095	0.048	0.024	0.057	0.054	0.065	0.151	0.129	0.088	0.098	0.090	0.036	0.010
	RFCMc	0.055	0.025		0.081	0.030	0.031	0.049	0.047	0.049	0.037	0.059	0.027	0.050	0.041	0.011	
	RFCWc	0.010	0.041		0.017	0.005	0.009	0.010	0.010	0.002	0.012	0.014	0.004	0.015	0.006	0.005	
	RMPAc	0.034	0.040		0.019	0.011	0.011	0.011	0.023	0.017	0.032	0.025	0.010	0.037	0.020	0.004	

Table 2: Fractions of eGRID regions in climate zones in terms of construction volumes of commercial prototypes (continued)

Climate Zone	Prototype	SO	MO	LO	SR	SM	PS	SS	OH	HO	SH	LH	WA	QR	FR	MA	HA
	CAMXc		0.011				0.001	0.000		0.012		0.035	0.003			0.035	
6B	MROWc	0.022			0.020		0.008	0.008	0.007	0.009	0.073	0.012	0.025	0.016		0.006	
	NWPPc	0.824	0.807	1.000	0.757	0.772	0.707	0.670	0.758	0.710	0.569	0.707	0.748	0.667	0.846	0.643	0.716
	RMPAc	0.154	0.182		0.222	0.228	0.284	0.321	0.235	0.270	0.358	0.246	0.225	0.317	0.154	0.316	0.284
	AKGDc	0.335	0.471	0.846	0.328	0.172	0.141	0.172	0.325	0.156	0.168	0.226	0.340	0.175	0.358	0.083	
	AKMSc	0.005	0.010		0.003		0.020	0.064	0.034	0.037			0.019				
	MROEc	0.036	0.039		0.062		0.017	0.018	0.017	0.185	0.042	0.085	0.012		0.050	0.034	
7	MROWc	0.497	0.294	0.154	0.500	0.334	0.488	0.581	0.557	0.516	0.566	0.401	0.504	0.677	0.365	0.479	
	NEWEc	0.009	0.015		0.022		0.048	0.014	0.023		0.024		0.008	0.053	0.039	0.001	
	NWPPc	0.023	0.072		0.005	0.325	0.203	0.029	0.020	0.023	0.127	0.018	0.014		0.017	0.009	
	RMPAc	0.094	0.099		0.080	0.169	0.083	0.122	0.025	0.082	0.073	0.270	0.104	0.095	0.171	0.394	1.000
8	AKGDc	0.960	0.877		1.000	1.000	0.503	0.356	0.571	0.247	1.000	1.000	0.519	1.000	0.952		
	AKMSc	0.040	0.123				0.497	0.644	0.429	0.753			0.481		0.048	1.000	

Table 3. Fractions of eGRID regions in climate zones in terms of construction volumes of residential prototypes

Climate Zone	eGRID Region	Single-Family	Multifamily
1AWH	ERCTc	0.378	0.066
	FRCCc	0.482	0.887
	HIMSc	0.085	0.024
	HIOAc	0.054	0.023
2AWH	ERCTc	0.368	0.583
	FRCCc	0.436	0.351
	SRMVc	0.116	0.029
	SRSOc	0.071	0.029
	SRVCc	0.009	0.008
2B	AZNMc	0.948	0.981
	CAMXc	0.010	0.008
	ERCTc	0.042	0.011
3A	ERCTc	0.008	0.002
	RFCWc	0.001	
	SPSOc	0.077	0.015
	SRMVc	0.052	0.031
	SRMWc	0.000	0.000
	SRSOc	0.295	0.248
	SRTVc	0.102	0.262
	SRVCc	0.465	0.442
3AWH	ERCTc	0.520	0.561
	SPSOc	0.009	0.007
	SRMVc	0.016	0.003
	SRSOc	0.085	0.030
	SRVCc	0.369	0.398
3B	AZNMc	0.220	0.105
	CAMXc	0.659	0.874
	ERCTc	0.040	0.010
	NWPPc	0.038	0.005
	SPSOc	0.043	0.006
3C	CAMXc	1.000	1.000
4A	NYUPc	0.016	0.157
	RFCEc	0.263	0.440
	RFCWc	0.147	0.107
	SPNOc	0.092	0.048
	SPSOc	0.039	0.010
	SRMVc	0.001	0.000
	SRMWc	0.071	0.044
	SRTVc	0.183	0.066
	SRVCc	0.188	0.128
4B	AZNMc	0.526	0.738
	CAMXc	0.170	0.023
	NWPPc	0.150	0.187
	RMPAc	0.011	
	SPSOc	0.143	0.052
4C	CAMXc	0.009	0.005
	NWPPc	0.991	0.995
5A	MROEc	0.037	0.102
	MROWc	0.150	0.136
	NEWEc	0.128	0.225
	NYUPc	0.062	0.108
	RFCEc	0.079	0.110
	RFCMc	0.125	0.063
	RFCWc	0.392	0.245
	RMPAc	0.001	
	SPNOc	0.001	0.000
	SRMWc	0.015	0.010
	SRVCc	0.009	0.000
5B	AZNMc	0.042	0.033
	CAMXc	0.006	
	NWPPc	0.582	0.484
	RMPAc	0.369	0.483
5C	AKMSc	0.024	
	NWPPc	0.976	1.000
6A	AKMSc	0.002	0.000
	MROEc	0.084	0.041
	MROWc	0.565	0.792
	NEWEc	0.199	0.079
	NYUPc	0.059	0.033
	RFCMc	0.059	0.014
	RFCWc	0.005	0.003
	RMPAc	0.028	0.037
6B	CAMXc	0.008	
	MROWc	0.002	
	NWPPc	0.832	0.897
	RMPAc	0.158	0.103
7	AKGDc	0.174	0.215
	AKMSc	0.005	0.010
	MROEc	0.023	
	MROWc	0.439	0.511
	NEWEc	0.015	
	NWPPc	0.088	0.016
	RMPAc	0.255	0.248
8	AKGDc	0.450	0.818
	AKMSc	0.550	0.182