RESNET Load Flexibility Task Group: Developing Ratings that Incentivize Demand Responsive Buildings and a Cleaner Grid

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ABSTRACT

To realize a societal goal to reduce greenhouse gas emissions from energy consumption in buildings, it is necessary to develop a metric to calculate these emissions. This calculation is not simple because the marginal impact of energy consumption depends strongly on the characteristics of the energy grids, whose emissions vary over the hours of the year and the location of the building.

The goals of creating this metric are twofold: 1) To establish location-specific hourly factors to weight the value of energy to effectively incentivize technologies and strategies that reduce greenhouse gas emissions and minimize the cost of maintaining a reliable energy infrastructure; and 2) To develop modeling methodologies to characterize the impact of a variety of demand responsive technologies and strategies, including but not limited to: battery storage, thermal energy storage, and smart appliances.

RESNET has responded to this need by creating a "Load Flexibility Task Group". The purpose of the group is to develop new methods of incentivizing demand responsive technologies and strategies within the context of a whole building emissions budget.

This paper describes the accomplishments and future work plans of the task group, including the definition of a CO2 Rating Index based on localized, hourly emissions factors. Although RESNET's use case for this data is limited to residential dwelling units, the task group is intentionally designing this data such that it can be used as the basis for other building energy rating systems, code compliance pathways, and utility incentive programs.

Introduction

Climate change is mostly caused by carbon dioxide emissions, and in the U.S. some 35 percent of these emissions result from burning fossil fuels to power, heat, and cool buildings.[1] Decarbonization of our buildings is critical if we hope to meet the climate goal of reducing U.S. emissions by well over half by 2030 (Goldstein 2018; IEA 2021). But until now we have lacked an accurate tool to calculate the carbon impacts of an individual house or building and the savings we are achieving through clean energy measures. RESNET, a nonprofit standards development organization (https://www.resnet.us/) has developed such a tool.

Climate change threatens our health and our economy (IPCC 2022). And increasingly, climate change affects each of us individually. Both authors of this paper recently experienced first-hand impacts or threats from climate change. One author experienced this on September 9,

[1] Estimates of buildings' impact on climate vary, depending on whether and how Scope 3 effects are considered and whether the methods discussed in this paper, which consider long-term marginal emissions rather than short term or average emissions are used. See https://www.epa.gov/climateleadership/scope-3-inventory-guidance.

2020 when the view in the photo confronted him from his home: a dark orange sky (the picture shows the true color) that made midday look like late twilight.

(Photo credit: David B. Goldstein 2022)

But things got worse, as the next day the smoke—from wildfires 500 miles away linked to climate change (Denchak and Turrentine 2021)—descended to breathing level and produced some two weeks of the unhealthiest air on earth extending from north of Portland, Oregon to Los Angeles (Limaye 2020).

The other author saw fires come within 2.5 miles of his home when record-warm and record-dry conditions, both made more frequent by climate change, combined with intense wind to cause the rapid spread of flames destroying nearly 1,000 nearby homes.

(Photo credit: Bmurphy380, 2022)

Climate change is not a distant threat affecting strangers across the ocean. It is a crisis that has already arrived on most of our doorsteps.

Reducing Buildings' Contribution to Climate Change

Improving our buildings or other parts of our economy—to reduce or eliminate these emissions is called "decarbonization".

Decarbonization of our buildings is critical if we hope to meet the climate goal of reducing U.S. emissions by well over half by 2030 (Goldstein 2018).

It can be achieved through:

- increasing the energy efficiency of our buildings,
- adding renewable energy to a facility or the grid,
- changing the time at which electricity is consumed so that most, or all of it, can be supplied by renewables – like solar and wind power, and
- changing from a fuel with higher emissions to electricity (Mejia-Cunningham 2021)

Several efforts are underway worldwide to incentivize decarbonization of new and existing buildings. Historically, the characterization of carbon emission has relied on overly simplistic accounting based on annual average emissions rates. This appears to be the case most everywhere in the world. When confronted with the task of evaluating emissions from a building or a set of buildings, even experts still rely on generic studies of average emissions over a year; or inaccurate assumptions that annual carbon emissions are directly proportional to annual energy consumption.

Recent initiatives have attempted to better characterize the variation in carbon emissions depending on geographic region and time-of-year. New Buildings Institute's GridOptimal® Buildings Initiative defines a collection of metrics aiming at characterizing building-grid integration, including "Grid Carbon Alignment" (Miller and Carbonnier, 2020). The "Grid Carbon Alignment" metric only accounts for the carbon associated with electricity used in buildings.

Thus, until now, the U.S. has not had access to a recognized national standard to consistently and accurately predict how much carbon emissions we are producing or saving from a particular building: a standard that allows us to compare the effectiveness of one decarbonization measure over another. The criterion of accuracy will be explored next: it depends critically on the time of the day and the season in which electricity is consumed.

Addressing Climate Change with Energy Asset Ratings

No one cares about energy *per se*. They care about costs and emissions. Focusing on energy alone does not directly incentivize building designs, technologies, and operational strategies that reduce greenhouse gas emissions or make our energy infrastructure more reliable and less expensive to maintain. For example, we know energy storage is going to be a crucial part of the solution, but storage typically requires more site energy due to charge/discharge efficiencies. Batteries have no value in existing energy asset ratings, including RESNET's signature HERS Index.

The U.S. Department of Energy has established a program of research, development, demonstration, and deployment of efficiency technologies that reduce overall carbon emissions from buildings (DOE 2022) that advances these technologies. Such programs have as their goal the reduction of CO2-equivalent emissions, but they currently lack a metric for quantifying them and thus for comparing different technologies and energy management strategies.

RESNET has responded to this need by creating a "Load Flexibility Task Group". The group has met monthly since early 2021 and has developed recommendations that are implemented through its U.S. National Standard, "ANSI/RESNET/ICC 301: Standard for the Calculation and Labeling of the Energy Performance of Dwelling units and Sleeping units using an Energy Rating Index" (RESNET 2019). This standard is under continuous maintenance, so that further improvements that this Task Group recommends can be reviewed according to consensus procedures approved by ANSI (the American National Standards Institute).

The objectives of the RESNET Task Group, as they pertain to the development of Standard 301 are twofold:

1. Defining an asset rating metric, to complement the RESNET HERS Index, that incorporates the time value of energy.
2. Describing home rating procedures and calculation methodologies to characterize the impact of energy storage and other demand-responsive technologies and strategies on the defined asset rating metric.

The technical content of the standard and its proposed future directions is discussed next.

More About "When" Than "How Much"

Historically, building energy rating systems, code compliance pathways, and utility incentive programs have focused on the reduction of annual energy use through efficiency measures, and in some cases also on-site renewable energy, to minimize the costs and emissions associated with annual energy use of buildings. While energy efficiency plays a significant role in reducing costs and emissions, there have been important advancements in the valuation of energy based on when it is used that are being successfully applied to ratings, code compliance, and incentive programs. Two such advancements are described in this section.

Time Dependent Valuation (TDV)

California's Title 24 "Building Energy Efficiency Standards" have been addressing this issue since 2005 (Energy & Environmental Economics and Heschong Mahone Group 2006). Energy & Environmental Economics (E3) developed TDV as a metric to characterize the long-term cost effectiveness of code requirements that accounts for generation, future generation capacity expansion, system losses, future transmission and distribution capacity expansions, emissions related costs, and retail adjustments. These costs are based on large-scale energy market simulations of all generators and load centers in the Western Interconnect using the PLEXOS software (Energy Exemplar 2022). When TDV was developed, the main issue it was intended to address was control of peak loads, which are much more expensive to serve by the utility system than off-peak loads. The difference in cost turned out to be well over an order of magnitude between costs for a kWh during late afternoon on a hot summer day and costs at 3 AM. Even though TDV is a metric to reflect energy costs to the consumer, it is much more variable than many rate structures employed by utilities today, making a TDV-based asset rating a challenging concept to convey to builders, building owners, and building tenants.

For the 2022 update to Title 24, E3 evaluated other metrics in addition to TDV, including emissions and source energy factors. Source energy was ultimately adopted as secondary performance metric as a proxy for characterizing environmental benefits similar to how an emissions metric would (Energy & Environmental Economics 2020).

TDV follows a similar pattern to emissions (and source energy): a steady base-level during sleeping hours, low during peak solar, and high in afternoon/evening as the sun sets and people return home. However, the magnitude of differences is very different between the two, and this is illustrated in Figures 1 and 2, taken from the emissions and TDV factors developed by E3 for the month of June in Climate Zone 12 (Northern California Central Valley). There are two important differences to note: First, the magnitude of the peak values for emissions are only 2-3 times higher than the base value, whereas the magnitude of the peak values for TDV are 100 times higher than the base value (note the log scale needed to illustrate TDV variations). Second, carbon emissions factor values drop to zero in the middle of the day when the electric demand is almost entirely met by solar power, whereas there is a non-zero minimum TDV representing fixed costs seen by rate payers.

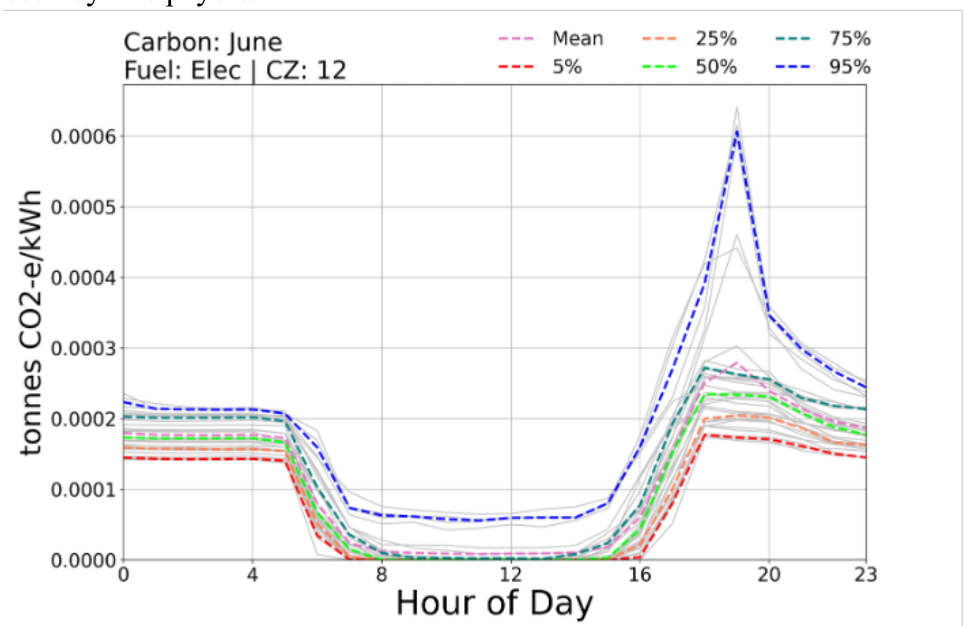

Figure 1. CO2 emissions factors for June in California Climate Zone 12 (Northern California Central Valley). Each gray line represents a single day, and the colored lines represent the mean and percentile values across all days.

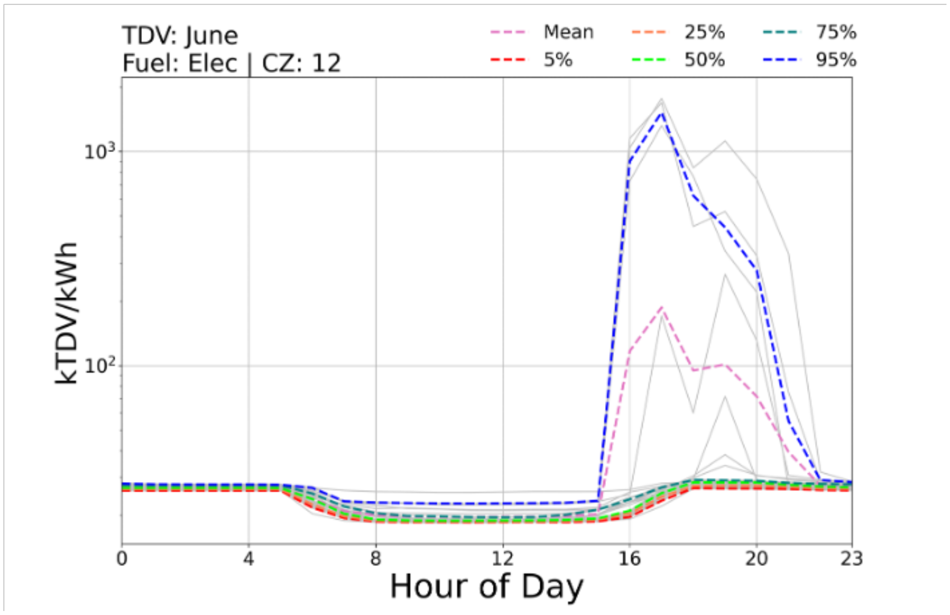

Figure 2. TDV factors for June in California Climate Zone 12 (Northern California Central Valley). Each gray line represents a single day, and the colored lines represent the mean and percentile values across all days.

The differences between TDV and emissions factors can result in substantially different incentives for fuel choice and/or for demand-responsive technologies. However, the trends are the same as seen in the figures: a measure that reduces carbon will almost always reduce costs, although the magnitudes of the change will differ. California has effectively adopted both metrics in the evaluation of code compliance to ensure that such technologies reduce both long-term operational costs and long-term emissions. The methodology used by California and E3 can be applied anywhere in the world. Its methods allow calculations of carbon emissions at little or no additional cost to the user, so it is a good starting point for developing time differentiated carbon evaluation methods.

Cambium

Cambium is a tool developed by the U.S. National Renewable Energy Laboratory (NREL) that assembles datasets of simulated hourly emissions, costs, and operational data for modeled futures of the U.S. electric sector, with metrics designed to be useful for long-term decision making (Gagnon et al. 2021). Cambium draws from PLEXOS simulations of all three interconnects in the continental U.S. based on future renewable-penetration scenarios projected by NREL's Regional Energy Deployment System (ReEDS) model.

The Cambium methods and outputs allow the user to select a range of scenarios for future emissions values. For the purposes of a standard, we must select one of these. The RESNET standard selected the low-renewables-cost scenario (the scenario that has the largest market penetration of renewable energy), evaluated over the time period 2025-2050, and looked at long-run marginal emissions. "Long-run" means that the effect of a kWh saved or consumed is evaluated, considering how that end use decision will affect the amount of renewable capacity that will be built[2]. In contrast, "short run" means that only the dispatch order of existing generation is considered. The criterion for emissions is CO2 equivalence, meaning that other greenhouse gas emissions, such as from methane, are also considered from a Scope 3 perspective.

RESNET selected the low-renewables-cost scenario for two reasons: First, in order to meet the global policy goal of limiting climate change to 1.5 C, the world will need a wide variety of measures. The goal cannot be met without much more efficiency and much more renewable energy (Goldstein 2018; IEA 2021). Thus, our policies for the buildings sector must coordinate with the policies for the generation sector—otherwise the renewable generation might be less effective because we cannot find efficient uses for it when it is abundant and instead will use fossil generation during hours when renewables are not abundant. Conversely, if we design buildings based on a high-or mid-range-cost renewables future, then if reality is low-cost-renewables, our buildings will not be able to contribute as effectively to integrating them into the grid.

A second reason is that government projections of renewable energy have almost always underestimated what later turned out to happen. This is true in the U.S. and in other important carbon-emitting countries such as India and China.

The time period of 2025-2050 was selected because buildings are long-lived, but a new standard will not affect that many of them until about 2025 due to time lags in planning, decision-making, permitting, and construction. And beyond 2050 predictions of any sort become problematic for making policy decisions concerning what carbon reduction measures should be applied to a building.

Marginal emissions are used because if a region currently is dominated by low- or zero-emissions generation, such as legacy hydro or nuclear, the output of these plants will not be affected by the presence of these new buildings.

Long run calculations are used because buildings that are grid-responsive such that they reduce emissions will favor the economic value of renewable generation, in addition to the legal effect they will typically have. (See footnotes 1 and 2.)

Challenges

In general, the methodologies employed by Cambium and E3's TDV to develop California projections are very similar in that they both are based on whole-interconnect PLEXOS simulations under projected renewable-penetration scenarios. Three key differences between Cambium and TDV data sets are:

1. Geographic scope: Cambium includes the entire continental U.S., whereas TDV applies only to the State of California

[2] Most states in the U.S. have Renewables Portfolio Standards, by which an additional kWh of energy demand will result in a legal requirement to construct renewables capacity that will generate x kWh, where x varies from state to state and may increase over time. Many states have also increased x through additional legislation or regulation.

2. Scope of costs: TDV includes the significant costs of more localized transmission and distribution expansion that Cambium does not yet include
3. Alignment with weather files used in building performance models: Cambium's outputs represent 2012 weather data (used to drive the PLEXOS simulations), whereas the TDV values are synchronized with the weather files used for Title 24 compliance analysis.

Both methodologies are currently limited by the geographic scope of their underlying PLEXOS simulations. This means that there is not yet data identified by the task groups for locations such as Alaska and Hawaii, or locations outside of the United States (should other countries want to adopt similar asset rating calculation methodologies).

Asset ratings are based on simulated building performance based on typical weather for a given location. The weather files include data on temperature, humidity, wind speed, solar radiation, cloud cover, and other variables for a wide variety of locations. To make the asset ratings mutually comparable for a given location, the weather is held constant. But the Cambium outputs are based on 2012 weather data and not same data used for the asset rating. For example, a sunny day in the Cambium data set may be an overcast day in the asset rating simulation. In these cases, any demand responsive strategies that attempt to shift electric energy use into periods of high solar production will not see the benefits of the low carbon grid during that time. Initial analysis based on California's emission and TDV factors show that misalignment between the factors and the simulation weather data can cause underpredictions of long-term annual emissions up to 15%, and underpredictions of long-term annual costs (TDV) up to 50%.

This is more problematic for cost-based performance metrics because of the high-magnitude, weather-driven events that push the grid to the limits of its generation, transmission, and/or distribution capacity. Emissions, on the other hand, have a much smoother overall diurnal pattern and less extreme peak values. They can be used in asset ratings by averaging that considers a typical result for a given hour and a given month (for example, using the pink "mean" line in Figure 1 for every day of June).

This averaging process allows the RESNET standard to be used in operational ratings calculations (as opposed to only asset ratings calculations). Since operational ratings are based on metered data, it would be self-inconsistent to use emissions factors that apply to a typical year, since a grid-interactive building would be responding in the simple case to a time of use tariff and in a sophisticated case to an internet signal on the availability of renewables on the grid, neither of which is related to the values for a typical year on a weather file.

Averaging hourly emission factors across a month will provide a reasonable signal for operational-ratings-based programs such as EnergyStar for commercial buildings to begin incentivizing decarbonization, but an asset rating ideally would use emissions factors that are connected to the weather files, which would likely show that the highest emissions occur on the fourth day of a hot spell at around 6 PM when solar generation drops and there is little wind and all available generation must be dispatched. It is much less the case for long-term cost factors. Synchronizing emissions and cost factors with typical year weather files requires additional analytics, which RESNET hopes to develop in the near future. In the meantime, RESNET is proceeding to using the averaged emissions factor for an emissions-based asset rating.

CO2 Rating Index

ANSI/RESNET/ICC Standard 301 has always prescribed how emissions from homes should be estimated, but these have historically been based on constant emissions factors by fuel type. The availability of hourly, annual emissions factors from Cambium enables more accurate estimation of annual emissions for homes and, more directly to the objective of RESNET's Task Group, it provides the basis for RESNET's new CO2 Rating Index.

The calculation procedure for the CO2 Rating Index was published in Addendum D of the 301 Standard in March 2022 (RESNET 2022). Similar to the Energy Rating Index (ERI) already defined in the 301 Standard, the CO2 Rating Index is an integer value, where an index of:

- 100 indicates that the rated home incurs the same total emissions as a similar, all-electric home built to 2006 efficiency standards[3] (identical to the ERI reference with only electric end uses); and
- Zero indicates that the rated home incurs net-zero emissions over the course of the year (a more difficult scenario than a zero HERS Score unless the home is generating on-site renewable energy at times when the grid is carbon-intensive).

The calculation of the CO2 Rating Index is simply the ratio of the annual hourly CO2 emissions of the rated home divided by the annual hourly CO2 emissions from the all-electric reference home. While the concept has now been vetted, approved, and published through the ANSI process, the Task Group expects that further amendments will be available for public review throughout 2022, at least.

The introduction of the CO2 Rating Index will spur changes in design and construction practices to minimize carbon emissions by providing quantification of the effect that they have on emissions reductions for a particular dwelling in a particular location. There are two sorts of changes in practice that will be affected:

First, technologies that change the time of use of energy can be credited. Technologies for doing so are discussed next. Second, changes in heating fuel can reduce emissions by an amount that depends on the cleanliness of the grid from which the power is provided and the efficiency of the heat pump or furnace that are being compared. The current HERS Index and ERI are fuel-neutral by design, but the CO2 index is likely to favor electricity in most cases. The CO2 index remains fuel neutral in that it does not put a thumb on the scales of inter-fuel comparisons, but it does evaluate what the incremental emissions consequences of a given choice are and will tend to favor heat pump options based on their emissions being lower when they are evaluated accurately.

Technologies

With RESNET CO2 Index the value of energy varies for each hour of the year, whereas in the HERS Index, each hour is given equal weight. This variable valuation of energy now means that technologies that store energy or shift energy demand can take advantage of the stock market adage, "buy low, sell high". Or in more exact terms, "use or store energy when the grid is relatively clean, and offset energy user when the grid is dirtier." The mechanisms of such energy

[3] IECC 2006 for envelope and 2006 federal minimum equipment and appliance efficiencies

arbitrage are both technological and behavioral, and the line between the two when it comes to evaluating the building as an asset is not always clear. For example, many utility demand response programs require homeowner and/or occupant opt-in. The question becomes: To what extent should the home, as an asset, get credit for having technologies that enable demand response that may never be utilized by some occupants during the actual operation of the home?

The Consortium for Energy Efficiency (CEE) develops specifications for connected product functionality that enables load management. The requirements for these products can be used by raters to verify that an installed product in a home qualifies for credit in the CO2 Index calculation. The RESNET Load Flexibility Task Group is coordinating with CEE to establish a prioritized list of product categories to be included in the 301 Standard, including:

- On-site battery storage
- Heat pump water heaters
- Electric variable capacity HVAC systems
- Connected thermostats
- Clothes washers
- Clothes dryers
- Electric vehicle supply equipment

The working group is starting with on-site battery storage and heat pump water heaters, leveraging existing work done for California’s Title 24 code compliance for these technologies. Both of these technologies are discussed in this paper, while the other technologies are still being evaluated by the Task Group.

On-Site Battery Storage

The first technology explored by the task group, though not yet included in CEE’s product specifications, is on-site (i.e., behind-the-meter) battery storage. The California Energy Commission (CEC) established qualification requirements for battery storage systems for use in the performance path of the California Title 24 energy code (California Energy Commission 2019). These requirements and the corresponding modeling methods can be adopted in the RESNET 301 Standard to allow credit for batteries in the CO2 Index.

The initial proposal will apply only to battery storage systems that are used in conjunction with on-site power generation (e.g., photovoltaics). Batteries will initially be modeled with basic charge and discharge control, where a battery is only charged when on-site generation exceeds the home’s electrical load, and discharges to meet the home’s electrical load as soon as the electrical load exceeds the on-site generation. Charging from and discharging to the grid will not be allowed for the initial evaluation.

Future versions will evaluate more advanced time-of-use and utility signal controls, but for now, this basic level of control represents the default control for most battery storage systems and is likely to provide less value than time-of-use or utility signal controls for both emissions and long-term costs.

Heat Pump Water Heaters

Heat pump water heating technology offers an efficient electric alternative to the traditional gas storage water heaters. In addition to replacing the carbon-intensive gas burners, heat pump water heaters can also use their tanks for thermal energy storage; heating the tank with the compressor to a higher-than-normal setpoint during the low-carbon mid-day hours. This will eliminate the need for the water heater to operate its heating elements during high-carbon hours in the afternoon and evening.

Similar to battery storage systems, the CEC has also established qualification requirements for heat pump water heater demand management systems (California Energy Commission 2020). The CEC maintains a list of certified heat pump water heater products that meet these requirements, making it simple for product verification conducted by a rater. The development of heat pump demand management systems in California's code compliance software is described by Boranian et al. (2022).

Challenges

As mentioned previously, the amount of credit to attribute to certain technologies or strategies depends on the building occupant relinquishing some amount of control over their home to either a predetermined schedule or a signal from their utility. Should a home get full credit if it's not guaranteed that the occupants will cede control to utility signals? The answer likely depends on the application. Some energy codes won't give credit for household appliances or HVAC equipment since they may not be present at time of inspection and their lifetimes are usually substantially shorter than the life of the building, whereas a utility incentive program may want to include more opportunities for their customers to demonstrate the potential impact on CO2 emissions.

Next Steps

Cost Rating Index

Emissions are only part of the story and, although it is becoming increasingly important to reduce greenhouse gas emissions, many builders, building owners, and building tenants are also very concerned about the long-term costs associated with operating a building. Over the lifetime of a building asset, the consumer energy rates will evolve as the sources of energy and the demand for energy change over time. For an asset rating, these costs need to reflect all future costs of operating the energy utility infrastructure that are eventually passed along to the rate payers. Like California's TDV, these costs should include eventual expansion of generation, transmission and distribution capacity that will be required if peak energy demand is not effectively reduced. As mentioned previously, the current barrier to establishing a Cost Rating Index is both the absence of transmission and distribution capacity costs in the Cambium datasets as well as misalignment between the source Cambium weather data and the typical-year weather data used to determine asset ratings. The RESNET Task Group hopes to work on both of these issues in the near future.

Weather-data-synchronized long-term energy cost will serve another important role beyond simply the calculation of a cost rating index: These cost factors will resemble the driving motivation behind utility control signals for demand-responsive technologies and can be used as a proxy for a signal when modeling these technologies in rating software tools. Without this data, asset ratings cannot represent the full potential of these technologies.

Alignment

RESNET is not alone in its need to establish a metric that quantifies carbon reduction. Many other organizations are also seeking ways to provide carbon reduction, however they all face the same barrier of needing to characterize hourly, annual emissions factors that can be used in conjunction with building performance models. Such organizations include: ASHRAE (Standards 90.1, 90.2, and 189.1), IECC, USGBC (LEED), EPA (ENERGY STAR), IRS (179D and 45L tax credits). Many of these organizations are already exploring the potential of Cambium data for their programs. RESNET will liaise with organizations with similar needs to strive for consistency in how energy is valued throughout a day/season/year.

Conclusions

In order to meet the aggressive goals set by countries, states, and municipalities to provide affordable, reliable energy while reducing greenhouse gas emissions, we need measurable performance ratings for homes that go beyond simply how much energy they use. RESNET's CO2 Rating Index is a significant step in that direction. It is a tool that can help drive policy and incentive programs and give credit to building designs, technologies, and operational strategies that reduce greenhouse gas emissions. The approach behind RESNET's Load Flexibility Task Group has been to build on existing, well-vetted methodologies employed by the CEC and NREL. Combined with RESNET's reputation as the most recognized national standards-making body for residential energy efficiency rating and certification systems, we expect few barriers to adoption of the CO2 Index in energy codes, reach/stretch codes, and certification programs (e.g., ENERGY STAR).

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