Taking the (Fuel) Blinders off Energy Codes Part 2: Metrics and Mechanics in the Modern Era

Jim Edelson
ASHRAE Member

Alexi Miller, PE
ASHRAE Member

ABSTRACT

The current generation of building energy codes was born in the 1970s and 1980s, amidst a backdrop of the 1973 Arab Oil Embargo and the perception of limited worldwide energy resources. The intent of energy codes has been rooted in conservation of resources. Several factors including global climate change and the shale gas revolution have changed the picture fundamentally. It now has become critical that energy codes must reduce carbon emissions from the buildings sector. This paper follows upon a recently published paper examining how climate policy now impacts energy code policy. A variety of drivers, including greenhouse gas emission goals, regulation, market forces, and new technologies, is changing the relationship between buildings and the grid. As this relationship evolves, it is increasingly important to find metrics that enable useful and clear comparisons at the national level, while remaining regionally relevant. Similarly, it is increasingly important to move beyond annual metrics and find a way to consider hourly or other granular time scale impacts. Some leading jurisdictions, including California and New York, are currently working to resolve these issues; this paper includes an examination of those ongoing efforts. By encouraging building designers to consider hourly and regional building-grid implications, these metrics can support more distributed generation integration and reduced carbon impacts. This provides a benefit to the building and also enables the building to support the grid. Through updating the code basis metrics for buildings, model energy codes can play an important role in achieving jurisdictional carbon goals. This paper lays out new metric terms for model energy codes to move beyond their current basis and better align with current and future priorities, including consideration of the impacts and mechanics of those metrics. The authors provide specific recommendations concerning model code basis options, metrics, and mechanics; consider technical challenges to implementation and some potential solutions; and discuss first-order impacts that these code basis considerations may have on building design.

INTRODUCTION

Why bother with energy codes? Is energy savings really the point? Well, why do we have energy codes anyhow? The current generation of energy codes was initially created in response to a perception of resource scarcity, in the years following the Arab Oil Embargo of 1973. These codes were intended to conserve energy in buildings, and have been broadly successful at doing so. However, things have changed since the 1970s. Today, more and more jurisdictions and decision makers, in the United States and abroad, have concluded that the primary driver for enhancing energy efficiency is not resource conservation, or reduced energy costs, but rather achieving reductions in carbon emissions. Reducing carbon emissions from the built environment is one of the most important tools available to policymakers and governments to reduce carbon emissions. Against this modern backdrop, it is time to reconsider the basis of our current energy codes.

Jim Edelson is the Director of Codes and Policy at New Buildings Institute (NBI) in Portland, Oregon. **Alexi Miller** is a Senior Project Manager at NBI.

A variety of efforts and conversations have been underway for the last several years to consider these issues. Several jurisdictions have enacted laws, regulations, or policies encouraging or mandating efficiency performance improvements, Zero Energy Buildings (ZE Buildings; also often referred to as Zero Net Energy or Net Zero Energy Buildings), electrification of fossil-fuel-powered building systems, and renewable portfolio standards. In many of these cases, the intent of the policy or law is to reduce carbon emissions (NEEP 2017). Why, then, is the basis of our energy codes stuck in the past? The International Energy Conservation Code (IECC) uses energy as its basis (IECC 2018). ASHRAE 90.1 uses energy cost (ASRHAE 90.1 2016). California's Title 24 codes use Time-Dependent Value (TDV), an adjusted energy basis (California Title 24 2016). Fundamentally, none of these model codes uses a carbon basis to calculate the performance of a project demonstrating compliance with code.

Substantial strides have been made in data gathering and software development, enabling the calculation of carbon impacts associated with building design and operations choices. The datasets available have expanded significantly in recent years. For example in the non-governmental sector, a nonprofit organization is enabling devices to be controlled based on the minute-by-minute marginal carbon emissions impacts of their operation (WattTime 2018). Decision makers in California, Washington, and New York are considering how to calculate carbon emissions factors for electricity consumed by buildings (Waltner 2016).

It will be critical to come to a consensus framework with regards to the metrics and methodologies used to reorient the code basis from energy savings to carbon emissions reductions. This paper describes common terminology that can be used in model energy codes to move to a carbon basis. The impacts and mechanics of those metrics are considered and specific recommendations concerning model code basis options, metrics, and mechanics are provided. It is true that other considerations, including embedded carbon, construction emissions, operations and maintenance emissions, refrigerant fugitive emissions, and transportation to the building are also valid. We acknowledge that these considerations are important but they are beyond the scope of this paper.

OPTIONS FOR CODE METRICS BASED ON CARBON

There are a variety of metrics available that may form the basis of a model code. Several metrics are in use today. Despite the moniker "energy code," today's model codes are capable of, and indeed already use, a variety of different metrics. The US Department of Energy analyzes the efficiency improvements from one model code cycle to the next. The DOE's most recent determination (DOE 2018) found the following improvements for commercial buildings between ASHRAE 90.1-2016 and ASHRAE 90.1-2013:

- 8.3% energy cost savings
- 7.9% source energy savings
- 6.8% site energy savings

The fact that the DOE is evaluating model energy codes using a variety of metrics clearly shows that it is reasonable to consider alternate metrics and that impacts and implications may vary depending on what metric is used.

The above metrics (those used in national model codes) are not the only options. The California Title 24 code's Time Dependent Value (TDV) metric relies on modeled hourly site energy (kWh and therms) estimates. Each hour of the year is assigned a unique site-to-TDV adjustment factor. The values of these hours may be set based on the grid operator's cost to provide power at that particular time, the marginal (or average) carbon emissions per hour, and/or other factors. In this way, the TDV adjusted kWh estimate reflects some societal and grid-related implications associated with providing power to the building when and where it is needed.

The following table shows a selection of the most common metrics that are, or could be, used in model codes:

Table 1. Metrics, Applications, Data Requirements, and Key Features

Metric	Current Applications in Codes	Requirements to Keep Data Current	Key Technical Features
Site Energy	2018 IECC	None	Easily applied and widely understood No conversion required from utility meter data or simulation model outputs Does not reflect primary fuel consumption
Source Energy	2015 IgCC	Update: 3-year code cycles	Better reflects primary energy use Conversion required from utility meter data or simulation model outputs
Energy Cost	ASHRAE 90.1	Update: 3-year code cycles	Cost is major criteria for end-user Many factors can impact utility cost which changes rapidly – not just energy (e.g. demand charge, location…)
Time Dependent Valuation	California Title 24	Update: 3-year code cycles	Hourly site energy adjustment serves as proxy for variety of grid, societal implications
Carbon Emissions	ASHRAE 189.1-2017	Update: 3-year code cycles	Most complete metric for environmental impacts Temporal, locational factors influence conversions from other metric(s)

Buildings often use fuels other than electricity, and these fuels have upstream impacts in their own right. The national average site-to-source ratio for natural gas is listed by ASHRAE Standard 105-2014 as 1.09. (ASHRAE 2014). However, this may not fully account for the impacts from fugitive emissions of methane and other greenhouse gases. According to research by the California Air Resources Board (CARB), fugitive emissions may account for CO2 equivalent (CO2e) values of approximately an additional 10% (Mrowka 2018). Other energy sources, such as fuel oil, district energy, and biofuels, will have their own site-to-source ratios. The considerations at play when calculating these ratios will also influence the site-to-carbon ratio.

DEVELOPING SOURCE CARBON METRICS AND MECHANICS

Several factors come into play when considering how to develop and define the methodological framework that undergirds the calculation of source carbon metrics. There is a tradeoff in each of these choices between full accuracy and the real-world practicality of implementing metrics in the setting of a national model code. This section discusses some key elements and considerations to consider when crafting a carbon metric.

Geographical Specificity and Temporal Granularity

The energy sources used to generate electricity vary widely from one region to another. Figure 1 shows the *annual* estimated mix of fuels used to generate electricity in several regions across the US. It is immediately apparent that regional differences in fuel mix will have substantial impacts on the carbon emissions impacts associated with energy consumption.

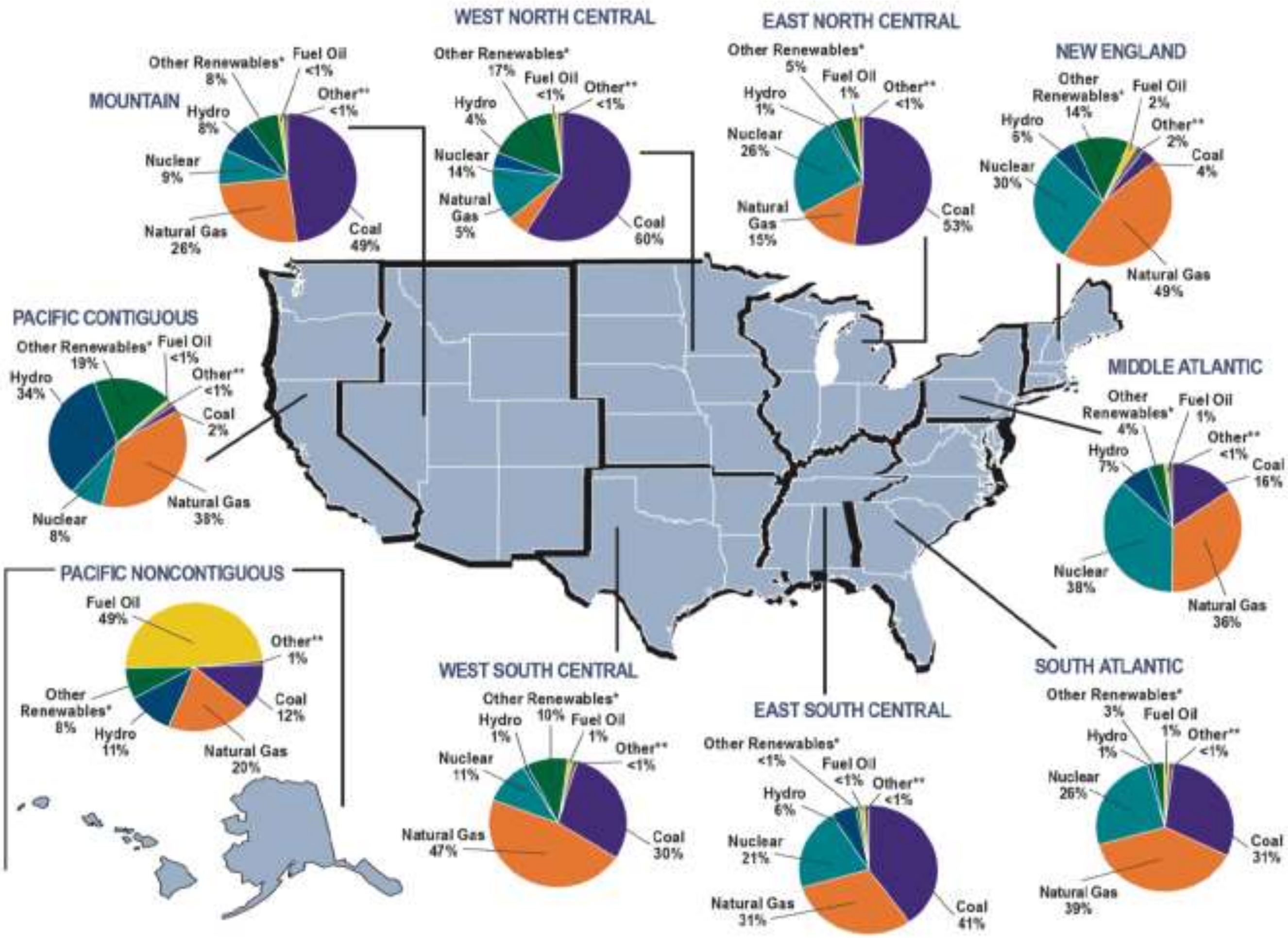

Figure 1. Source energy mix for electricity generation across the US (EEI 2017).

The North American power grid is a complex and intricate system. A wide variety of geographical demarcations are used to manage, the North American electricity grid. The North American Reliability Corporation (NERC) defines four separate interconnections (Western, Eastern, Texas, and Quebec) and eight regional entities; a total of 86 balancing authorities exist within this framework. These regional distinctions are somewhat, but not perfectly, aligned with the US Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID) subregions. eGRID provides aggregated hourly emissions data. The eGRID subregions are used to define site-to-source energy and carbon factors by region in various standards, including the 2015 International Green Construction Code (ICC 2015) and ASHRAE Standard 105 (ASHRAE 2014). Several other electricity system demarcations exist but are not discussed here, including Independent System Operators (ISOs), Regional Transmission Organizations (RTOs), and a variety of public and private entities.

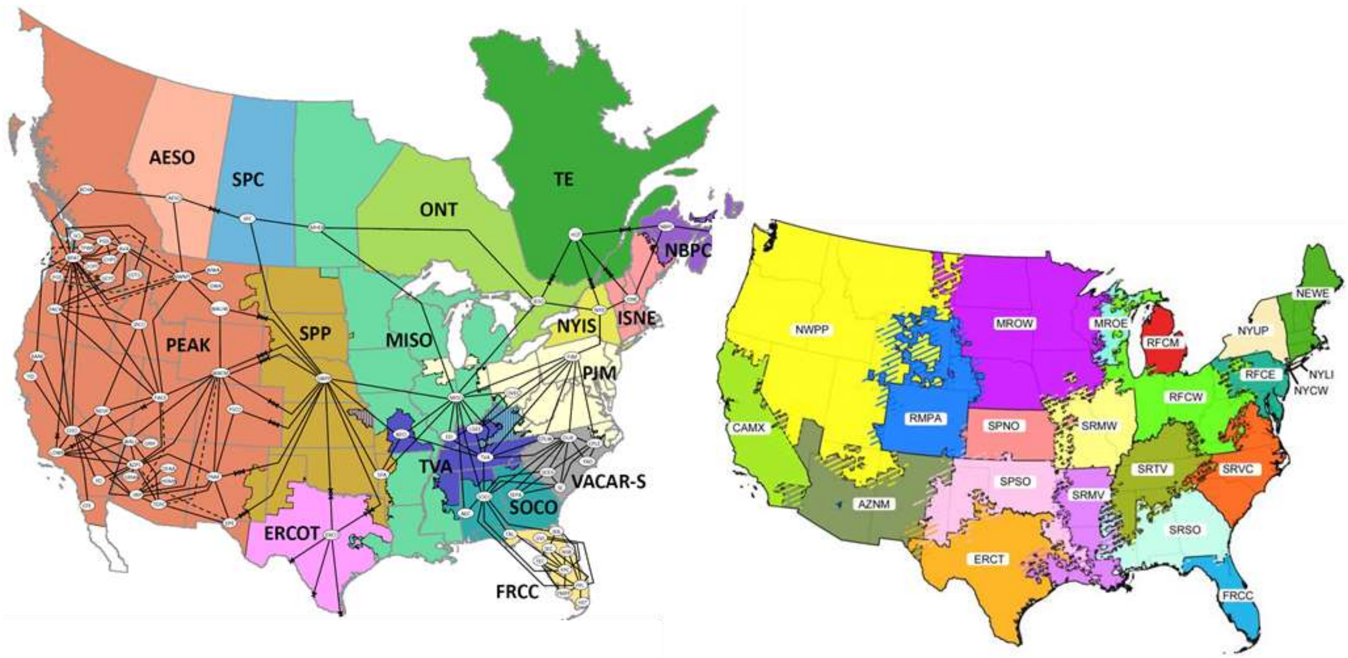

Figure 2. NERC Balancing Authorities and Reliability Coordinators (left) and EPA eGRID Subregions (right) (NERC 2015, EPA 2018). Regional alignment between these geographical divisions is imperfect.

Variations in electric grid carbon impacts can be dramatic. The following table shows selected locations to illustrate the variability in site-to-source and carbon emissions factors (ASHRAE 2014).

Table 2. Selected Average Electricity Site-to-Source and Carbon Emissions Factors

Region	Site-to-Source Conversion Factor	Greenhouse Gas Emissions (kg/kWh)
National	3.15	0.692
California	2.89	0.370
Washington/Oregon (WECC-Northwest)	2.32	0.453
New York - Upstate	2.66	0.369
New York – Long Island	3.47	0.698
Wyoming (WECC-Rockies)	3.82	1.149

Due to this variability, the authors feel it necessary to go beyond national and annual averages when developing carbon metrics. The variability is increasing over time as more renewable energy generating resources are added to the grid (DOE 2016). The increases in carbon content variability temporally also are likely to increase in variability as more renewables are added to the grid. "We argue that quantification of the time variability of carbon intensity is necessary to understand the detailed patterns of carbon emissions in electricity systems, particularly as future systems are likely to increasingly rely on a mix of time-variable generation types such as wind, hydro and solar" (Khan 2018). The "Hourly Energy Emission Factors for Electricity Generation" compiled by NREL show that the range of CO2e emissions associated with electricity delivered shows wide hourly variability throughout the year: the ratio between minimum and maximum CO2e emissions factors can vary by a factor of more than three times (NREL 2017).

The precise primary energy mix used to deliver electricity varies continuously, but it is not feasible (in a model code context) to re-evaluate carbon impacts on a continuous basis and within electricity distribution networks in a complex manner. But a reasonable standardization of the carbon metric may be found by evaluating carbon impacts using one-hour increments within eGRID sub-regions.

Data Availability

Naturally, to include a carbon metric in a model code the source data must be readily available and reliable. The EPA's eGRID subregion hourly emissions factors are updated every two years currently and are already in use in other standards. Building energy simulation tools are typically capable of providing 8760 load shape data as an output. The reference building simulation models used by DOE to formally determine energy savings in model energy codes use 8760 data (DOE 2018). While a more granular temporal scale, such as five- or 15-minute intervals, might better match the precise operation of the grid, expanding the metric beyond the hourly scale risks adding substantial complexity and data availability challenges, reducing the ability of the metric to be easily and conveniently implemented in model codes.

Information on one-hour increments are accessible both from building simulations and from grid operators. The challenge is determining how to standardize the information based on historical or projected data, either near-term or long-term. Buildings typically consume energy for 80-100 years, and it may be most valuable to account for known policy requirements, such as renewable portfolio standards, that will impact the emissions characteristics of electricity consumption for the foreseeable future.

Recommended Carbon Emissions Metric Methodology

In order to best account for the most important impact of energy consumption (i.e. greenhouse gas emissions), it may be simplest to define a metric on the basis of CO2e by defining factors converting site energy consumption to CO2e. It is common in domestic and global policy discussions to discuss greenhouse gas emissions in terms of CO2e. The authors recommend this metric, or a similar metric, form an alternate basis in model codes.

$$CII = \frac{\sum_{hour\ 1}^{8760}\left(kWh_{site} \times F_{elec} + Therms_{site} \times F_{gas} + [\ldots]\right)}{sf}$$

Where:

- CII represents the building's *Carbon Intensity Index*: its normalized annual greenhouse gas emissions impact in kg CO2e/sf
- kWh_{site} represents the building's delivered hourly predicted (or actual) electric usage
- F_{elec} represents an hourly conversion factor between site kWh and CO2e
- $Therms_{site}$ represents the building's delivered hourly predicted (or actual) natural gas usage
- F_{gas} represents a conversion factor between site therms and CO2e
- […] represents the same calculation for all other fuels (district energy, biomass, etc.)
- sf represents the building's size in total gross square feet

The hourly conversion factor between site kWh and CO2e (F_{elec}) will vary by hour. The conversion factor for gas (F_{gas}) is more likely to be a single annual value. Renewable energy consumed by the building and generated on-site or directly contracted off-site and delivered to the building will generally have a CO2e factor of zero, provided that the Renewable Energy Certificates for that power are retained or retired by the project.

POLICY AND IMPLEMENTATION: STATE OF THE ART

As discussed above, the current slate of energy code metrics have a range of relationships to actual carbon emissions. Because site energy, source energy, and energy cost are metrics of energy use, with no calculation for actual emissions, they at best are a rough surrogate for greenhouse gas emissions. Though source energy does not explicitly account for greenhouse gas emissions, it more directly relates to the quantities of primary fossil fuel combusted and generally is a better surrogate than site-energy or energy cost for greenhouse gas emissions.

But the list of policy drivers and implementation efforts to meet the challenges of global climate change is extensive and continues to grow. For building energy codes and standards, much of the technical basis remains rooted in an emphasis on saving energy and reducing energy costs. Both of these are critical, but the emphasis on climate change has risen in importance, and there are now several models to revise energy code metrics.

ASHRAE 189.1/IgCC

Since their first editions, both ASHRAE 189.1 and the International Green Construction Code (IgCC) have included in their respective energy sections that projects also comply with CO2 equivalent (CO2e) requirement. As the 189.1 User's Manual states, "unlike energy cost, the CO2e reduction of buildings that include on-site renewable energy systems is directly based on the energy produced and the energy consumed." While this moves towards a true carbon metric, it must be noted that ASHRAE 189.1 relies on a single CO2e emission factor, while IgCC relies on EPA eGRID subregion CO2e rates.

"Emissions associated with the use of electric power shall be calculated by … multiplying by the CO2e conversion factor in Table 602.3.1 based on the EPA eGRID Sub-region in which the building is located." (ICC 2015)

The IgCC certainly made progress towards a more accurate CO2e metric, but that will be eliminated in the 2018 IgCC that will embed technical requirements from 189.1-2017.

California

Several analyses have found that TDV, while it embeds a small cost of carbon in its formulas, does not correspond well with emissions impacts. And according to a study by Waltner, that divergence will grow as California's energy codes get closer to net zero.

"Overall, the results show that the TDV metric does not directly correspond to emissions for residential space and water heating in any scenario and is particularly poorly correlated to the likely and best case emissions scenarios… While further analysis is warranted, the results are clear that the TDV metric as currently constructed is no longer an adequate tool for helping achieve California's economic and environmental objectives. TDV is fundamentally a consumer-cost metric, directed by the energy and cost-effectiveness requirements specified by the Warren-Alquist Act for Title 24." (Waltner 2016)

The California Energy Commission will be considering updates or a replacement to TDV to better account for both emissions impacts and for grid congestion. It is too early to speculate on the form of a proposal, but the movement to recognize both emissions and grid impacts in defining a new metric is a significant signal from a national leading state.

New York

New York and New York City both have significant emission reduction goals and these leading policies are beginning to impact how the state and the city look at the effect of the metrics in their energy codes. It has become evident that applying energy cost to evaluating energy code decisions in a high-priced electricity market discourages designs that would switch out gas equipment for heat pumps. The NY Department of Public Service whitepaper, following from Governor Cuomo's 2018 State of the State addresses, clearly recommended moving towards a "carbon metric" as being in New York's interest.

"New York should work collaboratively with other states (through the U.S. Climate Alliance or other appropriate venues) to develop carbon-focused metrics to support deeper carbon savings." (NYDPS 2018)

Washington

Washington's Legislature in 2009 set a limit on greenhouse gas emissions at 25% below 1990 levels by 2035 and 50% below 1990 levels by 2050. The Legislature also passed a law to reduce energy use allowed by the 2031 code to be 70% less than that allowed by the 2006 code. In the 2018 development cycle for the next energy code, there is a first attempt to bridge the gap between the energy and carbon objectives in state statutes. The leading proposal would require that showing compliance by modeling would require that the CO2 emission impacts of the proposed building be less than the CO2 emission impacts of the baseline building. The code proposal from the Pacific Northwest National Laboratory, using calculated emission factors for the State of Washington, reads,

"C407.3.1 References to energy cost in Section 4.2.1.1 and Appendix G shall be replaced by carbon emissions calculated by multiplying site energy consumption by the carbon emission factor from Table C407.1." (WBCC 2018)

POLICY AND IMPLEMENTATION: ISSUES AND OPTIONS

Scale: National Model Codes, State Codes, and City Codes: In terms of the implementation of carbon-based metrics, it is essential to understand the impact of differing levels of code development on obstacles for its realization. The most salient feature of converting to a carbon metric might be geographical. That is, does the code jurisdiction have a single supplier of electricity and relative trackability of the sources of electricity emissions? This will be most likely the case in a city-wide code, and some codes in smaller states. Other larger states are well aligned with ISOs, which may be able to provide relatively detailed emission factors. These states include Texas, California, and New York. On the other hand, the diversity of electricity supply across something like the contiguous United States, for which model codes such as the IECC are generally designed for, makes converting to carbon metrics more challenging.

Transparency: There is an inherent tension between achieving the most precise representation of carbon emissions and publishing a clear and easily enforceable energy code. As soon as a table of emission factors exceeds, perhaps, a full page in a code book, it becomes more difficult to interpret and keep current. Yet, the ideal carbon factors would be based on fifteen-minute intervals spaced in each sub-regional grid in the country. A table like this could be constructed in theory based on historical data and be required to be applied in models, and in determinations of prescriptive energy codes, but it would be unwieldy and potentially unenforceable. A better technical option would be to automate the calculation, but the algorithms would need to be printed in the IECC and the calculation might be accused to be a "black box". Transparency of how the emission factors are calculated is critical to a successful transition to a carbon metric.

GHG Emissions Relation to Modeling Rules and Energy Cost in Appendix G: As seen in the Washington proposal described above, it is relatively straightforward to convert the calculation basis in a building simulation to CO2 equivalent. It is similarly possible to convert to a source metric, as has been done in the Massachusetts Stretch Code and is proposed for the New York Stretch Code. All of these source and GHG conversions must provide an acceptable methodology to identify applicable electricity generation sources and their respective emissions. This shift to a source or emissions metric explicitly supplants the reliance on energy cost - which perhaps raises doubts about whether this could lead to more expensive fuel costs for buildings – but low energy designs with the potential for onsite generation generally have lower fuel costs regardless of the remaining energy sources consumed by the building. It also should be noted that site energy based purely on BTUs measured at the meter does not have a direct nexus to energy cost, whereas source and carbon both have a nexus to the ultimate amount of primary energy actually consumed, and thus a closer nexus to energy cost.

Renewable Portfolio Standards and Clean Electricity Grids: As is clearly stated in the DOE report on the captured energy methodology, both renewable portfolio standards and market forces are altering the carbon impacts of generating electricity in the U.S. Even using the conservative projections of the Energy Information Administration, for the purposes of the Captured Energy approach they assume a 26% renewable fraction in 2040, more than double the 12% fraction in 2015 (DOE 2016). Bloomberg New Energy Finance is projecting that in the U.S. electricity sector in 2050, "emissions are 58% lower than they are today." (BloombergNEF 2018)

Buildings constructed to today's energy codes will no doubt be around in 2040 and 2050. In order to account for the impact on carbon emissions for those decades, and probably many decades beyond, energy codes could begin to account for the "long-range marginal carbon impacts." As the energy codes begin to embrace carbon metrics based on current and historic hourly carbon data, it is essential that research and methodologies continue to be developed that can account for the future electric grid that will no doubt have significantly lower carbon emissions per kWh consumed. This is important to send the correct regulatory signal in choosing between electricity and other fuels in the design of the building.

CONCLUSION

Energy codes have been an important policy tool for more than a generation. They have served to increase the efficiency of buildings, have saved building owners and homeowners billions of dollars in energy costs, and have significantly reduced the nation's consumption of fossil fuels (Athalye 2016). Energy codes have been highly successful in working towards many of the objectives for which they were implemented. Now, the rapidly escalating impacts of climate change are leading to demands from governments and citizens around the world that effective policies to reduce carbon emissions be implemented as soon as possible. Fortunately, with residential and commercial building energy codes, an effective policy tool already exists that can be slightly reoriented to achieve additional substantive reductions in carbon emissions. Those steps to further reduce carbon emissions from the building sector are well within reach. The use of a carbon basis will modernize building energy codes to better meet today's policy goals.

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