Right on Target: Developing a Prescriptive Net Zero Model Commercial Energy Code

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ABSTRACT

Building energy code updates have historically focused on incremental energy efficiency improvements for specific systems and equipment. This can lead to highly variable performance in prescriptively code-compliant commercial buildings, depending on building type, systems, climate zone and grid region. However, in recent years, specific performance targets have been set at the state and local levels, extending all the way to “net zero” codes. The development of model stretch codes – with or without specific performance targets – would alleviate the burden on resource-constrained states and jurisdictions of developing their own.

ASHRAE 90.1-2025 includes a new optional Appendix N with prescriptive and performance paths that achieve net zero operational energy emissions. The ASHRAE 90.1 working group leading the effort, subcommittee members and Pacific Northwest National Laboratory encountered several unique questions, including: How accurate are prototype models for predicting energy usage of increasingly complex HVAC systems? How do exceptions to provisions affect energy usage? How can these concerns be addressed without pushing relatively simple buildings to the performance path?

This paper lays out the challenges, consensus-based solutions, and the path ahead. It focuses on several unique elements, including: (1) the structure and provisions of an energy code that meets a specific performance target (net zero carbon) rather than incremental efficiency improvements in assemblies, equipment and systems; (2) the process for evaluating and updating ASHRAE 90.1 holistically instead of assessing individual provisions, and (3) lessons learned and how this process is being extended to performance targets other than net zero.

Introduction

Energy code development in the U.S. has traditionally consisted of a long series of incremental updates to specific prescriptive energy efficiency provisions – increased roof insulation, decreased lighting power, more efficient fans, and the like. Each of these incremental steps is debated at length between the advocates for increased efficiency and representatives of affected industries. The result is an overall advance – if often modest – in building stock-weighted average energy performance, but the process also leads to highly variable performance in code-compliant buildings, depending on systems, climate zone and grid region (Curtz et al 2024). Performance variability can be particularly significant for commercial buildings given the diversity of energy needs among different building types and the wide range of building systems and designs available to meet those needs. The “performance path” of an energy code attempts to match the overall energy performance of the prescriptive code requirements through computer simulation; however, performance paths are often evaluated on energy cost, which can lead to even greater variation in energy usage and greenhouse gas (GHG) emissions performance.

States and local jurisdictions do not generally develop their own energy codes but rather rely on model energy codes developed through consensus committees on three-year cycles and applicable across climate regions of the U.S. (and internationally). States and jurisdictions often amend the model codes, which can result in reduced energy efficiency in new construction; however, some states (e.g. California, Washington and Vermont) are already going beyond model codes and increasing interest among others in strengthening the model codes (Wu 2025). The benchmark commercial energy code is ASHRAE Standard 90.1 (Mickaeal 2024), developed by ASHRAE’s Standing Standard Project Committee (SSPC) 90.1.[1]

Some states have developed their own “stretch codes” (ClimateXChange 2026), codes available to local jurisdictions that go beyond the state’s base energy code. The impact of these stretch codes ranges from “reach codes” that are voluntary for building projects (e.g. California and Oregon) to the two true stretch codes in New York and Massachusetts; Massachusetts sees near-statewide adoption of their stretch codes (MA DOER 2025). There are other states and localities – as well as building portfolio owners, large corporations and institutions, and above-code programs looking for a stronger prescriptive rubric – interested in more ambitious building energy policies to reduce energy costs or to align with broader climate policies (see Figure 1).

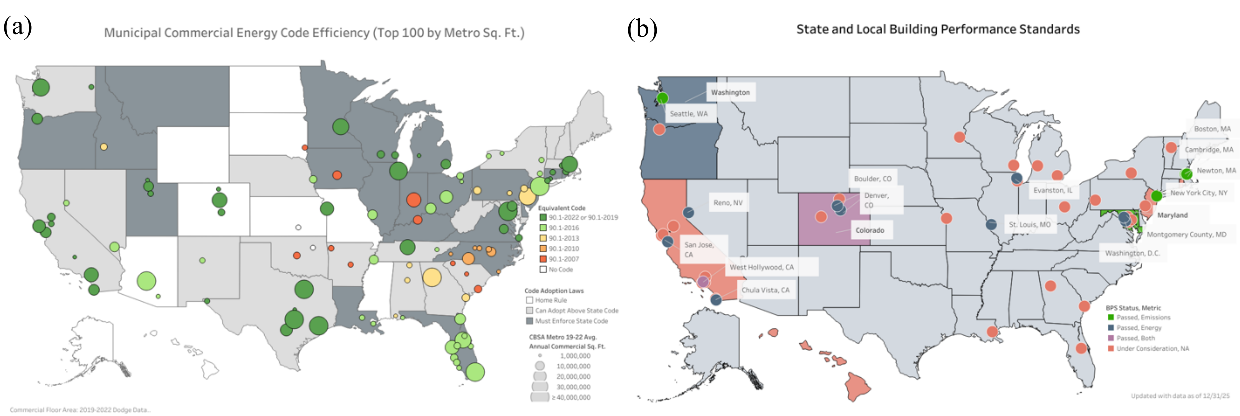

Figure 1. Indicators of interest in advanced commercial energy codes: (a) localities with energy codes that exceed state energy codes and (b) states and localities with building performance standards. *Source*: U.S. Department of Energy Building Energy Codes Program.

Colloquial usage the term ‘stronger energy codes’ is useful, and the intent is clear. However, ambitious energy or climate policies typically include absolute energy or emissions goals instead of relative improvements over a previous code. Building energy performance varies significantly at the aggregate levels of climate zone and building type (see Figure 2). The impact of energy codes on individual buildings is even more highly variable, making it difficult to determine whether new construction is achieving the desired efficiency improvements.

[1] While ASHRAE 90.1 is the benchmark commercial building energy code, it is generally adopted by reference in the International Energy Conservation Code (IECC). However, an increasing number of states are adopting ASHRAE 90.1 directly, particularly those with ambitious building energy and climate policies

Energy codes contain multiple compliance paths at the whole building and individual system level, complex exceptions that can increase energy usage over what would be expected from the (unexcepted) requirements, and differing standards for different system and equipment types. Significant structural changes in energy codes are thus needed if we are to ensure construction of code-compliant buildings that meet specific performance targets.

	0A	0B	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Small Office	50.8%	46.1%	49.4%	45.3%	48.9%	45.3%	47.3%	45.5%	46.6%	46.7%	46.5%	44.9%	47.0%	46.9%	44.4%	47.8%	46.7%	48.9%	44.9%
Medium Office	51.1%	47.0%	50.3%	47.6%	52.9%	50.2%	52.2%	49.9%	56.5%	51.8%	51.4%	53.0%	50.9%	51.1%	52.6%	50.4%	51.2%	60.3%	58.8%
Large Office	35.3%	29.3%	32.9%	29.3%	36.0%	27.7%	34.6%	26.6%	33.0%	37.8%	29.3%	33.0%	39.3%	31.9%	32.3%	41.1%	32.8%	42.8%	44.4%
Stand-alone Retail	55.5%	54.2%	56.6%	54.1%	61.3%	60.8%	57.8%	57.3%	61.3%	56.5%	57.3%	55.7%	53.3%	54.9%	54.3%	52.4%	53.3%	61.4%	59.2%
Strip Mall	56.4%	57.3%	57.3%	55.8%	58.9%	61.0%	59.1%	59.5%	57.0%	57.6%	56.7%	54.2%	54.8%	54.1%	53.9%	55.7%	54.4%	55.5%	55.3%
Primary School	56.3%	49.5%	52.4%	48.8%	52.5%	46.7%	51.4%	47.8%	49.7%	60.1%	50.9%	52.2%	58.3%	52.3%	53.4%	58.7%	57.8%	61.2%	60.3%
Secondary School	56.9%	52.4%	54.7%	49.2%	55.1%	51.3%	53.2%	51.6%	54.9%	60.5%	56.1%	53.8%	59.1%	57.4%	54.7%	59.8%	61.2%	61.7%	59.4%
Outpatient Healthcare	37.7%	39.0%	38.7%	39.4%	38.6%	41.3%	41.5%	41.4%	43.7%	43.0%	42.7%	44.2%	42.4%	43.1%	43.4%	42.4%	43.2%	41.2%	39.5%
Hospital	41.8%	43.7%	45.0%	43.3%	45.7%	45.5%	45.1%	43.2%	47.5%	44.3%	41.9%	44.6%	44.0%	43.0%	35.0%	43.5%	36.3%	36.1%	36.5%
Small Hotel	40.7%	39.8%	39.1%	38.8%	39.8%	39.7%	39.3%	39.5%	38.3%	40.3%	39.3%	37.6%	41.3%	40.0%	38.2%	42.9%	41.3%	43.8%	43.8%
Large Hotel	40.0%	45.2%	40.6%	43.9%	42.3%	41.4%	41.6%	41.8%	43.6%	42.9%	44.5%	41.5%	43.9%	49.4%	40.4%	44.4%	52.4%	44.8%	46.0%
Quick Service Restaurant	25.2%	25.5%	24.5%	25.8%	24.7%	25.2%	23.2%	22.9%	22.4%	25.9%	23.8%	26.0%	26.1%	24.1%	26.7%	26.6%	25.6%	26.8%	25.6%
Full Service Restaurant	31.0%	32.1%	31.8%	32.6%	32.8%	33.4%	32.7%	31.5%	31.1%	34.8%	32.0%	33.7%	33.7%	31.6%	34.1%	30.8%	31.1%	30.9%	29.3%
Mid-rise Apartment	35.1%	34.8%	33.0%	33.1%	33.6%	33.3%	34.0%	32.7%	35.8%	38.5%	34.4%	34.9%	40.9%	38.3%	35.7%	42.4%	41.4%	42.9%	40.0%
High-rise Apartment	30.5%	30.6%	29.3%	29.7%	32.1%	32.2%	33.9%	30.8%	33.8%	40.6%	33.9%	37.8%	43.9%	38.7%	37.4%	45.7%	44.2%	45.8%	42.9%

Figure 2. Net site energy savings of ASHRAE 90.1-2022 vs. 90.1-2004 by building type and climate zone. *Source*: Analysis by the authors using data from the U.S. Department of Energy Building Energy Codes Program [end-use database](#).

Further, a call for “net zero carbon” or “net zero emissions” energy codes has emerged in recent years. While limited progress has been made, states and jurisdictions were awarded $642 million in Inflation Reduction Act funding for development of pathways to net zero codes, indicating a latent demand for such codes. When the aim is emissions reduction, and the varying carbon content of grid electricity in different regions and uncertainty in how those will change over time are added to the equation, it becomes even more challenging to determine whether a building designed to the energy code achieves a GHG emissions target (including “net zero carbon”).

This landscape provides motivation for the development of model stretch energy codes with reasonable precision in performance expectations, potentially including net zero. ASHRAE SSPC 90.1 initiated a process to meet this end; as a result, ASHRAE 90.1-2025 (ASHRAE 2026) includes a new optional “Appendix N” that provides an overlay to ASHRAE 90.1’s prescriptive and performance paths aimed at achieving net zero operational energy emissions (NZOEE) for new commercial buildings. First, however, we must review the challenges inherent to this effort to attain net zero whole building performance in order to understand the structure of Appendix N and its development process within a longstanding committee organized primarily for its traditional role of incremental progress within building system silos.

Right on Target: Challenges of hitting specific performance targets in a prescriptive code

There is a fundamental difference between expectations of traditional energy codes and those that are intended to hit a specific performance target, referred to here as “targeted energy codes”:

- Traditional energy codes are developed with incremental energy efficiency updates, evaluated through a set of prototype building models for 16 building types in all climate zones with a single set of representative systems and assemblies for each building type. The overall energy code performance improvement is then calculated based on these models and using construction weightings by building type and climate zone (Tyler, Tillou and Rosenberg 2024).
- Targeted energy codes intend for every building built to that code to meet a specific performance target (which could be an absolute value or a value relative to some baseline), and the provisions of the code are developed to ensure this target is met for any combination of building type, climate zone, systems and equipment.

The challenges to modifying a traditional energy code to become a targeted energy code are numerous. Some examples include:

- Within a particular system category (e.g. building envelope), there are different prescriptive requirements depending on the specific system or construction (e.g. steel-framed walls vs. mass walls).
- For many systems – particularly HVAC systems in larger buildings – there are different code-compliant system configurations that can lead to significant variations in energy usage. This variability can be narrowed through design and control requirements, but the resulting precision of generalized models for such systems is not clear.
- The minimum energy efficiency of HVAC and water heating equipment can vary widely depending on the system selection (e.g. a water-cooled chiller vs. an air-cooled unitary air conditioner) and fuel type (e.g. a gas furnace vs. an electric heat pump).
- Minimum efficiency performance is set at levels that are not tailored to a specific building type within a specific jurisdiction: minimum mechanical equipment efficiencies are the same for all buildings, and while envelope requirements vary by climate zone, the only building type delineation is between residential and non-residential buildings.
- Certain loads – both those regulated under 90.1 and unregulated loads – vary significantly across buildings. This can be clear in the case of different building types, such as a hospital vs. a school. But even within a building type like "office," the difference in energy usage between an executive suite and 24-hour call center is substantial. Further, some buildings of the same type have significant energy-using equipment (e.g. elevators and parking garage ventilation) while others of the same type do not have these systems.

In addition, energy codes have numerous exceptions that have various justifications (e.g. indoor air quality concerns, size thresholds that affect upfront costs or were modified to appease certain interests in order to reach consensus). Even with all else above being equal, exceptions lead to unequal energy usage. Further, these items focus largely on differences in energy usage. If the target is emissions, the emissions factor of the electricity grid supplying the building varies significantly across the country, and across different time horizons as the grid incorporates more renewable energy; Figure 3 shows projected emissions factors for U.S. grid regions in 2025 and 2045.

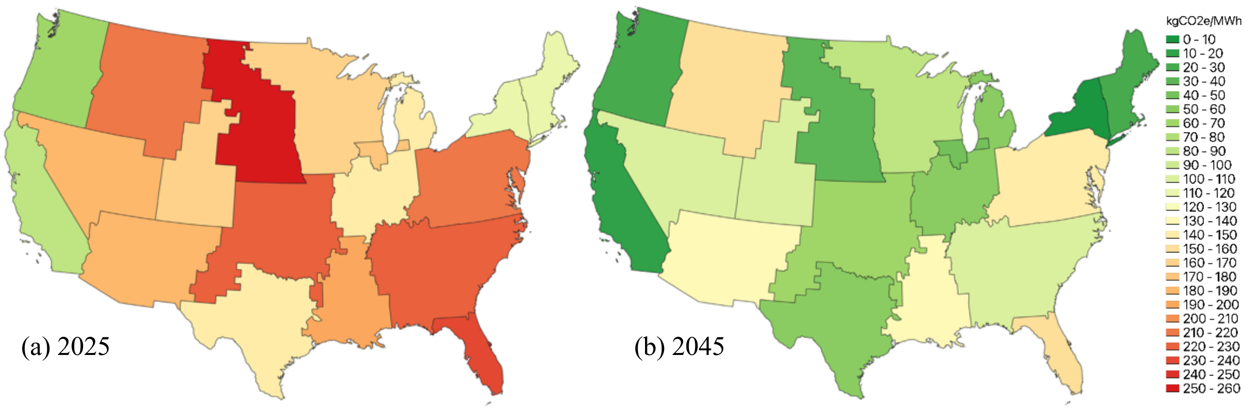

Figure 3. Electricity emissions factor by grid region in: (a) 2025 and (b) 2045. *Source*: Long-run marginal emissions factors from Cambium 2024 (Gagnon et al 2025).

To address these issues, and to bridge this gap, SSPC 90.1 flipped the development process on its head for Appendix N.

"We have a strategic plan, it's called getting stuff done:" The 90.1 Appendix N development process

Anyone involved in the development of consensus standards can attest that it is a slow and arduous process. From inception of the prescriptive net zero operational energy emissions (NZOEE) idea to completion and approval of Appendix N, SSPC 90.1 accomplished the following in 16 months:

- A complete assessment of the entire ASHRAE 90.1standard in the context of its transition to a net zero operational energy emissions standard.
- Modification of existing provisions and procedures to ensure "equal energy" for reasonable precision for each particular building type in a particular climate zone with particular HVAC and water heating systems.
- Identification of potential energy efficiency improvements over the base standard and potential areas of compliance flexibility.
- Thousands of model runs by Pacific Northwest National Laboratory (PNNL) to calculate energy usage by building type, system types and climate zone.
- Calculation of GHG emissions from the PNNL model outputs by electricity grid region, and the calculation of building-specific renewables required to offset those emissions.
- Incorporation of an earlier developed NZOEE performance path to ensure consistency.
- Development of the Appendix N document: an NZOEE overlay to 90.1 that incorporates the results of all the above into an optional appendix that jurisdictions can adopt.

How was all of this accomplished?[2] First, an SSPC-level working group was established: the Net Zero Operational Carbon (NZOC) Working Group, the overall structure of which is compared to the typical “continuous maintenance” process of ASHRAE 90.1 in Figure 4. Rather than a diffuse collection of incremental energy efficiency improvements, the Working Group approached Appendix N more like an integrated design workshop, asking itself, “what should we expect from *every* net zero carbon building?” This led to wide-ranging discussions, with consensus around stronger energy efficiency, as well as less agreement on some more contentious ideas, such as prohibiting on-site fuel combustion or requiring energy storage. After developing some general parameters and targeted energy efficiency improvements within broad categories (envelope, HVAC, water heating and lighting), the relevant ASHRAE 90.1 subcommittees were engaged and the primary roles of the NZOC Working Group were defined: (1) to coordinate and integrate the subcommittee input and (2) to scope and review modeling and analysis by the PNNL team.

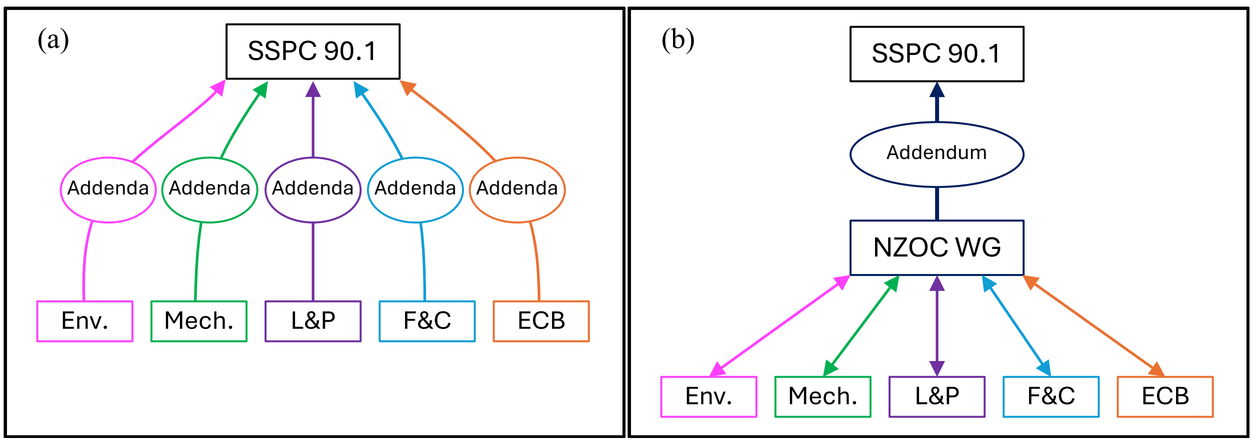

Figure 4. (a) Typical structure of SSPC 90.1 for standard development through addenda to the previous version and (b) structure of SSPC 90.1 Net Zero Operational Carbon Working Group and integration with subcommittees (SCs). SCs: Envelope (Env.), Mechanical (Mech.), Lighting.& Power (L&P), Format and Compliance (F&C), Energy Cost Budget (ECB)

Each of the technical subcommittees operated differently depending on the regular processes of those subcommittees, the Working Group members’ assessments of the best path to reaching consensus, and issues specific to the technical areas of each section. In brief summary:

- The Envelope Subcommittee used its existing cost-effectiveness analysis tool to determine consensus insulated assembly and fenestration performance levels. Key to this was working with the NZOC Working Group and PNNL to develop an approach specific to Appendix N that could move envelope efficiency forward while alleviating the concerns of some of its members (see additional detail in the following section).

[2] Full disclosure by the authors, who were all involved in this process: we cannot say it all went perfectly or that, upon reflection and given more time, we would not have done some things differently. Some modifications and editorial cleanup were needed later before 90.1-2025 publication, and there were a host of lessons learned as detailed in a later section of this paper.

- The Mechanical Subcommittee's standing Decarbonization Working Group evaluated and constrained systems, reviewed HVAC and water heating sections line-by-line, and adjusted exceptions to ensure "equal energy" usage for systems in the same building and climate zone.
- The two members of the NZOC Working Group who also served on the Lighting & Power Subcommittee largely brought a complete proposal to that subcommittee, gained approval, and brought it back to the Working Group.

The bullet points above are intentionally broad to give a sense of the process, with more detail on the outcome of each provided in the next section.

Because Appendix N is informative (rather than normative), it was not required by ANSI procedures to go through the full public review, commenting and response process. However, a draft of Appendix N was released for an Advisory Public Review, which provided valuable input from experts and interested parties outside the SSPC that improved the final version of Appendix N and led to a list of future expansions and improvements. In the end, Appendix N was approved overwhelmingly by the full SSPC with a vote of 25 in favor against only two opposed.

The Beast Within: Structure and provisions of 90.1 Appendix N and how they differ from a typical energy code

While the approximately 25-page overlay of modifications to 90.1 may seem modest to transition the traditional commercial energy code to one that aims for all buildings to be NZOEE, it in fact marks a significant departure from previous codes in terms of content and structure. This overlay includes strikethrough/underline of existing 90.1 provisions, replacement of sections requiring significant changes and the addition of new sections necessary to achieve the goals of Appendix N. The potential complexity is motivating consideration of a new manner of publishing such modifications of the base standard in the future, but unfortunately for this edition of Appendix N, much of that work of integrating the language of the appendix with that of the base standard would need to be done by the adopting jurisdictions manually.

General Overview of the Prescriptive Path

One of the key differences between the Appendix N-modified Standard 90.1 and the base standard is that of restrictions on the building types that are allowed to use the prescriptive path. These restrictions are due to the challenges of creating a "targeted energy code" described above, namely our reliance on prototype building models and their ability to reliably predict the energy performance of compliant buildings. (This also leads to limitations on system types in the prescriptive path, which are described below.) While the performance path within Appendix N is available to all building types, the prescriptive path is restricted to buildings without significant process loads (office, hotel, retail, school, multifamily, or warehouse) and further excludes buildings with commercial kitchens, dehumidifiers, computer rooms, pools, or any of several other process loads. This may also push buildings designed with leased spaces that could be occupied by a tenant with any of the prohibited process loads (e.g. restaurant, grocery or gymnasium) into the performance path. As a result, while a majority of new construction permits may qualify for the prescriptive path, the majority of new building floor area (and a relatively small number of permits) in a jurisdiction adopting this appendix would likely be required to follow the performance path.[3]

Renewable Energy Requirements

In both its prescriptive and performance paths, Appendix N mandates that the GHG emissions associated with a building's annual energy usage be offset by on-site or procured off-site renewable electricity generation. This balance, averaged over a one-year period, represents the "net" in net zero emissions.

While the essence of this compliance path is that sufficient renewable energy (RE) must be acquired to balance the energy-related emissions of the building, it also implements an "efficiency first" principle by requiring above-code efficiency for several systems. Therefore, before even considering GHG emissions, the NZOC Working Group and SSPC 90.1's Subcommittees first evaluated cost-justified increases in energy efficiency for a NZOEE building (detailed in the subsections below). This generally involved using the SSPC's standard cost-effectiveness analysis procedures and national average energy prices, as well as the elimination of several energy-increasing exceptions. Prototype models were then used to calculate the annual energy usage – both fuel and electricity – of each building type by climate zone, HVAC system type and water heating system type. Annual GHG emissions were then calculated from this data with the added dimension of electricity grid region.[4] The same emissions factors were then used to calculate the amount of RE that would have to be generated on-site or procured from elsewhere to offset the energy-related emissions over the course of the year.

These calculations produce a set of RE requirements dependent on the following:

- Building use type
- Climate zone
- Electricity grid region
- HVAC system type
- Water heating system type

Figure 5 illustrates the output of these calculations for a subset of building types, systems, climate zones and grid regions; a detailed quantitative assessment is beyond this paper's scope.

There are also RE requirements associated with common large 90.1-regulated loads that may not be in every building of a particular building use type, including the following "discretionary" loads: elevators, exterior lighting, parking garage lighting and parking garage ventilation. Maximum limits were set on some other significant regulated-but-discretionary loads where we determined the base models without the additional RE requirements offered sufficient precision.

[3] The SSPC is working to expand coverage of the prescriptive path going forward, as discussed in the "Lessons Learned" section below. This is relevant to several items in "The Beast Within" subsections, but we do not repeat this caveat throughout.

[4] The electricity-related emissions calculations use annual long-run marginal emissions rates (LRMER) (Gagnon and Cole 2022) from the National Renewable Energy Laboratory (NREL) Cambium 2024 datasets (Gagnon et al 2024) for 18 U.S. grid regions; LRMERs are averaged over 20 years, 2026-2045, to account for projected grid changes.

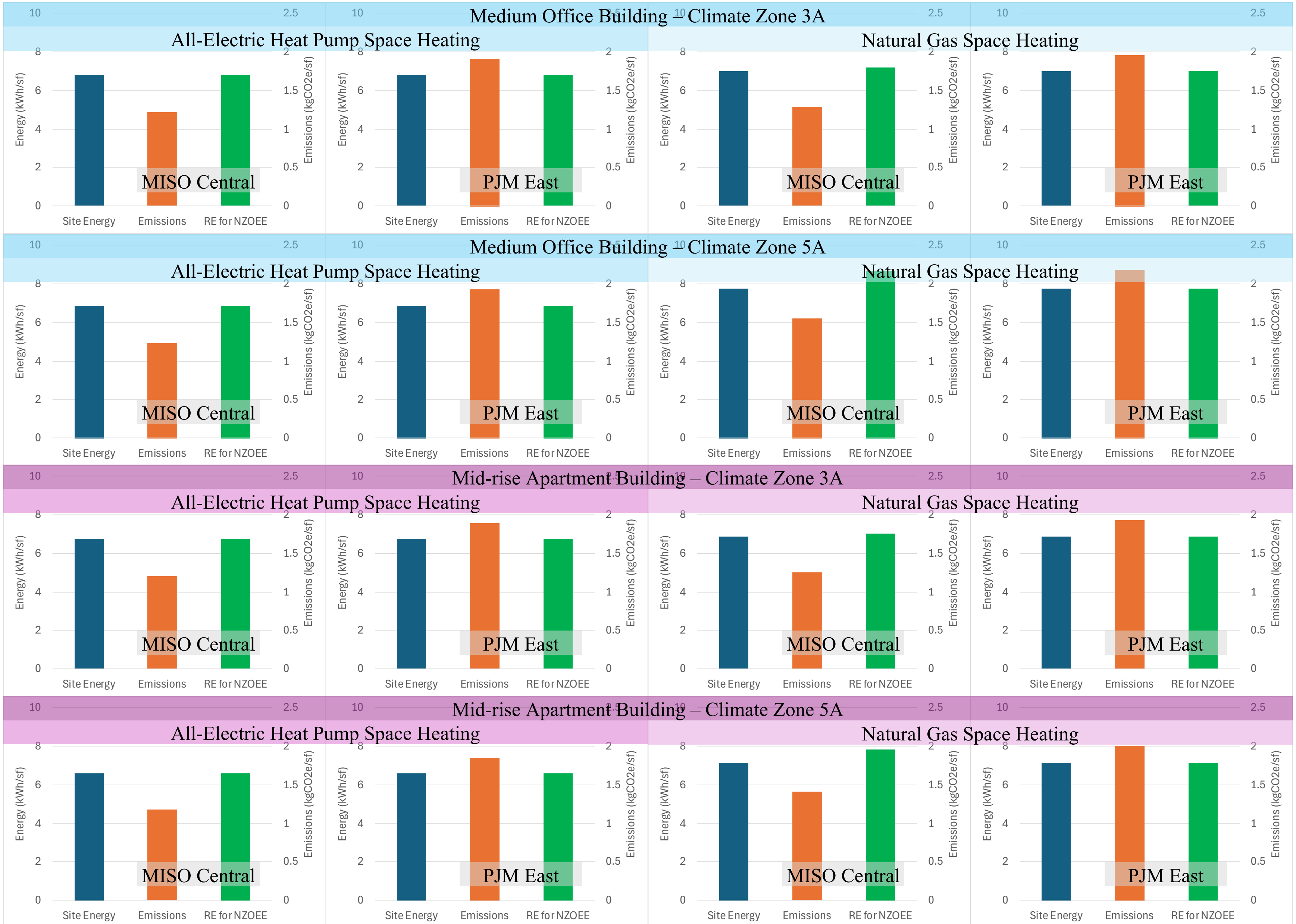

Figure 5. Appendix N calculations for a subset of building types (Medium Office and Mid-rise Apartment), HVAC systems, climate zones, grid regions (MISO Central and PJM East): Site energy (sum of electricity and natural gas in kWh/sf), GHG emissions (kgCO2e/sf), renewable energy required for NZOEE (kWh/sf)

Because of the different factors considered in setting RE requirements (as well as reductions in those requirements for higher efficiency equipment, described in subsections below), this results in over 100 pages of tables. The complexity of thousands of values in this format is certainly a weakness of Appendix N, particularly when only a few of those values may be applicable to an individual building project. ASHRAE published these tables in an electronic format for easier use than in a printed document or PDF.[5]

Building Envelope

The primary structural change in Appendix N is that, rather than tables of prescriptive requirements by envelope assembly type (e.g. steel-framed walls vs. mass walls, roofs insulated entirely above deck vs. attic and other roof types, fixed vs. operable fenestration), designers are required to meet an overall envelope standard through use of the envelope trade-off calculations (ASHRAE 90.1 Appendix C). The envelope trade-off option utilizes a behind-the-scenes model to calculate an overall Envelope Performance Factor. This was motivated by a need to reach consensus on improved envelope efficiency in Appendix N, together with a desire by affected industries not to publish new sets of prescriptive tables that jurisdictions might interpret as being endorsed by SSPC 90.1 as new minimum design requirements. This approach would require that buildings input envelope data into a yet-to-be-modified COMcheck.

A modification to the ASHRAE 90.1 envelope trade-off method was also required: because Appendix N is a targeted energy code, it could not allow variability in performance depending on the types of envelope assemblies used. The method was modified to use a fixed envelope performance baseline with set construction types and U-factors, building type-specific window-to-wall ratios, lower air leakage rates than those in 90.1-2022, and fixed thermal bridging in all climate zones. This alone improved envelope efficiency on average; the required maximum Envelope Performance Factors were then generally decreased (i.e. the minimum envelope efficiencies were strengthened) by building type and climate zone to achieve further energy savings.

HVAC Systems

The major restriction in this area in Appendix N is that only single-zone HVAC systems are allowed to show compliance through the prescriptive path. This was not based on a judgement that these are the best systems for NZOEE buildings but rather was implemented to eliminate the variability in energy performance common in multiple-zone HVAC systems. Appendix N further eliminated many HVAC system-related exceptions that increased energy usage or would produce different modeled energy usage for the same system types.

There was significant debate within the NZOC Working Group and SSPC 90.1's Mechanical Subcommittee about whether any fuel-burning HVAC systems should be allowed in NZOEE buildings under Appendix N. Consensus was reached in requiring either all-electric systems or primary electric heat systems with secondary fuel-burning equipment. Even some of the

[5] Appendix N also includes an equivalent emissions calculation method that allows for the use of alternative lower-carbon fuels and other means of offsetting GHG emissions. This is not otherwise materially different from the renewable approach and is not detailed in this paper.

advocates for eliminating on-site emissions in NZOEE buildings viewed this as a reasonable approach, as the grid supply continues to incorporate more RE and heat pump technology improves over the life of the building.

A significant restriction on advanced energy codes is federal preemption law that does not allow many equipment efficiency requirements to be set higher than the federal minimum standard. To account for the benefits of improved equipment efficiency, Appendix N allows the RE requirement to be decreased with higher efficiency equipment.

Water Heating

Appendix N takes a similar approach to water heating systems as for HVAC systems, though with significantly less complexity: (1) restricting systems to electric heat pump primary systems with allowances for secondary fuel-burning equipment; (2) eliminating exceptions, and (3) allowing RE requirements to be decreased when utilizing higher efficiency equipment.

Lighting

ASHRAE 90.1 provides three lighting compliance pathways—the Simplified Building Method, Building Area Method, and Space-by-Space Method—generally progressing in both complexity and allowable energy use. Because Appendix N is a targeted energy code, it cannot accommodate multiple compliance methods with differing energy outcomes. The Simplified Building Method was selected for its relatively higher energy efficiency, and it was expanded to cover all building types eligible for the prescriptive NZOEE approach. While lighting power allowances change modestly, this method eliminates several significant additional allowances, (e.g. retail display lighting). Since lighting is fully electric and ASHRAE 90.1 already captures the energy and cost benefits of LEDs, lighting contributes minimally to overall emissions.

Energy Monitoring and Load Management

Monitoring energy usage to determine potential operational savings can support continued good building operation after occupancy. However, the models that underly the calculations for Appendix N use fixed operating schedules and controls that do not change over the life of the building. Based on the judgement that expanded monitoring would benefit NZOEE buildings, Appendix N expands the scope of 90.1's electricity monitoring requirements to include all forms of energy supplied to the building and its end uses.

ASHRAE 90.1 requires achievement of load management credits from a list of options for grid-interactive technologies (e.g. battery and thermal storage) and controls (e.g. smart thermostats and lighting controls) that are quantified on an energy cost basis with building type- and climate zone-specific requirements. However, the use of annual emissions values in Appendix N does not capture the impacts of load shifting or other time-of-use-related control strategies on emissions that higher temporal resolution would. Appendix N simply sets a fixed number of load management credits that must be achieved by all buildings.

Performance Path

ASHRAE 90.1 has two whole-building performance paths that use computer simulation:

- The Energy Cost Budget (ECB), Section 12, compares the proposed design to a "budget building design" that meets all prescriptive requirements.
- The Performance Rating Method (PRM), Appendix G, compares the modeled performance of a proposed design to a baseline building design aligned with 90.1-2004.

Appendix N allows only the PRM because it is best designed to meet a specific performance target. This is accomplished through the use of "Building Performance Factors (BPFs)" that represent a percentage improvement over the baseline building design performance by building type and climate zone (Franconi et al 2024a, Franconi et al 2024b). In the base standard, the default BPF metric is energy cost; in Appendix N it is site energy (excluding RE generation), with BPFs set to achieve approximately one-third of the potential site energy reductions identified in Glazer 2017 relative to ASHRAE 90.1-2022. A second requirement is added that all modeled building energy-related emissions must equal zero when including the impacts of on-site and procured renewable electricity. Otherwise, there are no changes to Standard's 90.1 PRM.

~~Where we screwed up~~ Lessons learned and how this is being extended in the 2028 cycle

We certainly cannot claim that Appendix N was perfect. We met a very tight deadline with a robust consensus effort but did learn some lessons that will inform the path forward. Further adjustments will be needed, as ASHRAE and SSPC 90.1 goals and plans have shifted over the past three years. In the 90.1-2028 cycle, Appendix N is expected to be replaced by a new annex, tentatively titled, "Annex E: Enhanced Energy Efficiency and Operational Emissions Reduction." Although Annex E will use Appendix N as a foundation, through lessons learned and a new focus, several changes are being made as its development gets underway.

Process

The Working Group structure for Appendix N development did prove effective and is continuing for Annex E, albeit with NZOC renamed the "Operational Emissions Working Group (OEWG). Rather than meeting a specific target, however, Annex E is intended to go as far as possible to reaching two-thirds emissions reduction vs. 90.1-2022 while being constrained by the SSPC 90.1's standard cost-effectiveness analysis approach. However, this analysis will include a social cost of greenhouse gas emissions (SC-GHG) that adds the costs of climate change-related externalities to the price of energy.

Given that there is more time for development in the current cycle, the SSPC also intends for Annex E (and any future modifications) to be subjected to the same full public review process as the base standard. While this will add time and work, it will allow for more robust public input and the ANSI process for reaching consensus.

Expansion

One of the primary shortcomings of Appendix N is the restriction on the types of buildings that are allowed to comply through the prescriptive path. The intent behind Appendix N was to provide a NZOEE prescriptive path in addition to the already-developed performance path. Due to the time pressures to accomplish this and the challenges of a targeted energy code vis-à-vis a traditional energy code (described above), the resulting prescriptive path was restricted more than many would have liked. In developing Annex E, the SSPC intends to expand the building types that are permitted to follow the prescriptive path, incorporate more common-but-not-universal loads that currently push buildings into the performance path, and expand the range of covered HVAC system types (discussed further below).

Appendix N's approach to existing buildings is another significant shortcoming: additions are generally required to comply as new buildings are, but the appendix includes no requirements for alterations beyond those of the base standard 90.1. Appendix N was primarily intended for NZOEE new construction, but if it were adopted, it would create an even wider gulf between how new and existing building projects are treated in the energy code. This can be particularly problematic when considering that jurisdictions adopting such an advanced energy code are also likely to have existing building energy or decarbonization policies, such as building performance standards (see Figure 2 above). The OEWG is currently working to incorporate alterations into the Appendix N framework for Annex E, but this is raising an entirely new set of questions as to how existing buildings should be treated in a targeted energy code vs. a traditional energy code.

Restructuring

Often on a large project needing to be done on a short timeline, the course set at the start leads to unforeseen complexities later for which there is not enough time to iterate and fix. Appendix N is no exception. In particular, the Administration and Enforcement section – traditionally a brief set of overall instructions for users and code officials – balloons to include multiple calculation methods, numerous large tables and substantive requirements that might otherwise be found in the more technical sections. In developing Annex E, the OEWG intends to keep the Administration section more streamlined and move renewable requirements and reduction allowances/credits to a dedicated section.

There were also lessons learned in the publication of an appendix that modifies the base standard, as is the case with Appendix N. The portions of the overlay that show strikethrough/underline created challenges for cleanly publishing the appendix. Going forward, the SSPC intends to show all modifications to the base standard as complete section replacements. This will also make the results of ASHRAE's digitization efforts clearer with less potential for errors, as ASHRAE intends to publish a separate version of Standard 90.1 as modified by Annex E that will not require users to track individual modifications.

Prescriptive Requirements

In general, the OEWG and the Subcommittees are reviewing all energy efficiency requirements in the base standard 90.1 to evaluate whether such provisions could be made more stringent in Annex E when using cost-effectiveness analysis that includes SC-GHG. It appears that the HVAC system provisions of Section 6 may have the most potential here.

Annex E is expected to use the same general approach to the building envelope as Appendix N, which requires use of the envelope trade-off method. The OEWG is reviewing whether the efficiency requirements can be made more stringent, but this has raised some questions about how cost-effectiveness analysis should be done for the overlay that includes significant RE requirements. For the base standard, a single electricity price is used; for Annex E, the OEWG is working through the evaluation of increased envelope efficiency while considering three potential sources of electricity:

- Electricity from the grid: prices for purchased electricity + SC-GHG price adder, both on a per-unit energy basis
- On-site renewable electricity: upfront cost for equipment, no price per unit of energy, no SC-GHG price adder, potential benefit from selling excess electricity to the grid
- Procured off-site RE: price per unit of energy different from that purchased directly from the utility, no SC-GHG price adder

Beyond potential strengthening energy efficiency provisions, the most significant difference for HVAC systems in Annex E is anticipated to be the expansion of the types of systems that can comply through the prescriptive path. Some initial analysis indicates that the energy performance of multiple-zone HVAC systems varies less with different system configurations than originally anticipated, although, energy use of VAV systems varies as a group compared to other allowed systems. The OEWG is currently working to incorporate several common multiple-zone HVAC systems. Further, in developing the RE requirement reductions allowed with higher efficiency HVAC equipment, we found that the current models likely do not accurately capture the performance of higher efficiency direct expansion equipment (e.g. air conditioners and heat pumps) at non-standard operating conditions; SSPC 90.1 plans to work to improve those equipment models in the 2028 cycle, which would also be incorporated into Annex E.

As noted earlier in this paper, lighting systems in Appendix N must use the Simplified Building Method. While this is the simplest and lowest-energy usage lighting compliance option among the three in 90.1, it is also not widely used to show compliance with 90.1. Annex E is likely to shift to allow only the Building Area Method, which is much more widely used. However, as a starting point, we expect Annex E to include a modified Building Area Method that meets or exceeds the energy efficiency performance of Appendix N-compliant lighting systems. A lighting performance credit is also under consideration.

The OEWG is also working to improve how the benefits of load management technologies (e.g. batteries and thermal energy storage) and controls are accounted for in Annex E vs. the highly simplified approach in Appendix N. This will require significant analysis of load management approaches alone and in combination, which also requires time-of-use analysis that increases the complexity of the electricity grid-related emissions analysis. The hope is that some streamlined approach to the anticipated analysis could be used to develop empirical equations or heuristics to translate load management approaches into reductions in the RE requirements.

Conclusion

This paper describes the emerging demand for more advanced energy codes that meet a specific energy or emissions performance level, potentially extending all the way to "net zero emissions." However, a "targeted energy code" presents several challenges not typically encountered in traditional energy code development that focuses on individual incremental energy efficiency improvements. During the Standard 90.1-2025 development cycle, ASHRAE's Standing Standard Project Committee (SSPC) 90.1 started a new process to develop an overlay to ASHRAE 90.1 with a prescriptive path that achieves net zero operational energy emissions (NZOEE) for commercial buildings, resulting in Appendix N in ASHRAE 90.1-2025. A SSPC-level Net Zero Operational Carbon (NZOC) Working Group coordinated efforts through the relevant Subcommittees to achieve more stringent energy efficiency requirements than the base standard 90.1 in most technical sections (i.e. Envelope, HVAC, Water Heating and Lighting). To then reach NZOEE, the NZOC computed renewable energy requirements by building type, HVAC system type, water heating system type, climate zone and electricity grid region; these requirements can be reduced for projects that use more efficient mechanical equipment.

From inception to completion, Appendix N was accomplished on a very short timeline for development of a standard. However, this also led to certain limitations on the scope of Appendix N, the most significant of which is: While the performance path in Appendix N is available to all building types, the prescriptive path is restricted to building types without significant process loads or other large energy loads for which it is difficult to reliably model average energy usage; the prescriptive path is further limited to single-zone HVAC systems.

In the current 90.1-2028 development cycle, Appendix N is expected to be replaced by a new optional approach to reduce emissions, tentatively titled, "Annex E: Enhanced Energy Efficiency and Operational Emissions Reduction." This paper describes how, as part of the Annex E effort, the SSPC is working to expand the building types, loads and HVAC systems that are covered. There were also numerous other lessons learned in developing Appendix N that will be applied to Annex E development, including changes to cost-effectiveness analyses, evaluation of additional HVAC systems whose energy performance can be modeled to reasonable precision to include in the prescriptive path, modification of a more widely used lighting system compliance method, and quantification of the ability for load management technologies and controls to reduce the base renewable energy requirements.

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