Prescriptive Codes and Implications for Building Energy Use Variation

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ABSTRACT

Energy codes have always included prescriptive compliance pathways and they are the most commonly used path for compliance. These prescriptive requirements are expressed as verifiable metrics such as insulation R-value or chiller coefficient of performance (COP). Code development bodies such as ASHRAE develop these metrics on a component-by-component basis, typically by considering cost-effectiveness. Each prescriptive requirement is evaluated in isolation, and not examined for its whole building energy impact when combined with other building components and systems. Therefore, a prescriptive path does not define a level of energy performance for any building or system type. For example, a building with a packaged rooftop heat pump will have different energy consumption and greenhouse gas emissions than the same building with a packaged rooftop gas furnace. Policy objectives are driving energy codes toward requiring net-zero energy buildings, meaning that some prescriptively compliant buildings will be more likely to be net-zero than others. This paper will present results of a simulation analysis examining the performance of a wide variety of prescriptively compliant buildings and how they compare in terms of site energy use intensity (EUI). The analysis uses the existing set of EnergyPlus prototype buildings, applying configurations of prescriptively compliant features for building envelope, HVAC designs, lighting power and controls, and water heating systems. The research demonstrates that two minimally compliant buildings, using different prescriptive options, can exhibit energy use variation exceeding 200% and presents recommendations for reducing this variation through code requirements.

Introduction

Many current policies at national and local levels in the United States include increasingly ambitious goals for energy and emissions reductions in the buildings sector. For example, the U.S. Department of Energy's (DOE) recently announced building decarbonization blueprint is a plan to "reduce U.S. building emissions 65% by 2035 and 90% by 2050 vs. 2005 while enabling net-zero emissions economy-wide and centering equity and benefits to communities" (DOE 2024a). The ASHRAE Standard 90.1 Committee has a goal of net-zero operational emissions for new buildings built to the 2031 edition of the standard.[1] Policymakers are keenly interested in understanding potential building energy performance outcomes for new buildings that comply with existing energy codes.

Building Performance Standard (BPS) policies and net-zero energy codes are two innovative energy policies that are driving an increased need for better understanding of real-world building performance. BPS polices directly regulate building performance of existing buildings in operation, and typically increase in stringency over time. Net zero energy codes

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[1] This goal was approved in the Standard 90.1 2025 workplan.

prescribe a capacity of renewable energy needed to offset building energy use in operation, based on predicted building energy consumption.

Conventional energy codes are established and effective policy tools to reduce energy consumption and associated emissions in buildings. The typical focus of conventional energy codes has been implementation of cost-effective, energy-efficient infrastructure in new construction and renovation projects. Energy codes regulate minimum efficiency levels for various infrastructure components of the building (such as envelope, HVAC, lighting, water heating, etc.). Because the component requirements in prescriptive codes are not developed wholistically, they are not designed to deliver a performance outcome with certainty. Although energy codes have consistently improved the energy efficiency in buildings over the years, multiple design options that comply with a prescriptive energy code will not achieve the same energy performance.

Furthermore, if the energy code is not aligned with energy performance goals, it could result in the need to retrofit physical infrastructure in a recently constructed building in order to meet BPS policies (DOE 2023c). In such a case, operational changes (identified via commissioning/retro commissioning) would not result in sufficient performance improvements, triggering a need for more significant retrofits. Ideally, policy alignment would ensure that newly constructed buildings are equipped to achieve policy performance targets for the lifespan of the building system or equipment. This desire for greater policy alignment is sparking continued interest in understanding the energy performance outcomes resulting from current energy codes.

In this study, Pacific Northwest National Laboratory (PNNL) used energy models to investigate variation in energy performance outcomes for prototype buildings compliant with the minimum requirements of the prescriptive path of ASHRAE Standard 90.1-2022 (Standard 90.1-2022). The analysis focused on how much variation in energy performance is obtained by changing the physical infrastructure in prototype buildings, while maintaining compliance with the prescriptive energy code minimum requirements and holding all operational factors constant. The models were generated to span a range of code compliant design solutions and were not weighted to reflect their likelihood of real-world occurrence. The annual energy use of the simulated buildings varied by a factor of 1.6 to 2.2 times depending on the building use type.

Methodology

Approach

The study included three building use types: multifamily housing, office, and retail. PNNL evaluated the performance variability for these building use types using the prescriptive path of Standard 90.1-2022 in four different ASHRAE climate zones: 2A, 4A, 5B and 6A. PNNL identified a matrix of design features that may vary when implementing the prescriptive code path requirements and simulated all valid combinations from that parameter space, while holding constant operational variables such as the modeled schedules of operation, occupancy and other internal load densities. This process resulted in more than 160,000 energy model simulations.

Commercial Building Prototypes

DOE's commercial building prototype models (DOE 2023a; Lei et al. 2020) were created to support the development and evaluation of building energy codes. PNNL used the Standard 90.1-2022 prototype models for Medium Office, Stand-alone Retail, and Mid-Rise Apartment prototypes to represent hypothetical buildings that might be constructed in the near future. These three prototypes represent 22.2% of national new construction floor area. When including other related prototypes (Large Office, Small Office, Strip Mall, and High-rise Apartment,) these building use types represent 38% of national new construction floor area (Lei et al. 2020). The analysis used typical weather year data for Tampa, Florida (climate zone 2A); New York City, New York (climate zone 4A); Denver, Colorado (climate zone 5B) and Rochester, Minnesota (climate zone 6A) (DOE 2023b).

Figure 1 shows the geometry of the prototype models used in the analysis. Note that the glazing amounts shown in the image do not reflect the values used throughout the analysis. Variation of glazing amounts and other model parameters is discussed in the following section.

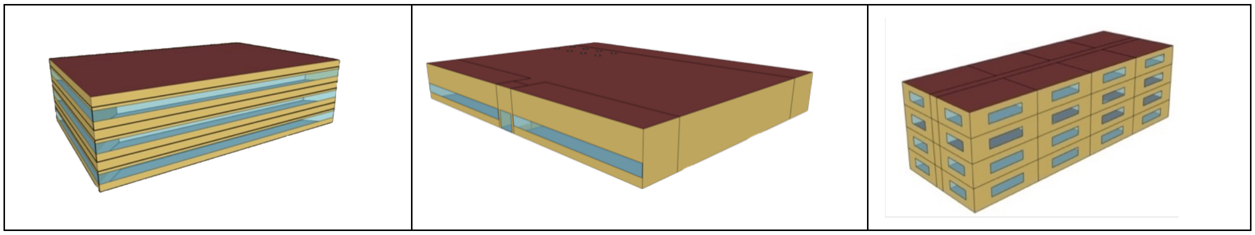

Figure 1. Commercial building prototype geometry. From left: Medium Office, Stand-alone Retail, Mid-rise Apartment.

Variations to the Prototypes

The analysis modified various performance parameters of the prototype building design, while maintaining minimum compliance with the prescriptive path of Standard 90.1-2022, to generate model variants. The model variants included design changes to the building envelope systems, HVAC systems, service water heating systems, and lighting systems. All of the model variants comply with, but do not exceed the requirements of the prescriptive path of Standard 90.1-2022.

Parameters for building envelope variations including the roof construction, wall construction, glazing area, glazing operability/performance, and building orientation are listed below. Some of these envelope design parameters result in U-value modifications. For example, when building designers choose to include operable windows instead of fixed windows in their building design, the prescriptive path of Standard 90.1-2022 allows a higher U-value window. U-values for climate zone 4A are listed below, however the analysis included the applicable prescriptive code requirements for each climate zone, per Standard 90.1-2022 Table 5.5.

- Glazing Area (% of gross wall area): **20% / 30% / 40%**
- Glazing Operability: **Fixed windows** (CZ 4A U-value = 0.38) **/ Operable Windows** (CZ 4A U-value = 0.45)

- Roof Construction Type: **Insulation above deck** (CZ 4A U-value = 0.032) / **Attic** (CZ 4A U-value = 0.027)
- Wall Construction Type: **Metal frame construction** (CZ 4A U-value = 0.064) / **Mass Wall Construction** (CZ 4A U-value = 0.090)
- Building Orientation: **0° Rotation / 90° Rotation**

Many different HVAC system types may be designed under the prescriptive path. When a system designer chooses a system type, the designer must ensure all equipment and other system design characteristics comply with the requirements of the energy code. Some HVAC system technologies are typically more energy efficient than others. For example, a heat pump heating system minimally compliant with the prescriptive code is more energy efficient than a minimally compliant electric resistance or gas-fired heating system. To reflect the range of energy performance outcomes using different HVAC systems, PNNL selected a variety of HVAC systems to simulate. Table 1 lists the HVAC systems applied in the analysis and indicates which systems were applied to each building. The analysis included 18 different HVAC system types.

Table 1. HVAC system types and application to building use types

HVAC system type	Medium Office	Stand-alone Retail	Mid-rise Apartment
Split or packaged air conditioner (AC) with gas furnace	x	x	x
Split or packaged air conditioner (AC) with electric resistance heat	x	x	x
Split or packaged heat pump (HP)	x	x	x
Packaged terminal air conditioner (PTAC) with hot water heat			x
Packaged terminal air conditioner (PTAC) with electric resistance heat			x
Packaged terminal heat pump (PTHP)			x
Four pipe fan coil unit (FCU) with water-cooled chiller and gas boiler			x
Variable refrigerant flow (VRF)	x	x	x
Ground source heat pump (HP)	x	x	x
Water source heat pump (WSHP) with gas boiler and cooling tower	x	x	x
Water source heat pump (WSHP) with electric boiler and cooling tower	x	x	x
Water source heat pump (WSHP) with air-water heat pump and cooling tower	x	x	x
VAV (variable air volume) reheat with air-cooled chiller and gas boiler	x		
VAV reheat with water-cooled chiller and gas boiler	x		
VAV reheat with air-cooled chiller and electric reheat	x		
VAV reheat with water-cooled chiller and electric reheat	x		
VAV reheat with water-cooled chiller and air to water heat pump heat	x		
Packaged D/X (direct expansion) VAV reheat with gas boiler	x		
Packaged D/X VAV reheat with electric resistance heat	x		
Packaged D/X VAV reheat with air to water heat pump heat	x		
Count	16	8	12

The HVAC systems were configured and controlled in the simulations in accordance with all the Standard 90.1-2022 prescriptive path requirements. Note that for the Mid-rise Apartment, airside economizer was excluded from apartment systems for all model variants. The analysis assumed those systems qualify for exception 6 to Section 6.5.1 of Standard 90.1-2022, that allows individual fan systems with capacities below 22.5 tons serving residential spaces to exclude airside economizer. Airside economizer was also excluded from the three water source heat pump systems, the ground source heat pump system, and the variable refrigerant flow system for all variants, assuming those systems qualify for exception 1 to Section 6.5.1 of Standard 90.1-2022, that allows individual fan systems with capacities below 4.5 tons to exclude airside economizer.

The analysis also included the following variations to some HVAC system parameters that are allowable on the Standard 90.1-2022 prescriptive path:

- Higher and Lower airside system fan power values (reflecting the fan power allowances for optional equipment pressure drops such as high efficiency filtration, or heat recovery devices.)
- Removing airside economizer, using the exception 1 to Section 6.5.1 of Standard 90.1-2022, that allows small cooling capacity systems (less then 54,000 Btu/h) to exclude airside economizer. Because single zone systems are most likely to meet the capacity restrictions for this exception, model variations without airside economizer were only applied to the three single zone “split or packaged” systems with direct expansion (DX) cooling (from Table 1: “split or packaged air conditioner with gas furnace,” “split or packaged air conditioner with electric resistance heat,” “split or packaged heat pump”).
- Equipment efficiency differences based on equipment size (heating or cooling capacity). Equipment efficiency is regulated in Tables 6.8.1(1-21) of Standard 90.1-2022, but the requirements vary based on the capacity of the equipment. Equipment size could vary in a building depending on how the HVAC system designer sets up thermal zones. PNNL included “Lower” capacity and “Higher” capacity equipment to reflect the possible variation in code required equipment efficiency.

The HVAC system related parameters included in the analysis are listed below:

- Fan Power: **Low fan power** (2.5 in. w.g. TSP constant volume fans; 4.0 in. w.g. TSP variable volume fans) **/ High fan power** (4.1 in. w.g. TSP constant volume fans; 5.6 in. w.g. TSP variable volume fans)
- Economizer operation: **No airside economizer / Airside economizer**. This parameter variation was applied only for the three single zone “split or packaged” system options: “split or packaged air conditioner with gas furnace,” “split or packaged air conditioner with electric resistance heat,” “split or packaged heat pump.”
- Capacity of individual equipment: **Lower capacity equipment** (lower range of efficiency from Tables 6.8.1 (1-21)) **/ Higher capacity equipment** (higher range of efficiency from Tables 6.8.1 (1-21))

Many different service water heating system types may be designed under the Standard 90.1-2022 prescriptive path. Just as for HVAC systems, there are inherent efficiency differences based on the technologies deployed. To capture the energy performance of different water heating systems, the analysis included six service water heating system types. The systems are listed in Table 2 including indication of which systems were applied to each building use type.

Table 2. Service water heating system types and application to building use types

Service water heating system type	Medium Office	Stand-alone Retail	Mid-rise Apartment
Electric tankless, in-unit			x
Electric storage, in-unit			x
Gas storage, in-unit			x
Electric resistance storage, central with circulation loop	x	x	x
Heat pump storage, central with circulation loop	x	x	x
Gas storage, central with circulation loop	x	x	x

The lighting power values used in the simulations are the maximum allowed by Standard 90.1-2022. The lighting schedules represent typical prototype schedule values, as documented for the Standard 90.1 Commercial Prototype Building scorecard spreadsheet (DOE 2023a). The prescriptive path of Standard 90.1-2022 provides for additional interior lighting power for both decorative lighting and retail display lighting in Section 9.5.2.2. To reflect this allowed addition of lighting power under the prescriptive code path, PNNL simulated three different options for retail display lighting, and two options for decorative lighting. Retail display lighting was applied at retail sales spaces in the Stand-alone Retail models. Decorative lighting was applied to the Medium Office models and to the corridors in the Mid-rise Apartment models.

The lighting system related parameters included in the analysis are summarized in the list below:

- Retail display lighting allowance, calculated from Table 9.5.2.2(b) assuming 1,000 sf retail spaces with 50% of the floor area for sales: **None / Med** (Retail 2 = 0.9 w/sf additional lighting power) **/ High** (Retail 4 = 1.125 w/sf additional lighting power)
- Decorative lighting allowance, calculated from (Table 9.5.2.2)(a): **None / Med** (Office: 0.109 w/sf, Corridors: 0.175 w/sf)

Additional Efficiency Measures

To achieve compliance using the prescriptive path of Standard 90.1-2022, additional efficiency measures must be incorporated into the building design to earn the required number of energy credits, as specified in Chapter 11 of the standard. In practice, these measures are chosen by the building design team from a set of available options detailed in the code. PNNL selected measure packages for each of the prototypes and included those packages in the simulations. Where the other design options of a model variant in the analysis would earn energy credits (for example ground source heat pump HVAC system type, or heat pump service water heating system, the energy credits package was adjusted accordingly so that only the required number of energy credits is earned by each design variant.

Results and Discussion

Range of Energy Performance in Prescriptive Code Compliant Buildings

Simulating all possible variations to the models resulted in 40,176 unique energy model variants, resulting in 160,704 total simulation runs across the four climate zones. For each subset of models grouped by building prototype and climate zone, Table 3 shows the number of models in the subset, the range of modeled EUI results and the ratio of the maximum EUI to the minimum EUI.

Table 3. EUI for model subsets grouped by prototype model and climate zone

Prototype model subset	ASHRAE Climate Zone	Standard Prototype (PNNL 2023) Net Site EUI (kBtu/ft^2/yr)	Minimum Model Net Site EUI (kBtu/ft^2/yr)	Maximum Model Net Site EUI (kBtu/ft^2/yr)	Ratio: (Max EUI/Min EUI)	Number of Models in Subset
Medium Office	2A	24.7	20.8	34.5	1.7	16,992
Medium Office	4A	25.3	20.5	32.3	1.6	16,992
Medium Office	5B	24.2	19.9	32.1	1.6	16,992
Medium Office	6A	31.2	21.2	40.7	1.9	16,992
Mid-rise Apartment	2A	32.0	24.7	42.3	1.7	11,520
Mid-rise Apartment	4A	34.4	24.2	45.0	1.9	11,520
Mid-rise Apartment	5B	33.2	23.7	43.4	1.8	11,520
Mid-rise Apartment	6A	42.8	25.6	55.2	2.2	11,520
Stand-alone Retail	2A	32.2	28.0	58.9	2.1	11,664
Stand-alone Retail	4A	38.1	27.4	52.9	1.9	11,664
Stand-alone Retail	5B	36.4	27.8	52.9	1.9	11,664
Stand-alone Retail	6A	51.8	31.2	67.6	2.2	11,664

Although all the modeled buildings minimally comply with, but do not exceed prescriptive energy code, the ratio of maximum to minimum energy performance varies from 1.5 to 2.1. These results demonstrate that the Standard 90.1-2022 prescriptive path allows a wide range of potential building energy performance outcomes. The previously discussed differences in the building envelope, HVAC system types, service water heating system types, lighting, and additional efficiency measures are the root cause of this substantial energy variation. Figures 2 through 4 show results for ASHRAE Climate Zone 4A, for each building type as a histogram, with the site EUI as the x-axis. A lower site EUI indicates a more energy efficient building. Each figure includes a red vertical line indicating the EUI for the standard version of the prototype model (PNNL 2023). The standard version for each building prototype is a configuration, as selected by the ASHRAE 90.1 committee, intended to represent good, standard design options.

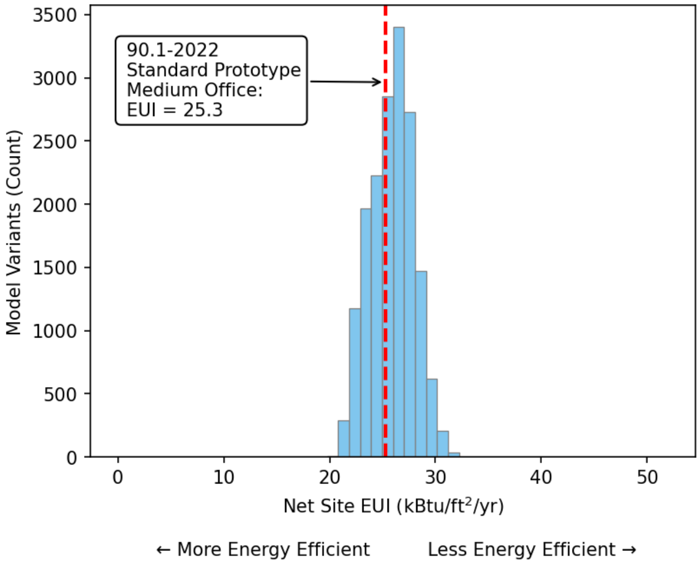

Figure 2. Medium Office, climate zone 4A: modeled net site EUI. 16,992 model variants.

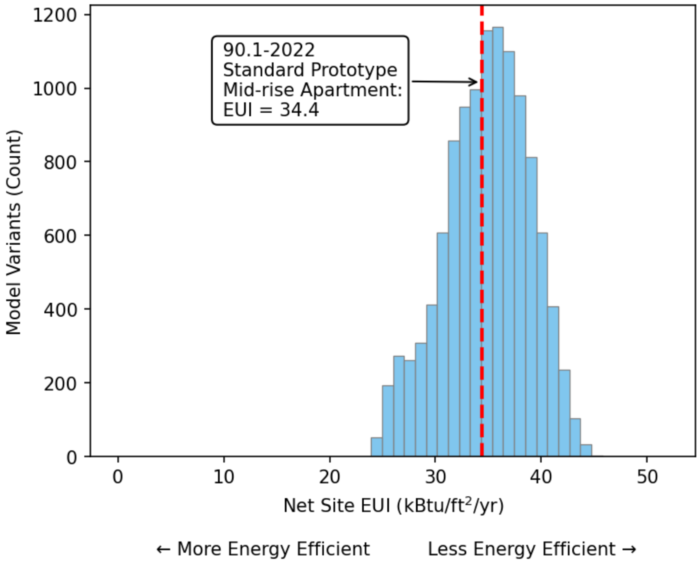

Figure 3. Mid-rise Apartment, climate zone 4A: modeled net site EUI. 11,520 model variants.

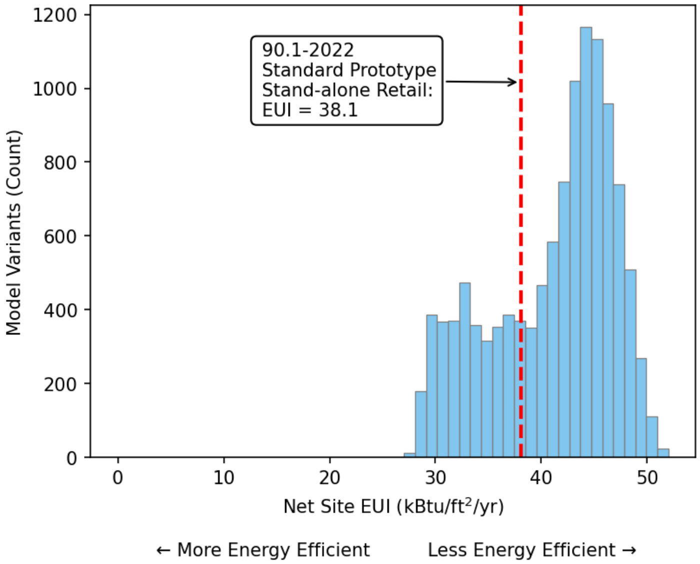

Figure 4. Stand-alone Retail, climate zone 4A: modeled net site EUI. 11,664 model variants.

Influential Model Parameters

This analysis also explored the most influential building parameters using random forest analysis' feature importance. Each building use type was individually examined to identify the parameters that had the most substantial impact on the modeled EUI. The following findings were identified:

- HVAC system type was one of the four most influential parameters for all the building types.
- Window to wall ratio was an influential factor for the Medium Office and Mid-rise Apartment prototypes but was not highly influential for the Stand-alone Retail prototype.
- For the Mid-rise Apartment prototypes, service water heating system type was the most influential parameter, followed by HVAC system type.
- For both Medium Office and Stand-alone Retail, additional lighting power (for decorative or display purposes) was the most influential parameter, followed by fan power level.

Figures 5 through 7 are strip plots with each model variant EUI represented as a point in the graph. Key parameters of each variant are shown in different colors and the model variant EUI is represented along the x-axis. These plots help compare the performance variation resulting from changing a specific design feature in the energy model.

Medium Office HVAC Systems.

HVAC system choice was among the four most influential factors for all the model prototypes. The energy performance of the Medium Office model variants grouped by HVAC system type is shown in Figure 5. The color of each point on the plot represents the percent electricity of total energy use for that model variant (refer to the legend). Those with 100% electric energy are blue (electric heating and electric service water heating), while those with the lowest percentage of electric energy (~65%) are red. The % electricity for a model is driven by the space heating fuel and the service water heating fuel since all other energy uses are electric.

In Figure 5, HVAC systems with gas or electric resistance for heating tend to have a higher range of EUI values, since heat pumps deliver heating energy at higher efficiencies. There is a lot of overlap in the of EUI performance range achieved by different HVAC system options. Some model variants with HVAC systems using gas or electric resistance heating obtain the same EUI performance as model variants with HVAC systems using heat pump heating, despite the heating efficiency penalty. The plot shows the highest variation in EUI within the three single zone "split or packaged" systems (first three rows from Table 1). These three systems are constant volume and are the only systems where an airside economizer can be toggled off – a parameter change that resulted in substantially higher EUIs.

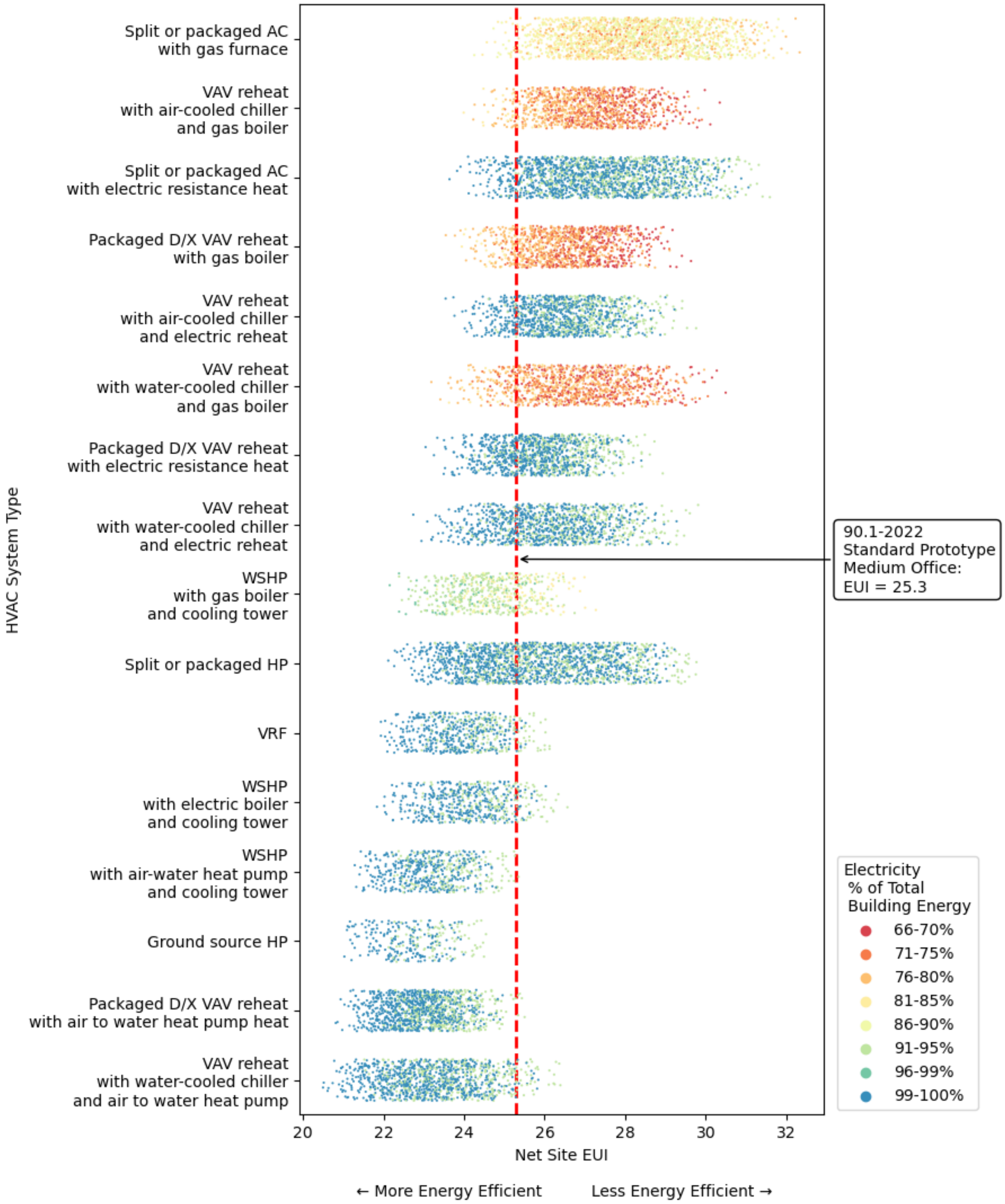

Figure 5. Medium Office, climate zone 4A: modeled site EUI. 16,992 model variants.

Comparing with the standard prototype EUI target of 25.3 kBtu/ft2/yr for Offices as an example, Figure 5 shows that any of the HVAC system types in the Medium Office analysis achieved that target value for at least some of the model variants. However, for some of the HVAC system types the target is near the very lowest model EUI results and for others the target is near the very highest model EUI results. By choosing one of the more efficient HVAC system types near the bottom of the plot, a design team would set the building on track to more readily achieving an EUI target in the future, especially if targets reduce over time. Choosing one of the most efficient HVAC systems can give building designers greater latitude with other design choices while still achieving energy performance targets. It can also give building operators greater latitude to operate their systems to meet BPS energy performance targets.

Stand-alone Retail lighting.

Figure 6 is a graph for the Stand-alone Retail modeling results in climate zone 4A, which visually highlights the impact of additional display lighting on the building model EUI. The color of the data points indicates whether that model variant includes "None" "Medium," or "High" levels of retail display lighting.

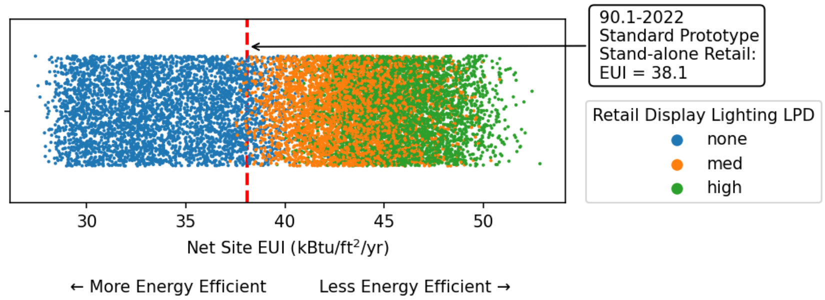

Figure 6. Stand-alone Retail, climate zone 4A: modeled site EUI. 11,664 model variants.

When display lighting allowances are fully used the energy impact is substantial. When compared against the median EUI of the climate zone 4A Stand-alone Retail model variants without retail display lighting (33.5 kBtu/ft2/yr), the median EUI for the climate zone 4A Stand-alone Retail model variants with "High" display lighting power density (45.6 kBtu/ft2/yr), is 36% higher.

Mid-rise Apartment service water heating.

The strong influence of service water heating system type on the EUI results for the Mid-rise Apartment models is visually apparent in the plot shown in Figure 7 for climate zone 4A. Each point on the plot represents the EUI result for a model variant. The plotted data points are grouped into rows, where each row contains the data for an HVAC system type, as indicated along the y-axis. The color of each point on the plot represents the service water heating system type (refer to the legend). Apartment buildings have relatively high service hot water use. The service water heating percentage of total energy in the Mid-rise Apartment model variants ranges from 11% to 45%, while it is less than 11% of total energy for the Medium Office variants.

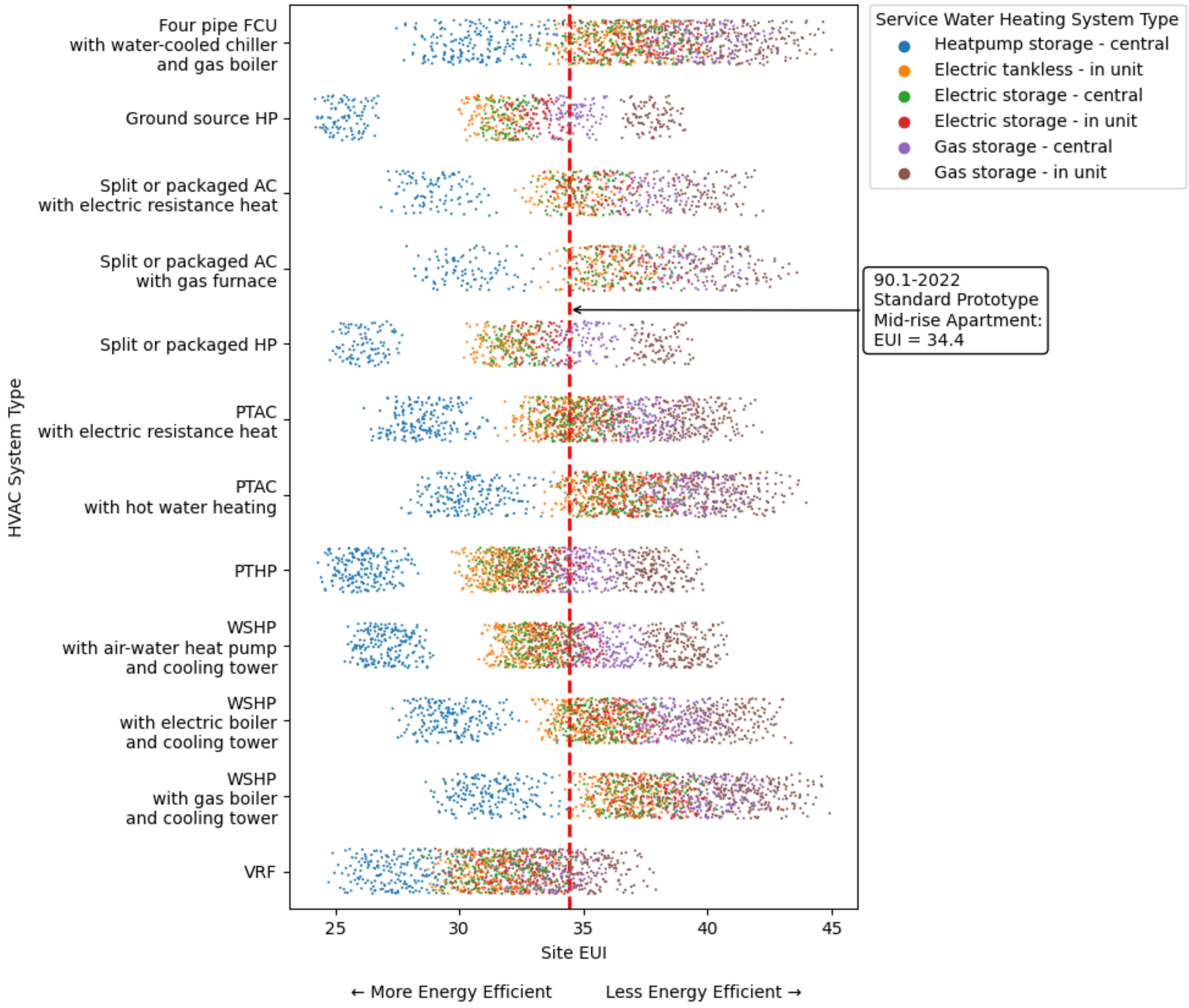

Figure 7. Mid-rise Apartment, climate zone 4A: modeled site EUI. 11,520 model variants.

Conclusions

Innovative energy policies are elevating the importance of understanding performance outcomes for newly constructed and existing buildings. Net zero energy codes and BPS polices are two examples of this. Net zero energy codes will result in net zero buildings only if the renewable energy generation requirement in the code truly offsets the operational energy use of the code compliant buildings. BPS policies directly regulate operational energy performance of existing buildings. In the context of these performance focused policies, energy codes have a continued vital role to ensure that new buildings are equipped to meet the policy-targeted performance outcomes.

This analysis assessed the variation in energy outcomes for protype buildings using the prescriptive compliance path of Standard 90.1-2022. The results indicate, when holding operational assumptions (schedules, internal loads, weather) constant, that the potential design differences across a set of minimally compliant prescriptive buildings will result in a substantial variation in whole building energy performance. Depending on building type, the worst performing building models used from 1.6 times to 2.2 times more energy than the best performers.

Ultimately, meeting performance-based policy goals may require shifting away from or severely restricting prescriptive energy code pathways, toward performance pathways. If prescriptive pathways are to be retained (a desire of many stakeholders), various energy code policy options need to be considered to reduce the range of performance outcomes. These policy options might include:

- Increase the stringency of the energy code by removing prescriptive options that result in higher energy use. Designers could still use the whole building performance compliance approach for designs that include these options.
- Continue points-based energy credit requirements, such as the current energy credit requirements in ASHRAE 90.1-2022, with the following modifications:
    - Calibrate energy credit points to a baseline representing the most energy intensive minimally compliant prescriptive building that the code allows.
    - In addition to energy credits that incentivize exceeding minimum prescriptive criteria, adopt new credits that incentivize selecting different minimally prescriptive requirements with a higher energy performance than the baseline. For example, credits could be earned for selecting minimum efficiency heat pump heating instead of electric resistance heating.
    - Select an energy credit point target that can be met by some of the minimally compliant prescriptive building designs. Some designs would meet the energy credit point target due to the minimally compliant prescriptive design elements selected for the design; other designs would need to earn credits for increased efficiency above prescriptive minimum levels to meet the energy credit point target.
    - Align the energy credit point target with policy-targeted performance outcomes (BPS performance targets or net zero energy code EUI values/requirements for renewable energy generation).

  This new approach to energy credits would incentivize higher performing prescriptive code compliance outcomes and help ensure new construction energy performance outcomes meet the goals targeted by energy policies.
- Require a predictive energy model be submitted with the permit application. A predictive energy model is different from a code compliance energy model in that more attention is given to characterize the anticipated operation of the proposed building. The predictive energy model would encourage design teams to consider future performance targets and where applicable, would provide an opportunity for the AHJ (authority having jurisdiction) to engage with the building owner to discuss future BPS policy requirements (Karpman et al. 2024).

Because energy use in buildings is not determined solely by the physical infrastructure that energy codes primarily regulate, policymakers and other stakeholders should pursue programs and policies that support user success in operating buildings efficiently over their lifespan:

- Require development and transparency of building energy use data through energy benchmarking and disclosure policies (DOE 2024b).
- Increase requirements for submetering and monitoring equipment to provide building operators and owners information to understand their building's energy use and identify faults and opportunities for improvement.
- Increase commissioning and O&M requirements to support verification of performance according to the design intent and the ongoing maintenance of systems to ensure performance.
- Support occupant feedback on energy consumption, and occupant engagement on energy use reduction goals. When tenants are aware of their ability to influence building energy use, they can better collaborate with building owners to reduce energy use in buildings (EPA 2024).
- Educate design teams and owners on the importance of building energy performance so they will be more likely to consider performance during design and construction.

Energy efficient infrastructure and the efficient operation of that infrastructure are both critical elements in meeting societal goals to reduce building energy use and associated emissions.

References

ASHRAE. 2022. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA. ASHRAE.

DOE. 2024a. "Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector" Department of Energy, Office of Energy Efficiency and Renewable Energy. Accessed February 21, 2024. https://www.energy.gov/eere/decarbonizing-us-economy-2050-national-blueprint-buildings-sector.

DOE. 2024b. "State and Local Energy Benchmarking and Disclosure Policy" Department of Energy, Office of Energy Efficiency and Renewable Energy. Accessed February 28, 2024. https://www.energy.gov/scep/slsc/state-and-local-energy-benchmarking-and-disclosure-policy.

DOE. 2023a. "Prototype Building Models" Department of Energy, Office of Energy Efficiency and Renewable Energy. Accessed December 8, 2023. https://www.energycodes.gov/prototype-building-models.

DOE. 2023b. “Prototype Building Models – TMY3 Weather Files: Tampa/MacDill AFB, Florida; New York/John F Kennedy International Airport, New York; Denver/Aurora/Buckley AFB, Colorado; Rochester International Airport, Minnesota. Department of Energy, Building Technologies Office. Accessed December 8, 2023. https://www.energycodes.gov/prototype-building-models.

DOE. 2023c. Energy Codes and Building Performance Standards. Department of Energy, Office of Energy Efficiency and Renewable Energy. Washington, DC. https://www.energycodes.gov/sites/default/files/bps/2023-11/BPS_and_Energy_Codes_Guide.pdf.

EPA. 2024. “Successes in Sustainability: Landlords and Tenants Team Up to Improve Energy Efficiency” Environmental Protection Agency. Washington, DC. Accessed March 1, 2024. https://www.energystar.gov/sites/default/files/buildings/tools/EPA_ES_Tenant_Report_508.pdf.

Karpman, M., M. Rosenberg, and A. Mengual, 2024. *Building Performance Standards and Energy Code Alignment*. Pacific Northwest National Laboratory PNNL-34451. Richland, WA. https://www.energycodes.gov/sites/default/files/bps/2024-06/BPS_and_Codes_Tech_Brief_April_2024.pdf.

Lei, X., J. Butzbaugh, Y. Chen, J. Zhang, and M. Rosenberg. 2020. Development of National New Construction Weighting Factors for the Commercial Building Prototype Analyses (2003-2018). Pacific Northwest National Laboratory PNNL-29787. Richland, WA. https://doi.org/10.2172/1764643.

PNNL. 2023. End-Use Breakdown Analysis Standard 90.1-2022. Building Energy Codes Program, Pacific Northwest National Laboratory. https://www.energycodes.gov/sites/default/files/2023-12/2022EndUseTables.zip.

Rosenberg, M., R. Hart, J. Zhang, and R. Athalye. 2015. Roadmap for the Future of Commercial Energy Codes. Pacific Northwest National Laboratory PNNL-24009. Richland, WA. https://www.osti.gov/biblio/1169376.