Can High-Performance Equipment Lead to a Low-Performance Building?

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ABSTRACT

The performance-based compliance alternative available in most energy codes, intended to provide energy efficiency equivalent to that of prescriptive compliance while allowing innovation and design flexibility, can instead result in sub-standard energy performance in both the short and the long term. The potential deficiencies in modeled buildings originate with subtleties in the energy modeling rules, allowing building systems that consume more energy than their real-world, prescriptively-designed counterparts. This performance gap is exacerbated over subsequent decades as less efficient permanent features of the building remain while elements with shorter lives are regularly upgraded in most buildings. This paper summarizes an investigation into the topic for Pacific Northwest National Laboratory and the City of Seattle, including identification of the principal deficiencies exploited in the modeling path, and several potential code amendments that could resolve these deficiencies and establish better equivalency between prescriptive and performance compliance paths. The study, focusing on Seattle and Washington State energy codes, offers lessons and implications for other jurisdictions and energy codes.

Introduction

Energy codes in North America typically provide a "performance path," an alternate compliance method based on energy modeling (ICC 2015, ANSI/ASHRAE/IESNA 2013). Using this method, the proposed project is compared with its virtual code-minimum identical twin. This allows capable design teams to balance the higher efficiency of some elements against other lower-performing but desirable components, creating a building that performs (on paper) just as well as that code-minimum twin building whose every regulated component performs exactly at the minimum efficiency level defined in the energy code. As prescriptive codes become more stringent and jurisdictions and code promulgating bodies strive to reach aggressive energy reduction goals, reliance on performance based compliance will likely become more common. Therefore, it is imperative that this path does not become a loophole leading to less efficient buildings. This paper summarizes an investigation into the topic by Efficiency Solutions and Thornton Energy Consulting for Pacific Northwest National Laboratory and the City of Seattle, including identification of the principal weaknesses in the performance path, and several potential code amendments that could resolve these deficiencies and establish better equivalency between prescriptive and performance compliance paths. The project, funded by the U.S.

Department of Energy, was inspired by the City of Seattle's commitment to achieving carbon neutral operations by the year 2050, including all of its buildings, vehicles, waste disposal and street lighting (Seattle, 2013)

In most cases, taken from a sample of performance compliance projects in Seattle, high-performing lighting and mechanical systems were traded for a building envelope with larger glazing areas, reduced slab edge insulation, and other changes that increase the building's heat loss and gain (Thornton et al. 2015). Avoidance of economizer requirements was another common trade-off. According to the logic of the performance path though, this shouldn't matter. Haven't the modeling calculations just demonstrated that the building will perform at least as well as the code requires? This would be true, but for two fundamental problems: The first problem is that the systems typically installed in real prescriptively-designed buildings are better – sometimes much better – than those modeled in the virtual code-minimum baseline building. The second problem is that different building systems have very different energy impacts over the course of a building's life.

How close to code minimum are real code minimum buildings?

In energy modeling, the standard reference model baseline case assumes that most components of the building are the worst-performing components allowed by code, while in reality a building will be composed of some elements that truly are "code-minimum," and others that are simply the least costly models in stock meeting code requirements. These latter elements can sometimes perform considerably better than code, unlike their virtual counterparts in the standard reference model. When the code minimum for roof insulation is R-5.5 SI (R-38 IP), that's just what will be installed in a prescriptively-designed building, no more and no less. Other components, such as lighting, fans and gas boilers in real buildings often have higher efficiencies than the prescriptive code minimum components assumed in energy modeling.

A savvy designer keeps in mind a list of building components that are relatively standard but that perform better than their respective code minimums, for use as trade-offs. Sometimes the anomalies that make up this list arise from unintentional loopholes in the code, but there are additional sources stemming from the pace of technological change. Between the year when a code edition is finalized and the year when a project applies for a permit under that code, energy technology continues to move forward, with LED lighting currently the most remarkable case in point. In addition, federal standards that define minimum equipment performance can paradoxically serve to worsen energy performance, because federal preemption law prevents the states from enacting anything more stringent, even as technology advances (42 U.S.C. 6297).

Some energy codes mitigate a portion of these differences between theoretical and real energy use, in addition to the potential inaccuracy and variability in implementation of energy models, by requiring the proposed building model to show less energy use than the standard reference building. In the Washington State code, the proposed model energy use must be 7% lower than the standard reference model, while in the International Energy Conservation Code (IECC) it must be lower still (ICC 2015)[1]. However as described above, the energy efficiency assumed in the standard reference model for certain systems can be worse than what is typical in their prescriptively-design peers.

[1] The difference is 15 percent in the IECC, but the additional efficiency credit from Section C406 is not required, making the net difference from prescriptive compliance closer to 11-12 percent.

How does building energy use evolve over time?

The facades of new commercial buildings remain largely intact for generations. These facades need relatively little maintenance to keep functioning as intended, although their energy performance can't be improved without significant investment and disruption. Meanwhile, the lighting, water heating and HVAC systems wear out or become obsolete every decade or two, and their replacements generally meet next generation codes and include the latest technology improvements. In addition, although the energy model assumes that these virtual components and their controls function perfectly, in real buildings they are frequently in need of tune-ups and repairs. When energy modeling calculations are performed, they often trade the theoretical energy savings of relatively unreliable and short-lived components (e.g. daylighting controls) for the reliable and long-lived energy conservation of a code-compliant building envelope. Consider the simplified example of a building complying prescriptively versus the same building complying through performance trade-offs shown in Table 1:

Table 1. Hypothetical prescriptive versus performance compliant buildings over time

Prescriptive compliance – No trade-off	Performance compliance – With trade-off
Year one	Year one
Roof insulation = R-5.3 SI (R-30 I-P)* (code minimum)	Roof insulation = R-3.5 SI (R-20 I-P) (below code minimum)
HVAC efficiency = 4.1 SCOP (14 SEER)* (code minimum)	HVAC efficiency = 5.0 SCOP (17 SEER) (higher efficiency required for trade-off)
Year 20	Year 20
Roof insulation = R-5.3 SI (R-30 I-P) (existing unchanged)	Roof insulation = R-3.5 SI (R-20 I-P) (existing remains substandard)
HVAC efficiency = 5.0 SCOP (17 SEER) (potential future code minimum)	HVAC efficiency = 5.0 SCOP (17 SEER) (potential future code minimum)

*R-xx I-P is thermal resistance, in $h \cdot ft^2 \cdot °F/Btu$, SEER is seasonal energy efficiency ratio, SCOP is seasonal coefficient of performance

Although the modeled (and perhaps actual) energy use of the two hypothetical buildings is comparable in year one, the "performance compliance" case is decidedly worse after the first HVAC equipment replacement cycle.

This is the essence of the second problem. When better-than-code HVAC efficiency is used in energy modeling to offset worse-than-code window performance, the additional window heat loss is likely to persist for the life of the building. However, twenty years later most buildings will have installed higher-efficiency HVAC systems, while those buildings with sub-standard envelopes will continue to require more space heating energy than their peers, and the gap will continue to widen over time. If a city or state goal is to reach carbon-neutrality at some future date, then new and extensively-remodeled buildings should be evaluated on how they're likely to be operating at that point in the future, not how they operate on opening day.

Insights from an expert review

In early 2015, the US Department of Energy awarded Seattle a “technical assistance” grant, administered by Pacific Northwest National Laboratory (PNNL), which retained Efficiency Solutions and Thornton Energy Consulting to propose solutions that would ensure that buildings following the performance-based compliance path would perform as well as prescriptively-designed buildings, decades into the future. A report detailing the study entitled Preserving Envelope Efficiency in Performance Based Code Compliance is available from Pacific Northwest National Laboratory (Thornton et al. 2015).

The study reviewed energy models from a number of recent Seattle permit submittals in order to determine which above- and below-code elements were typically utilized. Sixteen “Total Building Performance” energy modeling reports submitted to the Seattle Department of Planning and Development were examined. These include most of the buildings seeking compliance under the Total Building Performance method (Seattle 2012, Section C407) from October 2014 to March 2015, and a sample of older projects dating back to June 2013. These buildings include 530,000 m2 (5.7 million square feet) of occupied space plus additional enclosed parking areas and were primarily mid-rise and high-rise multi-family buildings and office buildings. Table 2 summarizes the characteristics of the buildings analyzed and identifies the trade-offs pursued. Table 3 provides additional detail regarding the trade-offs and identifies the energy end use categories that showed the greatest reduction in energy use.

Table 2 shows that most of the multi-family projects included worse than code wall U-values, some were missing economizers, and half included more than the Washington State code baseline of 30% allowable window to wall ratio (WWR). Most of the projects achieved these trade-offs primarily by use of fan controls and improved fan efficiency, along with condensing gas service water heating and/or space heating. The office buildings included more variability in trade-offs although most included greater than 30% WWR and most achieved savings with HVAC improvements.

The study considered the potential impact on envelope and building performance that could be allowed under the performance method. The example Seattle projects showed average savings of 15.7% when a 7% savings is sufficient to comply. These buildings could have varied further from the prescriptive envelope requirements and still met code. Of those projects that varied window to wall ratio (WWR) above the prescriptive 30% allowed, the average WWR was 40%. This average could have been even higher. Demand for expansive views from high-rise buildings remains very strong, particularly in the high-end residential and office markets, despite the consequent increase in HVAC equipment capacity.

Table 2. Significant energy modeling trade-offs

	10 multi family residential buildings										6 office buildings					
	High-rise							Mid-rise		Lo-rise	Hi-rise	Mid-rise				
Building area in m^2 (ft^2 x 1000)	37,800 (407)	30,500 (328)	38,800 (418)	20,100 (216)	46,800 (504)	50.600 (545)	45,000 (484)*	19,900 (214)	22,900 (247)	11,600 (125)	105.900 (1,140)	9,400 (101)**	16,600 (179)**	26,400 (284)	16,700 (180)***	29,800 (321)***
Worse than code																
Wall U-value	X	X	X			X	X	X	X	X	X					
Roof U-value							X			X						
Window area				X		X		X	X		X		X	X	X	
Window SHGC†																X
Economizer	X	X	X	X		X		X	X	X	X	X				
Better than code: Most significant impact																
Space heating (gas)	X			X	X						X	X	X		X	X
Fan efficiency/operation	X	X	X		X	X	X	X	X	X	X		X			X
Cooling efficiency						X	X	X								
Heat/cool efficiency										X				X		
Pumping														X		
Water heating (gas)	X	X	X	X	X	X	X	X	X	X						
Lighting			X	X					X				X			X

*with hotel spaces **with lab spaces ***with retail spaces †SHGC is Solar heat Gain Coefficient

Table 3. Building characteristics and trade-offs for performance based code compliance

Building Type	Occupied Area in m^2 (ft^2)	Areas Worse than Code	Areas Better than Code	Top three energy savings categories
High-rise Multi-family	37,800 (407,000)	wall u-values, economizers	condensing boiler, WSHP heat/cool and fan efficiency, ventilation fan operation, condensing service water heating (SWH)	heating (gas), fans, SWH[1] (gas)
High-rise Multi-family	3,500 (328,000)	wall u-values, economizers	ventilation fan operation, VRF heat/cool and fan efficiency, condensing SWH	fans, SWH (gas), cooling
High-rise Multi-family	38,800 (418,000)	wall u-values, economizers	ventilation fan operation, condensing SWH, parking lighting, stair lighting controls, efficient chillers, window SHGC	fans, SWH (gas), lighting
High-rise Multi-family	20,400 (216,000)	window area, economizers	condensing boiler (WSHP), condensing SWH, parking lighting	heating (gas), SWH (gas), lighting
High-rise Multi-family	46,800 (504,000)	window area, wall u-values, economizers	ventilation fan operation, condensing SWH, condensing boiler (WSHP), parking lighting	fans, SWH (gas), heating (gas)
High-rise Multi-family	50,600 (545,000)	window area, wall u-values, economizers	ventilation fan operation, condensing SWH, condensing boiler (WSHP), WSHP heat/cool efficiency, parking lighting	fans, SWH (gas), cooling
High-rise Multi-family /Hotel	45,800 (484,000)	wall and roof u-values	ventilation fan operation, condensing SWH, condensing boiler (WSHP), WSHP heat/cool efficiency, parking lighting	fans, SWH (gas), cooling
Mid-rise Multi-family	19,900 (214,000)	window area, wall u-values, economizers	ventilation fan operation, condensing SWH, parking and commons lighting, window u-value	fans, SWH (gas), lighting
Mid-rise Multi-family	22,900 (247,000)	window area, wall u-values, economizers	ventilation fan operation, VRF heat/cool and fan efficiency, condensing SWH, parking and commons lighting, window u-value	fans, SWH (gas), lighting
Low-rise Assisted Living	11,600 (125,000)	wall and roof u-values, economizers	ventilation fan operation, VRF and packaged terminal heat pump (PTHP) heat/cool and fan efficiency, condensing gas furnace for kitchen for	fans, SWH (gas) heating/cooling (electric)

			ventilation, window SHGC	
High-rise Office	105,900 (1,140,000)	window area and u-values, economizers	waste heat from off-site, condensing boilers, efficient chillers	fans, heating (gas)
Mid-rise Lab/Office	9,400 (101,000)	missing economizers	dedicated outdoor air system (DOAS) with energy recovery, efficient chiller and boiler, VRF for space heating/cooling	heating (gas)
Mid-rise Lab/Office	16,600 (179,000)	window area	chilled beams, lab lighting power, window, skylight, wall and roof u-values	heating (gas), fans, lighting
Mid-rise Office	26,400 (284,000)	window area	WSHP heat/cool efficiency, variable air volume (VAV) chiller efficiency, VAV fan power, pumping control, window u-value	cooling, heating (gas and electric), pumping
Mid-rise Office/Retail	16,700 (180,000)	window area	DOAS with energy recovery, VRF	heating (gas and electric)
Mid-rise Office/Retail	29,800 (321,000)	window SHGC	ventilation heat recovery, chilled beams, condensing boiler, interior lighting power, pumping control	heating (gas), fans, lighting

The study used energy modeling with prototype buildings to consider the potential for even greater envelope trade-offs. The modeling used Seattle climate data and the Seattle Energy Code baseline. This revealed that with combined savings from common strategies, such as improved service water heating (SWH) efficiency and HVAC system configuration and efficiency, very substantial trade-offs may be possible. The modeling also showed that once sufficient savings is achieved to reach the 7% minimum required, the additional savings needed to achieve high levels of envelope variance is more modest. For example, with the mid-rise apartment prototype, a 40% WWR can be achieved with a 20% reduction in both SWH and HVAC, and a 70% WWR can be achieved with 34% savings in both SWH and HVAC. Graphs and tables are presented in the study with the modeling results. There are technologies available for SWH efficiency, heat recovery and HVAC system configuration—such as dedicated outdoor air systems—that can achieve these higher levels of savings (Thornton et al. 2015). The analysis used energy end-use reduction to consider the potential for trade-offs rather than detailed modeling of the SWH and HVAC improvements, while modeling was used to analyze envelope changes and lighting power density variations.

The study also looked at the impact of varying envelope performance. In addition to increasing annual energy use, building envelopes that are worse than prescriptive code requirements increase peak heating and cooling demands, thus requiring larger and potentially more complex HVAC systems. They may also increase peak electricity demand, requiring larger building power systems and, if a large number of buildings are affected, larger electric utility systems. The energy modeling revealed that the impact on peak heating and cooling and in some cases electricity demand was significantly greater than the impact on energy usage. For example, with the medium office prototype, a 50% WWR compared to a 30% baseline WWR resulted in a 5.6% increase in energy usage. This also resulted in a 16.1% increase in cooling capacity requirements, a 12.4% increase in heating capacity requirements and a 14.4% increase in peak electricity demand.

Based on a review of these 16 projects, the consultants identified several major issues with the performance path that could adversely impact energy efficiency, peak HVAC capacity requirements and electricity demand, and then identified a set of potential code changes to help remedy those problems. Some of the major issues and proposed solutions identified in the report are summarized below.

4.1 Causes.

Examples of four fundamental problems uncovered with the performance path include:

1. Errors embedded in the modeling rules. A flaw in the IECC's energy modeling rules regarding fan power was highlighted by the PNNL/Thornton study (ICC 2013, Section 2.1). The code used the fan power of central ducted systems as the baseline for zonal fan coil systems that in reality use only about 40% as much fan energy, and it used constant volume fan energy as a baseline for HVAC systems that run many hours at reduced speeds (ICC 2013, Section 2.1). Code amendments are now in process for the Washington State code to correct these flaws (Washington State, 2015). These will subsequently be incorporated into the 2015 Seattle code and proposed for inclusion in the 2018 IECC.

2. Rapidly-evolving technology. The advent of cost-effective LED lighting has made it easy to beat the maximum lighting power density (LPD) allowed by the code. LED technology has already become the norm in several categories of lighting, including downlights, high-bay lighting, exterior lighting and parking garage lighting (VA 2014). Although linear fluorescent fixtures have themselves improved significantly in the past few years, LED technology is rapidly making inroads in that market sector as well (DOE 2015). Currently however, energy modelers can still incorporate the old LPDs as an artificially low baseline standard, even while their clients are installing high-efficiency lighting as a matter of course.

3. Outdated federal standards. A large portion of the gas-fired boilers for space heating and service water heating installed in new construction today are condensing-type boilers with efficiency ratings over 92%. However, a federal standard in place since 1992 holds the required efficiency requirement down around 80% (LBL 2012), and the federal preemption clause prohibits states and cities from imposing any more stringent rule. Thus energy modelers can continue to use 80% efficient boilers for their baseline model, even while the higher-efficiency condensing boilers are now the typical standard, at least in the Seattle market. Also, condensing boiler energy usage may be higher in practice than in some energy models which may over-simplify boiler efficiency that varies with return water temperatures and part-load conditions.

4. Comfort impacts of less efficient glazing. One aspect of performance modeling that is generally not accounted for is that higher U-factors or increased glazing area can decrease occupant comfort, leading to changes in heating or cooling setpoints, and consequent increases in energy use.

4.2 Solutions.

Among the most common objectives for using energy modeling instead of prescriptive compliance are increases in the allowable window area and reductions to insulation levels. If the city's intent is to achieve carbon neutrality over the next three to four decades, envelope systems that may well last the entire life of the building should carry more weight in the trade-off formula than shorter-lived components. The PNNL/Thornton study identified several potential pathways to achieve this balance:

1. Update the energy code to incorporate newer technology. For example, proposed changes to the Washington State Energy Code would reduce the lighting power allowance 20% below the current standards and require dedicated outside air systems (DOAS) or high-performance variable air volume systems for many HVAC applications.

2. Eliminate energy modeling loopholes. Ensure that the performance path is kept free of loopholes that artificially inflate the baseline building energy use. A proposed change to the Washington State Energy Code would reduce the baseline fan power allowance for zonal fan coil systems.

3. Account for rapidly changing technology and construction practice. In the performance path account for the fact that almost every prescriptively designed building will include some systems or components that exceed the minimum code requirements. Some buffer may be necessary in the performance path (such as Washington State's 7%) to ensure that buildings designed under the performance path do not use more energy than those designed prescriptively.

4. Place a cap on envelope compromises. One possibility would be to limit the overall heat loss of the building envelope to some set percentage greater than that of a building with prescriptive window area and other building envelope components. The report (Thornton et al. 2015, Section 4.3) concludes that a value 25% above that baseline would still have permitted all of the modeled design submittals that were examined in this research, but would disallow designs with significantly greater heat loss.

5. Incorporate the ASHRAE 90.1 glazing limits. Instead of a straight-across glazing limit of 30% of the wall area for all building types, the baseline case for glazing area could be different for each building type, based on a modified version of ASHRAE 90.1, Appendix G, as shown in Table 4. These allowable glazing areas would range from 6% for warehouses to 30% for offices, corresponding to the typical fenestration areas for each occupancy type. Tradeoffs would still be allowed, but the baseline case would utilize the glazing area percentage shown in the table, and any additional fenestration area would then be balanced by additional efficiency in other systems.

Table 4. Performance path baseline window-to wall ratio (WWR).

Building Type	WWR
Grocery Store	7%
Healthcare (outpatient)	21%
Hospital	27%
Hotel/motel (≤75 rooms)	24%
Hotel/motel (> 75 rooms)	30%
Office (≤464 m2) (≤5000 ft2)	19%
Office (464 m2 – 4645 m2)	30%
Office (>4645 m2) (>50,000 ft2)	30%
Restaurant (quick service)	30%
Restaurant (full service)	24%
Retail (standalone)	11%
Retail (strip mall)	20%
School (primary)	22%
School (secondary and university)	22%

Warehouse (non-refrigerated)	6%

6. Weight envelope energy deficiencies more heavily. Another proposed solution would be to incorporate a factor in the modeling calculation to account for the longer life of the envelope in the performance analysis. This could be done by requiring full or simplified life-cycle cost analysis of all building components and energy usage.

A simplified method is described in the report (Thornton et al. 2015, Section 5.0), which suggests that a 40-year life be assumed for the envelope and a 20-year life for all other systems. The energy impact of the envelope would then simply be doubled relative to other energy impacts according to the following procedure:

After creating a proposed building model, the analyst would remove the impact of the building envelope component trade-offs by replacing them in the model with code baseline values. This allows quantification of only the envelope trade-offs by whatever metric is appropriate for the code (i.e., site energy, source energy, energy cost, or greenhouse gas emissions). Then, the analyst would double the value of the envelope impact on energy usage, add it to the proposed design energy usage, and compare the result to the code baseline to determine compliance.

Note that a code requirement such as the above would have to be carefully constructed in order not to run afoul of federal law (42 U.S.C. 6297). This law, a clarification of federal preemption rules, requires that such a trade-off formula in an energy code function as “a one-for-one equivalent energy use or equivalent cost basis” in order to not have the effect of requiring mechanical equipment to be more efficient than otherwise required by federal standards. Since the code concepts addressed in this paper do not require higher-efficiency equipment, and in fact have the effect of limiting such trade-offs, they may pass legal muster.

Conclusion and Policy Implications

The City of Seattle is committed to achieving carbon neutral operations by the year 2050. Certainly, the envelopes of Seattle buildings that are designed and properly constructed today will not be substantially upgraded during those 35 years. To reach the city’s carbon-neutral target, long-lived components such as the building envelope and basic HVAC system type must be constructed now to meet that 2050 standard. This will be politically challenging. It may turn out that some long-lived components, built today to the standard required for a carbon-neutral 2050, have unacceptably long payback periods. Seattle would then be faced with three choices: abandon (or postpone) its 2050 target, change policies (incentives, utility costs or taxes) that would alter the cost-effectiveness of achieving the target, or mandate the higher-level efficiency despite the additional construction cost.

The performance path embedded in our energy codes is generally expected to provide energy efficiency over a building’s life at least on par with that of prescriptively-designed buildings. Such equivalency is not always achieved, and steps should be taken to ensure that the two compliance paths are harmonized. The first demand that should be made when code compliance is based on energy modeling calculations is that a building designed under this compliance path must be at least as efficient as a real-world prescriptively-designed building and not merely a virtual code-minimum building. The second demand should be that short-lived efficiencies are not traded on an equal basis for long-term deficiencies. Energy modeling should be structured to provide a useful alternate pathway for achieving, not evading, the energy and carbon emission reductions that form the fundamental intent of our energy conservation codes.

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