Potential Energy Cost Savings from Increased Commercial Energy Code Compliance

Michael Rosenberg, Reid Hart, Rahul Athalye, & Jian Zhang, Pacific Northwest National Laboratory, David Cohan, United States Department of Energy

ABSTRACT

An important question for commercial energy code compliance is: “How much energy cost savings can be achieved through better compliance?” This question is in sharp contrast to prior efforts that used a checklist of code requirements, each of which was graded pass or fail. Percent compliance for any given building was simply the percent of individual requirements that passed. A field investigation method has been developed, which goes beyond the binary approach, to determine lost savings due to non-compliance. Prototype building simulations were used to estimate the energy cost impact of varying levels of non-compliance for newly constructed office buildings in climate zone 4C.[1] Field data collected from actual buildings on specific conditions relative to code requirements was then applied to the simulation results to find the potential lost energy savings for a single building and for a sample of buildings. This new methodology was tested on nine office buildings in climate zone 4C. The amount of additional energy cost savings they could have achieved had they complied fully with the 2012 International Energy Conservation Code was determined. For each building, the annual lost energy cost savings ranged from a minimum of $101 to a maximum of $638 and 2% to 29% of total annual energy cost. For the entire nine-building sample, the annual lost cost savings was $3,372 and 13% of total annual energy cost. This paper presents the results of the test and lessons learned that can guide future development and application of this methodology.

Introduction

The U.S. Department of Energy (DOE) has recently moved from a binary assessment of commercial building code compliance to a compliance methodology that focuses on estimating lost savings due to non-compliance. The development of the new method and a pilot field test are reviewed here.

Background and DOE’s Previous Commercial Compliance Work

DOE developed a commercial compliance methodology and associated tools focused on determining a percent compliance rating for states (DOE 2010) to support the American Recovery and Reinvestment Act of 2009 (ARRA 2009). Section 410 of ARRA requires states to develop “a plan for the jurisdiction achieving compliance with the building energy code … in at least 90% of new and renovated residential and commercial building space.” The approach developed by DOE for this work calculates an average compliance score for the sample set. For each code requirement that was applicable to a particular building and observable, a binary decision was made regarding whether or not the requirement complied. The percentage of requirements that complied established the score for each individual building. Note that this approach does not explicitly distinguish between varying levels of non-compliance nor does it

---

[1] Climate zone 4C includes the western portions of Oregon and Washington, and northwestern California.

evaluate the energy impact of individual requirements. Details of this previous work are summarized in the report 90% Compliance Pilot Studies (DOE 2013A).

A Value Based Compliance Methodology

The binary approach of the previous compliance determination methodology failed to answer a critical question: What is the dollar value of increasing compliance with the energy code? Ultimately, this is the question that policy makers, funders, and program implementers care about. With this in mind, the current research set out to develop a new methodology capable of determining, for a sample of buildings, how much energy cost savings[1] could potentially be gained through better compliance with the code.

Fundamental Approach and Scope

Several approaches could be taken to quantify potential savings from increased energy code compliance for a sample of buildings. Probably the most accurate would be to create a custom energy model to simulate each building as constructed to determine energy costs and compare them to the energy costs of a parallel model where all systems and components not meeting code are brought up to compliance. Those exceeding code would be included as is in both the code baseline and as found model. A different approach would be to also consider the energy cost benefit of systems and components exceeding code; however, to answer the main research question posed by this project—how much energy cost savings could potentially be gained through better compliance with the code?—it makes sense to quantify only the parameters of the building that fail to meet code requirements. That is because parameters below the code still have room for improved compliance regardless of whether other parameters just meet the code or exceed the code.

The drawback of any approach requiring custom energy simulation is cost. It would be unrealistic and cost prohibitive to design a methodology that required custom simulation for each building. On the other hand, modeling is a necessity to overcome the limitations of DOE's previous methodology. To estimate the value of energy cost savings that could be gained with increased compliance, it is necessary to assign a lost energy savings cost value to any below-code condition likely to be encountered in a compliance assessment.

To determine the lost savings, the actual conditions in the building have to be collected as opposed to simply assigning a pass or fail condition for each code requirement. For instance, in certain climate zones the International Energy Conservation Code (IECC) has a requirement for economizers to have a high limit shutoff when the outdoor air temperature exceeds 75°F (ICC 2012). The lost energy savings will clearly vary depending on how the economizer high limit is set and modeling is the only reasonable way to determine this for the wide range of conditions that might be encountered in the field. Therefore, we decided to estimate lost energy savings using a prototype building model approach; then allocate prototype energy impacts to the actual buildings in a compliance study.

Developing a Value-Based Energy Code Compliance Methodology

Given the complexity of the commercial code and the diversity of commercial buildings, the current test of the compliance method was limited to new construction impacting a single

---

[1] Energy cost savings is the expected reduction in utility bills.

building type (office buildings) with simple heating, ventilation, and air-conditioning (HVAC) systems (packaged single zone systems) in one climate zone (4C) looking at the requirements of the 2012 IECC (ICC 2012). Additional limitations of the current research include the following:

- Only projects complying via the prescriptive approach of the code were considered.
- The goal of this research is focused on testing methodology not results, therefore the sampling and recruitment procedures were not intended to be statistically valid.
- While codes in Oregon and Washington are IECC-based and at least as efficient as the 2012 IECC, they include state-specific amendments (DOE 2015). This research measured the pilot project buildings against the 2012 IECC rather than applicable state codes.

Overall Methodology for Tested Approach

The tested approach to assessing potential energy cost savings from increased energy code compliance in commercial buildings can be summarized by the following steps:

- Identifying applicable code requirements for the building types, HVAC system types, and climate zones of interest.
- Developing a range of conditions for each requirement group (measure) covering the range of expected field conditions from worst to code-compliant.
- Estimating energy cost impacts using prototype energy simulations of the conditions for each measure for each building type, HVAC system type, and climate zone of interest.
- Identifying an appropriate sample of buildings from which to collect data.
- Investigating in the field to determine actual building measure conditions.
- Assigning lost cost savings to the found conditions for each building in the sample.
- Combining individual measure lost savings to determine total lost energy cost savings for each individual building, on both an annual and life-cycle cost basis.
- Determining lost energy cost savings for the sample of buildings, unitized based on metrics of interest, such as building type and floor area.
- Reviewing, on a sample-wide basis, the impacts of measure interaction, and if significant, applying adjustment factors to the unitized savings.

Identifying Applicable Code Requirements. Before compliance could be assessed, it was first necessary to identify the code requirements that apply to the building type being studied. The first step in that process was to inventory all the requirements in the non-residential provisions of the 2012 IECC. A total of 396 individual requirements were identified. Next, requirements not applicable to this project or not verifiable in a compliance assessment were removed. This was done if:

1. There were no energy savings directly attributable to the requirement. For example, air barriers are permitted on the interior, exterior, or within the building envelope assembly. While the air barrier requirement itself affects energy use, the location of the air barrier does not. Administrative requirements also fall under this category.
2. The requirement does not apply to office buildings with simple HVAC systems (e.g., requirements for retail display lighting or chilled water systems).
3. The requirement does not apply to climate zone 4C. For example, cool roof requirements.

4. The requirement is a parent requirement. For example, the general requirement that thermal envelope components comply with R-value or U-factor tables is implicitly met when wall, roof, door, and floor sub-requirements are verified.

After applying these filters to the requirements, 149 remained from the original 396. Next, the 149 requirements were grouped into 63 “measures” containing related requirements. For example, the mass wall insulation measure contains requirements for the U-factor of the assembly and the weight and density of the wall, as well as requirements for how continuous insulation must be installed. These three requirements were grouped into a single “mass wall insulation” measure. Table 1 includes an example of six selected measures. Table 2 lists the 44 measures that were applicable to the buildings in this pilot and the complete list of all 63 measures is shown in the compliance methodology technical support document (Rosenberg et al. 2016).

Developing a Range of Conditions. For each of the 63 measures, a range of likely conditions that could reasonably be expected to occur in a building was identified including the code compliant condition and at least two conditions worse than code (below code and worst).[1] To set the “worst” boundary, the authors’ professional judgment was used with input from other Pacific Northwest National Laboratory (PNNL) engineers and scientists. The worst condition selected is not always the worst condition possible, but rather the worst condition expected in the field. If additional conditions are found outside of this range during field investigation, they were added later. In some cases, only one below-code condition was identified. For example, the tandem wiring measure requires that all single- and three-lamp fixtures use tandem wiring (a single two-lamp ballast shared between two fixtures). For this measure there is only a single below-code condition. The fixture is either tandem wired or it is not. Table 1 includes six selected measures and the identified conditions. The complete list of all 63 measures and identified conditions is shown in the full compliance methodology (Rosenberg et al. 2016).

Table 1. Example of code measures and identified conditions

Measure Name	Measure abbreviation	Code-condition	Below-code condition	Worst condition
Roofs insulated to meet CZ requirements	RoofIns	100% required U-factor	150% required U-factor	No insulation
Window-to-wall ratio meets maximum limits	MaxWWR	30% WWR no DL controls	50% WWR with DL controls	90% WWR no DL controls
Packaged air conditioner efficiency	ACCoolingEff	100% code required efficiency	NA	100% code required efficiency
Thermostat deadband requirement	TempDeadband	Deadband 5°F as required	NA	Deadband 1°F
Optimal start controls	OptStart	Optimum start as required	NA	No optimum start
Interior lighting power allowance	IntLPD	Meets whole building LPD	Exceeds whole building LPD by 50%	Exceeds whole building LPD by100%

---

[1] Although conditions better than minimum code were identified in the pilot field study for each measure, they are not factored into the calculation of lost energy cost savings for the reasons discussed previously.

Estimating Energy Cost Impacts Using Prototype Models. Prototype building models were used to quantify lost energy cost savings for this research. PNNL has developed a suite of 16 prototype building models using EnergyPlus to analyze non-residential energy codes (Thornton et al. 2011). The current project used the PNNL small office prototype model compliant with the 2012 IECC in climate zone 4C to represent office buildings with simple HVAC systems.

Once the range of potential found conditions for each measure was identified, a sensitivity analysis was performed using energy simulation of the prototype model to determine lost energy cost savings associated with each condition. To estimate the energy cost, PNNL used annual national average commercial building energy prices of $0.1075/kWh of electricity and $0.8645/therm of natural gas based on Energy Information Administration (EIA) statistics for 2014. Each identified condition for each of the 63 measures was simulated and the energy cost was compared to the code value and the increase normalized to an appropriate metric. For example, the cost impact of a wall insulation measure is normalized to the applicable area of exterior wall, while other measure impacts are normalized to the square feet of conditioned building area. The normalized energy cost impact of each condition for each measure is available in the technical support document associated with this paper (Rosenberg et al. 2016).

Using this approach, lost energy cost savings can then be attributed to a similar building based on the quantity of each metric to which a given condition applies. The savings for duct and pipe insulation and commissioning could not be readily simulated using EnergyPlus, and calculations were therefore performed outside of the energy model. Savings for duct and pipe insulation were estimated using standard engineering calculations.

Since identifying and modeling the explicit implications of missing or poor commissioning is very difficult and time consuming, the impact of non-compliant commissioning was based on typical commissioning savings as determined by several studies (Mills 2004). The IECC requires commissioning for lighting controls and some HVAC controls, depending on HVAC system capacity. If measures that require commissioning were not commissioned, then up to 8% of the “worst” condition energy impact for each non-commissioned measure is tallied as commissioning lost savings. The overall commissioning quality was evaluated by the field auditor to determine the portion of worst impact to be applied as lost savings.

For some measures, an infinite number of conditions could occur between the code and worst conditions. An example is lighting power density (LPD). While it would be impossible to simulate every LPD below code that may be found in a building, by capturing the endpoints (range) of possibilities and some intermediate conditions, interpolation can be used when conditions in the field do not exactly correspond to a simulated condition.

Assigning Lost Energy Cost Savings to a Single Building and a Sample of Buildings. Using a combination of plan review and site visit, the condition of each code measure can be determined. Using the found condition and the quantity of the associated system the condition applies to, the impact on lost savings for that condition can be determined. An example of the steps required to determine the cost impact of roof insulation is as follows:

- Identify the code required U-factor for roofs in climate zone 4C is 0.039 Btu/h·ft^2·°F.
- A field assessment determines that the U-factor of a particular roof is 0.059 Btu/h·ft^2·°F., which is 150% of the code required U-factor.
- Looking at **Error! Reference source not found.** in **Error! Reference source not found.** of the technical support document, we can see that the U-factor of 150% of the code

requirement costs a building \$0.015/ft^2 of roof per year (Rosenberg et al. 2016). If there are 5,000 ft^2 of roof with that U-factor, the loss to the building is \$75/yr.

- If the U-factor does not exactly meet one of the conditions identified, the lost cost savings can be interpolated from the values there.

For each measure in the building, the above steps are completed, and then the cost impacts of conditions that do not meet code are totaled for the building as a whole. Life-cycle factors are used to determine long-term impact of lost energy savings (application of a life-cycle perspective is discussed later in this paper). This process answers the question: What cost savings could be achieved through better compliance with the code?

There are several reasons why this calculation is only an estimate. First, the lost savings are being determined using a prototype building, which, while similar to the actual observed building, will differ to some degree. Second, the cost savings impact for each measure is determined in isolation from the conditions of the other measures. In other words, it does not consider interactive effects. For example, poor windows will have a greater energy cost impact in a building where HVAC efficiency is below code compared with a building in which HVAC efficiency just meets code. However, it is likely that those interactive impacts will be small if most components meet code. There is evidence that this assumption is correct (NYSERDA 2014), but it was tested for the pilot sample of buildings as described later. Once the cost savings impact is known for each building in a sample, it is relatively simple to total those to determine the impact for the entire sample.

Testing the Approach

To ensure that the developed approach could be reasonably applied to determine potential cost savings from better code compliance, and to gather data to improve the approach and ancillary analyses, PNNL hired Ecotope[1] to conduct a field study for a small sample of buildings.

Sample Size and Recruiting

The sample size was determined by the budget and was not intended to provide statistically significant results, as the purpose was to test the method. The original goal was 15 buildings; however, difficulty in recruiting eligible buildings reduced the final number to 9. To identify the pool of candidate buildings, Ecotope used the Dodge database of new construction (F.W. Dodge). The intent was to recruit only office buildings in climate zone 4C of Washington and Oregon and those constructed under those states' current codes that are at least as stringent as the 2012 IECC. Recruiting challenges resulted in one site being located in climate zone 5B and three sites being built under the previous code. Also, mixed-use buildings were added to the recruiting pool provided there was significant office occupancy and it was reasonably separate from the non-office occupancy portion which could be ignored in the study. Relaxing the selection criteria in this manner resulted in a pool of 121 potential buildings. Recruiters began by contacting the project architect or engineer to screen the buildings and request owner consent for the study. The resource requirements of the recruiting process are summarized as follows:

- Recruiting success rate was 7.4% (9 out of 121 candidates).

---

[1] http://www.ecotope.com/

- On average, 10 phone contacts were necessary to screen, recruit, and schedule each successful site.
- Recruiters spent about 135 person-hours to secure the nine buildings.

If these results are typical, it is likely that a different approach to recruitment will be necessary, as it will be cost-prohibitive to include a statistically representative sample, especially for multiple building types. A potential alternative approach for future studies is discussed later.

Data Collection Forms

To ensure field data was collected consistently and all information needed was collected, standardized spreadsheet forms were provided. The intent was to make the results as consistent and unbiased as possible by determining conditions for each measure in an objective and repeatable way. In general, the forms collected descriptive information about the building (size, location, occupancy type, area, etc.) and specific information regarding the conditions encountered for each code measure. In addition, Ecotope was asked to record the amount of time spent verifying each measure during plan review and in the field. Time for general activities (meeting with the owner's representatives, collecting plans, travel to site, etc.) was also collected. A sample data collection form is shown in the technical support document associated with this paper (Rosenberg et al. 2016).

Results of the Field Study

Of the 63 measures evaluated in the nine buildings, 19 were not applicable to any building (e.g., below-grade wall insulation). Fourteen measures applied to all buildings (e.g., lighting power and frame wall insulation), while the remaining 30 applied to some of the buildings. Five of the non-applicable measures are associated with the optional efficiency packages required by Section C406 of the 2012 IECC; however, both Oregon and Washington have removed those optional efficiency requirements from their codes, so they never applied. Others such as snow melt system controls are rare (except in very cold climates) and may not be encountered even in a much larger sample, and some such as skylight U-factor or below-grade wall insulation would likely be triggered with a larger sample size.

While the goal of this study was to look at building compliance in a more informative way than a pass/fail approach, it is interesting to also look at the results in accordance with this simplistic approach. Based on the results using this approach, the percent compliance for each building ranged from 62% to 91%, with an average of 74%. Of the 289 code measures applicable in all nine buildings, 271 (95%) could be verified either in plan review or on-site inspection. Of the 271 measures verified, 202 (75%) complied.

Inability to Verify Some Measures. As mentioned previously, it was not possible to verify all code measures. The condition of some measures could be confirmed in plan review or during site inspection, while the condition of other measures could not be confirmed in either. If the condition of a measure was specified in plans, but could not be observed, it was assumed construction matched the plans.

The timing of the site visit affects available data. The approach for this project was to conduct a single site visit, which requires construction to be completed or near completion. That meant some measures could not be field verified, particularly envelope components. In cases where it was not possible to determine compliance, those measures were not rated, and no lost energy cost was assigned, which has the same impact as if they just met code requirements. Suggestions for avoiding some of these issues are discussed later.

Converting Field Results to Lost Savings. Based on auditor evaluation, the condition of each applicable code measure in a building was determined and matched to a cost impact per unit calculated from the sensitivity analysis simulations described previously. The applicable metric was found and used to determine the energy cost impact for each measure. Summing the cost impact of only those measures that are below code answers the question: how much energy cost savings could potentially be gained for that building through better compliance with the code?

The cost impacts for a sample of buildings, such as the nine buildings evaluated in this study, are simply the sum of the cost impacts of each building. Table 2 summarizes the results for the nine-building sample and shows the annual cost impact of each measure found in each building in the sample, due to non-compliance. The annual lost cost savings for each measure—totaled across the nine-building sample—ranged from no lost savings (everything complied in all buildings) for 19 measures to a maximum of $1,018 lost per year for HVAC equipment oversizing in eight of the buildings. For each building, the annual lost energy cost savings ranged from a minimum of $101 to a maximum of $638. For the entire nine-building sample, the annual lost cost savings was $3,372. In other words, $3,372 could be saved each year if full compliance with the code was achieved.

A Life-Cycle Perspective: Present Value of Lost Savings. The results presented up to this point considered the annual energy cost impact from the perspective of the first year of building operation. It is more representative of building owner or tenant impact to consider the value of lost savings for the life of the building or component affected. To find present value, future savings are discounted with a real discount rate of 3.0% and an energy escalation factor. This follows the methodology established by the Federal Energy Management Program (Lavappa and Kneifel 2015).

The different types of measures are listed in Table 3 along with their assumed life, percentage fuel type use, and weighted uniform present value (UPV) factor.[1] These factors are applied to the annual lost energy cost savings previously calculated to find the long-term savings that could accrue from better compliance.

---

[1] UPV factors are pre-calculated factors used to project the present value of annually recurring energy costs based on measure life, current DOE discount rates, and projected energy price escalation rates that are variable during the measure life, as determined by DOE’s Energy Information Administration.

Table 2. Annual energy cost impact of below code conditions found in the pilot sample

	Building identifier									Sample lost life-cycle savings per measure
Measure	A	B	C	D	E	F	G	H	I	
Roofs insulated to meet requirements	$11	$0		$0	$94	$0		$0	$0	$105
Frame walls insulated to meet requirements	$6.20	$15	$0	$0	$0	$0	$0	$0	$0	$21
Slab-on-grade floors insulated & protected	$5.44		$5.48	$0	$9.50	$0	$0	$0	$0	$20
Opaque doors meet U-factor limits	$0		$0		$0	$0	$0		$0	$0
Window-to-wall ratio maximum limits	$0	$0	$0	$129	$0	$0	$0	$16	$0	$145
Windows meets U-factor limits	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Door glazing meets U-factor limits		$0	$0	$0	$0	$0	$0	$0	$0	$0
Windows meet SHGC requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Continuous air barrier requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Recessed lighting sealed, rated & labeled		$0		$0	$3.91					$3.91
Fenestration air leakage requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Openings to shafts, chutes, stairways, & elevator lobbies meet air leakage requirements						$0				$0
Vestibules where required				$0		$0			$81	$81
Equipment sizing requirement	$39	$206	$218	$87	$57	$0	$309	$6.54	$96	$1,018
Packaged air conditioner efficiency	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Packaged heat pump efficiency	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gas furnace efficiency		$0							$0	$0
Thermostatic control for individual zones	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Heat pump supplementary heat control				$28	$0	$0	$0			$28
Thermostat deadband requirement	$12	$68	$120	$145	$0	$0	$0		$0	$345
Thermostat setback & start/stop controls	$64	$93	$0	$19	$0	$0	$214		$0	$389
Optimal start controls		$0	$0	$0	$0	$0	$0		$0	$0
Damper control when space is unoccupied		$0.14	$0	$0	$0	$0	$0		$0	$0.14
Demand control ventilation			$0	$0	$0					$0
Duct insulation requirement		$0.53	$0.79	$0	$0	$0	$0		$4.60	$5.92
Duct leakage requirement		$0	$0	$0	$0	$0	$0		$0	$0
Lighting Commissioning requirement	$15	$11	$19	$5.92	$13	$42	$32	$27	$35	$200
Mechanical systems Commissioning				$128						$128
Economizer supplies 100% design air		$56	$47	$0	$0	$0	$0		$11	$114
Economizers integration & high limit		$53	$65	$23	$32	$55	$37		$0	$265
Water heater efficiency, electric	$0	$0.21	$0	$0.21	$0	$0	$0	$0	$0	$0.42
SWH heat trap	$0	$0		$1.92	$0	$0	$0	$0		$1.92
SWH pipe insulation - recirculated							$0			$0
SWH pipe insulation - non-recirculated		$0.39		$4.60		$0		$0		$4.99
Manual lighting control	$17	$0	$0	$0		$0	$47	$16	$0	$80
Automatic time switch control	$22								$0	$22
Occupancy sensor control	$31	$9.97	$31	$0	$0	$0	$0	$0	$0	$73
Daylight zone control	$0	$0	$0		$9.55	$0	$0	$0	$0	$9.55
Task lighting control		$0			$0	$0		$0	$0	$0
Exterior lighting control	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Tandem wiring				$0					$0	$0
Exit sign maximum power	$0	$0	$0	$0	$0	$3.63	$0	$0	$13	$17
Interior lighting power allowance	$0	$0	$44	$0	$0	$0	$0	$138	$110	$293
Exterior lighting power allowance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Base energy cost (estimated from prototype)	$ 884	$ 1,288	$ 2,424	$ 3,810	$ 2,460	$ 5,920	$ 2,171	$ 753	$ 3,012	$22,722
Lost energy cost savings per building	$ 223	$ 515	$ 550	$ 573	$ 218	$ 101	$ 638	$ 204	$ 351	$ 3,372
Percent energy cost due to non-compliance	20%	29%	19%	13%	8%	2%	23%	21%	10%	13%

*Gray cells signify the measure was not applicable in that building.

Table 3. Measure lives and UPV for simplified present value savings analysis

Measure type	Life	% Elec	% Gas	UPV
HVAC controls	15	83%	17%	12.82
Lighting controls	15	100%	0%	12.65
Building envelope	30	83%	17%	21.82
Light fixture (ballasts)	15	100%	0%	12.65
HVAC equipment (gas heat)	15	83%	17%	12.82
Service hot water (gas)	15	0%	100%	13.66
HVAC equipment (heat pump)	15	100%	0%	12.65
Service hot water (electric)	15	100%	0%	12.65

The measures that had below-code conditions in the nine building sample are shown in Table 4. For each measure, the number applicable in the sample and the number below code are shown. The lost savings for all nine buildings in the sample is shown both annually ($3,372 total for all measures and buildings) and on a life-cycle present value basis ($46,430 total). Also shown is the present lost savings value per 1,000 ft^2 of applicable floor area ($1,710 total). The measures are sorted by unitized life-cycle lost savings (present value $/1,000 square foot).

Table 4. Impact of measures with lost savings—ranked by total sample present value $/1000 ft^2

Measures with lost savings	Number applicable in each building	Number below code	Sample Lost Savings Annual	Life-cycle	Life-cycle/1,000 ft^2
Equipment sizing	9	8	$1,018	$13,054	$481
Thermostat setback & start/stop controls	8	4	$389	$4,990	$184
Thermostatic deadband	8	4	$345	$4,426	$163
Interior lighting power	9	3	$293	$3,705	$136
Economizer integration & high limit	7	6	$265	$3,353	$123
Window-to-wall ratio maximum limits	9	2	$145	$3,163	$116
Lighting commissioning	9	9	$200	$2,525	$93
Roofs insulated to meet CZ requirements	7	2	$105	$2,288	$84
Vestibules where required	3	1	$81	$1,758	$65
Mechanical systems commissioning	1	1	$128	$1,647	$61
Economizer supplies 100% design supply air	7	3	$114	$1,444	$53
Manual lighting control	8	3	$80	$1,015	$37
Occupancy sensor control	9	3	$73	$918	$34
Frame walls insulated to meet CZ requirements	9	2	$21	$468	$17
Slab-on-grade floors insulated & protected.	8	3	$20	$446	$16
Heat pump supplementary heat control	4	1	$28	$356	$13
Automatic time switch control	2	1	$22	$280	$10
Exit sign maximum power	9	2	$17	$216	$8
Daylight zone control	8	1	$10	$121	$4
Recessed lighting shall be sealed, rated & labeled	3	1	$4	$85	$3
Duct insulation requirement	7	3	$6	$76	$3
SWH pipe insulation - non-recirculated	4	2	$5	$64	$2
SWH heat trap	7	1	$2	$25	$1
Water heater efficiency, electric	7	2	$0	$5	$0
Damper control when space is unoccupied	7	1	$0	$2	$0
Total	**169**	**69**	**$3,372**	**$46,430**	**$1,710**

Interactive Savings Impacts. The results described so far do not consider the interactive effects of more than one measure at a time varying from code. For example, as discussed previously, poor windows will have a different energy cost impact in a building where HVAC efficiency just meets code compared with a building in which HVAC efficiency is below code. Interactive impacts were not considered in the method for two reasons.

- First, it greatly simplifies the process. Energy cost impact can be estimated immediately after a building audit with no additional technical analysis. Savings for each measure condition is predetermined by the prototype simulations. To truly account for potential interactive effects, a separate energy simulation would be needed for each building which would be prohibitive on a large scale because of time and cost considerations.
- Second, the hypothesis is that since most measures will comply with code, ignoring the interactive impacts is justifiable. To test the hypothesis that the interactive effects are modest, interactive simulations were performed using the average condition for each measure from the sample and compared to the sum of the standalone measure cost impact determined above.

Interactive results shown in Table 5, confirm that the interactive impacts are modest. When evaluating the annual lost energy cost savings for the total sample, the sum of the individual measure savings underestimates the potential lost savings by $231, or 6.8%, compared to the interactive results. This approach is conservative as it demonstrates that analyzing the measures without interaction may underestimate the annual lost energy savings potentially recovered from better compliance. Additional testing of the interactive impacts can be completed when a larger sample size is evaluated in the future and if necessary, an adjustment factor can be developed to apply to the non-interactive results.

Table 5. Comparison of savings potential: individual measures vs. interactive impact

	Annual lost energy cost savings
From Single Building Prototype Simulation	
Lost savings from interactive simulation ($/yr.)	$826.14
Lost savings from sum of the individual measures ($/yr.)	$779.25
Lost savings from interactive simulation ($/ft^{2}yr)	$0.133
Applied to Nine Building Sample	
Lost savings from interactive simulation ($/yr.)	$3,602.93
Lost savings from sum of the individual measures ($/yr.)	$3,372.33
Lost savings difference	$230.60
Interactive effect	6.8%

Observations and Lessons Learned

Observations about compliance studies both general and specific to this pilot field test are discussed in this section.

Observations and Lesson Learned About Field-Based Compliance Studies in General

Several of the issues encountered during this study likely apply to any type of commercial compliance assessment activities.

Accessing Design Documents. Getting building design documents can be very time consuming and for this study often required multiple phone calls and emails with various contacts. The preferred scenario is to get plans before a site visit, to make the best use of time in the field. However, often that is not possible and plans are only available upon arrival at the site. Specifications are typically not available. For this study, not having plans until reaching a site (sometimes requiring travel of hundreds of miles) meant that the building often differed from the description given by the contact over the phone. In fact, two of the buildings ended up having an HVAC system that would have disqualified the building based on the limited system type simulation for this pilot. Fortunately, those systems only served part of the building and, based on the difficulty in recruiting and the effort spent to secure and travel to the site, we decided to analyze only the sections of the buildings with the qualifying HVAC system.

Commissioning Reports are Not Easy to Access. For the category of building in the current study, many projects do not require mechanical commissioning, as the IECC threshold for commissioning mechanical systems is 40 tons cooling or 600 MBH heating capacity. Even for those that required mechanical commissioning; commissioning reports are often not available. For more complex buildings, this would have been a much bigger problem. Lighting functional testing was always required and documentation was rarely available.

Recruiting. Recruiting was very time consuming, with a response rate for this study of 7.4% successful recruits per candidate buildings identified. Approximately 15 person-hours were required for each successful recruit. It is important to note that these metrics were the result of third-party compliance assessment, basically cold calling potential candidates. Compliance assessments conducted directly by code officials or their agents would likely have very different results. An alternative approach (since part of the purpose of compliance studies is to provide feedback to code officials) would be to have buildings selected for inclusion in a compliance study as part of the code enforcement process. This has the advantage that the independent compliance activity would carry the authority of the jurisdiction and the building information would be received directly from the code officials.

Timing and Frequency of Site Inspection. Timing of site visits affects data availability. If the approach is to conduct a single site visit to gather as much compliance information as possible, construction must be completed at or near completion. That means some measures cannot be field verified, particularly envelope components. For this study, it was not possible to field-verify slab insulation, wall insulation, continuous air barriers, or (sometimes) roof insulation. Labels on windows verifying thermal properties and leakage rates are never left in place once a building is occupied. Therefore, compliance was inferred from design documents and discussions with design teams or contractors. Interestingly, the projects that were close to completion (1 to 2 weeks away from occupancy) posed an additional problem. As-built drawings had not yet been produced and construction documents often differ from as-built conditions. To verify control requirements, it is necessary to conduct a site visit very close to issuance of the certificate of occupancy, preferably after commissioning. Control requirements such as temperature setbacks, thermostatic dead bands, lighting sweep controls, and daylight dimming controls, among others, are often not established until close to project completion.

The longer it has been since construction was completed, the more difficult it is to get design documents that verify compliance. As-built drawings are typically available, but submittals, specifications, commissioning reports, code compliance forms, and other documents are often not. In addition, control requirements that may have complied at project acceptance may be overridden shortly after. Often the owner listed in the F.W. Dodge database is no longer valid. The further away from project completion, the more difficult it is to determine if a project complied via the performance path as records of this are often not retained. Several options may be preferable to the single site visit approach as used in the current study:

- Perform a single site visit after construction is completed, but rely on photographs of early stage construction provided by the design team or contractor to help verify some components. Examples include slab insulation, wall insulation, window labels, roof insulation, continuous air barrier, and duct and pipe insulation. For this approach to succeed, agreements need to be made with the appropriate parties long in advance of the verifier's site visit. This approach would likely result in greater compliance and thus bias the results.
- Conduct several site visits at each building during construction. Slab, wall, and roof insulation must be observed well before construction completion while building controls should be verified as close to the request for a certificate of occupancy or final inspection as possible. This approach could potentially lead to improved compliance after the first site visit as those responsible will know additional inspections are forthcoming.
- Conduct only a single site visit but only gather compliance information for those parameters of the building that can be observed at the time. Observe different buildings at various stages of construction covering all code requirements, but never all for the same building. This approach will likely require a much larger sample size to create a representative sample, and given the difficulties recruiting, may not be less resource intensive than the previous approach.

Verifier Expertise. The verifier for the pilot study is a mechanical engineer with over 25 years of experience and particular expertise in economizers. Yet in several instances he was unable to verify proper operation of the economizer and other controls and had to rely on conversations with the design engineer, mechanical contractor, or HVAC service provider. If an auditor with this level of experience had trouble verifying systems and controls in these simple buildings, the problem is likely to be much greater in more complex building and where less qualified auditors are used. This leads to inconsistency in compliance assessment activities, whether undertaken by a code official or a third-party verifier.

Observations and Lessons Learned Specific to this Pilot Study

The following observations apply specifically to future studies that build on the methodology developed and piloted here.

Data Collection Forms. The Excel-based field take-off form developed for this study proved to be unwieldy for the verifier and was typically filled out later based on field notes. The field use of this type of form could be greatly improved through development of a tablet application. The auditor for this study was extremely knowledgeable and experienced. Only a brief explanation of the compliance forms was given to him by phone before site visits. Although he felt prepared, numerous questions came up during the auditing process. Future studies carried out on a larger scale should include standardized in-person training for the field auditors, which could even include accompanying auditors on their first inspection.

Verifier Bias. Every verifier brings personal experience and expertise to a compliance assessment. While the field forms were designed to make the process more objective, using multiple verifiers would improve the representativeness of sample study results.

Compliance via the Performance Path. This study did not observe any buildings that appeared to comply via total building performance. However, there appears to be no reason why the methods used here cannot apply to those buildings, as long as there is sufficient documentation of the tradeoffs. Documentation of those tradeoffs essentially defines new prescriptive requirements which can be evaluated in the same manner as variations from the base code.

Implications for Regulatory Compliance Assessment

Commercial code compliance verification is complicated and expensive, whether performed by a building official or a third-party verifier. It is unlikely that there will ever be enough resources available to fully judge compliance for all code measures in every building. The current study identified a number of metrics that can be used to potentially rank code requirements to help inform code officials where to focus their compliance verification efforts. This topic is explored in great detail in the technical support document associated with this paper (Rosenberg et al. 2016).

Conclusion and Acknowledgments

The pilot field test of a value-based commercial compliance verification method showed that a prototype-based method can be applied to determine lost energy cost savings in a sample of buildings, providing important data that was not gathered in previous binary assessments. Applying the protocol to a nine building sample identified potential savings of $3,372 annually and $46,430 over the buildings lives. That represents $1,710 per 1000 ft^2 potential saving from full energy code compliance. The pilot also determined that there are a number of significant hurdles that should be addressed if this approach is to be rolled out on the broader scale necessary to accurately access the cost savings available from better compliance with commercial energy codes.

The authors would like to acknowledge support from the U.S. Department of Energy's Building Energy Codes Program.

References

AARA. 2009. *American Recovery and Reinvestment Act of 2009.* Available at http://www.gpo.gov/fdsys/pkg/BILLS-111hr1enr/pdf/BILLS-111hr1enr.pdf.

DOE. 2010. *Measuring State Energy Code Performance*. Washington, D.C.: U.S. Department of Energy. Available at http://tinyurl.com/zax8ddv

DOE. 2013A. *90% Compliance Pilot Studies*. Washington, D.C.: U.S. Department of Energy. Available at https://www.energycodes.gov/sites/default/files/documents/Compliance%20Pilot%20Studies%20Final%20Report.pdf

DOE. 2013B. Energy Plus Energy Simulation Software, Version 8.0. U.S. Department of Energy, Washington, D.C. Available at http://apps1.eere.energy.gov/buildings/EnergyPlus/.

DOE. 2015. Building Energy Codes Program. *Status of State Energy Code Adoption.* Washington, D.C.: U.S. Department of Energy. Available at http://www.energycodes.gov/adoption/states.

EIA. 2015. *U.S. Energy Prices, of the October 2015 Short Term Energy Outlook Table 2.* Washington, D.C.: U.S Energy Information Administration. Available at http://www.eia.gov/forecasts/steo/report/

F.W. Dodge database (F.W. Dodge). Available for a fee at http://dodge.construction.com

ICC. 2012. *2012 International Energy Conservation Code*. Washington, D.C. International Code Council.

Lavappa P and JD Kneifel. 2015. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2015: Annual Supplement to NIST Handbook 135*, 2015. NISTIR 85-3273-30, Washington, D.C.: National Institute of Standards and Technology.

Mills E, H Friedman, T Powell, N Bourassa, D Claridge, T Haasl, and MA Piette. 2004. *The Cost-Effectiveness of Commercial-Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States*. Report 56637. Berkeley, CA. Lawrence Berkeley National Laboratory.

NYSERDA. 2014. *New York Energy Code Compliance Study*. Report Number 14-05, New York State Energy Research and Development Authority, Albany, NY. Available at http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Energy-Efficiency-Services/NYSERDA-Code-Compliance-Study.pdf

Rosenberg, M., R. Hart, R. Athalye, J.Zhang, W. Wang, B. Liu, 2016. *An Approach to Assessing Potential Energy Cost Savings from Increased Energy Code Compliance in Commercial Buildings*. PNNL-24979. Richland, Washington: Pacific Northwest National Laboratory.

Thornton B, M Rosenberg, E Richman, W Wang, Y Xie, J Zhang, H Cho, V Mendon, R Athalye, and B Liu. 2011. *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*. PNNL-20405. Richland, Washington: Pacific Northwest National Laboratory.