PNNL- 24979

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

An Approach to Assessing Potential Energy Cost Savings from Increased Energy Code Compliance in Commercial Buildings

February 2016

M Rosenberg
R Hart
R Athalye
J Zhang
W Wang
Bing Liu

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

PNNL- 24979

An Approach to Assessing Potential Energy Cost Savings from Increased Energy Code Compliance in Commercial Buildings

M Rosenberg
R Hart
R Athalye
J Zhang
W Wang
Bing Liu

February 2016

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

The U.S. Department of Energy's most recent commercial energy code compliance methodology and associated tools focused on determining a percent compliance rating for states to support the *American Recovery and Reinvestment Act of 2009*. That approach included 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. With its binary approach to compliance determination, the previous methodology failed to answer a critical question: What is the potential value of increasing compliance with the energy code? Ultimately, this is the question that policy makers, funders, and program implementers care about. To answer it, a far more sophisticated approach is needed, one which addresses not only the question of value, but also the resource requirements to determine that value.

Determining Lost Energy Cost Savings

With the above in mind, the current research set out to develop and test a new methodology capable of determining, for a sample of buildings, how much energy cost savings could potentially be gained through better compliance with the code? To estimate this, it is necessary to be able to assign a lost energy cost value to any condition likely to be encountered in a compliance assessment. Given the complexity of the commercial code and the diversity of commercial buildings, the current research was limited to new construction impacting a single 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 International Energy Conservation Code (IECC).

The process began with the development of an inventory of energy code requirements from the 2012 IECC applicable to the selected building type and climate zone. This resulted in 149 requirements that directly affect energy use. These requirements were then grouped into 63 measures consisting of related requirements. A sensitivity analysis was then performed using prototype building simulation to estimate the energy cost impact of variation from code requirements for each of the 63 measures. This allowed lost energy cost savings to be assigned to the range of conditions likely to be encountered in newly constructed buildings.

A building field verification method was developed to determine the condition compared to code requirements for each measure applicable in a particular building. By using the estimates of lost energy cost savings from the sensitivity analysis and field data collected from actual buildings, potential lost energy savings can be assigned to a single building or sample of buildings. Applying this methodology, nine office buildings in climate zone 4C were examined and the energy cost impact of non-compliant measures was determined. Table E.1 summarizes the results for the nine-building sample. Table E.2 provides the detailed results for each of the 9 buildings in the sample. The table shows that had all measures that did not comply with the code instead complied, this group of buildings would have saved $3,372 each year or $46,430 over the life of the buildings.

Table E.1. Summary of Lost Energy Cost Savings for a Nine-Building Sample

Metric	Minimum	Average	Maximum
Annual Lost Energy Cost Savings, per building	$101	$375	$638
Present Value of Lost Life Cycle Savings, per building	$1,272	$5,159	$8,494
Annual Lost Energy Cost Savings, per 1000 ft^2	$14	$169	$334
Present Value of Lost Life Cycle Savings, per 1000 ft2	$180	$2,292	$4,358

Table E.2 Detailed Cost Savings for a Nine-Building Sample

	Building Identifier									
	A	B	C	D	E	F	G	H	I	Total Sample
Building floor area, ft^2	1,056	1,540	2,897	4,554	2,940	7,075	2,595	900	3,600	27,157
Annual Lost Energy Cost Savings	$223	$515	$550	$573	$218	$101	$638	$204	$351	$3,372
Annual Lost Energy Cost Savings, per 1,000 ft^2	$211	$334	$190	$126	$74	$14	$246	$227	$97	$124
Present Value of Lost Life-Cycle Cost Savings	$3,044	$6,711	$7,071	$8,494	$3,749	$1,272	$8,164	$2,730	$5,196	$46,430
Present Value of Lost Life Cycle Savings, per 1,000 ft^2	$2,883	$4,358	$2,441	$1,865	$1,275	$180	$3,146	$3,033	$1,443	$1,710

Cost of Compliance Verification

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. One goal of this research is to test a methodology to identify measures that have the highest potential lost savings for the effort required to find their compliance condition. During the plan reviews and site inspections, the compliance reviewer tracked total hours and hours spent specifically verifying individual measures. This allows us to calculate the lost savings cost in dollars per verification hour. In other words, *what possible savings could occur through better compliance per hour spent on the verification process based on this field study?*

The results from the sensitivity analysis and field verification were analyzed to develop a method for ranking the measures considering both their energy cost impact and the resources required to verify compliance. This type of ranking can identify high-impact measures, which can inform the focus of compliance evaluation efforts or energy code training in the future. Table E.3 summarizes the ranking results for this study. In the table, the 63 measures are grouped by their potential lost energy cost divided by verification time required. There are potentially 567 measure instances to be verified in this sample (9 buildings × 63 measures). However, not all measures applied to each building. For this sample, there were 289 applicable instances of measure verification. Of the 289 applicable instances, 9 (21%) were responsible for 81% of the lost energy cost saving, indicating that the Pareto principle[1] applied to this study.

Table E.3. Summary of Measures and Instances in this Sample

Grouping by Lost Savings per Hour and Applicability	Measures #	Measures %	Applicable Instances #	Applicable Instances %	Life-Cycle Lost Savings	% Lost Life-Cycle Savings
High lost $/verification hour	9	14%	61	21%	$37,747	81%
Med lost $/verification hour	3	5%	18	6%	$4,886	11%
Low lost $/verification hour	13	21%	90	31%	$3,797	8%
Compliant with code	19	30%	120	42%	$0	0%
Not applicable this sample	19	30%	0	0%	$0	0%
Total	63		289		$46,430	

If future studies confirm this relationship holds true and a small fraction of the measures have a high impact on the lost energy savings, the following prioritized approach to compliance verification is proposed:

- Determine a set of high-impact lost energy saving measures that should always be verified in every building. These will likely vary by building type and climate zone. Whether there are 5 or 30 measures could vary depending on the purpose of the verification and the complexity of the building type.
- Verify the remainder of the measures on a rotating or randomized basis to ensure full compliance with the energy code.

This approach will lead designers and contractors to pay the most attention to the most impactful requirements, while ignoring none. Such an approach has a significant efficiency advantage in that high-energy-impact measures are fully investigated, while less effort is applied to less impactful measures.

[1] The Pareto principle (also known as the 80-20 rule) states that, in many interactions, approximately 80% of the effects come from 20% of the causes.

Acknowledgments

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program. The authors would like to thank the following people:

- David Cohan at DOE for providing insight
- Bing Liu, Manager, Building Energy Codes Program, PNNL
- The following people, who provided feedback on our project approach early in the process:
  - David Baylon, Ecotope
  - Poppy Storm, Ecotope
  - Ken Baker, Northwest Energy Efficiency Alliance
  - Steve Phoutrides, Northwest Energy Efficiency Alliance
  - Mike Kennedy, Mike D. Kennedy, Inc.
  - Mark Frankel, New Buildings Institute

Michael Rosenberg
Pacific Northwest National Laboratory

Acronyms and Abbreviations

AFUE	annual fuel utilization efficiency
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ARRA	*American Recovery and Reinvestment Act of 2009*
BECP	Building Energy Codes Program
CBECS	Commercial Buildings Energy Consumption Survey
cfm	cubic feet per minute
CZ	climate zone
DCV	demand controlled ventilation
DL	daylighting
DOE	U.S. Department of Energy
ECR	energy cost rating
EER	energy efficiency ratio
EV	expected value
HVAC	heating, ventilation, and air-conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society of North America
LPD	lighting power density
MBH	thousands of British thermal units per hour
PNNL	Pacific Northwest National Laboratory
PV	present value
R-value	thermal resistance in $h \cdot ft^2 \cdot °F/Btu$
SHGC	solar heat gain coefficient
SWH	service water heating
U-factor	thermal resistance in $Btu/h \cdot ft^2 \cdot °F$
UPV	uniform present value
WWR	window-to-wall ratio

Contents

Tables

Figures

1.0 Background

The U.S. Department of Energy (DOE) Building Energy Codes Program (BECP) supports the development and implementation of building energy codes and standards (DOE 2015a). This includes providing technical assistance to states to implement building energy codes, including increasing and verifying compliance to ensure consumer benefits. One key area in which BECP has worked over the past several years is providing resources and tools to assist states in evaluating compliance with building energy codes. The work described in this report expands on previous work in this area.

1.1 DOE's Previous Commercial Compliance Work

In 2010, 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 or codes described in subparagraphs (A) and (B) within 8 years of the date of enactment of this Act in at least 90 percent of new and renovated residential and commercial building space."

The tools that were developed and made available as part of DOE's work include 1) the State Sample Generator, an online tool that generates a representative sample set distributed across building size and climate zone for each state; 2) compliance checklists; and 3) Score+Store, an online tool that collects checklist data, determines individual building scores, and calculates an average compliance score for the sample set. Figure 1.1 shows an excerpt from the commercial code compliance checklist developed as part of DOE's previous effort. As can be seen, 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 distinguish between varying levels of non-compliance for individual requirements.

DOE worked with five Regional Energy Efficiency Organizations[2] to select states in which to conduct pilot studies using this DOE methodology and tools. Ultimately, eight studies covering nine states[3] were conducted. Details of this previous work are summarized in the report *90% Compliance Pilot Studies* (DOE 2013).

[2] Northeast Energy Efficiency Partnerships, the Southeast Energy Efficiency Alliance, the Midwest Energy Efficiency Alliance, the Southwest Energy Efficiency Project, and the Northwest Energy Efficiency Alliance.
[3] Studies were completed for Georgia, Iowa, Massachusetts, Montana, Utah, Wisconsin, Northwest Commercial Lighting Study (Washington, Oregon, Idaho, Montana), and Northwest Jurisdictional Survey.

2009 IECC Section #	Final Inspection	Complies?	Comments/Assumptions
502.4.6 [FI1][1]	Weatherseals installed on all loading dock cargo doors in all zones.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
503.2.4.1 [FI2][2]	Heating and cooling to each zone is controlled by a thermostat control.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
503.2.4.2 [FI3][2]	Thermostatic controls have a 5 °F deadband.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
503.2.4.3.1 [FI21][3]	HVAC systems equipped with at least one automatic shutdown control.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
503.2.4.3.2 [FI22][3]	Setback controls allow automatic restart and temporary operation as required for maintenance.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
503.2.4.1.1 [FI5][3]	Heat pump controls prevent supplemental electric resistance heat from coming on when not needed.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
502.4.8 [FI20iecc][3]	Recessed luminaires in thermal envelope to limit infiltration and be IC rated and labeled. Seal between interior finish and luminare housing.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
503.2.2 [FI21iecc][3]	HVAC systems and equipment capacity does not exceed calculated loads.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
504.3 [FI11][3]	Public lavatory faucet water temperature <=110 °F.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
504.5 [FI19iecc][2]	Insulate automatic circulating hot water systems and 1st eight feet of non-circulating systems without integral heat traps.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
504.7.1 [FI13][3]	Pool heaters are equipped with on/off switch and no continuously burning pilot light.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
504.7.3 [FI14][2]	Pool covers are provided for heated pools and pools heated to >90 °F have a cover >=R-12.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	
504.7.2 [FI15][3]	Time switches are installed on all pool heaters and pumps.	☐ Complies ☐ Does Not Comply ☐ Not Observable ☐ Not Applicable	

Figure 1.1. Excerpt from the Commercial Building Data Collection Checklist

2.0 Project Approach

2.1 Goals of the Current Research

With its binary approach to compliance determination, the previous methodology failed to answer a critical question: What is the value of increasing compliance with the energy code? Ultimately, this is the question that policy makers, funders, and program implementers care about. To answer it, a far more sophisticated approach is needed, one which addresses not only the question of value, but also the resource requirements to determine that value. With the above 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 could potentially be gained through better compliance with the code.

2.2 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 left as is. A variation would have been to also consider the energy cost impact of systems and components exceeding code; however, to answer the main research question posed by this project—i.e., 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 these approaches, or any other 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 due to increased compliance, it is necessary to be able to assign a lost energy savings cost value to any condition likely to be encountered in a compliance assessment. To accomplish this, 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. 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. We therefore decided to estimate lost energy savings using a prototype building model approach discussed in Section 0.

2.2.1 Scope Limitations

Given the complexity of the commercial code and the diversity of commercial buildings, the current research was limited to new construction impacting a single 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). The rationale for these choices is as follows:

Office buildings were selected because they represent almost 24% of the existing commercial building stock (EIA 2003) and a little more than 25% of new commercial construction between 2003 and 2007 (F.W. Dodge).[4] Simple HVAC systems were chosen because almost 80% of all office buildings are served by simple systems and because code requirements for complex systems are very diverse, but a large portion of them apply to only a small percentage of buildings (EIA 2003). For example, according to the Commercial Buildings Energy Consumption Survey (CBECS), only 3.7% of office buildings have hydronic heating and cooling systems (EIA 2003). However, there are 33 applicable code requirements and efficiency requirements for 27 categories of HVAC equipment including hydronic heating or cooling within the 2012 IECC (ICC 2012).The 2012 IECC was chosen because 20 states have adopted it or the parallel version of ANSI/ASHRAE/IES Standard 90.1 (ASHRAE 2010) (DOE 2015b), with additional states likely to adopt a more advanced code within the next several years.

Additional limitations of the current research include the following:

- Only projects complying via the prescriptive approach of the code are considered. Those complying via the performance approach are not considered.
- Since the goal of this research is focused on testing the methodology and not the results, no statistically valid sampling procedure was used and recruitment procedures were not developed.
- Although the codes in Oregon and Washington are based on the IECC and are at least as efficient as the 2012 edition, they include state specific amendments (DOE 2015b). Probably the most significant difference in the model code from those in Oregon and Washington is the omission of the additional efficiency package options in the state codes (Oregon 2014; Washington State 2014). The IECC requires that the design include either high efficiency lighting or HVAC systems or onsite renewable energy generation. That difference and others between the actual code and the specific code the pilot project buildings followed were ignored for this research. This is because the differences for the type and category of building studied are small and this study is more focused on testing the methodology than the actual results.

2.3 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:

- Identification of applicable code requirements for the building types, HVAC system types, and climate zones of interest.

[4] The CBECS defines commercial buildings as all buildings in which at least half of the floor space is used for a purpose that is not residential, industrial, or agricultural.

- Development of a range of conditions for each requirement group (measure) covering the range of expected field conditions from worst to code-compliant to best with intermediate conditions identified where appropriate.

- Energy simulation using prototype models of the identified conditions for each measure in each building types, HVAC system type, and climate zone of interest to estimate energy cost impacts.

- Identification of an appropriate sample of buildings to collect data from. *The process for this step is outside the scope of the present research*.

- Field investigation to determine actual building measure conditions.

- Assignment of lost cost savings to the found conditions for each building in the sample.

- Combining individual measure lost energy cost savings to determine total lost energy cost savings for each individual building, applying appropriate life-cycle cost factors to determine long term impact of lost energy savings.

- Determining lost energy cost savings for the sample of buildings, unitized based on metrics of interest, such as building type and floor area.

- On a sample-wide basis, reviewing the impacts of measure interaction, and if significant, apply adjustment factors to the unitized savings.

- Applying unitized savings to determine the lost energy cost savings for a population of buildings for the level of compliance present. *The process for this step is outside the scope of the present research.*

2.3.1 Identification of 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 that would not be verified 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. For example, requirements for retail display lighting or chilled water systems are not applicable.

3. The requirement does not apply to climate zone 4C. For example, cool roof requirements are not applicable in climate zone 4C.

4. The requirement is a parent requirement to a subset of more specific requirements. For example, there is a general requirement that thermal envelope components comply with the tables containing R-values and U-values. However, there are also specific sub-requirements for wall, roof, door, and floor U-values. There is no need for a separate verification of the general requirement.

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-value 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. There are related requirements that occupancy sensors be present in certain space types, that they shut lights off within 30 minutes, and that they automatically energize no more than 50% of the lights in a space upon detecting occupants. These three requirements were grouped into a single “occupancy sensor” measure. Table A.1 in Appendix A lists the 63 measures and the associated requirements. The assessment of compliance takes place at the measure level.

2.3.2 Development of Range of Conditions

For each of the 63 measures discussed in Section 2.3.1, we developed a range of likely conditions that could reasonably be expected to occur in a building. For each measure, we identified the code compliant condition and tried to identify at least two conditions better than code (above code and best) and two conditions worse than code (below code and worst)[5]. To set the boundaries (best to worst), the authors’ professional judgment was used with input from other PNNL engineers and scientists. The best and worst conditions selected are not the best and worst conditions possible, but rather the best and worst conditions expected in the field. If additional conditions are found outside of this range during field investigation, they will need to be added later. In some cases, not all five conditions were 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 no above-code measure and only a single below-code condition. The fixture is either tandem wired or it is not. Table 2.1 shows a sample of nine measures and the identified conditions. The complete list of all 63 measures and identified conditions is shown in Table A.1 in Appendix A.

2.3.3 Use of Prototype Models

As discussed in Section 2.2, prototype building models were used to quantify lost energy cost savings for this research. Pacific Northwest National Laboratory (PNNL) has developed a suite of 16 prototype building models using EnergyPlus6 to analyze non-residential energy codes (Thornton et al. 2011). Code-compliant versions of each prototype in each of the 15 climate zones in the United States are available for each version of ANSI/ASHRAE/IES7 Standard 90.1 and the International Energy Conservation Code (IECC) since 2004 (DOE 2015c).

---

[5] Although conditions better than minimum code were identified for each measure, they are not factored into the calculation of lost energy cost savings for the reasons discussed in Section 2.1.

[6] DOE. 2013. *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/.

[7] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers; IES – Illuminating Engineering Society of North America

Table 2.1 Example of Code Measures and Identified Conditions

Measure Name	Measure Abbreviation	Best Condition	Above-Code Condition	Code-Condition	Below-Code Condition	Worst Condition
Roofs shall be insulated to meet CZ requirements	RoofIns	50% req'd U-value	75% req'd U-value	100% req'd U-value	150% req'd U-value	No insul
Above grade frame walls shall be insulated to meet CZ requirements	FrmWallIns	40% req'd U-value	75% req'd U-value	100% req'd U-value	100% cavity, no C.I.	No insul
Window-to-wall ratio meets maximum limits	MaxWWR	5% WWR w/ DL controls	20% WWR w/ DL controls	30% WWR no DL controls	50% WWR with DL controls	90% WWR no DL controls
Packaged air conditioner efficiency	ACCoolingEff	165% code req'd efficiency	115% code req'd efficiency	100% code req'd efficiency	NA	100% code req'd efficiency
Gas furnace efficiency	FurnaceEff	97% AFUE	90% AFUE	78% AFUE or 80% Et	NA	78% AFUE or 80% Et
Thermostat deadband requirement	TempDeadband	Deadband 7^0F	NA	Deadband 5F as req	NA	Deadband 1F
Optimal start controls	OptStart	NA	NA	Optim start as req	NA	No optim start
Exit sign maximum power	ExitSign	Less than 3W per side	4W per side	5W per side	7W per side	Exceed 10W per side
Interior lighting power allowance	IntLPD	Whole building LPD lower than allowed by 50%	Whole building LPD lower than allowed by 15%	Meets whole building LPD	Exceeds whole building LPD by 50%	Exceeds whole building LPD by100%

AFUE = annual fuel utilization efficiency, CZ = climate zone, DL =daylighting, WWR = window-to-wall ratio.

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 since that prototype is served by packaged rooftop units. While the small office prototype includes typical construction characteristics, some modification was required to capture as many of the code requirements as possible. For example, the small office building prototype contains no skylights or basement, but it is likely that both will be encountered if a large enough sample of offices is assessed. The following changes were made:

- **Below-Grade Wall Insulation**. A 724 ft^2 conditioned basement zone was added. Below-grade wall insulation was modeled at code-required levels.
- **Skylight Curb Insulation, Skylight-to-Roof Ratio, Skylight Solar Heat Gain Coefficient (SHGC) and U-factor**. To capture the various requirements applicable to skylights, ten 4 ft by 4 ft skylights were added to the core zone, resulting in a 2.9% skylight-to-roof ratio.
- **Exterior Floor Insulation.** One of the perimeter zones (1,221 ft^2) was changed from slab-on-grade construction to exterior floor construction.

- **Opaque Door U-factor.** Two 3 ft by 7 ft opaque swinging doors with a U-factor = 0.37 Btu/h·ft^2 ·°F were added.
- **Heat Pump Heating Efficiency.** A parallel baseline model was created where the six packaged rooftop HVAC with gas furnace heating were replaced with heat pumps.
- **Demand Control Ventilation and Energy Recovery**. To trigger the code requirements for demand controlled ventilation (DCV) and energy recovery, it was necessary to add a space with high occupant density requiring substantial outdoor air. Therefore, the new basement zone described above was simulated as a conference room with peak occupancy of 50 people per 1,000 ft^2 and a lighting power density (LPD) **(866) 657-9737**of 1.2 W/ $ft^{2.}$
- **Economizer Requirements.** Since the cooling systems in the prototype were too small to trigger economizer requirements in the original prototype, economizers were added to three of the six systems so economizer requirements could be evaluated.

2.3.4 Assigning Lost Savings to the Range of Conditions

Once the range of potential found conditions for each measure were identified, a sensitivity analysis was performed using energy simulation of the prototype models to determine lost energy cost savings associated with each condition. The discrete conditions simulated for a sample of measures is shown with conditions simulated for all measures listed in Table B.1 in Appendix B.

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 statistics for 2014.[8] Each identified condition for each of the 63 measures was simulated and the energy cost for the building was determined. For each identified condition, the cost increase compared to the code value was determined and normalized to square feet of conditioned building area and, where appropriate, to a different metric quantifying the building system to which the condition applies. For example, an exterior wall insulation measure is normalized to area of exterior wall to which the condition applies. An occupancy sensor measure is normalized to the area of space controlled by (or required to be controlled by) occupancy sensors. A cooling equipment efficiency measure is normalized to the cooling capacity (tons) that the measure impacts. Table B.1 in Appendix B shows the normalized energy cost impact of each condition for each measure.

Figure 2.1 depicts, for each measure, the range of annual lost energy cost savings from code to worst as determined from the sensitivity analysis. The measures are ordered from largest to smallest cost impact of the worst case. Measure abbreviations are also documented in Table B.1 of Appendix B.

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.

[8] These prices are from the EIA and are listed in Table 2, U.S. Energy Prices, of the October 2015 Short Term Energy Outlook for commercial sector natural gas and electricity available at http://www.eia.gov/forecasts/steo/report/.

Commissioning measure impact was calculated using a different method, as commissioning is very difficult to model in a simulation program that is based on perfect control operation. Based on several studies, commissioning savings in new construction can reasonably be expected in the 8% to 10% range (Mills et al. 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 8% of the "worst" condition energy impact for each non-commissioned measure is tallied as commissioning lost savings. Conditions between code-required commissioning and no commissioning were based on the overall quality of the commissioning effort, and if it was different from the energy code requirements, then commissioned measures had an appropriate proportion of the 8% of worst impact applied as lost savings impact.

For some measures, an infinite number of conditions could occur between the best and worst conditions. An example is lighting power density (LPD). While it would be impossible to simulate every LPD 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. To aid in that process, each condition was assigned an energy cost rating (ECR) from +10 for the best condition (exceeding code) to -10 for the worst condition (below code). Conditions meeting code were assigned a rating of 0. Conditions in between were scored by the ratio of their cost savings or loss compared to the savings and loss of the best and worst conditions. This makes interpolation with field observed conditions easier and more consistent among auditors.

$$ECR_{above} = 10 \times \frac{(condition\ cost - baseline\ cost)}{(best\ conditon\ cost - baseline\ cost)} \tag{2.1}$$

$$ECR_{below} = 10 \times \frac{(baseline\ cost - conditon\ cost)}{(worst\ conditon\ cost - baseline\ cost)} \tag{2.2}$$

Where:

ECR_{above} = energy cost rating of conditions above code

ECR_{below} = energy cost rating of conditions below code

Condition cost = annual utility cost of a building given a single measure not equal to code

Baseline cost = annual utility cost of a building given all measures equal to code

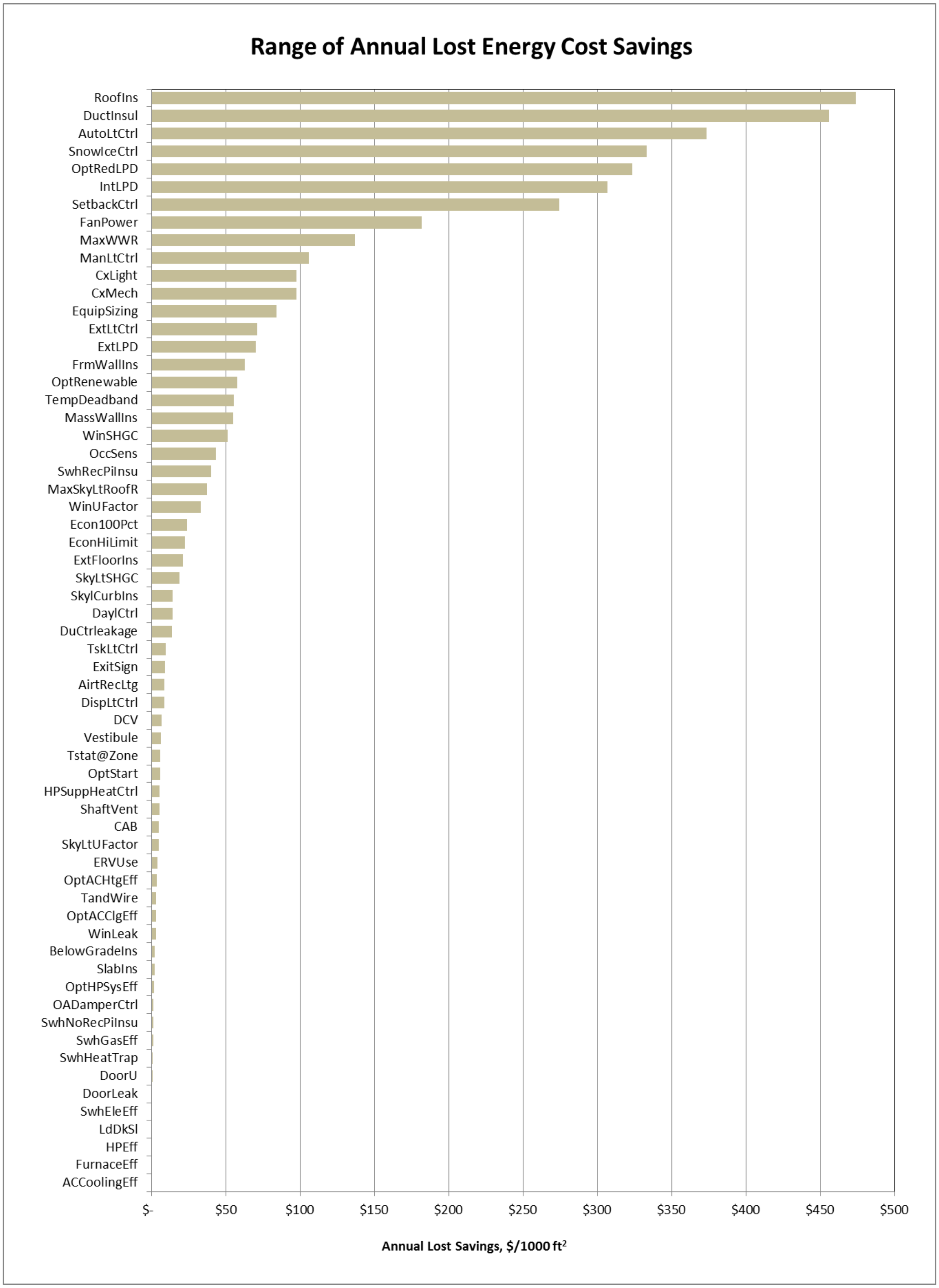

Figure 2.1 Annual Worst Case Energy Cost Impact for Each Measure from Sensitivity Analysis

2.3.5 Assigning Lost Energy Cost Savings to a Single Building and a Sample of Buildings

Using a combination of plan review and site visits, 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 Table B.1 in Appendix B, we can see that the U-factor of 150% of the code requirement costs a building \$0.015/ft^2 of roof per year. 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 in Table B.1, the lost cost savings can be interpolated from the values there.

Complete the above steps for each measure in the building and sum the cost impacts of conditions that do not meet code for the building as a whole. Apply appropriate life-cycle cost factors to determine long-term impact of lost energy savings (application of a life-cycle cost perspective is discussed further in Section 3.3.4). This process answers the question: how much energy cost savings could potentially be gained through better compliance with the code?

This calculation is only an estimate, for several reasons. First, the lost savings is 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 higher energy cost impact in a building where HVAC efficiency is worse than 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 will be tested for the sample of buildings as described in Section 3.3.3.2.

Once the cost savings impact is known for each building in a sample, it is relatively simple to sum those up to determine the impact for the entire sample.

3.0 Testing the Approach

All of the preceding sections describe the development of an approach which could be used to calculate the energy cost savings from individual buildings or a sample of buildings. To ensure that the approach could be applied, as well 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.

3.1 Sample Size and Recruiting

The sample size was determined by the budget. The original goal was 15 buildings; however, difficulty in recruiting and finding eligible buildings reduced the final number of buildings to nine. 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 (west of the Cascade Mountains) and those constructed under those states current code that are at least as stringent as the 2012 IECC, but 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 sites. Recruiters began by contacting the project architect or engineer to screen the buildings and proceeded to request owner consent for the study. Recruiting began in mid-August 2015 and site visits occurred during September and October. Recruiting was an ongoing effort that continued in parallel with site visits through mid-October. Some interesting data on the recruiting process provided by Ecotope:

- Recruiting success rate was 7.4% (9 out of 121 candidates).
- 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 in Section 4.1.

3.2 Data Collection Forms

To ensure field data was collected consistently and all information needed was collected, forms were provided to Ecotope to complete for each building. The intent is 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 collect 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

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

site, etc.) was also collected. A sample data collection form is shown in Appendix D. The forms include the following data fields to be completed by Ecotope:

General	
Building Identifier:	A unique number given to each building to anonymize the results.
City/State:	City and state location of the audited building.
Conditioned Floor Area:	Conditioned floor area.
Number of Floors:	Number of floors, both above and below grade.
Occupancy:	Identifies occupancy type. In most cases office, but project could have ancillary spaces such as storage. For mixed occupancies, percent of each is noted.
General Comments:	Any special comments the auditor thinks might be pertinent.
Plan Review Date:	Date of plan review. Multiple dates entered if necessary.
Site Visit Date:	Date of field inspection. Multiple dates entered if necessary.
Climate Zone:	Specific ASHRAE climate zone (Zone 4C in all cases but one in this study).
Actual Code:	Specific energy code project was permitted under.
Option Path:	Indicate which option path from Section C406 was chosen.
Total Tons Cooling:	Installed capacity of cooling equipment, tons.
Total MBH Heating:	Installed capacity of heating equipment, MBH.
Whole Building Performance:	Indicate whether the building complied via whole building performance (Section C407).
Time Accounting:	The contractor is asked to record the time spent for the categories of general activities, travel and indirect, envelope, lighting power, lighting controls, mechanical and SWH equipment, and mechanical and SWH controls.
Measure Specific:	The following fields are collected for each of the 63 measures that were applicable to each building.
Applies to Building:	Indicate whether specific measure applies to the building.
Exception Used:	Indicate whether an exception to the code was taken for each measure.
Plan:	Indicate whether compliance was verified in building plans.
Field:	Indicate whether compliance was verified by actual in-filed inspection.
Select Condition:	Select the measure condition closest to that observed from pull down menu.
Default Energy Cost Rating:	This automatically generated field shows the Energy Cost Rating (ECR) matching the selected condition based on the sensitivity analysis.
Override Energy Cost Rating:	This user input field allows the auditor to modify the automatically generated ECR when observed conditions do not specifically match the condition selected from the "select condition" pull down menu
Found Factor:	Auditor inputs a numeric factor representing the found condition if applicable. Examples include EER, U-factor, LPD, window-to-wall ratio.
Plan Review Comments:	Any comments pertaining to the measure from plan review, particularly, variations from the condition chosen from the pull down menu.
Field Inspection Comments:	Any comments pertaining to the measure from site inspection, particularly, variations from the condition chosen from the pull down menu.
Applicable Quantity Affected:	The quantity of systems or components to which the specific condition applies. Examples include cfm, tons, MBH, ft^2, watts, etc.

Plan Review Time:	Auditor enters the estimated time in hours spend verifying the measure during plan review.
Field Inspection Time:	Auditor enters the estimated time in hours spend verifying the measure in the field.
Commissioning Done:	If commissioning is required (all lighting controls and mechanical systems over 40 tons cooling capacity or 600 MBH heating capacity) auditor indicates if it was completed.

3.3 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. **Table 3.1** summarizes the applicability of each of the 63 measures in each of the nine buildings, shows whether or not each measure could be verified, and indicates if the measure complied with the code using the binary, pass/fail approach of previous compliance studies. While the goal of this study is to look at building compliance in a more informative way than the previous pass/fail approach, it is interesting to also look at the results in accordance with this simplistic approach. Green boxes in the table indicate that the measure complied with the code. Red boxes indicate the measure did not comply with the code. One measure, Electric Water Heater Efficiency, had two water heaters in one building, with one complying, and one not. This is represented in the table by the cell box that is half red and half green. White boxes indicate the measure was not applicable in the building or could not be verified. Reasons why a measure may have been unverifiable are discussed in Section 3.3.2.

Table 3.1. Summary of Measure Applicability, Ability to Verify, and Compliance

Measure	# Apply	# Scored	% Verified	# Comply	% Comply	Building Identifier								
						A	B	C	D	E	F	G	H	I
Roofs insulated to meet CZ requirements	7	7	100%	5	71%									
Skylight curbs shall be insulated	0	0	NA	0	NA									
Above grade frame walls insulated to meet CZ requirements	9	9	100%	7	78%									
Above grade mass walls insulated to meet CZ and density requirements	0	0	NA	0	NA									
Below grade walls meet insulation requirements and be protected	0	0	NA	0	NA									
Exterior floors meet the meet insulation requirements	0	0	NA	0	NA									
Slab-on-grade floors meet insulation requirements and be protected	8	8	100%	5	63%									
Opaque doors meet U-factor requirements	6	6	100%	6	100%									
Window-to-wall ratio meets maximum limits	9	9	100%	7	78%									
Skylight to roof ratio meet maximum limits	0	0	NA	0	NA									
Windows meets U-factor requirements	9	9	100%	9	100%									
Windows meets U-factor requirements in entry doors	8	7	88%	7	100%									
Windows meet SHGC requirements	9	9	100%	9	100%									
Skylights meets U-factor requirements	0	0	NA	0	NA									
Skylights meets SHGC requirements	0	0	NA	0	NA									
Building meets continuous air barrier requirements	9	9	100%	9	100%									
Recessed lighting shall be sealed, rated and labeled	3	2	67%	1	50%									
Fenestration assemblies meets air leakage requirements	9	9	100%	9	100%									
Building openings to shafts, chutes, stairways, and elevator lobbies meet air leakage requirements	1	1	100%	1	100%									
Stairway and shaft vents shall be provided with Class I motorized dampers	0	0	NA	0	NA									
Loading dock doors shall be equipped with weather seals	0	0	NA	0	NA									
Building entrances shall be protected with an enclosed vestibule	3	3	100%	2	67%									
Equipment sizing requirement	9	9	100%	1	11%									
Packaged air conditioner efficiency	8	8	100%	8	100%									
Packaged heat pump efficiency	6	6	100%	6	100%									
Gas furnace efficiency	2	2	100%	2	100%									
Thermostatic control is used for individual zones	9	9	100%	9	100%									
Heat pump supplementary heat control	4	4	100%	3	75%									

Measure	# Apply	# Scored	% Verified	# Comply	% Comply	Building Identifier								
						A	B	C	D	E	F	G	H	I
Thermostat deadband requirement	8	6	75%	2	33%									
Thermostat setback and start/stop controls	8	6	75%	2	33%									
Optimal start controls	7	3	43%	3	100%									
Damper control when space is unoccupied	7	6	86%	5	83%									
Snow melting system control	0	0	NA	0	NA									
Demand control ventilation	3	3	100%	3	100%									
Energy recovery requirement	0	0	NA	0	NA									
Duct insulation requirement	7	6	86%	3	50%									
Duct leakage requirement	7	7	100%	7	100%									
Lighting Commissioning requirement	9	9	100%	0	0%									
Mechanical systems Commissioning	1	1	100%	0	0%									
Fan power limit requirement	0	0	NA	0	NA									
Economizer supplies 100% design air	7	7	100%	4	57%									
Economizers have appropriate high-limit shutoff and be integrated	7	6	86%	0	0%									
Water heater efficiency, gas	0	0	NA	0	NA									
Water heater efficiency, electric*	8	8	100%	6	75%									
SWH heat trap	7	6	86%	5	83%									
SWH pipe insulation - recirculated	1	1	100%	1	100%									
SWH pipe insulation - non-recirculated	4	3	75%	1	33%									
Manual lighting control	8	8	100%	5	63%									
Automatic time switch control	2	1	50%	0	0%									
Occupancy sensor control	9	9	100%	6	67%									
Daylight zone control	8	8	100%	7	88%									
Display lighting control	0	0	NA	0	NA									
Task lighting control	5	3	60%	3	100%									
Exterior lighting control	9	9	100%	9	100%									
Tandem wiring	2	2	100%	2	100%									
Exit sign maximum power	9	9	100%	7	78%									
Interior lighting power allowance	9	9	100%	6	67%									
Exterior lighting power allowance	9	9	100%	9	100%									
Optional packaged air conditioner cooling efficiency	0	0	NA	0	NA									
Optional packaged heat pump efficiency	0	0	NA	0	NA									
Optional packaged air conditioner furnace efficiency	0	0	NA	0	NA									
Optional Reduced whole building LPD	0	0	NA	0	NA									
Optional onsite renewable	0	0	NA	0	NA									
Total # Applicable Measures	**289**	**271**		**202**	**Comply**	16	21	20	25	27	31	27	16	19
% Measures Verifiable	**93.8%**				**Not Comply**	10	12	9	11	7	3	5	5	7
% Total Compliance	**74.5%**				**% Comply**	62%	64%	69%	69%	79%	91%	84%	76%	73%
*Building B included 2 electric water heaters, one of which complied and one did not.														

3.3.1 Field Study Verification Results Distribution

In the pilot project field verification of nine buildings, the 63 measures were checked for applicability to each building and then scored relative to code compliance and the conditions identified in the sensitivity analysis. A score of -10 indicated the worst expected condition relative to energy code requirements, while a score of +10 indicated a best-case installation above code. A score of zero indicated compliance with code requirements. In some cases, there were multiple measure instances in one building. For example, one building had one electric water heater that met code and one that was below code. Figure 3.1 shows the distribution of scores (below, compliant, and above code) in ranges. This distribution indicates the frequency of verification instances for each measure type that is in each score range covering below, compliant, and above code. An average of the types is shown to keep the scale readable, and the average can simply be multiplied by 3 to find the overall number of verifications in each score range. It is clear that most verification instances meet code and that there are slightly more below-code instances than above. HVAC measures have more below-code instances, while envelope has more above-code instances. Lighting has more below-code instances, but with less extreme scores than HVAC.

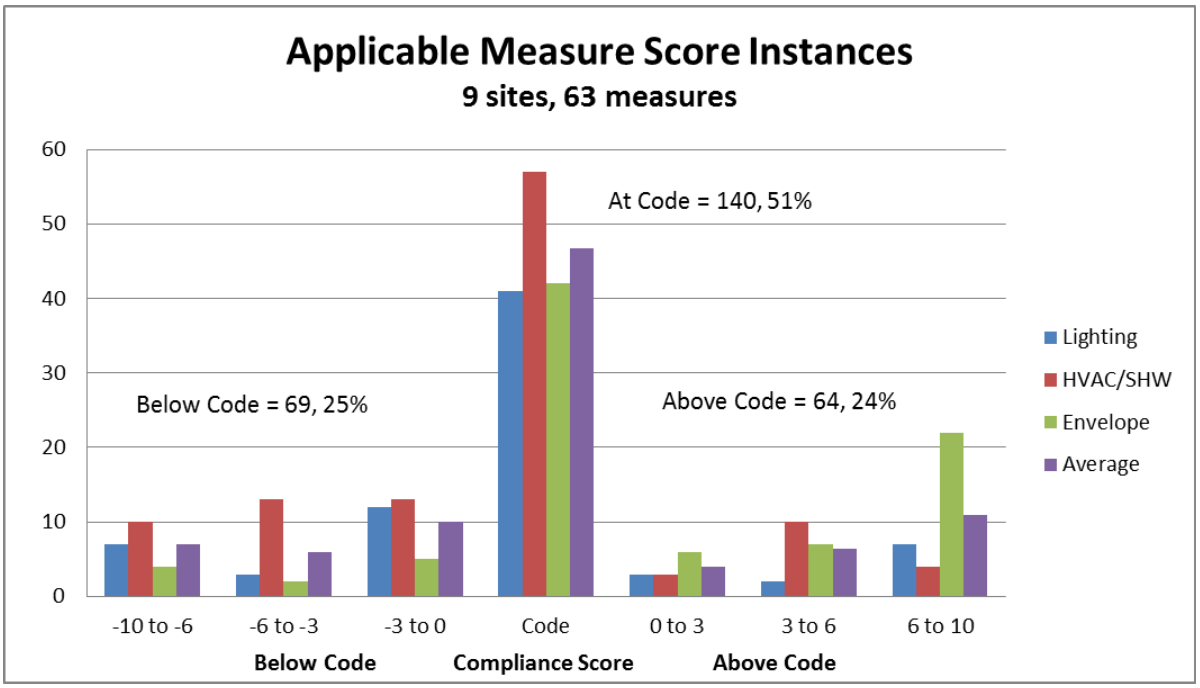

Figure 3.1. Distribution of Applicable Measure Code Compliance Scores

3.3.2 Verification Limitations

3.3.2.1 Some Measures Not Present in Sample

As described above and shown in **Table 3.1**, 19 of the measures that could be applied to office building with simple HVAC systems were not encountered in the sample. Some of those, such as snow melt system controls, are rare (except in very cold climates) and may not be encountered even in a much larger sample. Others, such as skylight U-factor or below-grade wall insulation, would likely be triggered with a larger sample size. Also, as noted in Section 2.2.1, the additional efficiency package options in the 2012 IECC were not included in the Oregon and Washington state specific codes that buildings in this sample were constructed to.

3.3.2.2 Unable 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.

Timing of 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. It was not possible to field-verify slab insulation, wall insulation, continuous air barrier, or, at times, 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 near completion (1 to 2 weeks away from occupancy) posed additional problems. As-built drawings had not yet been produced and construction documents often differ from as-built conditions. Controls sequences were often not specified on design documents. 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, off-hour lighting controls, and daylight dimming controls, among others, are often not established until close to project completion, and this was the case in several buildings.

HVAC load calculations were not provided for six of the buildings, and in those instances, the degree of equipment oversizing (if any) was determined by the auditor. In cases where it was not possible to determine compliance, those measures were not rated, which has the same impact as if they just met code requirements. Suggestions for avoiding some of these issues are provided in Section 4.0.

3.3.3 Converting Field Results to Lost Savings

3.3.3.1 Annual Lost Savings Energy Cost Impact

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 in Section 2.3.4. The cost impact was then multiplied by the appropriate unit quantity to provide the cost impact for each measure. For example, the cost impact per square foot of an exterior wall insulation measure was multiplied by the area of exterior wall to which the condition applied. An occupancy sensor measure is dependent on the area of space controlled by (or required to be controlled by) occupancy sensors. A cooling equipment efficiency measure is dependent on the cooling capacity (tons) that the measure impacts. This calculation provides the 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 3.2 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 for the nine-building sample ranged from no lost savings (everything complied) for 19 measures to a maximum of $1,018 for HVAC equipment oversizing in five 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 potentially be saved each year through better compliance with the code.

3.3.3.2 Sum of Savings for Individual Measures versus Interactive Savings

The method described above does not consider the interactive effects of more than one measure at a time varying from code. For example, as discussed in Section 2.3.5, 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 is below code. The approach of not considering interactive impacts is taken for two reasons. First, it greatly simplifies the process. This method allows energy cost impact to be estimated immediately after a building audit with no additional technical analysis. Savings for each measure condition is predetermined by the prototype simulations. To 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, following the steps below.

1. For each measure, the total lost energy cost savings per year for the nine buildings shown in Table 3.2 was divided by the sum of the area of the sample to determine an annual lost energy cost savings per square foot for each measure.

2. The lost energy cost savings was then matched to a specific measure condition using the sensitivity analysis of the prototype building described in Section 2.3.4 and documented in Table B.1in Appendix B. Where cost impacts fell between previously simulated conditions, interpolation was used to determine the appropriate condition for contiguous conditions (i.e., wall insulation or lighting power). Non-contiguous conditions (i.e., photo controls or manual lighting controls) can be applied to a portion of the systems or equipment simulated in step 3 to match the target energy cost impact.

3. Verification that the selected condition represents the target energy cost impact was done by simulating the selected condition in the prototype building model and comparing it to the target. Conditions were then adjusted as necessary until the cost impact was within 30% of the target or $10 for each measure, whichever was less.

4. The prototype building was simulated with the condition for each measure as determined from steps 1 through 3 above.

5. The annual energy cost of the simulated building was compared to the baseline energy cost where all measures meet code.

6. The cost impact of the three measures that were not modeled (commissioning and duct and pipe insulation) was added to the cost difference.

7. The cost difference from step 6 was normalized per square foot of prototype and multiplied by the total square footage of the nine-building sample.

8. This represents the annual interactive lost energy savings of the sample and was compared to the sum of the non-interactive annual lost energy cost savings.

Results from this process, shown in Table 3.3, confirm that the interactive impacts are modest. When evaluating the annual lost energy cost savings for the total sample (below-code measures only), 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 the non-interactive annual lost energy savings potentially recovered from better compliance may be slightly underestimated. Additional testing of the interactive impacts can be completed when a larger sample size is evaluated in the future. If it is determined that the interactive impacts are too significant to ignore, an adjustment factor can be developed to apply to the non-interactive results.

Table 3.2. Annual Energy Cost Impact of Below Conditions Found in the Sample

Measure	Building Indentifier									Sample Lost Savings per Measure
	A	B	C	D	E	F	G	H	I	
Roofs insulated to meet CZ requirements	$11	$0		$0	$94	$0		$0	$0	$105
Above grade frame walls insulated to meet CZ requirements	$6.20	$15	$0	$0	$0	$0	$0	$0	$0	$21
Slab-on-grade floors meet insulation requirements and be protected	$5.44		$5.48	$0	$9.50	$0	$0	$0	$0	$20
Opaque doors meet U-factor requirements	$0		$0		$0	$0	$0		$0	$0
Window-to-wall ratio meets maximum limits	$0	$0	$0	$129	$0	$0	$0	$16	$0	$145
Windows meets U-factor requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Windows meets U-factor requirements in entry doors		$0	$0	$0	$0	$0	$0	$0	$0	$0
Windows meet SHGC requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Building meets continuous air barrier requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Recessed lighting shall be sealed, rated and labeled		$0		$0	$3.91					$3.91
Fenestration assemblies meets air leakage requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Building openings to shafts, chutes, stairways, and elevator lobbies meet air leakage requirements						$0				$0
Building entrances shall be protected with an enclosed vestibule				$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 is used 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 and 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 have appropriate high-limit shutoff and be integrated		$53	$65	$23	$32	$55	$37		$0	$265
Water heater efficiency, electric	$0	.21/-$0.	$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
Lost Energy Cost Savings Per Building	**$223**	**$515**	**$550**	**$573**	**$218**	**$101**	**$638**	**$204**	**$351**	**$3,372**

Table 3.3. Comparison of Savings Potential: Sum of 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%

3.3.4 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. A more accurate approach is to consider the value of lost savings for the life of the building or the life of the component that is primarily affected. To account for the time value of money, future savings are discounted using a real discount rate of 3.0% with a factor accounting for escalation of energy prices faster than general inflation. Using a simplified method of projecting life-cycle value of savings, a uniform present value (UPV) factor[1] is applied to the annual savings to reflect the discounted value of savings over the measure life. This approach generally follows the methodology established by the Federal Energy Management Program for federal building energy projects (Lavappa and Kneifel 2015).

This analysis ignores replacement costs and in general uses the life of the components. For example, lighting fixtures may last 40 years and have multiple lamp and ballast replacements, or one can simply look at the 15-year ballast life, as when ballasts or electronics are replaced and an opportunity for higher efficiency technology can be used. A longer life than 30 years could be used for some envelope components; however, standard energy escalation rates are not available past 30 years. The different types of measures are listed in Table 3.4 along with their life, percentage fuel type use, and weighted UPV factor. 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.

Table 3.4. 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

[1] UPV factors are precalculated 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.

3.3.4.1 Present Value of Lost Savings for the Nine Building Sample

The measures that had below-code conditions are shown in Table 3.5. 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) and on a life-cycle present value basis ($46,430). Also shown is the present lost savings value per 1,000 ft^2 of applicable floor area ($1,710). The measures are sorted by unitized life-cycle lost savings (present value $/1,000 square foot). Figure 3.2 shows these results graphically. Measure abbreviations documented in Appendix B are used. Table 3.6 is similar to Table 3.2, except instead of annual lost savings, it shows the present value of lost life-cycle savings for each measure and each of the nine buildings.

Table 3.5. Measures with Lost Savings Ranked by Total Sample Present Value $/1000 ft^2

Measures with Lost Savings	Number Applicable	Number Below Code	Sample Lost Savings		
			Annual	Life-Cycle	Life-Cycle/1,000 ft^2
Equipment sizing requirement	9	8	$1,018	$13,054	$481
Thermostat setback and start/stop controls	8	4	$389	$4,990	$184
Thermostat deadband requirement	8	4	$345	$4,426	$163
Interior lighting power allowance	9	3	$293	$3,705	$136
Economizers should have appropriate high-limit shutoff control and be integrated	7	6	$265	$3,353	$123
Window-to-wall ratio meets maximum limits.	9	2	$145	$3,163	$116
Lighting commissioning requirement	9	9	$200	$2,525	$93
Roofs shall be insulated to meet CZ requirements	7	2	$105	$2,288	$84
Building entrances shall be protected with an enclosed vestibule	3	1	$81	$1,758	$65
Mechanical systems commissioning requirement	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
Above grade frame walls shall be insulated to meet CZ requirements	9	2	$21	$468	$17
Slab-on-grade floors meets insulation requirements and be 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 and 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

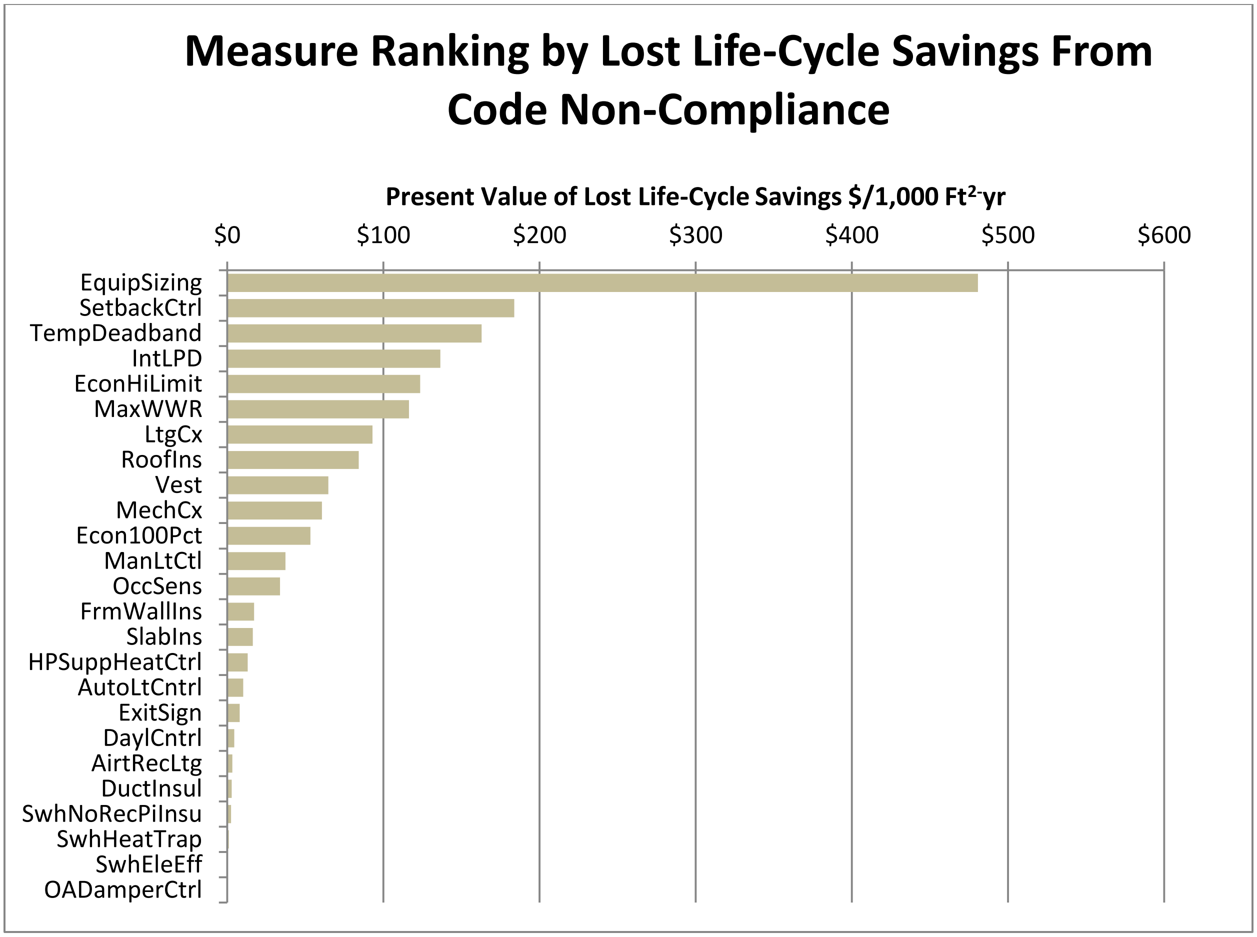

Figure 3.2. Measure Ranking by Present Value of Lost Life-Cycle Savings from Non-Compliance

Table 3.6. Present Value of Lost Life-Cycle Savings of Below Conditions Found in the Sample

Measure	Building Indentifier A	B	C	D	E	F	G	H	I	Sample Lost Life-Cycle Savings per Measure
Roofs insulated to meet CZ requirements	$245	$0		$0	$2,043	$0		$0	$0	$2,288
Above grade frame walls insulated to meet CZ requirements	$135	$333	$0	$0	$0	$0	$0	$0	$0	$468
Slab-on-grade floors meet insulation requirements and be protected	$119		$120	$0	$207	$0	$0	$0	$0	$446
Opaque doors meet U-factor requirements	$0		$0		$0	$0	$0		$0	$0
Window-to-wall ratio meets maximum limits	$0	$0	$0	$2,816	$0	$0	$0	$347	$0	$3,163
Windows meets U-factor requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Windows meets U-factor requirements in entry doors		$0	$0	$0	$0	$0	$0	$0	$0	$0
Windows meet SHGC requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Building meets continuous air barrier requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Recessed lighting shall be sealed, rated and labeled		$0		$0	$85					$85
Fenestration assemblies meets air leakage requirements	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Building openings to shafts, chutes, stairways, and elevator lobbies meet air leakage requirements						$0				$0
Building entrances shall be protected with an enclosed vestibule				$0		$0			$1,758	$1,758
Equipment sizing requirement	$503	$2,642	$2,793	$1,117	$725	$0	$3,963	$84	$1,229	$13,054
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 is used for individual zones	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Heat pump supplementary heat control				$356	$0	$0	$0			$356
Thermostat deadband requirement	$150	$876	$1,544	$1,856	$0	$0	$0		$0	$4,426
Thermostat setback and start/stop controls	$817	$1,191	$0	$245	$0	$0	$2,737		$0	$4,990
Optimal start controls		$0	$0	$0	$0	$0	$0		$0	$0
Damper control when space is unoccupied		$1.75	$0	$0	$0	$0	$0		$0	$2
Demand control ventilation			$0	$0	$0					$0
Duct insulation requirement		$6.74	$10	$0	$0	$0	$0		$59	$76
Duct leakage requirement		$0	$0	$0	$0	$0	$0		$0	$0
Lighting Commissioning requirement	$184	$142	$235	$75	$159	$535	$401	$348	$446	$2,525
Mechanical systems Commissioning				$1,647						$1,647
Economizer supplies 100% design air		$713	$593	$0	$0	$0	$0		$137	$1,444
Economizers have appropriate high-limit shutoff and be integrated		$672	$816	$296	$408	$690	$471		$0	$3,353
Water heater efficiency, electric	$0	$2.66	$0	$2.71	$0	$0	$0	$0	$0	$5
SWH heat trap	$0	$0		$25	$0	$0	$0	$0		$25
SWH pipe insulation - recirculated							$0			$0
SWH pipe insulation - non-recirculated		$4.98		$59		$0		$0		$64
Manual lighting control	$217	$0	$0	$0		$0	$592	$205	$0	$1,015
Automatic time switch control	$280								$0	$280
Occupancy sensor control	$395	$126	$397	$0	$0	$0	$0	$0	$0	$918
Daylight zone control	$0	$0	$0		$121	$0	$0	$0	$0	$121
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	$46	$0	$0	$170	$216
Interior lighting power allowance	$0	$0	$562	$0	$0	$0	$0	$1,746	$1,397	$3,705
Exterior lighting power allowance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Lost Life-Cycle Savings Per Building	**$3,044**	**$6,711**	**$7,071**	**$8,494**	**$3,749**	**$1,272**	**$8,164**	**$2,730**	**$5,196**	**$ 46,430**
Building floor area, ft^2	1,056	1,540	2,897	4,554	2,940	7,075	2,595	900	3,600	27,157
Lost Life-Cycle Savings per 1000 ft^2	**$2,883**	**$4,358**	**$2,441**	**$1,865**	**$1,275**	**$180**	**$3,146**	**$3,033**	**$1,443**	**$1,710**

3.3.4.2 Cost of Compliance Verification

One goal of the project is to test a methodology to identify measures that have the highest potential of lost savings for the effort required to find their compliance condition. During the plan reviews and site inspections, the compliance reviewer tracked total hours, travel and indirect hours, general inspection hours, and direct hours spent specifically verifying individual measures. This allows us to calculate the lost savings cost in dollars per verification. In other words, what possible savings could occur through better compliance per hour spent on the verification process based on this field study? The verification hours have the following elements:

- The direct hours attributed to applicable measures are included for the specific measure.
- The general, indirect, and travel hours along with direct hours not attributed to applicable measures are totaled, then prorated on a per-measure basis to all applicable measures, whether in compliance, better than code, or worse than code with identified savings. A measure applicable at many sites would receive a higher proration than a measure applicable at just a few sites.
- For those measures with identified lost savings, the life-cycle lost energy cost savings is divided by the verification hours that are the sum of the previous two items.

These components are summarized in Figure 3.3. This time collection does indicate that checking off measures as non-applicable does not take much time. The general time, while not allocated to discrete measures, is relative to the number of measures that require verification.

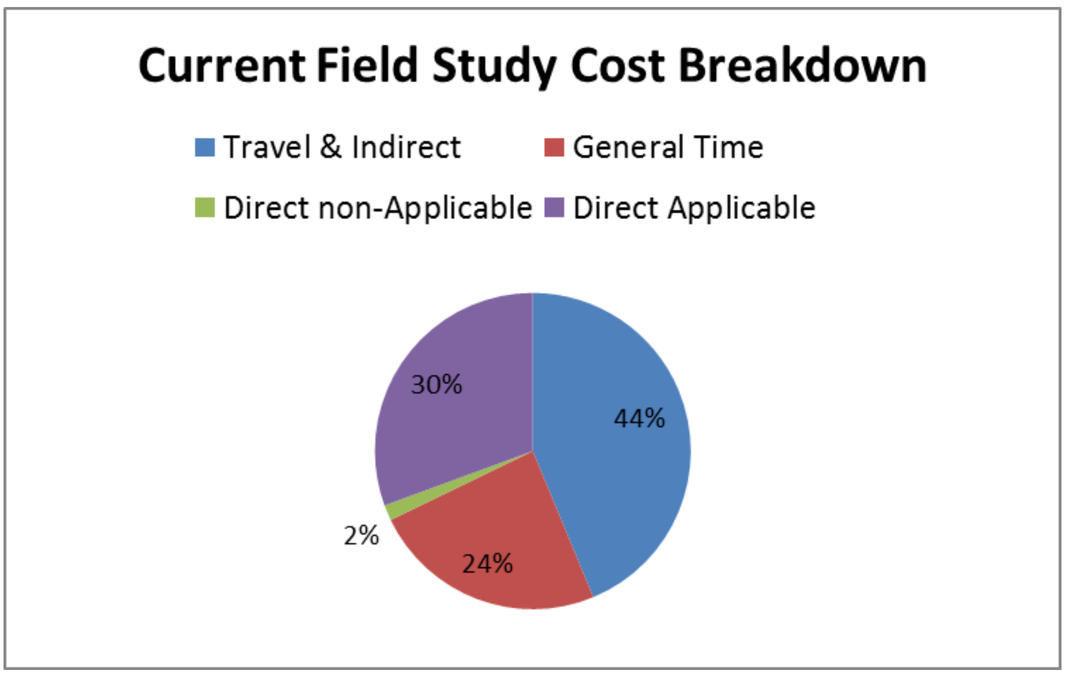

Figure 3.3. Cost Breakdown for Current Field Compliance Verification Study

Table 3.7 shows the annual and life-cycle lost savings for each measure, determined as previously discussed, divided by the verification hours required to provide a lost energy cost savings per hour for each measure. Figure 3.4 shows this data graphically.

Table 3.7. Ranking of Below-Code Measures with Lost Life-Cycle Savings by $ / Verification Hour

Measures with Lost Savings	# Applicable/	# Below	Sample Lost Savings Annual	Sample Lost Savings Life-Cycle	Verification hours	Lost Saving $ / Hour
Mechanical systems commissioning requirement	1	1	$128	$1,647	0.24	$6,741
Equipment sizing requirement	9	8	$1,018	$13,054	3.41	$3,829
Building entrances shall be protected with an enclosed vestibule.	3	1	$81	$1,758	0.87	$2,014
Thermostat setback and start/stop controls	8	4	$389	$4,990	2.55	$1,953
Thermostat deadband requirement	8	4	$345	$4,426	2.56	$1,726
Economizers should have appropriate high-limit shutoff control and be integrated	7	6	$265	$3,353	3.00	$1,118
Roofs shall be insulated to meet CZ requirements	7	2	$105	$2,288	2.47	$926
Lighting commissioning requirement	9	9	$200	$2,525	2.90	$871
Interior lighting power allowance	9	3	$293	$3,705	4.44	$835
Window-to-wall ratio meets maximum limits.	9	2	$145	$3,163	4.25	$744
Automatic time switch control	2	1	$22	$280	0.55	$510
Economizer supplies 100% design supply air	7	3	$114	$1,444	2.89	$499
Manual lighting control	8	3	$80	$1,015	2.74	$370
Occupancy sensor control	9	3	$73	$918	3.36	$273
Heat pump supplementary heat control	4	1	$28	$356	1.38	$259
Slab-on-grade floors meet insulation requirements and are protected	8	3	$20	$446	2.66	$167
Above grade frame walls shall be insulated to meet CZ requirements	9	2	$21	$468	3.34	$140
Recessed lighting shall be sealed, rated and labeled.	3	1	$4	$85	0.98	$87
Exit sign maximum power	9	2	$17	$216	2.78	$78
SWH pipe insulation - non-recirculated	4	2	$5	$64	1.08	$59
Daylight zone control	8	1	$10	$121	2.73	$44
Duct insulation requirement	7	3	$6	$76	2.39	$32
SWH heat trap	7	1	$2	$25	2.11	$12
Water heater efficiency, electric	7	2	$0	$5	2.93	$2
Damper control when space is unoccupied	7	1	$0	$2	2.17	$1
Total for measures with below-code potential savings	169	69	$3,372	$46,430	60.8	$764
Total for measures with no potential savings identified*			$0	$0	40.9	$0
Total for all applicable measures			$3,372	$46,430	102	$455

*Measures that met code (no potential savings identified) are shown in Table 3.8.

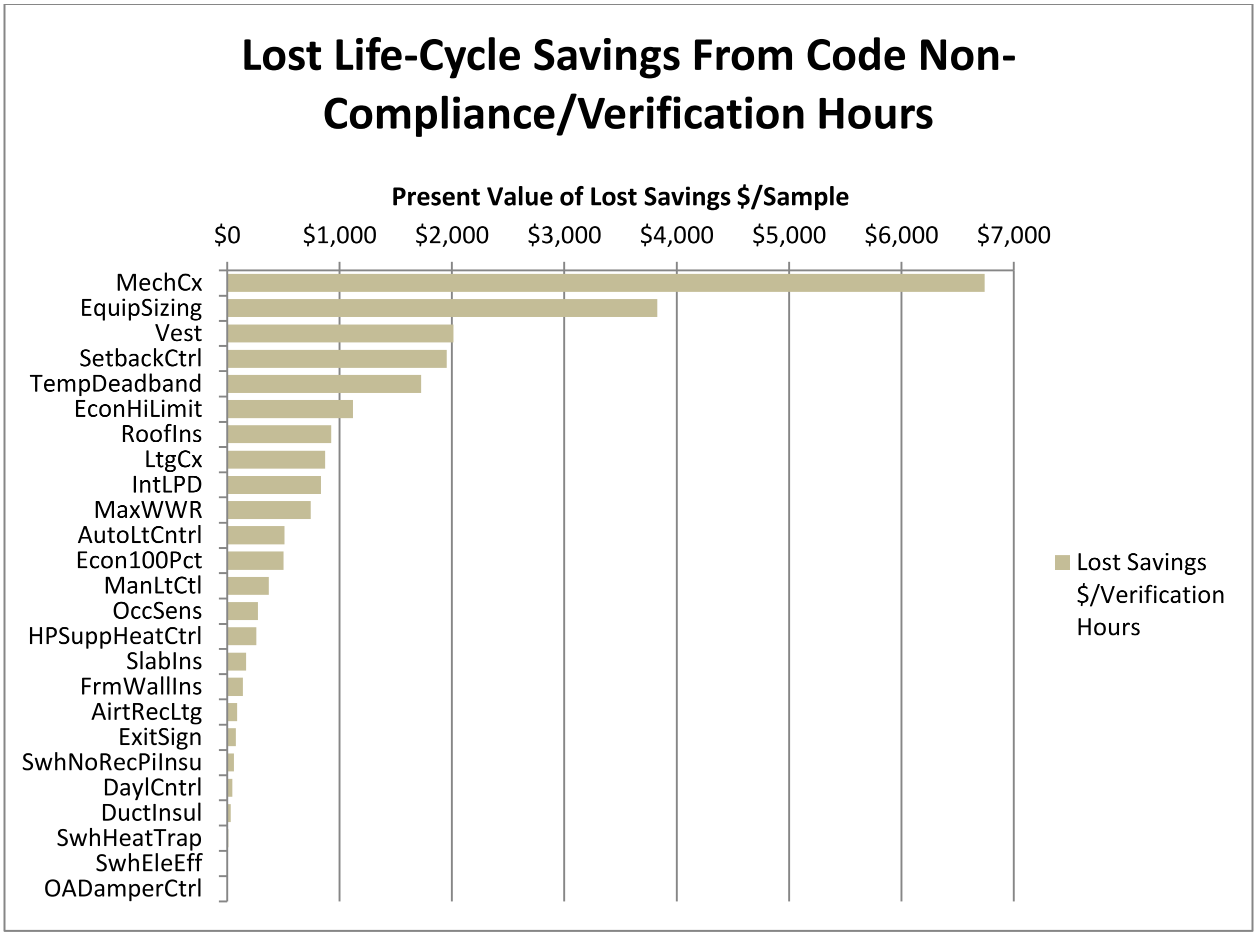

Figure 3.4. Present Value of Lost Life-Cycle Savings from Non-Compliance / Verification Hours

Cost data was also collected on the verification of measures that were applicable but met or exceeded code requirements. These hours are part of the base cost of the study, but are not allocated in determining the cost per below-code measure. These measures are shown in Table 3.8. In a larger sample, there are likely to be many more measures that are below code, and fewer of those that are not. So the combination of measures listed in both Table 3.7 and Table 3.8 represent the total hours for the compliance verification effort for the sample of nine buildings.

Table 3.8. Hours Verifying Measures that Met Energy Code Requirements

Applicable Measures Meeting Code	Number Applicable	Verification Hours
Windows meet U-factor requirements	9	3.7
Windows meet U-factor requirements in entry doors	9	2.7
Windows meet SHGC requirements	9	3.1
Building meets continuous air barrier requirements	9	3.1
Fenestration assemblies meet air leakage requirements	9	2.8
Thermostatic control is used for individual zones	9	3.3
Exterior lighting control	9	2.9
Exterior lighting power allowance	9	3.1
Packaged air conditioner efficiency	8	3.1
Optimal start controls	7	2.2
Duct leakage requirement	7	2.3
Opaque doors meet U-factor requirements.	6	2.0
Packaged heat pump efficiency	6	2.0
Task lighting control	5	1.4
Demand control ventilation	3	1.0
Gas furnace efficiency	2	0.7
Tandem wiring	2	0.7
Building openings to shafts, chutes, stairways, and elevator lobbies meet air leakage requirements	1	0.3
SWH pipe insulation - recirculated	1	0.4
Total hours to confirm code compliance	120	40.9

While the ranking by effort per savings is helpful in identifying important measures to verify, it should be noted that the data comes from a very small sample of one type of building in a limited geographic area and is limited to one verifier. Again, the purpose here is to develop an example methodology that can be applied to results from a larger field sample. Table 3.9 shows only the measures with identified lost savings that were applicable in this sample.

To get a better idea of how the measures were grouped for this sample, they are divided into high-, medium-, and low-value measures with lost savings (high is greater than $750 per hour and low is less than $400 per hour), those found compliant (equal or above code), and those that were not applicable in these nine buildings. These groupings are shown in Table 3.9. In the table, the 63 measures are grouped by their potential lost energy cost divided by verification time required. There are potentially 567 measure instances to be verified in this sample (9 buildings × 63 measures). However, not all measures are found in each building. For this sample, there were 289 applicable instances of measure verification. Of the 289 applicable instances, 61of them (21%) were responsible for 81% of the lost energy cost saving, indicating that the Pareto principle[1] applied to this study. If the next three measures in the medium group are included, 90% of the lost savings would be identified. Of course, final prioritization should be based on results from a larger sample set and could also consider less impactful measures that are inspected easily together with those that are more impactful.

[1] The Pareto principle (also known as the 80-20 rule) states that, in many interactions, approximately 80% of the effects come from 20% of the causes.

Table 3.9. Summary of Measures and Instances in this Sample

Grouping by Lost Savings per Hour and Applicability	Measures #	Measures %	Applicable Instances #	Applicable Instances %	Life-Cycle Lost Savings	% Lost Life-Cycle Savings
High lost $/verification hour	9	14%	61	21%	$37,747	81%
Med lost $/verification hour	3	5%	18	6%	$4,886	11%
Low lost $/verification hour	13	21%	90	31%	$3,797	8%
Compliant with code	19	30%	120	42%	$0	0%
Not applicable this sample	19	30%	0	0%	$0	0%
Total	63		289		$46,430	

3.3.4.3 Distribution of Worst-Case Measure Impacts

Based on the sensitivity analysis of a prototypical office building using simulation, the annual energy cost impact of the worst case for each measure was determined and a present value of lost savings calculated per 1,000 ft^2 of building area. In

Figure 3.5, the frequency of these lost savings is organized into bins that double in value, from the highest lost savings to the lowest. The dashed line shows that less than 30% of the measures cover all individual measure's worst-case impacts greater than $800 in life-cycle lost savings and more than 70% of the cumulative worst-case lost savings. This reinforces the Pareto principle concept of focusing on a limited number of high-impact measures to verify the majority of lost savings.

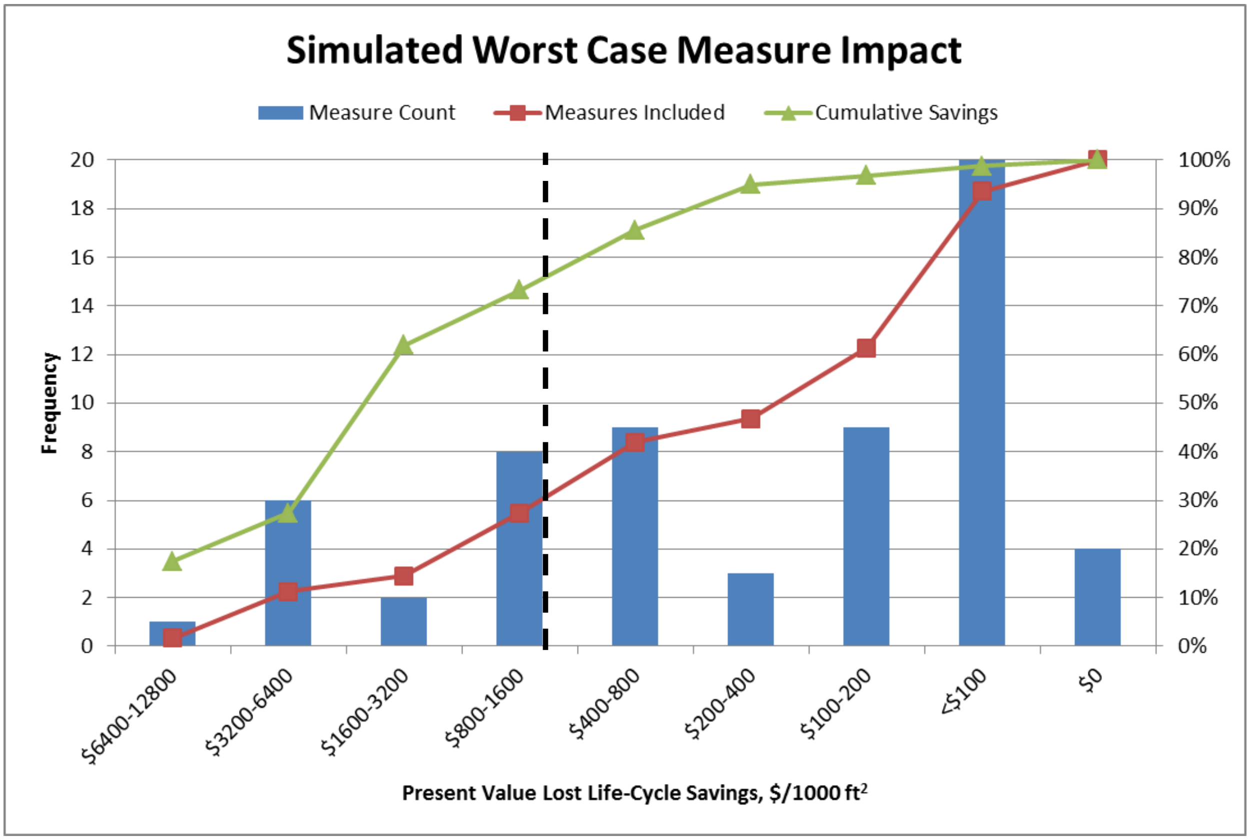

Figure 3.5. Distribution of Worst-Case Measure Impact

4.0 Observations and Lessons Learned

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

This Section discusses issues encountered during this study that likely apply to any type of compliance assessment activities. Additional barriers and recommended solutions are discussed by the verification contractor in Section 3.4 of the contractor report in Appendix D.

- **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 for preparation, 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. Fortunately, those systems only served part 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 (the IECC threshold for commissioning mechanical systems is 40 tons cooling or 600 MBH heating capacity). Even for those that required mechanical commissioning; those documents 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 (successful recruits/candidate buildings identified) of 7.4%. Over 11 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, so that the independent compliance activity carried the authority of the jurisdiction and the building information would be received directly from the code officials.

- **Timing 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 or near completion. That means some measures cannot be field verified, particularly envelope components. For this study, it was not possible to 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.

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.

– 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 current study is a mechanical engineer with over 25 years' 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 when less qualified auditors are used. This leads to inconsistency in compliance assessment activities, whether undertaken by a code official or a third party verifier.

4.2 Observations and Lesson Learned about Field-Based Compliance Assessment Specific to this Study

The observations discussed in the previous section are generally applicable to any compliance assessment. The following observations apply specifically to future studies building on the methodology piloted here.

- **Data Collection Forms.** The Excel-based field take-off form developed for this study (example shown in Appendix C) 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, which could even involve 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.

- **Buildings Complying 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 the there is sufficient documentation of the tradeoffs used. Documentation of those tradeoffs essentially defines new prescriptive requirements which can be evaluated in the same manner as variations from the base code.

4.3 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. This results of this analysis point to a potential solution. Based on the Pareto analyses in Table 3.9 and Figure 3.5, it is clear that a small fraction of measures have a high impact on the lost energy savings of below-code measures. This indicates it is possible to reduce the effort in both compliance studies and code verification efforts. A proposed prioritized approach is as follows:

- Determine a set of high-impact lost energy saving measures that should always be verified in every building. These will likely vary by building type and climate zone. Whether there are 5 or 30 measures could vary depending on the purpose of the verification and the complexity of the building type.
- Verify the remainder of the measures on a rotating or randomized basis to ensure full compliance with the energy code. This approach will lead designers and contractors to pay the most attention to the most impactful requirements, while ignoring none.

Such an approach has a significant efficiency advantage in that high-energy-impact measures are fully investigated, while less effort is applied to less impactful measures. The time information gathered in this field study was analyzed, and the time associated with a base inspection cost including general and travel time was isolated from specific measure verification. Then, the hours associated with high impact vs. low impact vs. applicable but complying measures were determined. Based on that time allocation and application of the prioritized approach discussed above, a possible time distribution for prioritized studies is shown in Figure 4.1. In this approach, 29% of time that would be avoided for direct inspection of measures that complied or that were low impact is shown as a potential savings. This represents a significant reduction in verification effort.

As discussed in Section 3.3.4.2 both the potential lost energy cost savings and the time allocations were determined from a very small sample of a single building type in a limited geographic area. The purpose is to develop an example methodology that can be applied to results from a larger field sample. Final prioritizations should be based on data from a more robust sample.

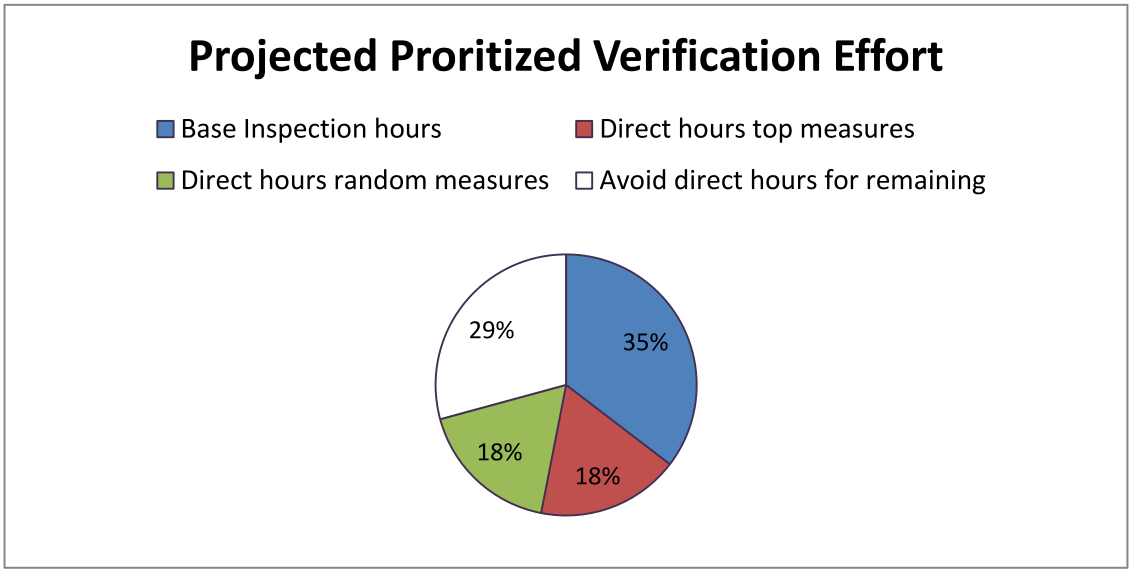

Figure 4.1. Potential Reduction in Verification Time

5.0 References

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

ASHRAE. 2010. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ANSI/ASHRAE/IES Standard 90.1-2010, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

DOE. 2010. *Measuring State Energy Code Performance*. U.S. Department of Energy, Washington, D.C. Accessed September 10, 2015, at https://www.energycodes.gov/sites/default/files/documents/MeasuringStateCompliance.pdf.

DOE. 2013. *90% Compliance Pilot Studies*. U.S. Department of Energy, Washington, D.C.

DOE. 2015a. *About Building Energy Codes*. U.S. Department of Energy, Washington, D.C. https://www.energycodes.gov/about.

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

DOE. 2015c. *Commercial Prototype Building Models*. U.S. Department of Energy, Washington, D.C. Accessed October 5, 2015 at https://www.energycodes.gov/commercial-prototype-building-models.

EIA. 2003. *Commercial Buildings Energy Consumption Survey 2003*. Energy Information Administration of the U.S. Department of Energy, Washington, D.C. http://www.eia.gov/consumption/commercial/data/2003/.

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

Hsu C-C and BA Sanford. 2007. "The Delphi Technique: Making Sense of Consensus." *Practical Assessment and Evaluation* 12(10), August 2007.

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

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, National Institute of Standards and Technology, Washington, D.C. Available at http://dx.doi.org/10.6028/NIST.IR.85-3273-30.

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, Lawrence Berkeley National Laboratory, Berkeley, CA.

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.

Oregon. 2014. *2014 Oregon Energy Efficiency Specialty Code*. International Code Council, Washington, D.C.

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, Pacific Northwest National Laboratory, Richland, WA.

Washington State. 2014. *2012 Washington State Energy Code.* International Code Council, Washington, D.C.

Appendix A

IECC 2012 Code Measures and Associated Requirements

Appendix A

IECC 2012 Code Measures and Associated Requirements

Table A.1. Code Requirements and Measures from the 2012 IECC

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
Envelope			
Roofs shall be insulated to meet CZ requirements	C402.2.1 C303.1.1 C402.2	Roofs meet minimum R-value or U-value by assembly type. Spray polyurethane foam shall have a certification letter. Multiple layers of continuous insulation must be overlapped properly.	
Skylight curbs shall be insulated	C402.2.1	Skylight curbs shall be insulated to the level of roofs with insulation entirely above deck or R-5, whichever is less.	
Above grade frame walls shall be insulated to meet CZ requirements	C402.2.3 C402.2 C303.1.1 C402.2	Above grade walls meet minimum R-value or U-value by assembly type. Multiple layers of continuous insulation must be overlapped properly. Spray polyurethane foam shall have a certification letter. If manufacturer's instructions for continuous insulation does not address multiple layers, edges shall be staggered.	
Above grade mass walls shall be insulated to meet CZ and density requirements	C402.2.3 C402.2.3 C402.2 C402.2	Above grade walls meet minimum R-value or U-value by assembly type. Mass walls meet specified pound per square foot of surface area and may require a specified density. Multiple layers of continuous insulation must be overlapped properly. If manufacturer's instructions for continuous insulation does not address multiple layers, edges shall be staggered.	
Below grade walls meet insulation requirements and be protected.	C402.2.4 C303.2.1 C402.2.4	Below grade walls meet minimum R-value or C-value. Exterior insulation for SOG and basement walls shall have rigid protective covering extending at least 6" below grade. Below-grade wall insulation shall extend to the level of the floor or 10' whichever is less.	
Exterior floors meet t minimum R-value or U-value by assembly type	C402.2.5 C402.2.5	Exterior floors meet t minimum R-value or U-value by assembly type. Mass floors must have a specified pound per square foot of wall area and may require a specified density.	
Slab-on-grade floors meet insulation requirements and be protected.	C402.2.6 C402.2.6	Slab-on-grade floors meet minimum R-value or F-factor requirements. Slab-on-grade insulation shall be positioned and of the appropriate length, by assembly type.	

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
	C402.2.6 C303.2.1	Exterior slab-on-grade insulation extending horizontally shall be protected by soil or paving. Exterior insulation for SOG and basement walls shall have rigid protective covering extending at least 6" below grade.	
Opaque doors meet U-factor requirements.	C402.2.7	Opaque doors meet maximum U-factor requirements by door type.	
Window-to-wall ratio meets maximum limits.	C402.3.1 C402.3.1.1	Vertical fenestration area shall not exceed 30% of gross above-grade wall area. In climate zones 1-6, up to 40% of gross above-grade wall area is allowed for vertical fenestration if >50% floor is daylit and daylighting controls are provided.	
Skylight area meets maximum limits.	C402.3.1 C402.3.1.2	Skylight area shall not exceed 3 % of gross roof area. Up to 5% of roof area in skylights is allowed if daylighting controls are provided.	
Windows meet U-factor requirements.	C402.3.3 C303.1.3 C303.1.3	Vertical fenestration meets maximum U-factor and SHGC requirements. U-factors of fenestration shall be NFRC rated. Products without an NFRC U-factor rating shall use default values.	
Windows meet SHGC requirements.	C402.3.3 C402.3.3 C303.1.3 C303.1.3 C402.3.3.5	Vertical fenestration meets maximum U-factor and SHGC requirements. The window projection factor shall be determined as the ratio of the length of the overhang horizontally (from the face of the window) divided by the height of the overhang vertically (from the bottom of the window). SHGC and VT shall be NFRC rated. Products without an NFRC SHGC or VT shall use default values. SHGC for dynamic glazing is the manufacturer's lowest-rated SHGC.	
Skylights meet U-factor requirements.	C402.3.3 C402.3.3.4 C303.1.3 C303.1.3	Skylights meet maximum U-factor and SHGC requirements. Skylights above daylight zones with automatic controls may have higher U-factors. U-factors of fenestration shall be NFRC rated. Products without an NFRC U-factor rating shall use default values.	
Skylights meet SHGC requirements.	C402.3.3 C402.3.3.3 C303.1.3 C303.1.3 C303.1.3 C402.3.3.5	Skylights meet maximum U-factor and SHGC requirements. In Climate Zones 1 through 6, skylights shall be permitted a maximum SHGC of 0.60 where located above daylight zones provided with automated daylighting controls U-factors of fenestration shall be NFRC rated. SHGC and VT shall be NFRC rated. Products without an NFRC SHGC or VT shall use default values. SHGC for dynamic glazing is the manufacturer's lowest-rated SHGC.	
Building meets continuous air barrier requirements.	C402.4.1	A continuous air barrier shall be provided throughout the building thermal envelope.	

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
	C402.4.1.1 C402.4.1.1 C402.4.1.1 C402.4.1.1 C402.4.2 C402.4.2 C402.4.2 C402.4.2 C402.4.1.2 C402.4.1.2.1 C402.4.1.2.1 C402.4.1.2.2 C402.4.1.2.2 C402.4.1.2.3	Air barriers shall be continuous across all assemblies in the thermal envelope of the building and across the joints and assemblies. Air barrier joints and seams shall be sealed, including sealing transitions in places and changes in materials. Air barrier penetrations shall be sealed. Joints and seals should be installed securely to resist positive and negative pressure. Air barrier penetrations shall be caulked, gasketed, or sealed. Joints and seams shall be caulked, gasketed, or sealed. Sealing materials shall be appropriate to the construction materials being sealed. Joints and seals should be installed securely to resist positive and negative pressure. The continuous air barrier must comply with one of three options - materials, assemblies, or testing. Materials with low air permeability are acceptable air barriers. Fifteen specific low permeability materials are listed. Assemblies with low air leakage are acceptable as air barriers. Coated concrete masonry walls and Portland cement/sand parge, stucco or plaster are acceptable as air barriers. A completed building with a low tested air leakage rate is acceptable for air barrier requirements.	
Recessed lighting shall be sealed, rated and labeled.	C402.4.1.1 C402.4.8 C402.4.8 C402.4.8	Recessed lighting fixtures shall be sealed and IC-rated and labeled. Recessed lighting shall be sealed. Recessed luminaires shall be IC-rated and labelled. Recessed luminaires shall be sealed between housing and wall or ceiling covering.	
Fenestration assemblies meet air leakage requirements.	C402.4.3	The air leakage of fenestration assemblies meet maximum values by assembly type.	
Building openings meet air leakage requirements.	C402.4.4	Doors and access openings to shafts, chutes, stairways, and elevator lobbies shall be labeled for leakage or gasketed, weather stripped or sealed.	
Stairway and shaft vents shall be provided with Class I motorized dampers	C402.4.5.1 C402.4.5.1	Stairway and shaft vents shall be provided with Class I motorized dampers Stairway and shaft vent dampers shall be installed with automatic controls and normally closed.	 Yes
Loading dock doors shall be equipped with weather seals.	C402.4.6	Cargo doors and loading dock doors shall be equipped with weather seals	
Building entrances shall be protected with an enclosed vestibule.	C402.4.7	All building entrances shall be protected with an enclosed vestibule	

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
	C402.4.7 C402.4.7	Vestibules shall be designed so that it is not necessary for the interior and exterior doors to open at the same time. The installation of revolving doors shall not eliminate the requirement that a vestibule be provided on any doors adjacent to revolving doors.	
Mechanical Systems			
Equipment sizing requirement	C403.2.2 C403.2.1	Heating and cooling equipment and systems shall not be oversized. Design loads must be calculated in accordance with ANSI/ASHRAE/ACCA Standard 183 or approved alternative.	
Packaged air conditioner efficiency	C403.2.3 C403.2.3	Heating and cooling equipment meets minimum efficiency requirements by equipment type. If the designer combines components from different manufacturers, it is the designer's responsibility to show that equipment meets requirements.	
Packaged heat pump efficiency	C403.2.3 C403.2.3	Heating and cooling equipment meets minimum efficiency requirements by equipment type. If the designer combines components from different manufacturers, it is the designer's responsibility to show that equipment meets requirements.	
Gas furnace efficiency	C403.2.3 C403.2.3	Heating and cooling equipment meets minimum efficiency requirements by equipment type. If the designer combines components from different manufacturers, it is the designer's responsibility to show that equipment meets requirements.	
Thermostatic control is used for individual zones	C403.2.4 C403.2.4.1	Heating and cooling systems shall have thermostatic controls. Individual heating and cooling zones shall have individual thermostatic controls.	Yes Yes
Heat pump supplementary heat control	C403.2.4.1.1	Heat pumps with supplementary heat shall have controls that lock out resistance heat when heat pump can meet heating load; e.g. OA lockout <= 40F or ramped startup setpoint.	Yes
Thermostat deadband requirement	C403.2.4.2	Thermostatic controls shall have a 5°F deadband.	Yes
Thermostat setback controls	C403.2.4.3 C403.2.4.3.1 C403.2.4.3.2	Each zone shall have thermostatic setback controls. Thermostatic setback controls shall have capability to set back or operate system to maintained higher or lower setpoints. Thermostatic setback controls shall have a manual override.	Yes Yes Yes
Optimal start controls	C403.2.4.3.3 C403.2.4.3.3	HVAC systems shall have optimal start controls. Automatic start controls shall adjust the HVAC start time to bring spaces to desired occupied temperature immediately prior to scheduled occupancy.	Yes Yes

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
Damper control when space is unoccupied	C403.2.4.4 C403.2.5 C402.4.5.2	Outdoor air supply and exhaust ducts shall have motorized dampers. Mechanical ventilation systems shall have the capability to reduce outdoor air supply to the minimum required in Chapter 4 of the IMC. Outdoor air supply and exhaust openings shall be provided with Class IA motorized dampers	 Yes Yes
Snow and ice-melting system control	C403.2.4.5	Snow and ice-melting systems shall have automatic controls.	Yes
Demand control ventilation	C403.2.5.1	Demand control ventilation is required for spaces > 500 sf with >= 25 p/sf. Ex: ERV; des OA < 1200 cfm; or process.	Yes
Energy recovery requirement	C403.2.6 C403.2.6 C403.2.6	Fan systems with large supply airflow and OA rates (Table C403.2.6) shall include an energy recovery system. The energy recovery system shall provide a change in the enthalpy of the outdoor air supply of not less than 50 percent of the difference between outdoor air and return air. Energy recovery systems shall have bypass and controls to work with economizers, where required.	 Yes
Duct insulation requirement	C403.2.7 C403.2.7.1.2	Supply and return air ducts and plenums shall be insulated. Duct and plenums operating at medium pressure shall be insulated and sealed.	
Duct leakage requirement	C403.2.7.1.1 C403.2.7.1.1 C403.2.7.1.2 C403.2.7.1.2	Longitudinal and transverse joints, seams, and connections in low-pressure ducts shall be fastened and sealed. Pressure classification of duct systems shall be marked on construction documents in accordance with the IMC. Duct and plenums operating at medium pressure shall be insulated and sealed. Pressure classification of duct systems shall be marked on construction documents in accordance with the IMC.	
Mechanical system commission requirement	C403.2.9 C408.2 C408.2.1 C408.2.2 C408.2.2.1 C408.2.3.1 C408.2.3.2 C408.2.3.3 C408.2.4 C408.2.4.1 C408.2.5.2	Mechanical systems shall be commissioned. Registered design professional shall provide evidence of mechanical systems commissioning. A commissioning plan must be developed. HVAC systems shall be balanced. Supply air outlets and zone terminal devices shall have means for air balancing. Equipment functional performance testing is required. HVAC control system testing is required. Air economizer functional testing is required. A preliminary commissioning report is required. The building owner must acknowledge receipt of the preliminary commissioning report. Operating and maintenance manuals shall be provided.	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
	C408.2.5.3 C408.2.5.4	A written report on testing and balancing is required. A final commissioning report is required.	Yes Yes
Fan power limit requirement	C403.2.10 C403.2.10.1 C403.2.10.1 C403.2.10.2 C403.2.10.2	HVAC systems with total fan system motor nameplate hp greater than 5 hp shall be properly sized. Fan system motor nameplate hp or fan system bhp shall be limited. Single zone VAV systems shall comply with constant volume fan power limitations. The fan motor shall be no larger than the first available motor size greater than the bhp. The bhp shall be indicated on design documents.	
Fan cooling systems include economizer as required	C403.3.1	Cooling systems with fans shall include an air or water economizer.	
Economizer supplies 100% design supply air	C403.3.1.1.1 C403.3.1.1.4 C403.3.1.1.4	Air economizer systems must be capable of providing 100% of design supply air as outdoor air for cooling. Economizer system shall be capable of relieving excess air (with motorized damper if required under C403.2.4.4) Relief air outlets shall be located to avoid recirculation.	
Economizer is integrated with mechanical cooling.	C403.3.1.1.2	Economizer dampers must be capable of being sequenced with mechanical cooling. Modulating OA and Return dampers are required.	Yes
Economizers should have appropriate high-limit shutoff control	C403.3.1.1.3 C403.3.1.1.3 C403.3.1.1.3	Air economizers shall be capable of reducing outdoor air intake to the minimum outdoor air quantity when economizer is not needed. Economizers should have appropriate high-limit shutoff control type. Economizers should have appropriate high-limit shutoff control settings.	Yes Yes Yes
Gas Water heater efficiency	C404.2	Water -heating equipment and hot water storage tanks must meet minimum efficiency standards.	
Electric Water heater efficiency	C404.2	Water -heating equipment and hot water storage tanks must meet minimum efficiency standards.	
SWH Heat Trap	C404.4	Water-heating equipment must have a heat trap.	
SWH Pipe Insulation - Recirculated	C404.5	Water-heating piping in automatic circulating and heat-traced systems must 1" of insulation, minimum conductivity of 0.27 Btu per inch/h × ft2 × °F.	
SWH Pipe Insulation - Non-recirculated	C404.5	First 8 feet of piping in water heating piping served by equipment without integral heat traps shall be insulated.	
Lighting			
Manual lighting control	C405.2.1 C405.2.1.1 C405.2.1.1	All buildings shall have manual lighting controls. Each room shall have at least one manual control. Required controls shall be accessible.	

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
	C405.2.1.2	Each area with a manual control shall have an occupant-controlled way of reducing connected lighting load by 50%.	
	C405.2.1.2	4 acceptable options for manually reducing connected lighting load by 50%.	
Automatic time switch control	C405.2.2	Each area with a manual control shall also have automatic lighting controls.	
	C405.2.2.1	Automatic time switch controls shall be installed to control lighting in all areas of the building.	Yes
	C405.2.2.1	Automatic time switch controls shall include an override switch.	Yes
Occupancy sensor control	C405.2.2	Each area with a manual control shall also have automatic lighting controls.	
	C405.2.2.2	Occupancy sensors are required in specific space types.	
	C405.2.2.2	Occupancy sensors shall turn off lights within 30 minutes of all occupants leaving.	Yes
	C405.2.2.2	Occupancy sensors shall be manual on or automatic on to no more than 50% power.	
Daylight zone control	C405.2.2.3	Daylight zone lights shall be controlled independently of general area lighting.	
	C405.2.2.3	Daylight control zones shall be smaller than 2,500 square feet.	
	C405.2.2.3	Contiguous daylight zones by vertical fenestration may be controlled by a single controlling device.	
	C405.2.2.3	Daylight zones under skylights shall be controlled separately from daylight zones adjacent to vertical fenestration.	
	C405.2.2.3.1	Manual controls shall be installed in daylight zones unless automatic controls are installed.	
	C405.2.2.3.2	Set-point and other controls for calibrating the lighting control device shall be readily accessible.	
	C405.2.2.3.2	Daylighting controls shall be continuous dimming or step dimming.	
	C405.2.2.3.2	Daylighting controls shall provide at least two control channels per zone and a minimum of three controls steps.	
Multi-level daylighting control	C405.2.2.3.3	When multi-level controls are required, general lighting in daylight zones shall be controlled by multi-level lighting controls.	
	C405.2.2.3.3	When daylit illuminance is greater than rated illuminance of general lighting, the power of the general lighting shall be reduced.	Yes
	C405.2.2.3.3	Multi-level lighting controls shall be readily accessible.	
Display lighting control	C405.2.3	Display and accent lighting shall be controlled separately.	
Task lighting control	C405.2.3	Supplemental task lighting shall have a luminaire mounted control device or accessible wall-mounted control device.	

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
Exterior lighting control	C405.2.4 C405.2.4	Lighting not designated for dusk-to-dawn operation shall be controlled by either a combination of a photosensor and a time switch, or an astronomical time switch. Lighting designated for dusk-to-dawn operation shall be controlled by an astronomical time switch or photosensor.	Yes Yes
Tandem wiring	C405.3	Tandem wiring of 1 or 3 lamp fluorescent luminaires is required.	
Exit sign maximum power	C405.4	Internally illuminated exit signs shall not exceed 5 watts per side.	
Interior lighting power allowance	C405.5.1 C405.5.1.2 C405.5.1.4 C405.5.2 C405.5.2 C405.5.2	The total connected interior lighting power (watts) shall be the sum of the watts of all interior lighting equipment. The wattage shall be the specified wattage of the transformer supplying the system. The wattage of the luminaires may be calculated three ways. Total interior power lighting allowance can be determined by Building Area Method or Space-by-Space Method. For the Building Area method, the ILPA equals the floor area of the building type times the allowed LPD for that building type. For the Space-by-Space method, ILPA equals the floor area of each space times the allowed LPD for that space type.	
Exterior lighting power allowance	C405.6 C405.6.1 C405.6.2 C405.6.2 C405.6.2 C405.6.2	Exterior lighting power through the building is subject to the code. Exterior building grounds luminiares shall have a minimum efficacy of 60 lumens per watt. Total ELPA equals the sum of the base site allowance plus the individual allowances for areas that are illuminated and permitted. Tradeoff among exterior spaces are allowed only for Tradeable Surfaces. Exterior lighting is to be categorized into the appropriate lighting zone. Exterior lighting luminaires shall have a minimum efficacy of 60 lumens per watt.	
Options			
Optional additional packaged air conditioner efficiency	C406.2 C406.1	Equipment meets higher minimum efficiencies than called for in the code. Buildings shall comply with one of 3 additional efficiency options.	
Optional additional packaged heat pump efficiency	C406.2 C406.1	Equipment meets higher minimum efficiencies than called for in the code. Buildings shall comply with one of 3 additional efficiency options.	
Optional additional gas furnace efficiency	C406.2 C406.1	Equipment meets higher minimum efficiencies than called for in the code. Buildings shall comply with one of 3 additional efficiency options.	
Optional reduced whole building LPD	C406.3	Whole building lighting power density shall be lower than called for in the code.	

Measure name	2012 IECC Section	Requirement Summary	Cx Check Required
	C406.3.1	ILP shall be calculated by multiplying the whole building requirements in this section by the floor area of the building types.	
	C406.1	Buildings shall comply with one of 3 additional efficiency options.	Yes
Optional onsite renewable	C406.4	The renewable energy option requires either 0.5 watts per square foot or 3% of the energy used for regulated loads.	
	C406.1	Buildings shall comply with one of 3 additional efficiency options.	

Appendix B

IECC 2012 Code Measures, Identified Conditions, and Annual Energy Cost Impact

Appendix B

IECC 2012 Code Measures, Identified Conditions, and Annual Energy Cost Impact

Table B.1. Code Measures, Conditions and Annual Lost Energy Cost Savings – Office Building Climate Zone 4C

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Roofs shall be insulated to meet CZ requirements	RoofIns	50% req'd U-value	75% req'd U-value	100% req'd U-value	150% req'd U-value	No insul
Lost $ savings	per ft2 building	-$0.013	-$0.007	$0.000	$0.013	$0.474
Lost $ savings	per ft2 net roof area	-$0.015	-$0.007	$0.000	$0.015	$0.537
Skylight curbs shall be insulated.	SkylCurbIns	75% Roof req'd U-value	Curb insulated to 100% Roof req'd U-value	Curb insulated to R-5	Curb insulated to R-2.5	No insul
Lost $ savings	per ft2 building	-$0.009	-$0.002	$0.000	$0.002	$0.014
Lost $ savings	per ft2 of skylight curb	-$0.498	-$0.117	$0.000	$0.118	$0.825
Above grade frame walls shall be insulated to meet CZ requirements	FrmWallIns	40% req'd U-value, installed per mfg	75% req'd U-value, installed per mfg	100% req'd U-value, installed per mfg	100% Cavity, no C.I., installed per mfg	No Insul
Lost $ savings	per ft2 building	-$0.008	-$0.003	$0.000	$0.012	$0.063
Lost $ savings	per ft2 net opaque wall area	-$0.016	-$0.007	$0.000	$0.025	$0.129
Above grade mass walls shall be insulated to meet CZ and density requirements	MassWallIns	50% req'd U-value/100%Dens,, installed per mfg	75% req'd U-value/100%Dens, installed per mfg	100% req'd U-value/100%Dens, installed per mfg	200% req'd U-value/75%Dens, installed per mfg	No Ins/75% Dens
Lost $ savings	per ft2 building	-$0.004	-$0.002	$0.000	$0.010	$0.055
Lost $ savings	per ft2 net opaque wall area	-$0.009	-$0.005	$0.000	$0.021	$0.113
Below grade walls meets insulation requirements and be protected.	BelowGradeIns	50% req'd U-value, insul protected	75% req'd U-value, insul protected	100% req'd U-value, insul protected	200% req'd U-value, insul protected	No Insul
Lost $ savings	per ft2 building	-$0.001	$0.000	$0.000	$0.001	$0.002
Lost $ savings	per ft2 net opaque wall area	-$0.005	-$0.003	$0.000	$0.003	$0.012
Exterior floors meet the minimum R-value or U-value by assembly type	ExtFloorIns	50% req'd U-value/100%Dens	75% req'd U-value/100%Dens	100% req'd U-value/100%Dens	200% req'd U-value/100%Dens	No Ins
Lost $ savings	per ft2 building	-$0.001	$0.000	$0.000	$0.002	$0.021
Lost $ savings	per ft2 exterior/ crawl floor	-$0.004	-$0.002	$0.000	$0.009	$0.109

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Slab-on-grade floors meet insulation requirements and be protected.	SlabIns	Full under Slab 100% R	200% R Full Depth	100% R Full Depth	50%-R 50% Depth	No Insul
Lost $ savings	per ft2 building	-$0.002	$0.000	$0.000	$0.001	$0.002
Lost $ savings	per LF-perimeter	-$0.034	-$0.003	$0.000	$0.021	$0.042
Opaque doors meet U-factor requirements.	DoorU	50% req'd U-value	75% req'd U-value	100% req'd U-value	150% req'd U-value	200% req'd U-value
Lost $ savings	per ft2 building	-$0.001	$0.000	$0.000	$0.000	$0.001
Lost $ savings	per ft2 doors, net of windows in doors	-$0.077	-$0.032	$0.000	$0.056	$0.099
Window-to-wall ratio meets maximum limits.	MaxWWR	5% WWR w/DL controls	20% WWR w/DL controls	30% WWR no DL controls	50% WWR with DL controls	90% WWR no DL controls
Lost $ savings	per ft2 building	-$0.056	-$0.056	$0.000	$0.022	$0.137
Lost $ savings	per ft2 Gross Exterior Wall	-$0.115	-$0.114	$0.000	$0.045	$0.282
Skylight to roof ratio meets maximum limits	MaxSkyLtRoofR	3% area, adv DL ctrl	3% area, DL ctrl	2.9% area, no DL ctl	5% area, no DL ctrl	7% area, no DL ctrl
Lost $ savings	per ft2 building	-$0.055	-$0.054	$0.000	$0.019	$0.037
Lost $ savings	per ft2 Gross Roof Area	-$0.063	-$0.061	$0.000	$0.021	$0.042
Windows meet U-factor requirements.	WinUFactor	58% req'd U-value	76% req'd U-value	100% req'd U-value	142% req'd U-value	237% req'd U-value
Lost $ savings	per ft2 building	-$0.005	-$0.003	$0.000	$0.005	$0.033
Lost $ savings	per ft2 window affected	-$0.032	-$0.019	$0.000	$0.037	$0.227
Windows meet SHGC requirements.	WinSHGC	50% req'd SHGC	75% req'd SHGC	100% req'd SHGC	170% req'd SHGC	113% req'd SHGC
Lost $ savings	per ft2 building	-$0.023	-$0.017	$0.000	$0.009	$0.051
Lost $ savings	per ft2 window affected	-$0.156	-$0.113	$0.000	$0.061	$0.351
Skylights meet U-factor requirements.	SkyLtUFactor	62% req'd U-value	90% req'd U-value	100% req'd U-value	216% req'd U-value	396% req'd U-value
Lost $ savings	per ft2 building	-$0.001	$0.000	$0.000	$0.002	$0.005
Lost $ savings	per ft2 skylight affected	-$0.024	-$0.006	$0.000	$0.075	$0.190
Skylights meet SHGC requirements.	SkyLtSHGC	50% req'd SHGC	75% req'd SHGC	100% req'd SHGC	195% req'd SHGC	170% req'd SHGC
Lost $ savings	per ft2 building	-$0.010	-$0.005	$0.000	$0.014	$0.019
Lost $ savings	per ft2 skylight affected	-$0.375	-$0.187	$0.000	$0.525	$0.712
Building meets continuous air barrier requirements.	CAB	Tested at 0.25 cfm/ft2	Tested at 0.3 cfm/ft3	CAB sealed and intact. Mtls or assemb comp	CAB not sealed and intact. Mtls or assemb comp	CAB not sealed and intact. Mtls or assemb don’t comp
Lost $ savings	per ft2 building	-$0.002	-$0.002	$0.000	$0.002	$0.005
Lost $ savings	per ft2 thermal envelope	-$0.001	-$0.001	$0.000	$0.001	$0.002

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Recessed lighting shall be sealed, rated and labeled.	AirtRecLtg	NA	NA	Sealed and labeled for leakage	Not sealed or not labeled	Not sealed and not rated and labeled
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.004	$0.009
Lost $ savings	# of fixtures	$0.000	$0.000	$0.000	$0.329	$0.776
Fenestration assemblies meet air leakage requirements.	WinLeak	Windows and doors labeled as below air leakage reqts	NA	Windows and doors labeled	NA	Windows and doors are not labeled and show leaks
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.003	$0.003
Lost $ savings	per ft2 fenestration	-$0.003	-$0.003	$0.000	$0.021	$0.021
Building openings to shafts, chutes, stairways, and elevator lobbies meet air leakage requirements.	DoorLeak	NA	NA	Labeled for leakage or weather stripped or sealed	Not labeled, poor weatherstripped or seal	NA
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.000	$0.000
Lost $ savings	per ft2 building openings	$0.000	$0.000	$0.000	$0.022	$0.022
Stairway and shaft vents shall be provided with Class I motorized dampers	ShaftVent	NA	NA	Class1-Normally Closed	Class3-Normally Closed	AutoDamper-NormallyOpen
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.001	$0.005
Lost $ savings	per ft2 vents	$0.000	$0.000	$0.000	$0.408	$2.463
Loading dock doors shall be equipped with weatherseals.	LdDkSl	NA	NA	Weather seals installed	NA	No weather seals
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.000	$0.000
Lost $ savings	per LF loading dock door edge	$0.000	$0.000	$0.000	$0.004	$0.004
Building entrances shall be protected with an enclosed vestibule.	Vest	Vestibules where not req'd	NA	Vestibule where req'd	NA	No vestibule where req'd
Lost $ savings	per ft2 building	-$0.006	-$0.002	$0.000	$0.006	$0.006
Lost $ savings	per building entrance	-$40.294	-$13.203	$0.000	$40.294	$40.294
Equipment sizing requirement	EquipSizing	NA	NA	No oversize (up to 1.33)	Oversize50%	Oversize100%
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.031	$0.084
Lost $ savings	per SA cfm affected	$0.000	$0.000	$0.000	$0.044	$0.118
Packaged air conditioner efficiency	ACCoolingEff	165% code req'd efficiency	115% code req'd efficiency	100% code req'd efficiency	NA	100% code req'd efficiency
Lost $ savings	per ft2 building	-$0.009	-$0.003	$0.000	$0.000	$0.000
Lost $ savings	per ton cooling	-$5.644	-$2.031	$0.000	$0.000	$0.000
Packaged heat pump efficiency	HPEff	169% code req'd efficiency	110% code req'd efficiency	100% code req'd efficiency	NA	100% code req'd efficiency
Lost $ savings	per ft2 building	-$0.004	-$0.002	$0.000	$0.000	$0.000
Lost $ savings	per MBh heating	-$0.327	-$0.119	$0.000	$0.000	$0.000

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Gas furnace efficiency	FurnaceEff	97% AFUE	90% AFUE	78% AFUE or 80% Et	NA	78% AFUE or 80% Et
Lost $ savings	per ft2 building	-$0.006	-$0.004	$0.000	$0.000	$0.000
Lost $ savings	per MBh heating	-$0.431	-$0.274	$0.000	$0.000	$0.000
Thermostatic control is used for individual zones	Tstat@Zone	NA	NA	One Thermostat Per Zone	NA	One Thermostat For Five Zones (North)
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.006	$0.006
Lost $ savings	per ft2 floor area incorrectly zoned	$0.000	$0.000	$0.000	$0.040	$0.040
Heat pump supplementary heat control	HPSuppHeatCtrl	Lock Out Sup Heat OA=30F; Comp Lock Out OA=0F	NA	Lock Out Sup Heat OA=40F; Comp Lock Out OA=10F	Lock Out Sup Heat OA=50F; Comp Lock Out OA=20F	Lock Out Sup Heat OA=70F; Comp Lock Out OA=35F
Lost $ savings	per ft2 building	-$0.002	-$0.002	$0.000	$0.000	$0.006
Lost $ savings	per MBh heating	-$0.176	-$0.176	$0.000	$0.018	$0.415
Thermostat deadband requirement	TempDeadband	Deadband7F	NA	Deadband5FAsReq		Deadband1F
Lost $ savings	per ft2 building	-$0.023	-$0.023	$0.000	$0.026	$0.055
Lost $ savings	per ft2 floor area affected	-$0.023	-$0.023	$0.000	$0.026	$0.055
Thermostat setback and start/stop controls	SetbackCtrl	Deep Setback; Fan Cycle Unoccp Schedule; Setback 50degFHt/ 90degFClg;	NA	Code Setback; Fan Cycle Unoccp Schedule; Setback 55degFHt/ 85degFClg;	No Setback; Fan Cycle Unoccp Schedule; 70degFHt/ 75degFClg;	No Setback; Fan ON Unoccp or ON/AUTO; 70degFHt/ 75degFClg;
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.061	$0.274
Lost $ savings	per ft2 floor area affected	$0.000	$0.000	$0.000	$0.061	$0.274
Optimal start controls	OptStart	NA	NA	Optim Start As Req	NA	No Optim Start
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.006	$0.006
Lost $ savings	per ft2 floor area affected	$0.000	$0.000	$0.000	$0.006	$0.006
Damper control when space is unoccupied	OADamperCtrl	Motorized Damper Used When No tReq-Meets Lkg	NA	OA Damper Ctrl As Req-Meets Lkg	OA Damper Ctrl As Req-Does Not Meet Lkg	Motorized Damper Not Used When Req
Lost $ savings	per ft2 building	-$0.001	-$0.001	$0.000	$0.000	$0.002
Lost $ savings	per cfm OA	-$0.009	-$0.009	$0.000	$0.000	$0.014
Snow and ice-melting system control	SnowIceCtrl	Snow Melt OA<35 & Pave<40 & precip	NA	Snow Melt OA<40 & Pave<50 & precip	NA	Snow Melt Season On (Dec. 1 to March 31)
Lost $ savings	per ft2 building	-$0.059	-$0.015	$0.000	$0.015	$0.333
Lost $ savings	per ft2 of heated surface area	-$1.965	-$0.500	$0.000	$0.500	$11.090
Demand control ventilation	DCV	DCV Used When Not Req	NA	DCV As Req	NA	DCV Not Used When Req
Lost $ savings	per ft2 building	-$0.007	-$0.007	$0.000	$0.007	$0.007
Lost $ savings	per ft2 space area	-$0.088	-$0.088	$0.000	$0.087	$0.087

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Energy recovery requirement	ERVUse	ERV Used When Not Req, 60% effic	ERV Use As Req, 60% effic	ERV Use As Req, 50% effic	NA	ERV Not Used When Req
Lost $ savings	per ft2 building	-$0.006	-$0.002	$0.000	$0.004	$0.004
Lost $ savings	per cfm OA	-$0.165	-$0.049	$0.000	$0.116	$0.116
Duct insulation requirement	DuctInsul	R8 Indoor Unconditioned R10 Outdoor	R7 Indoor Unconditioned R9Outdoor	R6 Indoor Unconditioned R8 Outdoor	No Insul Outdoor	No Insul Indoor & Outdoor
Lost $ savings	per ft2 building	-$0.005	-$0.003	$0.000	$0.367	$0.456
Lost $ savings	per ft2 exterior duct surface	-$0.016	-$0.009	$0.000	$1.059	$1.314
Duct leakage requirement	Duct Leakage	Tested When Not Req	NA	Seal As Req	Poorly Sealed	Disconnected
Lost $ savings	per ft2 building	-$0.003	-$0.003	$0.000	$0.007	$0.014
Lost $ savings	per SA cfm affected	-$0.005	-$0.005	$0.000	$0.010	$0.019
Commissioning requirement	Cx	Cx As Req'd, High Qual	NA	Cx As Req'd, Ave Qual	Cx As Req'd, Poor Qual	Cx Not Specified or Completed
Lost $ savings	per ft2 building	-$0.042	-$0.042	$0.000	$0.016	$0.097
Lost $ savings	per ft2 building	-$0.042	-$0.042	$0.000	$0.016	$0.097
Fan power limit requirement	Fan Power	40% Below Limit	20% Below Limit	Fan Power As Req, bhp >60% of nhp	20% Above Limit bhp <40% of nhp	50% Above Limit bhp <20% of nhp
Lost $ savings	per ft2 building	-$0.051	-$0.026	$0.000	$0.044	$0.182
Lost $ savings	per SA cfm	-$0.072	-$0.036	$0.000	$0.061	$0.255
Economizer supplies 100% design supply air	Econ100Pct	Full OA + Power Exhaust = 90% net OA	Full OA + Motor Relief = 80% net OA	Full OA + Gravity Relief = 70% net OA	50% OA	No Economizer
Lost $ savings	per ft2 building	-$0.003	-$0.002	$0.000	$0.012	$0.024
Lost $ savings	per Ton cooling	-$1.801	-$0.995	$0.000	$7.252	$15.037
Economizers should have appropriate high-limit shutoff control and be integrated	EconHiLimit	Diff DB Hi Lim, Integrated	NA	Hi Lim 75, Integrated	Hi Lim 65F, Integrated	Hi Lim 55, any integration
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.006	$0.023
Lost $ savings	per Ton cooling	$0.000	$0.000	$0.000	$3.555	$14.176
Water heater efficiency, Gas	SwhGasEff	EF = 0.8 Condensing	NA	EF = 0.67 - 0.0019V = 0.594	EF = 0.62 - 0.0019V = 0.544	NA
Lost $ savings	per ft2 building	-$0.001	-$0.001	$0.000	$0.001	$0.001
Lost $ savings	per SWH MBh	-$0.175	-$0.175	$0.000	$0.184	$0.184
Water heater efficiency, Electric	SwhEleEff	EF = 0.95	NA	EF = 0.97- 0.00132V = 0.9172	EF= 0.93- 0.00132V = 0.8772	NA
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.000	$0.000
Lost $ savings	per SWH kW	-$0.070	-$0.070	$0.000	$0.095	$0.095
SWH Heat Trap	SwhHeatTrap	NA	NA	With heat trap	NA	Without heat trap
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.001	$0.001
Lost $ savings	per SWH kW	$0.000	$0.000	$0.000	$0.427	$0.427

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
SWH Pipe Insulation - Recirculated	SwhRecPiInsu	Entire pipe length is insulated at the above code level (1.5")	Entire pipe length is insulated at the above code level (1.25")	Insul As Req	Half of the pipe length is insulated at the code level (1")	No insulation for entire pipe
Lost $ savings	per ft2 building	-$0.003	-$0.001	$0.000	$0.018	$0.040
Lost $ savings	per LF HW pipe	-$0.113	-$0.061	$0.000	$0.769	$1.695
SWH Pipe Insulation - Non-recirculated	SwhNoRecPiInsu	Entire pipe length is insulated at the above code level (0.5")	First 16 ft of pipe is insulated at the code level (0.5")	Insul As Req	First 4 ft of pipe is insulated at the code level (0.5")	No insulation for entire pipe
Lost $ savings	per ft2 building	-$0.018	-$0.001	$0.000	$0.001	$0.001
Lost $ savings	per ft2 floor area	-$0.018	-$0.001	$0.000	$0.001	$0.001
Manual lighting control	ManLtCtl	Manual controls w/<50% reduction increments in each room	NA	Manual controls w/50% reduction in each room	Manual controls for 100% only	No manual controls
Lost $ savings	per ft2 building	-$0.007	-$0.007	$0.000	$0.018	$0.106
Lost $ savings	per ft2 floor area	-$0.007	-$0.007	$0.000	$0.018	$0.106
Automatic time switch control	AutoLtCntrl	NA	NA	Automatic controls applied as required	Not all spaces have automatic controls	No automatic controls
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.140	$0.373
Lost $ savings	per ft2 floor area affected	$0.000	$0.000	$0.000	$0.140	$0.373
Occupancy sensor control	OccSens	Occupancy sensors in more spaces than required, 15 min delay, manual on	Occupancy sensors where required, 15 min delay, Auto on 50%	Occupancy sensors where required, 30 min delay, Auto on 50%	Occupancy sensors where required, 1 hr delay, Auto on 50%	No occupancy sensors where required
Lost $ savings	per ft2 building	-$0.047	-$0.015	$0.000	$0.019	$0.043
Lost $ savings	per ft2 floor area affected	-$0.047	-$0.015	$0.000	$0.019	$0.043
Daylight zone control	DaylCntrl	Daylight zone controlled; continuous dimming; less than 2,500 sf controlled per zone	Daylight zone controlled; stepped dimming; less than 2,500 sf controlled per zone	Daylight zone controlled; manual control; less than 2,500 sf controlled per zone	Daylight zone controlled; manual control; more than 2,500 sf controlled per zone	Daylight zone not controlled separately; manual control
Lost $ savings	per ft2 building	-$0.063	-$0.052	$0.000	$0.007	$0.014
Lost $ savings	per ft2 daylight floor area	-$0.108	-$0.088	$0.000	$0.012	$0.024
Display lighting control	DispLtCntrl	NA	NA	Display lighting controlled separately	NA	Display lighting not controlled separately
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.009	$0.009
Lost $ savings	per display Watt	$0.000	$0.000	$0.000	$0.214	$0.214
Task lighting control	TskLtCntrl	NA	Occupancy sensor controlled	Accessible control device	NA	No separate control device
Lost $ savings	per ft2 building	-$0.010	-$0.010	$0.000	$0.010	$0.010
Lost $ savings	per task Watt	-$0.212	-$0.212	$0.000	$0.212	$0.212

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Exterior lighting control	ExtLtCntrl	NA	Astro time switch with additional nighttime turn off (12-6 am)	Photocell control	Time switch but no seasonal correction	No exterior lighting controls
Lost $ savings	per ft2 building	-$0.035	-$0.035	$0.000	$0.024	$0.071
Lost $ savings	per exterior Watt affected	-$0.230	-$0.230	$0.000	$0.159	$0.473
Tandem wiring	TandWire	NA	NA	Fixtures wired in tandem	NA	No tandem wiring
Lost $ savings	per ft2 building	$0.000	$0.000	$0.000	$0.003	$0.003
Lost $ savings	# Fixtures	$0.000	$0.000	$0.000	$0.343	$0.343
Exit sign maximum power	ExitSign	Less than 3W per side	4W per side	5W per side	7W per side	Exceed 10W per side
Lost $ savings	per ft2 building	-$0.005	-$0.002	$0.000	$0.004	$0.009
Lost $ savings	# sign faces	-$1.700	-$0.682	$0.000	$1.346	$3.365
Interior lighting power allowance	IntLPD	Whole building LPD lower than allowed by 50%	Whole building LPD lower than allowed by 15%	Meets whole building LPD	Exceeds whole building LPD by 50%	Exceeds whole building LPD by100%
Lost $ savings	per ft2 building	-$0.150	-$0.045	$0.000	$0.152	$0.307
Lost $ savings	per ft2 floor area	-$0.150	-$0.045	$0.000	$0.152	$0.307
Exterior lighting power allowance	ExtLPD	Exterior lighting power lower than allowance by 50%, luminaire efficacy <= 60 lm/W	Exterior lighting power lower than allowance by 10%, luminaire efficacy <= 60 lm/W	Exterior lighting power meets allowance, luminaire efficacy <= 60 lm/W	Exterior lighting power exceeds allowance by 10%, luminaire efficacy <= 60 lm/W	Exterior lighting power exceeds allowance by 100%, luminaire efficacy <= 60 lm/W
Lost $ savings	per ft2 building	-$0.035	-$0.007	$0.000	$0.007	$0.070
Lost $ savings	per exterior Watts	-$0.234	-$0.047	$0.000	$0.047	$0.468
Optional Additional packaged air conditioner cooling Efficiency	OptACClgEff	143% Section 406 efficiency	120% Section 406 efficiency	100% Section 406 efficiency	NA	87% Section 406 efficiency
Lost $ savings	per ft2 building	-$0.006	-$0.003	$0.000	$0.003	$0.003
Lost $ savings	per Tons cooling	-$3.613	-$2.120	$0.000	$2.031	$2.031
Optional Additional packaged heat pump efficiency	OptHPSysEff	153% Section 406 efficiency	120% Section 406 efficiency	100% Section 406 efficiency	NA	95% Section 406 efficiency
Lost $ savings	per ft2 building	-$0.003	-$0.002	$0.000	$0.002	$0.002
Lost $ savings	per MBh heating	-$0.207	-$0.155	$0.000	$0.119	$0.119
Optional Additional packaged air conditioner furnace efficiency	OptACHtgEff	97% AFUE or 97% Et	94% AFUE or 94% Et	90% AFUE or 90% Et	NA	78% AFUE or 80% Et
Lost $ savings	per ft2 building	-$0.002	-$0.001	$0.000	$0.004	$0.004
Lost $ savings	per MBh heating	-$0.157	-$0.093	$0.000	$0.274	$0.274
Optional Additional Reduced whole building LPD	OptRedLPD	50% Section 405 Code LPD	NA	100% Section 406 Reduced LPD	100% Section 405 Code LPD	200% Section 405 Code LPD
Lost $ savings	per ft2 building	-$0.133	-$0.133	$0.000	$0.017	$0.324
Lost $ savings	per ft2 floor area	-$0.133	-$0.133	$0.000	$0.017	$0.324

Measure Name	Measure Abbreviation	Best-Condition	Above-Code-Condition	Code-Condition	Below-Code-Condition	Worst-Condition
Optional onsite renewable	OptRenewable	PV Watt Twice As Req	NA	PV Watt As Req	NA	PV Watt Zero
Lost $ savings	per ft2 building	-$0.058	-$0.058	$0.000	$0.058	$0.058
Lost $ savings	per Req'd W	-$0.115	-$0.115	$0.000	$0.115	$0.115

Appendix C

Sample Field Audit Form

Table C.1. Sample Data Collection Form

Building Code Verification Record

Building Information

Building Identifier	104953
City/St	Vancouver/WA
Conditioned Floor Area (sqft)	7,075
Number of Floors	1
Occupancy 1	Office 100%
Occupancy 2	0%
Occupancy 3	0%
Building comments:	New office adjacent to production/storage/repair facility for natural resource business. Total ft2 about 25000. Split system heat pump systems serve individual zones. Because of stage of constrcution, had to use permit set vs as-builts.

	Date
Plan Revu	10/5/2015
Site Visit 1	10/1/2015
Site Visit 2	
ASHRAE Climate Zone	4C
Actual code	2012 IECC with
Which option path?	
Total Tons Cooling	11
Total MBH Heating	209
Complied via whole building performance?	N

See timing inputs to right >>
Note record total plan and field time by area at right
For each measure record time estimate below
View reconciliation in column S and adjust estimates to match

Verification Time Record for this building

Area	Plan	Field	Plan Est	Field Est	
Travel & Indirect	1.50	1.00	1.50	1.00	
General	3.50	0.00	3.50	0.00	
Envelope	0.60	0.60	0.61	0.60	E
Lighting LPD	0.15	0.30	0.20	0.33	L
Lighting Controls	0.20	0.25	0.25	0.31	LC
Mechanical & SHW Equip	0.50	0.60	0.30	0.60	M
Mechanical & SHW Controls	0.10	0.25	0.08	0.25	MC
Total this building	**5.05**	**2.00**	**4.94**	**2.09**	

Measure (see requirements tab for items included)	Apply to Bldg	Excep-tion used?	Plan	Field	Select Closest to Identified Condition (if not exact condition, describe and apply rating to right)	Default Energy Rating +10/0/-10	Final Overide Energy Rating	Found Factor	Required Factor	Factor Units	Plan Review Comments and Description	Field Inspection Condition Comments and Description	Applicable quantity, affected	Applicabile units	Est Plan Time, hr	Est Field Time, hr	Area for Time Check	Comments about barriers to checking or special tools or expertise required	Cx Req'd ?	Cx done
Roofs shall be insulated to meet CZ requirments	Y	N	Rvu	Insp	0.0: 100%-U; GoodInstallation; ; Code	0.0	0.0	0.039	0.039	U-factor	metal stud building; continuous insulation layer added outboard of girts. R-30 between girts with contin R-11 outboard. Probably equiv to code req		6,997	ft2 net roof area	0.05	0.05	E		No	
Skylight curbs shall be insulated.	N	N							5.000	R-value			58	ft2 of skylight curb			E		No	
Above grade frame walls shall be insulated to meet CZ requirments	Y	N	Rvu	Insp	4.2: 75%-U; Installed PerMfg; ; Above	4.2	4.2	0.040	0.050	U-Factor	see notes for ceiling, above. For walls, same detail used (including R-30 batts as first layer) and then 1 in rigid over everything. Found factor is an estimate; has some derating due to metal studs.		2,660	ft2 net opaque wall area	0.08		E		No	
Above grade mass walls shall be insulated to meet CZ and density requirments	N	N							0.078	U-factor			2,660	ft2 net opaque wall area			E		No	
Below grade walls shall meet insulation requirements and be protected.	N	N							0.119	C-factor			0	ft2 net opaque wall area			E		No	
Exterior floors shall meet the minimum R-value or U-value by assembly type	N	N							0.074/0.033-factor mass/joist				6,997	ft2 exterior/ crawl floor			E		No	
Slab-on-grade floors shall meet insulation requirements and be protected.	Y	N	Rvu	Inacs	0.0: 100%-R; Full depth; Protected; Code	0.0	0.0	0.540	0.540	F-factor	R-10 perimter insulation (vertical) spec'd		380	LF-Perimeter	0.06		E		No	
Opaque doors shall meet U-factor requirements.	Y	N	Rvu	Insp	10.0: 50%-U; ; ; Best	10.0	10.0	0.19	0.370	U-Factor		foam core metal flush	189	ft2 doors, net of windows in doors	0.05	0.08	E		No	
Window-to-wall ratio shall meet maximum limits.	Y	N	Rvu	Insp	10.0: 20% WWR; DL Controls; ; Above	10.0	8.3	25.0%	0.300	% window area			3,800	ft2 Gross Ext Wall	0.08	0.1	E		No	
Skylight to roof ratio shall meet maximum limits	N	N						0.011	0.030	% skylight area			7,075	ft2 Gross Roof Area			E		No	
Windows shall meet U-factor requirements.	Y	N	Rvu	Insp	0.0: 100%-U; ; ; Code	0.0	0.0	0.41	0.38/ 0.45	U-Factor fixed/ operable	U-value in cell J is wtd avg of all window types		886	ft2 window affected	0.05	0.15	E		No	
Windows shall meet U-factor requirements. In entry doors	Y	N	Rvu	Insp	0.0: 100%-U; ; ; Code	0.0	0.0	0.75	0.77	U-Factor entry			65	ft2 window affected	0.03	0.05	E		No	
Windows shall meet SHGC requirements.	Y	N	Rvu	Insp	7.3: 75%-SHGC; ; ; Above	7.3	6.2	0.34	0.40	SHGC			886	ft2 window affected	0.03	0.05	E		No	
Skylights shall meet U-factor requirements.	N	N							0.500	U-Factor			78	ft2 skylight affected			E		No	
Skylights shall meet SHGC requirements.	N	N							0.400	SHGC			78	ft2 skylight affected			E		No	
Building shall meet continuous air	Y	N	Rvu	Phase	0.0: Not tested; CAB sealed and intact; Mtls or assemb	0.0	0.0		NA	NA	language on plans suggests air		17,872	ft2 thermal	0.06		E		No	

*Cells colored in ivory are user inputs.

Table C.2. Sample Data Collection Form, Continued

Measure (see requirements tab for items included)	Apply to Bldg	Exception used?	Plan	Field	Select Closest to Identified Condition (if not exact condition, describe and apply rating to right)	Default Energy Rating +10/0/-10	Final Overide Energy Rating	Found Factor	Required Factor	Factor Units	Plan Review Comments and Description	Field Inspection Condition Comments and Description	Applicable quantity, affected	Applicabile units	Est Plan Time, hr	Est Field Time, hr	Area for Time Check	Comments about barriers to checking or special tools or expertise required	Cx Req'd ?	Cx done
Recessed lighting shall be sealed, rated and labeled.	N	Y							2.000	cfm/ft^2		all recessed lights contained within air barrier of building	0	# of fixtures			E		No	
Fenestration assemblies shall meet air leakage requirements.	Y	N	Rvu	Phase	0.0: Windows and doors labeled as meeting; ; ; Code	0.0	0.0			cfm/ft^2 (Varies TableC402.4.3)	see last note (2 rows above)	no labels on site	886	ft2 fenestration	0.05	0.05	E		No	
Building openings to shafts, chutes, stairways, and elevator lobbies shall meet air leakage requirements.	Y	N	Rvu	Insp	0.0: Labeled for leakage or weather stripped and sealed; ; ; Code	0.0	0.0	NA	NA	NA		elevator to upper (later build-out planned) no labels found but assembly appears to meet reqs based on plan language	110	ft2 building openings	0.05	0.05	E		No	
Stairway and shaft vents shall be provided with Class I motorized dampers	N	N							4.000	cfm/ft^2			0	ft2 vents			E		No	
Loading dock doors shall be equipped with weatherseals.	N	N						NA	NA	NA			0	LF loading dock door edge			E		No	
Building entrances shall be protected with an enclosed vestibule.	Y	N	Rvu	Insp	0.0: Vestibule where required; ; ; Code	0.0	0.0	NA	NA	NA			1	Each, building entrances	0.02	0.02	E		No	
Equipment sizing requirement	Y	N	Rvu	Insp	0.0: Load calcs provided; ; ; Code	0.0	0.0	NA	NA	NA			4,000	SA cfm affected	0.04	0.08	M		No	
Packaged air conditioner efficiency	Y	N	Rvu	Insp	0.0: 100% code efficiency; ; ; Code	0.0	0.0	13	13	SEER	split systems; originally some type of VAV was planned for bilding but cost consids changed to set of HPs		10	Tons cooling	0.1	0.1	M		No	
Packaged air conditioner efficiency	Y	N	Rvu	Insp	3.6: 115% code efficiency; ; ; Above	3.6	3.6	16	13	SEER	DHP for elevator machine room	not sure how important this one is; did not do any interpolation above the 115% effic rating	1	Tons cooling			M		No	
Packaged heat pump efficiency	Y	N	Rvu	Insp	0.0: 100% code efficiency; ; ; Code	0.0	0.0	7.7	7.7	HSPF		capacity listed at right only for ducted split system compressors at 47 F vs adding in backup heat	118	MBh heating	0.05	0.08	M		No	
Packaged heat pump efficiency	Y	N	Rvu	Insp	3.7: 110% code efficiency; ; ; Above	3.7	3.7	8.5	7.7	HSPF	DhP for elevator machine room		12	MBh heating			M		No	
Gas furnace efficiency	N	N								AFUE/E_t/E_c Varies Table C403.2.3(1)			209	MBh heating			M		No	
Thermostatic control is used for individual zones	Y	N	Rvu	Insp	0.0: OneThermostatPerZone; ; ; Code	0.0	0.0	NA	NA	NA		zone sensors; main 'brain' in mech room deals with setpoints and schedules	0	ft2 floor area incorrectly zoned			MC		No	
Heat pump supplementary heat control	Y	N	Not	Insp	10.0: Lock Out Sup Heat OA=30F; Comp Lock Out OA=0F; ; Best	10.0	10.0	NA	NA	NA		capacity listed at right only for supplemental heat	79	MBh heating		0.1	MC		No	
Thermostat deadband requirement	Y	N	Rvu	Inacs					5	deg.F		not yet set up- bldg not occupied	7,075	ft2 floor area affected			MC		No	
Thermostat setback and start/stop controls	Y	N	Rvu	Inacs					55/85	deg.F		not yet set up- bldg not occupied	7,075	ft2 floor area affected			MC		No	
Optimal start controls	Y	N	Rvu	Insp	0.0: OptimStartAsReq; ; ; Code	0.0	0.0	NA	NA	NA			7,075	ft2 floor area affected	0.03	0.05	MC		No	
Damper control when space is unoccupied	Y	N	Rvu	Insp	0.0: OADamperCtrlAsReq; Damper meets leak reqts; ; Code	0.0	0.0	NA	NA	NA			4,000	cfm OA			MC		No	
Snow and ice-melting system control	N	N						NA	NA	NA			0	ft2 of heated surface area			MC		No	
Demand control ventilation	N	N						NA	NA	NA			0	ft2 space area			MC		No	
Energy recovery requirement	N	N						NA	NA	NA			0	cfm OA			M		No	
Duct insulation requirement	Y	N	Rvu	Insp	0.0: R6IndoorUnconditionedR8Outdoor; ; ; Code	0.0	0.0		6/8	R-value uncond/ outdoor		all ducts in cond space	0	ft2 exterior duct surface	0.03	0.04	M		No	
Duct leakage requirement	Y	N	Rvu	Insp	0.0: SealAsReq; ; ; Code	0.0	0.0	NA	NA	NA		mastic in mech room; all ducts in cond space	4,000	SA cfm affected	0.03	0.04	M		No	
Lighting Commissioning requirement	Y	N	Rvu	Phase				NA	NA	NA	plans call for functional testing of controls	site not yet occupied; no lighting testing report was found	0	NA	0.05	0.1	LC		No	
Mechanical systems Commissioning requirement	N	Y						NA	NA	NA	sequence of ops/functional testing language on plans		0	NA			MC		No	
Fan power limit requirement	N	N							0.001/0.0009	hp/cfm Bhp/cfm	no fans > 5 HP		0	SA cfm			M		No	

*Cells colored in ivory are user inputs.

Table C.3. Sample Data Collection Form, Continued

Measure (see requirements tab for items included)	Apply to Bldg	Excep-tion used?	Plan	Field	Select Closest to Identified Condition (if not exact condition, describe and apply rating to right)	Default Energy Rating +10/0/-10	Final Overide Energy Rating	Found Factor	Required Factor	Factor Units	Plan Review Comments and Description	Field Inspection Condition Comments and Description	Applicable quantity, affected	Applicabile units	Est Plan Time, hr	Est Field Time, hr	Area for Time Check	Comments about barriers to checking or special tools or expertise required	Cx Req'd ?	Cx done
Economizer supplies 100% design supply air	Y	N	Rvu	Insp	0.0: 100% OA Opening; Relief Damper; ; Code	0.0	0.0		100%	%	gravity damper	all HPs combined into one category given all have same effic spec; all systems connected to same OA plenum	11	Tons cooling	0.05	0.08	M		No	
Economizers should have appropriate high-limit shutoff control and be integrated	Y	N	Rvu	Insp	-3.5: HiLim 65; NonIntegrated; ; Cond3	-3.5	-3.5	NA	NA				11	Tons cooling	0.05	0.1	MC		No	
Water heater efficiency, Gas	N	N							EF/Et/SL Varies Table C404.2				0	SWH MBh			M		No	
Water heater efficiency, Electric	Y	N	Not	Insp	10.0: EF = 0.95; ; ; Best	10.0	10.0	0.95	0.92	EF		A. O. Smith ENT 50-100	5	SWH kW		0.08	M		No	
SWH Heat Trap	Y	N	Not	Insp	0.0: With heat trap; ; ; Code	0.0	0.0	NA	NA	NA			5	SWH kW		0.05	M		No	
SWH Pipe Insulation - Recirculated	N	N							1.0/0.27	inch/Btu/in/h*ft^{2}x^{0}F				LF HW Pipe			M		No	
SWH Pipe Insulation - Non-recirculated	Y	N	Not	Insp	0.0: InsuAsReq; ; ; Code	0.0	0.0		8/ 0.5/ 0.28	ft/inch/ Btu/in/h*ft^{2}x^{0}F		has integral trap and all in cond space	7,075	ft2 floor area		0.05	M		No	
Manual lighting control	Y	N	Rvu	Insp	0.0: Manual conrols w/50% redcution in each room; ; ; Code	0.0	0.0	NA	NA	NA		excepted mech/elevator/elect rooms	6,880	ft2 floor area	0.05	0.06	LC		No	
Automatic time switch control	Y	Y	Rvu	Insp	0.0: Automatic controls applied as required; ; ; Code	0.0	0.0	NA	NA	NA		entire space save mech/elev/elect rooms has either occ sensor or daylight sensor control		ft2 floor area affected			LC		No	
Occupancy sensor control	Y	N	Rvu	Insp	0.0: Occupancy sensors installed where required; Turn lights off in 30 minutes; On to 50%; Code	0.0	0.0	NA	NA	NA		excepted daylight control areas	5,937	ft2 floor area affected	0.05	0.05	LC		Yes	N
Daylight zone control	Y	N	Rvu	Insp	8.1: Daylight zone controlled; stepped dimming; less than 2,500 sf controlled per zone; Above	8.1	8.1	NA	NA	NA	could not find specific info on daylight control type in plans but all fixtures in DL areas called out as having dimmable ballasts	about 270 ft2 of the area to right has DL controls even though it is exempted by this section of code (2 or fewer fixtures in these areas)	943	ft2 daylight floor area	0.1	0.1	LC		Yes	N
Display lighting control	N	N						NA	NA	NA			500	Display Watts			LC		No	
Task lighting control	Y	N	Not	Phase				NA	NA	NA		can't rate at this Phase- bldg not yet occupied		Task Watts			LC		No	
Exterior lighting control	Y	N	Rvu	Insp	0.0: Photocell; ; ; Code	0.0	0.0	NA	NA	NA			526	Exterior Watts Affected			LC		Yes	N
Tandem wiring	N	N						NA	NA	NA			0	# Fixtures			LC		No	
Exit sign maximum power	Y	N	Rvu	Insp	-4.0: 7W per side; ; ; Below	-4.0	-1.8	5.7	5	W/side			6	# sign faces	0.06	0.08	L		No	
Interior lighting power allowance	Y	N	Rvu	Insp	10.0: Whole building LPD lower than allowed by 50%; ; ; Best	10.0	10.0	0.42	0.9	W/ft^2		T5s and LEDs…	7,075	ft2 floor area	0.1	0.2	L		No	
Exterior lighting power allowance	Y	N	Rvu	Insp	2.0: Exterior lighting power lower than allowance by 10%; Luminaire efficacy <= 60 lm/W; ; Above	2.0	2.0	526	600	W Varies Table C405.6.2(2)			526	Exterior Total Watts	0.04	0.05	L		No	
Optional Additional packaged air conditioner cooling Efficiency	N	N								SEER/EER/IEER Varies Table C406.2(1)			11	Tons cooling			M		No	
Optional Additional packaged heat pump efficiency	N	N								COP Varies Table C406.2(2)			209	MBh heating			M		No	
Optional Additional packaged air conditioner furnace efficiency	N	N								AFUE/E_t/E_cVaries Table C406.2(4)			209	MBh heating			M		No	
Optional Additional Reduced whole building LPD	N	N							0.9/0.85	W/ft^2			7,075	ft2 floor area			L		No	
Optional onsite renewable	N	N							0.500	W/ft^2 flr			0	Req'd W			L		No	

*Cells colored in ivory are user inputs.

Appendix D

Subcontractor Report - Commercial Code Compliance Project Final Report

Final Report:

Commercial Code Compliance Project

Pacific Northwest National Laboratories

October 21, 2015

Prepared by:

Bob Davis
Gia Mugford
Poppy Storm

TABLE OF CONTENTS

1. Introduction

This project, sponsored by Pacific Northwest National Laboratory (PNNL) and undertaken by Ecotope, is intended to assess the energy impacts of compliance with a selected set of commercial energy code elements. For this piece of work, only office buildings with simple HVAC systems were the intended target. (“Simple HVAC” here means single zone, unitary systems without hydronic heating or cooling.) PNNL created an inventory of selected code requirements and built a tool that incorporates sensitivity analysis in order to estimate the overall effect of code compliance.

The study was limited in scope, with a target of 15 buildings in Oregon and Washington. The desired code for the analysis was the 2012 IECC, but there was some range in code versions for study buildings because of challenges in recruiting sites. In addition, all buildings were originally intended to be in IECC Climate Zone 4C, but one building in Zone 5B was included in the final analysis set.

Ecotope implemented the study during August, September, and early October 2015. The study included an assessment of nine buildings. During the project’s first two weeks, Ecotope reviewed the rating/timekeeping spreadsheet and tested it on a couple of practice projects. After that point, most activity shifted to recruiting sites.

2. Methodology

2.1. Recruiting

Recruiting began in mid-August after final preparation of recruiting scripts was complete. The first sites were identified in late August and the first field visits were scheduled for early September. The initial screening process to produce candidates from the Dodge database of new construction starts produced 22 potential offices in the Seattle and Portland areas. Given the recruitment goals for the study, additional candidates were identified immediately by expanding the candidate counties to all western marine climates in Oregon and Washington,(16 additional sites) and including warehouses with office space and libraries (four additional sites). The first set of sites were in the IECC Marine climate zone (4C) and permitted in 2014 or 2015 to capture the 2012 IECC code window, as enforced by Oregon and Washington. Additional screens included an upper building size limit of 20,000 ft^2 and exclusion of sites flagged as remodels, renovations, alterations, tenant improvements, parking areas, low-rise residential, and manufacturing. Recruiters also used a set of more permissive screens to obtain additional possible sites with limits up to 40,000 ft^2 or buildings permitted in 2013.

Ecotope increased the pool again at the end of August by expanding the geographic range to include the eastside of the Cascades in Washington and Oregon, increasing building size limits, and including 2009 code submittals. On September 21, Ecotope added 35 additional sites from the “Other Health” category (which was expected to contain offices in some cases even though other parts of a site might involve different occupancy type(s).) This category included medical clinics, retirement communities and managed care facilities. These inclusions increased the list of potential sites to 118.

Recruiters also pursued three additional site candidates that came in through other channels (parallel research, internal design projects, and personal association with a new construction project). This resulted in 121 total candidates. None of these leads panned out in time to meet project deadlines. Another 2 or 3 weeks of project time might have resulted in completion of 10-12 field audits. Recruited buildings were required to be completed new or addition spaces with office type uses and simple, non-multizone mechanical systems. Recruiters began by contacting the architect or general contractor if they were provided in the Dodge database to screen the site. These parties could also provide a contact for the mechanical engineer, which often proved necessary to confirm the systems installed met PNNL's requirements. The mechanical auditor reviewed interviewee responses and called mechanical engineers as necessary to confirm HVAC systems were appropriate. Recruiters then proceeded with calls to identify owner contacts who could consent to the study and solicit them for participation. On average, 10 contacts were required (phone calls and emails) to screen, recruit and schedule each participant site. Recruiters performed approximately135 hours of recruiting activities over the course of the study.

2.2. Plan Review

The intent of the plan review process was to provide a solid basis for evaluating the design intent for a project and to provide the field auditor with enough detailed information so that the field time would be productive. The project's intent was to use as-built plan sets as reference for evaluation.

The biggest obstacle in this project was getting plans enough in advance of field review so that the auditor could sufficiently prepare for an efficient site visit. In several cases, only partial plans (or no plans) were available prior to field review, but given the project's compressed schedule, the auditor went ahead with the field visit.

Also, in some cases, the auditor did not have access to as-builts because of the phase of the project or because the project only provided a construction set. As-builts are typically prepared around the time a building gets its occupancy permit, and this meant most sites could theoretically provide as-builts, but some sites were a week or two from getting this permit, so only construction plans were available.). Getting plans would seem to be a very simple process but it often ended up taking much more time (and multiple phone calls/emails) to get access.

Once recruiters obtained plans, review of specific building elements generally proceeded smoothly. The main complications tended to be the mechanical system, since plan sets vary quite a lot in what is included. The most common omission is detailed sequence of operations information; sometimes this information is found in the site specification book, but this book is rarely available at plan review.

Having access to the specification book and/ or commission reports (both mechanical and lighting) can be very helpful. But these reports may not be typically available to a code official until on site for an inspection (and maybe not even then; an owner's manual may be all that can be found at the site, and this will generally not include very detailed information on settings and control).

A final word on plans: electronic plans are a mixed blessing: they facilitate rapid transfer of info but they can take a long time to look through. Paper plans can be harder to get, do not allow for easy capture in electronic form (for possible later review), but do allow somewhat better on the spot review characteristics.

2.3. Site Visits

The project's second major component, site review, was intended to occur after the as-built plans had been delivered and reviewed. In practice, this procedure occurred as desired at only about half of the sites. In other cases, plans arrived after the site visit (or still had not arrived even more than a month after the site visit, in one case) due to coordination challenges. The overall window available for site visits was only about seven weeks and because of the several points of contact typically needed to gain owner approval for inclusion in the project, there was really no way to avoid the uneven nature of the site visit/plan review process. The intention of the visit was to limit on-site to two hours if possible.

When on site, the field auditor organized work to minimize disruption to the occupants (when appropriate); in some cases he had an escort, but in other cases, he worked mostly/completely unsupervised. At two sites, the building was not yet occupied so not all details or settings had been established. In those cases, more reliance on plans (and key contacts) was needed to learn the design intent. But there were still cases where not all elements of the energy ratings could be determined.

Other notable challenges of this project had to do with the how building envelopes interacted with adjacent conditioned spaces and also HVAC systems that turned out to not fit within the study's desired category. Several of these spaces were small offices that shared a wall or floor with a conditioned adjacent space (such as a production warehouse or service bays in a maintenance facility). In these cases, the auditor made adjustments in component area. Where the mechanical systems at a site ended up being outside the intended project scope, the auditor made allowances and added additional descriptive language to make these issues as clear as possible.

2.4. Data Assembly & Case Studies

After implementing the plan reviews and site visits, the auditor assembled all building data into an Excel-based data entry forms provided by PNNL. The auditor used the building data to draft individual case study write-ups for each audited building, including an overview of building program, architectural, electrical, and mechanical systems. The auditor also made recommendations for designers and contractors to demonstrate energy code compliance to lessen the burden of code compliance assessors. In addition, the auditor assessed differences between data collected via the plan review vs the site visits. The results of this analysis are included in Section 3 below.

3. Findings

3.1. Recruiting

The final disposition of recruitment candidates for the code compliance study was as follows:

Site Disposition	Count
Disqualified	**61**
Building Type	13
Multi-Zone	11
Never Built	2
Bad Contact Info	5
No HVAC Installed	1
Not Completed	13
Remodel/TI	16
In Progress	**40**
Qualified to Recruit	3
Call Back	37
Recruited	**9**
Refused	**11**
Total Sites	**121**

Recruitment for PNNL office candidates can be compared to the recruitment process for NEEA's similar code compliance study, which included other health, warehouse, and office as did PNNL's protocol and additionally retail, multifamily and education uses. This study targeted buildings constructed under the Washington 2009 energy code. NEEA recruitment extended over five months and 331 candidate sites were called to recruit 12 participants. PNNL recruitment took place over about two months and 121 sites were called to recruit nine participants. While 40% of sites contacted were disqualified or refused the NEEA study, 60% of the PNNL candidates were eliminated. This higher attrition likely has two causes: A greater number of study limitations that excluded sites, and a higher rate of successful contacts due to the newer age of the Dodge contact information. For example, the recruiters were able to disqualify a higher percentage of sites because they were actually able to reach a higher percentage of buildings. 30% of the PNNL sample remained in "Call Back" status at the study conclusion: recruiters had been unable to successfully reach an appropriate party to screen or recruit the site. In comparison, 53% of the NEEA sample remained in "Call Back" status at study conclusion, likely due the greater distance from time of construction as well as the unstable economy at that time—many sites had been sold since construction, and many architect firms, contractors and owners called were no longer in business or had been bought out.

Another notable finding between the two studies was the difficulty in recruiting some use types. Recruiters were not able to recruit a bank for either study, nor were they able to recruit other health facilities with the exception of two general practice day clinics in the NEEA study, both with a religious nonprofit mission of service to the community. Interviewees at these sites often cited security and privacy issues. Military and GSA sites also unanimously refused participation for security reasons.

3.2. Case Studies

3.2.1. Description of Site 102488

Figure 1: Site 102488

Permitted under the 2010 Oregon Specialty Energy Efficiency Code and occupied since early 2015, this approximately 900 ft^2 marina office on the north Oregon coast sits adjacent to a new public restroom/bath house constructed under the same permit.

Envelope components that could be directly evaluated (windows/attic) complied with the code; the window to wall ratio is about 34% and window U-factor and SHGC are considerably better than the code required.

The site has a very simple HVAC system (small electric wall heaters); however, the HRV system that was specified on the plans (but not required by code) was not installed. A small electric tank with limited run piping provides service hot water.

Lighting was controlled primarily by occupancy sensors; given the small building footprint and switching scheme, most of the rooms also met daylighting zone requirements. The space was substantially over lit vs the target LPD; calculated interior LPD was about 50% greater than the target.

3.2.2. Description of Site 108198

Figure 2: Site 108198

Permitted under the 2010 WSEC and sited in eastern Pierce County, this building is a small, simple office. It has about 1,000 ft^2 of conditioned area and is directly adjacent to service bays that are used as part of a fish hatchery operation.

The only envelope feature that the auditor could directly evaluate was the windows; the window to wall ratio is relatively small here (under 10%) and windows were better than the code required. The building did use metal framing and given plan notes and correspondence with the site manager here, we were not convinced that thermal bridges were addressed adequately (so the wall and attic compliance ratings were adjusted accordingly).

The site originally was to have electric resistance wall heaters but this was changed so that a ductless heat pump (DHP) was installed in the office foyer. Interior doors from the foyer to a private office area and to a break room prevent the DHP from providing much heat or cooling to these rooms. The private office users now have a 120 VAC plug-in heater they use infrequently and there is a very small locker room off the break room that has a 1 kW baseboard heater that is also used infrequently. The site has three instantaneous electric water heaters (one in the break room and one in each restroom).

Lighting here is very simple and contains no automatic control except in the small locker room. The LPD comes in just under 0.9 W/ft^2, which is the code allowance.

3.2.3. Description of Site 103434

Figure 3: Site 103434

This site, the only one located in IECC Climate Zone 5B, is the new office for the maintenance department in a small city in eastern Washington. The building adjoins a semi-conditioned shop space. Overall, square footage of the complex is about 10,000 ft^2, with the office occupying about 3,600 ft^2. The office portion is nominally two stories but the upper story is a semi-conditioned mezzanine space meant for records storage. (So the square footage indicated above is just for the main floor.) This building was permitted under the 2012 WSEC and was 2-4 weeks away from occupancy. Therefore, the auditor examined the construction plans instead of as-built plans.

The thermal envelope of this building had to meet the WSEC Climate Zone 2 requirement so has a nominal wall R-value of about R-26. (Note this is a metal frame building but the details in the plans, and discussion with the general contractor, suggested that thermal bridging was dealt with effectively.) The windows and opaque doors here were high-performing and the window to wall ratio was under 10%.

Heating and air conditioning are provided by two split-system air-source heat pumps with total capacity of 5.5 tons, which is appropriate capacity for this building. There is provision for outside air but it was not determined if the one heat pump that was large enough to require an economizer actually had one that was operational. Also, the site was not yet occupied so HVAC system setpoints/set backs could not be gathered. Service hot water comes from an indirect tank that is supplied by a high efficiency LPG boiler that is primarily intended to provide radiant floor heat for the service bays.

The lighting system here was not fully installed/operational, but the plans suggest occupancy controls throughout and compliance with daylighting switching requirements. The plan-based interior LPD was just above the 0.9 W/ft^2 target.

3.2.4. Description of Site 111413

Figure 4: Site 111413

This site, the new office for a natural food producer, is located above the production facility in the Willamette Valley. The building was permitted under the 2010 Oregon Energy Efficiency Specialty Code and occupied in late 2014. The building has conditioned floor area of about 1,500 ft^2.

The envelope for this site has limited heat loss/gain. The floor and much of the walls are adiabatic surfaces since they directly adjoin the heated production floor. Windows and glazed doors are code-compliant and the window to wall ratio is about 20%.

Heating and cooling are provided by a 5-ton dual fuel air-source heat pump with slightly better box specs than code. This heat pump is quite oversized for the space requirements. Also, site has a zoned VVT system (4 zones) with bypass damper (which was not known until we arrived; plans were only available on site). The economizer opening is drastically undersized and the economizer controller was non-operational. A DDC controller is on site but occupants have access to the zone-by-zone settings and the cooling setpoint (72° F) was quite aggressive during the field audit. The site has twinned electric water heaters; part of the hot water produced goes to a washroom in the adjacent production space downstairs.

As far as lighting goes, the site has some daylighting provisions and occupancy sensors throughout. The interior LPD is about 15% better than required. Occupants reported some issue with occupancy sensor operation in the conference room but apparently, this is a very limited problem.

3.2.5. Description of Site 107179

Figure 5: Site 107179

This site is located just west of Portland and consists of about 2,900 ft^2 of conditioned floor area on one level. The occupancy is not strictly office (consisting of two multi-purpose rooms and a large classroom) but is the best fit for this project in terms of the type of HVAC system that was thought to be serving the space. (The second floor of this project, located on the floor above and with a similar amount of conditioned floor area, is open office but is served by a VAV system that incorporates a chiller/cooling tower and a hot water loop.) The project was permitted under the 2010 Oregon Energy Efficiency Specialty Code. Apparently the permitting and construction process were quite complicated and protracted. A complete set of mechanical and lighting plans were never completed for this project.

The envelope for this space is partly adiabatic to other conditioned space. The plan specifications suggested general compliance with prescriptive requirements. Windows make up about 16% of external wall area and were judged better than code in terms of solar shading: they incorporate an automatic electrochromic shading system on the south and west elevations.

The mechanical system for this space is made up of a set of rooftop packaged units that met code box specifications and which have total cooling capacity of 13 tons. Economizer systems meet code specifications and DCV control is present (which is appropriate given the variable loading in the space). The problem with this system, in terms of this study, is that heat turns out to be provided by hot water coils that are served by a central (highly efficient) boiler. This detail was not specified in the partial plans and the field auditor could not reach the site manager to fill in this detail before conducting the site visit. The deadband set in the DDC control does not meet code requirements. There is no service hot water provided to the study area.

Lighting at this site is slightly over the LPD target. There are occupancy sensors throughout the space.

3.2.6. Description of Site 106690

This site, located in Whatcom County, was permitted under the 2009 WSEC. The building is a library and IT center for a small college. The overall building is about 11,500 ft^2 and includes a large server room, IT training center, and perimeter offices, study rooms, and special collection rooms. Some of the plans provided were from the construction set vs as-builts.

Figure 6: Site 106690

Site contacts assured Ecotope that there were only split system heat pumps serving the space, but the field auditor found a combination of packaged heat pumps (with one 5-ton system serving the main part of the library), split system heat pumps, a 10 ton VRF system, and 5 kW total capacity of electric wall heaters for restrooms/service rooms. This meant the space had to be broken up into parts served by the simpler aspects of the HVAC system, which turned out to be the core part of the library (circulation area) and associated reception area, restrooms/service rooms and corridor.

Since this area was indeed the core of the building (and perimeter areas were served by the VRF), there is limited wall/window area to report under the envelope section of the audit. The window to wall ratio was over 50% for the core area (when adiabatic surfaces were removed) but about 34% for the entire building.

The 5-ton air-source heat pump met code efficiency specifications and was properly sized for the space. We could not get the full setpoint schedule from the DDC system (yet). The economizer system components are in place but we were not able to confirm all aspects of operation when on site. Core small rooms depend on small capacity electric wall heaters for comfort.

The lighting system has a central control/dedicated panel and occupants reported it took several months for the system bugs to get worked out. (Apparently, occupancy sensors were not working correctly and lights stayed on much longer than necessary. These issues have been addressed according the maintenance manager and the auditor noticed no problems.) The interior lighting power density came in at 1.2 W/ft^2, under the code allowance of 1.3 W/ft^2.

3.2.7. Description of Site 104493

Figure 7: Site 104493

Site 104493 is an approximately 2,600-ft^2 food bank office (adjacent to a distribution warehouse that includes refrigerated storage) located in southern Oregon. The site was built to the 2010 Oregon Energy Efficiency Specialty Code.

Defining the thermal envelope at this space was a bit tricky since two of the walls and the entire ceiling adjoin conditioned warehouse space. This issue did not affect the window to wall ratio much, however; the WWR for this site is about 26% and windows meet code specifications for U-factor and SHGC.

The HVAC plant at this site is a7.5 ton split system heat pump (up to code specs) with electric backup heat. The site was found to have a VVT duct system with bypass and was outfitted with a specialized (non-major manufacturer) zoning controller. However, consultation with the design engineer filled in many of the blanks and the economizer system appears to work properly. It should be noted that this system is considerably oversized for the space given the amount of envelope that is adjacent to conditioned space.

The lighting system at the site is controlled mostly with occupancy sensors; some areas also have complying manual daylighting controls. Interior LPD for this site is 0.7 W/ft^2.

3.2.8. Description of Site 104953

Figure 8: Site 104953

This medium size office (about 7,000 ft^2) is adjacent to a fabrication/repair/stocking facility in rural Clark County, WA. The site was built to the 2012 IECC with WAC amendments. The building was about two weeks from punch list when the field visit occurred. No as-builts have been created. Hence, the auditor based the plan review on the permit set.

This is a metal-framed building; the plans suggested good control of thermal bridging so opaque components would appear to meet or exceed performance required by the code. Windows and glazed doors met code requirements and the window to wall ratio was about 26%.

The mechanical system is somewhat complicated. The permit set showed a VAV system, but at some point (due to budget), the system was changed to one based on several split system air source heat pumps. Since the construction set showed VAV, Ecotope called the architect to confirm the HVAC system type. In this case, he was (mostly) right.

The heat pumps installed meet code minimum efficiency requirements and the overall system sizing is appropriate for the building. Economizer components are installed, although it is possible the current changeover temperature is not high enough. (However, note below that all settings have not yet been established.) When on site, Ecotope also noticed two of the heat pump systems were wired into a zoning board. A call to the mechanical installer confirmed two of the heat pumps have VVT ducting. No schedules/setbacks were available for this space. It is not occupied yet and the installer had only general information to provide.

Lighting at this site uses some automatic daylighting controls for about 1,000 ft^2 of floor area (on perimeter) and has occupancy sensors where needed. The LPD for the site is less than half of the allowance, at 0.42 W/ft^2.

3.2.9. Description of Site 106021

Figure 9: Economizer Control at Site 106021

This site is the new security office for a special district and is located in Clark County, WA. The site was built to the 2009 Washington State Energy Code and has about 2,800 ft^2 of conditioned floor area. The building is stand-alone and one story.

Envelope components that could be field-verified are attic insulation and windows. The attic insulation meets nominal R-value requirements but has been substantially disturbed, it appears, during the duct installation, derating its performance. Windows meet the code requirements for U-factor and SHGC and the window to wall ratio was about 13.4%.

The HVAC plant at this site is two split system heat pumps (total capacity 7.5 tons and meeting code efficiency specifications) with electric backup heat. Both systems have full economizer systems with outside air provided by ducts of sufficient capacity entering through the gable end of the building and routed through the attic and then into the mechanical room. System settings for heating and cooling setpoints meet code requirements and the economizer operates correctly. Service hot water is provided by an electric resistance tank with integral heat trap.

The lighting system at the site is controlled throughout with occupancy sensors; there is only one area that would meet the specifications for a daylighting zone (enough fixtures) and it has only manual controls (no automatic DL controls). Interior LPD for this site is 0.75 W/ft^2.

3.3. Plan Review vs Site Visits

3.3.1. Envelope

Because the project's timing meant that site visits typically occurred after the site was occupied, investigation of envelope components was somewhat inconclusive. Window and attic insulation details could typically be determined (even though window rating labels typically were gone by the time the audit occurred; the window manufacturer and sash type, plus additional details, typically were enough to determine window U-factor and Solar Heat Gain Coefficient (SHGC)) but wall and slab insulation typically could only be inferred. Plan details were more useful for the latter cases. As well, determination of air sealing compliance was not definitive but was based more on qualitative evaluation. In one case, language on the plans suggested a blower door test would be done but no report could be found that proved the testing was carried out.

3.3.2. Mechanical

This part of the evaluations proved most problematic. Even with careful screening, the nine sites included four that had systems that included elements that put them into the non "simple" category: VVT components or hot water fan coils. In all cases, these details were only discovered at the site (and in all cases but one, a follow-up phone call had already been made to confirm the type of HVAC system in place). These unfortunate issues aside, the HVAC system primary component (typically a rooftop or split heat pump) usually complied with box specs (SEER/HSPF) but showed varying levels of compliance with outside air and economizer requirements. In addition, about half of the systems were quite oversized versus heating and cooling loads. (The auditor obtained actual load calculations for only three sites, but this is in part due to limitations of the plan sets.) It would seem that mechanical designers still have not recognized changes in the envelope (especially windows with low-e coatings) and have stuck with outdated sizing rules of thumb. Systems setpoints and setbacks were also variable (but note that the auditor could not obtain full schedules at a few sites). Service hot water was usually provided by electric resistance tanks (some with recirculation pumps) and these tanks usually met efficiency requirements. None of the sites apparently had a full commissioning carried out (vs testing/balancing) but this is not surprising given most sites had under 10 tons of installed cooling (and mandatory commissioning is not required until 40 tons of cooling are installed).

3.3.3. Lighting

In all but one case, whole-site lighting power density (LPD) was at or below the level required by the code. Control systems typically included occupancy sensors in most rooms; application of daylighting controls was mixed and explicit mention of these controls on plans was confined to larger buildings. Only one site had a centralized lighting controller and dedicated panel, and this site was the only one that is thought to have carried out a full lighting commissioning process (vs functional testing). The majority of lighting in these spaces is provided by fixtures containing T-8 and T-5 tubes but some sites utilized a good number of LED fixtures (mostly down-lights). Given the permitting period observed, and given the rapid evolution of LED lamps, one should expect LPDs to drop even further in new buildings. Exterior lighting systems came in under allowances in all cases and were typically controlled by photocells.

3.4. Barriers to Determining Compliance and Recommendations to Improve Compliance Evaluation

The code official's role in enforcing energy codes is increasingly complex. Even in modest sized office buildings with "simple" HVAC, there are many elements to look at, and depending on the actual time of the inspection (and the availability of plans and related information), the site visit can range from frustrating to extremely fruitful.

Code officials' experience with all aspects of the built environment will of course vary; the most useful tool the official can possess is both long-term experience and familiarity with what is new, especially in mechanical and lighting.

Primary barriers encountered in this project include

1. Trouble procuring plans (especially the desired version) well in advance of field visits
2. Incomplete description of mechanical/lighting control
3. Inconsistent access to designers and tradesmen would could answer questions about the design intent and/or actual installation details
4. No easy access to photos of the site during construction (which could aid in determining compliance with envelope components such as slab insulation)
5. Timing of site visits (typically after the site had been occupied for some time, so items such as window rating labels were not available)

Here are specific recommendations that we believe will help the official in his effectiveness in assessing compliance:

1. Procure desired version of plans as far in advance as possible; also requires access to specification books and commissioning reports (in electronic form is best) so that there is a best chance of understanding the design intent.
2. Make sure list of contacts is up to date for the project. This will facilitate getting in touch with various key players with questions, whether they are on details of system operation or access to various building elements.
3. See if tradesmen can be available at the site, especially if there are mechanical questions. This may not be practical but there can be instances where it will work. This is especially important when reviewing HVAC controls—be careful what you touch.
4. Be prepared at the site. This can mean both the audit tool used and specific tools needed for access (ladders, etc.).
5. Keep notes organized. A printed protocol can help or, if using something digital, make absolutely sure it is stable before heading out.

Appendix A: Recruiting Scripts

Introduction

INTRO1 (Receptionist or longer return message) Hello, this is _______________, from Ecotope, calling on behalf of the Pacific Northwest National Laboratories (PNNL). We are working with PNNL on a Commercial Code Evaluation Study. Your building [building name] was randomly selected from a database of new construction in the Northwest.

The purpose of our study is to understand how commercial codes are impacting new construction. The study results will inform energy code development and identify future energy efficiency programs. I'd like to ask you a few questions about [building name, address] to determine its eligibility in our study. I can be reached at 855-855-6610.

[For VM] Hello, this is _______________, from Ecotope, calling on behalf of the Pacific Northwest National Laboratories (PNNL). If you could please give me a call, my # is 855-855-6610. Once again, my name is [name] calling from Ecotope on behalf of Pacific Northwest National Laboratories (PNNL) and my # is… I am calling about the [building name] located at [address] Please let us know the building you are replying about when you call. Thank you!

[If talking to a person, ask qualifying questions]

Phase 1: Design Contact

Introduction

INTRO1 Hello, this is ______________, from Ecotope, calling on behalf of the Pacific Northwest National Laboratories (PNNL). May I speak with [architect's name]?

INTRO2 I am contacting recently constructed office buildings in the Northwest to participate in an energy efficiency study for the Pacific Northwest National Laboratories (PNNL). The [building name] was randomly selected from a database of new construction in the Northwest for an evaluation. The study results will inform energy code development and enforcement efforts as well as identify energy efficiency program opportunities. We are contacting [the architect, general contractor, mechanical engineer] first and then will contact the building owner. Can I ask you a few questions about [building name, address] to determine eligibility?

Screening

SCN1 Has the building been completed?

1. Completed
2. Not completed but very close (get estimated completion date)
3. Not completed in near future [Skip to THANK1 and drop building]
4. Unknown

SCN2 Is the building new construction or an addition to an existing building?

1. New construction or addition
2. Remodel [Skip to THANK1 and drop building]
3. Unknown

SCN3 What code version year was the building permitted under? (We are particularly interested in the WA state energy code version (was it 2012, 2009, 2006)?)

1. 2012
2. Other [note] (any code version is acceptable)
3. Unknown

SCN4 Does the building employ a ground or water source heat pump?

1. No
2. Yes [Skip to THANK1 and drop building]
3. Unknown

SCN5 Does the building have a multi-zone system such as constant volume reheat, VAV with Reheat or a VRF?

1. No
2. Yes [Skip to THANK1 and drop building]
3. Unknown

SCN6 Does the building use any hydronic heating or cooling, or another water or evaporatively cooled system?

1. No
2. Yes [Skip to THANK1 and drop building]
3. Unknown

SCN7 What kind of HVAC systems are in place?

1. Type (record all) (see list of allowable types on included excluded tab)

SCN8 We would like to contact the building owner to request participation in an onsite audit. Do you have the building owner or operator’s name and contact information?

1. Yes [document]
2. No [ask if necessary to call back]
3. Unknown [ask if necessary to call back]

SCN9 Are the as-built plans available and if the building owner agrees to participate would you be able to provide them for the study?

1. Yes [Skip to THANK2]
2. No [Skip to THANK2]
3. Unknown [Skip to THANK2]

Thank You

THANK1 Thank you very much for your time, but buildings must meet PNNL's requirements in order to participate in the study. [Conclude call.]

THANK2 Thank you very much for your time. After we recruit the building for the onsite audit we may contact you again to request as-built plans.

Phase 2: Building Contact

The second outreach will be to a building level contact (either provided by the Phase 1 contact or by an Internet search for building contact info).

Introduction

INTRO1 Hello, this is _______________, from Ecotope, calling on behalf of the Pacific Northwest National Laboratories (PNNL). May I speak with [potential participant's name]?

INTRO2 I am calling to discuss participation in an energy efficiency research project including an onsite energy audit. Are you the right person to discuss this study?

INTRO3 I am contacting recently constructed buildings in the Northwest to participate in a Commercial Code Evaluation Pilot Study for Pacific Northwest National Laboratories (PNNL). Your building was randomly selected from a database of new construction in the Northwest. The study will include a review of building plans, an onsite audit, and analysis of building energy use. All data will remain confidential and will be used strictly for research purposes.

Screening

SCN1 Before we schedule a time for the onsite audit I have some questions about your building to determine eligibility and ensure we have correct information.

SCN2 When was the building completed?

1. Date [document]
2. Not completed [probe to determine if mainly completed, if not just finishing tenant improvements skip to THANK1]
3. Unknown [probe to find out if there is a different person to talk to]

SCN3 Is the building new or an addition and/or remodel?

1. New
2. Addition
3. Remodel [Skip to THANK1 and drop building]
4. Unknown [probe to determine information or if there is someone else to talk to]

SCN4 What is the total building area?

1. Area in SF
2. Unknown

SCN5 What is the building use type?

1. Type (Offices)
2. medical clinic, retail, multiple [Skip to THANK1 and drop building]
3. Unknown

SCN6 Is this building fully occupied?

1. Fully
2. In Tenant Improvement
3. Partially/some in TI
4. Partially: some vacant
5. Vacant

SCN7 Are the as-built plans available and who could provide them?

1. Yes and can provide
2. Yes and can't provide [Ask who can provide them]
3. No [Ask who can provide them]
4. Available for review on site

SCN8 Does the building employ a ground or water source heat pump?

1. No
2. Yes [Skip to THANK1 and drop building]
3. Unknown

SCN9 Does the building have a multi-zone system such as constant volume reheat, VAV with Reheat or a VRF?

1. No
2. Yes [Skip to THANK1 and drop building]
3. Unknown

SCN10 Does the building use any hydronic heating or cooling, or another water or evaporatively cooled system?

1. No
2. Yes [Skip to THANK1 and drop building]
3. Unknown

SCN11 What kind of HVAC systems are in place?

1. Type (record all) (see list of allowable types on included excluded tab)

Would your building be available for an energy audit on (Give appropriate date)?

1. Not interested in participation [Thank and conclude call]
2. Maybe [Provide additional information on study such as FAQ and try to recruit]

[AS NEEDED] Study results will inform energy code development and enforcement efforts as well as identify energy efficiency programs.

[AS NEEDED] In order to accomplish our project goals, we would like to examine the building plans and visit your building to document the insulation levels, window characteristics, lighting, HVAC equipment selection and similar features of the building that impact energy use. This will allow us to understand the current market, which helps us design better programs and accurately predict the savings that can be expected from particular conservation efforts.

[AS NEEDED] PNNL is prepared to offer a study incentive of ($150) dollars, to reimburse participants for their time.

3. Yes [Proceed to scheduling: get contact phone and email, discuss timeframes if offered day does not work, suggest alternates, discuss transfer of plans for review.]

Scheduling

Great, that is all of the initial questions I have for you. Now let's set up a time for the onsite audit. [The amount of time will vary depending on the size and complexity of the building. Refer to the list below and offer the appropriate timeframe for the building.]

[Approximate times for various building types and sizes here.

{Small} The onsite audit takes about 2 hours.

{Medium} The onsite audit takes about 3 hours.

{Large} The onsite audit takes up to 5 hours.

Now let's figure out a time that works. The FIRST available appointment I have is [date and time] will that work for you?

[Yes – schedule]

[No – Let's see if we can find another time that will work for you. I also have [date and time] open will that work?]

I have you scheduled for [date and time] with [energy surveyor's name].

[No workable time: I am sorry it doesn't seem like we are able to accommodate your schedule. I appreciate your interest. Would you like to go on a waiting list in case a time opens that will work for you? Waiting list participants will often be called with short notice to participate due to a cancelation or someone missing their scheduled appointment. [waiting list info if accepts} Thank you for your time.]

Prior to the survey you will receive information to acquaint you with the process and help you prepare. For example, we will need access to the building mechanical equipment, all gas and electric meters, and onsite O&M or Commissioning manuals. Is email the best way to send you this information? (get email, fax, mailing)

[Yes – May I confirm your email address? The email will be coming from energysurvey@ecotope.com, please look for it in case it gets swept into your junk mail/spam folder]

[No – May I confirm your mailing address?]

A day or so prior to your appointment we will be giving you a reminder phone call. [Skip to THANK2]

Thank You

THANK1 Thank you very much for your time, but buildings must meet PNNL's requirements in order to participate in the study. [Politely conclude call.]

THANK2 If you have any questions in the meantime you can reach the Ecotope at

(855)-855-6610 or energysurvey@ecotope.com. Thank you again for your time this [afternoon/evening] and for your willingness to participate in Pacific Northwest National Laboratories (PNNL) energy efficiency study. Your participation will inform the region's energy planning and is greatly appreciated. Have a nice [afternoon/evening].

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov