Energy Cost Impact of Non-Residential Energy Code Requirements

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ABSTRACT

The 2012 International Energy Conservation Code contains 396 separate requirements applicable to non-residential buildings; however, there is no systematic analysis of the energy cost impact of each requirement. Consequently, with limited building department resources, the efforts for plan review, inspection, and training may not be focused on the most impactful items. An inventory and ranking of code requirements based on their potential energy cost impact is under development and the approach is described in this study. The initial phase was a pilot project focused on office buildings with simple HVAC systems in Climate Zone 4C. Prototype building simulations were used to estimate the energy cost impact of varying levels of non-compliance. A preliminary estimate of the probability of occurrence of each level of non-compliance was combined with the estimated lost savings for each level to rank the requirements according to expected savings impact. The methodology to develop and refine further energy cost impacts, specific to building type, system type, and climate location is demonstrated. As results are developed, an innovative alternative method for compliance verification can focus efforts so only the most impactful requirements from an energy cost perspective are verified for every building and a subset of the less impactful requirements are verified on a random basis across a building population. The results can be further applied in prioritizing training material development and specific areas of building official training.

Introduction

The U.S. Department of Energy's (DOE) most recent commercial energy code compliance evaluation efforts focused on determining a percent compliance rating to help states meet requirements under the *American Recovery and Reinvestment Act of 2009* (ARRA 2009). That approach included a checklist of code requirements, each of which was graded pass or fail. A number of other approaches have been used to determining commercial energy code compliance and those have been reviewed by Bartlett et al. (2016).

With its binary approach to compliance determination, the previous DOE methodology failed to answer some important questions. In particular, how much potential energy cost savings could result from increased commercial energy code compliance and what are the relative priorities of code requirements from an energy cost savings perspective? The authors conducted a pilot study to explore an analytical approach using a single building type and climate zone to answer those two questions. The summary of the study is split into two papers. The first one, entitled *Potential Energy Cost Savings from Increased Commercial Energy Code Compliance* (Rosenberg et al. 2016a), addresses the first question. The second question is addressed here.

Commercial building energy code compliance is complex, code officials may not be energy code experts in every aspect of building design, and the budget established by building departments to enforce energy codes may be inadequate compared to the level of effort required for plan review, inspection, and training. It may be unrealistic to expect code officials to verify code compliance with all the requirements of the code. The goal of this second paper is to describe a methodology for determining the relative priorities of code requirements from an energy cost savings perspective and ranking code requirements. This paper examines five different approaches to ranking code requirements, and recommends a hybrid approach to come up with an overall ranking. The methodology to develop and refine further energy cost impacts, specific to building type, system type, and climate location is demonstrated.

Quantifying the Energy Impacts of the Code Requirements

The analysis began with the development of an inventory of energy code requirements from the 2012 International Energy Conservation Code (IECC) applicable to office buildings with simple heating, ventilation, and air-conditioning (HVAC) systems in Climate Zone 4C. 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 performed using prototype building simulation to estimate the annual 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, including the code-compliant condition and at least two conditions worse than code, i.e., below code and worst, likely to be encountered in newly constructed buildings. The difference between the annual energy cost of the code-compliant building model and that of a worse-than code building model is considered the lost savings from non-compliance for each condition. The present value of the lost savings over the life of the building was determined using simplified life-cycle economic calculations. The present value of simulated worst-case lost savings from non-compliance is listed in Table 1. This analysis used a period that was based on expected useful life of 15 years for HVAC, lighting, service hot water, and control measures and 30 years for envelope measures with a 3% real discount rate, and energy prices of $0.1075/kWh of electricity and $0.8645/therm of natural gas[1]. Using a simplified method of projecting life-cycle value of savings, a uniform present value (UPV) factor 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).

[1] 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/.

Table 1. Measure ranking by group and present value of simulated worst-case lost savings from Non-Compliance

Measure name	Measure abbreviation	Lost savings of worst condition, life-cycle/1,000 ft^2
Building Envelope Measures		
Roofs shall be insulated to meet CZ requirements	RoofIns	$10,345
Window-to-wall ratio shall meet maximum limits	MaxWWR	$2,992
Above grade frame walls shall be insulated to meet CZ requirements	FrmWallIns	$1,369
Above grade mass walls shall be insulated to meet CZ and density requirements	MassWallIns	$1,198
Windows shall meet SHGC requirements	WinSHGC	$1,119
Skylight to roof ratio shall meet maximum limits	MaxSkyLtRoofR	$817
Windows shall meet U-factor requirements	WinUFactor	$724
Exterior floors shall meet the minimum R-value or U-value by assembly type	ExtFloorIns	$467
Skylights shall meet SHGC requirements	SkyLtSHGC	$412
Skylight curbs shall be insulated.	SkylCurbIns	$308
Recessed lighting shall be sealed, rated and labeled	AirtRecLtg	$190
Building entrances shall be protected with an enclosed vestibule.	Vest	$141
Building shall meet continuous air barrier requirements	CAB	$111
Skylights shall meet U-factor requirements	SkyLtUFactor	$110
Stairway and shaft vents shall be provided with Class I motorized dampers	ShaftVent	$70
Fenestration assemblies shall meet air leakage requirements	WinLeak	$66
Below grade walls shall meet insulation requirements and be protected	BelowGradeIns	$53
Slab-on-grade floors shall meet insulation requirements and be protected	SlabIns	$44
Opaque doors shall meet U-factor requirements	DoorU	$15
Building openings to shafts, chutes, stairways, and elevator lobbies shall meet air leakage requirements	DoorLeak	$6
Loading dock doors shall be equipped with weather seals	LdDkSl	$0
HVAC and SWH system measures		
Equipment sizing requirement	EquipSizing	$1,079
Duct insulation requirement	DuctInsul	$5,845
Snow and ice-melting system control	SnowIceCtrl	$4,213
Thermostat setback and start/stop controls	SetbackCtrl	$3,516
Fan power limit requirement	FanPower	$2,302
Commissioning requirement	Cx	$1,233
Thermostat deadband requirement	TempDeadband	$711
SWH Pipe Insulation - Recirculated	SwhRecPiInsu	$518
Economizer supplies 100% design supply air	Econ100Pct	$305
Economizers should have appropriate high-limit shutoff control and be integrated	EconHiLimit	$288
Duct leakage requirement	DuctLeakage	$174

Measure name	Measure abbreviation	Lost savings of worst condition, life-cycle/1,000 ft^2
Demand control ventilation	DCV	$90
Thermostatic control is used for individual zones	Tstat@Zone	$76
Optimal start controls	OptStart	$76
Heat pump supplementary heat control	HPSuppHeatCtrl	$72
Energy recovery requirement	ERVUse	$53
Optional additional packaged air conditioner furnace efficiency	OptACHtgEff	$48
Optional additional packaged air conditioner cooling Efficiency	OptACClgEff	$41
Optional additional packaged heat pump efficiency	OptHPSysEff	$21
Damper control when space is unoccupied	OADamperCtrl	$19
SWH pipe insulation - non-recirculated	SwhNoRecPiInsu	$16
Water heater efficiency, gas	SwhGasEff	$16
SWH Heat Trap	SwhHeatTrap	$10
Water heater efficiency, electric**	SwhEleEff	$2
Packaged air conditioner efficiency**	ACCoolingEff	$-
Packaged heat pump efficiency**	HPEff	$-
Gas furnace efficiency	FurnaceEff	$-
Lighting and power system measures		
Automatic time switch control	AutoLtCtrl	$4,723
Optional additional reduced whole building LPD	OptRedLPD	$4,093
Interior lighting power allowance	IntLPD	$3,880
Manual lighting control	ManLtCtrl	$1,343
Exterior lighting control	ExtLtCtrl	$901
Exterior lighting power allowance	ExtLPD	$891
Optional onsite renewable	OptRenewable	$729
Occupancy sensor control	OccSens	$549
Daylight zone control	DaylCtrl	$177
Task lighting control	TskLtCtrl	$120
Exit sign maximum power	ExitSign	$116
Display lighting control	DispLtCtrl	$108
Tandem wiring	TandWire	$43

*Savings was negligible

**Federally regulated equipment was considered to have no below code conditions.

Field Compliance Results

The previous section provides an approach, which could be used to calculate the lost energy cost savings from individual 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 savings from the simulation 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 and documented in Rosenberg et al. (2016a and 2016b).

Ranking Measures Based on Field Data

By analyzing the results of the nine-building sample, we can rank code measures using several different metrics. In this section, we rank measures based on 1) present values of total lost energy cost savings for the sample population; and 2) present value of lost energy cost savings for the worst-case condition encountered in the sample population for each measure.

Ranking Measures Based on Field Sample Lost Savings

The measures that had non-zero lost savings in Table 1 have below-code conditions and some of these conditions were observed during the field audit. The total sample lost savings are shown in Table 2 as annual savings, which is then used to calculate the present value of lost savings for the sample and per 1,000 ft^2 of sample floor area.

Table 2. Measure ranking by total sample present value of lost savings from non-compliance

Measures with lost savings	Number applicable	Number below code	Total sample lost savings			Worst-case (among the samples) lost savings
			Annual	Life-cycle	Life-cycle/ 1,000 ft^2	Life-cycle/1,000 ft^2
EquipSizing	9	8	$1,018	$13,054	$481	$1,715
SetbackCtrl	8	4	$389	$4,990	$184	$1,055
TempDeadband	8	4	$345	$4,426	$163	$569
IntLPD	9	3	$293	$3,705	$136	$1,940
EconHiLimit	7	6	$265	$3,353	$123	$437
MaxWWR	9	2	$145	$3,163	$116	$618
LtgCx	9	9	$200	$2,525	$93	$362
RoofIns	7	2	$105	$2,288	$84	$695
Vest	3	1	$81	$1,758	$65	$488
MechCx	1	1	$128	$1,647	$61	$362
Econ100Pct	7	3	$114	$1,444	$53	$463
ManLtCtrl	8	3	$80	$1,015	$37	$228
OccSens	9	3	$73	$918	$34	$374
FrmWallIns	9	2	$21	$468	$17	$216
SlabIns	8	3	$20	$446	$16	$112
HPSuppHeatCtrl	4	1	$28	$356	$13	$78
AutoLtCtrl	2	1	$22	$280	$10	$265
ExitSign	9	2	$17	$216	$8	$47
DaylCtrl	8	1	$10	$121	$4	$41
AirtRecLtg	3	1	$4	$85	$3	$29
DuctInsul	7	3	$6	$76	$3	$16
SwhNoRecPiInsu	4	2	$5	$64	$2	$13
SwhHeatTrap	7	1	$2	$25	$1	$5
SwhEleEff	7	2	$0	$5	$0	$2
OADamperCtrl	7	1	$0	$2	$0	$1

Ranking Measures Based on Worst-Case Lost Savings From Field Sample

Ranking measures based on the total lost savings from the sample makes sense if the goal is to prioritize based on the average lost energy cost savings. However, some measures may have a high energy impact but are only encountered with a low frequency. Those measures may not be high in the ranking shown above, but for the buildings in which they occur they may represent a substantial energy loss. Another way to rank measures that accounts for this is by the lost energy cost savings of the worst-case condition encountered in any building in a sample. The last column of Table 2 shows the present value of the worst-case lost savings per 1,000 ft^2 among the samples.

Ranking Based on Sensitivity Analysis Simulation

The validity of the rankings from the field data is limited based on the small sample size. Even in a much larger study, it may not be appropriate to collect statistically valid data on all measures. Some measures may have a high energy impact but are only encountered with a low frequency. Although they are only encountered infrequently, their potential lost energy cost savings could be impactful if the magnitude of those rare cases of lost savings is large enough. It may not be reasonable to study a sample large enough to validate some low frequency measures. Instead, the sensitivity analysis simulation results can be further processed to arrive at expected values (EVs) and worst-case energy impacts for measures that may be infrequently encountered in a future field study. These results can be incorporated to arrive at a comprehensive set of high-impact measures.

Based on the lost energy savings from the prototypical building simulation analysis described previously, the worst case expected to be encountered in the field for each measure was developed using the authors' professional judgment with input from other engineers and scientists. In many instances, the worst case expected was thought to be short of absolutely ignoring a requirement. For most insulation requirements, the absence of insulation was considered possible and a U-factor for empty construction assemblies was calculated. For skylight area and lighting power, it was thought that the worst case might be slightly more than double the code-required limits. In some cases, the worst case was the same as code, such as mechanical equipment that has been at the same minimum manufacturing requirement for many years.

In the simulation-based sensitivity analysis process, the energy impact for at least two conditions per measure was determined: below code, and worst case. Then the authors assigned expected probabilities to the required code case, along with the other two cases. This assignment was based on general understanding of new building characterization, but without a robust set of data to draw from. The probabilities were simplified into a limited set of patterns, some weights for minimum code, below code, and worst case. This process was intended to give some idea of expected energy impact when a measure was applicable to a building. The purpose was to establish a methodology that could then be refined with a more robust set of field data from future compliance studies. The current set of field data was not used because the sample size is too small. While the process is not data driven, it can be useful in establishing a range of possible results. One thing is certain: evaluating measures from just the worst expected energy impact would not provide a good indication of the priority of different measures. How the process can be enhanced with a more robust set of field data is discussed later.

Once the probabilities were assigned, an EV of lost savings for below-code cases, referred to as Below-Code EV Impact could be calculated. It estimates the expected value of weighted lost savings of only below-code items. It applies an estimated probability of worst case to the worst-case impact and an estimated probability to the below-code impact. The result is the expected lost savings resulting from measures that do not comply with code. The Below-Code EV Impact is an important metric to identifying potential savings, prioritizing measures for inspection, and understanding where to focus code official training.

One important thing about EVs is that they are developed for all measures assuming the measure is applicable. Applicability is not included in the assessment of the probability estimate of where a particular measure will fall on the worst-to-code-condition scale. The estimate is for when a particular measure is applicable. The applicability is another layer of probability, and applying that would disguise the importance of inspecting a measure when it is applicable. For example, snow melting systems are rare, but they have a high potential worst-case lost savings and EV of lost savings. If an occurrence probability were applied in their ranking, it would water down the importance of the measure when it did exist. This distinction makes it difficult to compare either the present value or annual lost savings results—either EV or worst case—with the sample total results, as by default, the sample results include the impact of applicability.

A roll up of the Below-Code EV Impact results by measure group is shown in Figure 1. The potential lost savings is the present value in dollars per 1,000 ft^2 of building area. The tan bar represents the sum of the worst expected lost savings case for all the measures in the group, while the purple stripe represents the sum of EVs based on the estimated probability of below code installation and worst case occurrence. As can be seen, each group represents a relatively large share of the total impact that might be expected, and the EV is in the range of 6% to 20% of the worst case. Based on the probability assumptions, the results suggest that each measure group contains an important share of lost savings potential and all should be included in building compliance verification.

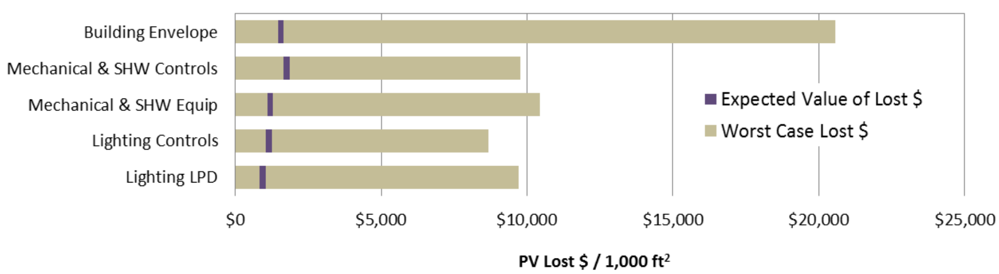
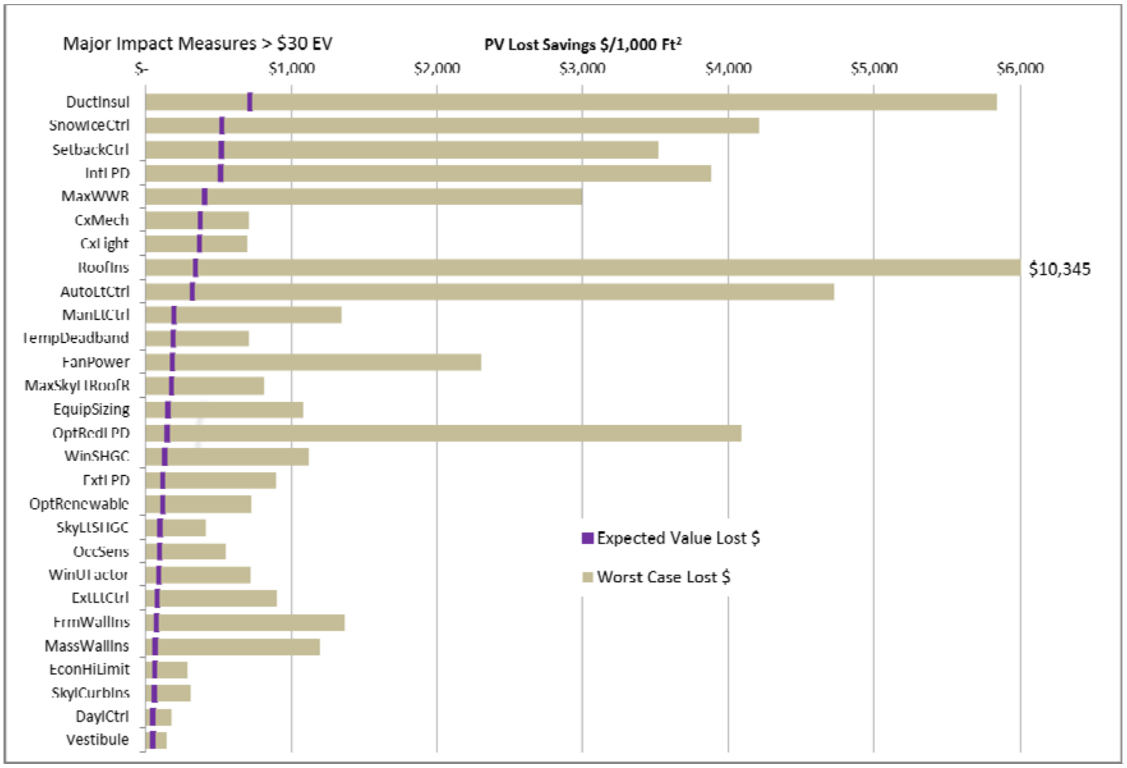


Figure 1. Worst case and expected value lost savings potential by measure group

Individual Below-Code EV Impact results are shown for individual measures in Figures 2 and 3. The potential lost savings is the present value over the measure life. The tan bar represents the worst expected lost savings case for each measure, while the purple stripe represents the EV of lost savings based on the estimated probability of below code installation and worst case occurrence. To provide better legibility of results relative to the scale, the measures are split between Figures 2 and 3, with those having more than $30 EV of lost savings per 1,000 ft^2 in the first figure and lesser-impact measures in the second figure. The measures are ranked with the largest EV of lost savings first, in descending order of lost savings. Note that the last three equipment efficiency measures were assumed in the analysis to have no savings, as the manufacturer-required HVAC equipment efficiency has not changed in multiple code cycles and equipment not meeting the efficiency requirements is not readily available for purchase. In reviewing the measures, the EV ranges from 2% to 51% of the worst case and half the measures have an EV from 10% to 17%. The EV is a better indicator of the overall benefit of looking at a particular measure in an inspection process; however, high-energy-impact, low-frequency measures should be included for regular verification, as when they are not applicable, there is little cost to verify that, and when they are out of compliance, they can have a large impact on an individual building's energy use. As more robust data is obtained to use in developing the expected probabilities, EV becomes an even better indicator of where verification efforts should be focused.



* Roof insulation worst case is not shown to scale

Figure 2. Lost savings potential for individual major impact measures

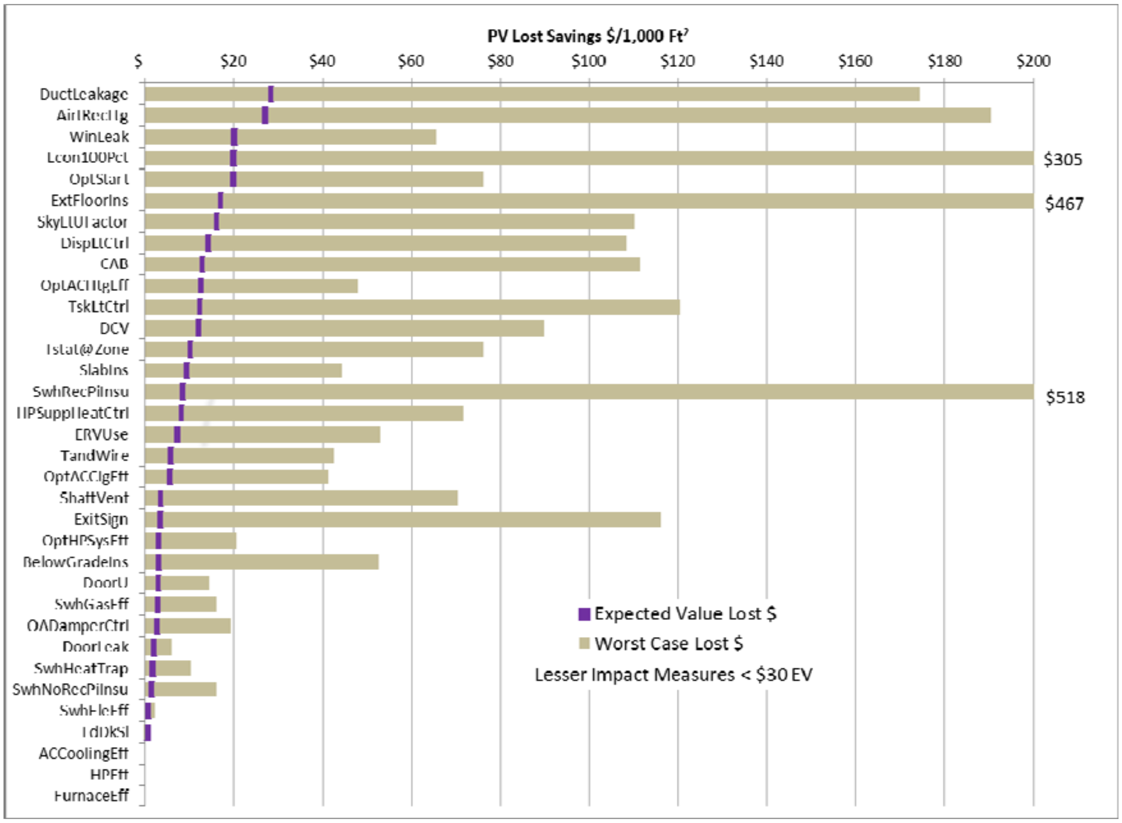


Figure 3. Lost savings potential for individual minor impact measures

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 4, the frequency of these lost savings is organized into bins that each have half the 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[2] concept of focusing on a limited number of high-impact measures to complete verification of the majority of lost savings.

[2] 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.

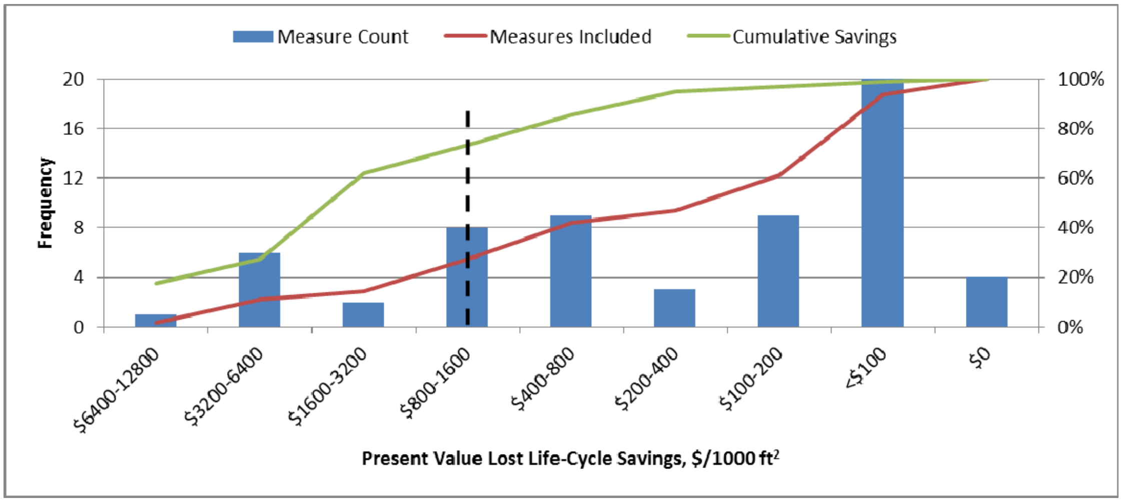


Figure 4. Simulated worst case measure impact with cumulative savings vs. measures included

Ranking Measures by Lost Savings Versus Cost of Compliance Verification

One goal of the pilot project is to test a methodology to identify the 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, travel and indirect hours, general building hours, and hours spent specifically verifying individual measures. To rank the field results, the lost savings cost in dollars per verification hour is found. 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 5. This time collection indicates 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. The field verification was all completed in one trip per building in this study. When separate trips are needed, the impact of travel and indirect time could be much larger.

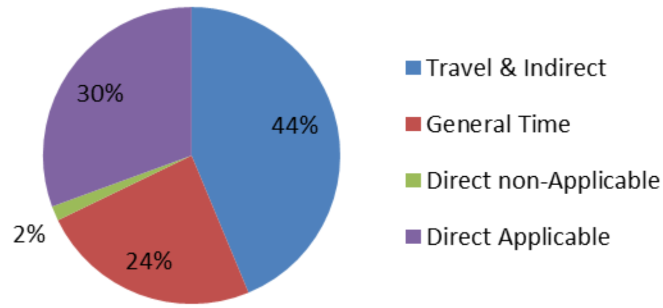


Figure 5. Cost breakdown for current field compliance verification study

We can rank the measures using the life-cycle lost savings for each measure divided by the verification hours required to provide a lost energy cost savings per hour for each measure. Figure 6 shows this ranking graphically.

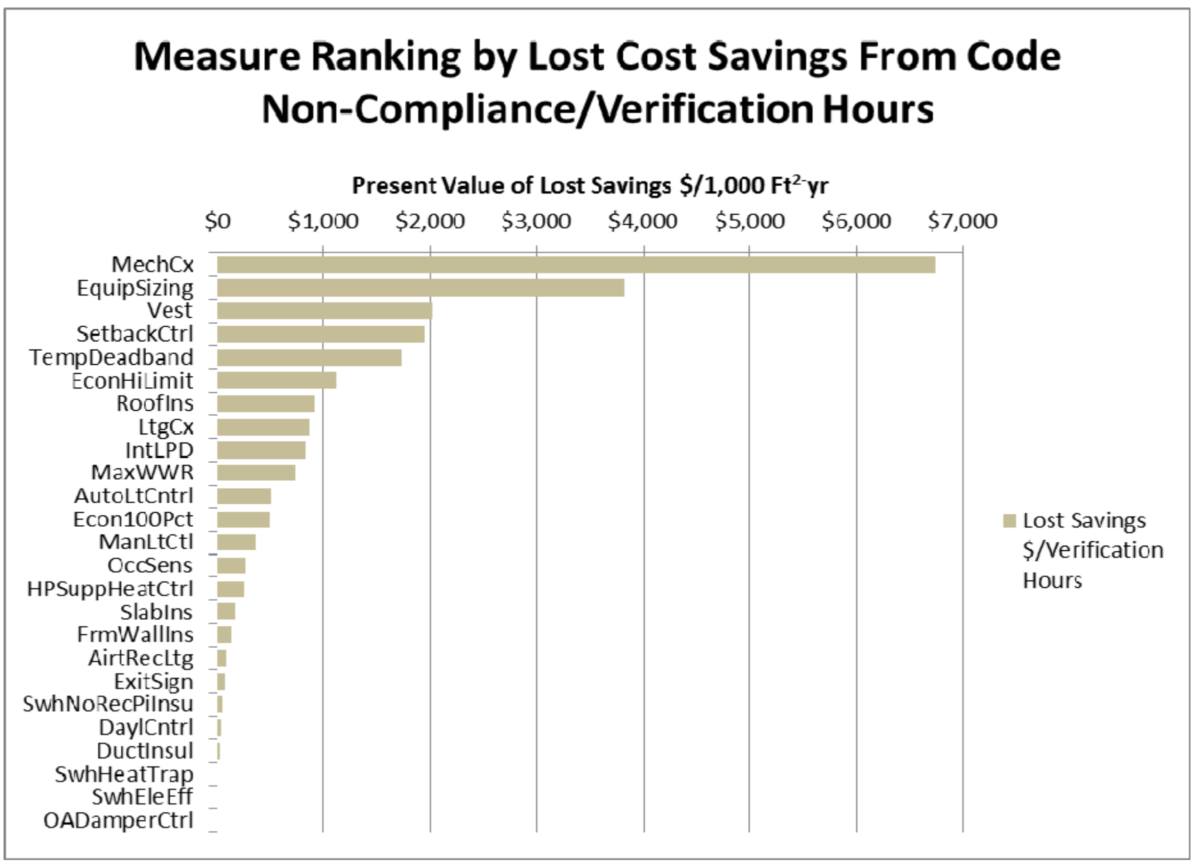


Figure 6. Measure ranking by the ratio of present value of lost savings from non-compliance to verification hours

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 6 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 6. 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, 9 of them (21%) were responsible for 81% of the lost energy cost saving, indicating that the Pareto principle 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.

Table 6. Summary of measures in pilot sample grouped by relative verification cost

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	100%	289	100%	$46,430	100%

A Proposed Hybrid Approach to Measure Prioritization

So far, multiple rankings have been shown for both field data and simulated sensitivity results. The purpose of this is not to arrive at a continuous ranking of measures, but to divide the measures into two groups: 1) measures that have a high energy impact and should always be verified and 2) measures that have lower energy impact and can be verified less often. To do that requires considering both the ranking based on field data and the ranking based on simulation results only.

To arrive at reasonable results with reasonable efficiency while controlling the level of effort required, measures should be divided into four groups based on energy impact and frequency of occurrence as represented in Table 7.

Table 7. Grouping measures based on energy impact and frequency of occurrence

	High frequency	Low frequency
High energy impact	HE-HF	HE-lf
Low energy impact	le-HF	le-lf

These measures should be addressed in the following levels of priority:

- High-energy-impact, high-frequency (HE-HF) measures have a high level of potential lost savings and occur relatively frequently in a building population. Examples include equipment oversizing and LPD. These measures are candidates for spending the most time verifying and are good candidates for the most extensive training efforts.
- High-energy-impact, low-frequency (HE-lf) measures have a high level of potential lost savings, but are not regularly found across a building population. An example of a low-impact measure with high potential lost savings is a heating-based snow melt system. While these have a very high potential for lost savings, they occur rarely, so their impact on population lost savings will be low. One thing to note about this type of measure is that if they are included on a list to always inspect due to a high potential for lost savings, discovering they are non-applicable to a particular site does not require much effort.
- Low-energy-impact, high-frequency (le-HF) measures have a lower level of potential lost savings, but occur in many buildings in a typical population. Examples include slab and above-grade frame wall insulation. While they occur often, there is not a large potential lost savings for these measures.
- Low-energy-impact, low-frequency (le-lf) measures have a lower level of potential lost savings, and do not occur in many buildings in a typical population. Examples from this population include recessed light sealing and loading dock door seals.

The measures that had below-code conditions, as identified in the field results, are shown in Table 8. For each measure, the number applicable in the sample and the number below code are shown. The lost savings is shown on a life-cycle present value basis per square foot of applicable area. The applicable life-cycle lost savings is the sorting key for the table. Also shown is the impact group, based on the high energy or frequency being in the upper quartile of the field data.

An example of how a ranking approach could combine field-verified and analysis-based data is presented here. As discussed previously, even if a large-scale study is completed in multiple climate zones with multiple field verifiers, it is unlikely that field samples of every measure will be statistically valid. For example, it is likely not reasonable to select a sample large enough to include a statistically valid number of snow melt systems or absorption chillers. Given the high potential impact where these do exist, it is important to be included on a list to be verified at every site, even though most sites will simply indicate the measure was not applicable. It may be valuable then to use the field data where it is statistically valid and temper it with simulated sensitivity analysis data where it is not. This especially applies to verifying the "worst expected" condition to be found in the field. Some code measures are very low frequency and will simply not be found in a reasonable sample of buildings for each climate zone investigated in adequate number to rule out outliers, especially where building practices vary from region to region. The various rankings that have been previously discussed include the following:

Table 8. Impact grouping of measures with lost savings

Measures with potential lost savings	Applicable / Below Number		PV $ / 1000 ft² Applicable	Impact group Energy	Frequency	Impact Group
Equipment sizing requirement	9	8	$481	High	High	HE-HF
Thermostat setback and start/stop controls	8	4	$190	High	High	HE-HF
Thermostat deadband requirement	8	4	$169	High	High	HE-HF
Interior lighting power allowance	9	3	$136	High	High	HE-HF
Economizers should have appropriate high-limit shutoff control and be integrated	7	6	$133	High	Low	HE-lf
Window-to-wall ratio meets maximum limits.	9	2	$116	High	High	HE-HF
Building entrances shall be protected with an enclosed vestibule.	3	1	$115	Low	Low	le-lf
Roofs shall be insulated to meet CZ requirements	7	2	$106	Low	Low	le-lf
Lighting commissioning requirement	9	9	$93	Low	High	le-HF
Automatic time switch control	2	1	$60	Low	Low	le-lf
Economizer supplies 100% design supply air	7	3	$57	Low	Low	le-lf
Manual lighting control	8	3	$42	Low	High	le-HF
Occupancy sensor control	9	3	$34	Low	High	le-HF
Heat pump supplementary heat control	4	1	$21	Low	Low	le-lf
Slab-on-grade floors meet insulation requirements and are protected	8	3	$17	Low	High	le-HF
Above grade frame walls shall be insulated to meet CZ requirements	9	2	$17	Low	High	le-HF
Recessed lighting shall be sealed, rated and labeled.	3	1	$9.5	Low	Low	le-lf
Exit sign maximum power	9	2	$8	Low	High	le-HF
Daylight zone control	8	1	$5.3	Low	High	le-HF
SWH pipe insulation - non-recirculated	4	2	$4.5	Low	Low	le-lf
Duct insulation requirement	7	3	$3.0	Low	Low	le-lf
SWH heat trap	7	1	$1.2	Low	Low	le-lf
Water heater efficiency, electric	7	2	$0.26	Low	Low	le-lf
Damper control when space is unoccupied	7	1	$0.07	Low	Low	le-lf

1. Field-sample-based energy impact. This is the total present value of energy cost impact based on measure conditions verified in the field. It represents the average impact across the population, accounts for measure applicability frequency and below-code condition frequency. It is the best indicator of total energy impact of new building construction variation from an energy code.
2. Field-sample-based worst-case energy impact. This is the total present value of energy cost impact, on a floor area basis, of the worst case found in a sample based on measure conditions verified in the field. It represents the largest energy impact that occurs in a particular building; however, it does not account for measure applicability frequency or below-code condition frequency. It indicates where particular measures can have a high impact in an individual building if the energy code is not complied with for that measure.

3. Field-sample-based energy impact per hour to verify. This is the total present value of energy cost impact verified in the field divided by the hours needed to investigate for the sample. It represents the most lost savings identified for the effort required to verify.
4. Sensitivity-analysis-based EV of energy impact. This is similar to ranking number 1, but is based on the measure being applicable in a building and does not include the issue of application frequency. It does include the probability of meeting different conditions relative to code, but while it is informed by the field study condition information, it is enhanced by expert opinion where the field frequency is low relative to desired statistical accuracy.
5. Sensitivity-analysis-based worst-case energy impact. This is similar to ranking number 2, but is based on the sensitivity analysis rather than field data. It does adjust for an expected worst case rather than the absolute absence of the measure energy code components. The expected worst case is informed by the field study condition information and is enhanced by expert opinion where the field frequency is low relative to desired statistical accuracy.

Table 8. Ranking code measures based on hybrid approach (low rank = high value)

High Priority Measures (Ranked by Group)	Field no.	Field sample based ranking: Sample impact	Worst case	Impact $/hour	Sensitivity analysis based ranking: Expected value	Worst case	Overall rank average
Building envelope measures							
Roofs shall be insulated to meet CZ requirements	*7*	8	4	7	8	1	5.6
Window-to-wall ratio meets maximum limits	*9*	6	5	10	5	8	6.8
Windows meet SHGC requirements	*9*	NA	NA	NA	16	13	14.5
Skylight to roof ratio meets maximum limits	*0*	NA	NA	NA	13	17	15.0
Above grade frame walls insulated to CZ requirements	*9*	14	15	17	23	10	15.8
Building entrances shall have an enclosed vestibule	*3*	9	7	3	28	33	16.0
Lighting and power system measures							
Interior lighting power allowance	*9*	4	1	9	4	6	4.8
Optional additional reduced whole building LPD	*0*	NA	NA	NA	15	5	10.0
Automatic time switch control	*2*	17	13	11	9	3	10.6
Lighting commissioning requirement	*9*	10	11	8	7	22	11.6
Manual lighting control	*8*	12	14	13	10	11	12.0
Occupancy sensor control	*9*	13	10	14	20	23	16.0
HVAC and SWH system measures							
Snow and ice-melting system control	*0*				2	4	3.0
Thermostat setback and start/stop controls	*8*	2	3	4	3	7	3.8
Equipment sizing requirement	*9*	1	2	2	14	14	6.6
Thermostat deadband requirement	*8*	3	6	5	11	20	9.0
Mechanical commissioning requirement	*1*	7	11	1	6	21	9.2
Fan power limit requirement	*0*	NA	NA	NA	12	9	10.5
Duct insulation requirement	*7*	21	21	22	1	2	13.4
Economizers: proper high-limit control and integrated	*7*	5	9	6	25	29	14.8

*NA indicates the measure was not applicable.

As an example of how this might work, the five ranking methods discussed above were combined by selecting the top 10 measures from each prioritization. As might be expected, there is some overlap between the top 10 from each ranking, so 21 code measures. To develop an overall ranking, the five individual rankings were averaged. These are grouped by building system and sorted by overall ranking in Table 8. The field sample number (n) shown represents the number of buildings where each measure was applicable. If all buildings were found in compliance, there was no lost savings, and therefore no ranking based on the field sample. This observation points out the advantage of using rankings from the sensitivity analysis where there are no or few instances for particular measures in the field sample.

Conclusion and Acknowledgments

Determining which energy code measures have the greatest impact on lost savings can be very useful in targeting inspections, verification, or training. This work shows that most of the potential lost savings can be attributed to a small set of measures. A method of measure ranking is proposed that uses a base set of simulated values that can be augmented with field data as it is collected. This will establish a set of preliminary rankings that can be improved over time.

The authors would like to acknowledge support from the U.S. Department of Energy Building Energy Codes Program and Dr. Weimin Wang and Bing Liu from PNNL for their contributions.

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