Pacific Northwest
NATIONAL LABORATORY

PNNL-31109

Data Analysis of Energy Code Compliance in Commercial Buildings

September 2021

M Tyler
J Huckett
R Hart

U.S. DEPARTMENT OF ENERGY

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

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Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program (BECP) provides resources and tools to assist states in evaluating compliance with building energy codes. A key question in this area is: What is the dollar value to commercial building owners and tenants of increasing compliance with the energy code? With this in mind, in 2015, Pacific Northwest National Laboratory (PNNL) developed a new methodology capable of determining how much energy cost savings could potentially be gained through better compliance with the code. This methodology was tested in a pilot study with a sample of nine new construction office buildings in one climate zone.

In March 2016, the DOE Building Technologies Office (BTO) issued Funding Opportunity Announcement (FOA) Number DE-FOA-0001532, requesting proposals to develop and test a methodology for identifying the commercial energy code requirements that can provide the maximum cost-effective energy and cost savings through increased compliance. While the pilot study tested the methodology and data collection instruments, this second project used the experience from the pilot project to refine the methodology and expand it to additional building types and climates. The three phases of this project included:

- **Protocol development.** Analyze code measures, develop a field study methodology, data collection protocol, and data collection form. Train field data collectors to implement methodology and collect all necessary data.
- **Data collection.** Recruit buildings for participation and collect all necessary information from plans and field site visits to complete the data collection forms based on the field protocols and sampling plans.
- **Data analysis.** Complete analysis of collected data.

This report is focused on the analysis of the collected data. The primary goal was to analyze the data collected during the field study and determine the actual energy cost impact of each measure in a non-compliance situation. The energy impact results allowed for ranking the measures to identify which have the highest potential for lost savings. These results combined with the time required to verify each measure will allow future compliance verification to focus on measures that had a large impact on energy use over the life of the building and those that have the greatest savings recovery potential per verification hour.

The project team visited 230 buildings, covering over 6 million square feet of commercial office and retail space, in climate zones 2A and 5A. The annual lost energy cost savings as found during the field study was $189 per thousand square feet, or a present value of $2,868 per thousand square feet over the life of the building, on average across all the buildings. The present value lost savings of some outlier buildings exceeded $20,000 per thousand square feet. The actual lost savings are underestimated, as only 69% of the applicable measures could be field verified due to site visit timing.

Only four buildings were fully compliant with the energy code and had zero lost savings. Lighting controls and HVAC controls provide some of the largest as-found lost energy cost savings.

One way to interpret these results is the impact on the utility bills. This can be estimated by comparison with the energy cost intensity (ECI). This study found that 15% of the annual energy costs can be saved with improved code compliance.

In a statistical analysis of measure-level present value lost savings, we estimated the expected (average) present value lost savings for each measure. We used a regression model to account for variability in present value lost savings due to building type, building size, ASHRAE climate zone, and observed measure compliance. We used the resulting regression estimates and their standard errors to rank measures according to which had the greatest mean present value lost savings (on the log scale), and the 80% confidence intervals for each. These results are provided in Figure ES 1, where we identified the top five, 10, and 25 measures with the highest average present value lost savings ($/ksf) out of 100 total measures included in this study.

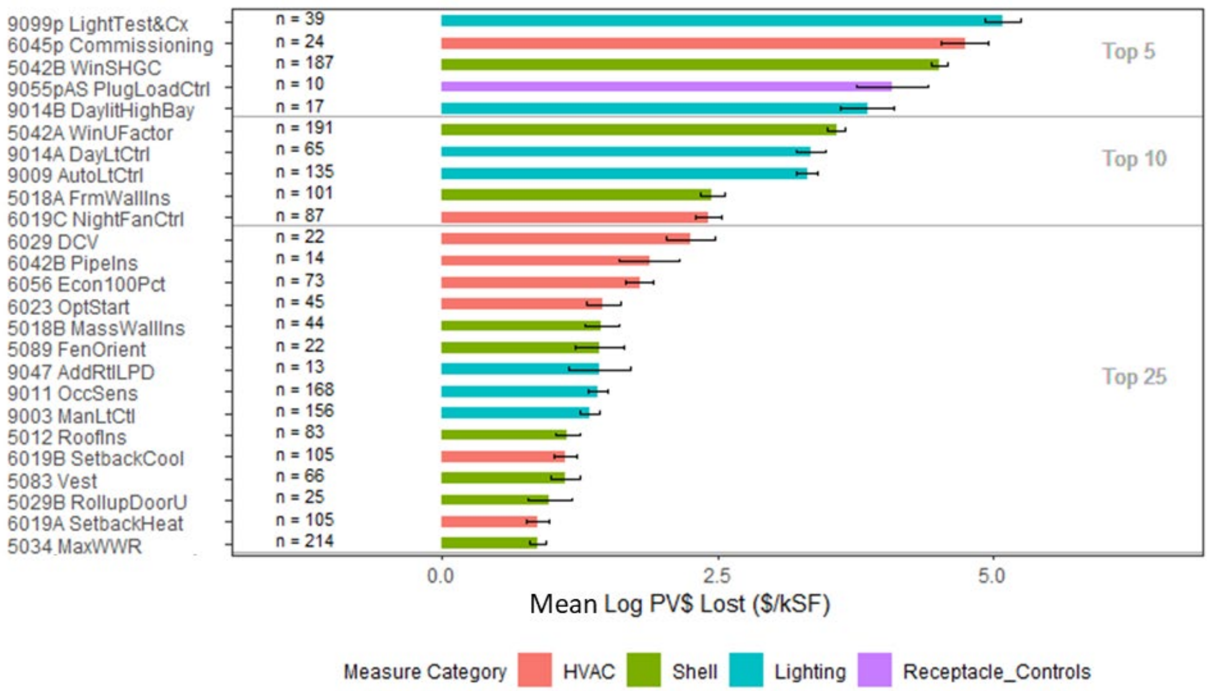

Figure ES.1. Top 25 Measures Ranked by Mean Log PV$ Lost Savings

This project attempted to observe enough instances of measures and buildings to obtain statistical significance. However, the project failed to accomplish this for many measures, given the typical challenges of recruiting buildings, verified observability of any given measure in a single site visit, and the unknown quantity of any measure being constructed in the field. Therefore, the results provide directional rather than definitive quantitative guidance.

The statistical analysis included calculating the precision of the present value of lost energy savings per square foot due to non-compliance with energy code measures at 80% confidence. This analysis also allowed estimating the sample size required by such a study to achieve statistical significance. Data were combined to present the calculated sample sizes to achieve 80/20 confidence and precision for an estimated mean value based on various coefficients of variation (CVs) as shown in the table below. Sample sizes range from 67 to 1,888, and the required sample sizes are smallest for estimating the mean lost savings when the lost savings are non-zero. These results show that any future projects using this approach will require substantially more resources to achieve statistical significance.

Table ES.1. Estimated Required Sample Sizes for Future Studies Seeking Statistical Significance

Strata	CV	Confidence Level	Precision Target	Sample Size	Expected Precision (with FPC[1])
Max CV across verified measures	6.78	80%	20%	1,888	20%
75th quartile CV across verified measures	4.15	80%	20%	708	20%
Median CV across verified measures	3.04	80%	20%	380	20%
Max CV excluding 0	3.61	80%	20%	534	20%
75th quartile CV excluding 0	1.73	80%	20%	122	20%
Median CV excluding 0	1.28	80%	20%	67	20%
Max CV across Climate Zones	5.61	80%	20%	1,294	20%

[1] FPC is Finite Population Correction

Acknowledgments

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program (BECP). The authors appreciate the program oversight provided by Jeremy Williams at DOE.

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Acronyms and Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
CI	confidence interval
CV	coefficient of variation
CZ	climate zone
DCV	demand control ventilation
DOE	U.S. Department of Energy
ECI	energy cost intensity
EER	energy efficiency ratio
FEMP	Federal Energy Management Program
hp	horsepower
HVAC	heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
ksf	thousand square feet
LPD	lighting power density
MBH	thousand British thermal units per hour
OSA%	outside air percent
PNNL	Pacific Northwest National Laboratory
PV	present value
PV$LS	present value dollar lost savings
SE	statistical error
SEER	seasonal energy efficiency ratio
SWH	service water heating
UPV	uniform present value

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1.0 Introduction

The U.S. Department of Energy (DOE) Building Energy Codes Program (BECP) supports the development and implementation of building energy codes and standards. This includes providing technical assistance to states to implement building energy codes, including identifying and quantifying opportunities to ensure consumer benefits. One key area in which BECP has worked over the 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.

A key question in this area is: What is the dollar value of increasing compliance with the energy code? With this in mind, in 2015, Pacific Northwest National Laboratory (PNNL) developed a new methodology capable of determining how much energy cost savings could potentially be gained through better compliance with the code. This methodology was tested in a pilot study with a sample of nine new construction office buildings in one climate zone.

The project described in this report used the experience from the pilot project to refine the methodology and expand it to additional building types and climates. The project team visited 230 buildings, covering over 6 million square feet of commercial office and retail space, in climate zones 2A and 5A.

This report is focused on the analysis of the collected data. The primary goal was to analyze the data collected during the field study and determine the actual energy cost impact of each measure in a non-compliance situation. The energy impact results allowed for ranking the measures to identify which have the highest potential for lost savings. These results combined with the time required to verify each measure will allow future compliance verification to focus on measures that had a large impact on energy use over the life of the building and those that have the greatest savings recovery potential per verification hour.

The following sections of this report present the concept of present value of lost savings, describe the calculation tool that estimates the lost energy savings, outline the data analysis approach, and present the results of the analysis.

2.0 Present Value of Lost Savings

This section presents the concept of present value of lost savings, which is a key element of the data analysis and the results presented later in this report. The results from building energy simulations provide the annual energy cost impact from the perspective of the first year of building operation. However, from an energy code perspective, the energy impact and thus the value of lost savings on a building over a measure's lifetime due to code provisions is more important than first year impact.

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 future savings over the measure life, expressed in current dollars. This approach generally follows the methodology established by the Federal Energy Management Program (FEMP) for federal building energy projects (Lavappa et al. 2017). FEMP also has a website on the methodology.[2]

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 2.1 along with their assumed lifetimes. The UPV factors by life and fuel are shown in Table 2.2. These factors are applied to the annual lost energy cost savings to find the long-term savings that could accrue from better energy code compliance.

Table 2.1. Measure Lives for Simplified Present Value Savings Analysis

Measure Type	Life
HVAC controls	15
Lighting controls	15
Building envelope	30
Light fixture (ballasts)	15
HVAC equipment (gas heat)	15
Service hot water (gas)	15
HVAC equipment (heat pump)	15
Service hot water (electric)	15

Table 2.2. Measure UPV for Simplified Present Value Savings Analysis

Life	UPV Electric	UPV Natural Gas
15	12.81	15.5
30	21.27	26.88

FEMP UPV, 3% discount rate (Lavappa et al. 2017)

[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.
[2] https://www.energy.gov/eere/femp/building-life-cycle-cost-programs

3.0 Lost Savings Calculation Tool

PNNL developed a spreadsheet-based calculation tool that estimates the present value of lost energy savings for each measure and a subsequent total for each building when measures were not in compliance with the energy code. Development of the calculation tool is described in detail by Hart et al. (2019). Briefly, it includes using prototype building energy simulation to estimate lost savings for a range of possible conditions that could be found in the field for each code measure. From those results, regressions are developed that can be applied to any found field condition to estimate lost savings.

This tool is populated with data collected during the site visits. Data are typically transferred from a completed data collection form into this tool after a site visit is completed. The data transfer is part of the quality control process, where more experienced staff review the collected data for reasonableness. To ensure field data will be collected consistently and all needed information is collected, forms were given to field verification teams to complete for each building and training was provided. 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 (e.g., location, occupancy type, floor area, etc.) and specific information regarding the conditions encountered for each code measure. The forms include the data fields shown in Table 3.1 and Table 3.2.

In addition to filling out the form, the field team was asked to record the amount of time spent verifying each measure during plan review and in the field. Time for general activities (e.g., meeting with the owner's representatives, collecting plans, travel to site, etc.) was also collected.

3.1.1 General Building Information

The following fields in Table 3.1 were observed and recorded for each building in the field study.

Table 3.1. Field Study Building Characteristics

Characteristic	Explanation
Conditioned Floor Area	Conditioned floor area
Building Type	Office or retail
ASHRAE Climate Zone	2A or 5A
Number of Floors	Number of floors, both above and below grade
Scope	Full building; part of building; shell/fill; second infill
Option Path	2012 International Energy Conservation Code (IECC) C406 extra efficiency option used
Compliance Path	Prescriptive; envelope tradeoff; performance (Section C407)
Building Identifier	A unique number given to each building to anonymize the results
City/State	City and state location of the audited building
Actual Code	Specific energy code project was permitted under
HVAC System Type	Identify main system type serving the building
Occupancy	For mixed occupancies, percent of floor area for main and other types is noted

Characteristic	Explanation
General Comments	Any special comments the auditor thinks might be pertinent
Equipment in Building	Check off which of 8 types of HVAC equipment are in the building
Time Accounting	The contractor is asked to record the time spent for each measure instance

3.1.2 Measure Specific Information

The following fields in Table 3.2 were observed and recorded for each measure that was applicable to each building.

Table 3.2. Field Study Measure Characteristics

Characteristic	Explanation
Applies to Building	Indicate whether specific measure applies to the building
Factor Units	Where more than one type of unit could apply, select; e.g., energy efficiency ratio (EER) vs. seasonal energy efficiency ratio (SEER)
Plan	Indicate whether compliance was verified in building plans
Condition or Input Factor	Select either the measure condition closest to that observed from pull-down menu or enter actual condition for measures where a pull-down menu is not available. These are input separately for the code requirement, plan takeoff, and as-found condition. Examples include EER, U-factor, lighting power density (LPD), window-to-wall ratio. The request for factor or condition are generally mutually exclusive. In envelope installation cases, the U-factor is input along with a general assessment of installation quality.
Field Verification Level	Indicate whether compliance was verified by actual field inspection, inferred, or not verified at all
Applicable Quantity Affected	The quantity of systems or components to which the specific condition applies. Examples include cfm, tons, MBH, ft^2, watts, etc.
Measure Specific Comments	Any comments pertaining to the measure, particularly, variations from the condition chosen from the pull-down menu
Measure Time	Auditor enters the estimated time in hours spend verifying the measure during plan review
Surveyed Floor Area	If less or more than the conditioned area is surveyed for this measure, overwrite the default building value

As mentioned above, the field named “Applies to Building” is used to indicate if a specific measure applies to the building. The possible responses are described here:

"Y" means the measure is in the code, applies to the building, and includes the following:

- If an exception requiring another action is taken (e.g., no demand control ventilation (DCV) if heat recovery or higher efficiency cooling instead of economizers) explain in measure comment; in this case, the required condition of the other requirement would be adjusted
- All prescriptive requirements in a building that complied via the performance path, although the “required” condition or factor may be different from prescriptive to match the proposed building performance as simulated in the performance path submittal.

"N" means the measure is in the code but does not apply to this building, and includes the following:

- That type of equipment does not exist in the building (e.g., chiller measures in building with no chillers)
- An exception just gets them out of it (e.g., economizers not required in grocery)
- Below a requirement threshold (e.g., total system fan horsepower below 5 hp; total system capacity too small to require economizers; supply airflow and outside air percent (OSA%) below threshold for ERV/HRV).

"x" is inserted in the initialization phase in the following situations:

- The measure is not in the applicable code, or
- Data are not collected for this measure in this climate zone. Some measures are not collected in specific climate zone/building type combinations, based on previous analysis (Hart, et al. 2019).

"u" (unsurveyed) is entered in the case that applicability cannot be determined at this stage, for example:

- Occupancy sensor area in empty tenant infill areas that have not been designed yet
- System type and efficiency where systems have not been designed; however, where all designed parts of the building have the same system type, you can infer that undesigned areas will be similar
- Where retail areas have been designated, but it is not known if those areas will have display lighting; measure 9047 would be "u" applicability.

Also as mentioned above, the field named “Field Verification Level” is used to indicate whether compliance was verified by actual field inspection, inferred, or unknown.

- ver = verified through observation or with evidence such as photos during construction
- inf = inferred, e.g., on the plans but not directly observed in the field
- unk = unknown, i.e., no way to tell if it meets requirements.

4.0 Data Analysis Approach

As described in the prior section, the project team transferred data from the field forms into the measure calculation worksheet. The worksheet applied simulation-based regressions to the code-required and as-found parameters or conditions and determined potential lost savings. PNNL reviewed each building's worksheet for quality assurance, and questionable entries were corrected by the field teams. The project team extracted collected building and measure data to a database for lost savings analysis. PNNL developed a semi-automated data extraction process that takes site visit data from all the individual Excel workbooks for each building and compiles it into a single composite spreadsheet for analysis. The field data collection, extraction, and analysis process generally follow these steps:

1. Energy code measures are identified and analyzed for worst case lost savings.
2. Measures are selected for field study, and the best case and sometimes an intermediate case, is analyzed for the included measures.
3. Prototype building energy simulation is used to estimate lost savings for a range of possible conditions that could be found in the field for each code measure.
4. Regressions are developed from the simulation results that can be applied to any found field condition to estimate lost savings.
5. Lost savings building data are summarized and the calculation workbook is developed.
6. Field staff visit buildings and collect data that are transcribed onto the building report sheet.
7. Collected data are reviewed, and data quality questions are resolved.
8. Building and measure data are extracted from the building worksheets and compiled into the composite workbook with all the building data.
9. Building measure data are screened for possible quality issues.
10. Measure verified lost savings are rolled up by case and applied to non-verified measures in buildings where applicable to estimate total population lost savings.
11. Lost savings per measure verification hours are calculated.
12. Lost savings impact is summarized by measure and building type/climate zone case.
13. Individual measure results are reviewed statistically for confidence.
14. Results are screened based on statistical confidence analysis.
15. Measure list is reviewed for future studies based on the following criteria: Field applicability and lost savings found, lost savings per hour input, and potential lost savings.

Significant effort was made for data quality control. The following steps were taken in reviewing individual building inputs:

- Verify that building level data were complete.
- Review the data form measure inputs for consistency with building type and building equipment.
- Verify that installation quality inputs are provided for insulation measures.
- Confirm that both "code required" and "as found" factor or condition inputs are provided for all measures indicated as verified or inferred.

Once the measure and building data were extracted from individual building worksheets into a single, common data file, additional checks could be performed and resolved where outliers were found:

- Confirm that input factors were within the measure regression x-value best to worst range unless relatively close and the lost savings regression was linear.
- All measures verified or inferred were also indicated as applicable to the building.
- Measures indicated as applicable to the building were not excluded from data collection for the building type or climate zone in the data collection plan.
- Applicable floor area for measures was not greater than the conditioned building area.
- Calculated lost savings per applicable square foot by measure case was within reasonable bounds.
- Calculated lost savings per observation time by measure case was within reasonable bounds.

The following data were extracted from the common data file for use in the statistical analysis:

- Building identifier
- Building type
- ASHRAE climate zone
- Measure number
- Measure name
- Verification level
- Building conditioned floor area
- Measure verification time
- Measure verification time per thousand square feet
- Annual lost savings ($/yr)
- Present value lost savings (PV$LS)
- Present value lost savings per thousand square feet

In some cases, measures are split in the building where some installations meet the code and others do not. For these cases, we collapsed the multiple instances of measures within each building. When a building has multiple entries for packaged air conditioner efficiency, for example, the sum of the lost savings across the multiple entries is analyzed. This approach is essentially a weighted average impact by building. This approach is reasonable as it is indicative of a total building population impact.

5.0 Analysis Results

This project attempted to observe enough instances of measures and buildings to obtain statistical significance. However, the project failed to accomplish this for many measures, given the typical challenges of recruiting buildings, verified observability of any given measure in a single site visit, and the unknown quantity of any measure being constructed in the field. Therefore, the results provide directional rather than definitive quantitative guidance.

The project teams visited 230 buildings, covering over 6 million square feet of commercial office and retail space. An explanation of how these buildings were selected and recruited is described in an associated report (IMT 2020). The final data set is presented in Table 5.1.

Table 5.1. Number of Buildings Surveyed by Type and Location

	Climate Zone 2A		Climate Zone 5A		
	Office	Retail	Office	Retail	**Total**
Small-medium (<75 kft^2)	58	47	49	50	**204**
Large (≥75 kft^2)	4	8	12	2	**26**
Total	**62**	**55**	**61**	**52**	**230**

This compilation of field study energy code compliance data includes 107 retail and 123 office buildings from both climate zones, for a total of 230 buildings. One building had no verified measures, so the sample size of buildings with verified measures was 229.

5.1 Lost Savings Analysis

In determining the impact of building construction that falls short of code, several factors must be considered:

1. Is the code requirement applicable to the building or part of the building?
2. What is the case, defined by measure, climate zone, and building type?
3. What condition is installed (field-verified) relative to the code requirement?

The first two factors can be readily determined, but as previously discussed, a high confidence in the field information is only possible if the field inspection occurs when direct verification of the conditions is possible (third factor). The reliability of the verified information depends on the number of actual field observations for each case. When there is verified information for a case, an estimate of lost savings can be calculated (Rosenberg et al. 2016; Hart et al. 2019) and it can be reasonably applied to other cases where the measure was applicable, but not directly observed. Once the statistical review of measure results was complete, a general measure result from all verified cases was applied where measures are applicable but not verified. For some measures there are no verified cases, and no estimate can be made.

5.2 Overall Lost Savings

What is the total verified lost savings for all buildings surveyed? This roll-up includes the concept of applicability, as lost savings are not estimated where the measures are not applicable. Figure 5.1 shows estimated verified present value dollar lost savings (PV$LS) per thousand square feet (ksf) by measure (measure reference numbers and short names are used). The estimates reflect both building types and climate zones, and details on calculations are provided below. Measures with present value lost savings below $10/ksf are excluded in the figure and included in Table 5.4. Measures with no verified observations are excluded from both Figure 5.1 and Table 5.4. Table 5.2 shows results by case. Full measure descriptions indexed by measure number are found in Table 5.4.

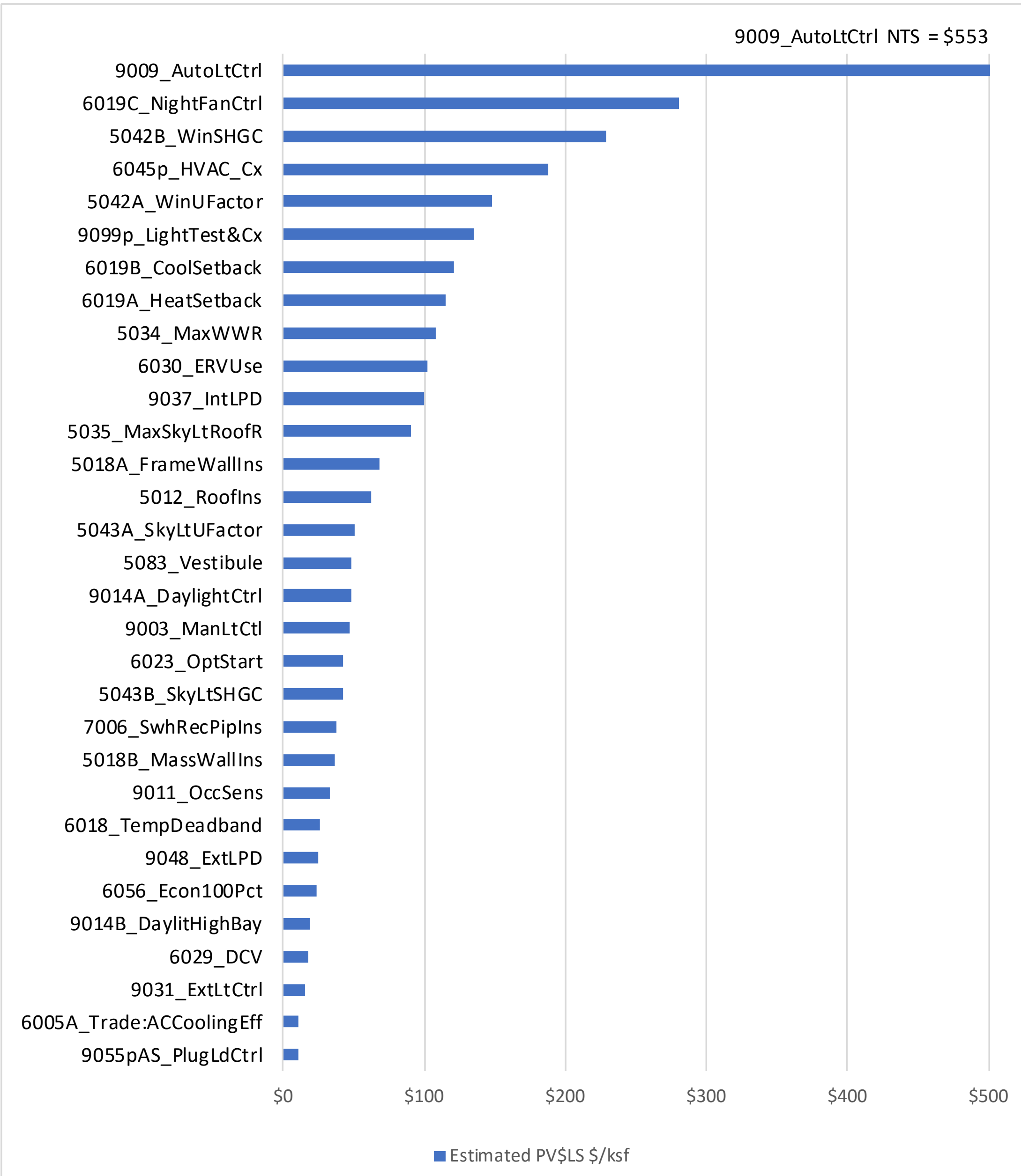


Figure 5.1. Estimated Measure Lost Savings for All Cases

To represent the true cost of lost savings over the life of the building, the annual lost savings from each measure is converted to a present value (PV) using discount rates based on the measure life. This represents the value today of all lost savings over the life of each measure. Then, the data are divided by thousand square feet (ksf) of building area to normalize the values, resulting in verified present value dollar lost savings (PV$LS) per ksf. These values are calculated as follows:

$$Verified\frac{PV\$LS}{ksf} = \frac{\sum(PV\ factor * \$/year\ lost\ savings)}{\sum verified\ surveyed\ floor\ area\ /1000}$$

Estimates for the entire sample (or within building type and/or climate zones) are calculated as follows:

$$Estimated\frac{PV\$LS}{ksf} = Verified\frac{PV\$LS}{ksf} * \frac{\sum Applicable\ floor\ area}{\sum Verified\ floor\ area}$$

Table 5.2. Estimated Lost Savings by Building Type and Location

Building type	Climate Zone	Buildings surveyed	Average floor area, ft^2	Lost savings from non-compliance		
				$/year	$/year/ksf	PV$/ksf
Office	2A	62	17,406	208,442	193	2,778
Office	5A	61	36,127	277,679	126	1,951
Retail	2A	55	33,487	446,646	243	3,468
Retail	5A	52	18,817	223,388	228	3,901
All Buildings		**230**	**26,535**	**1,156,155**	**189**	**2,868**

One way to interpret these results is considering impacts on utility bills, estimated by comparison to energy cost intensity (ECI)[1] as shown in Table 5.3. The final row is the total weighted average by floor area, which shows the lost savings as a percent of ECI is 15%. Thus, 15% of the annual energy costs are recoverable with improved code compliance.

Table 5.3. Lost Savings Results as a Percent of ECI

Building type	Climate Zone	Lost Savings $/year/ft^2	ECI, $/ft^2-yr	Savings as a percent of ECI
Office	2A	0.193	1.14	17%
Office	5A	0.126	1.07	12%
Retail	2A	0.243	1.41	17%
Retail	5A	0.228	1.35	17%
All Buildings		**0.189**	**1.26**	**15%**

5.3 Building Lost Savings Distribution

Figure 5.2 shows the distribution of present value lost savings by building type and climate zone, and overall. Review of the distribution reveals several things:

- Only 4 out of the 229 buildings had zero lost savings or were fully compliant with the energy code.
- One-quarter of the buildings have lost savings (PV$LS) $724 or less per 1,000 ft^2.
- Half of the buildings have lost savings (PV$LS) $1,682 or less per 1,000 ft^2.
- The upper quartile of lost savings (PV$LS) has a greater spread, ranging from $4,065 to $9,000 per 1,000 ft^2, excluding outliers.
- There are several outlier buildings with very large lost savings, between $9,000 and $22,000 present value lost savings (PV$LS) per 1,000 ft^2.

These results reflect minimum lost savings, as only 69% of applicable measure instances were able to be verified by the field crew. Envelope verification was higher at 80%, with lighting at 73% and mechanical (HVAC and water heating) at 48%. Actual lost savings are likely in the range of 1.3 to 1.6 times the lost savings reported here.

[1] ECI values are based on ASHRAE 90.1-2016

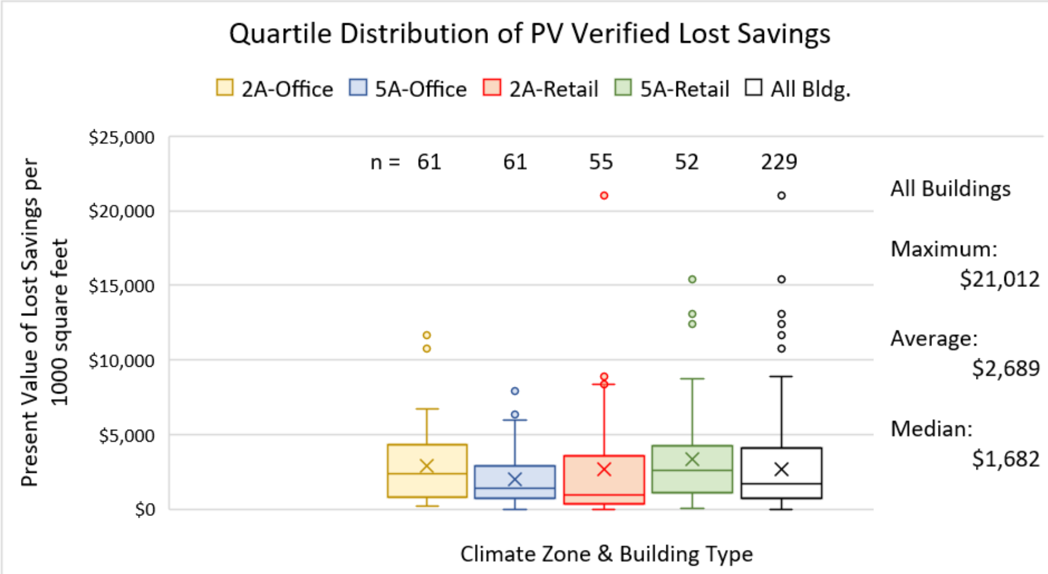


Figure 5.2. Distribution of Present Value Lost Savings by Climate Zone and Building Type

5.4 Normalized Measure Lost Savings

What is the estimated lost energy cost savings found in the field by measure, normalized per thousand square feet? Table 5.4 shows the estimated lost energy cost savings by measure normalized per thousand square feet and includes the impact of applicability. The ID's match those in Figure 5.1. The values are calculated as discussed previously under overall savings, except on a per-measure basis. When there were no verified cases below code in the sample, the lost savings are shown as zero in the table, even though a larger sample or more measure instances may reveal some lost savings. This table also shows the number of buildings in which the measure was applicable and the number of buildings in which it was verified. Note that numerous measures applied to only a very small number of buildings. In these cases, the lost energy cost savings is presented below, however, it is certainly not statistically representative of the population. Two lost savings values from non-compliance are shown:

- $/year is the estimated lost savings for all buildings.
- $/yr/ksf is the $/year divided by the total building conditioned floor area.

Table 5.4. Lost Savings by Measure

Measure		# Buildings		Lost Energy Cost Savings	
ID	Description	Appl.	Ver.	$/year	$/yr/ksf
5012	Roofs shall be insulated to meet CZ requirements	48	19	$16,861	$2.76
5014	Low slope roofs in CZ 1-3 shall be cool roofs	18	6	$2,439	$0.40
5018A	Above grade frame walls shall be insulated to meet CZ requirements	90	53	$17,079	$2.80

Measure		# Buildings		Lost Energy Cost Savings	
ID	Description	Appl.	Ver.	$/year	$/yr/ksf
5018B	Above grade mass walls shall be insulated to meet CZ and density requirements	27	13	$9,359	$1.53
5023B	Exterior mass floors shall meet the minimum R-value or U-value by assembly type	2	1	$555	$0.09
5029B	Opaque rollup doors shall meet U-factor requirements	8	6	$1,111	$0.18
5034	Window-to-wall ratio shall meet maximum limits	40	40	$30,192	$4.95
5035	Skylight to roof ratio shall meet maximum limits	1	1	$25,332	$4.15
5042A	Windows shall meet U-factor requirements	143	138	$37,636	$6.17
5042B	Windows shall meet SHGC requirements	154	147	$69,980	$11.47
5043A	Skylights shall meet U-factor requirements	7	4	$12,470	$2.04
5043B	Skylights shall meet SHGC requirements	7	6	$12,815	$2.10
5056	Building shall meet continuous air barrier requirements	3	3	$354	$0.06
5077	Stair and shaft vent leakage	2	1	$547	$0.09
5083	Building entrances shall be protected with an enclosed vestibule	12	12	$12,763	$2.09
5089	Fenestration orientation	12	11	$492	$0.08
6005A	Packaged air conditioner efficiency	35	16	$5,244	$0.86
6005B	Packaged heat pump efficiency	6	2	$2,189	$0.36
6005C	Gas furnace efficiency	1	0	$0	$0.00
6005D	Boiler efficiency	2	1	$45	$0.01
6017	Heat pump supplementary heat control	3	1	$4	$0.00
6018	Thermostat deadband requirement	30	12	$11,796	$1.93
6019A	Thermostat heating setback	49	22	$48,221	$7.90
6019B	Thermostat cooling setback	47	25	$57,511	$9.42
6019C	Night fan control	48	30	$130,563	$21.39
6023	Optimal start controls	17	13	$18,249	$2.99
6026p	Snow and ice-melting system control	1	0	$0	$0.00
6029	Demand control ventilation	22	10	$7,120	$1.17
6030	Energy recovery requirement	3	1	$37,739	$6.18
6035	Duct leakage requirement	1	1	$611	$0.10
6042B	Hydronic Piping Insulation Requirement HW	10	9	$400	$0.07
6045p	Commissioning requirement	64	18	$88,502	$14.50

Measure		# Buildings		Lost Energy Cost Savings	
ID	Description	Appl.	Ver.	$/year	$/yr/ksf
6046A	Fan power limit requirement for PkgAC	8	2	$832	$0.14
6056	Economizer supplies 100% design supply air	38	25	$11,123	$1.82
6070	Multi-zone systems shall be VAV and fans with motors ≥threshold hp shall have variable speed, variable pitch axial, or fan demand reduction	1	0	$0	$0.00
6071	Static pressure sensors used to control VAV fans shall be properly placed	1	0	$0	$0.00
6110pAS	Zone Isolation	1	0	$0	$0.00
7006	SWH Pipe Insulation - Recirculated	3	1	$14,628	$2.40
9003	Manual lighting control	40	38	$19,353	$3.17
9009	Automatic time switch control	69	57	$265,212	$43.45
9011	Occupancy sensor control	51	47	$15,875	$2.60
9014A	Daylighting control	49	44	$23,006	$3.77
9014B	For large, high-bay spaces total daylight zone under skylights at least 1/2 of floor area	12	11	$9,235	$1.51
9031	Exterior lighting control	25	22	$7,081	$1.16
9037	Interior lighting power allowance	20	17	$47,690	$7.81
9047	Additional retail lighting power allowance	3	3	$2,500	$0.41
9048	Exterior lighting power allowance	23	15	$11,629	$1.91
9055pAS	Plug load controls	10	7	$4,898	$0.80
9099p	Lighting Testing or Commissioning	101	34	$64,487	$10.57
6005E	WSHP efficiency	2	0	$0	$0.00
5023A	Exterior frame floors shall meet the insulation requirements	1	1	$6	$0.00
6109pAS	Parking garage fan controls	1	0	$0	$0.00
9054AS	Parking garage lighting controls	1	1	$296	$0.05

5.5 Ratio of Measure Lost Savings to Inspection Hours

What is the overall PV lost savings for each measure per total hours invested in verifying the measures in the field? Figure 5.3 gives an indicator of where field time investigating measures is best spent. Unverified or zero lost savings measures are excluded here. Actual dedicated field time data were collected for about 30% of the measure instances. A number of measures applied to only a very small number of buildings; thus, the results are not statistically representative of the population.

The idea is to emphasize large savings measures with low field verification effort. The values are calculated as follows:

$$\frac{PV\$LS}{verification\ hour} = \frac{\sum PV factor * \frac{\$}{year} verified\ measure\ lost\ savings}{\sum hours\ to\ survey\ measure}$$

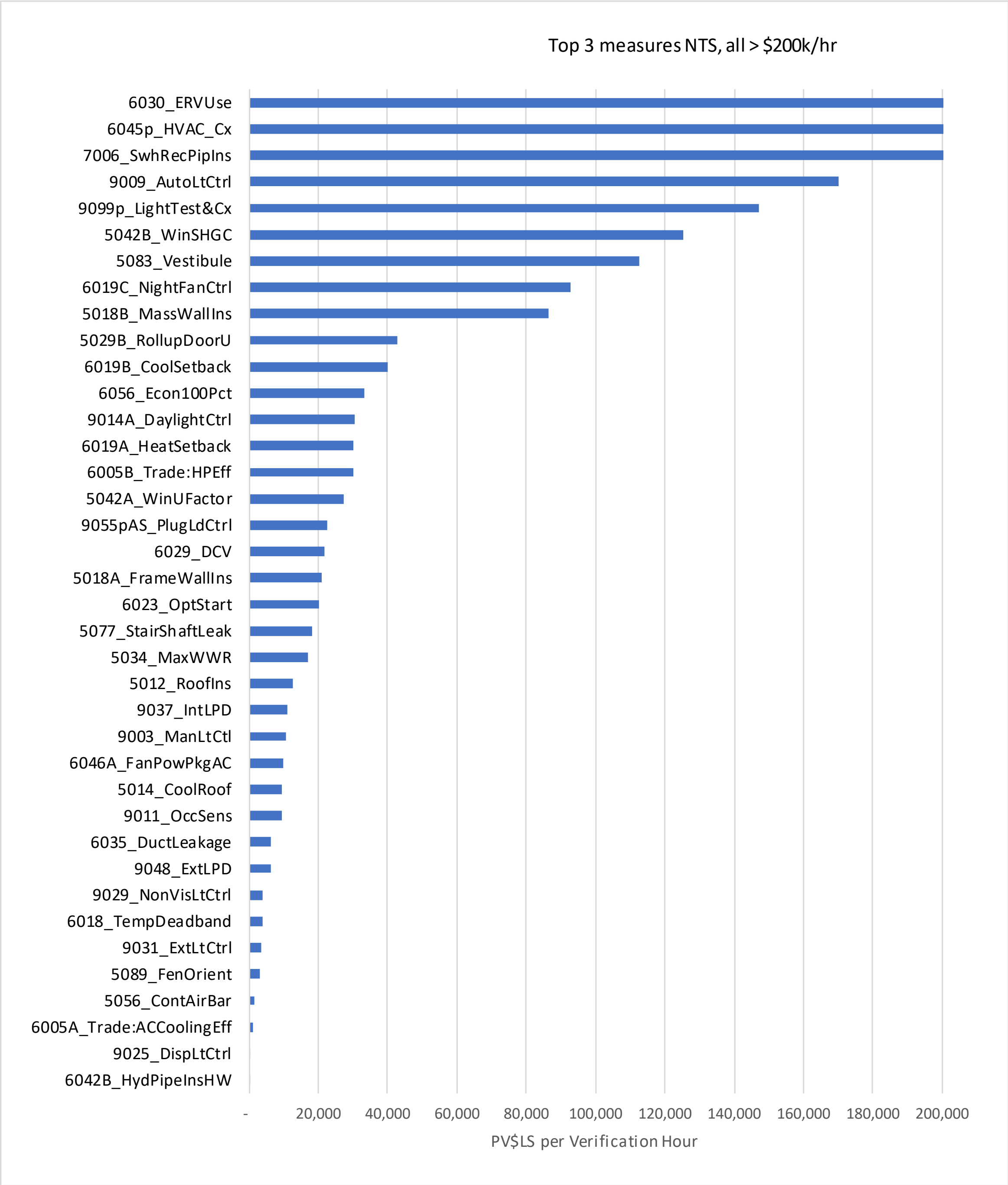


Figure 5.3. Measure Verified Savings per Inspection Time

5.6 As-Found vs. Worst-Case Lost Savings

Figure 5.4 through Figure 5.7 show the lost energy cost savings by building type and climate zone. Both the potential and observed (actual) worst cases are shown in each figure. The worst-case analysis included subjective assessments of what might occur and often assumed complete non-compliance for each measure (Hart et al. 2019). For example, designers and builders typically do not omit all of the roof insulation in practice (worst case potential). Rather, they provide less than the code requires (worst case actual). Measure 5012, roof insulation, is a good example of this difference. Lighting controls and HVAC controls provide some of the largest as-found lost energy cost savings.

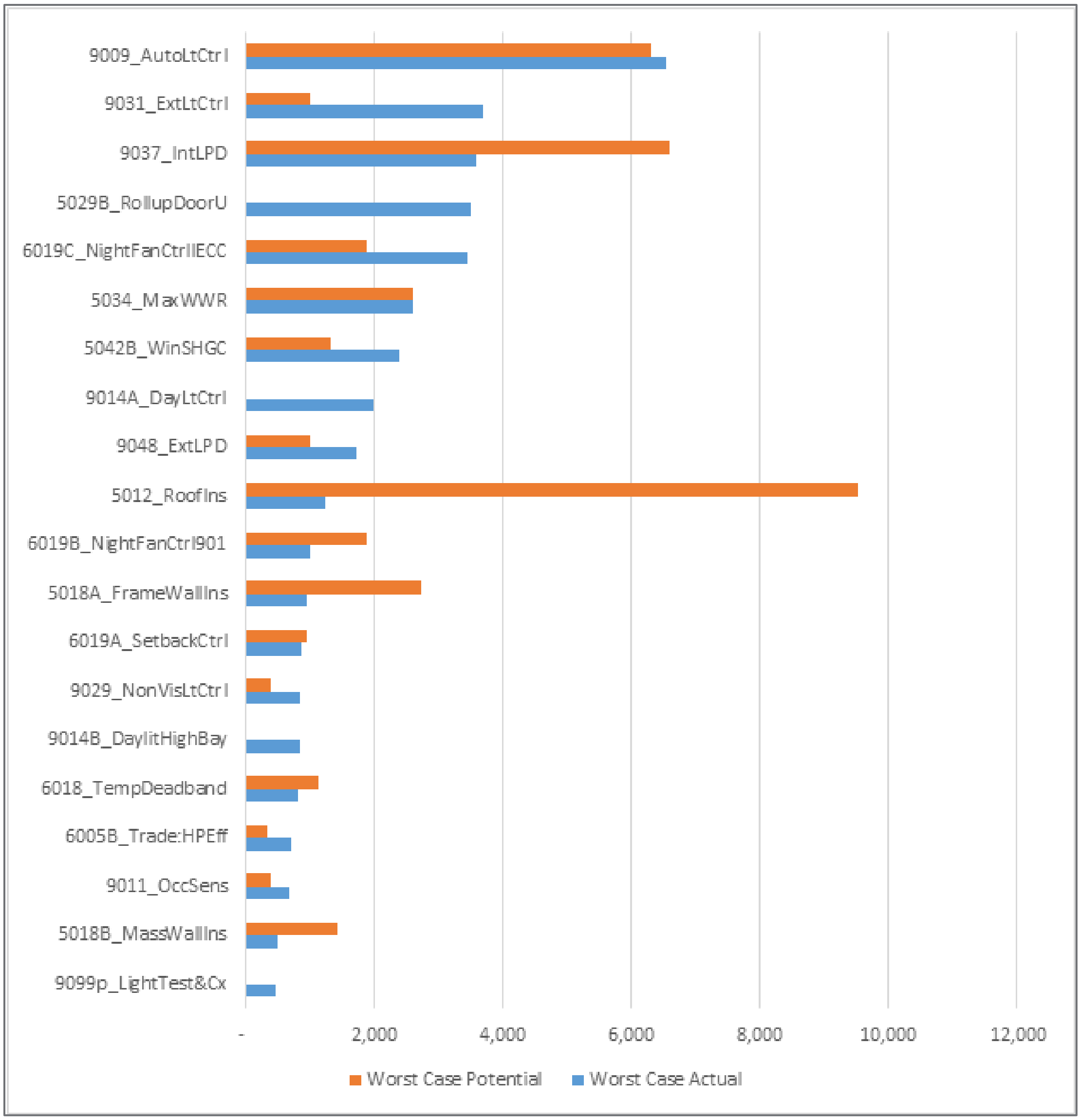


Figure 5.4. Climate Zone 2A Retail Lost Savings, PV$/1,000 ft^2

In some cases, the actual lost savings is much higher than the originally estimated worst-case potential. This can occur when the estimated prototypical results cover a small portion of the typical building, but a particular building had a large area affected by that measure. Some instances include: 6019c – Night fan control, 7006 – SHW recirculation piping insulation, 9009 – Auto light control, 9011 – occupancy sensor, and 9047 – Additional retail lighting power allowance.

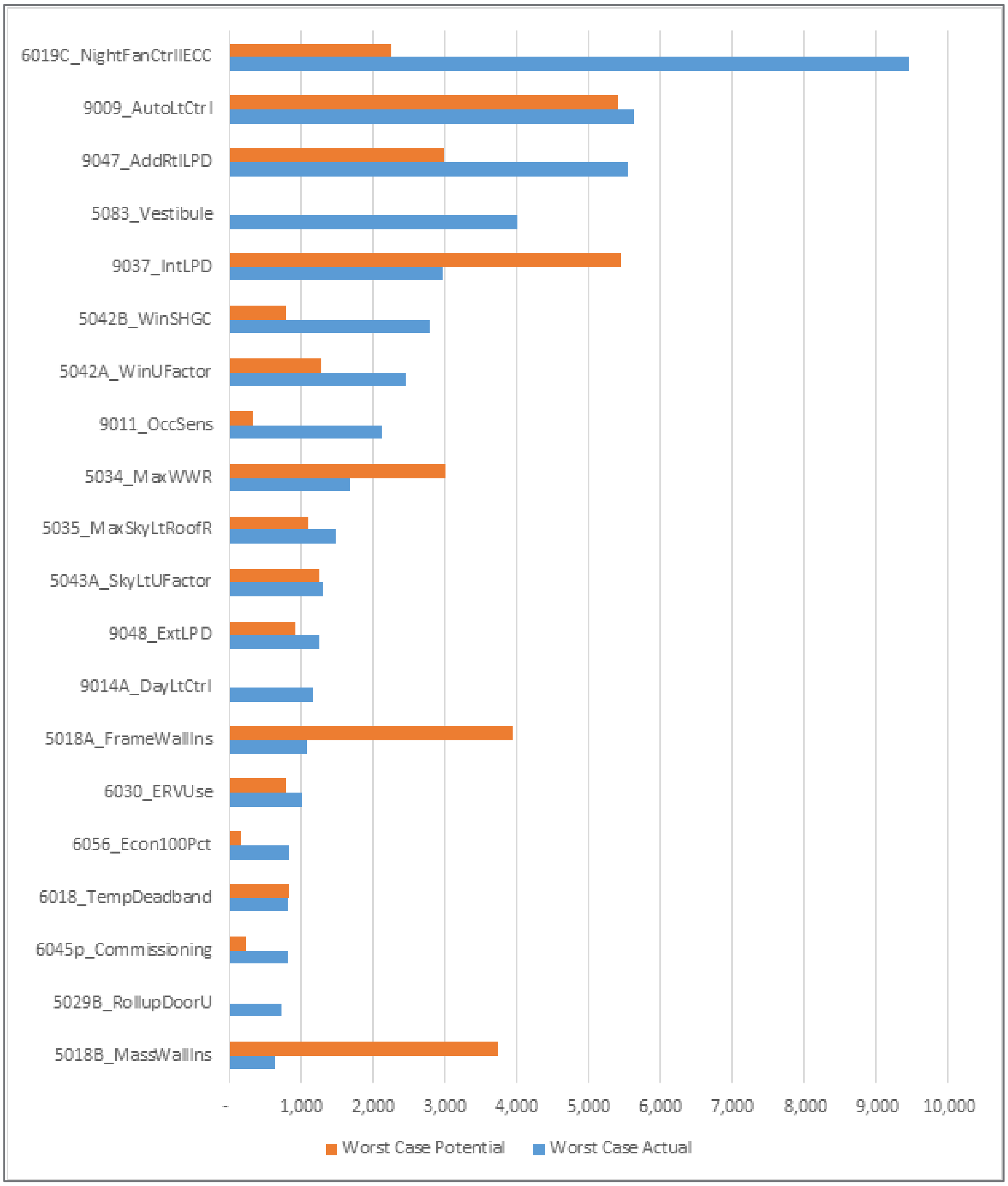


Figure 5.5. Climate Zone 5A Retail Lost Savings, PV$/1,000 ft^2

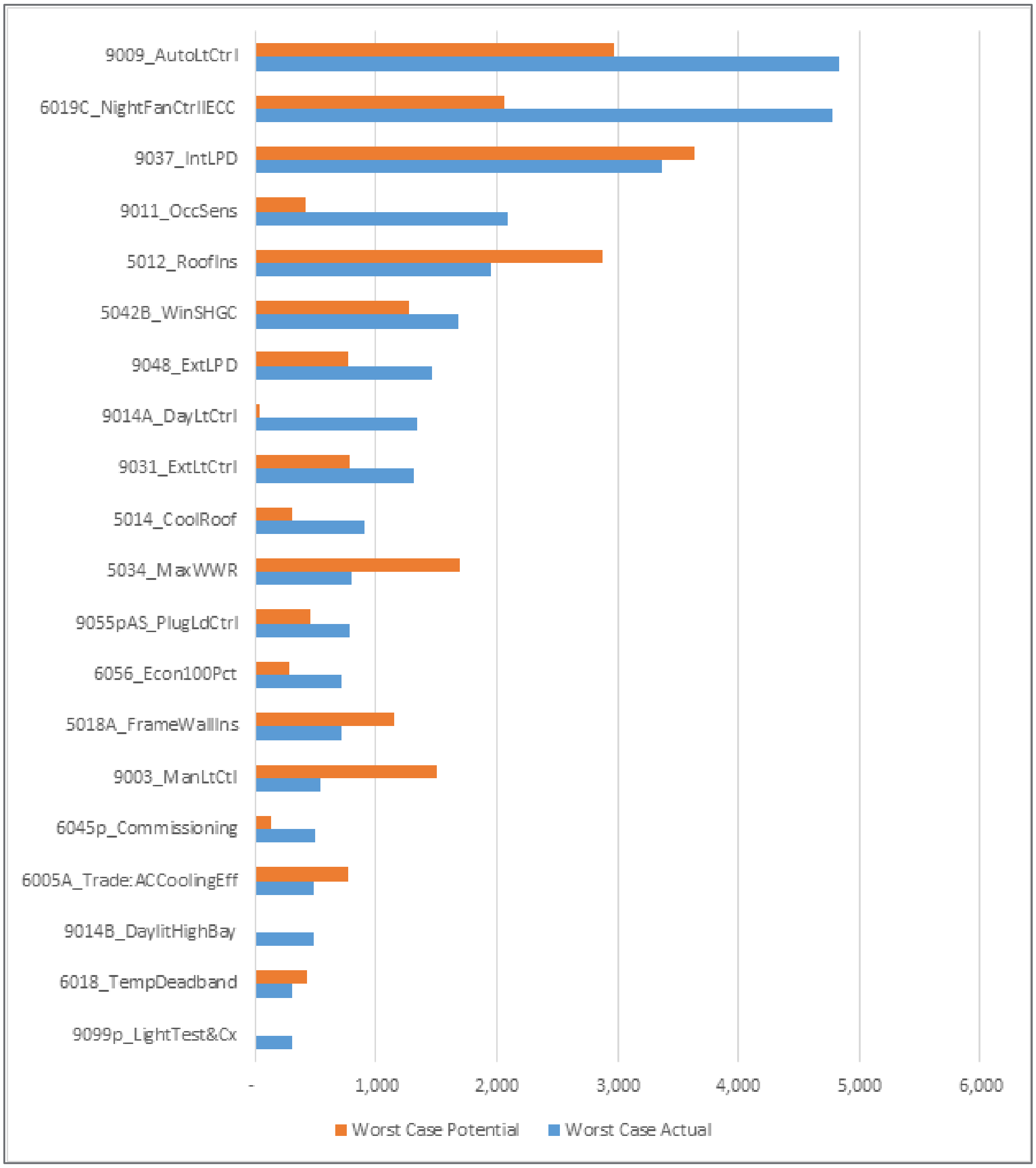


Figure 5.6. Climate Zone 2A Office Lost Savings, PV$/1,000 ft^2

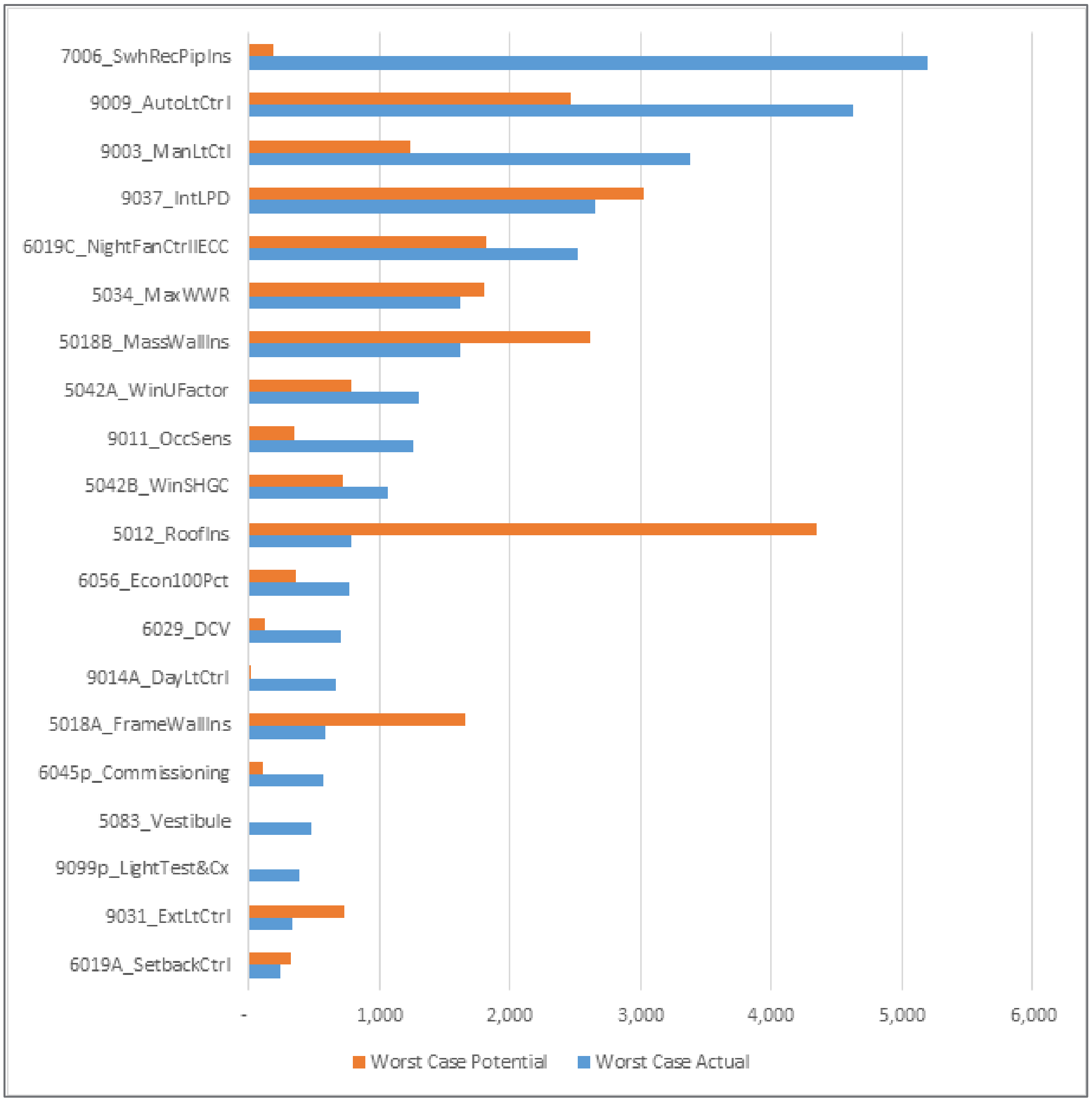


Figure 5.7. Climate Zone 5A Office Lost Savings, PV$/1,000 ft^2

6.0 Initial Statistical Analysis

This project attempted to observe enough instances of measures and buildings to obtain statistical significance. However, the project failed to accomplish this for many measures, given the typical challenges of recruiting buildings, verified observability of any given measure in a single site visit, and the unknown quantity of any measure being constructed in the field. Therefore, the results provide directional rather than quantitative definitive guidance in many cases. The project team completed a statistical analysis based on the collected data.

This analysis included calculating the precision of the estimated present value of lost energy savings per square foot due to non-compliance with energy code measures at 80% confidence. Overall, the results show that lost savings were larger for retail buildings than office buildings, although not significant except between office and retail buildings in climate zone 5A (at 90% confidence). This initial analysis incorporated stratification and weights from the sampling plan. An overview of the data and high-level results are included with detailed tables for each analysis type presented in Appendix A. It was superseded by the additional statistical analysis described in the next section, so results are provided there.

The initial analysis also included calculating coefficients of variation (CVs) and using them to estimate the sample size of measures required for a future study to achieve statistical significance. The sample sizes were calculated to achieve 80/20 confidence and precision for an estimated mean PV$ lost saving values based on various CVs shown in Table 6.1. These CVs represent a range of possibilities so that future studies can plan for realistic scenarios based on their priorities. Sample sizes ranged from 67 to 1,888 and are smallest for estimating the mean lost savings when the lost savings are non-zero. These results show that any future studies using this approach will require substantial resources to achieve statistical significance.

Table 6.1. Estimated Required Sample Sizes for Future Studies Seeking Statistical Significance

Strata	CV	Confidence Level	Precision Target	Sample Size (Measures)
Max CV across verified measures	6.78	80%	20%	1,888
75th quartile CV across verified measures	4.15	80%	20%	708
Median CV across verified measures	3.04	80%	20%	380
Max CV excluding 0	3.61	80%	20%	534
75th quartile CV excluding 0	1.73	80%	20%	122
Median CV excluding 0	1.28	80%	20%	67
Max CV across Climate Zones	5.61	80%	20%	1,294

7.0 Additional Statistical Analysis

Using the collected field data for verified measures only, we applied an additional statistical method to improve precision in the lost savings estimates and rank measures accordingly. We updated the rankings based on those results.

7.1 Approach

We applied the following methods to address limitations in the initial approach.

- Transformed PV$ lost savings and building conditioned ksf to the log scale to address skewness/non-normality
- Applied regression analysis to model log PV$ lost savings as a function of building type, ASHRAE CZ, log building conditioned ksf, and compliance to account for these sources of variation (in addition to sampling uncertainty) and improve precision of the resulting estimates
- Used the estimated regression coefficients and their standard errors to estimate mean log PV$ lost savings and 80% confidence intervals, applying weights to account for differences between building floor areas observed in the sample and areas in the sample frame (2016 Dodge new construction data)
- Re-ranked the measures based on these estimates

7.2 Raw Data Review

The regression analysis data set included 3,102 verified measures verified in 229 new office and retail buildings. The number of verified measures and buildings with verified measures are shown in Table 7.1 by building type and climate zone.

Table 7.1. Measure and Building Sample Sizes by Building Type and ASHRAE CZ

Building Type	Measure Count 2A	Measure Count 5A	Building Count_2A	Building Count 5A
Office	873	893	61	61
Retail	580	756	55	52
Total	**1,453**	**1,649**	**116**	**113**

The number of measures and buildings are shown in Table 7.2 by measure ID.

Table 7.2. Measure sample sizes by measure ID

Measure Category	Measure ID	Measure Name	Office		Retail		Total
			ASHRAE CZ				
			2A	5A	2A	5A	
HVAC	6005A	Packaged air conditioner efficiency	53	41	23	21	138
HVAC	6005B	Packaged heat pump efficiency	14	3	3	1	21
HVAC	6005C	Gas furnace efficiency	25	30	8	18	81
HVAC	6005D	Boiler efficiency	4	7	1	1	13
HVAC	6005E	WSHP efficiency	0	0	1	1	2
HVAC	6007A	Air-cooled Chiller efficiency	1	0	0	0	1
HVAC	6017	Heat pump supplementary heat control	5	1	1	2	9
HVAC	6018	Thermostat deadband requirement	36	27	12	28	103
HVAC	6019A	Thermostat heating setback	37	25	15	28	105
HVAC	6019B	Thermostat cooling setback	38	24	15	28	105
HVAC	6019C	Night fan control	30	26	11	20	87
HVAC	6023	Optimal start controls	8	5	13	19	45
HVAC	6026p	Snow and ice-melting system control	0	3	0	0	3
HVAC	6029	Demand control ventilation	12	10	0	0	22
HVAC	6030	Energy recovery requirement	1	2	0	4	7
HVAC	6033p	Exterior (outside building) Duct insulation	0	1	0	1	2
HVAC	6035	Duct leakage requirement	0	5	1	2	8
HVAC	6042B	Hydronic Piping HW Insulation Requirement	10	4	0	0	14
HVAC	6045p	Mechanical Commissioning	2	10	1	11	24
HVAC	6046A	Fan power limit requirement for PkgAC	7	4	0	3	14
HVAC	6051	Outdoor heating: radiant and controlled	0	0	0	1	1
HVAC	6056	Economizer supplies 100% design supply air	26	23	7	17	73
HVAC	6066p	Water economizer capacity meets requirements	0	1	0	0	1
HVAC	6070	Multi-zone reheat systems shall be VAV with appropriate zone minimums, and fans with motors ≥threshold hp shall be variable speed or pitch	0	1	0	0	1
HVAC	6071	Static pressure reset for multi-zone VAV fans	0	2	0	0	2
HVAC	6089	Each WSHP in a system exceeding 10 hp pump shall have a two-position valve	0	2	0	0	2
HVAC	6101	Multiple zone HVAC systems shall have supply-air temperature reset controls	0	3	0	0	3
HVAC	6108AS	Single zone VAV	0	0	0	1	1

Measure Category	Measure ID	Measure Name	Office		Retail		Total
			ASHRAE CZ				
			2A	5A	2A	5A	
HVAC	6109pAS	Parking garage fan controls	0	2	0	0	2
HVAC	6110pAS	Zone Isolation	0	2	0	0	2
HVAC	7006	SWH Pipe Insulation - Recirculated	3	5	0	0	8
Lighting	9003	Manual lighting control	54	52	16	34	156
Lighting	9009	Automatic time switch control	42	32	27	34	135
Lighting	9011	Occupancy sensor control	56	43	32	37	168
Lighting	9014A	Daylighting control	14	26	12	13	65
Lighting	9014B	For large, high-bay spaces total daylight zone under skylights at least 1/2 of floor area	5	0	8	4	17
Lighting	9025	Display lighting control	0	0	4	8	12
Lighting	9029	Lighting for nonvisual applications shall be controlled separately	0	0	3	1	4
Lighting	9031	Exterior lighting control	48	47	34	41	170
Lighting	9037	Interior lighting power allowance	34	43	31	39	147
Lighting	9047	Additional retail lighting power allowance	0	0	5	8	13
Lighting	9048	Exterior lighting power allowance	33	50	34	41	158
Lighting	9054AS	Occupant based parking garage light control	0	2	0	0	2
Lighting	9099p	Lighting Testing or Commissioning	7	15	4	13	39
Receptacle_Controls	9055pAS	Receptacle controls	8	2	0	0	10
Shell	5012	Roofs shall be insulated to meet CZ requirements	20	24	16	23	83
Shell	5014	Low slope roofs in CZ 1-3 shall be cool roofs	18	0	27	0	45
Shell	5018A	Above grade frame walls shall be insulated to meet CZ requirements	26	30	20	25	101
Shell	5018B	Above grade mass walls shall be insulated to meet CZ and density requirements	10	11	19	4	44
Shell	5023A	Exterior frame floors shall meet the insulation requirements	0	1	0	0	1
Shell	5023B	Exterior mass floors shall meet the minimum R-value or U-value by assembly type	0	1	0	0	1
Shell	5029B	Opaque rollup doors shall meet U-factor requirements	3	2	9	11	25
Shell	5034	Window-to-wall ratio shall meet maximum limits	53	60	51	50	214
Shell	5035	Skylight to roof ratio shall meet maximum limits	2	2	6	2	12
Shell	5042A	Windows shall meet U-factor requirements	46	51	45	49	191
Shell	5042B	Windows shall meet SHGC requirements	46	49	45	47	187
Shell	5043A	Skylights shall meet U-factor requirements	1	2	2	2	7

Measure Category	Measure ID	Measure Name	Office		Retail		Total
			ASHRAE CZ				
			2A	5A	2A	5A	
Shell	5043B	Skylights shall meet SHGC requirements	1	2	2	2	7
Shell	5056	Building shall meet continuous air barrier requirements	16	33	5	31	85
Shell	5077	Stair and shaft vent leakage	3	9	0	3	15
Shell	5083	Building entrances shall be protected with an enclosed vestibule	5	33	1	27	66
Shell	5089	Fenestration orientation	10	2	10	0	22
HVAC	Measure Category Count	HVAC Measures	312	269	112	207	900
Lighting	Measure Category Count	Lighting Measures	293	310	210	273	1086
Receptacle_Controls	Measure Category Count	Plug Load Controls Measures	8	2	0	0	10
Shell	Measure Category Count	Shell Measures	260	312	258	276	1106
All categories	Total Measure Count	All Measures	873	893	580	756	3102

7.2.1 Raw PV$ Lost Savings Data

We used a log transformation to address the skewness in the distribution of PV$ lost savings and to improve precision of estimates for ranking purposes. Since numerous PV$ lost savings values were zero, we adjusted the raw data by adding one to all PV$ lost savings values prior to taking the log of the values. The resulting log-transformed values were equal to zero when the original PV$ lost savings value was zero and positive when the raw data were nonzero and positive.

Building type and measure category: Figure 7.1 shows the distribution of log-transformed PV$ lost savings per ksf by building type and measure category for verified measures, and Figure 7.2 provides the same information but includes noncompliant measures only.

- Among noncompliant measures, log-transformed PV$ lost savings distributions are more symmetric than PV$ lost savings on the original scale.
- Log-transformed PV$ lost savings distributions are similar in office and retail buildings.
- Log-transformed PV$ lost savings distributions cover similar ranges (min/max) in all measure categories but seem to have different shapes depending on the measure category.

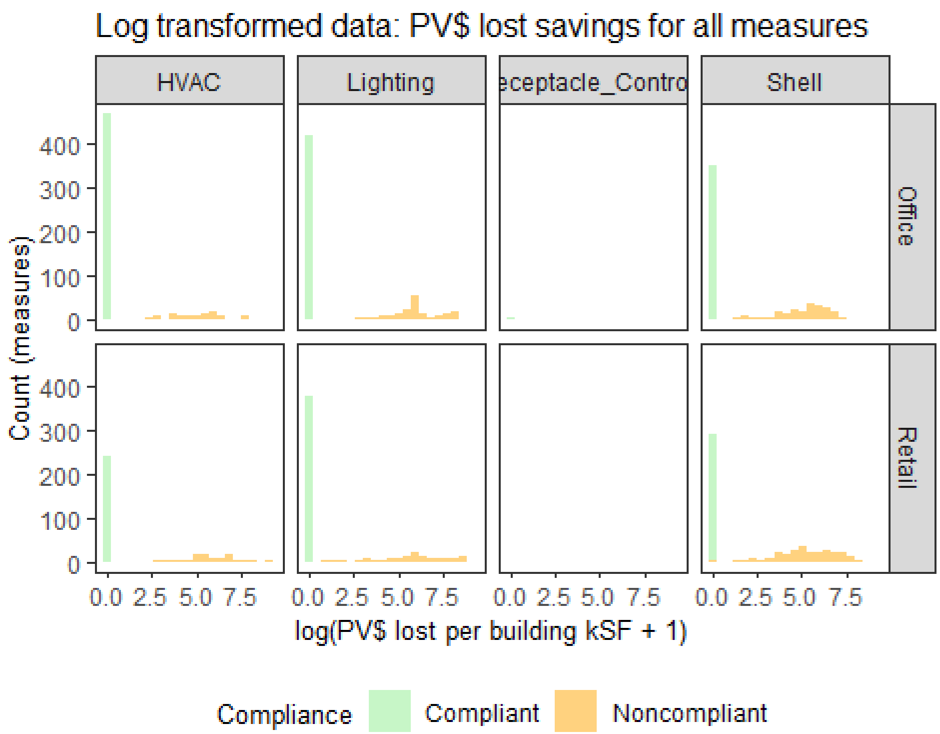


Figure 7.1. Log-Transformed Data: PV$ Lost Savings for Noncompliant Measures

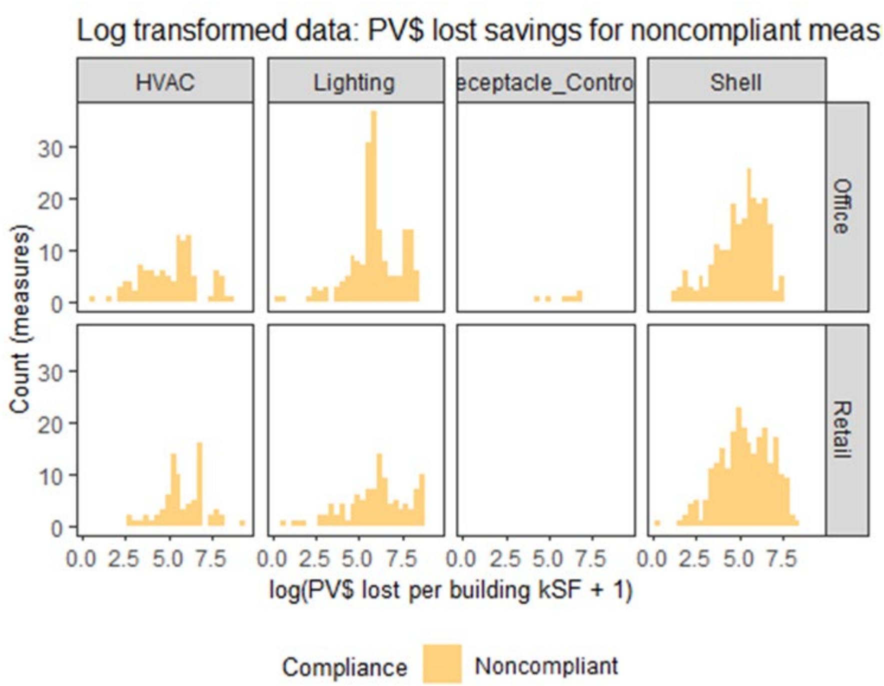
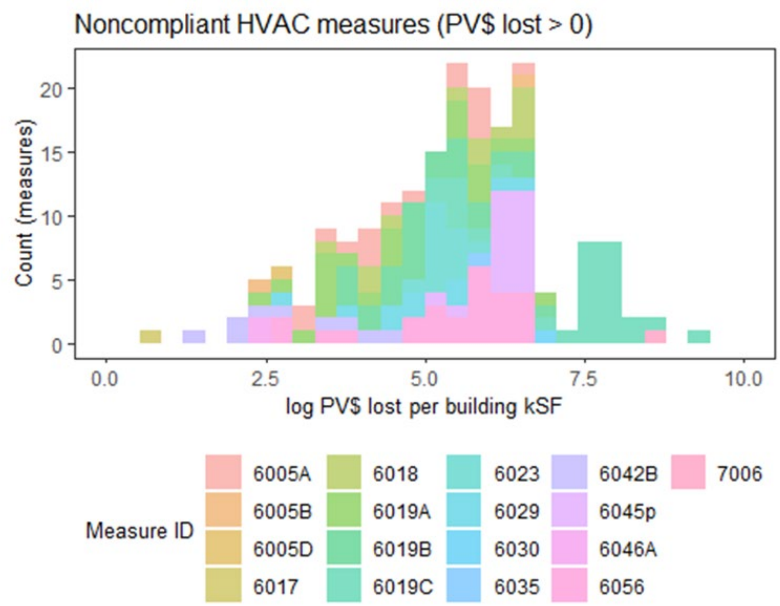


Figure 7.2. Log-Transformed Data: PV$ Lost Savings for Noncompliant Measures

The following three figures overlay the individual measure distributions.

HVAC measures: Figure 7.3 shows the distribution of log PV$ lost within individual HVAC measures in the sample. Full measure names are provided in a table below the figure.

- Although some measures occur less frequently (smaller peaks corresponding to measure counts), HVAC measures appear to have similar log PV$ lost savings distributions (similar shape and range of distributions).



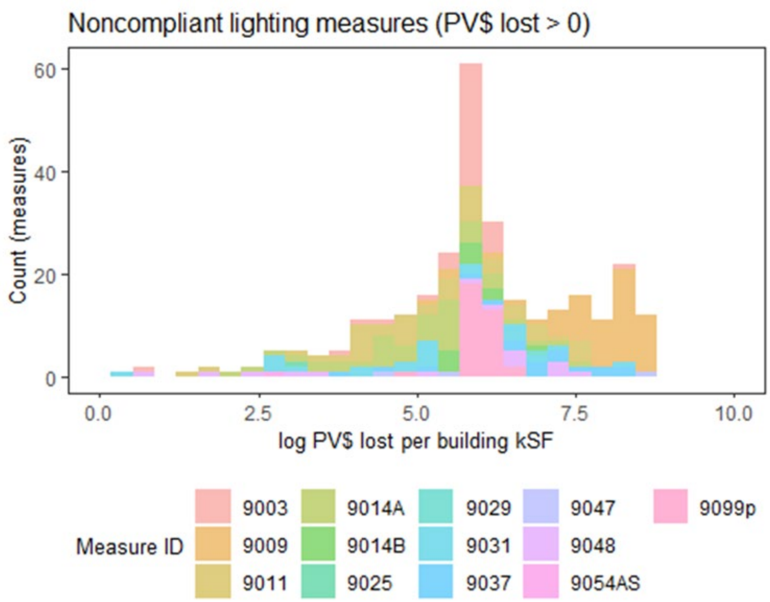
Measure ID	Measure Name	Measure ID	Measure Name
6005A	Packaged air conditioner efficiency	6042B	Hydronic Piping HW Insulation Requirement
6005B	Packaged heat pump efficiency	6045p	Mechanical Commissioning
6005C	Gas furnace efficiency	6046A	Fan power limit requirement for PkgAC
6005D	Boiler efficiency	6046B	Fan power limit requirement for VAV
6005E	WSHP efficiency	6051	Outdoor heating: radiant and controlled
6007A	Air-cooled Chiller efficiency	6056	Economizer supplies 100% design supply air
6007B	Water-cooled Chiller efficiency	6066p	Water economizer capacity meets requirements
6017	Heat pump supplementary heat control	6070	Multi-zone reheat systems shall be VAV with appropriate zone minimums, and fans with motors ≥threshold hp shall be variable speed or pitch
6018	Thermostat deadband requirement	6071	Static pressure reset for multi-zone VAV fans
6019A	Thermostat heating setback	6089	Each WSHP in a system exceeding 10 hp pump shall have a two-position valve
6019B	Thermostat cooling setback	6091p	Multiple chiller shall reduce flow when a chiller is shut down
6019C	Night fan control	6101	Multiple zone HVAC systems shall have supply-air temperature reset controls
6023	Optimal start controls	6106AS	VAV ventilation optimization

Measure ID	Measure Name	Measure ID	Measure Name
6026p	Snow and ice-melting system control	6108AS	Single zone VAV
6029	Demand control ventilation	6109pAS	Parking garage fan controls
6030	Energy recovery requirement	6110pAS	Zone Isolation
6033p	Exterior (outside building) Duct insulation	7006	SWH Pipe Insulation - Recirculated
6035	Duct leakage requirement		

Figure 7.3. Noncompliant HVAC Measures

Lighting measures: Figure 7.4 shows the log PV$ lost savings distributions for individual lighting measures in the sample.

- Although some measures occur less frequently (smaller peaks corresponding to measure counts), lighting measures appear to have similar log PV$ lost savings distributions (similar shape and range of distributions).

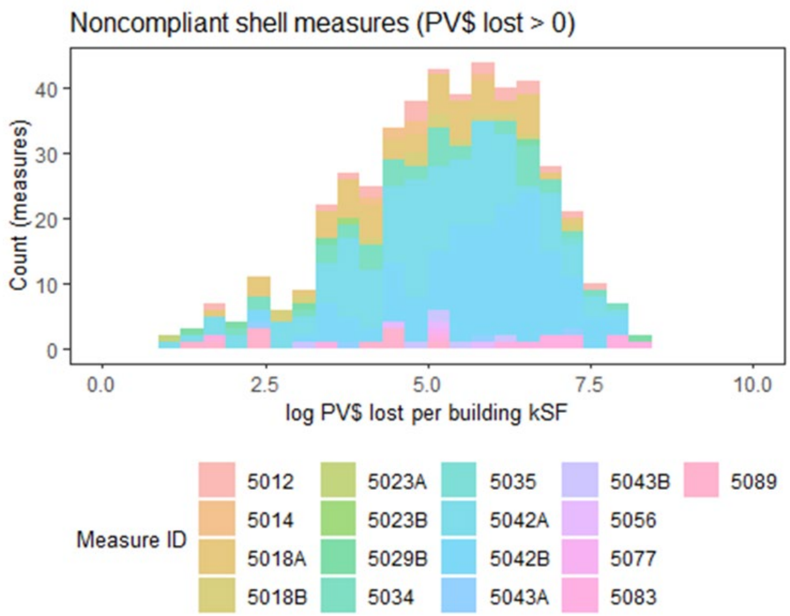


Measure ID	Measure Name	Measure ID	Measure Name
9003	Manual lighting control	9031	Exterior lighting control
9009	Automatic time switch control	9037	Interior lighting power allowance
9011	Occupancy sensor control	9047	Additional retail lighting power allowance
9014A	Daylighting control	9048	Exterior lighting power allowance
9014B	For large, high-bay spaces total daylight zone under skylights at least 1/2 of floor area	9054AS	Occupant based parking garage light control
9025	Display lighting control	9099p	Lighting Testing or Commissioning
9029	Lighting for nonvisual applications shall be controlled separately		

Figure 7.4. Noncompliant Lighting Measures

Shell measures: Figure 7.5 shows the distribution of PV$ lost within individual shell measures.

- Although some measures occur less frequently (smaller peaks corresponding to measure counts), shell measures appear to have similar log PV$ lost savings distributions (similar shape and range of distributions).



Measure ID	Measure Name	Measure ID	Measure Name
5012	Roofs shall be insulated to meet CZ requirements	5042A	Windows shall meet U-factor requirements
5014	Low slope roofs in CZ 1-3 shall be cool roofs	5042B	Windows shall meet SHGC requirements
5018A	Above grade frame walls shall be insulated to meet CZ requirements	5043A	Skylights shall meet U-factor requirements
5018B	Above grade mass walls shall be insulated to meet CZ and density requirements	5043B	Skylights shall meet SHGC requirements
5023A	Exterior frame floors shall meet the insulation requirements	5056	Building shall meet continuous air barrier requirements
5023B	Exterior mass floors shall meet the minimum R-value or U-value by assembly type	5077	Stair and shaft vent leakage
5029B	Opaque rollup doors shall meet U-factor requirements	5083	Building entrances shall be protected with an enclosed vestibule
5034	Window-to-wall ratio shall meet maximum limits	5089	Fenestration orientation
5035	Skylight to roof ratio shall meet maximum limits	5042A	Windows shall meet U-factor requirements

Figure 7.5. Noncompliant Shell Measures

Receptacle controls measures: Figure 7.6 shows the log PV$ lost savings distribution for receptacle controls measures.

- There was only one measure in this category (9055pAS, receptacle controls).
- The PV$ lost savings associated with receptacle controls had a smaller range of PV$ lost savings than the measures in the HVAC, lighting, and shell categories.

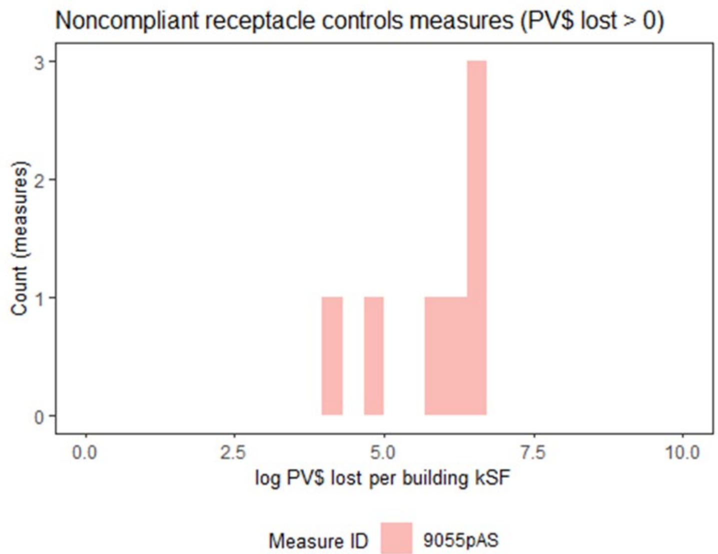


Figure 7.6. Noncompliant Receptacle Controls Measures

Conclusion: the log PV$ lost savings from both building types and all types of measures were in the same range and had similar distributions, indicating a model that included all building types and measures in all categories could be included in the same model. As described below, the differences were captured using independent variables in the regression.

7.3 Statistical Model

We hypothesized that using a statistical model would provide a way to improve precision by accounting for non-random variation in compliance and PV$ lost savings. This approach also retained information from all buildings and measures, explicitly modeling the effects of building type, climate region, and measure on PV$ lost savings without the "slicing and dicing" required by stratification in the traditional approach.

For comparison purposes, the traditional approach can be written as a statistical model where the dependent variable (i.e., PV$ lost savings) is modeled as a function of an overall mean β_0 and random error ϵ, where the terms are estimated within strata using a subset of the sample observations and then using them to calculate the estimates and their standard errors.

Traditional approach: *dependent variable* = $\beta_0 + \epsilon$

In a regression approach, the dependent variable is similarly modeled as a function of an overall mean (or within stratum mean) β_0 and random error ϵ, but with additional independent variables (x_i terms with $i=1,\ldots,k$) included in the model as well. The independent variables in this case, included building type, ASHRAE CZ, measure, and building conditioned ksf. In the regression analysis, the estimates of the β_0, β_1,…, β_k terms and their standard errors are estimated using all the sample observations.

Linear regression: *dependent variable* = $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \epsilon$

Specifically, we used the following linear regression model to model log PV$ lost savings as a function of log building conditioned ksf, ASHRAE CZ, building type, measure ID, and observed compliance.

log PV$ lost savings = β_0 + β_1 log(Building Conditioned ksf) + β_2 ASHRAE CZ + β_3 Building Type + β_4 Measure ID + β_5 compliance + ϵ

We found that the additional independent variables were significant (α=0.05) and that accounting for their effects on log PV$ lost savings indeed provided estimates with improved precision over the traditional approach. We also tested whether measure category, building fixed effects, interactions between building type and ASHRAE CZ, or interactions between building type and conditioned square footage were significant or resulted in better fitting models, but they did not, so we did not include these in the model.

7.3.1 Model Fitting

Model fitting is the process of estimating the model parameters (i.e., the β coefficients and their standard errors). We used *R* statistical software through the *RStudio* platform, both publicly available at no cost.[1,2] In particular, we used the *lm* function in the *stats* package to fit the linear regression model.

Table 7.3 lists the β estimates, standard errors, corresponding test statistics, and p-values. These estimates correspond to the effects of the independent variables on *log PV$ lost savings*. These results show that compliance, building kSF, ASHRAE CZ and building type independent variables were significant (α=0.05), and that although not every measure ID had a significant effect, many did and thus we retained them in the model.

[1] R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/. RStudio Team (2020).
[2] RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

Table 7.3. Linear Regression Model of PV$ Lost Savings: Parameter Estimates

Independent Variable	Estimated β	Std. Error	Statistic	p-value
(Intercept)	6.25	0.14	45.13	0.00
factor(compliance)1	-5.45	0.04	-151.85	0.00
log(Building_condit_kSF)	-0.09	0.01	-8.11	0.00
ASHRAE_CZ5A	0.02	0.03	0.80	0.42
Building_TypeRetail	0.04	0.03	1.36	0.18
Measure_ID5014	-0.01	0.15	-0.05	0.96
Measure_ID5018A	-0.30	0.12	-2.57	0.01
Measure_ID5018B	-0.05	0.15	-0.36	0.72
Measure_ID5023A	-4.14	0.79	-5.24	0.00
Measure_ID5023B	-1.39	0.79	-1.76	0.08
Measure_ID5029B	-0.24	0.18	-1.33	0.18
Measure_ID5034	-0.04	0.10	-0.41	0.68
Measure_ID5035	0.35	0.24	1.44	0.15
Measure_ID5042A	-0.32	0.10	-3.02	0.00
Measure_ID5042B	0.33	0.11	3.11	0.00
Measure_ID5043A	-0.19	0.31	-0.60	0.55
Measure_ID5043B	-0.22	0.31	-0.72	0.47
Measure_ID5056	0.04	0.12	0.37	0.71
Measure_ID5077	0.14	0.22	0.63	0.53
Measure_ID5083	0.23	0.13	1.76	0.08
Measure_ID5089	-1.18	0.19	-6.24	0.00
Measure_ID6005A	-0.06	0.11	-0.55	0.58
Measure_ID6005B	-0.07	0.19	-0.35	0.73
Measure_ID6005C	0.02	0.12	0.16	0.87
Measure_ID6005D	-0.03	0.23	-0.13	0.90
Measure_ID6005E	0.13	0.56	0.23	0.82
Measure_ID6007A	0.23	0.79	0.29	0.77
Measure_ID6017	-0.51	0.28	-1.86	0.06
Measure_ID6018	0.02	0.12	0.17	0.86
Measure_ID6019A	-0.17	0.12	-1.51	0.13
Measure_ID6019B	-0.08	0.12	-0.70	0.48
Measure_ID6019C	0.64	0.12	5.32	0.00
Measure_ID6023	-0.02	0.15	-0.16	0.87
Measure_ID6026p	0.20	0.46	0.42	0.67
Measure_ID6029	-0.10	0.19	-0.55	0.58
Measure_ID6030	0.25	0.31	0.81	0.42
Measure_ID6033p	0.03	0.56	0.05	0.96
Measure_ID6035	0.12	0.29	0.40	0.69
Measure_ID6042B	-1.50	0.23	-6.61	0.00
Measure_ID6045p	0.75	0.18	4.09	0.00
Measure_ID6046A	-0.30	0.23	-1.33	0.18
Measure_ID6051	0.04	0.79	0.05	0.96
Measure_ID6056	0.04	0.13	0.28	0.78
Measure_ID6066p	0.04	0.79	0.05	0.96
Measure_ID6070	0.17	0.79	0.21	0.83

Independent Variable	Estimated β	Std. Error	Statistic	p-value
Measure_ID6071	0.11	0.56	0.19	0.85
Measure_ID6089	0.18	0.56	0.32	0.75
Measure_ID6101	0.09	0.46	0.19	0.85
Measure_ID6108AS	0.27	0.79	0.34	0.73
Measure_ID6109pAS	0.21	0.56	0.37	0.71
Measure_ID6110pAS	0.19	0.56	0.34	0.74
Measure_ID7006	0.57	0.29	1.95	0.05
Measure_ID9003	0.08	0.11	0.78	0.44
Measure_ID9009	1.08	0.11	9.83	0.00
Measure_ID9011	-0.01	0.11	-0.09	0.93
Measure_ID9014A	-0.23	0.13	-1.74	0.08
Measure_ID9014B	0.43	0.21	2.04	0.04
Measure_ID9025	-0.22	0.24	-0.89	0.37
Measure_ID9029	0.33	0.40	0.83	0.41
Measure_ID9031	-0.03	0.11	-0.29	0.77
Measure_ID9037	0.14	0.11	1.33	0.18
Measure_ID9047	0.25	0.23	1.05	0.29
Measure_ID9048	0.00	0.11	-0.01	0.99
Measure_ID9054AS	-0.98	0.56	-1.74	0.08
Measure_ID9055pAS	0.37	0.26	1.42	0.16
Measure_ID9099p	0.43	0.15	2.81	0.01

7.3.2 Estimating Population Quantities

After fitting the regression model, we estimated population means using the estimated β coefficients, and the *x* values observed in the sample. We used the *predict.lm* function in R to obtain predicted responses and their standard errors in terms of log-transformed PV$ lost savings from the linear regression model. We reconciled differences between the sample and sample frame by applying weights to calculate means and 80% confidence intervals.

7.3.2.1 Sample Frame Review

We compared observed sample distributions to the sample frame (2016 Dodge New Construction data, which provides the best available data on counts and floor area in the population) to determine if the sample provided representative distributions of the overall population or if adjustments would be required.

Table 7.4 provides a summary of the sample and Table 7.5 shows them in the sample frame. We compared the building counts and floor area in each and developed the following assumptions based on our observations:

- Having no comparison point in the Dodge data, we assumed that the measure and compliance distributions observed in the sample were representative of their occurrence in the population.
- The proportion of buildings within building type and ASHRAE CZ subpopulations in the sample and sample frame were significantly different (α=0.05), so we applied weights to calculate overall mean PV$ lost savings estimates.

- Although average building conditioned ksf in the sample and sample frame were not equal, they were not significantly different (α=0.05). Therefore, we assumed the sample provided a representative distribution of building conditioned area and did not apply additional weighting.

Table 7.4. Means and Proportions in the Sample

Building Type	ASHRAE CZ	Measures	Proportion Measures	Buildings	Proportion Buildings	Average Conditioned ksf	Standard Error
Office	2A	873	0.28	61	0.27	17,647	3,112
Office	5A	893	0.28	61	0.27	36,127	7,403
Retail	2A	580	0.19	55	0.24	33,487	7,622
Retail	5A	756	0.24	52	0.23	18,817	4,514

Table 7.5. Means and Proportions in the Sample Frame

Building Type	ASHRAE CZ	Buildings	Proportion Buildings	Proportion Significantly Different from Sample (α=0.05)?	Average Conditioned ksf	Average Significantly Different from Sample (α=0.05)?
Office	2A	145	0.25	No	22,352	No
Office	5A	62	0.11	Yes	28,871	No
Retail	2A	295	0.50	Yes	23,519	No
Retail	5A	85	0.14	No	19,824	No

7.3.2.2 Implementation

To implement these assumptions, we started with the analysis data set as input to calculate predictions from the regression. This produced 3,102 predicted values, or one for each measure in the data set. Next, we aggregated these predicted values and their standard errors using a weighted average of the predicted values, with weights corresponding to the proportion of buildings in the sample frame in each building type-ASHRAE CZ category and calculated standard errors of the resulting average values accounting for the weights. We used the resulting standard errors to calculate 80% confidence intervals for each predicted log PV$ lost savings estimate. We re-ranked the measures based on these estimates.

Initially, we considered back transforming the mean log PV$ lost savings estimates to the non-logged scale. However, it is a well-known issue in statistical literature that such back-transformation results in highly biased mean estimates on the original scale. Although corrections for such bias exist, and we attempted some of the common correction methods, most studies found that the non-logged means remain biased and recommend keeping estimates on the log scale. The estimated means below, in terms of log PV$ lost savings should be used for ranking purposes only.

7.4 Results

Using the methods described above, we calculated results within each building type, each ASHRAE CZ, combination of building type and ASHRAE CZ, and by measure.

The results labeled as All Measures include PV$ lost savings from noncompliant and compliant measures (with PV$ lost savings equal to zero). The results labeled as Noncompliant Measures Only included the subset of noncompliant measures only (with PV$ lost savings greater than zero). The precision of the results for noncompliant measures tends to be better than for results including all measures because there is less variation between the PV$ lost savings in that subset of measures.

Building type: Table 7.6 provides PV$ lost savings estimates by building type with 80% confidence interval lower and upper bounds (CI80 LB and CI80 UB) and precision at 80% confidence (Precision 80).

Table 7.6. Building Type Mean PV$ Lost Savings

Building Type	All Measures					Noncompliant Measures Only				
	Measures	Estimate	CI80 LB	CI80 UB	Precision 80	Measures	Estimate	CI80 LB	CI80 UB	Precision 80
Office	1,766	1.53	1.39	1.67	9%	523	523	5.39	5.25	5.53
Retail	1,336	1.73	1.60	1.87	8%	430	430	5.43	5.30	5.56

Figure 7.7 shows these estimates and the 80% confidence intervals.

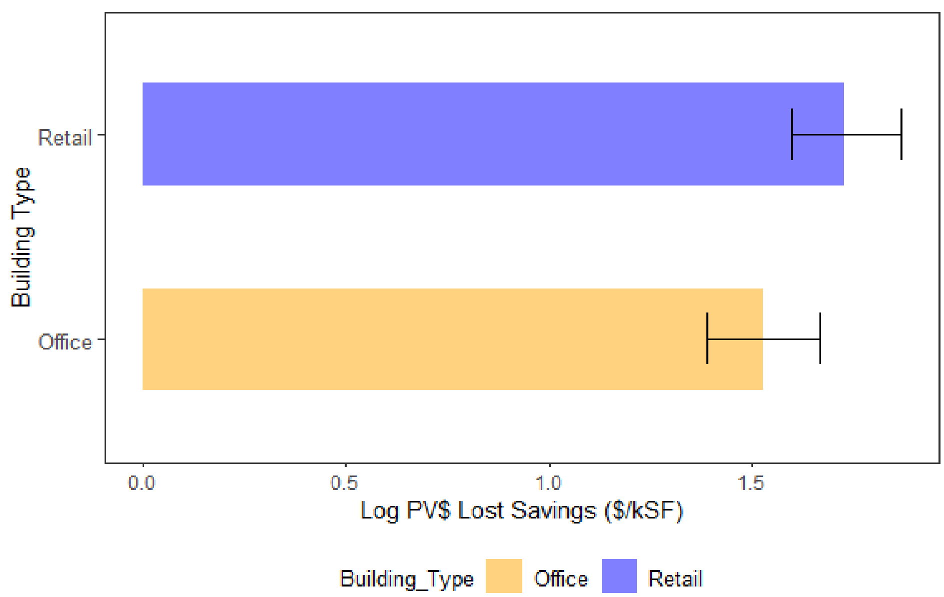


Figure 7.7. Overall Mean PV$ Lost Savings by Building Type with 80% Confidence Intervals

ASHRAE CZ: Table 7.7 provides PV$ lost savings estimates by ASHRAE CZ with 80% confidence interval lower and upper bounds (CI80 LB and CI80 UB) and precision at 80% confidence (Precision 80).

Table 7.7. ASHRAE CZ Mean PV$ Lost Savings

ASHRAE CZ	All Measures					Noncompliant Measures				
	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80
2A	1,453	1453	1.74	1.61	1.87	8%	485	485	5.39	5.26
5A	1,649	1649	1.51	1.36	1.66	10%	468	468	5.43	5.28

Figure 7.8 shows these estimates and their 80% confidence intervals.

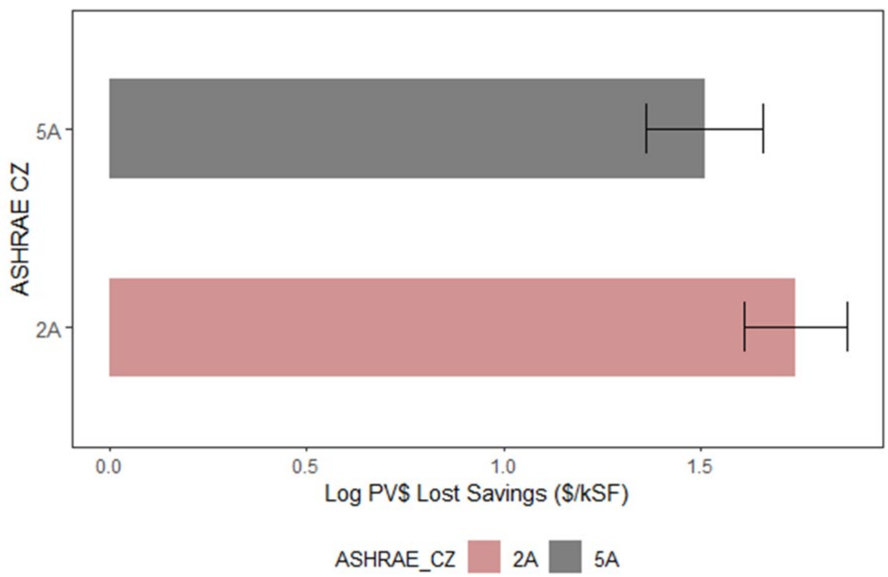


Figure 7.8. ASHRAE CZ Overall Mean PV$ Lost Savings with 80% Confidence Intervals

Building type and ASHRAE CZ: Table 7.8 provides PV$ lost savings estimates by building type and ASHRAE CZ with 80% confidence interval lower and upper bounds (CI80 LB and CI80 UB) and precision at 80% confidence (Precision 80).

Table 7.8. Mean PV$ Lost Savings by Building Type and ASHRAE CZ

Building Type	All Measures						Noncompliant Measures				
	ASHRAE CZ	Measure Count	Estimate	CI80 LB	CI80 UB	Precisio n 80	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80
Office	2A	873	1.66	1.53	1.79	8%	277	277	5.41	5.28	5.55
Office	5A	893	1.41	1.24	1.58	12%	246	246	5.36	5.20	5.52
Retail	2A	580	1.86	1.73	2.00	7%	208	208	5.35	5.22	5.48
Retail	5A	756	1.63	1.49	1.77	9%	222	222	5.51	5.37	5.64

Figure 7.9 shows these estimates and their 80% confidence intervals.

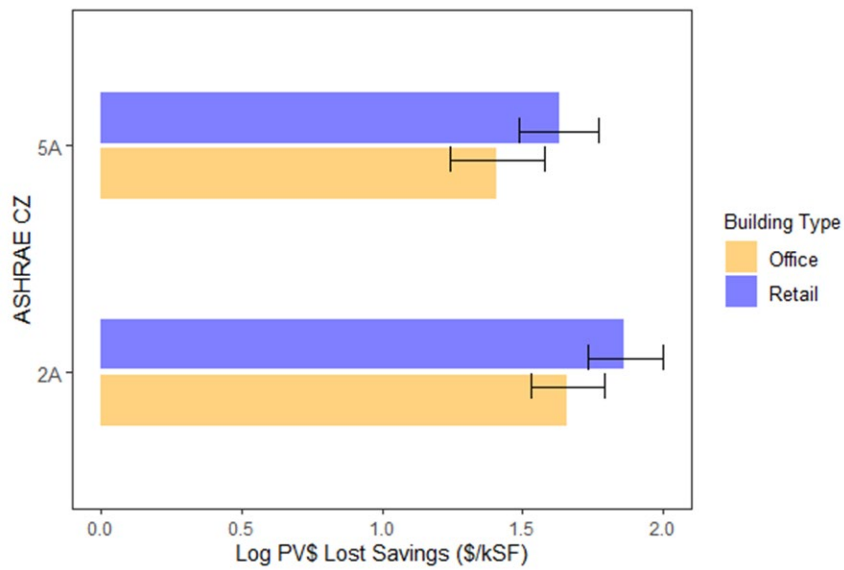


Figure 7.9. Estimated Mean PV$ Lost Savings by Building Type and ASHRAE CZ with 80% Confidence Intervals

Measure ID: Table 7.9 provides mean PV$ lost savings estimates by measure, ranked in order from highest to lowest overall mean PV$ lost savings, with 80% confidence intervals lower and upper bounds (CI80 LB and CI80 UB) and precision at 80% confidence (Precision 80). NA indicates there were no corresponding noncompliant measures in the sample and thus estimated means could not be calculated for the specific measure. Measures below the double-line had sample sizes less than ten, so those estimates are more uncertain.

Table 7.9. PV$ Lost Savings Estimates by Measure ID

Measure	All Measures					Noncompliant Measures Only				
	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80
9099p LightTest&Cx	39	5.08	4.92	5.25	3%	34	5.79	5.62	5.95	3%
6045p Commissioning	24	4.74	4.53	4.95	4%	18	6.11	5.90	6.31	3%
5042B WinSHGC	187	4.51	4.43	4.59	2%	147	5.68	5.60	5.76	1%
9055pAS PlugLoadCtrl	10	4.08	3.76	4.40	8%	7	5.72	5.40	6.03	6%
9014B DaylitHighBay	17	3.86	3.61	4.10	6%	11	5.79	5.54	6.03	4%
5042A WinUFactor	191	3.58	3.49	3.66	2%	140	5.03	4.95	5.11	2%
9014A DayLtCtrl	65	3.35	3.22	3.48	4%	44	5.11	4.98	5.24	3%
9009 AutoLtCtrl	135	3.32	3.22	3.41	3%	58	6.42	6.33	6.52	1%

Measure	All Measures					Noncompliant Measures Only				
	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80
5018A FrmWallIns	101	2.45	2.35	2.56	4%	53	5.05	4.94	5.16	2%
6019C NightFanCtrl	87	2.41	2.30	2.53	5%	30	5.99	5.87	6.11	2%
6029 DCV	22	2.25	2.03	2.47	10%	10	5.23	5.01	5.44	4%
6042B PipeIns	14	1.88	1.61	2.15	14%	9	3.84	3.57	4.11	7%
6056 Econ100Pct	73	1.80	1.67	1.92	7%	25	5.38	5.26	5.51	2%
6023 OptStart	45	1.46	1.31	1.62	11%	13	5.34	5.19	5.50	3%
5018B MassWallIns	44	1.44	1.29	1.60	11%	13	5.28	5.12	5.44	3%
5089 FenOrient	22	1.43	1.21	1.65	15%	11	4.16	3.94	4.37	5%
9047 AddRtlLPD	13	1.43	1.15	1.71	20%	3	5.63	5.34	5.91	5%
9011 OccSens	168	1.41	1.32	1.50	6%	47	5.34	5.25	5.43	2%
9003 ManLtCtl	156	1.34	1.25	1.43	7%	39	5.41	5.32	5.50	2%
5012 RoofIns	83	1.14	1.03	1.26	10%	19	5.35	5.23	5.47	2%
6019B SetbackCool	105	1.12	1.01	1.22	9%	25	5.26	5.15	5.37	2%
5083 Vest	66	1.12	0.99	1.25	11%	12	5.60	5.47	5.73	2%
5029B RollupDoorU	25	0.98	0.78	1.18	2%	6	5.16	4.95	5.36	4%
6019A SetbackHeat	105	0.87	0.76	0.97	12%	22	5.17	5.06	5.28	2%
5034 MaxWWR	214	0.87	0.79	0.95	9%	40	5.29	5.21	5.38	2%
5035 MaxSkyLtRoofR	12	0.69	0.40	0.98	42%	1	5.76	5.46	6.05	5%
9037 IntLPD	147	0.67	0.58	0.76	14%	17	5.48	5.39	5.58	2%
5014 CoolRoof	45	0.60	0.45	0.76	25%	6	5.33	5.17	5.48	3%
9031 ExtLtCtrl	170	0.57	0.48	0.65	15%	22	5.31	5.22	5.40	2%
6018 TempDeadband	103	0.55	0.45	0.66	19%	12	5.37	5.26	5.48	2%
6005A ACCoolingEff	138	0.46	0.37	0.55	20%	16	5.28	5.18	5.38	2%
9048 ExtLPD	158	0.41	0.32	0.50	21%	15	5.35	5.25	5.44	2%
5077 StrSftVentLkg	15	0.38	0.12	0.65	68%	1	5.55	5.28	5.81	5%
6046A FanPowerPkgAC	14	0.37	0.10	0.64	73%	2	5.02	4.75	5.30	5%
6005B HPEff	21	0.34	0.12	0.56	65%	2	5.25	5.02	5.48	4%
6005D BoilerEff	13	0.27	-0.01	0.55	106%	1	5.32	5.04	5.60	5%
9025 DispLtCtrl	12	0.16	-0.13	0.46	177%	1	5.11	4.82	5.41	6%
5056 CAB	85	0.14	0.02	0.25	83%	3	5.42	5.30	5.54	2%
6005C FurnaceEff	81	-0.09	-0.21	0.03	-130%	NA	NA	NA	NA	NA
5043B SkyLtSHGC	7	4.34	3.96	4.73	9%	6	5.13	4.75	5.51	7%

Measure	All Measures					Noncompliant Measures Only				
	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80	Measure Count	Estimate	CI80 LB	CI80 UB	Precision 80
5023B MassFloorIns	1	3.92	2.91	4.92	26%	1	3.92	2.91	4.92	26%
5043A SkyLtUFactor	7	2.82	2.44	3.21	14%	4	5.19	4.80	5.57	7%
9054AS GarageLtgCtrl	2	1.60	0.89	2.31	45%	1	4.32	3.61	5.04	16%
9029 NonvisLtCtrl	4	1.59	1.09	2.10	32%	1	5.66	5.16	6.17	9%
5023A FrmFloorIns	1	1.16	0.16	2.17	86%	1	1.16	0.16	2.17	86%
7006 SwhRecPiInsu	8	1.12	0.76	1.47	32%	1	5.87	5.52	6.23	6%
6030 ERVUse	7	0.95	0.56	1.33	40%	1	5.66	5.27	6.04	7%
6035 DuctLeakage	8	0.68	0.32	1.04	53%	1	5.52	5.16	5.88	6%
6108AS SZVAV	1	0.22	-0.78	1.23	453%	NA	NA	NA	NA	NA
6007A AirChillerEff	1	0.13	-0.88	1.13	792%	NA	NA	NA	NA	NA
6109pAS GarFanCtrl	2	0.06	-0.65	0.77	1216%	NA	NA	NA	NA	NA
6026p SnowIceCtrl	3	0.05	-0.53	0.63	1205%	NA	NA	NA	NA	NA
6110pAS ZoneIsolate	2	0.04	-0.67	0.75	1689%	NA	NA	NA	NA	NA
6089 WSHPvalve	2	0.04	-0.68	0.75	2022%	NA	NA	NA	NA	NA
6005E WSHPEff	2	0.04	-0.67	0.75	1634%	NA	NA	NA	NA	NA
6070 FanVSD	1	0.02	-0.98	1.03	4648%	NA	NA	NA	NA	NA
6017 HPSuppHeatCtrl	9	0.00	-0.34	0.33	-6778%	1	4.84	4.50	5.17	7%
6051 OutdoorHeat	1	-0.01	-1.01	1.00	-13156%	NA	NA	NA	NA	NA
6071 FanPresReset	2	-0.04	-0.75	0.67	-1879%	NA	NA	NA	NA	NA
6101 SATreset	3	-0.06	-0.64	0.52	-963%	NA	NA	NA	NA	NA
6033p DuctInsul	2	-0.07	-0.78	0.64	-1007%	NA	NA	NA	NA	NA
6066p WaterEconCap	1	-0.11	-1.12	0.89	-907%	NA	NA	NA	NA	NA

Figure 7.10 shows these estimates and their 80% confidence intervals. It indicates which five, 10, and 25 measures have the highest expected PV$ lost savings.

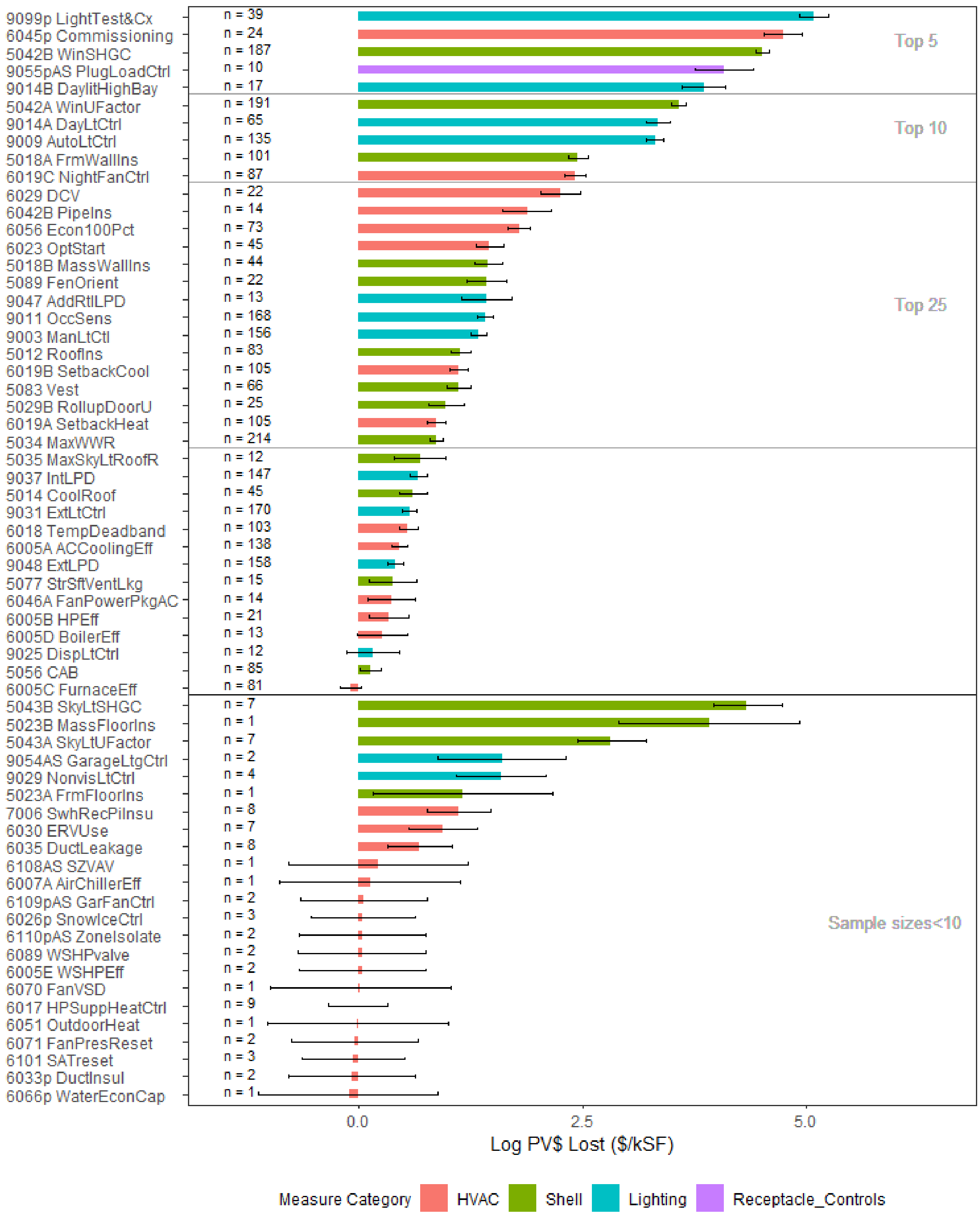


Figure 7.10. Measures Ranked by Mean Log PV$ Lost Savings with 80% Confidence Intervals

8.0 Conclusions

The project team visited 230 buildings, covering over 6 million square feet of commercial office and retail space, in climate zones 2A and 5A. The lost energy cost savings as found during the field study was $189 per thousand square feet, with present value of $2,868 per thousand square feet, on average across all the buildings. The present value lost savings of some outlier buildings exceeded $20,000 per thousand square feet. The actual lost savings are likely underestimated, as only 69% of the applicable measures could be field verified due to site visit timing.

Only four buildings had zero lost savings or were fully compliant with the energy code. Lighting controls and HVAC controls included some of the largest as-found lost energy cost savings.

Overall, the results show the lost savings are larger for retail buildings than office buildings, and the difference between the value for office and retail buildings in climate zone 5A is statistically significant at the 90% level.

One way to interpret these results is using the impact on the utility bills. This can be estimated by comparison with the energy cost intensity. This study found that 15% of the annual energy costs are recoverable with improved code compliance.

This project attempted to observe enough instances of measures and buildings to obtain statistical significance. However, the project failed to accomplish this for many measures, given the typical challenges of recruiting buildings, verified observability of any given measure in a single site visit, and the unknown quantity of any measure being constructed in the field. Therefore, the results provide directional rather than definitive quantitative guidance.

Screening could be used to eliminate measures that even at the worst case did not have a large impact. Measures with a low lost savings potential per verification hour could also be eliminated from future field studies if desired. With respect to field inspections, code officials should always verify measures with high worst case potential lost savings and those with high savings potential per verification hour. They could randomly check the rest. To achieve these goals, the sample size would need to be significantly increased.

Other potential opportunities for these studies include using them to document which energy efficiency measures and practices are most typical and preferred. One could baseline those technologies over time as the market changes and track the degree of market adoption of new technologies.

9.0 References

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Appendix A – Full List of Measures by Name, ID, Abbreviation, and Worst Case

Measure ID	Measure Name	Abbreviation	Worst Case
15007	Optional onsite renewable	OptRenewable	No option installed
5012	Roofs shall be insulated to meet CZ requirements	RoofIns	No insulation
5013	Skylight curbs shall be insulated	SkylCurbIns	No insulation
5014	Low slope roofs in CZ 1-3 shall be cool roofs	CoolRoof	Reflectance = 0.1
5018A	Above grade frame walls shall be insulated to meet CZ requirements	FrmWallIns	No insulation
5018B	Above grade mass walls shall be insulated to meet CZ and density requirements	MassWallIns	No insulation
5021p	Below grade wall insulation requirements and protection	UnGdWall	No insulation
5023A	Exterior frame floors shall meet the insulation requirements	FrmFloorIns	No insulation
5023B	Exterior mass floors shall meet the minimum R-value or U-value by assembly type	MassFloorIns	No insulation
5025	Slab-on-grade floors shall meet insulation requirements and be protected	SlabIns	No insulation
5029A	Opaque swing doors shall meet U-factor requirements	SwingDoorU	Uninsulated double layer metal door
5029B	Opaque rollup doors shall meet U-factor requirements	RollupDoorU	Uninsulated single layer metal door
5034	Window-to-wall ratio shall meet maximum limits	MaxWWR	~90% WWR
5035	Skylight to roof ratio shall meet maximum limits	MaxSkyLtRoofR	~7% SRR
5036	Daylighting control when required	DLCtrlHiWWR	No automatic daylighting controls
5038	For large, high-bay spaces total daylight zone under skylights at least 1/2 of floor area	DLCtrlHiBay	No automatic daylighting controls
5042A	Windows shall meet U-factor requirements	WinUFactor	Single pane, metal frame
5042B	Windows shall meet SHGC requirements	WinSHGC	Single pane, clear.
5043A	Skylights shall meet U-factor requirements	SkyLtUFactor	Single pane clear, metal frame
5043B	Skylights shall meet SHGC requirements	SkyLtSHGC	Clear, 1/8" glass

Measure ID	Measure Name	Abbreviation	Worst Case
5056	Building shall meet continuous air barrier requirements	CAB	3 x base leakage (3 cfm/ft2 exterior surface at 75Pa.)
5063	Recessed lighting shall be sealed, rated and labeled	AirtRecLtg	Unsealed recessed lights
5075	Fenestration assemblies shall meet air leakage requirements	WinLeak	Leaky windows 5x requirement (1cfm/ft window at 75 Pa)
5077	Stair and shaft vent leakage	StrSftVentLkg	Dampers always open, leaky doors
5082	Loading dock doors shall be equipped with weather seals	LdDkSl	No weather seals
5083	Building entrances shall be protected with an enclosed vestibule	Vest	No vestibule
5089	Fenestration orientation	FenOrient	All windows on E/W orientation
6004A	Equipment sizing requirement for PkgAC	EquipSizingPkgAC	Oversized by 250% for heating and 230% for cooling
6004B	Equipment sizing requirement for PkgVAVEleRe	EquipSizingPkgVAVEleRe	Oversized by 250% for heating and 230% for cooling
6005A	Packaged air conditioner efficiency	ACCoolingEff	Code efficiency when high performance tradeoff is used
6005B	Packaged heat pump efficiency	HPEff	Code efficiency when high performance tradeoff is used
6005C	Gas furnace efficiency	FurnaceEff	Code efficiency when high performance tradeoff is used
6005D	Boiler efficiency	BoilerEff	Code efficiency when high performance tradeoff is used
6005E	WSHP efficiency	WSHPEff	Code efficiency when high performance tradeoff is used
6007A	Air-cooled Chiller efficiency	AirChillerEff	7.65 EER
6007B	Water-cooled Chiller efficiency	WaterChillerEff	0.816 kW/Ton
6014	Thermostatic control is used for individual zones	TstatZone	1 Tstat per building
6016	Humidity control device for each humidity system	ActiveRHCtrl	No humidistat with constant subcooling and reheat
6017	Heat pump supplementary heat control	HPSuppHeatCtrl	OA lockout 70°F.Compressor lockout 35°F

Measure ID	Measure Name	Abbreviation	Worst Case
6018	Thermostat deadband requirement	TempDeadband	1°F (72/73)
6019A	Thermostat setback	SetbackCtrl	No setback
6019C	Night fan control	NightFanCtrl	Fan runs during unoccupied hours
6023	Optimal start controls	OptStart	No optimal start
6025	Damper control when space is unoccupied	OADamperCtrl	Gravity damper open during night cycle and optimum start
6026p	Snow and ice-melting system control	SnowIceCtrl	Runs during winter when OA <45°F
6029	Demand control ventilation	DCV	No DCV
6030	Energy recovery requirement	ERVUse	No ERV
6033p	Duct insulation requirement	DuctInsul	No duct insulation
6035	Duct leakage requirement	DuctLeakage	30% SA leakage
6042A	Hydronic Piping Insulation Requirement CHW	PipeIns	No insulation
6042B	Hydronic Piping Insulation Requirement HW	PipeIns	No insulation
6045p	Commissioning requirement	Commissioning	No commissioning
6046A	Fan power limit requirement for PkgAC	FanPowerPkgAC	150% of limit
6046B	Fan power limit requirement for VAV	FanPowerVAV	150% of limit
6051	Outdoor heating shall be radiant and controlled with occupancy sensor	OutdoorHeat	Unit heater runs continuously all winter
6056	Economizer supplies 100% design supply air	Econ100Pct	No economizer
6058	Economizers should have appropriate high-limit shutoff control and be integrated	EconHiLimit	55°F db high limit
6066P	Water economizer capacity meets requirements	WaterEconCap	No economizer
6067P	Pre-cooling coils have low pressure drop	WaterEconCoilDeltaP	25 ft.
6070	Multi-zone systems shall be VAV and fans with motors ≥threshold hp shall have variable speed, variable pitch axial, or fan demand reduction	FanVSD	Inlet vane control
6071	Static pressure sensors used to control VAV fans shall be properly placed	FanPresReset	No reset
6075P	Multiple boiler systems must include sequencing controls	BoilerLoadDistr	Uniform loading

Measure ID	Measure Name	Abbreviation	Worst Case
6082	WSHP shall have a deadband between heat rejection and addition	WSHPDeadband	5°F deadband
6089	Each WSHP in a system exceeding 10 hp pump shall have a two-position valve	WSHPvalve	Constant flow
6090	Hydronic systems > 300 MBH shall reset supply water temp or reduce system flow	HydRstTmpFlow	Constant flow, no reset
6091P	Multiple chiller shall reduce flow when a chiller is shut down	ChillerIsol	No isolation
6093P	Multiple Boilers plants shall reduce flow when a boiler is shut down	BoilerIsol	No isolation
6094	Tower Fans ≥ 75 hp shall have variable speed control	TwrFanVSD	Constant speed
6101	Multiple zone HVAC systems shall have supply-air temperature reset controls	SATreset	Fixed SA setpoint
6105p	Hot gas bypass only allowed with multiple steps of unloading or capacity modulation	HotGasBypass	Single compressor no staging
6106AS	Dynamic ventilation reset for MZ systems	DynVentReset	No reset
6108AS	Single zone VAV	SZVAV	Constant Volume
6109PAS	Parking garage fan controls	GarFanCtrl	Fans run full during occupied hours
6110PAS	Zone Isolation	ZoneIsolate	No isolation
7002A	Water heater efficiency, Gas	SwhGasEff	No worst case
7002B	Water heater efficiency, Electric	SwhEleEff	2009 IECC. EF= 0.93-0.00132V = 0.8772
7004	Outlet temperature of lavatories in public facility rest rooms is limited to 110°F (43°C)	LavTempLmt	120°F
7005p	SWH Heat Trap	SwhHeatTrap	No heat trap
7006	SWH Pipe Insulation - Recirculated	SwhRecPiInsu	No pipe insulation
7007	SWH Pipe Insulation - Non-recirculated	SwhNoRecPiInsu	No pipe insulation
7008	Circulating hot water system pumps and heat trace must have readily-accessible controls to turn them off when not needed	ShwRecCtrl	Pumps run continuously
9003	Manual lighting control	ManLtCtl	Lights on during all occupied hours
9009	Automatic time switch control	AutoLtCtrl	All lights on all night
9011	Occupancy sensor control	OccSens	No occupancy sensors where required

Measure ID	Measure Name	Abbreviation	Worst Case
9025	Display lighting control	DispLtCtrl	No separate controls. On during occupancy
9028	Task lighting control	TskLtCtrl	No separate controls. On during occupancy
9029	Lighting for nonvisual applications shall be controlled separately	NonvisLtCtrl	Runs continuously (24/7)
9031	Exterior lighting control	ExtLtCtrl	Always on
9034	Tandem wiring	TandWire	2 ballasts per fixture
9035	Exit sign maximum power	ExitSign	10 W/exit sign
9037	Interior lighting power allowance	IntLPD	200% code requirement
9047	Additional retail lighting power allowance	AddRtlLPD	7.5W/ft2
9048	Exterior lighting power allowance	ExtLPD	200% of allowance
9049pAS	Electric feeder and branch circuit maximum voltage drop	MaxVoltDrop	7% voltage drop
9054AS	Parking garage lighting controls	GarageLtgCtrl	Lighting on 100% during occupied hours and 30% during unoccupied
9055pAS	Plug load controls	PlugLoadCtrl	No controls

Appendix B – Statistical Significance Analysis

This appendix provides results of Cadmus' analysis of the compliance data in this study. Cadmus' primary role was to calculate the confidence and precision of the estimated average present value of lost energy savings per square foot due to non-compliance with multiple energy code measures.

To begin the statistical analysis, the present value of lost energy savings for each measure in each building was estimated and recorded as either $0 if the measure complied or a non-zero value based on the degree of non-compliance. The data were stratified by verification level, building type, and climate zone. Verification level is either verified (ver) or inferred (inf). Null records were removed, but records with a calculated value of $0 cost of noncompliance were retained. For each strata, the sum of the lost energy savings for each measure was calculated and divided by the sum of the conditioned floor of buildings to which the measure was applicable.

For various groupings of measures, the data were presented with the average present value of lost savings (PV$ lost/ft^2), standard error (SE) of the average lost savings, number of observations (count), statistical t-value (T-score), absolute precision, and relative precision of the estimated average as shown in Table A.1. All estimates were completed for a 90% confidence interval. The relative precision varied greatly at the measure level (22% to 612%) as the number of observations per measure and the amount of variation in the data per measure varied.

Cadmus also calculated the coefficient of variation (CV) for the estimated mean PV$ lost/ft^2 calculated for each group of observations. The CV is the ratio of the standard deviation of observations divided by the mean value. It is a measure of the dispersion of the observed values, with larger CVs indicating the values vary more around the mean.

B.1 Measures by Building Type and Climate Zone

This section presents the statistics for each measure by building type and climate zone. Only the verified (ver) measures are included here, while inferred (inf) measures are excluded. Relative precisions range from 4% to nearly 1,300%. The largest relative precisions are for measure groups where observation counts are small, typically less than 10.

Table B.1. Statistical Analysis by Measure, Building Type, and Climate Zone

Group	PV$ lost/sqft	SE	Count	T-score	Absolute Precision	Relative Precision
5012, Office, 2A, ver	$0.06	0.03444	20	1.7291	$0.06	108%
5012, Office, 5A, ver	$0.01	0.00627	24	1.7139	$0.01	175%
5012, Retail, 2A, ver	$0.14	0.08292	16	1.7531	$0.15	102%
5012, Retail, 5A, ver	$0.12	0.09065	22	1.7207	$0.16	132%
5014, Office, 2A, ver	$0.02	0.01286	18	1.7396	$0.02	128%
5014, Retail, 2A, ver	$0.02	0.01339	27	1.7056	$0.02	146%
5018A, Office, 2A, ver	$0.02	0.00992	26	1.7081	$0.02	96%
5018A, Office, 5A, ver	$0.11	0.05946	30	1.6991	$0.10	93%
5018A, Retail, 2A, ver	$0.07	0.03356	20	1.7291	$0.06	84%

Group	PV$ lost/sqft	SE	Count	T-score	Absolute Precision	Relative Precision
5018A, Retail, 5A, ver	$0.17	0.04847	25	1.7109	$0.08	49%
5018B, Office, 2A, ver	$0.07	0.06347	10	1.8331	$0.12	175%
5018B, Office, 5A, ver	$0.02	0.01264	11	1.8125	$0.02	126%
5018B, Retail, 2A, ver	$0.06	0.03336	19	1.7341	$0.06	93%
5018B, Retail, 5A, ver	$0.46	0.19014	3	2.9200	$0.56	120%
5023A, Office, 5A, ver	$0.00	0.00000	1	NA	NA	NA
5023B, Office, 5A, ver	$0.05	0.00000	1	NA	NA	NA
5029B, Retail, 2A, ver	$0.02	0.02482	9	1.8595	$0.05	237%
5029B, Retail, 5A, ver	$0.02	0.01742	11	1.8125	$0.03	160%
5034, Office, 2A, ver	$0.08	0.06754	53	1.6747	$0.11	135%
5034, Office, 5A, ver	$0.21	0.07584	60	1.6711	$0.13	59%
5034, Retail, 2A, ver	$0.04	0.00984	51	1.6759	$0.02	42%
5034, Retail, 5A, ver	$0.04	0.03181	49	1.6772	$0.05	140%
5035, Office, 2A, ver	$-	0.00000	2	6.3138	$0.00	NA
5035, Office, 5A, ver	$-	0.00000	2	6.3138	$0.00	NA
5035, Retail, 2A, ver	$-	0.00000	6	2.0150	$0.00	NA
5035, Retail, 5A, ver	$1.27	0.36817	2	6.3138	$2.32	184%
5042A, Office, 2A, ver	$0.03	0.00632	46	1.6794	$0.01	36%
5042A, Office, 5A, ver	$0.21	0.04725	51	1.6759	$0.08	38%
5042A, Retail, 2A, ver	$0.04	0.01154	45	1.6802	$0.02	53%
5042A, Retail, 5A, ver	$0.37	0.08185	48	1.6779	$0.14	38%
5042B, Office, 2A, ver	$0.43	0.08782	46	1.6794	$0.15	34%
5042B, Office, 5A, ver	$0.18	0.03891	49	1.6772	$0.07	35%
5042B, Retail, 2A, ver	$0.18	0.05627	45	1.6802	$0.09	52%
5042B, Retail, 5A, ver	$0.27	0.06093	46	1.6794	$0.10	38%
5043A, Office, 2A, ver	$0.04	0.00000	1	NA	NA	NA
5043A, Office, 5A, ver	$-	0.00000	2	6.3138	$0.00	NA
5043A, Retail, 2A, ver	$0.01	0.00530	2	6.3138	$0.03	624%
5043A, Retail, 5A, ver	$1.20	0.23084	2	6.3138	$1.46	121%
5043B, Office, 2A, ver	$0.13	0.00000	1	NA	NA	NA
5043B, Office, 5A, ver	$0.05	0.07153	2	6.3138	$0.45	974%
5043B, Retail, 2A, ver	$0.23	0.21259	2	6.3138	$1.34	577%
5043B, Retail, 5A, ver	$0.24	0.02634	2	6.3138	$0.17	68%
5056, Office, 5A, ver	$0.00	0.00027	33	1.6939	$0.00	179%
5056, Retail, 5A, ver	$0.01	0.00587	30	1.6991	$0.01	132%
5077, Office, 5A, ver	$-	0.00000	9	1.8595	$0.00	NA
5077, Retail, 5A, ver	$0.02	0.02911	3	2.9200	$0.08	378%
5083, Office, 5A, ver	$0.00	0.00240	33	1.6939	$0.00	96%
5083, Retail, 5A, ver	$0.33	0.19030	26	1.7081	$0.33	99%
5089, Office, 2A, ver	$0.01	0.00429	10	1.8331	$0.01	137%
5089, Office, 5A, ver	$0.01	0.00289	2	6.3138	$0.02	270%
5089, Retail, 2A, ver	$0.04	0.03039	10	1.8331	$0.06	126%
6005A, Office, 2A, ver	$0.04	0.01769	53	1.6747	$0.03	79%
6005A, Office, 5A, ver	$0.00	0.00214	41	1.6839	$0.00	157%
6005A, Retail, 2A, ver	$0.01	0.00978	22	1.7207	$0.02	124%
6005A, Retail, 5A, ver	$0.00	0.00196	21	1.7247	$0.00	171%

Group	PV$ lost/sqft	SE	Count	T-score	Absolute Precision	Relative Precision
6005B, Office, 2A, ver	$-	0.00000	14	1.7709	$0.00	NA
6005B, Office, 5A, ver	$0.00	0.00228	3	2.9200	$0.01	383%
6005B, Retail, 2A, ver	$0.10	0.14005	3	2.9200	$0.41	397%
6005C, Office, 2A, ver	$-	0.00000	25	1.7109	$0.00	NA
6005C, Office, 5A, ver	$-	0.00000	30	1.6991	$0.00	NA
6005C, Retail, 2A, ver	$-	0.00000	8	1.8946	$0.00	NA
6005C, Retail, 5A, ver	$-	0.00000	18	1.7396	$0.00	NA
6005D, Office, 2A, ver	$0.00	0.00107	4	2.3534	$0.00	299%
6005D, Office, 5A, ver	$-	0.00000	7	1.9432	$0.00	NA
6007A, Office, 2A, ver	$-	0.00000	1	NA	NA	NA
6017, Office, 2A, ver	$0.00	0.00018	5	2.1318	$0.00	231%
6017, Office, 5A, ver	$-	0.00000	1	NA	NA	NA
6017, Retail, 2A, ver	$-	0.00000	1	NA	NA	NA
6017, Retail, 5A, ver	$-	0.00000	2	6.3138	$0.00	NA
6018, Office, 2A, ver	$0.02	0.01194	36	1.6896	$0.02	86%
6018, Office, 5A, ver	$0.00	0.00248	27	1.7056	$0.00	158%
6018, Retail, 2A, ver	$0.08	0.05878	12	1.7959	$0.11	126%
6018, Retail, 5A, ver	$0.02	0.01478	28	1.7033	$0.03	137%
6019A, Office, 2A, ver	$0.01	0.00698	37	1.6883	$0.01	114%
6019A, Office, 5A, ver	$0.01	0.00678	25	1.7109	$0.01	123%
6019A, Retail, 2A, ver	$0.31	0.17417	15	1.7613	$0.31	100%
6019A, Retail, 5A, ver	$0.02	0.01723	28	1.7033	$0.03	118%
6019B, Office, 2A, ver	$0.02	0.00929	38	1.6871	$0.02	77%
6019B, Office, 5A, ver	$0.00	0.00321	24	1.7139	$0.01	130%
6019B, Retail, 2A, ver	$0.33	0.16911	15	1.7613	$0.30	90%
6019B, Retail, 5A, ver	$0.01	0.00936	28	1.7033	$0.02	130%
6019C, Office, 2A, ver	$0.42	0.17372	29	1.7011	$0.30	70%
6019C, Office, 5A, ver	$0.02	0.02321	26	1.7081	$0.04	176%
6019C, Retail, 2A, ver	$0.44	0.27098	11	1.8125	$0.49	112%
6019C, Retail, 5A, ver	$0.30	0.18407	20	1.7291	$0.32	107%
6023, Retail, 2A, ver	$0.07	0.04378	13	1.7823	$0.08	105%
6023, Retail, 5A, ver	$0.06	0.03400	19	1.7341	$0.06	92%
6026p, Office, 5A, ver	$-	0.00000	3	2.9200	$0.00	NA
6029, Office, 2A, ver	$0.01	0.00613	12	1.7959	$0.01	85%
6029, Office, 5A, ver	$0.07	0.04316	10	1.8331	$0.08	119%
6030, Retail, 5A, ver	$0.62	0.32966	4	2.3534	$0.78	125%
6033p, Office, 5A, ver	$-	0.00000	1	NA	NA	NA
6033p, Retail, 5A, ver	$-	0.00000	1	NA	NA	NA
6035, Office, 5A, ver	$-	0.00000	5	2.1318	$0.00	NA
6035, Retail, 2A, ver	$-	0.00000	1	NA	NA	NA
6035, Retail, 5A, ver	$0.08	0.12883	2	6.3138	$0.81	1015%
6042B, Office, 2A, ver	$0.00	0.00321	10	1.8331	$0.01	149%
6042B, Office, 5A, ver	$0.00	0.00553	4	2.3534	$0.01	308%
6045p, Office, 2A, ver	$0.30	0.23285	2	6.3138	$1.47	485%
6045p, Office, 5A, ver	$0.40	0.06912	10	1.8331	$0.13	31%
6045p, Retail, 2A, ver	$-	0.00000	1	NA	NA	NA

Group	PV$ lost/sqft	SE	Count	T-score	Absolute Precision	Relative Precision
6045p, Retail, 5A, ver	$0.29	0.19818	11	1.8125	$0.36	125%
6046A, Office, 2A, ver	$0.00	0.00321	7	1.9432	$0.01	164%
6046A, Office, 5A, ver	$0.00	0.00308	4	2.3534	$0.01	191%
6046A, Retail, 5A, ver	$-	0.00000	3	2.9200	$0.00	NA
6051, Retail, 5A, ver	$-	0.00000	1	NA	NA	NA
6056, Office, 2A, ver	$0.05	0.02112	26	1.7081	$0.04	72%
6056, Office, 5A, ver	$0.03	0.01500	23	1.7171	$0.03	88%
6056, Retail, 2A, ver	$0.03	0.02558	7	1.9432	$0.05	179%
6056, Retail, 5A, ver	$0.01	0.00668	17	1.7459	$0.01	101%
6066p, Office, 5A, ver	$-	0.00000	1	NA	NA	NA
6071, Office, 5A, ver	$-	0.00000	2	6.3138	$0.00	NA
6089, Office, 5A, ver	$-	0.00000	1	NA	NA	NA
6101, Office, 5A, ver	$-	0.00000	2	6.3138	$0.00	NA
6108AS, Retail, 5A, ver	$-	0.00000	1	NA	NA	NA
6109pAS, Office, 5A, ver	$-	0.00000	2	6.3138	$0.00	NA
6110pAS, Office, 5A, ver	$-	0.00000	1	NA	NA	NA
7006, Office, 2A, ver	$-	0.00000	3	2.9200	$0.00	NA
7006, Office, 5A, ver	$0.24	0.30391	5	2.1318	$0.65	272%
9003, Office, 2A, ver	$0.11	0.04190	53	1.6747	$0.07	65%
9003, Office, 5A, ver	$0.06	0.03210	52	1.6753	$0.05	97%
9009, Office, 2A, ver	$0.76	0.25722	41	1.6839	$0.43	57%
9009, Office, 5A, ver	$0.47	0.19909	32	1.6955	$0.34	71%
9009, Retail, 2A, ver	$0.76	0.48986	27	1.7056	$0.84	110%
9009, Retail, 5A, ver	$0.46	0.27196	34	1.6924	$0.46	101%
9011, Office, 2A, ver	$0.05	0.01845	56	1.6730	$0.03	64%
9011, Office, 5A, ver	$0.05	0.02692	43	1.6820	$0.05	99%
9011, Retail, 2A, ver	$0.01	0.00365	32	1.6955	$0.01	102%
9011, Retail, 5A, ver	$0.05	0.04064	37	1.6883	$0.07	126%
9014A, Office, 2A, ver	$0.20	0.11156	13	1.7823	$0.20	98%
9014A, Office, 5A, ver	$0.06	0.03193	26	1.7081	$0.05	86%
9014A, Retail, 2A, ver	$0.04	0.02762	12	1.7959	$0.05	137%
9014A, Retail, 5A, ver	$0.10	0.06605	13	1.7823	$0.12	117%
9014B, Office, 2A, ver	$0.35	0.03635	5	2.1318	$0.08	22%
9014B, Retail, 2A, ver	$0.03	0.02870	8	1.8946	$0.05	163%
9014B, Retail, 5A, ver	$0.27	0.08537	4	2.3534	$0.20	73%
9025, Retail, 2A, ver	$0.00	0.00161	4	2.3534	$0.00	348%
9025, Retail, 5A, ver	$-	0.00000	8	1.8946	$0.00	NA
9029, Retail, 2A, ver	$0.01	0.01150	3	2.9200	$0.03	494%
9029, Retail, 5A, ver	$-	0.00000	1	NA	NA	NA
9031, Office, 2A, ver	$0.03	0.01259	47	1.6787	$0.02	79%
9031, Office, 5A, ver	$0.01	0.00584	47	1.6787	$0.01	104%
9031, Retail, 2A, ver	$0.02	0.01312	34	1.6924	$0.02	96%
9031, Retail, 5A, ver	$0.00	0.00164	41	1.6839	$0.00	126%
9037, Office, 2A, ver	$0.11	0.07352	34	1.6924	$0.12	109%
9037, Office, 5A, ver	$0.06	0.06339	43	1.6820	$0.11	176%
9037, Retail, 2A, ver	$0.19	0.12480	31	1.6973	$0.21	114%

Group	PV$ lost/sqft	SE	Count	T-score	Absolute Precision	Relative Precision
9037, Retail, 5A, ver	$0.01	0.01340	39	1.6860	$0.02	174%
9047, Retail, 2A, ver	$0.07	0.02825	5	2.1318	$0.06	87%
9047, Retail, 5A, ver	$0.04	0.03717	8	1.8946	$0.07	186%
9048, Office, 2A, ver	$0.07	0.06147	33	1.6939	$0.10	139%
9048, Office, 5A, ver	$0.00	0.00006	50	1.6766	$0.00	175%
9048, Retail, 2A, ver	$0.03	0.01888	34	1.6924	$0.03	107%
9048, Retail, 5A, ver	$0.01	0.00714	41	1.6839	$0.01	140%
9054AS, Office, 5A, ver	$0.01	0.00822	2	6.3138	$0.05	612%
9055pAS, Office, 2A, ver	$0.27	0.14792	7	1.9432	$0.29	105%
9055pAS, Office, 5A, ver	$0.10	0.04324	2	6.3138	$0.27	270%
9099p, Office, 2A, ver	$0.29	0.01575	7	1.9432	$0.03	10%
9099p, Office, 5A, ver	$0.30	0.01566	15	1.7613	$0.03	9%
9099p, Retail, 2A, ver	$0.03	0.02834	4	2.3534	$0.07	258%
9099p, Retail, 5A, ver	$0.53	0.03329	13	1.7823	$0.06	11%

B.2 Measures by Building Type, Climate Zone, and Combined Verification Level

The following table shows the statistics for each measure by building type (office, retail) and climate zone (2A, 5A). The verified (ver) and inferred (inf) instances are combined. The relative precisions range from 11% to nearly 1,000%. The largest relative precisions are for measure groups where observation counts are small, typically less than 10. When measure statistics are analyzed in these same groups, but verified and inferred observations are combined, the relative precisions are similarly large.

Table B.2. Statistical Analysis by Measure, Building Type, Climate Zone, and Combined Verification Level

Group	PV$ lost/ft^2	SE	Count	T-score	Absolute Precision	Relative Precision
5012, Office, 2A	0.09	0.04220	57	1.67252	0.07	83%
5012, Office, 5A	0.02	0.01921	55	1.67356	0.03	141%
5012, Retail, 2A	0.08	0.03235	51	1.67591	0.05	66%
5012, Retail, 5A	0.08	0.06493	37	1.68830	0.11	131%
5014, Office, 2A	0.04	0.01398	37	1.68830	0.02	57%
5014, Retail, 2A	0.01	0.01032	45	1.68023	0.02	129%
5018A, Office, 2A	0.02	0.00720	45	1.68023	0.01	66%
5018A, Office, 5A	0.13	0.05259	54	1.67412	0.09	67%
5018A, Retail, 2A	0.07	0.02415	39	1.68595	0.04	62%
5018A, Retail, 5A	0.27	0.08548	35	1.69092	0.14	53%
5018B, Office, 2A	0.07	0.04057	25	1.71088	0.07	93%
5018B, Office, 5A	0.02	0.01076	15	1.76131	0.02	101%
5018B, Retail, 2A	0.06	0.02937	29	1.70113	0.05	90%
5018B, Retail, 5A	0.54	0.20487	9	1.85955	0.38	71%
5023A, Office, 5A	0.00	0.00000	1	NA	NA	NA

Group	PV$ lost/ft^2	SE	Count	T-score	Absolute Precision	Relative Precision
5023B, Office, 5A	0.36	0.13610	5	2.13185	0.29	80%
5029B, Retail, 2A	0.03	0.01569	12	1.79588	0.03	112%
5029B, Retail, 5A	0.02	0.01639	13	1.78229	0.03	155%
5034, Office, 2A	0.07	0.05926	55	1.67356	0.10	136%
5034, Office, 5A	0.21	0.07584	60	1.67109	0.13	59%
5034, Retail, 2A	0.04	0.00975	53	1.67469	0.02	42%
5034, Retail, 5A	0.04	0.03181	49	1.67722	0.05	140%
5035, Office, 2A	-	0.00000	2	6.31375	-	NA
5035, Office, 5A	-	0.00000	2	6.31375	-	NA
5035, Retail, 2A	-	0.00000	6	2.01505	-	NA
5035, Retail, 5A	1.27	0.36817	2	6.31375	2.32	184%
5042A, Office, 2A	0.02	0.00551	54	1.67412	0.01	39%
5042A, Office, 5A	0.16	0.04532	57	1.67252	0.08	49%
5042A, Retail, 2A	0.04	0.01130	49	1.67722	0.02	53%
5042A, Retail, 5A	0.36	0.08053	50	1.67655	0.14	37%
5042B, Office, 2A	0.41	0.08266	54	1.67412	0.14	34%
5042B, Office, 5A	0.14	0.03626	56	1.67303	0.06	42%
5042B, Retail, 2A	0.18	0.05502	49	1.67722	0.09	52%
5042B, Retail, 5A	0.27	0.06049	47	1.67866	0.10	38%
5043A, Office, 2A	0.04	0.01070	2	6.31375	0.07	193%
5043A, Office, 5A	-	0.00000	2	6.31375	-	NA
5043A, Retail, 2A	0.42	0.21033	6	2.01505	0.42	100%
5043A, Retail, 5A	1.20	0.23084	2	6.31375	1.46	121%
5043B, Office, 2A	0.11	0.03296	2	6.31375	0.21	193%
5043B, Office, 5A	0.05	0.07153	2	6.31375	0.45	974%
5043B, Retail, 2A	0.15	0.10769	6	2.01505	0.22	141%
5043B, Retail, 5A	0.24	0.02634	2	6.31375	0.17	68%
5056, Office, 5A	0.00	0.00020	56	1.67303	0.00	173%
5056, Retail, 5A	0.01	0.00484	46	1.67943	0.01	127%
5077, Office, 5A	0.01	0.00718	14	1.77093	0.01	177%
5077, Retail, 5A	0.01	0.00886	4	2.35336	0.02	329%
5083, Office, 5A	0.00	0.00239	34	1.69236	0.00	96%
5083, Retail, 5A	0.33	0.19030	26	1.70814	0.33	99%
5089, Office, 2A	0.04	0.02916	12	1.79588	0.05	145%
5089, Office, 5A	0.01	0.00289	2	6.31375	0.02	270%
5089, Retail, 2A	0.04	0.03039	10	1.83311	0.06	126%
6005A, Office, 2A	0.03	0.01540	60	1.67109	0.03	79%
6005A, Office, 5A	0.00	0.00148	55	1.67356	0.00	104%
6005A, Retail, 2A	0.03	0.01536	45	1.68023	0.03	75%
6005A, Retail, 5A	0.02	0.01362	33	1.69389	0.02	114%
6005B, Office, 2A	-	0.00000	16	1.75305	-	NA
6005B, Office, 5A	0.00	0.00228	3	2.91999	0.01	383%
6005B, Retail, 2A	0.03	0.01410	10	1.83311	0.03	79%
6005B, Retail, 5A	-	0.00000	2	6.31375	-	NA
6005C, Office, 2A	-	0.00000	27	1.70562	-	NA
6005C, Office, 5A	-	0.00000	36	1.68957	-	NA

Group	PV$ lost/ft^2	SE	Count	T-score	Absolute Precision	Relative Precision
6005C, Retail, 2A	-	0.00000	14	1.77093	-	NA
6005C, Retail, 5A	-	0.00000	28	1.70329	-	NA
6005D, Office, 2A	0.00	0.00093	6	2.01505	0.00	240%
6005D, Office, 5A	-	0.00000	10	1.83311	-	NA
6005E, Office, 5A	-	0.00000	1	NA	NA	NA
6007A, Office, 2A	-	0.00000	1	NA	NA	NA
6007B, Office, 5A	-	0.00000	2	6.31375	-	NA
6017, Office, 2A	0.00	0.00012	7	1.94318	0.00	207%
6017, Office, 5A	-	0.00000	3	2.91999	-	NA
6017, Retail, 2A	-	0.00000	2	6.31375	-	NA
6017, Retail, 5A	-	0.00000	3	2.91999	-	NA
6018, Office, 2A	0.02	0.01016	47	1.67866	0.02	80%
6018, Office, 5A	0.00	0.00112	39	1.68595	0.00	148%
6018, Retail, 2A	0.09	0.05144	24	1.71387	0.09	100%
6018, Retail, 5A	0.01	0.00716	37	1.68830	0.01	140%
6019A, Office, 2A	0.01	0.00541	51	1.67591	0.01	90%
6019A, Office, 5A	0.03	0.02200	39	1.68595	0.04	129%
6019A, Retail, 2A	0.14	0.06285	29	1.70113	0.11	75%
6019A, Retail, 5A	0.01	0.00749	38	1.68709	0.01	123%
6019B, Office, 2A	0.02	0.00802	52	1.67528	0.01	64%
6019B, Office, 5A	0.02	0.01448	39	1.68595	0.02	141%
6019B, Retail, 2A	0.15	0.07522	29	1.70113	0.13	86%
6019B, Retail, 5A	0.01	0.00404	38	1.68709	0.01	135%
6019C, Office, 2A	0.38	0.12413	50	1.67655	0.21	55%
6019C, Office, 5A	0.02	0.01428	44	1.68107	0.02	124%
6019C, Retail, 2A	0.54	0.30760	30	1.69913	0.52	97%
6019C, Retail, 5A	0.12	0.07829	33	1.69389	0.13	114%
6023, Retail, 2A	0.03	0.01712	30	1.69913	0.03	103%
6023, Retail, 5A	0.02	0.01656	32	1.69552	0.03	113%
6026p, Office, 5A	0.44	0.37101	5	2.13185	0.79	180%
6026p, Retail, 5A	-	0.00000	1	NA	NA	NA
6029, Office, 2A	0.02	0.00651	22	1.72074	0.01	60%
6029, Office, 5A	0.19	0.13210	16	1.75305	0.23	121%
6030, Retail, 2A	0.19	0.00000	1	NA	NA	NA
6030, Retail, 5A	0.20	0.20712	7	1.94318	0.40	197%
6033p, Office, 5A	-	0.00000	2	6.31375	-	NA
6033p, Retail, 2A	-	0.00000	1	NA	NA	NA
6033p, Retail, 5A	-	0.00000	1	NA	NA	NA
6035, Office, 5A	-	0.00000	6	2.01505	-	NA
6035, Retail, 2A	-	0.00000	1	NA	NA	NA
6035, Retail, 5A	0.08	0.12883	2	6.31375	0.81	1015%
6042B, Office, 2A	0.00	0.00201	12	1.79588	0.00	139%
6042B, Office, 5A	0.00	0.00250	6	2.01505	0.01	240%
6045p, Office, 2A	0.31	0.07225	29	1.70113	0.12	40%
6045p, Office, 5A	0.47	0.02966	18	1.73961	0.05	11%
6045p, Retail, 2A	0.22	0.10948	24	1.71387	0.19	87%

Group	PV$ lost/ft^2	SE	Count	T-score	Absolute Precision	Relative Precision
6045p, Retail, 5A	0.31	0.16670	16	1.75305	0.29	94%
6046A, Office, 2A	0.14	0.12601	12	1.79588	0.23	165%
6046A, Office, 5A	0.52	0.40011	10	1.83311	0.73	142%
6046A, Retail, 2A	0.02	0.01611	10	1.83311	0.03	124%
6046A, Retail, 5A	-	0.00000	5	2.13185	-	NA
6046B, Office, 2A	-	0.00000	1	NA	NA	NA
6046B, Office, 5A	-	0.00000	4	2.35336	-	NA
6051, Retail, 5A	-	0.00000	2	6.31375	-	NA
6056, Office, 2A	0.04	0.01507	40	1.68488	0.03	66%
6056, Office, 5A	0.02	0.00726	40	1.68488	0.01	66%
6056, Retail, 2A	0.00	0.00156	23	1.71714	0.00	169%
6056, Retail, 5A	0.01	0.00347	27	1.70562	0.01	97%
6066p, Office, 5A	-	0.00000	1	NA	NA	NA
6070, Office, 5A	0.02	0.02313	4	2.35336	0.05	241%
6071, Office, 2A	-	0.00000	2	6.31375	-	NA
6071, Office, 5A	0.08	0.07376	8	1.89458	0.14	174%
6089, Office, 5A	-	0.00000	1	NA	NA	NA
6091p, Office, 5A	-	0.00000	2	6.31375	-	NA
6101, Office, 2A	-	0.00000	2	6.31375	-	NA
6101, Office, 5A	-	0.00000	7	1.94318	-	NA
6106AS, Office, 2A	-	0.00000	2	6.31375	-	NA
6106AS, Office, 5A	-	0.00000	5	2.13185	-	NA
6108AS, Office, 5A	-	0.00000	2	6.31375	-	NA
6108AS, Retail, 5A	-	0.00000	1	NA	NA	NA
6109pAS, Office, 5A	0.05	0.02861	3	2.91999	0.08	176%
6110pAS, Office, 2A	-	0.00000	1	NA	NA	NA
6110pAS, Office, 5A	0.01	0.00765	3	2.91999	0.02	162%
7006, Office, 2A	-	0.00000	3	2.91999	-	NA
7006, Office, 5A	0.15	0.17333	7	1.94318	0.34	218%
9003, Office, 2A	0.11	0.04064	57	1.67252	0.07	65%
9003, Office, 5A	0.04	0.02504	57	1.67252	0.04	96%
9009, Office, 2A	0.68	0.22099	48	1.67793	0.37	55%
9009, Office, 5A	0.33	0.13295	41	1.68385	0.22	68%
9009, Retail, 2A	0.78	0.41501	39	1.68595	0.70	90%
9009, Retail, 5A	0.52	0.27623	38	1.68709	0.47	90%
9011, Office, 2A	0.04	0.01540	61	1.67065	0.03	63%
9011, Office, 5A	0.03	0.01884	49	1.67722	0.03	97%
9011, Retail, 2A	0.01	0.00728	41	1.68385	0.01	98%
9011, Retail, 5A	0.05	0.03998	39	1.68595	0.07	123%
9014A, Office, 2A	0.13	0.07599	17	1.74588	0.13	101%
9014A, Office, 5A	0.04	0.02046	32	1.69552	0.03	78%
9014A, Retail, 2A	0.02	0.01375	22	1.72074	0.02	103%
9014A, Retail, 5A	0.06	0.04130	15	1.76131	0.07	129%
9014B, Office, 2A	0.38	0.04468	6	2.01505	0.09	24%
9014B, Retail, 2A	0.03	0.02870	8	1.89458	0.05	163%
9014B, Retail, 5A	0.27	0.08537	4	2.35336	0.20	73%

Group	PV$ lost/ft²	SE	Count	T-score	Absolute Precision	Relative Precision
9025, Retail, 2A	0.00	0.00455	6	2.01505	0.01	207%
9025, Retail, 5A	-	0.00000	10	1.83311	-	NA
9029, Retail, 2A	0.03	0.02684	5	2.13185	0.06	220%
9029, Retail, 5A	-	0.00000	2	6.31375	-	NA
9031, Office, 2A	0.02	0.01022	52	1.67528	0.02	79%
9031, Office, 5A	0.01	0.00506	56	1.67303	0.01	103%
9031, Retail, 2A	0.14	0.12828	46	1.67943	0.22	152%
9031, Retail, 5A	0.01	0.00554	45	1.68023	0.01	131%
9037, Office, 2A	0.08	0.03898	58	1.67203	0.07	81%
9037, Office, 5A	0.03	0.03220	52	1.67528	0.05	173%
9037, Retail, 2A	0.24	0.13852	42	1.68288	0.23	96%
9037, Retail, 5A	0.01	0.00658	46	1.67943	0.01	176%
9047, Retail, 2A	0.05	0.03005	7	1.94318	0.06	108%
9047, Retail, 5A	0.04	0.03717	8	1.89458	0.07	186%
9048, Office, 2A	0.06	0.04193	49	1.67722	0.07	118%
9048, Office, 5A	0.00	0.00035	55	1.67356	0.00	147%
9048, Retail, 2A	0.04	0.02095	45	1.68023	0.04	81%
9048, Retail, 5A	0.01	0.00665	42	1.68288	0.01	139%
9054AS, Office, 5A	0.01	0.00822	2	6.31375	0.05	612%
9055pAS, Office, 2A	0.44	0.12149	11	1.81246	0.22	50%
9055pAS, Office, 5A	0.10	0.04324	2	6.31375	0.27	270%
9099p, Office, 2A	0.14	0.03679	49	1.67722	0.06	45%
9099p, Office, 5A	0.28	0.02353	25	1.71088	0.04	14%
9099p, Retail, 2A	0.19	0.07279	37	1.68830	0.12	66%
9099p, Retail, 5A	0.41	0.09401	20	1.72913	0.16	40%

B.3 Estimated Required Sample Sizes by Measure

The table below shows the estimated sample sizes by measure for future studies seeking statistical significance at 80% confidence and 20% precision. Only the verified measures are included in the estimate, while inferred measures are excluded. Entries of “NA” result from too few observations to calculate the sample size. These results show that any future projects using this approach will require substantially more resources to achieve statistical significance.

Future studies that want to achieve statistical significance at the measure level can refer to this table for guidance. The results will of course vary with future studies. This table provides forward guidance, but future studies need to verify the precision they actually achieve.

It is important to appreciate the iterative nature of the statistical significance calculations. One doesn’t know which measures and how many instances will show up until they’ve already recruited a site, reviewed the plans, and go onsite. Thus, the sample sizes by building type and climate zone are more helpful than sample sizes by measure during project planning, budgeting, and recruiting sites. It appears that you may need a particular number of observations of each measure, but you really won’t know if that is enough until you are done (or almost done) with data analysis. The number and type of measures at each site will be unknown until you collect site-specific information. Thus, planning for the number of measures is not a direct function of the number of sites or vice versa. Finally, upon completion of the future study, the team should calculate the new CVs based on the actual measure count and results of that study to determine the precision achieved.

Table B.3. Estimated Required Sample Sizes for Future Studies Seeking Statistical Significance

ID	Description	Sample size, verified only
5012	Roofs shall be insulated to meet CZ requirements	882
5014	Low slope roofs in CZ 1-3 shall be cool roofs	766
5018A	Above grade frame walls shall be insulated to meet CZ requirements	342
5018B	Above grade mass walls shall be insulated to meet CZ and density requirements	298
5023A	Exterior frame floors shall meet the insulation requirements	NA
5023B	Exterior mass floors shall meet the minimum R-value or U-value by assembly type	NA
5029B	Opaque rollup doors shall meet U-factor requirements	420
5034	Window-to-wall ratio shall meet maximum limits	894
5035	Skylight to roof ratio shall meet maximum limits	451
5042A	Windows shall meet U-factor requirements	286
5042B	Windows shall meet SHGC requirements	137
5043A	Skylights shall meet U-factor requirements	165
5043B	Skylights shall meet SHGC requirements	34
5056	Building shall meet continuous air barrier requirements	1291
5077	Stair and shaft vent leakage	601
5083	Building entrances shall be protected with an enclosed vestibule	771
5089	Fenestration orientation	364
6005A	Packaged air conditioner efficiency	934
6005B	Packaged heat pump efficiency	935
6005C	Gas furnace efficiency	NA
6005D	Boiler efficiency	537
6007A	Air-cooled Chiller efficiency	NA
6017	Heat pump supplementary heat control	515
6018	Thermostat deadband requirement	595
6019A	Thermostat heating setback	1888
6019B	Thermostat cooling setback	1741
6019C	Night fan control	332
6023	Optimal start controls	211
6026p	Snow and ice-melting system control	NA
6029	Demand control ventilation	282
6030	Energy recovery requirement	46
6033p	Duct insulation requirement	NA
6035	Duct leakage requirement	435
6042B	Hydronic Piping Insulation Requirement HW	378
6045p	Commissioning requirement	107
6046A	Fan power limit requirement for PkgAC	196

6051	Outdoor heating shall be radiant and controlled with occupancy sensor	NA
6056	Economizer supplies 100% design supply air	259
6066p	Water economizer capacity meets requirements	NA
6070	Multi-zone systems shall be VAV and fans with motors ≥threshold hp shall have variable speed, variable pitch axial, or fan demand reduction	NA
6071	Static pressure sensors used to control VAV fans shall be properly placed	NA
6089	Each WSHP in a system exceeding 10 hp pump shall have a two-position valve	NA
6101	Multiple zone HVAC systems shall have supply-air temperature reset controls	NA
6108AS	Single zone VAV	NA
6109pAS	Parking garage fan controls	NA
6110pAS	Zone Isolation	NA
7006	SWH Pipe Insulation - Recirculated	435
9003	Manual lighting control	580
9009	Automatic time switch control	463
9011	Occupancy sensor control	748
9014A	Daylighting control	281
9014B	For large, high-bay spaces total daylight zone under skylights at least 1/2 of floor area	130
9025	Display lighting control	670
9029	Lighting for nonvisual applications shall be controlled separately	380
9031	Exterior lighting control	661
9037	Interior lighting power allowance	1513
9047	Additional retail lighting power allowance	263
9048	Exterior lighting power allowance	1630
9054AS	Parking garage lighting controls	77
9055pAS	Plug load controls	51
9099p	Lighting Testing or Commissioning	133

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