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Reducing Transaction Costs for Energy Efficiency Investments and Analysis of Economic Risk Associated With Building Performance Uncertainties

Small Buildings and Small Portfolios Program

Rois Langner, Bob Hendron, and Eric Bonnema

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Technical Report
NREL/TP-5500-60976
August 2014

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Prepared under Task No. BE4C.8101

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Nomenclature

AEDG	Advanced Energy Design Guide
AERG	Advanced Energy Retrofit Guide
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CBECS	Commercial Buildings Energy Consumption Survey
COP	coefficient of performance
DOE	U.S. Department of Energy
EEM	energy efficiency measure
EER	energy efficiency ratio
EIA	U.S. Energy Information Administration
EUI	energy use intensity
GSA	General Services Administration
HVAC	heating, ventilating, and air conditioning
IEA	International Energy Agency
LBNL	Lawrence Berkeley National Laboratory
LHS	Latin Hypercube Sampling
LPD	lighting power density
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
PGL	Preservation Green Lab
PSZ-AC	packaged single zone air conditioner
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
SEER	seasonal energy efficiency ratio
SBSP	Small Buildings and Small Portfolios
TSD	Technical Support Document

Terms

Cost Effective: A net positive cash flow, meaning that the annual energy cost savings is greater than the annual payment of an energy efficiency investment.

Energy Cost Savings: A reduction in utility bills resulting from an investment in energy efficiency.

Energy Performance Guarantee: A guarantee from an energy service company or contractor ensuring that a certain level of energy savings is achieved.

Energy Savings Threshold: The minimum desired energy savings that a building owner or evaluator expects to achieve cost effectively.

Energy Service Company: A business that provides a wide range of energy saving services to a building owner.

Energy Use Intensity: Normalized whole-building energy use by building square footage. EUI is represented in the units $kBtu/ft^2/year$.

Full Initial Costs: The total costs for an energy efficiency building improvement.

Incremental Costs: The additional cost of an efficiency improvement that goes beyond the cost of a code-minimum system.

Major Renovation: A comprehensive building renovation that includes an overhaul of the major building systems.

Net Cash Flow: The difference between the expected annual energy cost savings and the total first year cost for an energy efficiency building upgrade.

Net Initial Costs: Costs for energy efficiency building improvements that include relative first costs and incremental costs together.

Split Incentive: A dynamic between a building owner and a tenant where the energy savings benefits may not impact the person who pays for the transaction.

Service Provider: A trade ally or a contractor hired to implement a building improvement.

Transaction Costs: All costs related to an energy efficiency building improvement, including a building energy audit, time spent researching energy efficiency improvements, etc.

Executive Summary

The small buildings and small portfolios (SBSP) sector faces barriers that inhibit SBSP owners from adopting energy efficiency solutions. This pilot project focused on overcoming two of the largest barriers to financing energy efficiency upgrades in small buildings: disproportionately high transaction costs and unknown or unacceptable risk. Solutions to these barriers can often be at odds, because inexpensive turnkey solutions are often not sufficiently tailored to the unique circumstances of each building, reducing confidence that the expected energy savings will be achieved. To address these barriers, NREL worked with two lead partners, Michigan Saves and Energi Insurance Services, to develop technical solutions that provide a quick and easy process to encourage energy efficiency investments while managing risk.

The pilot project included two stages: the first stage focused on reducing transaction costs, and the second stage focused on reducing performance risk. In the first stage, NREL worked with the nonprofit organization, Michigan Saves, to analyze the effects of 11 energy efficiency measures (EEMs) on 81 baseline small office building models, using the OpenStudio energy modeling software, in Holland, Michigan (climate zone 5A). The results of this analysis (totaling more than 30,000 cases) are summarized in a simple spreadsheet tool, called the EEM Selection & Cost Evaluation Tool (http://www.nrel.gov/buildings/docs/2014_eemselection_costevaltool_smoffice.xlsm), which enables users to easily find low-risk small office EEM packages that meet a particular energy savings threshold and are likely to be cost effective. Snapshots of the tool can be found in Appendix A. In summary, the spreadsheet tool displays:

- More than **1,500** EEM package options that are expected to achieve **20%** energy savings cost effectively, for projects where the EEM package is part of a major renovation
- Approximately **30** EEM package options that achieve greater than **15%** energy savings cost effectively, for projects that are not planning major renovations
- More than **150** EEM package options that achieve greater than **10%** energy savings cost effectively, for projects that are not planning major renovations
- Energy and cost savings predictions for more than **30,000** EEM/baseline combinations.

If a low-risk EEM package is identified and recommended for a particular building, it should be noted that the investment may still present some uncertainty. To increase the chances of achieving the estimated savings, a number of risk mitigation strategies are recommended to control and optimize building operation in a manner that mitigates performance risk. The recommended strategies include policies and controls to better manage building operation, maximizing occupant density to reduce the need to condition and power unused office space, and retrocommissioning/recommissioning to ensure that building equipment is operating at its maximum efficiency. These strategies are described in detail throughout the report and summarized in Appendix B.

NREL also looked at the energy savings effects of individual EEMs. The results, displayed in Appendix C, show the effects of individual EEMs on building energy use averaged over all the energy models, averaged for stand-alone buildings and buildings adjacent to other buildings, and averaged for each heating, ventilation, and air-conditioning (HVAC) system type considered in the analysis. The key trends of this analysis include:

- Lighting, daylighting controls, and plug load EEMs have the greatest effect on reducing small office building energy use.
- Occupancy sensors also show strong energy savings in most of the small office building models.
- Reducing building leakage is highly impactful in older buildings, primarily pre-1980 vintages.
- Upgrading to high-efficiency windows has the least impact on building energy use.
- Upgrades of buildings with existing packaged terminal air-conditioner systems tend to see higher energy savings than the other HVAC system types considered in this analysis.

In the second stage of the pilot project, NREL worked with the energy insurance company, Energi, to quantify performance risk and the uncertainty in cash flow associated with EEM packages that are designed and installed correctly. The purpose of this analysis was to quantify the effects of uncontrollable uncertainties that go beyond typical performance guarantees. The uncertainties include variations in weather, occupant behavior, fuel escalation rates, and quality of preventative maintenance. To quantify performance risk associated with these uncertainties, NREL used the software R to generate a random sample for the key input variables according to a probability distribution that were applied to a subset of the energy models analyzed in the first stage. The key findings include calculated "buffers" that owners and lenders can apply to projected energy cost savings (defined as the reduction in utility bills resulting from an investment in energy efficiency), in an effort to control performance risk to an acceptable level. In summary, the following observations were made:

- Assuming that measures are designed and installed correctly, and that the building does not implement risk mitigation strategies to optimize building operation, we can be 95% confident that the energy cost savings will exceed **66%** of the expected value over a 1-year time period.
- Over a longer time period, variations in energy savings lessen when averaged over multiple years and results improve. For a 3-year time period, we can be 95% confident that the energy cost savings will exceed **80%** of the expected value. For a 5-year time period, we can be 95% confident that the energy cost savings will exceed **85%** of the expected value.
- For buildings that implement risk mitigation strategies to optimize building operation, we again see improved results. In this case, it should be noted that NREL reduced the range of input values for performance risk variables related to occupant behavior by 50%, to show a correlation between more stringent building operation and energy cost savings. The results show that we can be 95% confident that the energy cost savings will exceed **81%** of the expected value over a 1-year time period.
- Looking at 3- and 5-year projections for projects that implement risk mitigation strategies, we see the least performance risk. For a 3-year time period, we can be

95% confident that the energy cost savings will exceed **89%** of the expected value. For a 5-year time period, we can be 95% confident that the energy cost savings will exceed **91%** of the expected value.

NREL also looked at the effects of individual performance risk variables on energy cost savings. This study shows that the greatest uncertainties associated with the performance risk variables are due to fluctuations in occupant density, control of heating and cooling temperature set points that go beyond recommended bounds during occupied hours, and plug loads left on after working hours. Lights being left on after work hours and effects of weather have similar uncertainty ranges, but have lesser effects than the other variables that were analyzed.

In summary, this pilot project enabled NREL to identify numerous low-risk EEM packages that are likely to be cost effective in small office buildings in Michigan. To further reduce the risk in each investment, we strongly recommend that owners install controls for building equipment, enforce policies surrounding building energy management, optimize space utilization to reduce the amount of energy used to condition unoccupied space, and use retrocommissioning to ensure that the building equipment is operating at its maximum efficiency.

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1 Introduction

A number of barriers have been reported that inhibit small business and small portfolio (SBSP) owners from adopting energy efficiency solutions (Langner et al. 2013). The largest of these barriers include:

- Limited capital
- Higher transaction costs relative to energy cost savings
- Lack of time to research and implement energy efficiency solutions
- Split incentive obstacles between owners and tenants
- Lack of available sector-specific resources and technologies.

In an effort to help overcome some of these barriers and encourage energy efficiency investments within the SBSP sector, the National Renewable Energy Laboratory (NREL) worked with two pilot partners to develop a quick and easy process to determine appropriate energy efficiency solutions, reduce transaction costs, provide greater access to capital, and manage the risks associated with the investment.

As part of the first stage of this pilot project, NREL focused on overcoming the disproportionately high transaction costs that the SBSP sector faces. To address this barrier, NREL worked with Michigan Saves, a nonprofit dedicated to making energy improvements easier for Michigan energy consumers, to develop low-risk and cost-effective energy efficiency measure (EEM) packages that achieve 20% energy savings for one specific small building type. The team chose to focus the pilot project efforts on small commercial office buildings in Holland, Michigan (defined as climate zone 5A by ASHRAE). EEM packages developed as part of the pilot project will be pre-approved by Michigan Saves and its principal lender, allowing small commercial office building owners who meet a small number of specified criteria to obtain funding with minimal paperwork and without a detailed energy audit.

The second stage of the project addressed quantification of performance risk, which can deter building owners and lenders from investing in energy efficiency projects. For a retrofit project that receives a detailed energy audit, much of the performance risk can be borne by an energy insurance company or performance contractor, where the service provider or energy service company guarantees energy savings to the building owner and the insurance policy protects the service provider. However, not all risk to the owner is covered by a typical performance guarantee or energy insurance policy, both of which incorporate certain assumptions about how the building will be operated and how the savings will be verified. If these assumptions prove incorrect for reasons outside the service provider's control, and the owner's utility bills thus decreases by less than the expected amount, the cash flow available to the building owner to pay off the loan may be jeopardized, creating a risk for the owner and lender. As part of the second stage of this pilot project, NREL worked with the energy insurance company, Energi, to quantify the uncertainty in building energy costs caused by performance risks that go beyond typical performance guarantees. Performance risks considered in this analysis are associated with variations in weather conditions, operating conditions, utility rates, and quality of preventative maintenance. Using a sample of the pre-approved, cost-effective EEM packages for commercial office buildings up to 25,000 ft^2 (developed as part of the first stage of this project with Michigan Saves), NREL quantified the uncertainty in cash flow associated with EEM packages that are designed and installed correctly to allow owners and lenders to estimate a "buffer" needed to control performance risk to an acceptable level. In use, the predicted energy cost savings for a particular project should be multiplied by the buffers to calculate a de-rated savings, with higher confidence and certainty that the savings will actually be achieved. Table 1 categorizes the major sources of performance risk as those that are and are not typically covered by a performance guarantee.

Table 1. Major Sources of Performance Risk That Are and Are Not Typically Covered by a Performance Guarantee

Sources of Uncertainty Typically Covered by a Performance Guarantee (Not Addressed in This Study)	Sources of Uncertainty Typically *Not* Covered by a Performance Guarantee (Addressed in This Study)
Design and modeling errors	Uncontrollable variations in weather
Operating schedules and set points that deviate *within* specified limits from the assumed operational parameters	Operating schedules and set points that deviate *beyond* specified limits from the assumed operational parameters
Variations in equipment performance	Changes in utility rates
Substandard workmanship and ineffective commissioning	Inadequate preventative maintenance practices
Installation errors	–

This report is divided into two major efforts:

- Research conducted to develop EEM packages for small commercial office buildings that achieve 20% energy savings cost effectively. The results of this study are summarized in a simple spreadsheet tool (the EEM Selection & Cost Evaluation Tool [www.nrel.gov/buildings/docs/2014_eemselection_costevaltool_smoffice.xlsm]) and are intended to be used to engage small building customers in energy efficiency discussions by providing a business case (energy savings, energy cost savings, and an analysis of cost) for more comprehensive EEM packages that achieve higher energy savings cost effectively.
- Analyzing economic risk associated with building performance uncertainties that are not typically covered by performance guarantees. The result of this analysis are calculated buffers that building owners and lending institutions can apply to projected energy cost savings, in an effort to control performance risk to an acceptable level. The pilot partners have reviewed the results of both analyses and feedback has been incorporated into this final report.

1.1 Energy Efficiency Packages That Achieve Energy Savings Cost Effectively for Small Office Buildings

The first section of this report summarizes the analysis, results, and steps conducted by NREL to develop cost-effective EEM packages for existing small commercial office buildings to achieve 20% energy savings. We define *cost effective* as net positive cash flow, meaning that the annual energy cost savings are greater than the annual payment of the investment. The intent of developing these packages and providing associated cost data is to encourage the bundling of EEMs (which promotes more comprehensive building upgrades that can result in higher energy savings), while making the business case for the building owner and enabling an easier financing process. The results are not intended to replace a detailed audit when desired by the building owner or justified by the size of the investment.

Section 1.2 walks through the literature reviewed to identify data on typical small commercial office building characteristics, appropriate EEMs, and characteristics of the representative building energy models used to develop the EEM packages. Office buildings were chosen as the target building type for this pilot project in collaboration with Michigan Saves and Energi based on the large number of small commercial office buildings in their project bases and the feasibility of cost-effectively achieving 20% energy savings.

1.2 Available Literature on Small Office Characteristics and Efficiency Measures

A number of tools and resources have supported the analysis for this pilot project. The most prominent resources are described below and were used to define typical building characteristics for the representative baseline building energy models, and to determine appropriate EEMs to apply to the baseline energy models for small office buildings.

1.2.1 Commercial Reference Building Models

The U.S. Department of Energy (DOE) and the national laboratories developed standard or reference energy models for the most common commercial buildings to serve as starting points for energy efficiency research (Deru et al. 2011). The reference building models represent reasonably realistic building characteristics and construction practices, and are intended to be used for research to assess new technologies; optimize designs; analyze advanced controls; develop energy codes and standards; and conduct lighting, daylighting, ventilation, and indoor air quality studies (Deru et al. 2011). For this pilot project, we chose the small office Commercial Reference Building models for climate zone 5A (the same climate zone as Holland, Michigan, where the pilot project was implemented) as our baseline starting point. Three models are available for the small office Commercial Reference Buildings; the models vary by vintage and comply with typical construction practices for each vintage. The vintages include pre-1980, post-1980, and “new” construction that comply with ASHRAE Standard 90.1-2004. To accommodate a wider range of typical small commercial office buildings, NREL manipulated the three reference building models by varying characteristics such as square footage, heating, ventilation, and air-conditioning (HVAC) system type, and boundary conditions (stand-alone structures versus structures that adjoin other buildings). EEMs were then applied to the various baseline models to determine energy savings per EEM and develop appropriate EEM packages that achieve 20% energy savings.

1.2.2 179D DOE Calculator

The 179D DOE Calculator was developed to provide a fast and efficient solution for estimating savings from EEMs that meet the requirements of the 179D Federal Tax Code (NREL 2012). The 179D Federal Tax Code provided a tax deduction of up to $1.80/ft^2 to encourage EEMs in new construction and major renovations in commercial buildings (NREL 2012). We define the term *major renovation* as a fairly comprehensive building renovation, including an overhaul of the major building systems. The results displayed in the 179D DOE Calculator tool are based on nearly 250,000 whole-building energy simulations of 12 common building types and EEMs designed to cover a broad range of scenarios and locations (NREL 2012). The initial 12 common building type models used in this tool were based on the Commercial Reference Buildings, as described above. Leveraging the work and modeling processes developed for this tool, NREL used code developed for the 179D DOE Calculator to manipulate and manage the baseline small commercial office building models for this pilot project (in climate zone 5A). The 179D modeling processes were also used to apply EEMs and combinations of EEMs to each baseline model, allowing NREL to optimize the recommended EEM packages by analyzing every possible combination of baseline models and applied EEMs. This analysis was also used to understand the effects of individual EEMs and packages of EEMs on building energy use. Results showing the effects of individual EEMs on percent energy savings are displayed in Appendix C. Using the 179D modeling process, 81 baseline models were developed and 384 EEM combinations were evaluated against each baseline. In total, 31,104 simulations were run using NREL's supercomputer (the cloud is another computing option), each averaging about 1 minute of computer run time for a simulation of annual energy consumption.

1.2.3 Advanced Energy Retrofit Guide for Office Buildings

The Advanced Energy Retrofit Guide (AERG) for Office Buildings, developed by Pacific Northwest National Laboratory, was used to understand retrofit strategies that are appropriate for commercial office buildings (DOE 2011). The building-type-specific AERGs (five in total) work to achieve a common goal of improving existing building energy efficiency across the commercial building sector by providing project planning guidance as well as example financial payback metrics for the most common EEMs (DOE 2011). The primary audience for the AERG for Office Buildings consists of facility and energy managers of large existing office buildings (>100,000 ft^2), but also includes considerations for small and medium size office buildings (DOE 2011). These considerations were evaluated as part of operations and maintenance (O&M) strategies, EEM recommendations, and cost estimation for this pilot project.

1.2.4 Advanced Energy Design Guides

The Advanced Energy Design Guides (AEDGs) were developed to provide design strategies and recommendations that achieve 30% and 50% energy savings over the minimum code requirements of ASHRAE Standard 90.1-2004 for new construction (ASHRAE 2011). The 30% AEDG for office buildings targets small office buildings; the 50% AEDG applies to small and medium size office buildings with gross floor areas up to 100,000 ft^2 (ASHRAE 2011). Although these guides are for new construction, certain design recommendations can be applied to retrofits. These recommendations were considered as part of the EEMs analyzed in this project.

1.2.5 Technical Support Document: Large Office Buildings

NREL developed the Technical Support Document (TSD) for large office buildings to evaluate the potential for new large office buildings in the United States to achieve 50% energy savings compared to ASHRAE Standard 90.1-2004 (Leach et al. 2010). Detailed design recommendations are not provided in the Large Office TSD in recognition that they are outlined in the AEDGs (Leach et al. 2010). The intended audience for the TSD includes energy modelers and engineers who aim to simulate low-energy large office buildings as part of the design process and understand assumptions that inform low-energy building design (Leach et al. 2010).

As part of this pilot project, the TSDs were primarily used to understand the details and associated costs of specific EEMs applied to office buildings. Cost data were included as part of the TSDs to evaluate the feasibility of EEMs. NREL considered the same cost assumptions when appropriate (taking building size into consideration) for evaluating the cost effectiveness of recommended retrofit EEM packages for small commercial office buildings.

1.2.6 Asset Score Sensitivity Analysis

The Commercial Building Energy Asset Scoring Tool developed by DOE is intended to guide data collection, store building information, and generate Asset Scores and system evaluations of building envelopes and building systems (DOE 2013). To generate the Asset Score, the Asset Scoring Tool uses OpenStudio to perform whole-building energy simulations and generate a score, based on building envelopes and building systems (HVAC, lighting, and service hot water) (DOE 2013). The output of these models depends on the accuracy of user-supplied data, the sensitivity of the applied modeling assumptions, and the accuracy of the underlying simulation engine (NREL 2013).

The Asset Score sensitivity analysis screened 35 input variables in the Asset Scoring Tool for four building types, including small office buildings (NREL 2013). The results were useful in determining which input variables have negligible impact on whole building energy use intensities (EUIs) (NREL 2013). Conversely, the results also provided input on variables that have considerable effect on building EUIs. These variables were taken into consideration as part of this pilot project to help specify EEMs to apply to small office buildings. The variables with greater effects on EUIs include roof insulation, window-to-wall ratios, and interior lighting power density (LPD).

1.2.7 Data From the Michigan Saves Program

Michigan Saves has provided project data from participants of the Michigan Saves program since 2011. These data include information on building types and implemented EEMs for approximately 30 projects that participated in the Michigan Saves program. NREL used these data to determine the most common EEMs implemented in these projects, and considered these EEMs as part of the analysis to determine EEM packages most likely to be cost effective for small office buildings. The most common EEMs that were implemented by Michigan Saves program participants were upgrades to lighting, rooftop units, and gas furnaces.

1.2.8 Commercial Building Energy Consumption Survey

Data from the Commercial Building Energy Consumptions Survey (CBECS) 2003 were used to understand basic occupant density and hours of operation for small commercial office buildings. These data were used to inform the baseline building energy models and support the decision tree developed to aid in the selection of appropriate EEM packages. Although CBECS is a decade old, the data still provide valuable information on typical building use and energy consumption that is unrivaled in breadth by any other dataset.

1.2.9 Data From Preservation Green Lab

Preservation Green Lab (PGL), a subdivision of the National Trust for Historic Preservation, provided data for small office buildings in climate zone 5A from its survey of 800 small buildings across the United States. PGL conducted the building survey to establish a comprehensive building typology, adding details to building types derived from the CBECS database and identifying regional variations that influence small building energy use (PGL 2013). The survey did not include buildings in Michigan, but it did include buildings in Chicago, Illinois, which falls under the same climate zone as Holland, Michigan. We assumed that building construction was similar because the climate zone is the same and the cities are geographically proximate; therefore, the data could be used interchangeably. We then used the building typology data for Chicago to understand typical small office building characteristics and formulate the baseline building energy models.

1.3 Energy Model Development

In total, 31,104 OpenStudio models were run to complete the analysis. The following section discusses the modeling approach, model inputs, and cost data used to derive the results. The results were composed into a summary spreadsheet, called the EEM Selection & Cost Evaluation Tool, which can be easily filtered to evaluate the energy savings and cost effectiveness of EEM packages that are appropriate for particular categories of small office buildings.

1.3.1 Baseline Building Models

A variety of baseline building models were developed using the DOE Commercial Reference Building EnergyPlus models for small offices. As previously mentioned, the Commercial Reference Building models represent realistic building characteristics and construction practices for three vintages: pre-1980, post-1980, and new construction practices that comply with ASHRAE Standard 90.1-2004.

To accommodate typical variations in small office buildings, NREL manipulated the baseline reference building models to account for a range of sizes, HVAC system types, and boundary conditions. PGL determined that the average size of small commercial buildings (across all building types) is approximately 8,000 ft^2 (PGL 2013). In setting some boundaries on this pilot project we assumed that because the average small commercial building is relatively small, certain building characteristics would probably have little variation from building to building. These particular characteristics remained constant in our models and include the aspect ratio, the number of floors, the floor-to-floor height, and the window-to-wall ratio, which are described in Table 2. Even though window-to-wall ratio can have a large effect on building EUI, we assumed that the average value used in the Commercial Reference Building model was appropriate for most small office buildings, and that in general, asking a small building owner to provide an accurate window-to-wall ratio may be too time intensive or difficult, and detract from the simplicity and celerity of the tool. We also assumed that typical small office buildings are operated from 9:00 a.m. to 5:00 p.m. Monday through Friday, and with reduced occupancy, from 9:00 a.m. to 12:00 p.m. on Saturdays. This operation schedule is the same as the schedule represented in the Commercial Reference Building models. The baseline building characteristics that remained constant throughout the analysis are summarized in Table 2.

Table 2. Baseline Building Characteristics That Remained Constant Throughout the EEM Analysis

Building Characteristic	Value
Aspect Ratio	1.5
Number of Floors	1
Floor-to-Floor Height	10 ft
Window-to-Wall Ratio	21%
Building Occupancy	9:00 a.m. to 5:00 p.m. Monday through Friday, 9:00 a.m. to 12:00 p.m. Saturday

The building occupancy schedule assumption was also validated by CBECS 2003 data, which indicate that the average number of weekly operating hours for an office building is 55 (EIA 2003). This, however, includes buildings of all sizes. Assuming that many small office buildings are occupied by small businesses, as derived in an NREL technical report that characterizes the SBSP sector (Langner et al. 2013), we assumed that it was appropriate for the small office occupancy schedule to be about 11 hours shorter than that of a larger office building, and that the 9:00 a.m. to 5:00 p.m. Monday through Friday operation schedule was representative of most small office buildings. If a building's occupancy schedule extends beyond our assumption, our modeling experience indicates that a small change of an hour or two in the schedule is not likely to significantly affect the EEM package recommendations or the resulting energy savings.

The building characteristics that varied between the baseline models include vintage, building square footage, HVAC system type, and the exterior wall boundary condition (stand-alone structure versus structures that adjoin other buildings). These characteristics are summarized in Table 3 and described in the following paragraphs.

Table 3. Baseline Building Characteristics That Were Varied for the EEM Analysis

Building Characteristic	Value
Vintage	Pre-1980
	Post-1980
	New – ASHRAE Standard 90.1-2004
Building Size	5,500 ft^2
	10,000 ft^2
	25,000 ft^2
HVAC System Type	Packaged single zone air-conditioners (PSZ-ACs: rooftop unit with gas furnace)
	Packaged terminal air-conditioners (PTACs: split system air-conditioner with gas furnace)
	Packaged terminal heat pumps (PTHPs: heat pump)
Exterior Wall Boundary Condition	Stand-alone
	Adjacent building on 1 side
	Adjacent building on 2 sides

The size of the small office Commercial Reference Building models is 5,500 ft^2. The medium office reference model is approximately 50,000 ft^2. For a next step of this project, it may be beneficial to expand this research to include the medium office Commercial Reference Building;

however, for this pilot project, we focused efforts on EEM recommendations specifically for small office buildings. To account for differences in small office sizes, we varied the small office building models to accommodate three size ranges that match size categories recorded by CBECS 2003: 5,500 ft^2, 10,000 ft^2, and 25,000 ft^2.

NREL also modeled three variations of HVAC system types for each small office baseline model. The modeled HVAC system types are typical of small office buildings across the nation and include PSZ-ACs – a single system rooftop unit with direct expansion cooling and a gas forced air furnace, and two split systems: PTACs – direct expansion air conditioner with gas forced-air furnace and PTHPs – heat pump with electric supplemental heat. The baseline heating, cooling, and fan efficiencies for these units were derived from ASHRAE Standard 90.1-2004. The efficiencies for the pre-1980 and post-1980 HVAC systems were de-rated from the ASHRAE Standard 90.1-2004 values, to simulate HVAC efficiencies typical to systems found in those building vintages (Deru et al. 2011). Efficiencies for pre-1980 buildings are higher than post-1980 based on the assumption that the HVAC equipment has been more recently replaced. The efficiencies for the baseline units are noted below in Table 4.

Table 4. Baseline HVAC System Efficiencies

System Type	Pre-1980		Post-1980		90.1-2004	
	Cooling Efficiency (COP*)	Heating Efficiency	Cooling Efficiency (COP)	Heating Efficiency	Cooling Efficiency (COP)	Heating Efficiency
PSZ-AC	2.81	78%	2.55	80%	3.05	80%
PTAC	2.92	78%	2.65	80%	3.17	80%
PTHP	2.92	1.95 (COP)	2.65	2.00 (COP)	3.17	2.00 (COP)

* Coefficient of performance

Because many small office buildings reside in downtown or main street districts, we varied the boundary conditions of the baseline models to accommodate structures that adjoin other buildings and buildings that are stand-alone. For stand-alone buildings, the reference building models were left unchanged. For those that adjoin other buildings, we changed the boundary conditions from exterior wall to adiabatic wall (which mimics an interior wall) on either one exterior side (if the building adjoins another building on one side), or on two exterior sides (if the building is between two other buildings). For adjacent walls, windows were also removed. The configurations of these buildings greatly influence the building's heating and cooling loads.

1.3.2 Decision Tree/Energy Efficiency Measure Screening Questions

The variations in the baseline building models were used to develop a very simple decision tree, or list of screening questions, that are used in the EEM Selection & Cost Evaluation Tool to help users select appropriate EEM packages for their specific small office buildings. The screening questions, listed in Table 5, are necessary to understand the basic characteristics of the participating small office building, such as vintage, size, boundary conditions, HVAC system, and age of equipment, and to recommend appropriate EEM packages. The screening questions also include questions about whether the building owner plans to conduct any major renovations or equipment upgrades. As previously mentioned, we define the term *major renovation* as a fairly comprehensive building renovation, including an overhaul of the major building systems. In this case of a major renovation, the EEM Selection & Cost Evaluation Tool considers incremental costs instead of full first costs when analyzing the cost effectiveness of the EEM packages. Incremental costs include the additional costs for an energy efficient product, when compared to a standard product. For example, if a building owner is already planning to replace a defective roof-top unit, the incremental cost would be the additional cost to purchase a high-efficiency model compared to a standard-efficiency model. The full first cost assumes that a major renovation is not planned, and includes the entire cost of the energy-efficient piece of equipment. The output of this tool is also intended to help the reviewer or financial institution to choose an EEM package that is likely to achieve a certain threshold of energy savings (specified by the user) cost effectively. Conversely, if there is no cost-effective EEM package for a building, or the building characteristics are not consistent with any baseline, the analysis results will inform the reviewer or financial institution that a more detailed energy audit is required.

Table 5. Screen Questions To Aid in the Selection of Appropriate EEM Packages

EEM Package Screening Questions:	
When was your building built?	
	Post-2004
	1980–2004
	Pre-1980
Roughly, what size is your building?	
	5,500 ft^2
	10,000 ft^2
	25,000 ft^2
Is your building:	
	A stand-alone structure?
	Adjacent to another building on 1 side?
	Adjacent to buildings on 2 sides?
What type of HVAC system do you have?	
	Packaged single zone air-conditioner (rooftop unit with gas furnace)
	Packaged terminal air-conditioner (split system air-conditioner with gas furnace)
	Packaged terminal heat pump (heat pump with electric supplemental heat)
Are you planning for any of the following actions in the near future?	
	Major renovation of building
	Roof replacement
	HVAC equipment replacement

Even if a building complies with the screening questions, the results may not fully conform to the particular office building under consideration. The spreadsheet tool is intended to be used as an engagement tool, informing the user of possible low-risk EEM combinations where there is high confidence of cost effectiveness. These packages are recommended for financing, yet it must also be understood that the investment still presents some uncertainty. As part of the second part of this study, uncertainty that goes beyond typical performance guarantees is analyzed, and risk mitigation strategies are recommended to increase the chances of achieving the estimated savings. These strategies are noted in upcoming sections of this report, and are summarized in Appendix B. The building owner should ensure that the building is being operated in a manner that uses the least amount of energy and still maintain operating goals. Retrocommissioning is also recommended to ensure that the building equipment operates at its maximum efficiency potential following a retrofit. Commissioning has been shown to reduce energy consumption by an average of 5% at very little cost, providing a buffer for energy savings estimates in our analysis (Mills 2009).

If a particular building's characteristics fall outside the decision tree options, we recommend that the building owner pursue a detailed building audit to determine appropriate EEM packages and cost information. In a parallel effort, if the building has HVAC equipment older than 10 years and the building owner is not planning a major renovation or HVAC equipment replacement, we also recommend that the financial institution or program administrator work with the building owner to recommend a high-efficiency HVAC equipment replacement when the equipment must be replaced.

1.3.3 Small Office Energy Efficiency Measures

Most EEMs evaluated in this analysis were derived from the AERG for Office Buildings, the 30% and 50% AEDGs for Office Buildings, the TSD for Large Office Buildings, the Asset Score Sensitivity Analysis, and data collected by Michigan Saves through its project participants. Additional design sources were evaluated to determine lighting and plug load retrofit measures, as well as HVAC efficiencies. Each measure and the design sources are noted in the following sections.

1.3.3.1 Building Envelope

Results from the Asset Score Sensitivity Analysis for small office buildings show the significance of various building characteristics on overall building EUI (NREL 2013). From these results, along with recommendations from the AERG for office buildings, data provided by Michigan Saves on past projects, and design values from the 50% Office AEDG, we concluded that increasing roof insulation, replacing windows, and reducing building leakage were appropriate EEMs to consider for small office efficiency retrofit projects. These EEMs are summarized in Table 6, along with the baseline assumptions (found in the Commercial Reference Building models) for reference.

Table 6. Building Envelope EEMs Applied to Baseline Building Models

EEM	Baseline Value	Efficient Value
Increase Roof Insulation	R-30 for attic (post-1980 and 90.1-2004 construction) R-14 for pre-1980 construction	R-49 for attic (post-1980 and 90.1-2004 construction) R-30 continuous insulation for insulation entirely above deck (pre-1980 construction)
Replace Windows	U-0.62 (pre-1980) U-0.59 (post-1980) U-0.57 (90.1-2004 construction)	Improved windows U-0.45, SHGC 0.25: double-glazed, low-e, spectrally selective, aluminum frame with thermal break
Reduce Building Leakage	1.5 cfm/ft^2 (average leakage rate (per ft^2 of exterior wall) for pre-1980 and post-1980 construction) 0.4 cfm/ft^2 (average leakage rate (per ft^2 of exterior wall) for 90.1-2004 construction)	Reduce infiltration by: 40%, pre-1980 construction 25%, post-1980 construction 10%, 90.1-2004 construction

A number of references were reviewed to determine appropriate values for improving the air sealing of a building (reducing building leakage). These references included the Large Office TSD, retrofit percent reduction goals proposed by Xcel Energy, and the experience of the authors.

1.3.3.2 Lighting

A number of lighting EEMs were applied to the baseline models that include LPD reductions, lighting controls, and adding daylighting sensors. Based on LPD design recommendations for new construction noted in the Office AEDG, and consultation with NREL's lighting experts, we analyzed two options for reducing LPD. Alternative, cost-effective lighting approaches may also be used to reach the energy savings targets that we recommend; however, these approaches should be determined from an energy audit. In both lighting recommendations, we assumed that 0.5 W/ft^2 of the current office lighting would remain in place, and the rest would be reduced by retrofitting lamps to high-performance lamps (as an example, we analyzed T8s) and either maintaining a lighting level of 40 fc, or delamping or increasing the fixture spacing to achieve an ambient illuminance of 25 fc plus task lights. Also, the 25-fc case assumes that the project installs new, high-efficiency fixtures that require fewer fixtures per square foot to meet the illuminance criteria. This retrofit option is more expensive because it involves overhauling the lighting system. The LPD reductions and illuminance criteria for both options are summarized in Table 7.

Table 7. LPD EEMs Applied to Baseline Models

Vintage	Reference Building LPD (W/ft^2)	Retrofit to T8s, 40 fc (W/ft^2)	Retrofit to T8 and Change Design (e.g., delamp fixtures, increase fixture spacing), 25 fc (W/ft^2)
Pre-1980	1.8	1.4*	1.1**
Post-1980	1.8	1.4*	1.1**
90.1-2004	1.0	1.0	0.8

*Assume 0.5 W/ft^2 of the office lighting will remain in place (office ambient LPD moves from 1.3 W/ft^2 to 0.9 W/ft^2).
**Assume 0.5 W/ft^2 of the office lighting will remain in place (office ambient LPD moves from 0.9 W/ft^2 to 0.6 W/ft^2). For the ASHRAE 90.1-2004 model, the percent of lighting that would remain in place was prorated.

Lighting controls were applied to the baseline models as EEMs. The baseline lighting schedule remained the same as the assumptions in the small office Commercial Reference Building models, and occupancy sensors were applied to the entire building model, assuming that they reduce the total power associated with the daytime lighting schedule by 20% in open office and 40% in auxiliary spaces. This is an aggressive assumption, assuming that vacancy, manual-on sensors are used.

We assumed that photosensors for daylight response also alter the baseline lighting schedule, reducing the total lighting power to 50% in perimeter zones of the building. The daylight sensors were assumed to be continuous dimming with a daylighting set point of 25 fc. This measure added dimming ballasts in perimeter zones.

1.3.3.3 Plug Loads

Recent research has shown that advanced power strips can reduce office building plug load power to approximately 10% at night (Metzger et al. 2012). Advanced power strips offer an affordable option to reduce energy consumption in an office building. Costing $15–$30 each, the advanced power strips allow occupants to easily turn off all the office equipment in their workspaces when they leave at the end of the day. For our EEM analysis, we assumed that the plug load equipment schedule was reduced to 10% total power at night.

1.3.3.4 HVAC Systems

Pending whether a building is due for HVAC system equipment upgrades, we analyzed energy savings for replacing existing HVAC equipment with high-efficiency equipment. Leveraging efforts associated with the DOE High Performance Rooftop Unit Challenge, we used recommended efficiencies proposed in the Tier 2 category of the Consortium for Energy Efficiency Commercial Unitary AC and HP Specification (Jensen 2012). Cooling and heating efficiencies for the baseline and high-efficiency systems are noted in Table 8 and Table 9, respectively.

Table 8. HVAC System Cooling Efficiency Comparison for Baseline and High-Efficiency Cases

System Type	Pre-1980		Post-1980		90.1-2004	
	Baseline (COP)	Low-Energy (COP)	Baseline (COP)	Low-Energy (COP)	Baseline (COP)	Low-Energy (COP)
PSZ-AC	2.81	3.52	2.55	3.52	3.05	3.52
PTAC	2.92	3.66	2.65	3.66	3.17	3.66
PTHP	2.92	3.66	2.65	3.66	3.17	3.66

Table 9. HVAC System Heating Efficiency Comparison for Baseline and High-Efficiency Cases

System Type	Pre-1980		Post-1980		90.1-2004	
	Baseline	Low-Energy	Baseline	Low-Energy	Baseline	Low-Energy
PSZ-AC	78%	80%	80%	80%	80%	80%
PTAC	78%	90%	80%	90%	80%	90%
PTHP (COP)	1.95	2.64	2.00	2.64	2.00	2.64

NREL assumed the cooling seasonal energy efficiency ratio (SEER) for the PTAC and PTHP system types to be 12.0 SEER, as listed in ASHRAE Standard 90.1-2004 (tables 6.8.1A and 6.8.1B) – also assuming that the units were installed after January 23, 2006. To convert between SEER and the energy efficiency ratio (EER), we used the methodology noted by Deru et al. (2011). The equation used is noted below:

$$EER = SEER * 0.697 + 2.0394$$

The COP values for the PSZ-AC system noted in Table 8 apply to the entire unit. Because this is not a split system, and the EnergyPlus input for COP is for the compressor COP only, we had to remove the fan efficiency from the overall COP to model it correctly in EnergyPlus. To do so, we again used the methodology noted by Deru et al. (2011). The equation is as follows:

$$COP_{comp} = ((EER / 3.413) + R) / (1 + R),$$

where R is assumed to be 0.12, a reasonable value to represent a broad class of products (Deru et al. 2011).

Lastly, the baseline COP values for the PTAC and the PTHP systems were de-rated to account for building vintage in the same proportion that the PSZ-AC system was de-rated in the Commercial Reference Building models.

1.4 Energy Efficiency Measure Packages and Cost Data for Small Office Buildings

The results of this analysis are summarized in a simple spreadsheet tool (the EEM Selection & Cost Evaluation Tool) that based on answers to the screening questions, provides users with bundled EEM packages that meet a particular energy savings threshold and are likely to be cost effective. The tool includes a macro to facilitate the process and the user specifies the desired energy savings threshold. If there is no EEM package for a particular building, the building is likely already energy efficient and it should be re-evaluated at a later date. If the screening questions indicate that the building is not consistent with any baseline, an energy audit may be necessary to identify cost-effective EEM packages. The tool contains energy savings data from each EnergyPlus simulation for every combination of EEMs applied to the 81 baseline building models, totaling more than 30,000 scenarios. It also includes estimated cost data for each EEM and EEM package; however, it is highly recommended that the user enter updated cost data for their specific region and available products. The estimated cost data in the tool were accumulated from a number of resources, including the Large Office TSD, RSMeans, and the AERGs. The cost data include full costs, incremental costs, and costs associated with O&M, which can all be edited by the user in the spreadsheet tool if better cost data are available. The cost data were then used to determine:

- Net initial cost (adjusted for equipment replacement costs that would have occurred without the efficiency upgrade) and full initial cost for each EEM package
- Quality assurance fees associated with the Michigan Saves program
- Annual lease payments
- Measurement and verification costs
- Total first year investment costs
- Net cash flow during a typical 5-year lease period.

Depending on the approved loan amount and building characteristics, the EEM Selection & Cost Evaluation tool outputs EEM packages that achieve energy savings above the user-specified energy savings threshold and offer a net positive cash flow. The net cash flow is based on the annual energy cost savings (calculated using average electricity and gas prices for Michigan) versus the total first-year costs of implementing the selected EEM package. The average electricity and gas prices for Michigan were determined using the U.S. Energy Information Administration (EIA) 2010 average rates for electricity and natural gas for commercial buildings (EIA 2012a, 2012b). Those rates are $0.10/kWh for electricity and $9.14/1,000 ft^3 (approximately $0.03/kWh) for gas.

The total first-year costs equate to the sum of the annual energy-related lease payment (which includes annualized fees and rebates), O&M costs, and measurement and verification costs.

$$\text{Total 1}^{\text{st}}\text{ Year Costs} = \text{Annual Payment} + \text{Operation \& Maintenance Costs} + \text{Measurement \& Verification Costs}$$

The annual energy-related lease payment is a factor of the net initial cost, the interest rate (set at 5.9%), a 5-year lease period, fees associated with the loan transaction, and any potential rebates.

Annual Energy-Related Lease Payment = (Net Initial Cost + Quality Assurance Fee – Rebate) * (Monthly Interest/(1-(1+ Monthly Interest) $^{-(\text{Number of Months})}$)The net initial costs are used to calculate cost effectiveness of the investment, and include incremental costs when equipment would have to be replaced even without the energy efficiency upgrades. The full initial costs are used to quantify total project costs covered by the lease. The net and full initial costs are calculated by summing the relevant first cost or incremental costs together for each measure noted in the EEM package.

$$\text{Net Initial Cost} = \text{Sum of Either Incremental or Full Costs for a Project}$$

The decision tree questions related to whether the building owner is planning a major renovation, roof replacement, or replacement of HVAC equipment determine whether the incremental cost or full cost is used. The actual cost data, including each data source, are summarized in Table 10. NREL reviewed these costs with Michigan Saves and several of its partners to ensure that the cost assumptions are realistic. Accurate cost data are difficult to obtain because they can vary considerably with specific building types and location. Regardless, the overall feedback on our cost data suggested that the costs were conservative but not unrealistic, which could mean that in some instances the proposed packages are more cost effective than predicted. With the partners' input, we decided to refine and update the spreadsheet tool to allow the user to change the cost data if more accurate cost data are found. The costs used in this study and the associated data sources are listed in Table 10.

The decrease in O&M costs for lighting accounts for a couple of factors. If a retrofit involves delamping or increased fixture spacing, fewer lamps need to be maintained and replaced after the retrofit. Typically, the higher performance lamps have longer lives as well, so lamps are replaced less often. Similarly, occupancy sensors can promote longer lamp life, but the O&M savings from this measure are often negated because more maintenance is needed to calibrate the sensors, program the controls, and monitor their operation.

In the end, the EEM Selection & Cost Evaluation Tool displays 1,597 EEM package options that are expected to achieve 20% energy savings cost effectively for projects undergoing major renovations. For projects that are not undergoing major renovations, 20% energy savings are harder to achieve cost effectively. Only one cost-effective EEM package option is available that achieves 20% energy savings for small office buildings that are not planning major renovations. For these cases, we recommend that the user reduce the energy savings threshold. For example, reducing the energy savings threshold to 15% yields approximately 30 cost-effective EEM package options; 10% energy savings yields 164 cost-effective EEM options. Snapshots of the EEM Selection & Cost Evaluation Tool can be found in Appendix A.

Table 10. Cost Data for Individual EEMs

EEM	Incremental Cost ($/ft^2)	Full Cost ($/ft^2)	O&M Cost Decrease ($/ft^2)	Source
Increase Roof Insulation to R-49 (for attics, post-1980 and 90.1-2004 construction)	$3.00	$12.15	$ –	TSD Large Office
Increase Roof Insulation to R-30 Continuous Insulation (for insulation entirely above deck, pre-1980 construction)	$1.32	$10.47	$ –	TSD Large Office
Replace Windows	$7.18	$43.00	$ –	AERGs
Reduce Building Leakage	$0.43	$0.43	$ –	AERGs
LPD Reduction, Retrofit to T8s, 40 fc	$0.66	$2.06	$0.12	AERGs
LPD Reduction, Retrofit to T8s and change design (e.g., delamp) to 25 fc plus task lights	$0.79	$11.15	$0.19	TSD Large Office
Daylighting Controls	$0.55	$3.41	$ –	TSD Large Office, AERGs
Occupancy Sensors	$0.36	$0.36	$ –	TSD Large Office
Advanced Power Strips	$0.15	$0.15	$ –	GSA* Plug-Load Control Document
Replace HVAC Equipment (PSZ-AC)	$0.41	$6.09	$ –	TSD Grocery Stores
Replace HVAC Equipment (PTAC)	$0.66	$2.85	$ –	Residential Measures Database
Replace HVAC Equipment (PTHP)	$1.53	$3.30	$ –	Residential Measures Database

* U.S. General Services Administration

1.5 Energy Savings for Individual Energy Efficiency Measures

To enhance our understanding of the energy savings effects of individual EEMs, NREL filtered the results from this analysis to understand the mean energy savings of each EEM (see Appendix C). It should be noted that the results take into account only the small buildings considered in this project and are not intended to be conveyed as an average over a larger cross-section of buildings. The graphs in Appendix C show the energy effects of individual EEMs on building energy use averaged over all energy models. They also show more detailed results that look at the energy effects of individual EEMs averaged for stand-alone buildings and buildings adjacent to other buildings, as well as averaged effects for each HVAC system type (PSZ-AC, PTAC, and PTHP).

A number of trends emerged from this analysis. Overall, the lighting, daylighting sensors (photosensors for daylighting response), and plug load EEMs have the greatest effect on reducing small office building energy use. Occupancy sensors also show high energy savings in most building models. In older buildings, primarily pre-1980 buildings, reducing building leakage is highly impactful. Likewise, upgrading the HVAC system with a higher efficiency system shows a greater effect in older buildings, as does increasing roof insulation. In general, upgrading windows with high-efficiency windows shows the least effect on building energy use. However, the results might vary from building to building, especially for cases where the window-to-wall ratio is significantly larger than what was used in the energy models of this study. Lastly, buildings with PTACs tend to see higher savings than the other two HVAC system types analyzed in this study.

2 Analysis of Economic Risk Associated With Building Performance Uncertainties Not Covered by Performance Guarantees

For the second stage of this pilot project, NREL worked with the energy insurance company, Energi, to quantify building performance risks that are not typically covered by performance guarantees. The performance uncertainties are associated with uncontrollable variations in weather, occupant behavior, fuel escalation rates, and quality of preventative maintenance. The following sections describe the approach, analysis, and results of the study quantifying the performance uncertainties, and provide recommendations to help mitigate these risks.

2.1 Data Sources for Performance Risk Analysis

The result of this analysis quantifies uncertainties in building performance that are outside the control of designers and installers. The results are intended to be used by contractors that provide energy savings guarantees, or by lending institutions and other loan managers beyond energy insurance companies. The starting point of this analysis began with a sample of the pre-approved EEM packages that achieve close to 20% energy savings developed in the first stage of this project with Michigan Saves. As discussed earlier in this report, these energy models were generated using the small office Commercial Reference Building models as a starting point (Deru et al. 2011). Table 11 provides a summary of the models.

Table 11. Summary of Models Used for the Performance Risk Analysis

Baseline Office Building Model	Bundled EEMs Applied to Model	Energy Savings	Net Cash Flow	Planned Major Renovation?
Post-1980, 5,500-ft^2, PTAC HVAC System, Stand-Alone Building	Reduced LPD, daylight sensors, occupancy sensors, advanced power strips for plug loads	17%	$1,172	Yes
Post-1980, 5,500 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	Reduced infiltration, reduced LPD, daylight sensors, occupancy sensors, advanced power strips for plug loads	19%	$1,138	Yes
Post-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	Reduced LPD, occupancy sensors, advanced power strips for plug loads	21%	$6,658	Yes
Post-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	Reduced LPD, daylight sensors, advanced power strips for plug loads	23%	$6,792	Yes
Post-1980, 25,000-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	Reduced infiltration, reduced LPD, occupancy sensors, advanced power strips for plug loads	21%	$6,850	Yes
Post-1980, 25,000-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	Reduced LPD, daylight sensors, advanced power strips for plug loads	22%	$7,273	Yes
Pre-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	Reduced infiltration, reduced LPD, advanced power strips for plug loads	20%	$7,380	Yes

For the statistical analysis of the performance risk, NREL used the free software, R, for statistical computing and graphics to generate a random sample of inputs for the key input variables according to a probability distribution.   The sample of inputs were then applied to each OpenStudio model to determine the range and standard deviation in energy cost savings caused by uncontrollable variations in weather, operating conditions, unexpected utility rate fluctuations, and the quality of preventative maintenance. The data sources described in the following subsections were used to determine realistic ranges (minimum, maximum, and mean/mode values) for each variable, which were then input into R to generate the random sample of realistic inputs. Table 12 provides a summary of the variables considered in this analysis, their associated ranges, and probability distribution. Normal distributions were approximated by a triangular distribution to ensure that random variables would not deviate beyond realistic maximum and minimum values.

Table 12. Summary of Performance Risk Variables, Associated Ranges, and Probability Distribution Used in This Analysis

Units	Weather	Heating Set Point (Occupied Hours)	Cooling Set Point (Occupied Hours)	Lighting Schedule (Unoccupied Hours)	Equipment Schedule (Unoccupied Hours)	Occupant Density	Utility Price Escalation Electricity	Utility Price Escalation Gas	Quality of Preventative Maintenance
	Year of weather data used in simulation	°F	°F	Multiplier applied to schedule	Multiplier applied to schedule	Multiplier applied to occupied density	Multiplier applied to calculated electricity cost	Multiplier applied to calculated gas cost	Multiplier applied to whole building energy use
Probability Distribution	Uniform	Triangular	Triangular	Discrete	Triangular	Triangular	Triangular	Triangular	Triangular
Range: Minimum	1988	66.56	72.86	N/A	0.10	0.75	0.94	0.85	0.96
Range: Maximum	2012	72.32	77.90	N/A	0.30	1.25	1.07	1.15	1.04
Mode	N/A	69.80	75.20	N/A	0.20	1.00	1.00	1.00	1.003
Scenario 1	N/A	N/A	N/A	1.00	N/A	N/A	N/A	N/A	N/A
Scenario 2	N/A	N/A	N/A	1.63	N/A	N/A	N/A	N/A	N/A
Scenario 3	N/A	N/A	N/A	0.38	N/A	N/A	N/A	N/A	N/A
Probability of Scenario 1	N/A	N/A	N/A	0.90	N/A	N/A	N/A	N/A	N/A
Probability of Scenario 2	N/A	N/A	N/A	0.05	N/A	N/A	N/A	N/A	N/A
Probability of Scenario 3	N/A	N/A	N/A	0.05	N/A	N/A	N/A	N/A	N/A

2.1.1 Weather Data

NREL purchased 25 years of Actual Meteorological Year climate files from Weather Analytics (www.weatheranalytics.com) for Holland, Michigan, to provide a sufficient range in data that portrays realistic variations in actual weather data. These data draw from a full range of weather data taken from meteorological stations around the country (primarily at airports). The data are delivered in a clean format (missing data are filled in and erroneous readings are removed) and packaged for direct use in OpenStudio models. The data downloaded for this analysis included actual weather data for Holland, Michigan between 1988 and 2012. NREL then used R to randomly choose the year of weather data that were then applied to the OpenStudio models.

2.1.2 Operating Conditions Data

A number of data sources and assumptions were used to define the ranges in operating conditions used in this analysis. To bound the scope of this pilot project, NREL focused efforts on a few key operating conditions that have high impact on building energy use and are influenced by daily occupant behavior. Those operating conditions include:

- Ranges in heating and cooling set points during *occupied* hours of the building
- Ranges in the percentage of lights and plug loads left on during *unoccupied* hours of the building
- Ranges in occupant density caused by typical fluctuations in employee numbers.

The following subsections describe the data sources that were used to determine the ranges of each variable.

2.1.2.1 Heating and Cooling Set Points

Measured heating and cooling temperature set points for commercial buildings are not well documented. Many datasets record surveyed temperature set points, but few record actual measured data of observed temperatures. This is an important distinction for this analysis because surveyed temperature set points are often unreliable and do not reflect the actual behavior of occupants who adjust thermostat settings daily. For this study, NREL used a robust dataset containing measured temperature set points from 100 buildings. The study, conducted by Lawrence Berkeley National Laboratory (LBNL), used data from the U.S. Environmental Protection Agency's Building Assessment Survey and Evaluation Study (Mendell and Mirer 2008). This study was conducted from 1994 to 1998 to evaluate parameters related to indoor air quality. Part of the study focused on indoor thermal factors and how temperature ranges influenced health symptoms reported by office workers. The study used temperature observations from 100 buildings, and recorded minimum, maximum, and mean values for heating and cooling. For this analysis, NREL applied these ranges to the baseline temperature schedule used in the OpenStudio office building models. Figure 1 illustrates the modeled baseline temperature set point schedule (assumed as the average) with the minimum and maximum schedule values for heating and cooling during occupied hours. NREL then input these ranges into R to generate a triangular distribution of temperature values that was applied to each model.

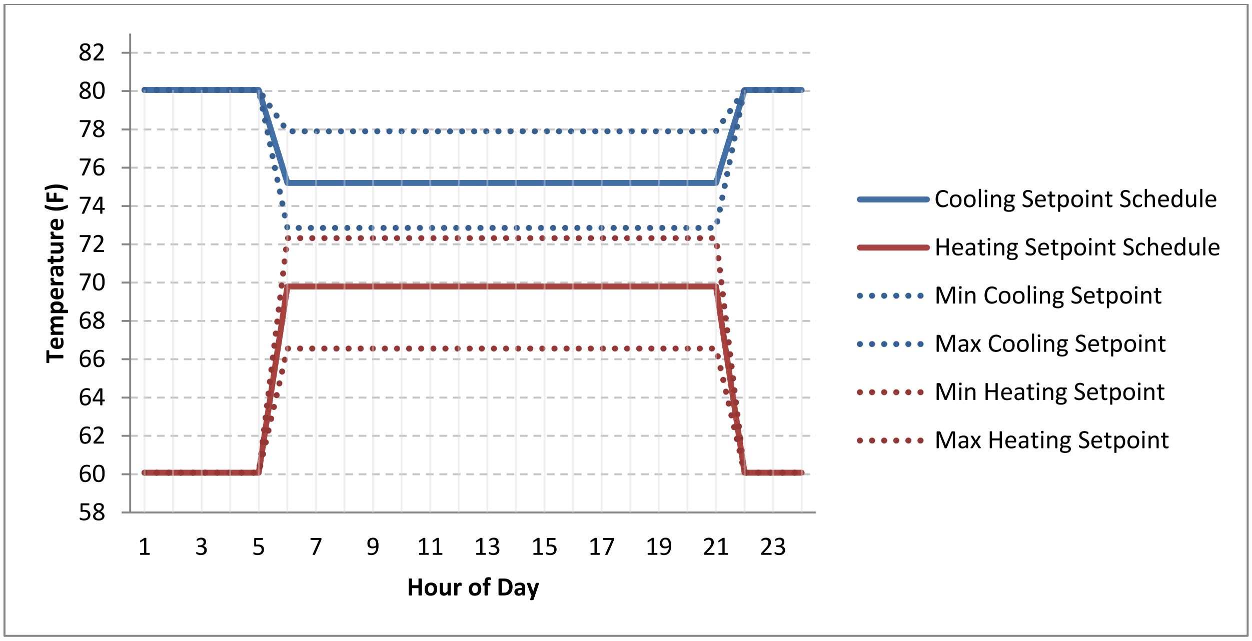

Figure 1. Range of heating and cooling temperature values used in this analysis

Although temperature setback schedules are often implemented as EEMs for office building retrofits, temperature setback was already included as typical operation in the Commercial Reference Building model, so we did not change it. We also assumed that the temperature setback would occur at the same time of day after a retrofit as it did before the upgrades were made.

2.1.2.2 Lighting Loads

We reviewed a number of studies to understand the energy impact of lights being left on during unoccupied hours, and the potential rebound effects of people leaving lights on more frequently after a retrofit. A report by Roth et al. (2004) was used to determine a typical range in energy use caused by lights left on when a space is unoccupied. The study looked at the energy impact of faults in U.S. commercial buildings and concluded that lights left on after occupied hours can account for a 5%–10% increase in lighting energy use.

The International Energy Agency (IEA) wrote a report quantifying rebound effects in 2005 (IEA 2005). The rebound effect results from a tradeoff between energy savings and some other benefit to occupants or owners, such as greater comfort or security. The IEA study tries to resolve criticisms that argue against energy efficiency policies and programs; one criticism is that rebound effects erode most or all energy savings. The study indicates that rebound effects in commercial office buildings are actually quite low, and specifically for lighting, represent an energy savings degradation of only 0%–2% (IEA 2005).

Combining the data from the IEA study, the Roth et al. (2004) study, and a third study on rebound effects by Nadel (1993), NREL concluded that 90% of post-retrofit buildings do not experience a change in occupant behavior associated with lighting use. For the remaining 10%, the studies suggest that 5% of the buildings increased their lighting use and 5% decreased their lighting use during unoccupied hours.

To model this effect, NREL first determined multipliers to apply to the lighting schedule (during unoccupied hours) to increase or decrease the total lighting energy by 10% in each model (based on the Roth 2004 study). The high bound represents rebound effects associated with lighting after a retrofit. The low bound represents the effects of people turning off more lights during unoccupied hours after a retrofit, perhaps because of increased awareness of energy efficiency issues or a change in policy combined with the retrofit. NREL then used R to generate a random but realistic sampling of inputs bound by this discrete probability distribution, that was applied to the OpenStudio models.

2.1.2.3 Plug Loads

Metered plug load data are becoming more prolific as the energy industry realizes that plug loads consume a significant amount of energy in commercial buildings. Nevertheless, only a few studies record metered data of daily energy use trends for individual occupants of office buildings. Fortunately, the NREL Commercial Buildings Research Group has been conducting research in this area and has data on plug loads in individual workspaces for a number of office buildings, including the Research Support Facility located on the NREL campus.

For this study, NREL chose to use plug load data from the Research Support Facility that were collected over 2 years, 2012 and 2013 (OpenEI 2013). The approach and methodology for collecting the data are summarized in a study by Sheppy et al. (2013). Based on averages of the 2 years of data, NREL found a 5%–10% difference in the percentage of plug load use (percentage of the peak load) during unoccupied hours from year to year. This difference identifies normal changes in occupant behavior that should be expected over time. NREL assumed that major rebound effects are unlikely for plug load use following a retrofit; thus, the minimum and maximum schedule values were assumed to have a 10% decrease and 10% increase from the mean. The lower value for the plug loads was left at 10%, which is achievable with advanced power strips (Metzger et al. 2012). To achieve the assumed 10% increase and decrease from the mean, the mean value was then assumed to be 20% of the total peak load, and the upper value was bound at 30%.

2.1.2.4 Occupant Density

A few sources of data were reviewed to determine typical year-to-year fluctuations in average occupant density, assuming that the building, after a retrofit, does not experience a major tenancy change. Unfortunately, available datasets such as CBECS 2003 have such a wide range of occupant density data that the statistical span of inputs was unrealistic for typical small office buildings (EIA 2003). To determine a more realistic range for an individual building over time, NREL used engineering judgment to describe a typical range of fluctuations in occupancy: a 25% increase and decrease from the baseline occupant density was modeled. These values were reviewed by our partner, Energi, and deemed appropriate. Occupant loads and plug loads were adjusted by the same multiplier for occupant density to reflect a corresponding increase or decrease in plug loads caused by the building occupancy fluctuation.

2.1.3 Utility Price Escalation

Utility and fuel escalation rates were gathered from the EIA website. The EIA provides historical energy prices for electricity and natural gas for select states (EIA 2013a, 2013b). NREL used 20 years of data for Michigan (1990 to 2011) to determine the minimum, maximum, and average percent changes in electricity and natural gas prices from one year to the next over the 20-year time period. Electricity and natural gas prices for Michigan are illustrated in Figure 2.

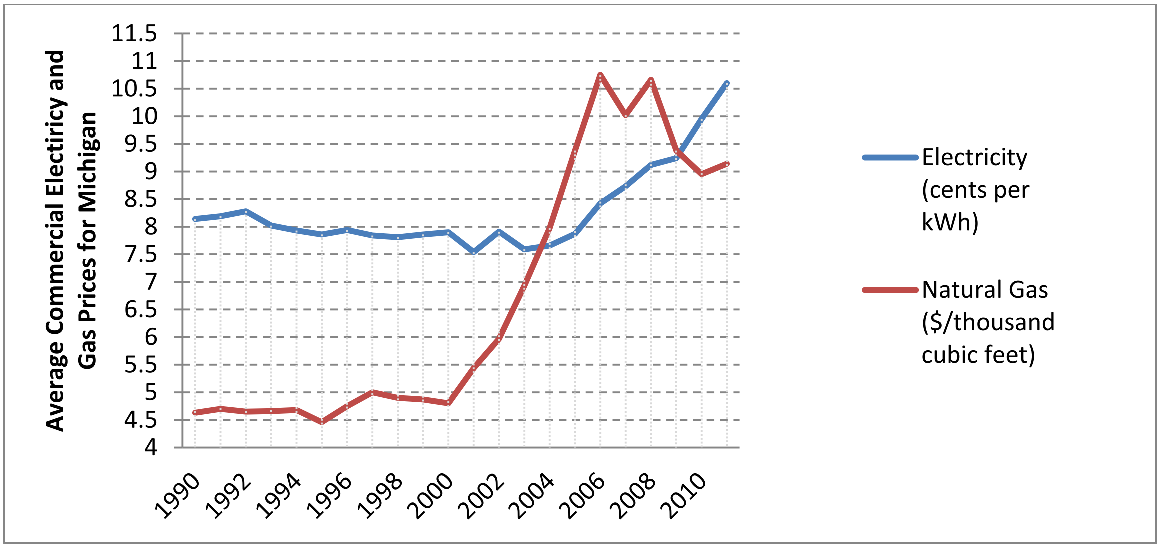

Figure 2. Historical electricity and natural gas prices for Michigan

Typically, projected utility and fuel cost escalation rates are factored into the financing of an energy retrofit loan. Energi and its financial partners confirmed that they often factor in a 3%–5% escalation rate every year. Based on data from the EIA, the range in fuel cost multipliers over the 20-year period includes a minimum value of 0.95 (or 5% price reduction), a maximum value of 1.08, and an average of 1.01 for electricity. For natural gas, a minimum value of 0.88, a maximum value of 1.18, and an average of 1.03 for natural gas were calculated. Because the financing of an energy retrofit loan already considers the expected increase in utility costs, NREL shifted the range values found in the EIA data for both electricity and gas so that the average value was fixed at 1.0. The new ranges, as displayed in Table 12, include a minimum value of 0.94, a maximum value of 1.07, and an average of 1.00 for electricity, and a minimum value of 0.85, a maximum value of 1.15, and an average of 1.00 for natural gas. These ranges were then input into R to generate a triangular distribution of the annual percent change in cost data for electricity and gas in Michigan.

2.1.4 Quality of Preventative Maintenance

NREL used an LBNL study on ongoing commissioning to estimate the effects of continuous maintenance, and quality of maintenance, on EEMs after a retrofit (Mills 2009). The study summarizes the "persistence" of energy savings from commissioning projects and concludes that although some projects exhibit an erosion of savings over time, many do not and the tendency is for level—or even slightly increased—savings over time (Mills 2009). Based on the data presented in this report, the whole-building energy savings from the first year after a retrofit either increased or decreased by approximately 4%; the average was slightly higher than the expected energy savings. A distribution using this range was applied to each model's whole-building energy use.

2.2 Statistical Analysis

The statistical computing and graphics freeware, R, was used to generate a realistic Latin Hypercube Sampling (LHS) of input values for the performance risk variables analyzed in this study, forming a multidimensional distribution. LHS is inspired by the Latin square experimental design, which tries to eliminate confounding effects of various experimental factors without increasing the number of subjects in the experiments (Cheng and Druzdzel 2000). LHS uses an even sampling method that ensures that each value (or range of values) is represented in the samples, no matter which value might turn out to be more important (Cheng and Druzdzel 2000). The resulting set of random inputs yields a very smooth distribution that minimizes the number of runs needed to obtain an accurate distribution of output variables.

Based on the available data for each variable studied in this analysis, NREL first generated approximate triangular distributions for all the normally distributed variables based on the minimum, maximum, and mean values. For these variables, the mean value was assumed to be a good approximation of the modal value (or most common value), which coincides with the peak of the triangle. The triangular distribution characteristics were then fed into the LHS to generate a realistic collection of the parameter values, forming a multidimensional distribution. An example of how a triangular distribution approximates a normal distribution is illustrated in Figure 3.

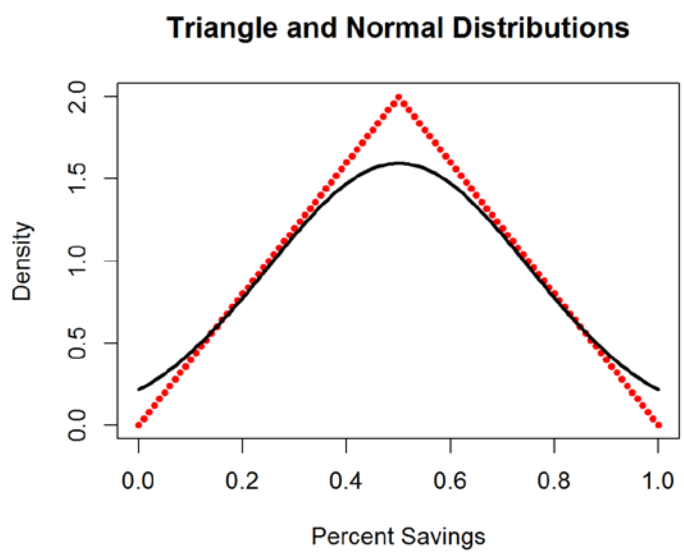

Figure 3. Example of how a triangle distribution approximates a normal distribution

For this pilot study, NREL chose to keep the baseline cases as-is. For future studies, NREL could consider applying the a random sample of inputs to both the baseline and the energy-efficient cases, which would provide an estimate of performance risk associated with uncertain operating conditions that exist both before and after a retrofit. In this pilot study, however, NREL assumed that the baseline building operation before a retrofit is known based on an energy audit, but how that operation will change over time is unknown.

To apply the multidimensional distribution to the building energy models, NREL used OpenStudio to manipulate the models and manage runs. A comma-separated values worksheet containing the random sampling of inputs (generated by R) from distributions was fed into OpenStudio using Ruby scripts. The OpenStudio models were then run on one of NREL's supercomputers; however, this process can be replicated by other organizations using the new OpenStudio feature that allows users to run multiple simulations in parallel on the cloud.

A grid sensitivity analysis was also conducted to determine the appropriate sample size of inputs; i.e., how many OpenStudio runs were needed to generate a smooth distribution curve that illustrates the magnitude of performance risk. To conduct the sensitivity analysis, NREL tested the sample size in the following intervals: 100 samples, 500 samples, 1,000 samples, 2,000 samples, and 5,000 samples. Figure 4 shows an illustration of the distribution curves associated with each sample size. NREL ultimately chose a sample size of 5,000 based on engineering judgment, the smoothness of the distribution curve, and repeatability of the results. Note that the black line illustrates the density curve fit to each histogram.

2.3 Results

NREL generated four sets of results for this study:

- The combined effects of all performance risk variables on energy cost savings (expressed as the actual reduction in annual utility costs)
- The combined effects of all performance risk variables on energy cost savings, assuming a reduced range in uncertainties resulting from the implementation of risk mitigation behavior and policies that ensure optimal building operation
- The effects of individual performance risk variables on energy cost savings
- The combined effects of all performance risk variables on energy cost savings over 3- and 5-year time periods.

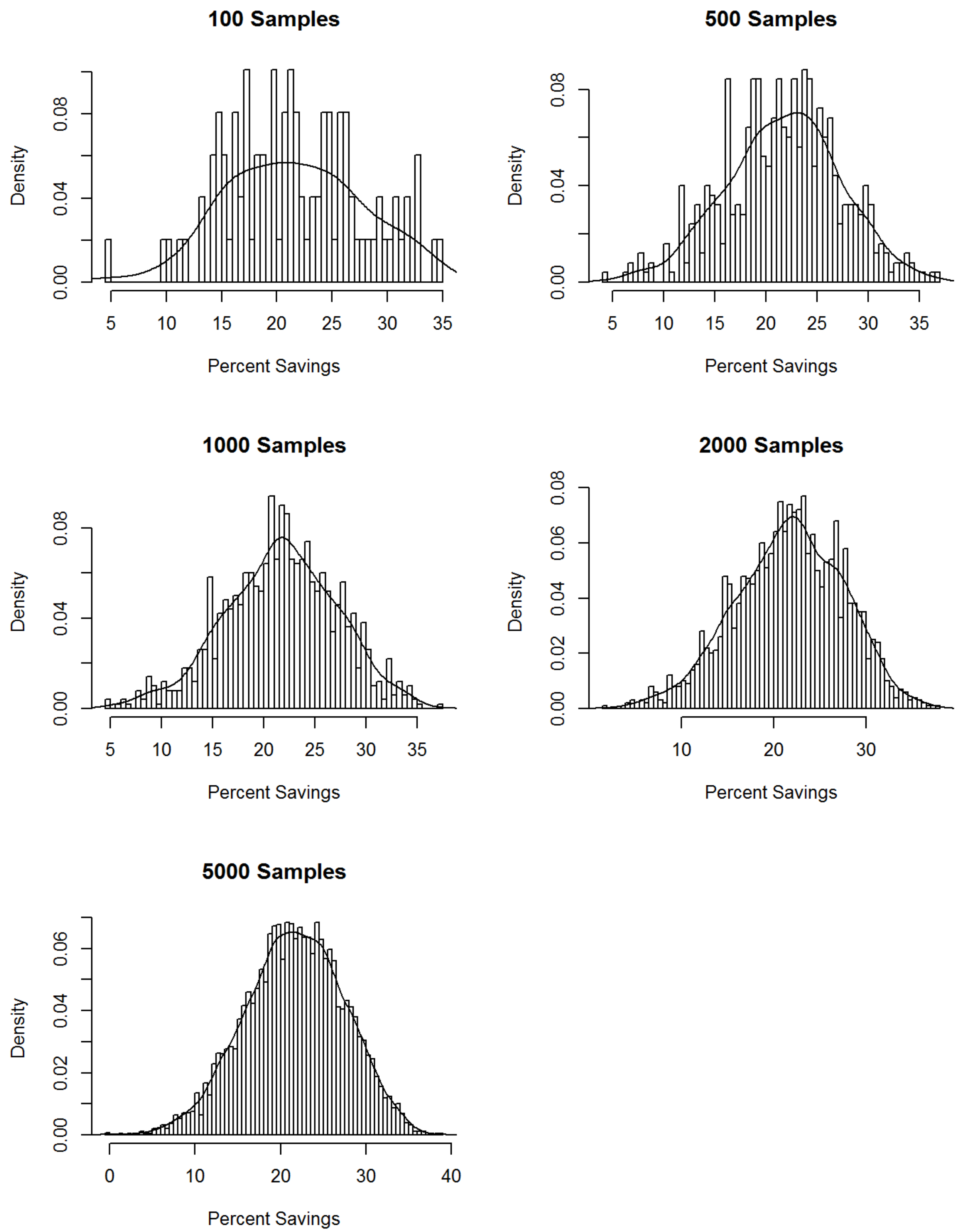

Figure 4. Illustration of output distribution curves for different sample sizes

The first set of results looks at how the performance risk variables analyzed in this study affect energy cost savings in the subset of energy-efficient models developed for Michigan Saves. These models, summarized in Table 11, achieve close to 20% energy savings and offer a net positive cash flow. The results of this analysis, illustrated in Figure 5, show the calculated mean (noted in red) and standard deviation (noted in blue) in energy cost savings due to the effects of the performance risk variables; the mean standard deviation across all of the models is 5.02%, which is equal to about 20% of the mean energy cost savings (approximately 25%) for the packages (this is also called the coefficient of variance, where the standard deviation is divided by the mean). The buffers calculated for this study are summarized in Table 13 and can be applied to the energy cost savings of a retrofit project at various confidence levels. For example, the average buffer of 34% across all building types at a 95% confidence level indicates that the actual energy cost savings will exceed 66% of the expected value 95% of the time. In other words, 5% of the time the savings will be less than 66% of the expected energy cost savings. When reviewing the results in Figure 5, note that the code "ad-e&w&flr" is for cases where the building is adjacent to other buildings on two sides. The black line in each graph shows the density curve fit to the histogram.

Table 13. Buffers To Be Applied to Energy Cost Savings, Calculated at Various Confidence Levels

Confidence Level	90% (1.282 Standard Deviations)	95% (1.645 Standard Deviations)
Coefficient of Variation (ratio of the standard deviation to the mean)	**Calculated Energy Cost Savings Buffers**	
Post-1980, 5,500 ft^2, PTAC HVAC System, Stand-Alone Building: 18%	24%	30%
Post-1980, 5,500 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides: 16%	21%	27%
Post-1980, 25,000 ft^2, PTAC HVAC System, Stand-Alone Building: 23%	30%	39%
Post-1980, 25,000 ft^2, PTAC HVAC System, Stand-Alone Building: 19%	24%	31%
Post-1980, 25,000 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides: 22%	28%	36%
Post-1980, 25,000 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides: 18%	23%	29%
Pre-1980, 25,000 ft^2, PTAC HVAC System, Stand-Alone Building: 29%	38%	49%
Average: 21%	27%	34%

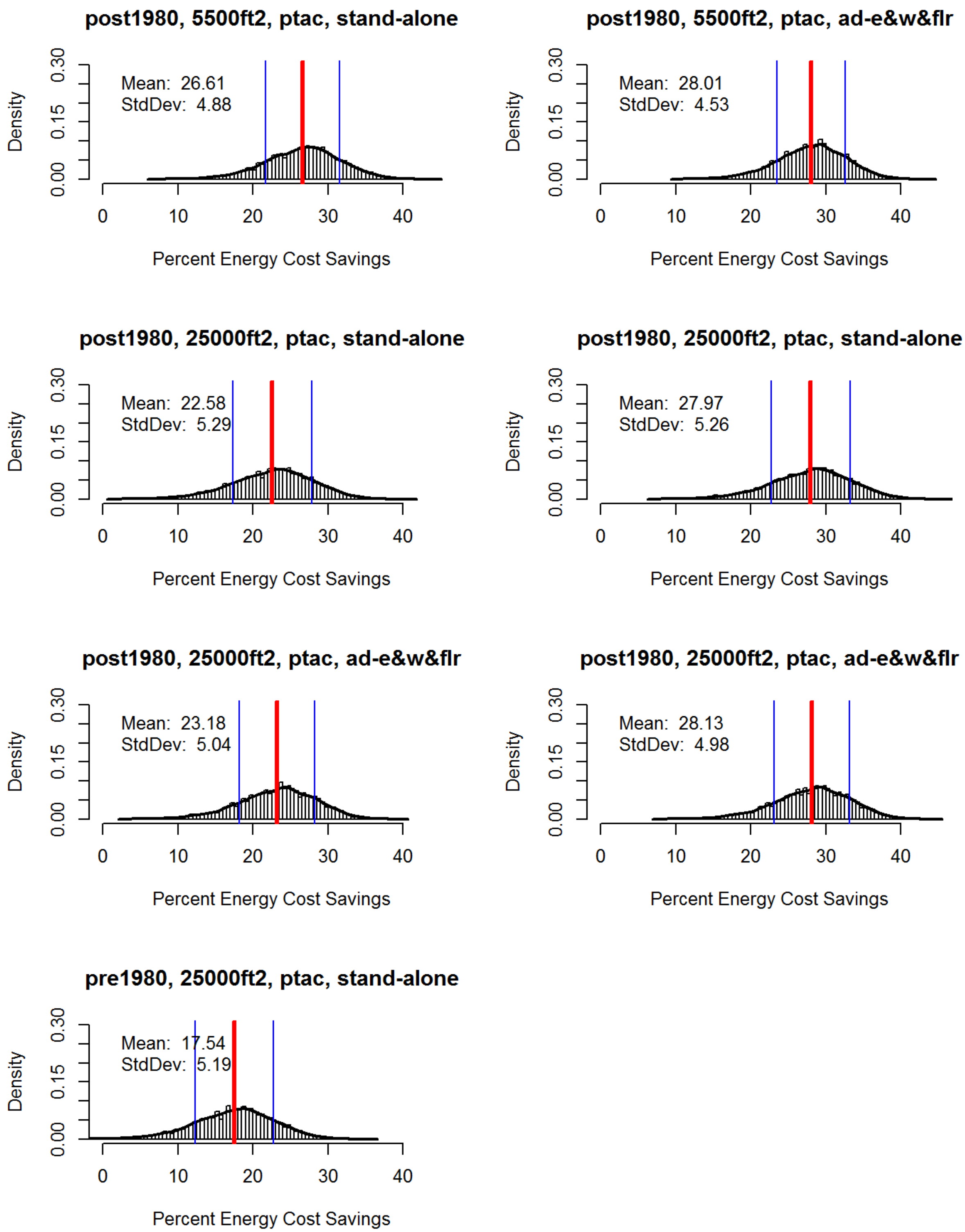

Figure 5. Results showing the average energy cost savings (red) and standard deviations (blue) resulting from building performance uncertainties not covered by performance guarantees for various EEM packages developed for small commercial office buildings. The black line illustrates the density curve fit to each histogram.

The second set of results evaluates how performance risk variables affect building energy cost savings, assuming that risk mitigation strategies are being implemented to control and optimize building operation in a manner that reduces performance risk. Not all performance risk uncertainties can be easily mitigated; for example, weather and fuel escalation rates are completely uncontrollable by the building owner, and very little can be done to reduce the impact. However, uncertainties associated with occupant behavior and quality of preventative maintenance can be controlled to a certain degree. To help reduce these risks, we recommend that the building owner:

- Use controls and set policies around building operation to confirm that the building is operated within the intended bounds. These controls and policies can be placed to better guarantee appropriate thermostat settings during occupied hours, and to encourage lights and plug load equipment to be turned off at night and when not in use during the day.
- Regularly check and confirm that the building is being operated within intended bounds, and always look for operational improvements. Maximizing occupant density by maintaining appropriate occupancy levels or, if possible, consolidating employee workspaces to a particular floor or wing of a building can also help reduce energy consumption by reducing the need to condition and power unused office space.
- Schedule retrocommissioning to ensure major building equipment is being operating at its maximum efficiency.
- If building owners have tenants, it may be appropriate to shift some of the performance risk to tenants that have control over building operations and occupancy levels. Green leases are one way to achieve this. These risk mitigation strategies are summarized in Appendix A.

For this particular study, we assumed that controls, policies, and risk mitigation strategies such as retrocommissioning reduce the ranges in uncertainties associated with heating and cooling temperature set points, lighting and plug load equipment schedules, and the quality of preventative maintenance. We also assumed that the building owner would take steps to optimize space utilization in the building, thus reducing the need to heat, cool, light, and power unused office space. Because there are limited data on how risk mitigation strategies truly affect the range of operational values for each performance risk variable, NREL chose to reduce the range, somewhat arbitrarily, by 50% to illustrate the correlation between a building with more stringent controls and the resulting distribution of energy savings. The 50% reduction can also be viewed as an operational target for the building owner. If the building owner can operate the building within the tighter ranges, there is high confidence that greater energy savings will be achieved. The tighter distribution ranges used in this particular study are highlighted in red in Table 14.

Table 14. Summary of Performance Risk Variables With Tighter Distribution Ranges, Accounting for Best Practices and Efficient Building Control. The Reduced Values are Highlighted in Red and Can Be Compared to Table 12.

Reduced Ranges (Reduced by 50%)	Weather	Heating Set Point (Occupied Hours)	Cooling Set Point (Occupied Hours)	Lighting Schedule (Unoccupied Hours)	Equipment Schedule (Unoccupied Hours)	Occupant Density	Utility Price Escalation Electricity	Utility Price Escalation Gas	Quality of Preventative Maintenance
Units	**Year of weather data used in simulation**	**°F**	**°F**	**Multiplier applied to schedule**	**Multiplier applied to schedule**	**Multiplier applied to occupied density**	**Multiplier applied to calculated electricity cost**	**Multiplier applied to calculated gas cost**	**Multiplier applied to whole building energy use**
Probability Distribution	Uniform	Triangular	Triangular	Discrete	Triangular	Triangular	Triangular	Triangular	Triangular
Range: Minimum	1988	68.18	74.03	N/A	0.1	0.88	0.94	0.85	0.98
Range: Maximum	2012	71.06	76.55	N/A	0.2	1.13	1.07	1.15	1.02
Mean	N/A	69.80	75.20	N/A	0.15	1.00	1.00	1.00	1.003
Scenario 1	N/A	N/A	N/A	1.00	N/A	N/A	N/A	N/A	N/A
Scenario 2	N/A	N/A	N/A	1.32	N/A	N/A	N/A	N/A	N/A
Scenario 3	N/A	N/A	N/A	0.69	N/A	N/A	N/A	N/A	N/A
Probability of Scenario 1	N/A	N/A	N/A	0.90	N/A	N/A	N/A	N/A	N/A
Probability of Scenario 2	N/A	N/A	N/A	0.05	N/A	N/A	N/A	N/A	N/A
Probability of Scenario 3	N/A	N/A	N/A	0.05	N/A	N/A	N/A	N/A	N/A

The results of this analysis, illustrated in Figure 6, show the calculated mean (noted in red) and standard deviation (noted in blue) in energy cost savings due to the effects of the tighter distribution of the performance risk variables. The average standard deviation across the models, in this case, is 3.08%, which is equal to about 11% of the mean energy cost savings (approximately 27%) for the packages. Again, expressed another way, the results indicate that we can be 95% confident that energy cost savings will exceed 81% of the expected value. This means that only 5% of the time, the savings will be less than 81% of the expected value, indicating that energy savings are much more predictable than the first set of results. The buffers calculated for the tighter uncertainty ranges are summarized in Table 15 and can be applied to the energy cost savings of a retrofit project at various confidence levels.

Table 15. Buffers Calculated From the Tighter Ranges of Performance Risk Variables, To Be Applied to Energy Cost Savings at Various Confidence Levels

Confidence Level	90% (1.282 Standard Deviations)	95% (1.645 Standard Deviations)
Coefficient of Variation (ratio of the standard deviation to the mean)	**Calculated Energy Cost Savings Buffers**	
Post-1980, 5,500 ft^2, PTAC HVAC System, Stand-Alone Building: 11%	14%	18%
Post-1980, 5,500 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides: 10%	13%	16%
Post-1980, 25,000 ft^2, PTAC HVAC System, Stand-Alone Building: 12%	16%	21%
Post-1980, 25,000 ft^2, PTAC HVAC System, Stand-Alone Building: 10%	13%	17%
Post-1980, 25,000 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides: 12%	15%	20%
Post-1980, 25,000 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides: 10%	13%	16%
Pre-1980, 25,000 ft^2, PTAC HVAC System, Stand-Alone Building: 16%	21%	27%
Average: 12%	15%	19%

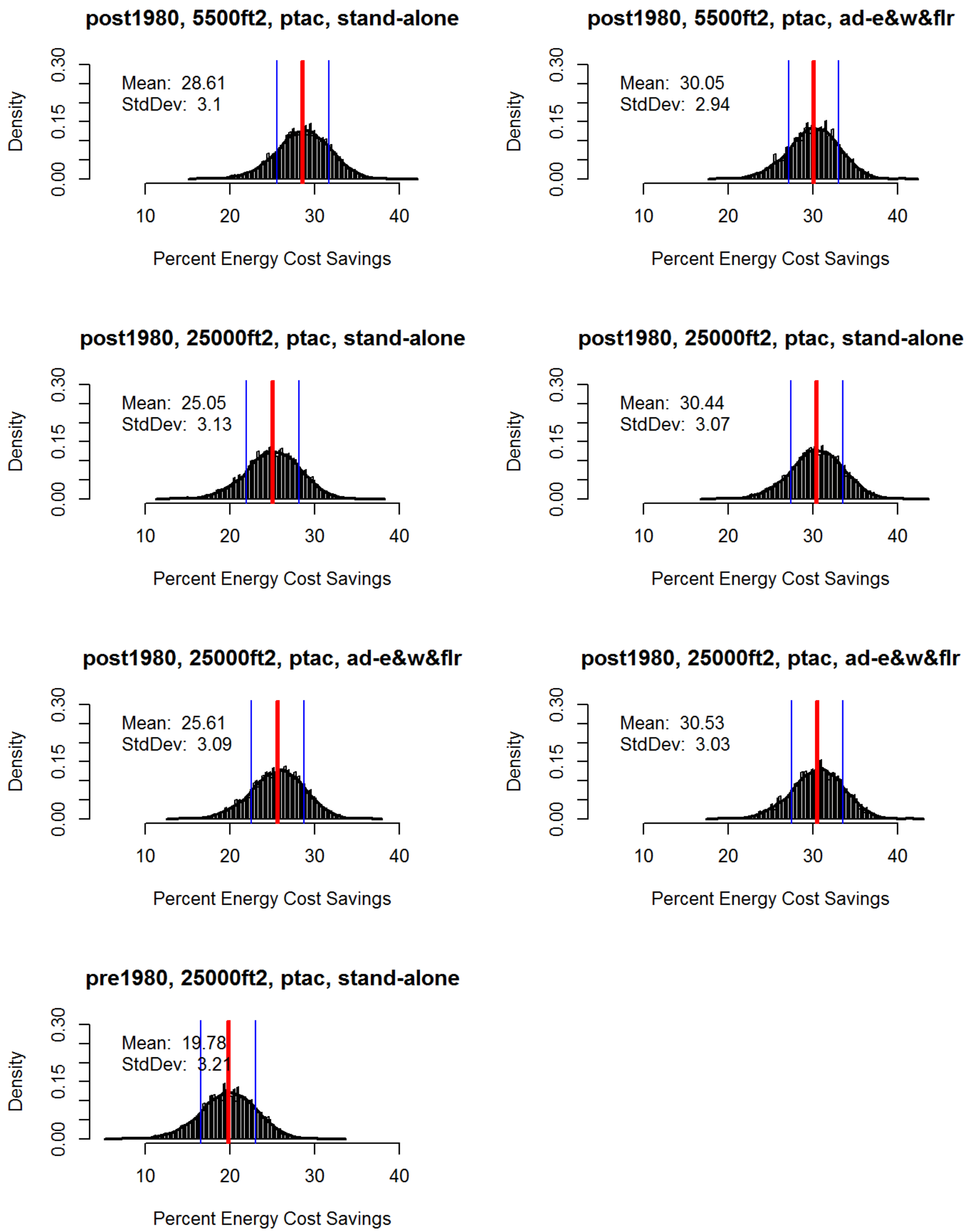

Figure 6. Results showing the average energy cost savings (red) and standard deviation (blue) resulting from a tighter range in building performance uncertainties not covered by performance guarantees for various EEM packages developed for small commercial office buildings. The black line illustrates the density curve fit to each histogram.

A third study was conducted to determine the effects of each performance risk variable on energy cost savings. For this study, we used the post-1980, stand-alone, 25,000-ft^2 office building model. All EEMs were applied to the model to avoid showing preference to any particular measure or group of measures. The results, as seen in Figure 7, highlight the impact of each uncertainty on energy cost savings. The performance risk variable with the highest impact on energy cost savings is occupant density, which makes logical sense because occupants drive the major loads within the building. Following occupant density are the heating and cooling temperature set points, plug loads left on at night, lights left on at night, and lastly, weather. These results pose an interesting perspective: if a building is controlled and managed correctly, the risk associated with these performance uncertainties can decrease. Paired with the previous results, by implementing risk mitigation strategies (summarized in Appendix A), the owner and lender can have much higher confidence in achieving the estimated energy savings.

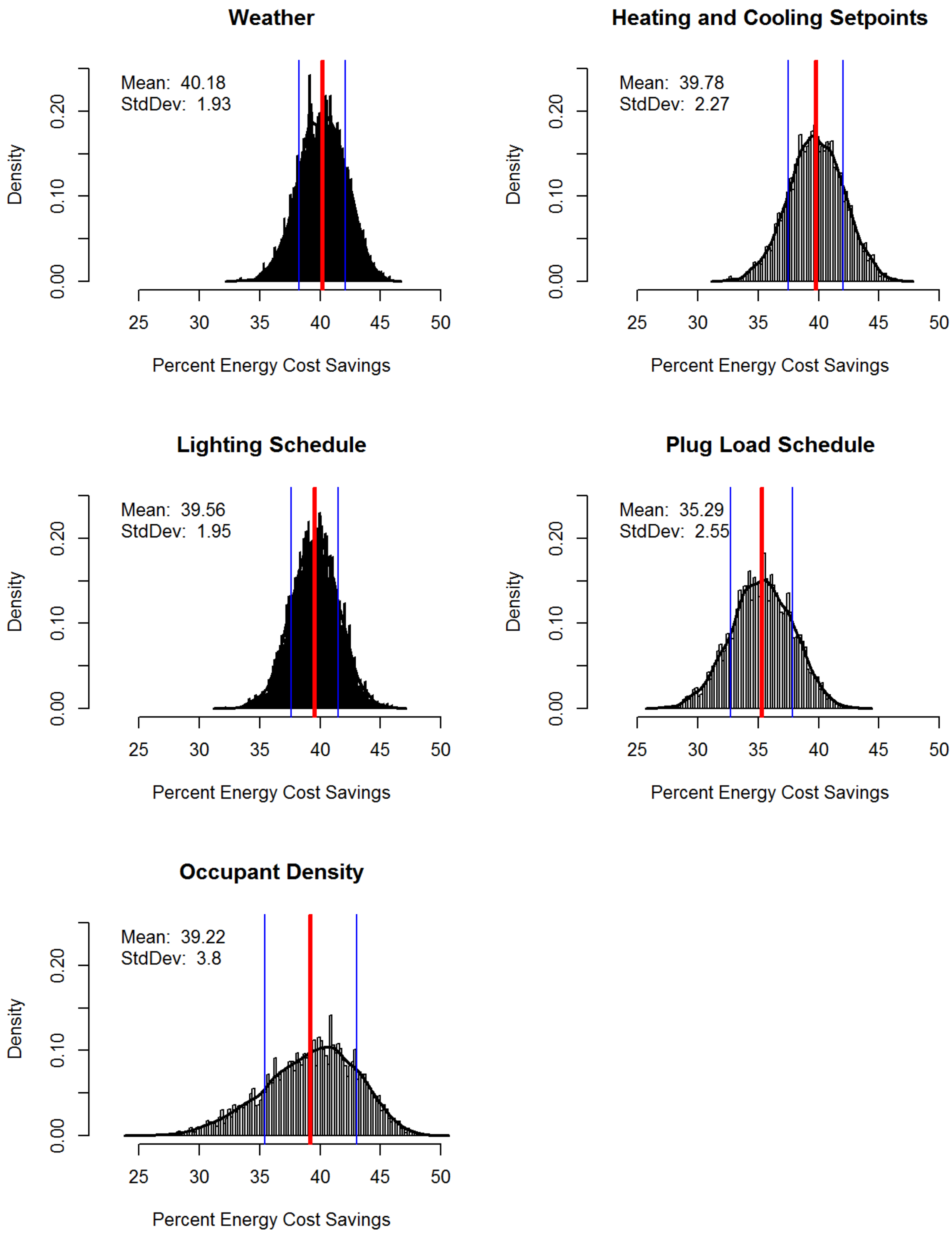

Figure 7. Results showing the average energy cost savings (red) and standard deviation (blue) resulting from individual performance uncertainties on energy cost savings. This study was conducted on the post-1980, 25,000-ft^2, stand-alone, small office building model. All EEMs were applied to this model.

Going a step further, NREL looked at the effects of the uncertainties on energy cost savings over 3- and 5-year time periods, because most performance agreements look at savings over multiple years. To do so, NREL randomly selected and averaged groups of 3 or 5 of the 5,000 results of the study (while maintaining the same sample size of 5,000 outputs) to generate a distribution of the uncertainty effects on energy cost savings over 3- and 5-year time periods, respectively. The results are summarized in the following four figures. Figure 8 and Figure 9 show the effects of the uncertainties using the original distribution ranges over 3- and 5-year time periods, respectively. Likewise, Figure 10 and Figure 11 show the effects of the uncertainties using the tightened distribution ranges over a 3-year and a 5-year time period, respectively. Overall, the longer-term results indicate that for a given confidence level, the energy cost savings are likely to exceed a much higher percentage of the expected value than the results from the 1-year intervals. With these results, we encourage financial institutions and building owners to consider the energy cost savings over a longer time period, because the effects of the uncertainties tend to lessen over time. The buffers in this study are summarized in Table 16 and Table 17. Figure 8 through Figure 11 follow.

Table 16. Buffers Calculated Using the Original Distribution Ranges Over 3- and 5-Year Time Periods

Effects of Uncertainties Over 3- and 5-Year Time Periods, *Original Distribution Ranges*	Confidence Level		90% (1.282 Standard Deviations)		95% (1.645 Standard Deviations)	
	Coefficient of Variation (% of mean)		Calculated Energy Cost Savings Buffers			
	3-Year	5-Year	3-Year	5-Year	3-Year	5-Year
Post-1980, 5,500-ft^2, PTAC HVAC System, Stand-Alone Building	11%	8%	14%	11%	18%	14%
Post-1980, 5,500-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	9%	7%	12%	9%	16%	12%
Post-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	14%	11%	17%	14%	22%	17%
Post-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	11%	8%	14%	11%	18%	14%
Post-1980, 25,000 ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	13%	10%	16%	13%	21%	16%
Post-1980, 25,000-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	10%	8%	13%	10%	17%	13%
Pre-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	17%	13%	22%	17%	28%	22%
Average	12%	9%	16%	12%	20%	15%

Table 17. Buffers Calculated Using the Reduced Distribution Ranges Over 3- and 5-Year Time Periods

Effects of Uncertainties Over 3- and 5-Year Time Periods, *Reduced Distribution Ranges*	Confidence Level		90% (1.282 Standard Deviations)		95% (1.645 Standard Deviations)	
	Coefficient of Variation (% of mean)		Calculated Energy Cost Savings Buffers			
	3-Year	5-Year	3-Year	5-Year	3-Year	5-Year
Post-1980, 5,500-ft^2, PTAC HVAC System, Stand-Alone Building	6%	5%	8%	6%	10%	8%
Post-1980, 5,500-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	6%	4%	7%	6%	9%	7%
Post-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	7%	6%	9%	7%	12%	9%
Post-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	6%	5%	7%	6%	10%	8%
Post-1980, 25,000-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	7%	5%	9%	7%	11%	9%
Post-1980, 25,000-ft^2, PTAC HVAC System, Adjacent to Buildings on 2 Sides	6%	4%	7%	6%	9%	7%
Pre-1980, 25,000-ft^2, PTAC HVAC System, Stand-Alone Building	9%	7%	12%	9%	15%	12%
Average	7%	5%	9%	7%	11%	9%

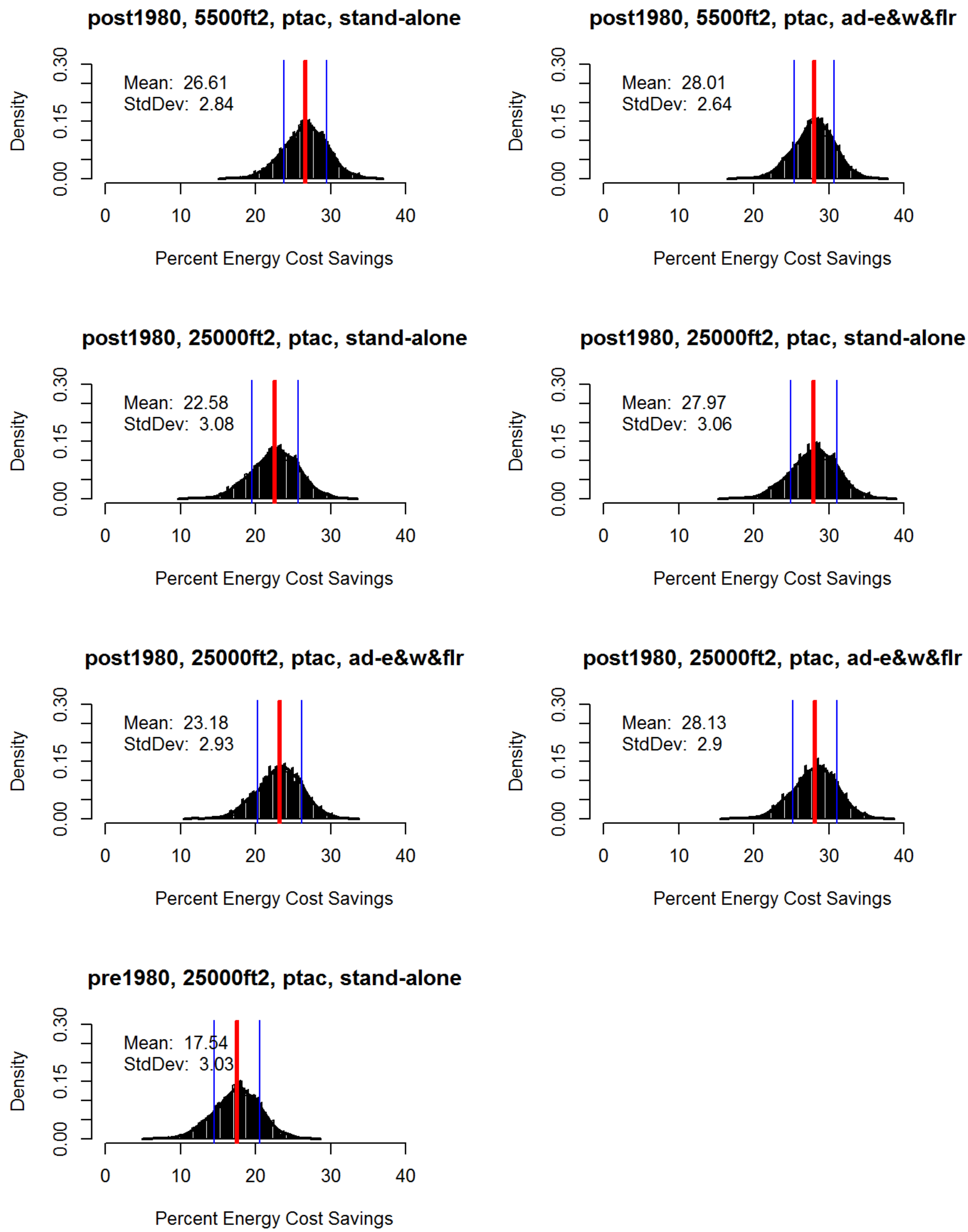

Figure 8. Results showing the average energy cost savings (red) and standard deviation (blue) over a 3-year time period resulting from building performance uncertainties not covered by performance guarantees for various EEM packages developed for small commercial office buildings. The black line illustrates the density curve fit to each histogram.

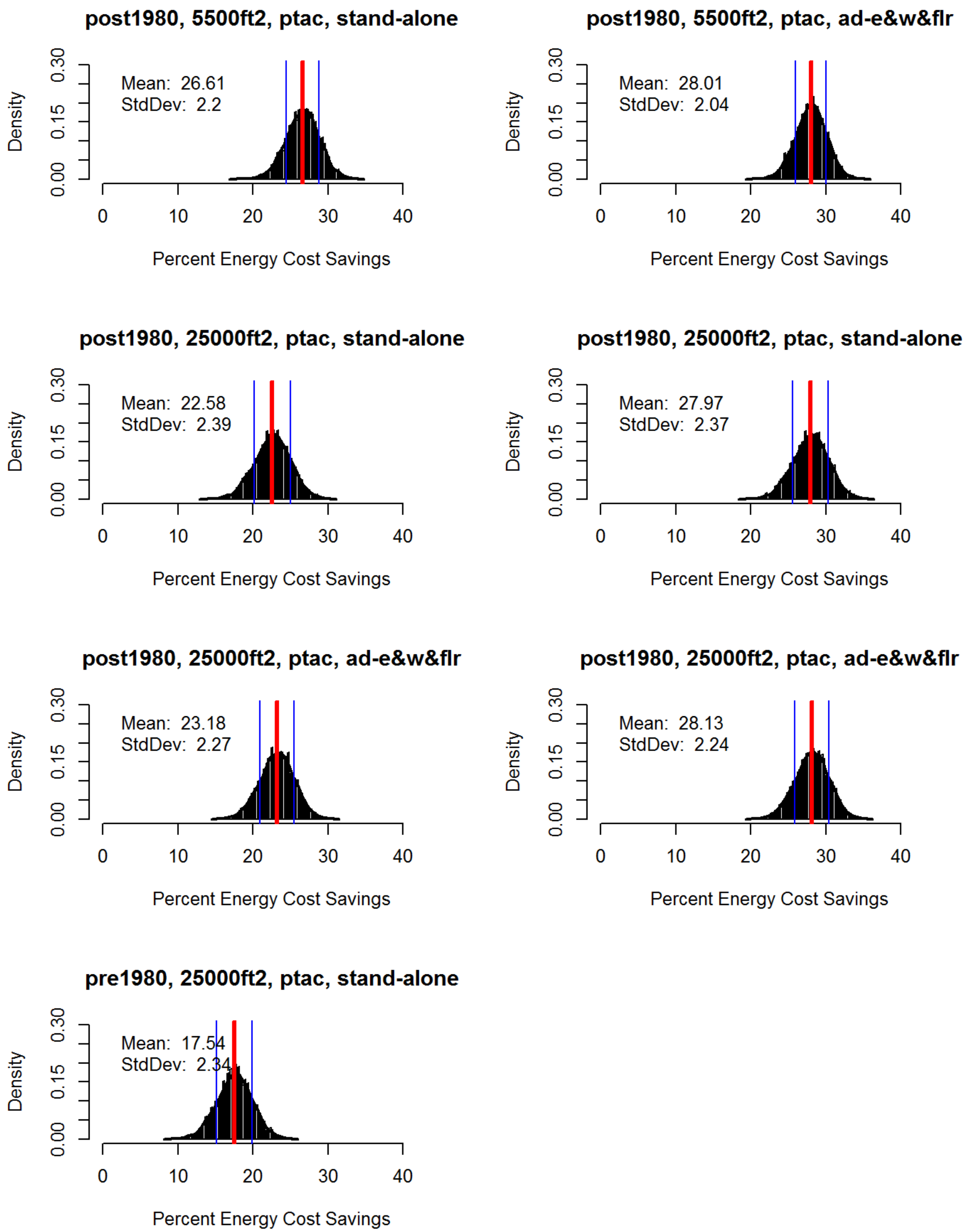

Figure 9. Results showing the average energy cost savings (red) and standard deviation (blue) over a 5-year time period resulting from building performance uncertainties not covered by performance guarantees for various EEM packages developed for small commercial office buildings. The black line illustrates the density curve fit to each histogram.

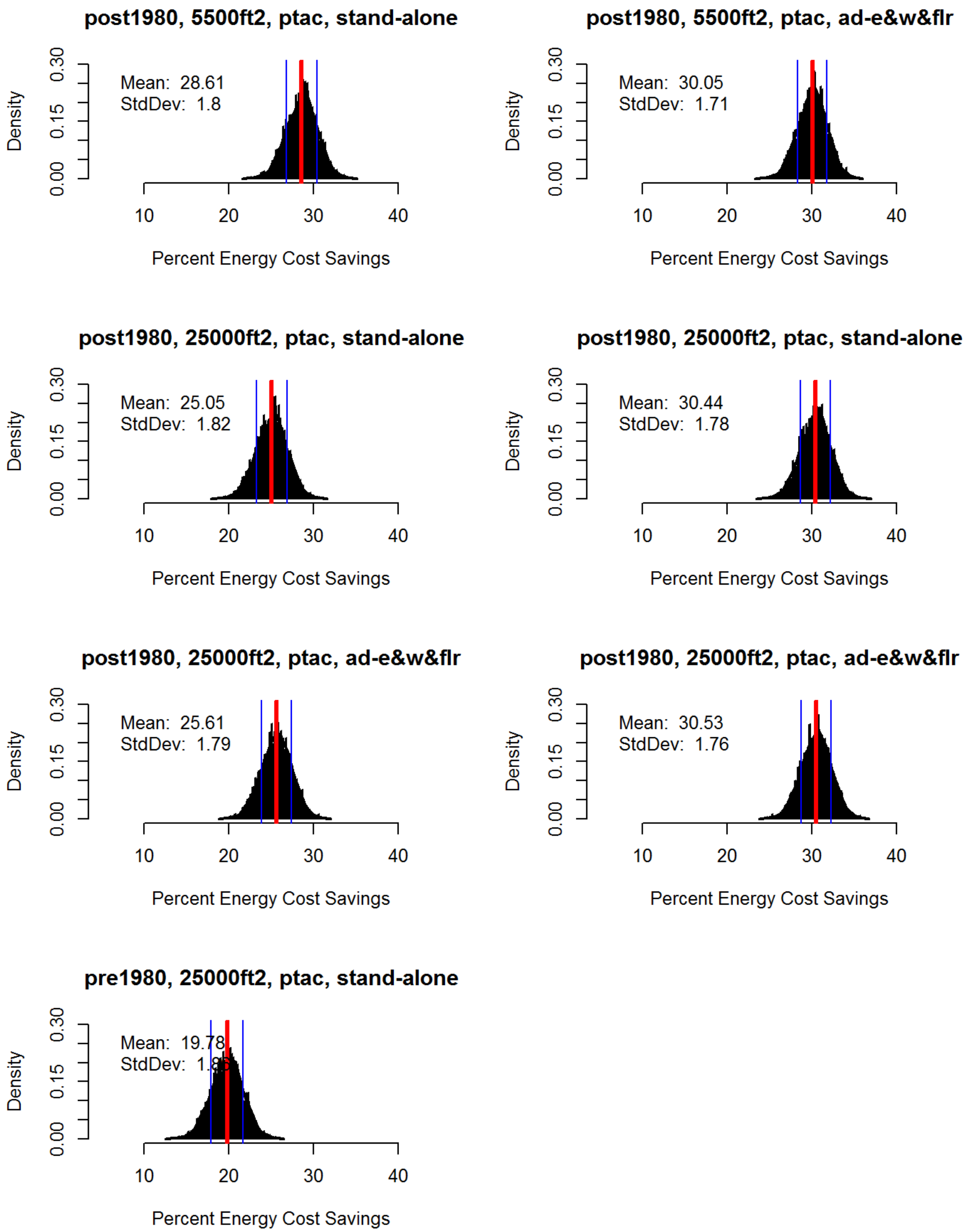

Figure 10. Results showing the average energy cost savings (red) and standard deviation (blue) over a 3-year time period, resulting from a tighter range in building performance uncertainties not covered by performance guarantees for various EEM packages developed for small commercial office buildings. The black line illustrates the density curve fit to each histogram.

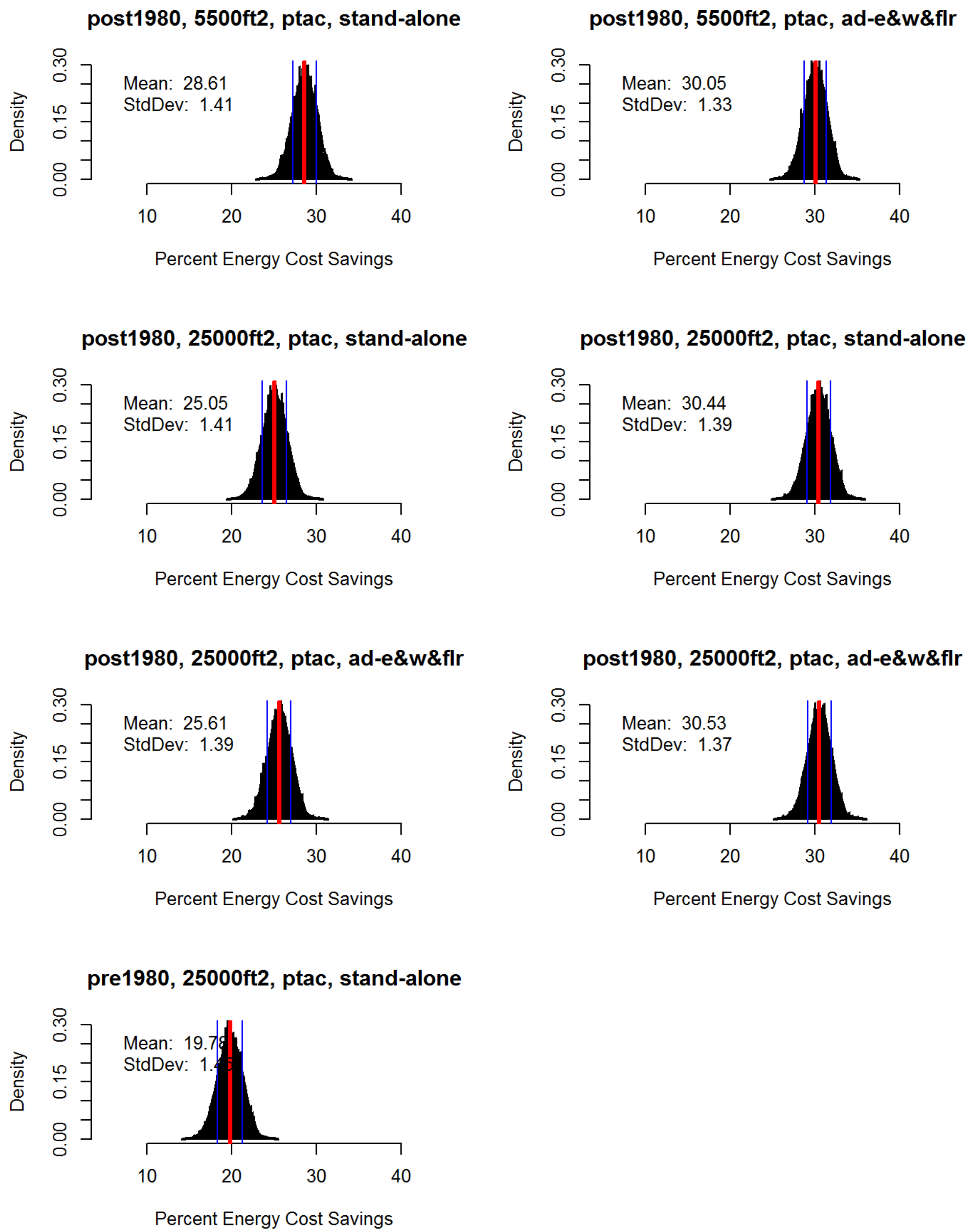

Figure 11. Results showing the average energy cost savings (red) and standard deviation (blue) over a 5-year time period, resulting from a tighter range in building performance uncertainties not covered by performance guarantees for various EEM packages developed for small commercial office buildings. The black line illustrates the density curve fit to each histogram.

3 Conclusions and Next Steps

This pilot project targeted two of the largest barriers to financing energy efficiency projects in small commercial buildings: disproportionately high transaction costs and unknown performance risk. NREL collaborated with two lead partners, Michigan Saves and Energi Insurance Services, along with several contractors, service providers, utilities, and lenders, to develop technical products that address both barriers in a complementary manner.

To reduce transaction costs, NREL assisted Michigan Saves in the development of low-risk EEM packages for one specific building type: small office buildings. These packages can be integrated into third-party service provider offerings and coordinated with utility rebates to create pre-approved turnkey solutions targeting a specific level of energy savings. The EEMs included in each recommended EEM package, summarized in the EEM Selection & Cost Evaluation Tool, were selected to maximize the predictability of energy savings and financial returns and meet a particular energy savings target. The EEM Selection & Cost Evaluation was developed for the project, providing the complete set of more than 30,000 simulations, and allowing flexibility to change the cost assumptions and financing parameters.

To reduce performance risk, NREL partnered with Energi to quantify the drivers of uncertain energy savings and provide direction for mitigating that uncertainty. Although much of the performance risk can be controlled through contractor guarantees and insurance against performance risk stemming from equipment, design, modeling, and workmanship, lenders currently have no parameters or approach to understand risks outside these sources. NREL performed this analysis of performance risk using the same building type, climate zone, and EEMs selected for the Michigan Saves recommended retrofit packages. NREL also recommended methods for managing uncertainty throughout the life of the loan. By providing greater confidence in the actual range of cash flows that can be expected for an energy efficiency project, more lenders may be willing to provide affordable financing to small building owners who can effectively control the performance risk. The results can also be applied to rating and securitization of energy efficiency loans, providing a consistent buffer range and approach for analysis and control of building performance risk that falls outside of typical performance guarantees. Although this study was conducted in the context of the Energi collaboration, it is a very challenging source of risk for all financed projects, and even those that are paid for using the owner's capital funds.

The methodology used for this pilot project can be replicated in other small building sectors, in other locations, and with other financing models to help increase lender confidence, reduce investment risk and transaction costs, and motivate small building and business owners to invest in efficiency upgrades. This report documents the processes and resources used to perform the analysis of low-risk, pre-approved packages, as well as the uncertainty analysis of building performance risk, allowing other organizations to expand on the results in a consistent, efficient, and repeatable manner.

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Appendix A: EEM Selection & Cost Evaluation Tool Snapshot

Appendix A provides a snapshot of the EEM Selection & Cost Evaluation Tool (www.nrel.gov/buildings/docs/2014_eemselection_costevaltool_smoffice.xlsm). This tool is available to the public upon request. The tool has a simple user interface, where the user can input basic building data, run a simple built-in macro, and see applicable EEM packages that are appropriate and cost effective for a particular building. The building data required to run the tool include the building vintage, square footage, HVAC system type, and boundary condition (whether the building is a stand-alone building, or attached to other buildings on either one or two sides). The user can also select an energy savings threshold, defined as the minimum energy savings that the building owner or evaluator expects to achieve cost effectively. By running the built-in macro (the user selects the "Run" button), the tool filters presimulated results to select EEM bundles that meet the energy savings threshold and are calculated to be cost effective. Again, cost effective is defined as a net positive cash flow, where the annual energy cost savings is greater than the annual payment of an energy efficiency investment.

A few things should be noted about the tool:

1. The predicted energy and energy cost savings represented in the EEM selection and Cost Evaluation Tool may not be accurate for all small office buildings. It is intended to be used by building owners to gain understanding of a wider range of possible EEM options that can be implemented within a building cost effectively.
2. There may be other EEMs not represented in this tool that are also cost effective and appropriate for a particular building. The EEMs included in this tool represent "typical" EEMs that are commonly applied to small office buildings.
3. The full set of EEM combinations, energy savings results, and energy cost savings results (used as input for this tool) are located in the *Results* tab. It is not intended that the user use this tab; however, these results are provided in case the user wants to understand or modify how the cost savings calculations are calculated.

Figure 12 shows the main user interface of the EEM Selection & Cost Evaluation Tool. The user inputs information about a particular building in the "Input Building Data" section. After hitting the "Run" button, the built-in macro sorts the results and displays cost-effective EEM package options under the gold-colored column headers. Each row of results describes a particular EEM package that is cost effective. The energy savings and cost analysis is also provided as part of this output.

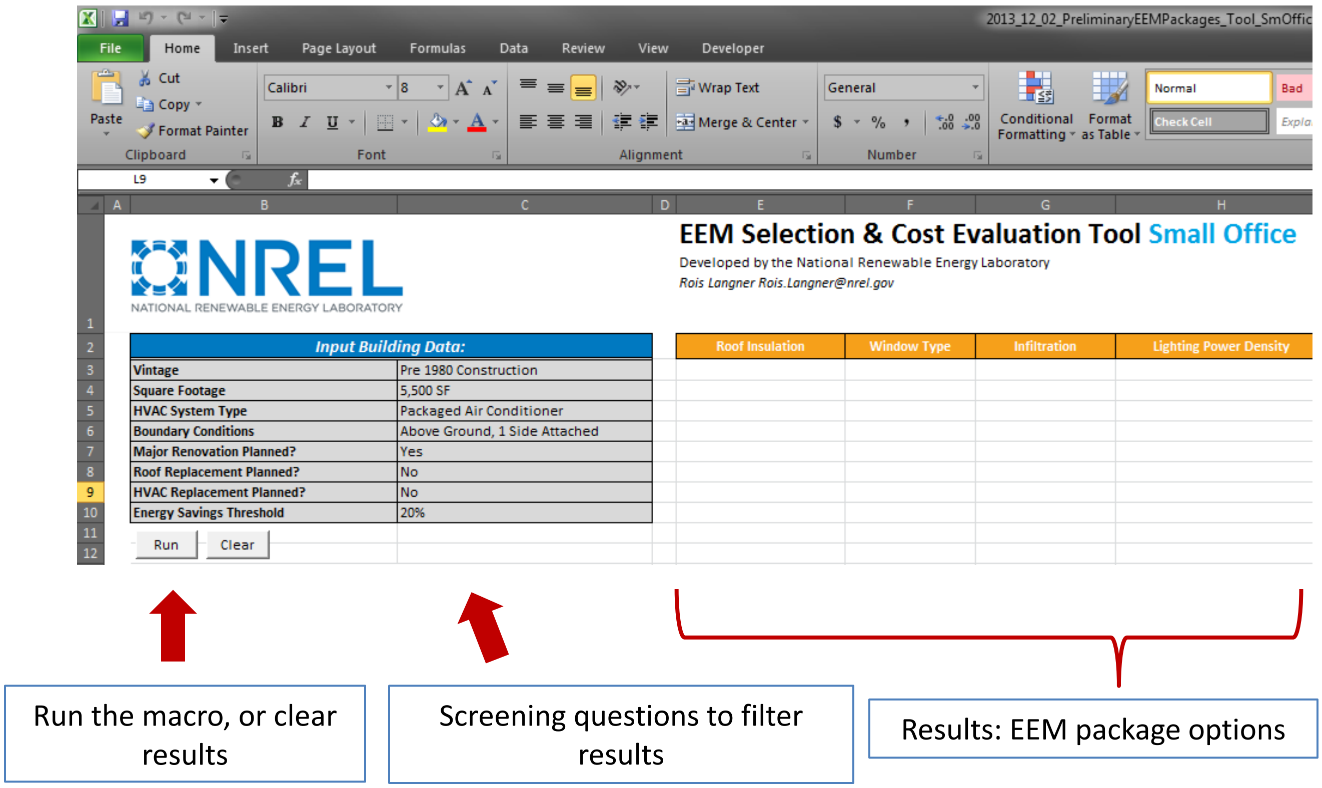


Figure 12. Snapshot of the EEM Selection & Cost Evaluation Tool's graphical user interface

Because the costs for energy efficiency improvements can vary per building project and location, the tool allows the user to modify cost values. If a cost value is modified, the results and cost analysis will reflect the updated cost value. A snapshot of the tool's graphical user interface where the user can modify efficiency measure costs is shown in Figure 13.

13	**Additional Data - Update as Necessary**		
14	***Efficiency Measure Costs***		
15	**Increase Roof Insulation ($/ft2 of Roof Area)**		
16	Incremental Cost:	$	3.00
17	Full Cost:	$	12.15
18	O&M Cost:	$	-
19	**Replace Windows ($/ft^2 of Window Area)**		
20	Incremental Cost:	$	7.18
21	Full Cost:	$	43.00
22	O&M Cost:	$	-
23	**Reduce Building Leakage ($/ft^2 of Exterior Wall Area)**		
24	Incremental Cost:	$	0.43
25	Full Cost:	$	0.43
26	O&M Cost:	$	-
27	**LPD Reduction: Retrofit from T12s to T8s, 40fc ($/ft^2)**		
28	Incremental Cost:	$	0.66
29	Full Cost:	$	2.06
30	O&M Cost:	$	(0.12)
31	**LPD Reduction: Retrofit to T8s and Change Design, 25fc ($/ft^2)**		
32	Incremental Cost:	$	0.79
33	Full Cost:	$	11.15
34	O&M Cost:	$	(0.19)
35	**Daylighting Controls Added to Perimeter Zones ($/ft^2)**		
36	Incremental Cost:	$	0.55
37	Full Cost:	$	3.41
38	O&M Cost:	$	-
39	**Occupancy Sensors Applied to Entire Office Building ($/ft^2)**		
40	Incremental Cost:	$	0.36
41	Full Cost:	$	0.36
42	O&M Cost:	$	-
43	**Advanced Power Strips ($/ft^2)**		
44	Incremental Cost:	$	0.15
45	Full Cost:	$	0.15
46	O&M Cost:	$	-
47	**Replace HVAC Equipment PSZ-AC: Rooftop Unit with Gas Furnace ($/ft^2)**		
48	Incremental Cost:	$	0.41
49	Full Cost:	$	6.09
50	O&M Cost:	$	-
51	**Replace HVAC Equipment - PTAC: Split System Air-Conditioner with Gas Furnace ($/ft^2)**		
52	Incremental Cost:	$	0.66
53	Full Cost:	$	2.85
54	O&M Cost:	$	-
55	**Replace HVAC Equipment - PTHP: Heat Pump ($/ft^2)**		
56	Incremental Cost:	$	1.53
57	Full Cost:	$	3.30
58	O&M Cost:	$	-

Figure 13. Snapshot of the EEM Selection & Cost Evaluation Tool's graphical user interface, where the user can modify estimated energy efficiency improvement costs

Similarly, the user can modify the utility costs (for electricity and gas) and specifics for a particular loan (interest rate and loan term). A snapshot of this part of the EEM Selection & Cost Evaluation Tool is shown in Figure 14.

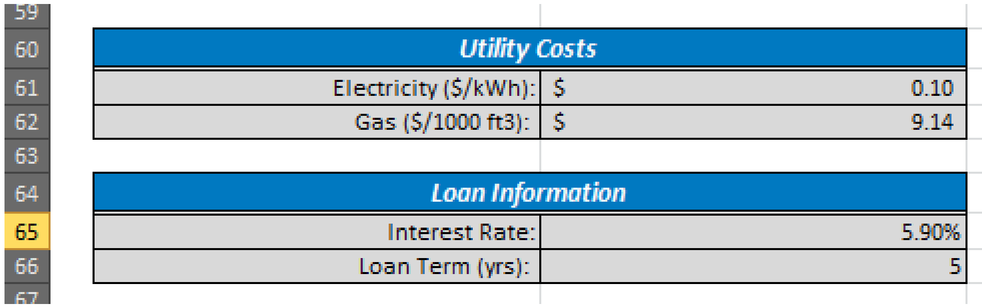


Figure 14. Snapshot of the EEM Selection & Cost Evaluation Tool's graphical user interface, where the user can modify utility costs and loan information

Once the macro has been run, the tool lists descriptions of possible EEM package options that meet the user-specified energy savings threshold cost effectively. Each row provides a different EEM package with data regarding the energy and energy cost savings, and complete cost analysis to implement each package. A snapshot of this part of the tool is shown in Figure 15.

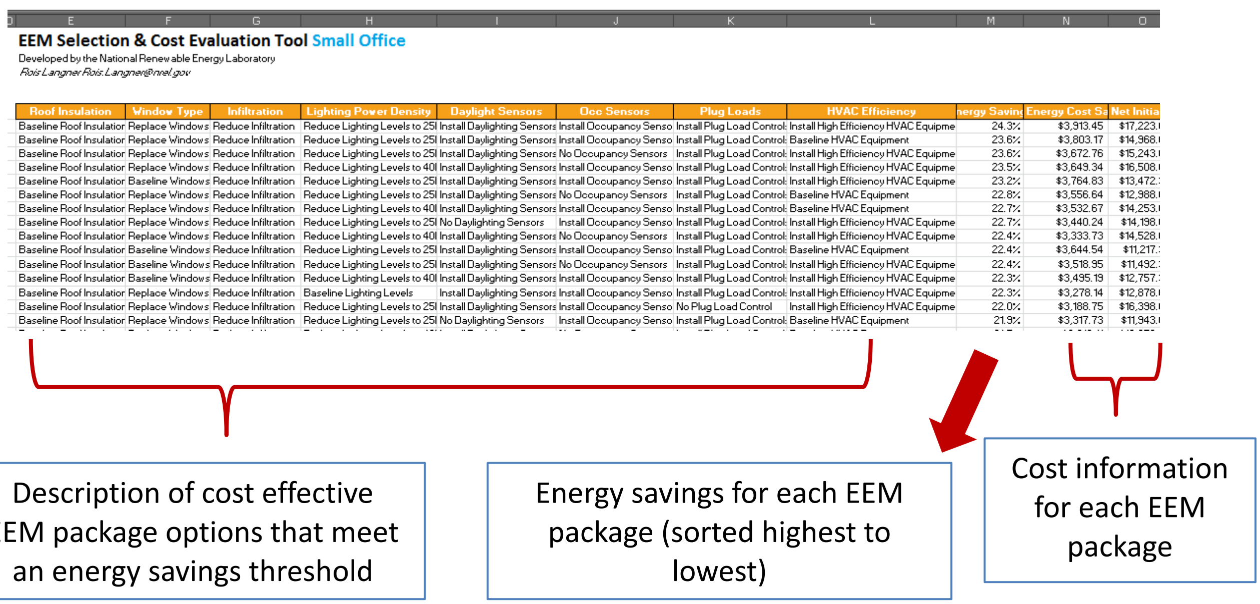


Figure 15. Snapshot of the results of the EEM Selection & Cost Evaluation Tool after running the built-in macro

Appendix B: Recommended Risk Mitigation Strategies

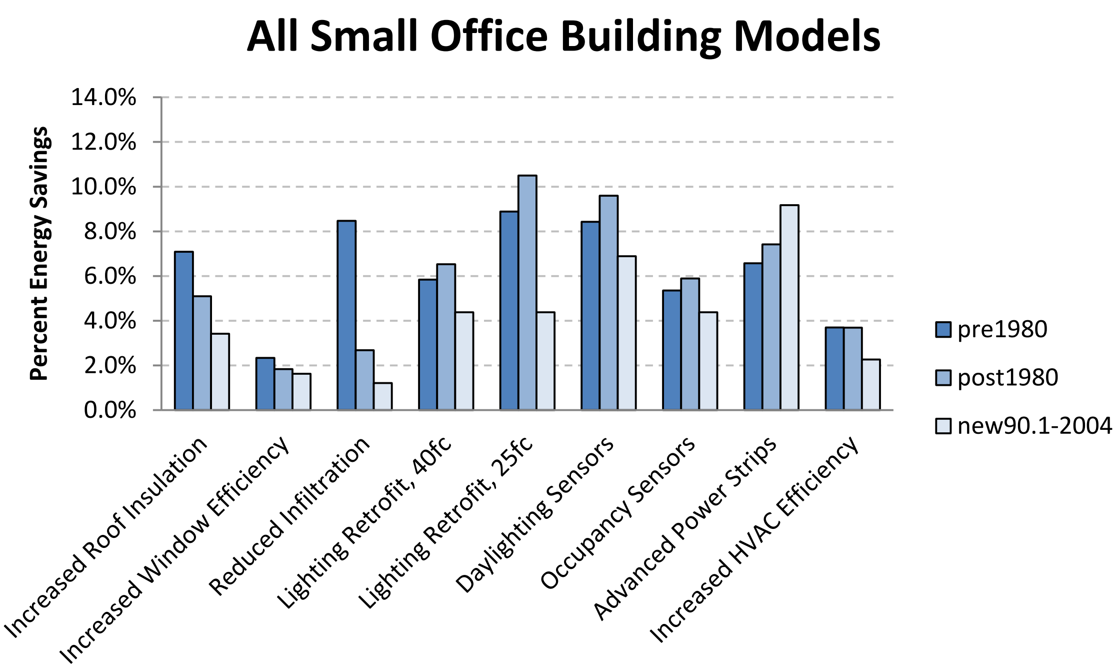
To increase the chances of achieving the estimated savings for a recommended EEM package, NREL has recommended a number of building performance risk mitigation strategies, based on the statistical analysis looking at the effects of individual performance risk variables on energy cost savings. The recommended strategies are intended to control and optimize building operation in a manner that mitigates performance risk. The strategies encourage building owners to:

- Use controls and set policies around building operation:
    - Turn off lights and plug loads at night, and throughout the day when not needed.
    - Control heating and cooling temperature set points within appropriate ranges.
    - Regularly check and confirm that the building is being operated within intended bounds, and look for operational improvements.
    - For building owners with tenants, use leasing language to shift relevant components of performance risk to tenants who are in control of building operations and occupancy levels, and consider green leases.
- Optimize the use of building space, reducing the need to condition and power unused office space.
- Recommission the building regularly to ensure the building equipment is operating at its maximum efficiency.

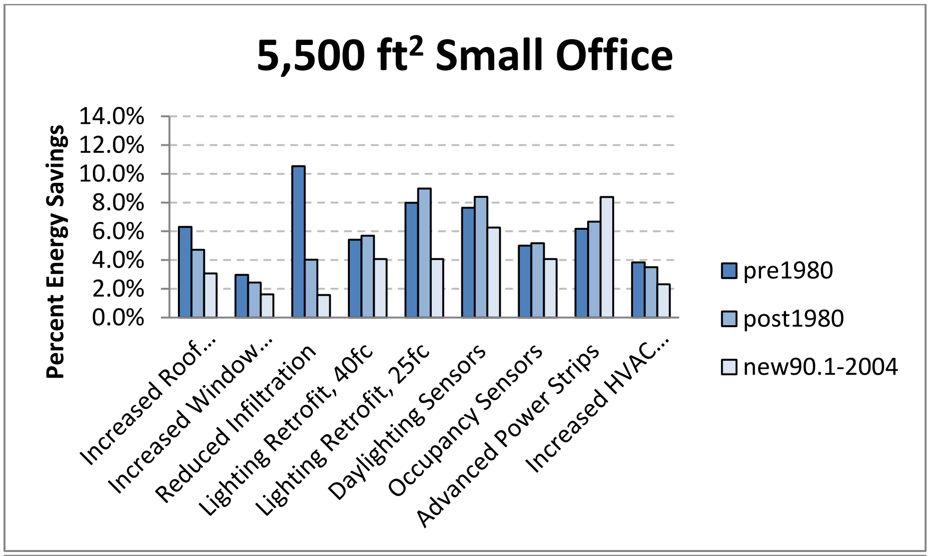
Appendix C: Effects of Individual EEMs on Percent Energy Savings

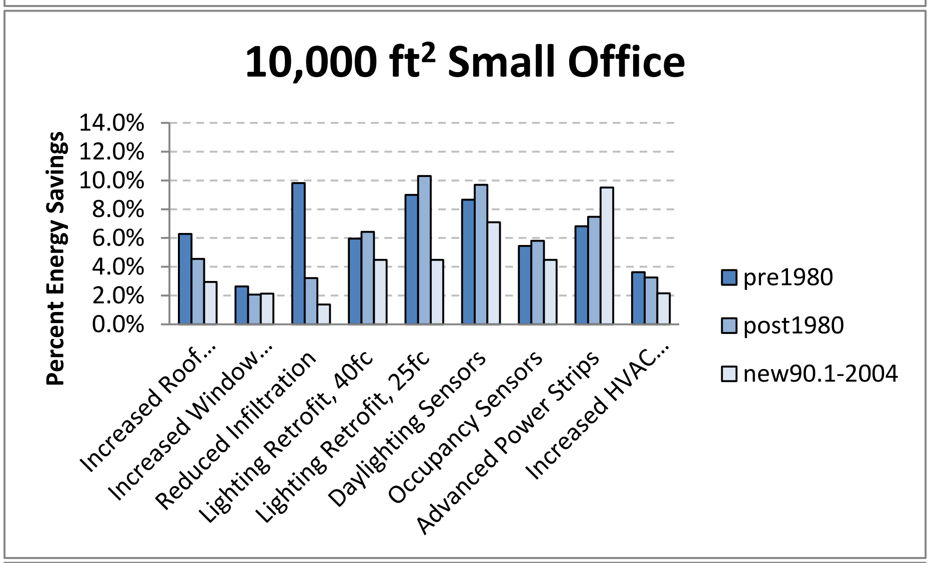
Appendix B shows results for the study conducted to determine the effects of individual EEMs on percent energy savings. The first set of results is averaged over all the small office building models used in this pilot project. The subsequent sets of results show the effects of each EEM on percent energy savings averaged over HVAC system type (for stand-alone buildings and buildings that adjoin buildings on two sides), and averaged over boundary condition (for buildings with PSZ-AC, PTAC, and PTHP HVAC system types).

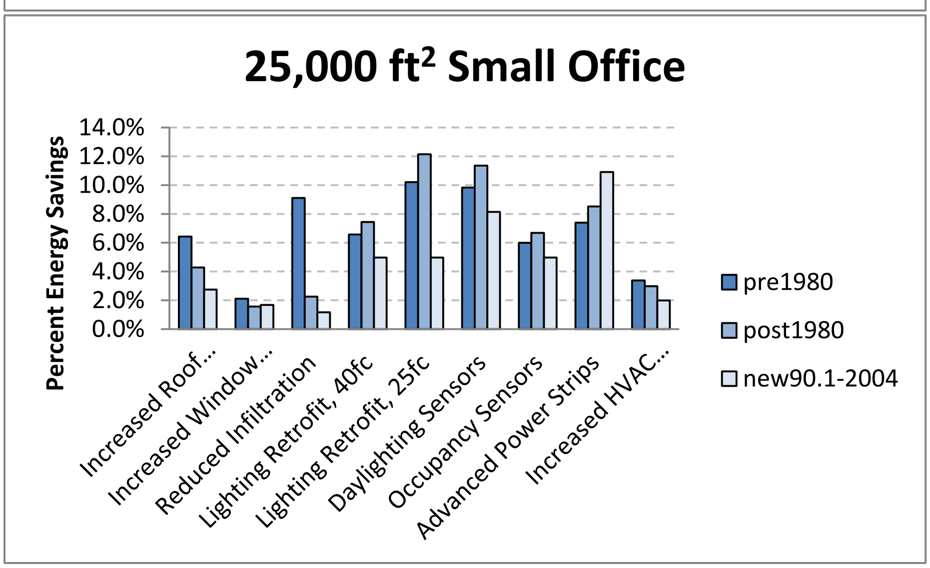
Results averaged over all small office building models:



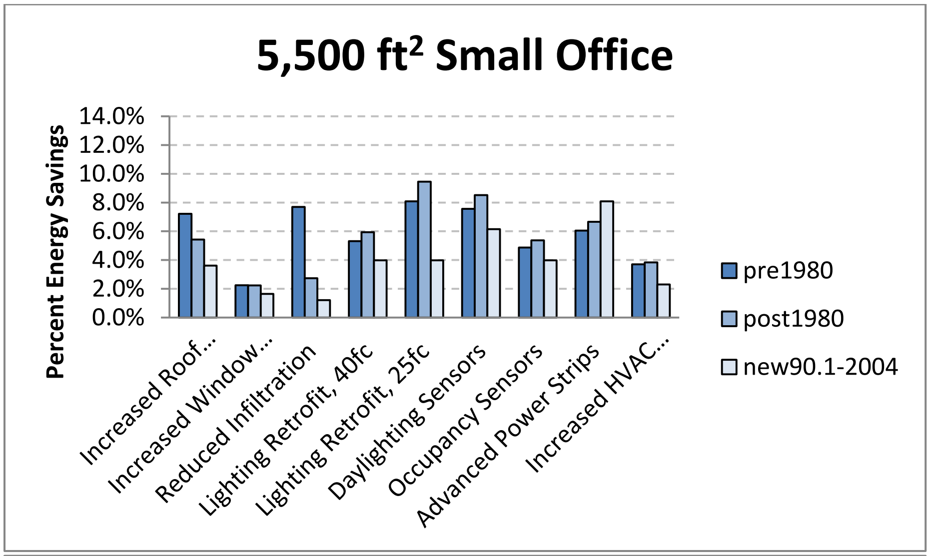
Stand-alone office buildings, averaged over HVAC system type:

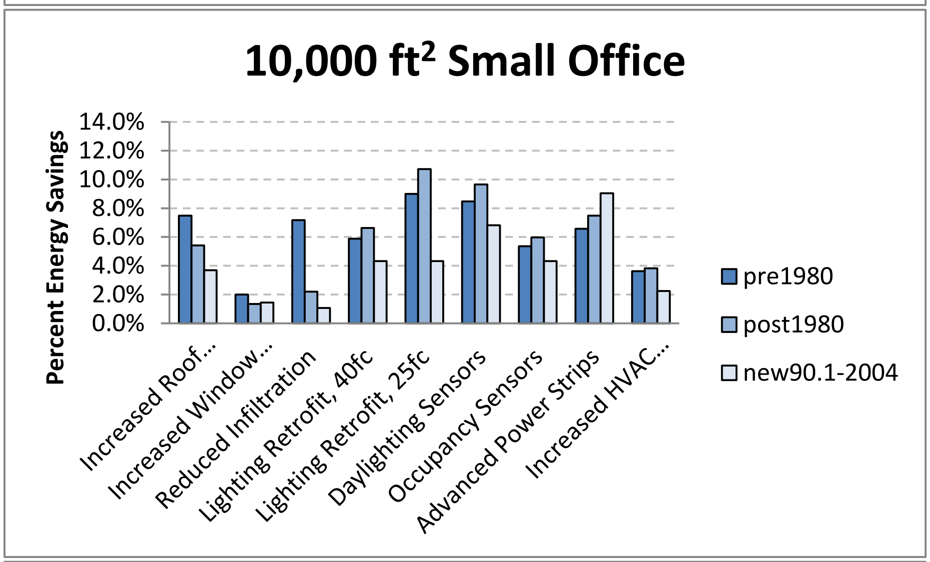


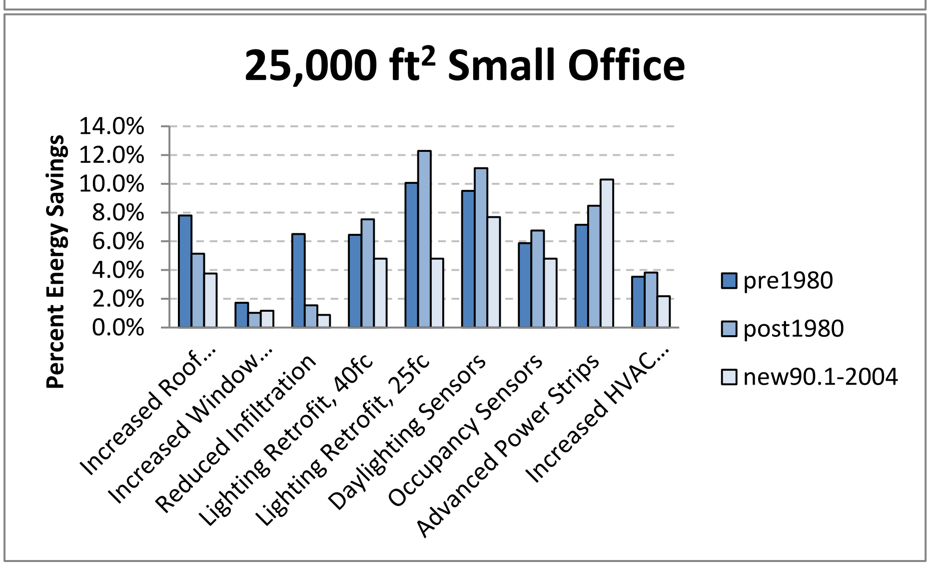




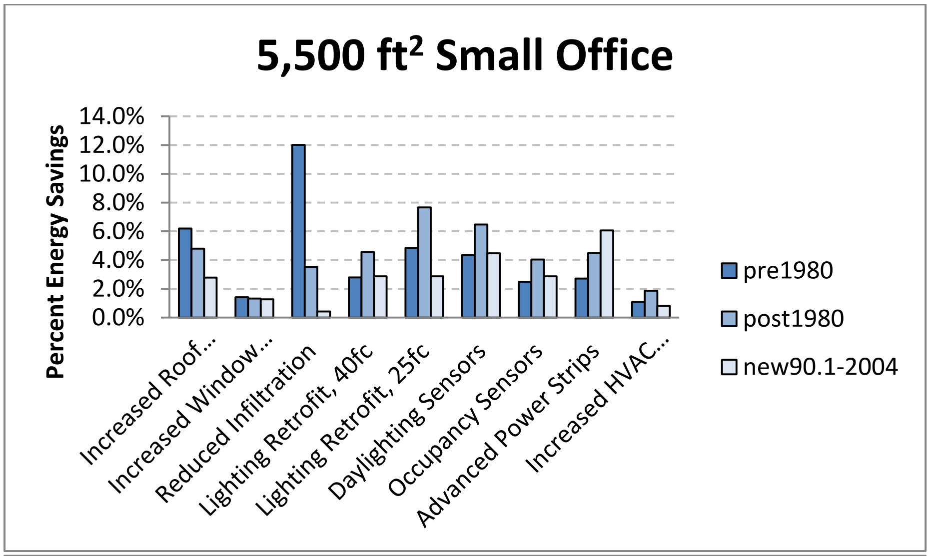
Office buildings that adjoin buildings on two sides, averaged over HVAC system type:

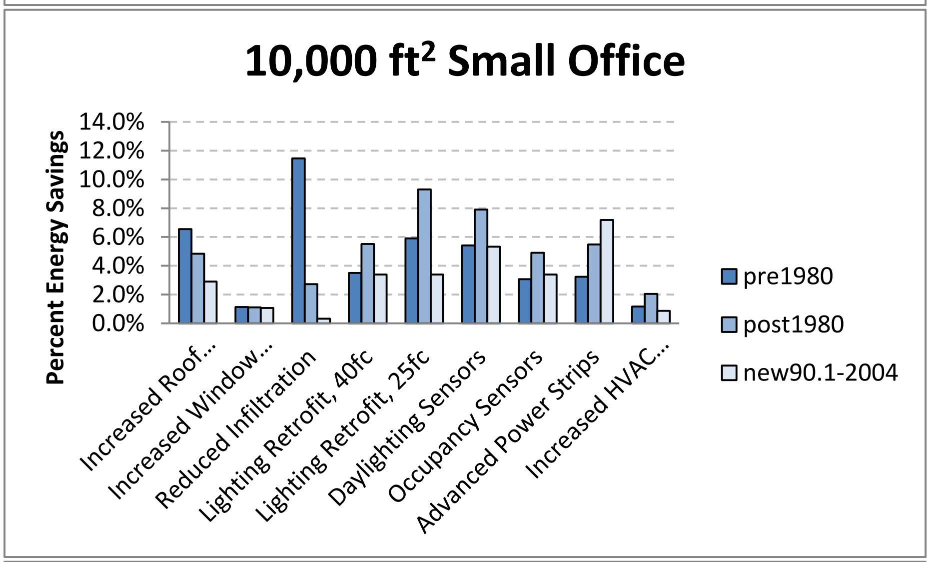


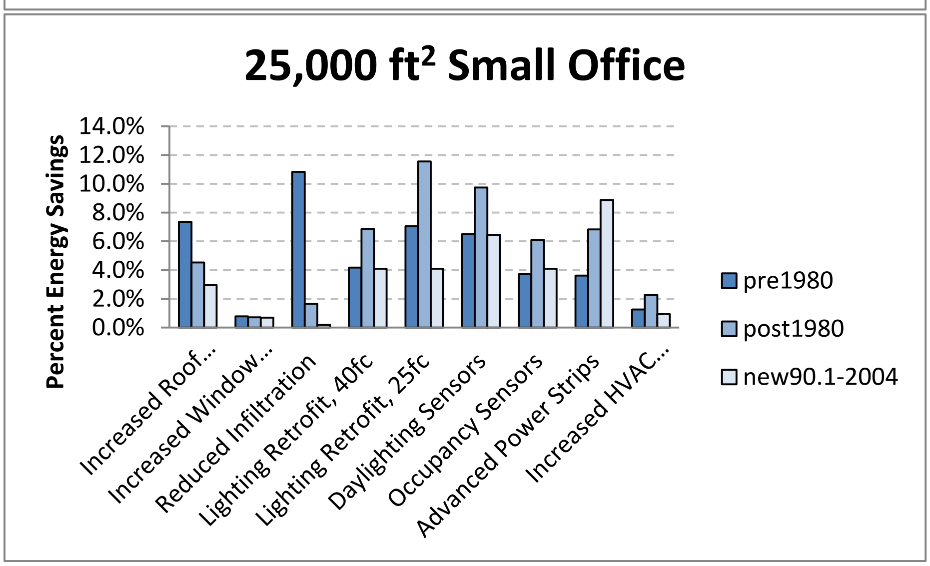




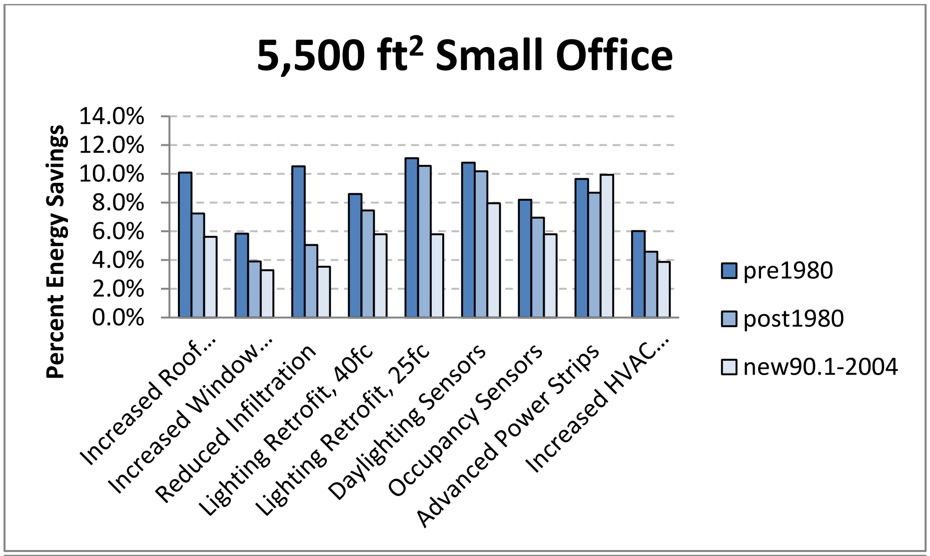
Office buildings with PSZ-ACs, averaged over boundary conditions:

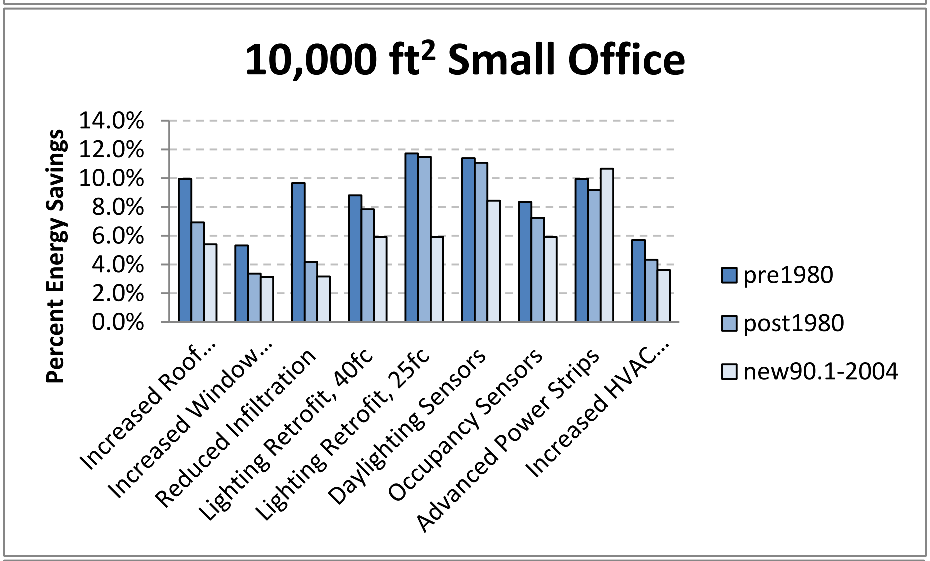


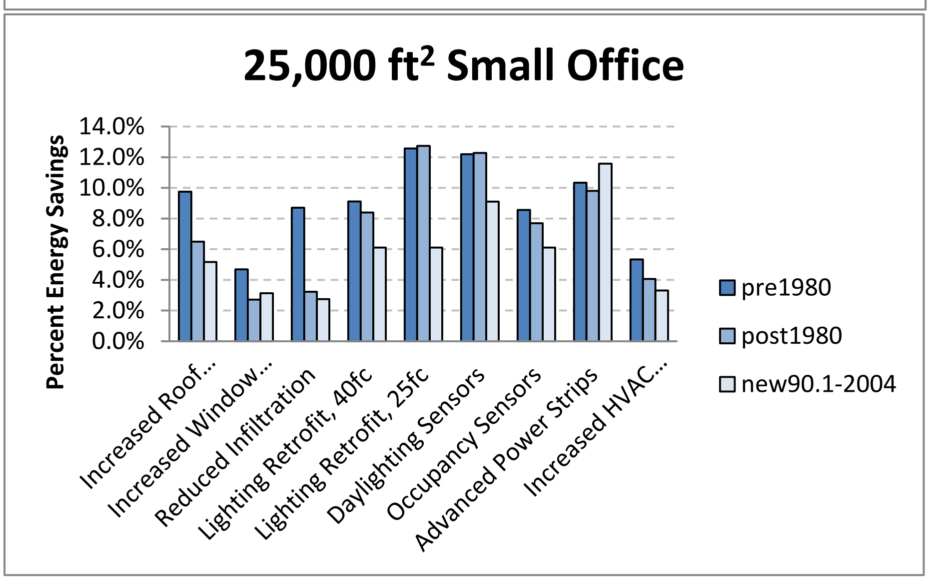




Office buildings with PTACs, averaged over boundary conditions:







Office buildings with PTHPs, averaged over boundary conditions: