Study of Deemed HVAC Measures

Year 1 Report

HVAC Roadmap 4

California Public Utilities Commission, Energy Division
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0. Executive Summary

The energy savings claimed by California's Investor Owned Utilities (IOUs) for deemed HVAC energy efficiency measures are calculated before installation (ex ante) based on a range of methods and assumptions. For some deemed measures, program-level impact evaluations are conducted subsequent to the measure implementations to quantify the post-installation (ex post) energy savings at a representative sample of the installation sites. When impact evaluations are performed, the results—along with the associated precision and confidence levels—are published and help to test the accuracy of ex ante savings estimates. A nuanced comparison of ex post impacts to ex ante estimates, however, has historically been limited by the fact that ex ante savings claimed by the IOUs are not provided with precision metrics of any sort.

This study seeks to advance the understanding of the uncertainties associated with claimed energy savings in California by assessing the ex ante estimates for a few key HVAC measures that are not captured by the separate (but related) impact evaluations of the Quality Installation, Quality Maintenance, or the upstream HVAC programs. The objectives of this study include:

- Producing uncertainty values associated with the selected measures' ex ante savings, using Monte Carlo simulations, to facilitate a more nuanced comparison of the ex post impacts to the ex ante savings; and
- Identifying the input parameters (assumptions) with the greatest influence on ex ante savings uncertainty in order to help guide future data collection efforts.

This report discusses findings for Year 1 of the study, and provides recommendations for further evaluation activity in Year 2.

0.1 Measures Studied in Year 1

The study team selected three HVAC measures to analyze in Year 1 based on review and analysis of 2013 and 2010-2012 IOU tracking data. Measures with increasing savings trends were selected. The selected measures include:

1. Residential Furnace Measures: Furnace measures were selected because they yielded the highest ex ante natural gas savings in 2013, they experienced a sharp rise in annual ex ante electric savings, and they are being implemented with increasing frequency.
2. Residential Quality Maintenance & Blower Motor Replacements: While blower motor replacements make up a small portion of total HVAC Roadmap savings, they experienced a dramatic increase in activity in 2013. This measure has been increasingly implemented in mobile homes, and the IOUs have indicated that they expect more growth of this measure.

3. Mini-Split and Variable Refrigerant Flow (VRF) Systems: Mini-split and VRF retrofits were selected due to a dramatic surge in participation, which contributed to a steadily growing proportion of the total ex ante savings in 2013. (This measure was reviewed in coordination with the literature review performed under the Upstream HVAC contract, HVAC-1, to avoid redundancies.)

0.2 Uncertainty Analysis Methodology

For each of the selected HVAC measures, DNV GL performed an in-depth review of the sources of the ex ante savings—either IOU workpapers, secondary sources cited in workpapers, or the Database for Energy Efficient Resources (DEER) —to assess the savings methodology and sources of the input parameters.

Based on this review, it was decided that propagation of error analyses using Monte Carlo simulations[1] performed in Year 1 of this study would be conducted to assess uncertainty in the annual electric energy (kWh) savings estimates for 1) the residential furnace measures that include a fan motor replacement, and 2) the residential quality maintenance measures (excluding the blower motor retrofit). Monte Carlo simulations were not performed for mini-split and VRF systems—nor for natural gas (therm) savings associated with the prior two measures—because the mathematical formulae and processes used to determine the ex ante savings were considerably more involved.

In cases where Monte Carlo simulations were not performed, the study team reviewed the available literature to assess the validity of the input parameters and assumptions used by the IOUs, and to identify any significant shortcomings or data gaps.

In cases where Monte Carlo simulations were performed, the study team began by creating a model of the measure's energy consumption or savings using the same input parameters applied by the IOUs. Monte Carlo simulations were run in the model by varying the input parameter values for each of the selected measures to determine:

- The most likely ex ante savings outcome and its associated uncertainty, and

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[1] Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos offering games of chance. Games of chance, such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance resembles how Monte Carlo simulation randomly selects variable values to simulate a model. When rolling a die, the roller knows that a 1, 2, 3, 4, 5, or 6 will come up, but cannot know the outcome for any given roll. Each time a Monte Carlo simulation is run, it randomly selects the values of the input variables, within their predetermined ranges, and determines the outcome for that run (e.g., interest rates, staffing needs, stock prices, inventory, phone calls per minute).

- The relative sensitivities of the ex ante savings values to changes to the input parameter values.

0.3 Key Findings

A comprehensive list of key findings is presented in Chapter 6 of this report. Among these findings, the following are especially notable because they reveal opportunities to significantly reduce the uncertainty in ex ante saving estimates for deemed HVAC measures using exiting or future research.

1. For the savings associated with the retrofit of variable speed motors at the blower fans, the greatest uncertainty is generated by building vintage categories. These should be updated by using either the 2009 Residential Appliance Saturation Study (RASS) or 2012 California Lighting and Appliance Saturation Study (CLASS) results. Also, the actual power drawn by these motors needs to be determined. The secondary sources cited by the workpapers had serious flaws.
2. For the savings claimed by the residential quality maintenance programs, the greatest uncertainty is due to DEER-based thermostat bins. In 2004, five thermostat bins were established —based on results of the 2003 RASS—to categorize residential thermostat usage patterns for each climate zone, building type, and vintage. Since the basis for the bin definitions and the bin weights is outdated (over 10 years old), this stands out as an opportunity to reduce the savings uncertainty for residential quality maintenance (and likely other residential HVAC measures). Since this measure was the subject of a workpaper disposition from the California Public Utilities Commission, a new study is further warranted. This study recommends revising the thermostat bins according to the results of the 2009 RASS unless even more recent information is available.
3. For mini-split systems, the basis for the savings for this measure is particularly weak and must be fortified. There is little reason to believe that, for a given unit size, the rate at which the savings increase at commercial buildings for each step up in equipment efficiency matches that at residential buildings.

0.4 Recommended Future Efforts

A comprehensive list of recommendations is presented in Chapter 6 of this report. From these recommendations, those listed below are especially noteworthy because they offer high value, would be easy to implement, or both.

1. The selected uncertainty analysis approach can readily be applied to non-weather dependent measures; for weather-dependent HVAC measures, however, propagation of error analysis and Monte Carlo simulations require additional steps. For Year 2 of this study, we propose executing the additional steps: a) generating simplified engineering

equations to simulate DEER savings; and b) using these equations to perform Monte Carlo simulations and uncertainty analyses. The simulations would be performed by reusing the model for the annual electric savings simulations that was developed in Year 1 of this study. The sensitivity analysis performed for the interactive effects of lighting will be leveraged, too, since it provides a useful framework and some results that are directly applicable to this study.[2]

2. Review the 2014 tracking data to identify any new trends and insights to inform future efforts. Consider analyzing measures that were identified as good candidates based on 2013 tracking data, but were not reviewed in Year 1 including, HVAC boiler measures, fan VFDs, and HVAC controls measures. Also, deemed refrigeration measures are currently not the subject of planned evaluations, but are assigned to the HVAC Roadmap and could be considered.
3. Further support the mini-split measure evaluation by coordinating with the Upstream Impact Evaluation and improving simulation estimates with performance maps rather than scaling factors and assumptions.
4. More easily identify which building simulation models should be produced by implementing consistent building type field designations in the tracking data for deemed HVAC measures.
5. Collect field data or conduct telephone surveys to validate or improve the assumption, used in ex ante savings estimates for VRF systems that half of the zones are ducted and half are ductless. Key data could be collected as part of the HVAC-1 evaluation. This should be added to the existing survey instrument which only surveyed 2010-12 installations.

For Year 2 of this study, we propose either pursuing recommendations 1 or 2. Recommendations 3 through 5 could be considered for other HVAC Roadmap evaluations currently under way or as additional studies to be pursued in the future.

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[2] A Study of the Sensitivity of DEER HVAC Interactive Effects Factors to Modeling Parameters. 2012. ftp://deeresources.com/HVACInteractiveEffects/IE_Sensitivity_Report_Draft_Mar_2012.pdf

1. Introduction

The California Public Utilities Commission (CPUC) engaged DNV GL in early 2014 to conduct a two-year study examining the energy savings for selected heating, ventilation, and air conditioning (HVAC) energy efficiency measures promoted through California's 2013-2014 rebate programs. The goal of this study is to assess the uncertainty of ex ante (pre-installation) savings estimates for the selected HVAC measures. This report discusses the results associated with Year 1 of our study, and recommends additional research for Year 2.

1.1 Background Information

Prior to the beginning of every energy efficiency rebate program, the Investor Owned Utilities (IOUs) in California—Pacific Gas & Electric (PG&E), Southern California Edison (SCE), Southern California Gas (SCG), and San Diego Gas & Electric (SDG&E)—describe how the energy savings will be determined for each measure to be rebated and implemented. For many types of energy efficiency measures, the energy savings are determined prior to the program's start based on factors such as the measure location's climate zone, building type, and baseline equipment; these measures are called *deemed measures*. For other energy efficiency measures, called *custom measures*, predetermining the savings is not practical due to the wide variability of influencing factors among projects. Some HVAC measures involve a wide variability of influencing factors, but—because it would not be cost-effective to implement them as custom measures–they are deemed.

IOUs present the savings for every deemed measure using one of the following two vehicles:

1. DEER[3]: This is an online database documenting the energy savings associated with deemed measures in California. DEER savings are determined by combining the following information:
    a. Building prototypes generated using CPUC's Measure Analysis Software Control (MASControl),
    b. Base case unit energy consumption (UEC) generated by MASControl,
    c. For residential measures, weights for climate zones, building types, building vintages, etc., from the California Residential Appliance Saturation Study (RASS), and

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[3] The Database for Energy Efficient Resources (DEER) is a database sponsored by the California Energy Commission and the CPUC to provide well-documented estimates of annual energy and peak demand savings, costs, effective useful life (EUL), and costs of energy efficiency measures.

   d. Measure-specific performance characteristics that correspond to established input parameters for eQuest/DOE2.2 .

2. Non-DEER workpaper: This is a technical document that provides the equations, input parameters, and baseline assumptions used to estimate the energy savings that will result from the implementation of a given measure. Workpapers must use the same types of methods as those currently used for DEER.

Once an energy efficiency program has begun, every measure implemented under that program is logged in the IOU's program tracking database along with its description, the street address of its location, and the associated energy savings (whether deemed or custom). The savings recorded in the tracking database are referred to as the ex ante[4] savings, or the claimed savings.

Throughout the program cycle, these databases are used by the IOUs to track and report the ex ante energy savings produced (or claimed) by the program. They are also provided to the CPUC as one component of the required IOU reporting. Subsequently, the tracking databases are provided to independent program evaluation contractors selected by the CPUC. For energy efficiency measures that yield directly measureable energy savings (rather than educational or marketing programs), direct impact evaluations are often performed for a sample of the projects listed in the tracking database. This process is intended to determine the actual energy savings realized at each of the sites in the sample; the savings values produced by this review are referred to as ex post[5] savings or impacts.

To determine the project-specific ex post savings, a measurement and verification (M&V) process is established by the evaluation team using an agreed-upon level of rigor that is appropriate for the evaluation budget. The project-level M&V process often includes a site visit or telephone interview to achieve the following goals: confirm the baseline equipment that was replaced, verify the installation of the measure, and gather data to determine the ex post measure savings. In instances where the evaluation plan does not include project-level M&V, the evaluation might focus, instead, on gathering data to refine some of the specific inputs used for the ex ante savings calculations. For example, a study may measure lighting time of use and average fixture wattages across a sample to inform an ex post savings average for lighting measures. In both cases, the ex post savings within the sample are used to estimate the ex post savings across all IOU territories in California.

Since the ex post savings determined by the evaluation team often differ from the ex ante savings claimed by the IOUs, program evaluation results are very closely scrutinized by all

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[4] *Ex ante* savings are determined by the IOU or the program implementer before the installation of the energy efficiency measure.

[5] *Ex post* savings, or impacts, are determined by the evaluation team for a sample of measures or project sites selected for the program evaluation.

stakeholders, including the CPUC and its advisors, the IOUs, the program implementation contractors, and the IOU ratepayers. Hence, Evaluators' Protocols[6] were established to prescribe how the impacts are to be determined and reported in California. For each ex post savings value reported by an impact evaluation—typically annual electric savings, peak demand savings, and annual natural gas savings—evaluators are required to report the following precision metrics:

- Relative precision,
- Error bounds,
- Coefficient of variation,
- Standard deviation, and/or
- Error ratio.

Once the gross ex post impacts have been estimated by the evaluators at the program level, they are then compared with the ex ante savings that were recorded in the tracking database, or claimed, by the IOUs. Thereafter, much discussion ensues among the many stakeholders. One limitation to the discussion, however, is that the ex ante savings claimed by the IOUs are not required to—and often do not have available—report precision or uncertainty metrics of any sort. Hence, the standard measure for comparing the ex post impacts to the ex ante claimed savings is a simple ratio, known as the realization rate.[7] While realization rates are typically published with associated precision statistics, these are presently determined without consideration for the uncertainty of the ex ante savings. If the statistical precision associated with ex ante savings are determined, the statistical precision of the realization rates can be better understood. Logically, measures with evaluated savings will have known savings and uncertainties and new measures, without evaluated savings, will have estimated savings and greater uncertainties.

1.2 Study Objectives

This study sets out to determine the uncertainty of the ex ante savings for a few key HVAC measures by using the same information source used by the IOUs—either a workpaper or DEER, depending on the measure. This is intended to achieve the following:

- Produce uncertainty values associated with ex ante savings, including standard deviation, using a Monte Carlo simulation method. This would facilitate a more nuanced comparison of the ex post impacts to the ex ante savings.

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[6] California Public Utilities Commission. April 2006. *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals* (a.k.a. Evaluators' Protocols).

[7] The realization rate is the ratio of the *ex post* savings to the *ex ante* savings; it is often reported as a percentage.

- Determine the relative influence of input parameters on the ex ante savings uncertainty. These results could help to guide future data collection efforts aimed at gathering information related to the input parameters with the greatest influence on ex ante savings.

1.3 Uncertainty Analysis Methods

To assess the uncertainty of ex ante savings, the study team primarily utilized Oracle Crystal Ball, a Microsoft Excel-based application designed to perform the following kinds of analyses:

- Monte Carlo simulations. These simulations use computational algorithms to repeatedly and randomly sample a given model to obtain the distribution of an unknown probabilistic output. They are most useful when it is difficult or impossible to apply a deterministic algorithm to the input parameters of influence. Crystal Ball can be used to run thousands of Monte Carlo simulations and assess the probability of each simulation.
- Sensitivity analyses. Upon concluding the Monte Carlo simulations, the results can be used to indicate which input parameters contribute the greatest variance to the output value.

For our analysis, the input parameters to the model were identical to those used by the IOUs, but the numerical value of each input parameter was randomly varied, within specified ranges, for each of the thousands of Monte Carlo simulations. Relationships between parameters can be established as co-variances, but the Year 1 of this study treated all inputs as indepependent. After running a specified number of simulations (typically 10,000), the outputs were generated; these outputs included the mean result and a list of statistical metrics for the mean (e.g., standard deviation). The simulationoutputs were either annual energy consumption, for both the post-retrofit and the baseline cases, or the annual energy savings..

There were several cases, however, when Monte Carlo simulations were not performed during Year 1 of the study because the mathematical formulae for determining the ex ante savings were not immediately available. This was due to one of two reasons:

- The savings had been determined by using an elaborate analysis tool such as eQuest or EnergyPro and, hence, general mathematical formulae were not immediately available. The analysis tool outputs will need to be simulated before Monte Carlo simulations can be performed.
- The savings were provided by DEER and, again, were generated using MASControl-produced building prototypes and eQuest outputs. If they become available in Year 2, the uncertainty analysis using Monte Carlo simulations may proceed.

For both of these cases, Year 1 efforts included reviewing the available literature and reporting significant shortcoming or data gaps.

1.4 Study Tasks

DNV GL performed the following tasks to complete the uncertainty analysis study:

1. Review the HVAC Roadmap tracking data and rank their contribution to the savings.
2. Select the measures to study.
3. Perform an in-depth review of the sources of the ex ante savings to assess the savings methodology and sources of the input parameters.
4. Create a model of the energy consumption or savings that used the same input parameters used by the IOUs. Run the Monte Carlo simulations by varying the input parameter values for each of the selected measures to determine:
    a. The mean of the distribution of ex ante savings outcomes and its associated uncertainty, and
    b. The relative sensitivities of the ex ante savings outputs to changes to the input parameter values.
5. In cases where Monte Carlo simulations are not feasible, perform an alternate assessment. For measures whose savings are determined by the use of elaborate analysis tools, the scope of the study was limited to an assessment of the validity of the input parameters and assumptions used by the IOUs.
6. Prepare report to present uncertainty analysis results, recommendations for reducing the ex ante savings uncertainty or updating the sources for the input parameters, and provide a list of options for the second phase of this study.

1.5 Report Organization

The report consists of the following sections and appendices:

- Section 2, “HVAC Measure Review & Selection,” describes the criteria used to select the deemed measures examined in Year 1 of our study.
- Section 3, “Residential Furnaces,” describes the methods and references used to determine the ex ante savings for residential furnace measures, the input parameters used for the Monte Carlo simulations, the simulation output distributions and input parameter sensitivities, and resulting recommendations.
- Section 4, “Residential Quality Maintenance,” describes the methods and references used to determine the ex ante savings for residential quality maintenance measures, the input parameters used for the Monte Carlo simulations, the simulation output distributions and input parameter sensitivities, and resulting recommendations.

- Section 5, “Mini-Split & Variable Refrigerant Flow Systems,” describes the methods and references used to determine the ex ante savings for these types of measures, and the limitations therein.
- Section 6, “Overall Findings & Recommendations,” summarizes the findings and recommendations for each of the three deemed HVAC measures studied during Year 1.
- Appendix A, “2013 Tracking Data Details,” provides more detailed tables than was appropriate for the body of the report, but which may be of interest to some readers.
- Appendix B, “Residential Furnaces Details,” provides more detailed tables and figures than was appropriate for the body of the report, but which may be of interest to some readers.
- Appendix C, “Residential Quality Maintenance and Blower Motor Replacements,” provides more detailed tables and figures than was appropriate for the body of the report, but which may be of interest to some readers.

2. HVAC Measure Review & Selection

Significant background work was required to prepare for the uncertainty analysis effort. This chapter discusses the three major tasks conducted by our study team to select ideal HVAC measures to analyze in Year 1 of our study. These steps included: a thorough review of IOU tracking data, selection of measures for further analysis, and a review of sources for deemed ex ante savings for the selected measures. The goal of this task was to forecast future evaluation needs by analyzing energy savings trends from the beginning of the 2010-2012 program cycle through the end of 2013 (halfway through the 2013-2014 program cycle).

2.1 Tracking Data Review

The team began its effort in early 2014 by reviewing the tracking database[8] that contained the complete list of deemed HVAC measures implemented in 2013,[9] the first year of the 2013-2014 program cycle in California. Predefined measure groups were used to identify HVAC measures. Since this tracking database combined data provided by each IOU—because each IOU managed their transition to the new data standard somewhat differently—the database included many inconsistencies that required significant time and attention to correct. This was a result of using interim tracking data at the time of our analysis for this study and not the final 2013-14 data that recently became available in April 2015.

For instance, each IOU employed a different practice for flagging whether a given measure was deemed, was provided via the upstream HVAC program, or was implemented at a residential property. While these are the most basic elements of the data specification, review of the more complex data fields also revealed inconsistencies. Definitions of building vintage bins and building types were also applied inconsistently across the IOUs. Furthermore, the data fields that were intended to contain workpaper numbers and DEER sources were very often left blank.

The greatest challenge with the 2013 tracking database was overcoming the great variety of entries in the “measure name” fields, where no measure group existed. For example, Table 1 shows the various measure names used across IOU databases to indicate “mini-split system and Variable Refrigerant Flow (VRF)” measures. After exporting the relevant portions of the database to a spreadsheet, the team began to map some of the data entries to a consistent set of options. There was no other way but to go through the entries, one by one, to determine which measure name had likely been intended so that appropriate aggregation was possible.

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[8] Tracking data extracts were created using the standard data provided via the CPUC Data Management Team.

[9] While parts of the 2014 tracking database became available during the course of this study, these updates were not considered since the first year of the study was already underway.

Table 1. Example of Variability of Measure Names in Tracking Data

Measure Names in Workpapers re Mini-Split and VRF Systems	Measure Names Found in Tracking Data
Ductless mini-split heat pump, ductless multi-split heat pump, VRF system, and VRF heat pump and heat recovery	Ductless AC DX equipment replacements, mini-split heat pump DX equipment, heat pump DX equipment, heat recovery DX equipment, and VRF heat pump and heat recovery (only exact match)

Once satisfied that the working spreadsheet contained the necessary tracking data in a sufficiently uniform fashion, the team's efforts turned toward merging the 2013 tracking data with the 2010-2012 program cycle tracking data. This was done to observe implementation trends over a longer period of time.

This step also proved to be tricky because the categorization and sub-categorization of measures differed between the two program cycles. In the 2010-2012 program cycle, 32 HVAC measure groups were defined; 50 were defined in the 2013-2014 program cycle. Once the measure groups in the 2010-2012 data were modified to match those used in the 2013 data, a true comparison was possible.

2.1.1 Measure Group Savings and Trends

To help identify ideal HVAC measures for our study, the next step was to determine which measures yielded the highest ex ante savings, and to identify significant increases in the rate at which specific measures were being implemented. Using the 2013 dataset, we aggregated the ex ante savings by HVAC Measure Group. It should be noted that going forward, the finding from the P4 Uncertainty Analysis[10] using stakeholder estimates could provide a basis for selecting measures for additional study. However, for Year 1 of this study, the 2013 tracking dataset provided enough insight into measure trends.

Table 2 shows the groups that produced the greatest natural gas savings during the 2013 program, ranked from 1 to 10.

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[10] The P4 Uncertainty Analysis is an assessment of uncertainty of net lifecycle savings due to underlying parameters including quantity, UES, installation rate, net-to-gross ratio, and effective useful life. Stakeholders surveyed include Energy Commission staff and consultants, IOU program staff, and IOU evaluation staff. (No published report located.)

Table 2. Top Ten Natural-Gas-Saving HVAC Measure Groups in 2013*

Rank	Measure Group	Annual Ex Ante Savings, therms	Proportion of Savings
1	HVAC Furnace	2,830,079	27.8%
2	HVAC Duct Sealing	1,578,223	15.5%
3	HVAC Boiler	1,427,112	14.0%
4	HVAC Controls: Energy Management Systems (EMS)	875,857	8.6%
5	HVAC Controls: Thermostat	470,346	4.6%
6	HVAC Controls: Boiler	388,470	3.8%
7	HVAC Controls: Fan	355,273	3.5%
8	HVAC Heating: Other	340,807	3.4%
9	HVAC Chiller, Water-Cooled	332,323	3.3%
10	HVAC Ventilation, Other	241,737	2.4%
	Total of Top 10 Groups	8,840,227	86.9%

* Since this analysis was performed prior to the completion of the cross-study tracking data cleaning effort, actual savings values may differ from those determined at a later time.

Since furnace measures accounted for slightly more than 25% of the annual natural gas savings across all HVAC measure groups for 2013, they were given very high consideration for further analysis during Year 1 of this study. Duct sealing measures and boiler measures were also identified as good candidates for further assessment.

In further consideration of studying furnace measures, we reviewed the merged dataset containing both the 2010-2012 program cycle measures and the 2013 measures to assess the measure implementations over time. The ex ante savings attributable to furnace measures, once aggregated by the year/quarter of implementation, are shown in Figure 1.

Figure 1. Natural Gas Savings for Furnace Measures, 2010-2013

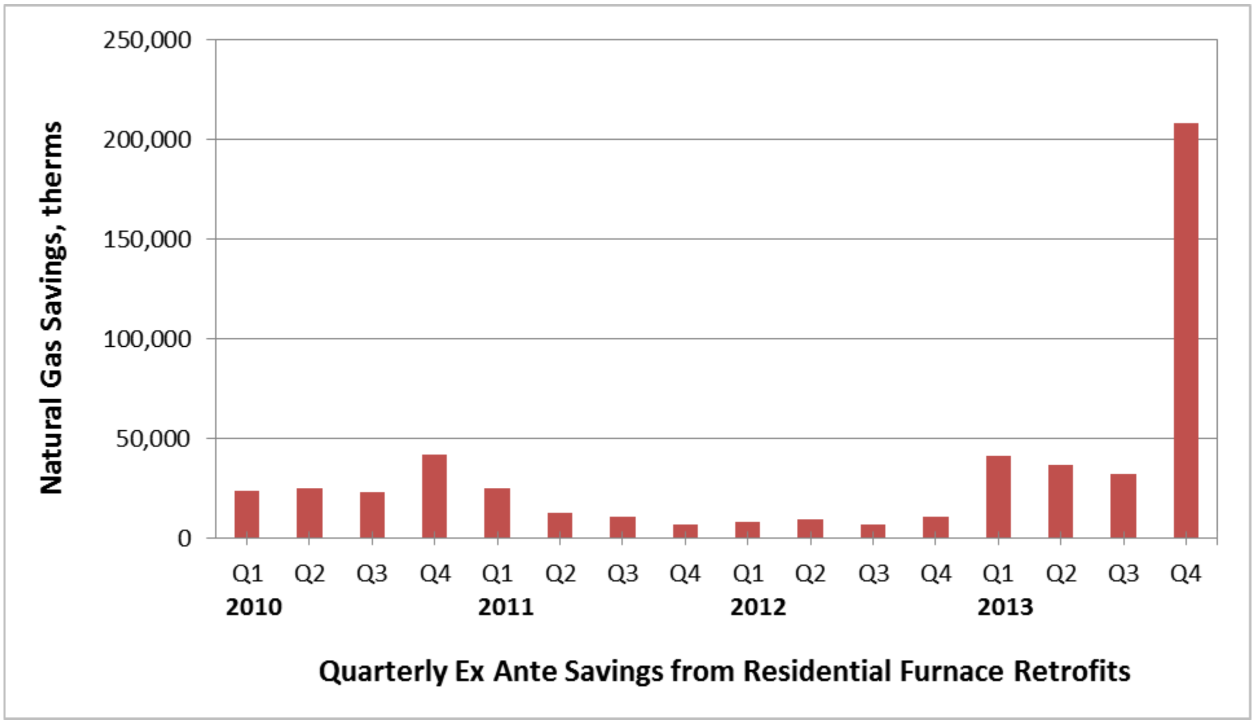

Figure 1 shows that ex ante natural gas savings due to furnace measures increased substantially during the fourth quarter of 2013. In fact, total ex ante savings for furnace measures throughout 2013 were much higher than those in 2012. This finding further supported the selection of furnace measures as a candidate for uncertainty analysis.

After reviewing the ex ante natural gas savings, we turned our attention to electric energy savings. Table 3 shows the top ten HVAC measure groups that yielded the greatest annual ex ante electric savings.

Table 3. Top Ten First-year Electric-Saving HVAC Measure Groups in 2013*

Rank	Measure Group	Annual Ex Ante Savings, kWh	Proportion of Savings
1	HVAC Rooftop or Split System	37,981,291	12.8%
2	HVAC Motor Replacement	28,987,677	9.7%
3	HVAC Chiller, Water-cooled	22,339,413	7.5%
4	HVAC Chiller, Air-cooled	21,756,495	7.3%
5	HVAC Fan Variable Frequency Drive (VFD)	17,612,888	5.9%
6	HVAC Controls EMS	13,379,610	4.5%
7	HVAC Controls Thermostat	11,139,910	3.7%
8	HVAC Ventilation Fan	10,866,582	3.6%
9	HVAC Central Plant	9,801,951	3.3%
10	HVAC Controls Other	8,433,424	2.8%
	Total of Top 10 Groups	182,981,291	61.1%

* Since this analysis was performed prior to the completion of the cross-study tracking data cleaning effort, actual savings values may differ from those determined at a later time.

Unlike the natural gas savings, the first year ex ante electric savings were somewhat more evenly distributed across the top-saving measure groups. The top two groups—rooftop or split systems, and motor replacement—were thought to be the most worthy of further study. The next four highest-saving groups—water-cooled chillers, air-cooled chillers, fan VFDs, and HVAC EMS—were also significant contributors, and should be considered for Year 2.

2.2 Measure Selection

After a thorough review of the 2013 and 2010-2012 tracking databases, three HVAC measures were selected for analysis during Year 1 of the study using the following criteria:

- Measure accounts for a significant portion of the 2013 tracking data.
- Measure experienced an uptick in participation.
- Measure was not among those being considered for evaluation according to the HVAC Roadmap impact evaluation plans, unless it was on the 2013 Energy Savings Performance Incentive (ESPI) uncertain measure list[11].

The measures that were selected for further review and analysis are described below.

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[11] "Decision Adopting Efficiency Savings and Performance Incentive Mechanism," Order Before the Public Utilities Commission of the State of California, Decision 13-09-023, September 5, 2013. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M076/K775/76775903.PDF

Residential Furnace Measures: Furnace measures were selected for uncertainty analysis during Year 1 of the study primarily because they yielded the highest ex ante natural gas savings in 2013 (as shown in Table 2), and because they are being implemented with increasing frequency (as shown in Figure 1). Furnace measures also experienced a sharp rise in annual ex ante electric savings (see Figure 2, on page 2-7). This is because some furnace upgrade measures were implemented in concert with variable-speed fan motor component upgrades and, therefore, comprised a growing proportion of the claimed annual electric savings for variable speed motor measures. Furnaces have historically yielded a high proportion of the HVAC therm savings, and were a known measure of concern. In 2013, our preliminary tracking data analysis indicated that residential furnaces yielded ex ante savings of 2,830,079 therms, 3,382,567 kWh, and 22.6 kW.

Residential Quality Maintenance & Blower Motor Replacements: While blower motor replacements make up a small portion of total HVAC Roadmap savings, they experienced a dramatic increase in activity in 2013. Although the increase in kWh savings is not on the same scale as the other measure groups shown in Figure 2 (below), the percentage growth was substantial; our preliminary tracking data analysis indicated that ex ante savings increased from 1,899 kWh in the first quarter of 2013, to 38,488 kWh in the fourth. This measure has been increasingly implemented in mobile homes, and the IOUs have indicated that they expect more growth of this measure. In 2013, blower motor replacements yielded ex ante savings of 58,132 kWh, 56.3 kW, and -1,191 therms.

Mini-Split and VRF Systems: Mini-split and VRF retrofits are contained within the HVAC Rooftop or Split System measure group,[12] the group that yielded the highest annual electric savings in 2013 (see Table 3). Further review of the measures included in that measure group showed that the mini-split, multi-split, and variable refrigerant flow (VRF) measures were not one of the top-saving measures therein. On the other hand, however, they comprised a steadily growing proportion of the total ex ante savings in 2013 (see Figure 2, below). This growth trend was further corroborated once the 2010-2012 tracking data were reviewed: far fewer savings from these measures were reported during the previous program cycle.

While this measure may be evaluated through the Upstream HVAC Program impact evaluation, it was selected for further scrutiny in this study, too, due to 1) its inclusion on the ESPI list due to the significant level of uncertainty of the ex ante savings, and 2) the rise in participation over the course of the first year of the 2013-2014 program cycle. In 2013, our preliminary analysis indicated that mini-split and VRF systems yielded ex ante savings of 78,274 therms of natural gas, 5,388 MWh of annual electric energy, and 2,084 kW of demand savings. During the third

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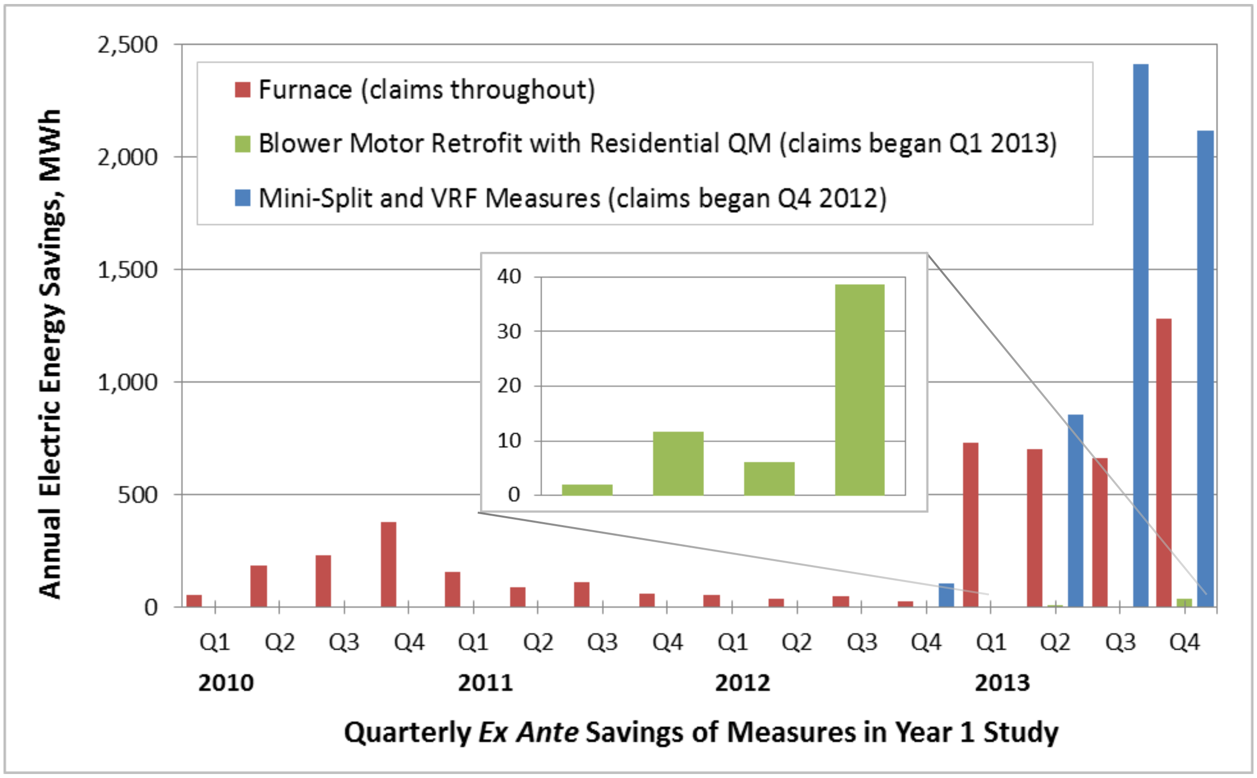
[12] There are a total of 117 measures listed in this Measure Group; 13 of the measures, across SCE and PG&E, are Mini-Split and VRF measures. A complete list is provided in Appendix A.

quarter of 2013, alone, the annual ex ante electric savings due to mini-split and VRF systems were nearly 2,500 MWh[13].

Figure 2. Annual Electric Savings for Selected Measures, 2010-2013



2.3 Review of Sources for Deemed Ex Ante Savings

Once we had selected the energy efficiency measures to include in this study, the next step was to investigate the sources of the ex ante savings values. As previously indicated, ex ante savings for all deemed measures are published using one of two options:

1. <u>Non-DEER Workpapers.</u> These typically employ one or both of the following approaches:

   a. *Engineering Calculations*. These rely upon equations, input parameters, and assumptions to calculate savings. Measures whose deemed savings are determined by engineering calculations lend themselves to Monte Carlo simulation uncertainty analyses.

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[13] 1 MWh = 1,000 kWh.

    b. *Building Simulations*. These use building models and complex engineering software tools to estimate savings. Such measures lend themselves to sensitivity analyses using parametric runs, but they do not readily lend themselves to Monte Carlo analyses. Running 10,000 trial building simulations is not practical. In such cases, numerous intermediate steps are necessary to assess uncertainty. Year 2 of this study could use specific simulation results to create parameters for simple engineering equations, which could be the basis of Monte Carlo Simulations.

2. <u>DEER.</u> For the 2013-2014 HVAC Roadmap, a number of measures use savings values either directly or indirectly from DEER 2011. DEER savings values are determined by running prototype building models and analyzing the associated measure impacts using MASControl to generate eQuest 3.64 input files. These prototype models exist for various building types, building vintages, and climate zones in California.
3. Each of the three measures selected for further analysis during Year 1 of this study had ex ante savings presented in workpapers published by California IOUs.

3. Residential Furnaces

The first uncertainty analysis undertaken in Year 1 of this study pertained to residential furnaces. As described in 2, residential furnaces were selected based upon their prevalence in the 2013 tracking data provided by the CPUC data management team. In this chapter, we describe the types of furnace measures that are incented, the methodology and input parameters used to determine the deemed savings, and the uncertainty analysis results. At the end, we summarize our findings and present recommendations based upon those findings.

3.1 Measure Description

Furnace measure savings primarily result from the higher annual fuel utilization efficiency (AFUE) rating of the replacement equipment relative to that of the baseline equipment. In some cases, the use of variable-speed fan motors (VSM) yields additional savings. Table 4 provides a complete list of the measures included in the furnace measure group, and their frequency in the 2013 tracking data. As shown below, replacement furnace AFUE ratings range from 92% to 97%.

Table 4. Furnace Measures within "HVAC Furnace Measure Group" in 2013

Measure Name	Frequency in Tracking Data
95% AFUE Furnace – without Built-In Variable Speed Motor (VSM)	1
AFUE >= 94% < 96% Gas Furnace Only	1,067
AFUE >= 94% < 96% Gas Furnace with Built-in VSM	100
AFUE >= 96% Gas Furnace Only	1,313
AFUE >= 96% Gas Furnace with Built-in VSM	262
Central Gas Energy Star 92% AFUE	30
Central Gas Furnace 95% AFUE	562
Central Natural Gas Furnace - 95% AFUE with VSM	2
Central Natural Gas Furnace - 95% AFUE without VSM	7
Central Natural Gas Furnace - 97% AFUE without VSM	1
Furnace - Energy Star Central Gas (AFUE>=95%)	87
Residential Furnaces and Boilers	36
Unit Heaters and Duct Furnaces	36
Grand Total	**3,504**

3.2 Deemed Savings Determination Methods

To learn how the ex ante savings are determined for residential furnace measures, the study team: 1) reviewed the workpapers published by the IOUs in which the ex ante savings for residential furnaces are established, and 2) reviewed secondary sources that were referenced by the workpapers or offered different but credible methodologies.

3.2.1 Review of IOU Workpapers

The study team identified and reviewed two workpapers pertaining to furnace measures.[14] The first pertains to installing furnaces with a minimum efficiency rating of 95 AFUE,[15] and the second addressed 97 AFUE[16] furnaces. The 95 AFUE workpaper applies to furnaces with ratings from 95 AFUE to 96.9 AFUE; the 97 AFUE workpaper applies to furnaces with an AFUE or 97 of greater. Though they pertain to furnaces of differing AFUE ratings, both workpapers utilize identical methodologies. Since there was only one instance of a 97 AFUE furnace implementation in 2013 (see Table 4), this chapter focuses almost exclusively on the 95 AFUE furnaces.

In both workpapers, deemed savings were determined using a replace-on-burnout (ROB) baseline. The efficiency rating of the baseline equipment was determined based upon Federal DOE 10 code of federal regulations (CFR) Part 430e, which stipulates a minimum AFUE of 80% for any non-weatherized gas furnace with a rating of less than 225,000 Btuh.

The annual natural gas savings are based directly on those reported by the 2011 DEER database. In DEER, the annual savings vary by climate zone and dwelling type, where dwelling types include: single family (SFM), multi-family (MFM), and mobile homes (DMO). Since the annual ex ante natural gas savings come directly from DEER, a Monte Carlo simulation was not possible for this component of the measure. Instead, we reviewed the information used to populate DEER.

For high-efficiency furnace replacements that also include VSMs, annual electric energy and demand savings are claimed in climate zones 11, 12, and 13. Although variable speed drive (VSD) fan motor replacements are included in the DEER database, the VSM measure—a different

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[14] Workpapers were located via: http://www.deeresources.com/index.php/non-deer-work-paper-values-13-14.

[15] "High Efficiency Furnace 95 AFUE (1.04 HIR) – Residential," Pacific Gas & Electric Company, 8/28/2012, PGECOHVC145.

[16] "High Efficiency Furnace 97 AFUE (1.02 HIR) – Residential," Pacific Gas & Electric Company, 8/28/2012, PGECOHVC147.

application of the same technology—is not. Hence, the ex ante savings for VSMs were calculated using the following steps:

- The same DEER prototype models were used, for the post-retrofit case, a fan motor power of 0.365 Watts/cu.ft. of air/minute (W/CFM) was used; for the baseline case a fan motor power of 0.65 W/CFM was used[17].
- The outputs of the models[18] are then weighted by five thermostat usage bins,[19] number of stories,[20] and five building vintage bins[21]. Baseline and post-retrofit cases follow the same approach, shown below:

$$kWh_{CZ,vint,story} = \sum_{i=1}^{5} T_i \times kWh_{CZ,vint,story,T_i}$$

$$kWh_{CZ,vint} = \sum_{story=1}^{2} S_{story} \times kWh_{CZ,vint,story}$$

$$kWh_{CZ} = \sum_{vint=1}^{5} V_{vint} \times kWh_{CZ,vint}$$

where,

$kWh_{CZ,vint,story}$ = annual savings at each combination of building-story number, building vintage, and climate zone, kWh

T_i = weight to represent distribution of each of five residential thermostat usage bins

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[17] The baseline case fan motor power is based on a combination of several studies; Pigg, Scott, Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research, ECW Report Number 241-1, May 2008 amended December 15, 2010. http://www.ecw.org/ecwresults/241-1.pdf, and“Efficiency Characteristics and Opportunities for New California Homes (ECO)”, John Proctor, Proctor Engineering Group, Ltd, March 2011.

[18] For VSMs, the model outputs provide the annual electric consumption per furnace fan for the post-retrofit and baseline cases. For VSD fans—the standard application—the model outputs include building types with multiple meters whereas for VSMs, the model outputs are divided by the number of meters to obtain the per-furnace consumption.

[19] “Programmable Thermostats Installed into Residential Buildings: Predicting Energy Saving Using Occupant Behavior & Simulation,” by James J. Hirsh & Associates, 2004.

[20] Number of stories is only considered for the single-family dwelling type; multi-family and mobile home analyses do not incorporate this factor.

[21] Building vintage bins are defined by DEER.

$kWh_{CZ,vint,story,T_i}$ = annual savings at each thermostat usage bin for each combination of number of stories, building vintage bin, and climate zone, kWh

$kWh_{CZ,vint}$ = annual savings at each combination of building vintage and climate zone, kWh

S_{story} = weight to represent distribution of 1- and 2-story, single-family homes

$kWh_{CZ,vint,story}$ = annual savings for each number of stories at each combination of building vintage and climate zone, kWh

kWh_{CZ} = annual savings for climate zone, kWh

V_{vint} = weight to represent distribution of each of five building vintage bins

$kWh_{CZ,vint}$ = annual savings within each building vintage bin and in each climate zone, kWh

The savings attributed to the implementation of a VSD furnace blower measure at dwellings within each combination of thermostat usage bin, building story number, building vintage, and climate zone are calculated as shown:

$$kWh_{savings} = kWh_{CZ,baseline} - kWh_{CZ,replacement}$$

where,

$kWh_{savings}$ = annual electric savings, kWh

$kWh_{CZ,baseline}$ = baseline annual electric energy usage, kWh

$kWh_{CZ,replacement}$ = replacement annual electric energy usage, kWh

Summaries of the distribution weights and annual savings for the 95 AFUE furnaces are provided in Appendix B. Even though the very same savings methodology was used for the 97 AFUE furnaces, the corresponding distribution weights and annual savings are largely ignored in this chapter since there was only one instance of a 97 AFUE implementation in 2013.

3.2.2 Review of Secondary Sources

In addition to reviewing the workpapers themselves, the study team reviewed the secondary sources cited in the workpapers. To calculate ex ante savings for VSM retrofit measures, the secondary sources were used to guide the determination of the fan motor power for the baseline and post-retrofit cases.

- In a Public Interest Energy Research (PIER) Study for the California Energy Commission[22], 45 single- and multi-family homes built in compliance with 2005 Building Energy Efficiency Standards were used to determine that permanent split capacitor (PSC) evaporator fan motors on split-system air handling systems drew an average of 0.65 (W/CFM) of airflow while in cooling mode. In these circumstances, however, the blower motor power would be lower when evaporator coils are not in cooling mode and dry. Further research would be needed to address the degree that fan power is affected as limited information is available on the topic. Another study, published by the Energy Center of Wisconsin[23], reported the results from two sets of measurements:
  - PSC motors at 37 homes drew an average of 0.528 (W/CFM).
  - Electronically commutated motors (ECMs) at 24 furnace air handlers drew an average of 0.341 (W/CFM). Again, motor load would be expected to vary with changing weather conditions. Insufficient detail regarding weather conditions was reported to facilitate an effort to correlate the motor load with weather conditions.

While three sets of measurements are cited in the workpapers, the adopted base case blower motor power levels appear to have been drawn exclusively from the PIER study. Since the PIER study reports the highest motor power of the three and no explanation was offered to support the use of that result, the possibility exists that the workpaper overestimates the VSM measure savings. Additionally, the average ECM power from the Energy Center of Wisconsin is not used for the measure case. However, this value supports the use of the DEER case, 0.341 W/CFM versus 0.365 (W/CFM), respectively. However, neither the DEER nor the ECM motor power references address how the measure motor speed will vary with weather conditions and usage behaviors.

3.3 Input Parameters for Monte Carlo Simulation

To simulate the annual electric savings for the furnace blower VSM retrofit, we created a model within Oracle Crystal Ball to use to conduct Monte Carlo simulations. The model was created to represent implementation of the “single family dwellings for the 95 AFUE” measure. This case was selected based on the measure’s frequency in the 2013 tracking data (659 instances); there was only one instance of the “single family dwellings for the 97 AFUE” measure.

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[22] Proctor, John. March 2011. *Efficiency Characteristics and Opportunities for New California Homes* (ECO). Prepared by Proctor Engineering Group, Ltd.

[23] Pigg, Scott. December 2010. *Central Air Conditioning in Wisconsin: A compilation of recent field research*. Prepared by the Energy Center of Wisconsin.

We performed 10,000 Monte Carlo simulations to assess the uncertainty of annual electric energy savings for each climate zone and dwelling type.[24] The annual electric savings for each scenario made up the inputs to the simulation. The distributions or weights associated with each input parameter—thermostat usage bins, number of stories, and building vintage—constituted the majority of the assumptions for the model[25].

Figure 3 illustrates the flow of the Monte Carlo simulation analysis to estimate the annual ex ante electric energy consumption of the baseline furnace blower motor for single family homes built before 1978 and located in Climate Zone 11, aggregated across both building story categories: 1-story and 2-story. Subsequently, to determine the annual ex post electric energy consumption of the replacement furnace blower VSM for the same scenario (using the same distribution weights), the illustrated analysis flow is repeated after replacing both columns of the annual ex ante electric consumption (shown in the upper left-hand table in Figure 3) with the corresponding annual ex post electric consumption.

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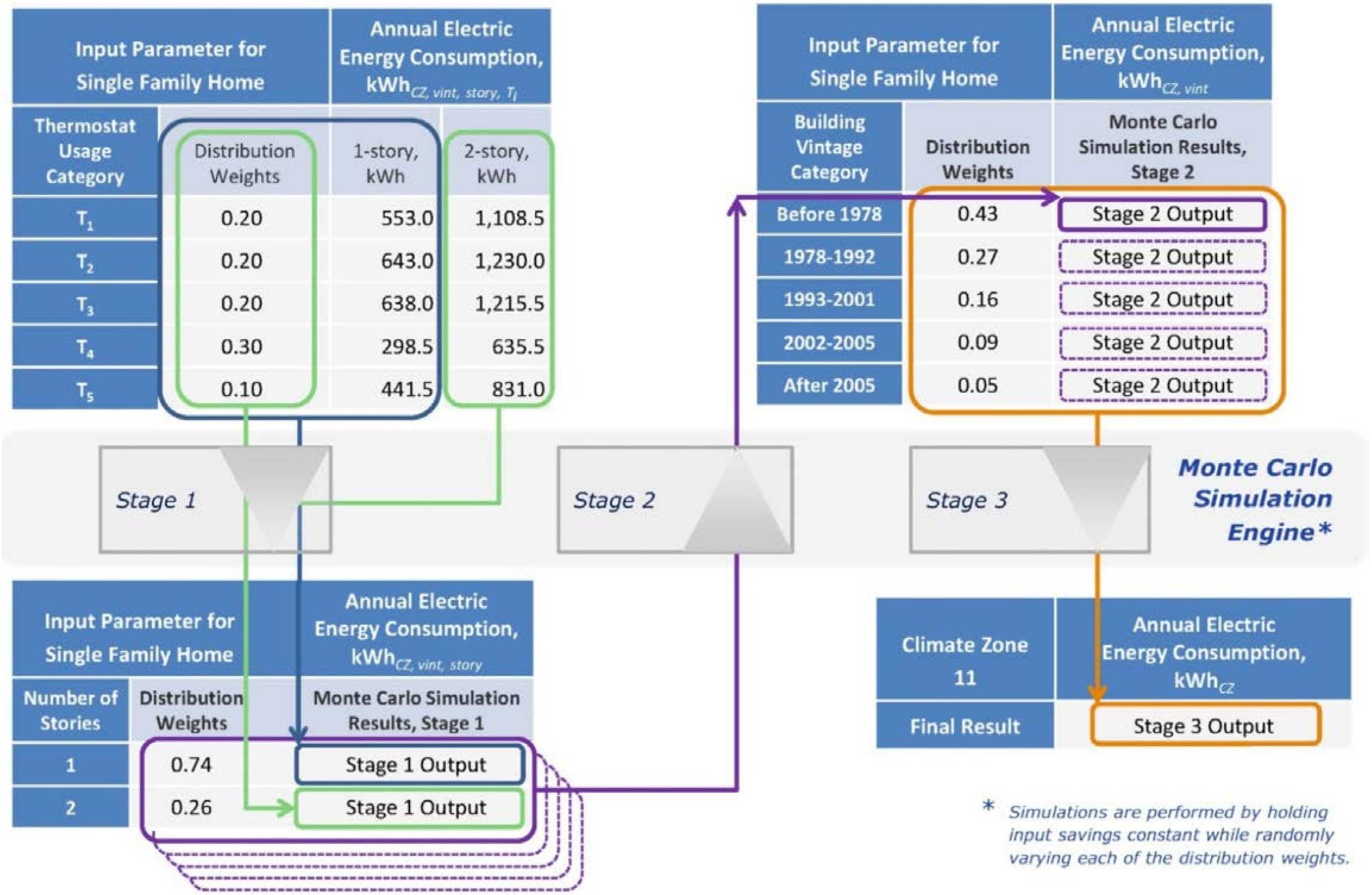
[24] Ten thousand combinations of the input parameters, or weights, are used to produce a probable distribution of the energy consumption by randomly deviating from each published weight—within predetermined ranges—of each input parameter.

[25] The distribution weights are provided by DEER, and based on the 2003 RASS.

Figure 3. Model Inputs at Each Stage of Monte Carlo Simulations for Furnace with VSM[26]



Input Parameter for Single Family Home		Annual Electric Energy Consumption, $kWh_{CZ, vint, story, T_i}$	
Thermostat Usage Category	Distribution Weights	1-story, kWh	2-story, kWh
T_1	0.20	553.0	1,108.5
T_2	0.20	643.0	1,230.0
T_3	0.20	638.0	1,215.5
T_4	0.30	298.5	635.5
T_5	0.10	441.5	831.0

Input Parameter for Single Family Home		Annual Electric Energy Consumption, $kWh_{CZ, vint}$
Building Vintage Category	Distribution Weights	Monte Carlo Simulation Results, Stage 2
Before 1978	0.43	Stage 2 Output
1978-1992	0.27	Stage 2 Output
1993-2001	0.16	Stage 2 Output
2002-2005	0.09	Stage 2 Output
After 2005	0.05	Stage 2 Output

Input Parameter for Single Family Home		Annual Electric Energy Consumption, $kWh_{CZ, vint, story}$
Number of Stories	Distribution Weights	Monte Carlo Simulation Results, Stage 1
1	0.74	Stage 1 Output
2	0.26	Stage 1 Output

Climate Zone 11	Annual Electric Energy Consumption, kWh_{CZ}
Final Result	Stage 3 Output

* *Simulations are performed by holding input savings constant while randomly varying each of the distribution weights.*

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[26] All distribution weights are as reported by the workpaper and are consistent with the DEER.

The process is nearly the same for DMO and MFM dwellings, except that the "number of stories" factor disappears; the energy consumption values for these dwelling types do not differentiate between 1- and 2-story buildings.

In addition to producing the most likely energy consumption for each case, Oracle Crystal Ball also produces a list of statistical metrics to quantify the uncertainty of the output value. Once this process has been executed for both the baseline equipment and the post-retrofit equipment, the difference between the two simulation results will determine the savings. Subsequently, all of the uncertainty metrics can also be combined using standard statistical methods.

3.4 Analysis Results

This section presents the annual electric energy savings results identified by the Monte Carlo simulations, identifies the percentage of savings uncertainty that can be attributed to key assumptions in the model (e.g., building vintage), and discusses the information gaps that have limited our ability to assess annual ex ante natural gas savings for residential furnace measures.

3.4.1 Monte Carlo Simulation Results

The results reported herein are limited to the savings for each of the three relevant climate zones at the prescribed distributions for building vintage, thermostat usage, and number of stories (1 or 2 stories) for single family homes, as shown in Figure 4.

Figure 4. Annual Electric Savings Distributions by Climate Zone at SFM

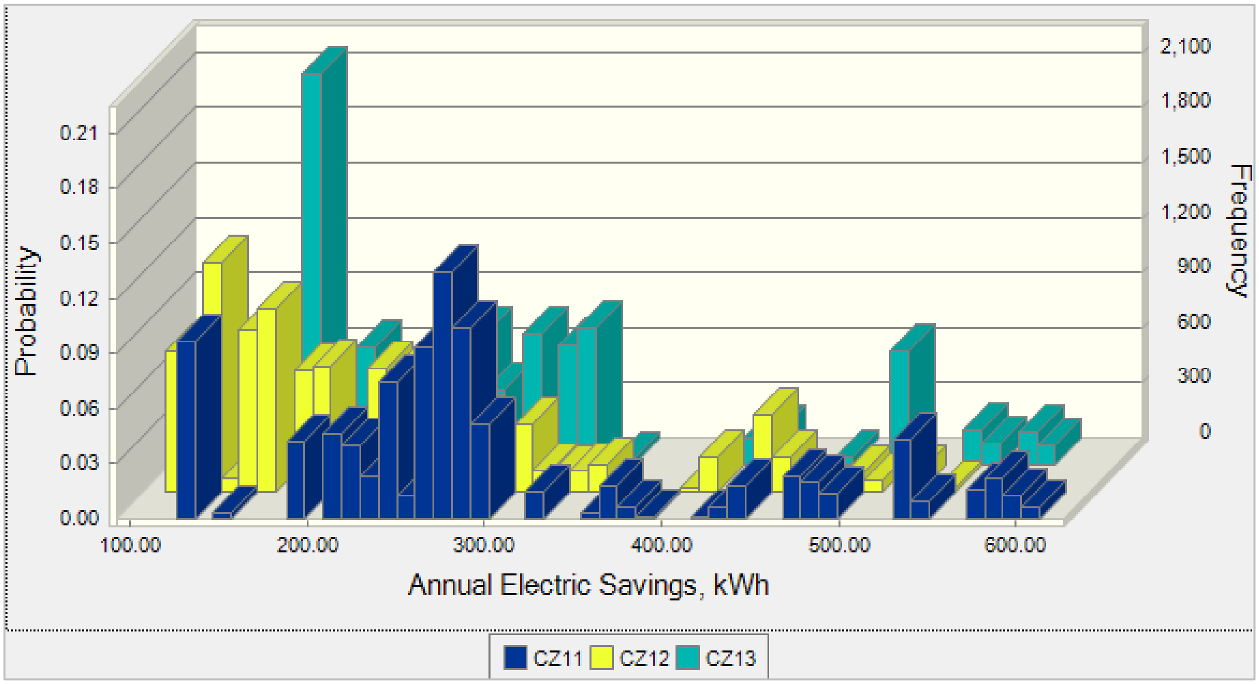

Figure 4 shows the distribution of the binned savings simulation results where the savings bins are shown on the horizontal axis and the corresponding probabilities of each savings outcome are shown on the left vertical axis. The right vertical axis shows the number of simulation runs, out of a total of 10,000, for which the savings result occurred within each savings bin. For single-family homes, the savings results have high variances in the three climate zones studied. This is not surprising since the simulation results represent a blend of two-story and one-story SFM buildings. The 2-story dwelling savings are significantly greater than those for 1-story dwellings, simply because the energy consumption is greater for both the baseline and the post-retrofit cases. Since this study was designed to prioritize the sources of uncertainty among the input parameters for the deemed UES for each climate zone, further parsing of the simulation results was not explored.

The Monte Carlo simulations showed that largest savings differences between 1- and 2-story single-family homes occurred at those in the T_2 thermostat usage bin, in the 1978-1992 building vintage bin, and located in Climate Zone 13. The annual electric energy savings were 719.5 kWh and 1,538 kWh for 1- and 2-story homes, respectively. This suggests that using the weights provided by DEER (for thermostat usage bins, number of stories, and building vintages) introduce substantial uncertainty into the savings estimates at each climate zone. Table 5 shows the statistical descriptors associated with the savings output of the simulations.

Table 5. Statistics for Simulated Annual Electric Savings by Dwelling Types

Statistical Descriptors, units	CZ11	CZ12	CZ13
Work Paper, kWh	296	315	224
Mean, kWh	297	320	225
Median, kWh	263	280	194
Mode, kWh	168	131	162
Standard Deviation, kWh	134	141	107
Coefficient of Variation	0.45	0.44	0.48
Minimum, kWh	149	131	85
Maximum, kWh	675	705	547
Range Width, kWh	526	574	462
Mean Standard Error, kWh	1.34	1.41	1.07

Figure 5 compares the distributions of savings outcomes by dwelling type in Climate Zone 11. Other climate zones showed similar patterns where the measure savings at the single-family homes had much higher variance than either the DMO or MFM dwelling types. While different weights are used for each dwelling type, the main difference is that the SFM type incorporates the story weight, while the other dwelling types omit this distinction. The large difference between measure savings at 1- and 2-story SFMs within each climate zone is a major contributor to the variance of the savings.

Table 6 shows the statistical descriptors associated with the savings output by the simulations for each dwelling type in CZ 11.

Figure 5. Annual Electric Savings Distribution by Dwelling Type in CZ11

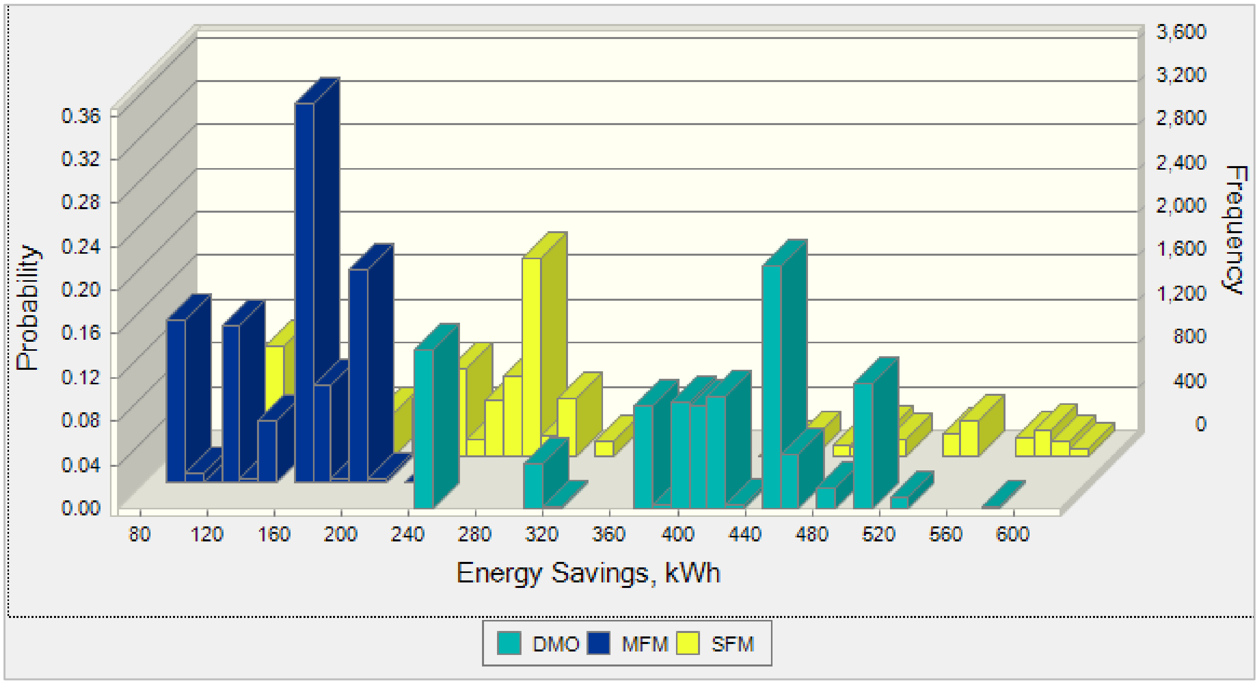

Table 6. Statistics for Simulated Annual Electric Savings by Dwelling Types in CZ11

Statistical Descriptors, units	CZ11 DMO Savings	CZ11 MFM Savings	CZ11 SFM Savings[27]
Work Paper, kWh	409	148	296
Mean, kWh	408	148	319
Median, kWh	420	160	280
Mode, kWh	247	122	131
Standard Deviation, kWh	81	36	142
Coefficient of Variation	0.20	0.24	0.44
Minimum, kWh	247	75	131
Maximum, kWh	590	227	705
Range Width, kWh	343	151	574
Mean Standard Error	0.81	0.36	1.42

3.4.2 Input Parameter Sensitivities

At the conclusion of the simulation runs, Oracle Crystal Ball provides the ranking of the correlation coefficients, or rank correlation coefficients, for each assumption, or input parameter. Positive coefficients indicate that the value contributes to an increase in the results. Negative coefficients indicate that the assumption decreases the results. The magnitude of the coefficients indicates the degree of influence that a particular assumption has on the measure savings results.

These correlation coefficients are then used to calculate the proportional contribution of each assumption to the overall variance; this calculation identifies the percentage of the uncertainty that can be attributed to each assumption. The proportional contributions to the variance are calculated by taking the square of the rank correlation coefficients and normalizing them to 100%. These results are often referred to as sensitivities. Figure 6 shows the sensitivities to each assumption used to determine the savings for the previously described example.

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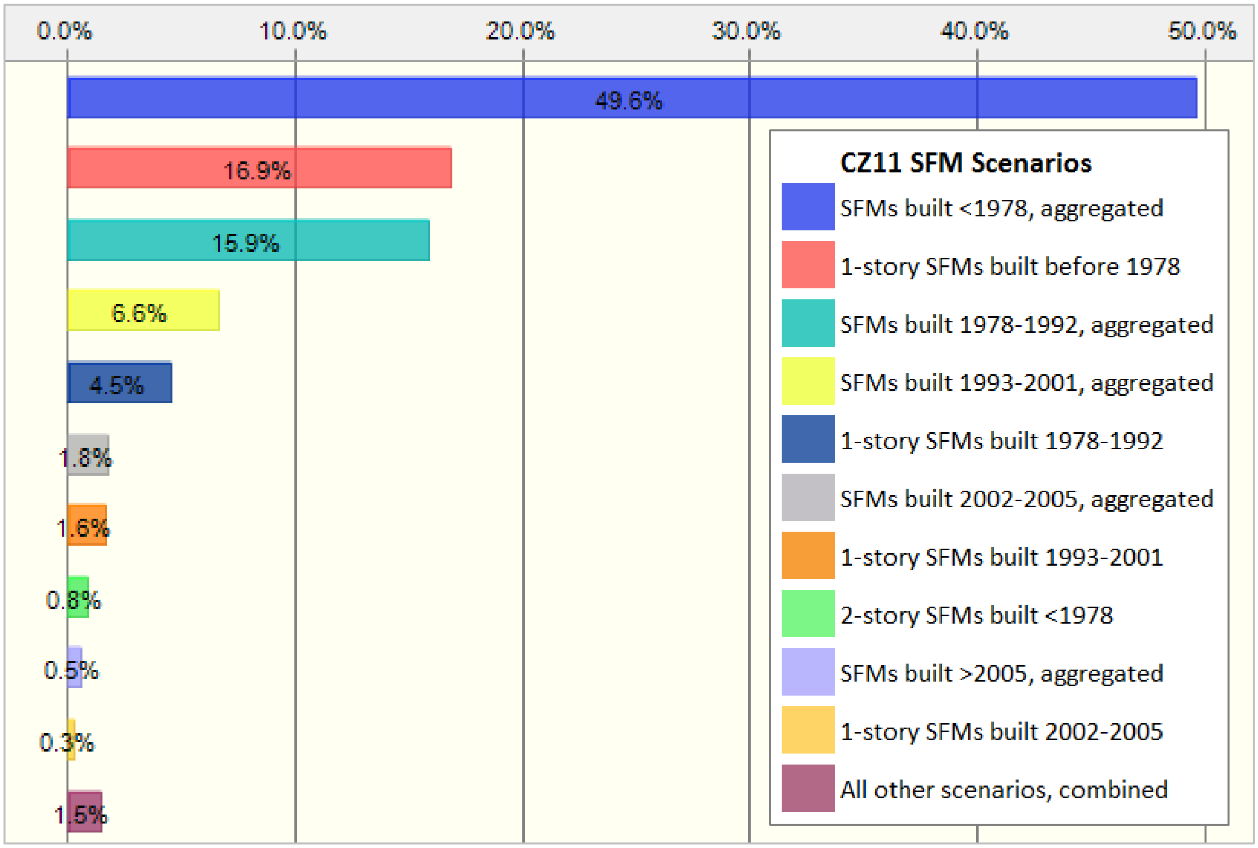
[27] While the reader might expect the mean value for CZ11 to equal 297 kWh as reported in Table 5, this is unrealistic. By randomly selecting the values in the weights of the input parameters, each Monte Carlo simulation run will yield slightly different results.

Figure 6. Top Contributors to Savings Variance for Single Family Homes in CZ11



In CZ11, the highest contributor to variance, at 49.6 percent, is the SFMs built before 1978. This means that the variance is largely driven by the story weights and thermostat usage bin weights for this particular vintage. This can be explained by the combination of the high proportion of homes of that vintage, as shown in Table 7, and the high variance of the associated story weights (highlighted in green).

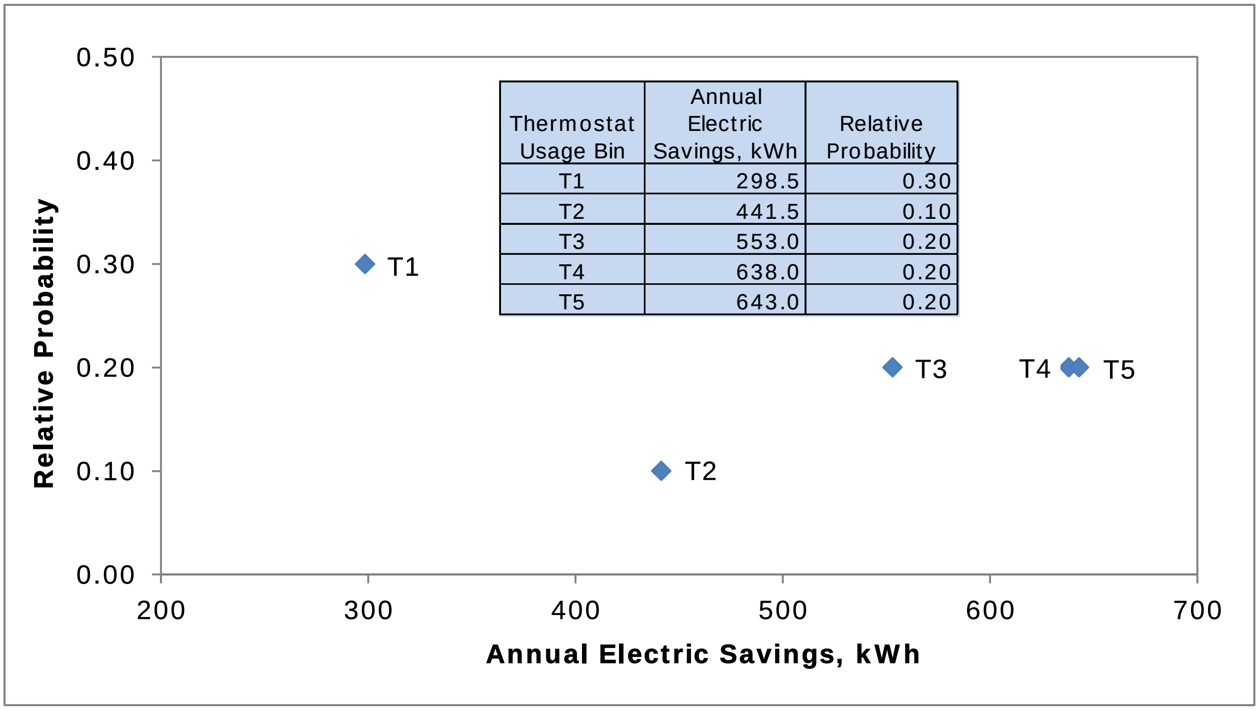
Table 7. DEER Story and Vintage Weights for Single Family Homes in CZ11

Building Vintage	Vintage Weights	1-Story Weight by Vintage	2-Story Weight by Vintage
Before 1978	0.43	0.74	0.26
1978-1992	0.27	0.77	0.23
1993 - 2001	0.16	0.60	0.40
2002 - 2005	0.09	0.60	0.40
After 2005	0.05	0.60	0.40

The next largest contributor to the savings variance is the 1-story homes of the same vintage. Again, this is not surprising since 1-story homes (74%) dominate the savings within this vintage. The high variance of 1-story savings in the thermostat usage bins is shown in Figure 7. For comparison, Figure 8 shows the distribution of savings for the 1993-2001 vintage, which has a much narrower distribution. The small vintage weight of 0.16 combined with the narrow distribution of savings across the thermostat usage bins for the 1993-2001 vintage results in a small contribution to variance (less than 2%), as shown in Figure 6.

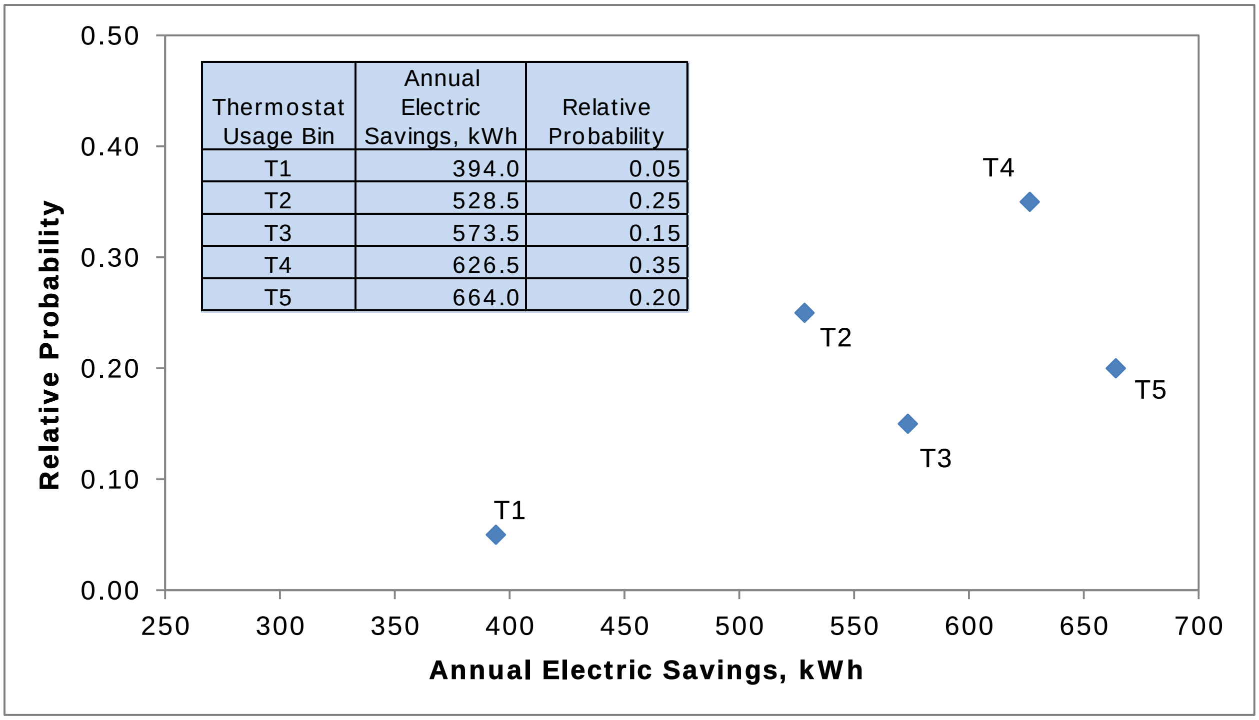
Figure 7 and Figure 8 show the energy savings distributions across the thermostat usages for two building vintages. As mentioned above, the distribution of the savings results is much broader for those homes built prior to 1978 than those of 1993-2001 vintage.

Figure 7. Savings by Thermostat Usage, 1-story SFM Built Before 1978



Thermostat Usage Bin	Annual Electric Savings, kWh	Relative Probability
T1	298.5	0.30
T2	441.5	0.10
T3	553.0	0.20
T4	638.0	0.20
T5	643.0	0.20

Figure 8. Savings by Thermostat Usage, at 1-story SFM Built 1993-2001



Thermostat Usage Bin	Annual Electric Savings, kWh	Relative Probability
T1	394.0	0.05
T2	528.5	0.25
T3	573.5	0.15
T4	626.5	0.35
T5	664.0	0.20

While this discussion focuses on SFM CZ11, each dwelling type and climate zone has a unique set of sensitivities. The results and sensitivities associated with each scenario are shown in Appendix B. Without going into great detail, the following list presents some of the key trends that emerged:

- With the exception of two scenarios, SFM and MFM in CZ11, dwelling vintage weights contribute the most variance to the savings for all other dwelling type and CZ combinations. In most cases, building vintage accounted for the majority of the variance (70% or more). This suggests that there is a high variance of savings between vintages in these climate zones.
- The distribution weights of the thermostat usage bins are the next highest contributor to the variance. This is due to the large differences of the savings between each of the thermostat usage bins. Furthermore, the weights for each thermostat usage bin are relatively even, ranging from 0.05 to 0.45 with the majority being between 0.20 and 0.25.
- For all climate zones and dwelling types, the “Before 1978” building vintage bin constitutes a substantial portion of the variance of the savings. This is because this vintage makes up the largest portion of the building stock, and many of those dwelling were constructed prior to the adoption of Title 24.
- Savings at SFM buildings vary significantly by the number of stories. Of course, this is due to the large differences in energy consumption and savings that would naturally occur between 1- and 2-story homes. In CZ11, it accounts for over 70% of the variance; in CZ12 and CZ13, it accounts for about 20% of the variance.

3.4.3 Information Gaps

Annual ex ante natural gas savings for residential furnace measures are based entirely on 2011 DEER values. In Year 1 of this study, it was not been possible to gather results of the parametric runs that were used to determine the savings due to limitations with the DEER MASControl. A Monte Carlo simulation is planned as part of the Year 2 scope once more information becomes available. Without specific information, each of the parametric runs would need to be executed to determine the un-weighted savings. Once these values become available, though, the Monte Carlo simulations can be executed with little effort since the existing model for the annual electric savings simulations would serve as a template.

The established DEER savings methodology for determining annual natural gas savings use unique weights for each climate zone, thermostat usage bin, and number of building stories. These weights are derived from the 2003 Residential Appliance Saturation Survey (RASS). It would seem more appropriate to use the weights provided by the 2009 RASS, instead.

Another barrier facing the evaluation team is that the 2013 tracking data does not consistently include the building vintage for furnace measures—that field is often left blank. Additionally, thermostat usages and number of stories are not tracked. Therefore, it is not possible to compare RASS weights to the tracking population weights for vintage, thermostat usages, and number of stories. As savings can vary considerably by each of these scenarios, it may be useful to determine if the participant population is similar to the RASS weights.

3.5 Recommendations

Residential furnace retrofits yielded total ex ante savings of 3,382 MWh and 317,641 therms for the 2013 cycle. Given that small adjustments to assumptions could have a substantial impact on California savings estimates, further research may be warranted for this measure, as described below:

1. The DEER Prototype models could be run to determine the therm savings for each scenario (thermostat usage, number of stories, vintage, and climate zone). Once these savings values were obtained, an uncertainty analysis could be completed. As the uncertainty analysis would be identical to the kWh savings analysis, this could be done with relative ease. This task could be included in Year 2 of this study,
2. We recommend determining a means to assess average blower motor power during non-cooling modes for the post-retrofit case. Presently, the modified eQuest models use a fixed fan power input and vary the fan power with operating conditions. In reality, though, both the W/CFM and CFM would be expected to vary with changes to outside weather conditions and motor operation. Specifically, the relationship between the motor power and hours of operation at different speeds would vary depending on whether the motor operates continuously or intermittently. The Energy Center of Wisconsin study addresses and examines this relationship, but these results may not be appropriate for California given the vast differences in usage behavior and weather conditions. Therefore, we recommend using eQuest to simulate variable speed operation for the measure case and to determine the hours of operation within appropriate motor speed bins. It will also be necessary to locate suitable power curves at multiple motor speeds. Such an approach would be far preferable to using the full load hours for a fixed fan motor speed.
3. Uncertainty of the climate-zone UES could be greatly reduced by focusing more attention on understanding the building vintages represented in the participant population. The vintage weights are by far the largest contributor to variance across all dwelling types. Currently, the vintage weights rely on 2003 RASS data. However, it is unclear whether the RASS data is representative of the measure population. Building vintage bins consistent with DEER vintage bins could be added to the rebate form. Checkboxes may be the easiest way to gather this information and could be added to tracking data. If enough data were collected, the vintage bins weights in the participant population could

be used. If sufficient data cannot be obtained, however, the 2009 RASS building weights would at least provide more current building vintage distributions across the building stock. Another option to overcome the uncertainty of the building vintage weights would be to provide deemed UES values for each building vintage within each climate zone.

4. After vintage weights, thermostat usage weights are the next highest contributor to variance for furnaces and likely other residential HVAC measures. Again, these weights are drawn from 2003 RASS data. Thermostat usage patterns and behaviors may have changed since this study was conducted. Additionally, the thermostat usage weights do not vary by dwelling types or building vintages. Another question that remains unanswered is whether thermostat behaviors change after implementing a furnace measure. While 2009 RASS data is more current than the 2003 RASS data, it still uses monthly bills and heating degree days. A mail and phone survey could focus on thermostat usage. Using hourly interval data and the self-reported schedules, new thermostat weights could be developed. Since thermostat usage weights influence other types of measures, there may be added value to such a study. A consideration for year two or three of this study would be to estimate the degree to which the thermostat usage bin uncertainty propagates to the residential HVAC savings.

4. Residential Quality Maintenance and Blower Motor Replacement

The second uncertainty analysis undertaken in Year 1 of this study pertained to residential quality maintenance and blower motor replacements. Consistent with the criteria described in Chapter 2, this measure was selected based upon 1) the sharp rise in participation in the 2013 tracking data and 2) the QM evaluation research plan includes the evaluation of commercial QM measures, only.

An additional argument for performing an uncertainty analysis for residential QM emerged once a workpaper disposition[28] was issued for this measure on May 2, 2013. In the disposition, the Commission indicates that the ex ante savings will be scaled downward for several reasons:

- The baseline input parameters yield unrealistically high baseline energy consumption values.
- Those input parameters for which DEER values exist should have used the DEER values.
- The duct insulation retrofit is not approved due to a lack of sufficient field data—the ex ante savings for this measure should be zero.
- The post-measure input parameters yield unrealistically low post-measure energy consumption values, and
- The known lack of skilled technicians will adversely affect the program savings.

Hence, the Commission revised the unit energy savings (UES), the effective useful life (EUL), and the net-to-gross ratio (NTGR) downward.

Since residential quality maintenance can include multiple and varied packages of services and retrofits, we begin this chapter by describing measure components included in each IOU’s program. We then describe the methodology and input parameters used to determine the deemed savings. While the savings methodologies are the same across the workpapers, we focus our in-depth discussion and uncertainty analysis on the workpaper by PG&E–a decision made because this workpaper provided the most detailed explanation of the methodology and analysis steps. At the end of the chapter we summarize our findings and present recommendations based upon those findings.

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[28] California Public Utilities Commission, Energy Division, May 2, 2013, *Workpaper Disposition for Residential HVAC Rooftop Quality Maintenance.*

4.1 Measure Descriptions

The residential quality maintenance (QM) programs offered by PG&E, SCE, and SDG&E usually include inspection services, active services, component retrofit measures (such as airflow adjustment, condenser coil cleaning, duct refurbishment, sealing, and insulation), and refrigerant charge testing and adjustment. The various blends of QM measures offered by the IOUs are shown in Table 8. For each of the electric IOUs—PG&E, SCE, and SDG&E—QM begins with an initial system assessment. Based on the assessment findings, a range of possible services and/or retrofits may be recommended to the customer.

Residential customers are eligible for QM if their HVAC system is either of two types: 1) central air conditioning systems that use direct-expansion (DX) cooling and natural gas heating, or 2) central heat pump systems. The program is offered to single-family homes, detached mobile homes, and multi-family homes (for SCE, this is restricted to those with up to four attached units.

The QM service offerings are consistent with the definitions provided by Air Conditioning Contractors of America, in Standard 4,[29] for basic maintenance inspection tasks. The ACCA standard also offers recommended corrective actions to maintain most residential HVAC systems. While there are many benefits to QM measures—such as prolonging equipment efficiency and equipment life, improving air quality, supporting lower utility costs, and guarding against unexpected failures—ex ante energy savings are deemed only for active services and retrofits, and not for passive services such as initial system assessments and preventive maintenance services. Blower motor replacements are a specific measure component shown below.

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[29] Air Conditioning Contractors of America. 2008. *The ANSI/ACCA Standard 4 Maintenance of Residential HVAC Systems.*

Table 8. Residential Quality Maintenance Measure Components by IOU[30]

Measure Name	Component Description	PG&E AC Quality Care	SCE Quality Maintenance	SDG&E AC Quality Care
Initial System Assessment	This service provides *Full ACCA Standard 4 HVAC System Assessment.* It's a prerequisite for services and retrofits below. Unlike PG&E and SCE, SDG&E includes additional bundled measures that yield savings (see blue cells).	✓ No direct savings	✓ No direct savings	✓ Some direct savings
Airflow Correction	Bundled measures that vary by IOU (see green cells).	✓		✓
System Optimization	Bundled measures offered by SCE (see grey cells).		✓	
Advanced Airflow Service	Bundled measures offered by SCE (see pink cell).		✓[31]	
Efficient Fan Delay Control Retrofit	This retrofit causes the indoor fan to remain on following: a) each heating cycle, for 3 minutes; and b) each cooling cycle, for a period of time proportional to the duration of preceding compressor-activation.		✓	✓
Condenser Coil Cleaning Service	This service removes pollen, dirt, dust, and debris from condenser coils.	✓	✓	✓

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[30] Shaded *Measure Names* may include other measures, as indicated by cells with matching shading in the IOU-specific columns.

[31] Where offered, customers are only eligible for rebate for airflow improvements ≥400 CFM per ton of cooling capacity.

Measure Name	Component Description	PG&E AC Quality Care	SCE Quality Maintenance	SDG&E AC Quality Care
Air Filter Change/ Cleaning Service	This service removes particulates from filters or replaces filters.	✓	✓	✓
Duct Sealing Service	This service, offered either as part of a duct system service or other service package, involves testing and sealing air ducts.	✓	✓	✓
Refrigerant Charge Adjustment (RCA) Service[32]	This service adjusts refrigerant charge (pressure) to within manufacturer specifications to optimize system cooling efficiency.	✓	✓	✓
Brushless Blower Motor (BPM) Retrofit	This measure replaces shaded-pole or permanent split-capacitor (PSC) fan motors with brushless permanent magnet (BPM) motors with selectable speed control.	✓ Prerequisite: Airflow Correction	✓ Prerequisite: System Optimization	✓ Prerequisite: Airflow Correction
Preventative Maintenance Service	This measure provides a one-year service contract for a minimum of two maintenance calls—a preseason cooling call and a preseason heating call.	✓ No direct savings	✓ No direct savings	✓ No direct savings

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[32] In SCE and SDG&E's climate zones 6, 7, 8, 9, 10, 13, 14, and 15, the QM programs require that, subsequent to the airflow correction service, the unit and system must be capable of delivering a supply air flow rate of at least 350 CFM/ton of cooling capacity before refrigerant charge is tested and/or adjusted. This requirement ensures that the refrigerant system can be accurately measured and appropriately charged.

4.2 Deemed Savings Calculation Methods

DNV GL identified and thoroughly reviewed three workpapers for QM and blower motor replacement measures:

1. Residential HVAC Quality Maintenance Workpaper PGECOHVC139, by PG&E;[33]
2. Residential HVAC Quality Maintenance and Evaporator Motor Retrofit Workpaper SCE13HC029, by SCE;[34] and
3. Residential HVAC Quality Maintenance and Motor Retrofit Workpaper WPSDGEREHC1065, by SDG&E.[35]

While these three workpapers use the same deemed savings methodology, an uncertainty analysis was conducted only for those climate zones in PG&E's territory to maintain project schedule and budget. While we focus our discussion below on PG&E's workpaper, it may be worthwhile to consider repeating the analysis for the other two IOUs in Year 2 if there are significant differences in methods and assumptions.

The residential QM and blower motor replacement measures, as a whole, are not included in DEER. The database does, however, contain some of the QM treatments as standalone measures with the assumption that all other factors have been held constant. The DEER standalone measures include: refrigerant charge adjustment, duct sealing, , and condenser coil cleaning (for commercial applications, only). The blower motor replacement measure is not included in the DEER database. Due to the high degree of interactivity between the QM measures included in DEER, it is not appropriate to sum the DEER savings for each measure to determine the combined savings.

The deemed savings methodology described in PG&E's workpaper uses the DEER 2008 single-family home prototype file[36] to perform eQuest batch runs.[37] PG&E's eQuest models use different baseline and post-measure input assumptions to determine the ex ante savings, at the whole-house level, due to QM measures. These results were then used to generate a multi-variable linear regression model for both the baseline and the post-measure cases for each of the following types of savings: annual electric consumption, peak demand, and natural gas

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[33] PG&E. 2012. *Residential HVAC Quality Maintenance Workpaper PGECOHVC139, Revision #0*. Last revised Aug 29, 2012.

[34] SCE. 2012. *Residential HVAC Quality Maintenance and Evaporator Motor Retrofit Workpaper SCE13HC029, Revision 0*. Last revised May 29, 2012.

[35] SDG&E. 2012. *Residential HVAC Quality Maintenance and Motor Retrofit Workpaper WPSDGEREHC1065, Revision 0*. Last revised June 26, 2012.

[36] Database for Energy Efficiency Resources (DEER) Single Family Prototype Input File. http://www.doe2.com/download/deer/mastool/

[37] For a description of the relationship between DOE2 and eQuest, see http://www.doe2.com/

consumption. Expected value analysis methods[38] were used to determine the baseline and post-measure consumption levels from each respective regression by varying input parameters to be described in 04.3.2. It should be noted that, according to workpaper PGECOHVC139 Residential HVAC Quality Maintenance, all DOE2 eQuest simulation results are based on single family homes with AC units with gas furnace. Therefore, the calculated deemed kW, kWh, and therm savings results apply only to those AC units with gas furnaces. The deemed savings for heat pumps only include the cooling energy savings at residential homes; the heating energy savings are not considered. These limitations are not clear to the reader since the workpaper indicates that the QM measures apply to all single family homes or duplexes located in PG&E's climate zones and cooled using a central air conditioner or heat pump.

Input Parameters for Monte Carlo Simulation. The difference between the consumption, by savings type, for the baseline and post-measure cases, respectively, yielded the estimated ex ante savings for each of the QM measures—except for the blower motor replacement.

For blower motor replacements, PG&E derived estimated savings separately, but again using eQuest simulation models and engineering calculations. First, PG&E used the post-measure outputs from the expected value analysis as the inputs to the eQuest model since, for PG&E, blower motor replacements can only occur following the implementation of the other QM measures that they offer. These inputs are applied to the model for 1- and 2-story houses in each climate zone. The baseline blower system efficiency is used with the baseline 1- and 2-story home models, and the simulation output equals the estimated baseline consumption. The post-measure eQuest models are used with the post-measure efficiency of the replacement blower motor. Again, the differences between the energy consumption using the baseline models and the baseline blower system efficiency, and the post-measure models combined with the post-measure blower motor efficiency, determine the ex ante savings for the blower motor replacement.

4.2.1 PG&E Workpaper Review

In the PG&E workpaper, all offered QM measures are consolidated into five measure codes: TK07, TK08, TK09, TK10, and TK12. Ex ante savings for each are estimated as follows:

- TK07 represents the *Initial System Assessment* measure and yields zero savings.
- TK08 savings for the *Airflow Correction* measure are simulated by making changes to the duct system in the building model to represent improvements in duct system efficiency.

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[38] Expected Value Analysis (EV) – Is a forecasting tool using probability-based analysis to make a projection of the likely values of input parameters, along with the probability of each, and the range of likely outcomes.

- TK09 savings for the *Refrigerant Charge Adjustment (RCA)* measure are simulated by reducing the energy efficiency rating (EER) of the installed air conditioner to represent the baseline case. PG&E reports an estimated measurement uncertainty of ±10% for refrigerant charge pressures.
- TK10, the *BPM Retrofit* measure for the evaporator blower, is handled a little differently by SCE than by PG&E and SDG&E: SCE always requires that the *System Optimization* measure precedes a blower motor replacement, whereas the other two always require that the *Airflow Correction* measure precede a blower motor replacement. In PG&E's workpaper, the post-measure calculation assumes the use of the same AC unit but with a BPM blower motor with selectable speed control retrofitted to replace the baseline of either a shaded pole or permanent split capacitor (PSC) motor. eQuest models were used again to isolate the evaporator blower motor usage and runtime hours. These values were input to the equation to determine baseline and post-measure energy consumption. The only variable that differs between the two cases is the fan system efficiency: the fan system with the baseline PSC motor uses 0.65 W/CFM as previously described in 3.2.2 Review of Secondary Sources; the same fan system with the replacement BPM motor uses 0.365 W/CFM based upon DEER values. This results in an improvement to the efficiency of the fan system from 17% (baseline) to 32% (post-measure).
- TK12 represents the *Preventive Maintenance Service* measure and yields zero savings.

The ex ante savings for all of the energy-saving measures are combined and reported in TK08 so that the interactivity of the duct system efficiency and the air conditioning system efficiency are consistently accounted for; the combined value provides a better representation of the outcome.

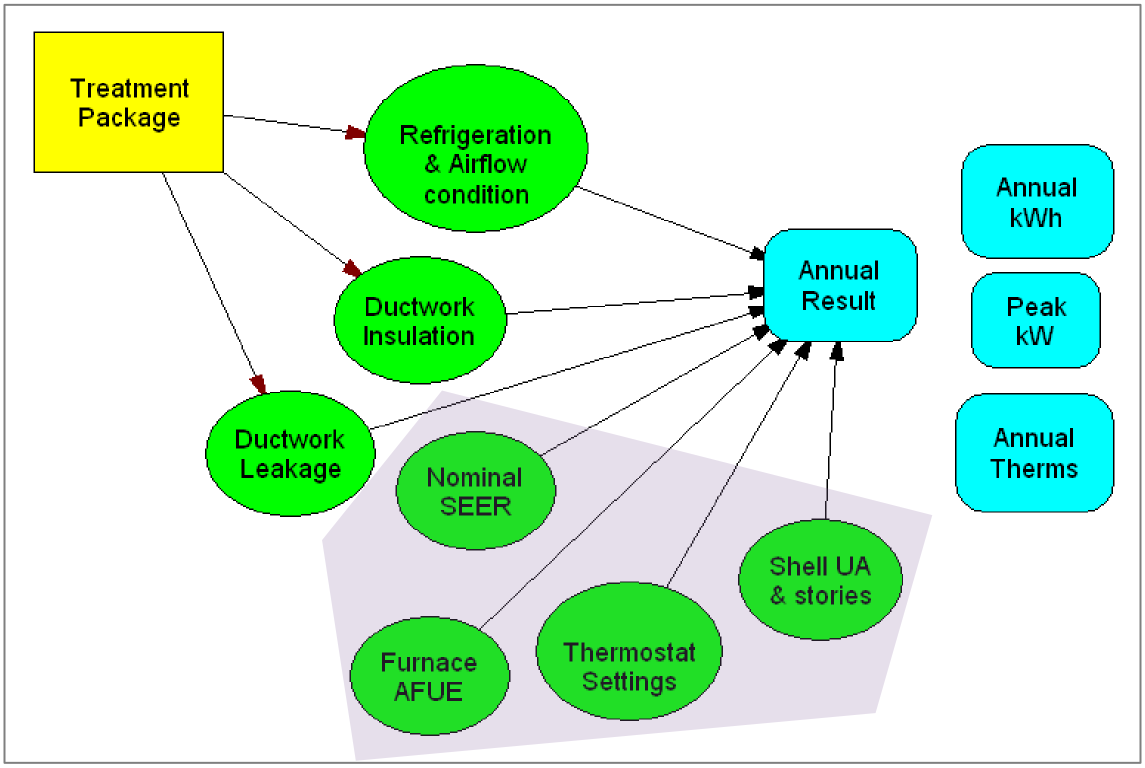
It should be noted that, according to workpaper PGECOHVC139 Residential HVAC Quality Maintenance, all DOE2 eQuest simulation results are based on single family homes with AC units with gas furnace. Therefore, the calculated deemed kW, kWh, and therm savings results apply only to those AC units with gas furnaces. The deemed savings for heat pumps only include the cooling energy savings at residential homes; the heating energy savings are not considered. These limitations are not clear to the reader since the workpaper indicates that the QM measures apply to all single family homes or duplexes located in PG&E's climate zones and cooled using a central air conditioner or heat pump.

4.3 Input Parameters for Monte Carlo Simulation

4.3.1 Overall Framework

As provided in the PG&E workpaper, Figure 9 shows the seven input parameters that could impact the energy consumption of the prototype eQuest model building that is used to determine the energy savings for residential QM measures. The green ovals are identified as "discrete choice nodes," where each node is assigned a set of possible values and the distribution (a.k.a. weights) of those values. All discrete choice nodes are used to determine the result nodes, represented by the blue rectangles. These are then used to generate the regression fit models that are used to estimate measure savings distributions.

Figure 9. Expected Value Analysis Influence Diagram



Source: PG&E Workpaper

The three choice nodes (a.k.a., input parameters) that represent refrigeration and airflow, ductwork insulation, and ductwork leakage have two sets of values and weights assigned to represent the baseline and post-treatment cases. The four discrete choice nodes within the shaded region—which represent nominal seasonal energy efficiency rating (SEER), furnace AFUE, thermostat usage, and building shell UAs—have one set of values and weights to represent the variety of single-family homes located in California; these are unchanged by the QM measures. For the purposes of the workpaper, it is assumed that the distributions of the characteristics of single-family homes that are held constant are equal to the distributions of those in the QM program participant population.

Using the described input parameters, we created a model within Oracle Crystal Ball with which to conduct Monte Carlo simulations to determine the energy savings attributed to QM measures. The Crystal Ball model was set up using the outputs from the multi-variable linear regression models and input parameters published in PG&E's workpaper. The simulations were run to estimate the distribution of the annual electric energy savings/tons of cooling capacity (CC), peak demand savings/tons CC, and natural gas savings/tons CC for both the baseline and the post-measure cases. The mean differences of the baseline and post-measure distributions estimate the ex ante energy savings of the QM measures for each climate zone. An uncertainty analysis was also performed to identify the input parameters that made the highest contributions to the variance of the ex ante savings.

Monte Carlo simulations and uncertainty analyses were not performed for the blower motor replacement measure within the residential QM measures (TK10). This is because the savings for blower motor replacements are based on the simulation results of the baseline and post-measure eQuest models. Performing parametric uncertainty analyses using simulations were outside the scope of Year 1 of this study.

4.3.2 Workpaper Assumptions that Informed Monte Carlo Inputs

The distributions of the input parameters for the baseline and post-measure cases are provided in tables within the workpaper and are briefly described below.

1. The refrigeration impact factors (RIF) consists of six discrete values, ranging from 1.0 to 1.257, that are used to scale down the whole-house energy consumption subsequent to the implementation of the refrigeration-related QM measures. These include: refrigerant charge correction, evaporator and condenser coil cleaning, filter replacement, and thermal expansion valve (TXV) sensor insulation. Table 9 shows the baseline and post-measure distributions of RIFs. Field data from an ACEEE paper by Robert Mowris[39] were used to establish the distribution of RIFs.

Table 9. Refrigeration Impact Factor Distributions

Refrigeration Impact Factor	Baseline Proportions	Post-Measure Proportions
1.257	0.107	0.011
1.150	0.286	0.029
1.087	0.250	0.025
1.051	0.214	0.021
1.015	0.143	0.043
1.000	0.000	0.871

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[39] Mowris, Robert, Anne Blankenship, and Ean Jones (Robert Mowris & Associates). 2004. *Field Measurements of Air Conditioners with and without TXVs*. ACEEE Summer Study Proceedings. http://www.aceee.org/proceedings-paper/ss04/panel01/paper19.

2. Duct leakage is reduced by QM; the assumed baseline and post-measure air leakage rates and their associated distributions are shown in Table 10. The weights are based on the 2010 PG&E Duct Test and Seal Program.

Table 10. Duct Leakage Rates and Distributions

Duct Conditions	Duct Leakage Rate, CFM / CFM	Baseline Proportions	Post-measure Proportions
Super Leaky	0.400	0.366	0.037
	0.240	0.282	0.101
Leaky	0.190	0.246	0.191
	0.120	0.105	0.197
OK	0.085	0.001	0.474

3. QM measures include installing new duct insulation or making repairs to existing insulation and ductwork to achieve an increased overall R-value. We are unaware of studies reporting the baseline and post-measure duct UAs. PG&E developed the distributions shown in Table 11, based on engineering judgment. When data becomes available, this table should be updated.

Table 11. Duct Insulation UA and Distributions

Equivalent R-Value	1-story SFM Duct UA, Btu / ft²·°F·h	2-story SFM Duct UA, Btu / ft²·°F·h	Baseline Proportions	Post-Measure Proportions
2.8	139	239	0.150	0.025
	110	189	0.200	0.139
5.8	81	139	0.400	0.359
	65	112	0.150	0.309
8.7	50	86	0.100	0.168

4. Thermostat usage bins are an important factor in determining energy consumption and, therefore, savings. Since the DEER thermostat usage bins were developed by considering only the cooling setpoints and schedules, offsets for the thermostat usage bins were used by PG&E to serve as a proxy for heating and cooling setpoints and schedules, as follows:

T-stat Offset = (24 hr. average of cooling setpoints, T-stat) - 79.7°F

The RASS database[40] was queried to get survey results of reported cooling thermostat setpoints. The data were statistically distributed into five daily schedules, which are shown in Table 12.

Table 12. Thermostat Usage Bins, Offset Values, and Weights

T-stat Bins, °F	T-stat Offset Bins, °F	T-stat Offset Bin Weight
82.00	2.30	0.068
79.29	-0.41	0.377
76.25	-3.45	0.308
75.13	-4.58	0.180
75.00	-4.70	0.067

5. The weights used for the distribution of nominal SEER in single-family homes were derived from the DEER Residential Lookup Table and the RASS survey. The average nominal SEER values and associated weights for each building vintage in each climate zone are shown in Table 13. While the nominal SEER of a given air conditioning unit remains unchanged by QM measures, the post-measure *effective* SEER is higher. For the purposes of the regression model, the PG&E workpaper treats the SEER value as an independent and fixed variable as shown in Table 13. To capture—and serve as a proxy for—the post-measure improvement to the *effective* SEER value, the distribution of the post-measure RIF values is shifted, as shown in Table 9.

Table 13. Nominal SEER Values and Weights by Building Vintage and Climate Zone

Building Vintage	Nom. SEER	CZ01	CZ02	CZ03	CZ04	CZ05	CZ11	CZ12	CZ13	CZ16
Before 1978	10	0.636	0.580	0.759	0.559	0.478	0.409	0.482	0.418	0.623
1978-1992	10	0.107	0.254	0.113	0.263	0.300	0.307	0.271	0.282	0.246
1993-2001	10	0.172	0.089	0.063	0.105	0.068	0.113	0.111	0.113	0.061
2002-2005	10	0.081	0.049	0.038	0.036	0.106	0.092	0.062	0.109	0.028
After 2005	13	0.004	0.028	0.027	0.037	0.049	0.079	0.074	0.078	0.043

6. The next input parameter used to determine the ex ante savings is the furnace AFUE (see Figure 9). The five bins defined to represent the furnace AFUE were generated by

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[40] California Statewide Residential Appliance Saturation Study, http://websafe.kemainc.com/RASS2009/Default.asp

choosing an upper limit of 0.95 and a lower limit of 0.70. According to the PG&E workpaper, no field data exist to produce AFUE bins in PG&E territory, so the values chosen for the analysis are based on informed engineering estimates and applying a normal distribution as shown in Table 14. As with SEER, the nominal furnace AFUE is not changed by QM measures, but the post-measure *effective* AFUE is higher.

Table 14. Estimated Furnace Efficiency Bins and Distributions

Furnace Efficiency, AFUE	AFUE Proportions
0.700	0.100
0.740	0.200
0.780	0.400
0.865	0.200
0.950	0.100

7. The whole-house UA is comprised of a combination of two values:
    a. The building shell UA is a single number that combines that R-values, weighted by surface area, for all of the exterior walls, windows, and the roof that surround all conditioned spaces.
    b. The building infiltration UA is a single number based on the number of air changes per hour as specified in a DEER look-up table.
8. The combined shell and infiltration UA values are used to determine the ex ante savings for QM measures. To generate the distribution of the combined UA, the lowest and highest UAs were used for the upper and lower limiting cases. The probability distribution of UAs for each building vintage in each climate zone is based on the information from RASS. Climate zones 1, 5, and 16 did not have sufficient data, however, to generate full probability distributions. Where gaps existed, the probabilities from adjacent climate zones were used.

4.4 Analysis Results

This section presents the output of the Monte Carlo simulations, annual electric energy consumption per cooling ton (kWh/ton) for the baseline and post-measure cases, identifies the percentage of savings uncertainty that can be attributed to key assumptions in the model (e.g., building vintage), and discusses any information gaps that have limited our ability to assess annual ex ante energy savings for residential QM measures. Note that, in 3. Residential Furnaces”, annual electric energy savings were output by the Monte Carlo simulations. For QM measures, however, annual savings could not be simulated directly and the annual energy consumption per ton was simulated for both the baseline and the post-retrofit cases, separately.[41] Hence, two simulations were necessary—one for the baseline case and one for the post-measure case. This shift is due to the differences between the ways that the two measure savings are determined as follows:

- For residential furnaces, the post-retrofit consumption equals the product of the baseline consumption and the ratio of the motor power draw of the post-retrofit motor to that of the baseline motor. For any given furnace VSM retrofit project, the very same input parameters are used for the baseline and the post-retrofit cases.

- For QM measures, the post-retrofit consumption is determined using different input parameters than the baseline consumption. Hence, the uncertainty analyses must be performed individually for each case. The savings are then determined by taking the difference between the baseline consumption and the post-retrofit consumption. The variance of the savings equals the sum of the variances for both cases.

4.4.1 Monte Carlo Simulation Results

For single family homes in each climate zone, the baseline and post-measure energy consumption values were aggregated across all of the input parameters, by using the regression models published in PG&E's referenced workpaper. For each fuel type, the difference between baseline and post-measure mean energy consumption equals the estimated energy savings. For this report, the energy consumption per cooling ton at each SFM in CZ03 is presented in the figures and tables that follow.

Figure 10 shows the binned annual electric energy consumption per cooling ton where the consumption bins are shown on the horizontal axis and the corresponding probabilities of each energy consumption outcome are shown on the vertical axis. The figure shows that the mean values are not those with the highest probability and the distribution is far from normal. There appear to be five distinct peaks in both consumption distributions, so the distribution appears to be highly influenced by one of the input parameters comprised of five bins—either the T-stat offsets or the building vintages.

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[41] DNV GL initially set up the Monte Carlo simulations to output UES values, but because the baseline and post-retrofit cases use different input parameters, randomly varying all input parameters simultaneously yielded inaccurate UES values.

Figure 10. Annual Electric Energy per Ton, Baseline and Post-Measure, in CZ03

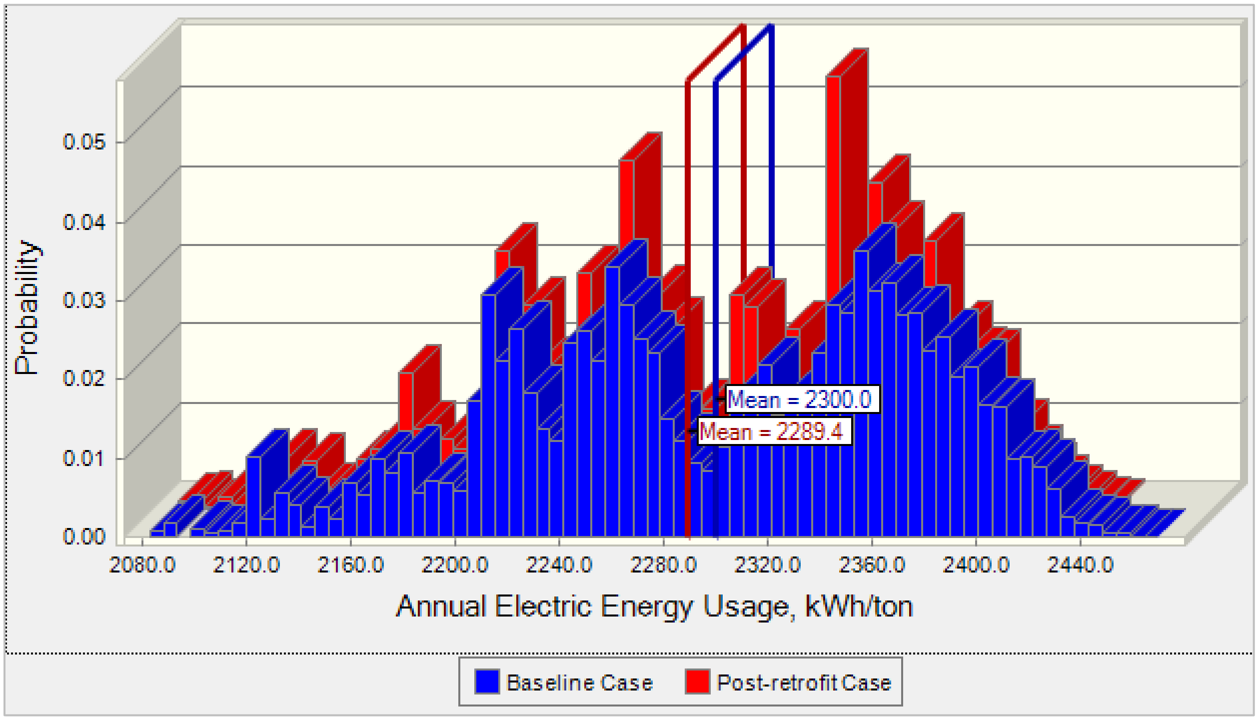


Table 15 shows the statistical descriptors associated with the energy consumption for the baseline and post-measure cases presented in Figure 10. Based upon the distribution plots, it is not surprising that the standard deviation around the mean is quite large: approximately 107 kWh/ton around the mean annual savings of 11 kWh/ton.

Table 15. Statistics for Annual Electric Energy Consumption per Ton in CZ03

Statistical Descriptors, units	Baseline	Post-Measure	Savings
Mean, kWh/ton	2,300	2,289	11
Median, kWh/ton	2,310	2,299	n/a
Mode, kWh/ton	2,215	2,205	n/a
Standard Deviation, kWh/ton	77.5	73.3	106.7
Coefficient of Variation	0.0337	0.032	n/a
Minimum, kWh/ton	2,050	2,048	n/a
Maximum, kWh/ton	2,470	2,443	n/a
Mean Standard Error, kWh/ton	0.8	0.7	1.1

Figure 11 and Table 16 provide the distribution of the hourly peak demand consumption per cooling ton and associated statistical descriptors, respectively, for both the baseline and the post-measure cases in Climate Zone 3. Unlike annual electric energy consumption and savings, the peak demand shows a normal distribution of the simulation outputs.

Figure 11. Peak Demand per Ton, Baseline and Post-Measure, in CZ03

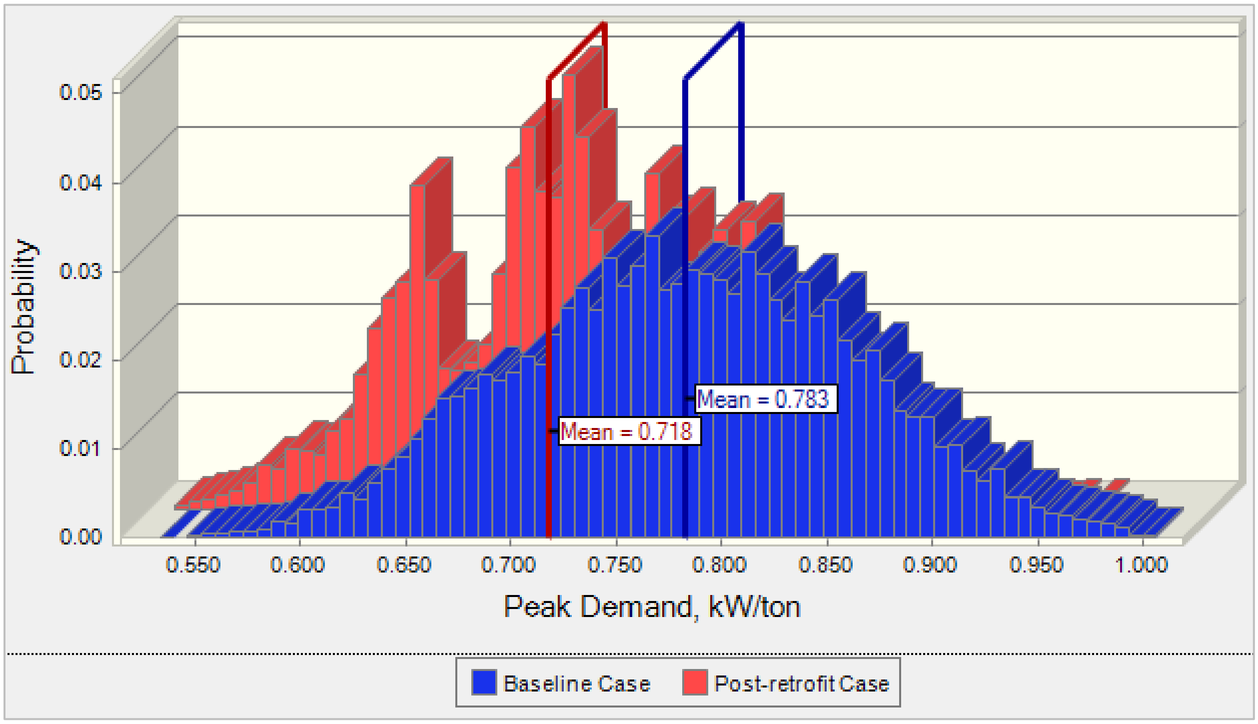


Table 16 shows that, once combined, the savings are estimated to be 0.065 kW/ton with a standard deviation of 0.105 kW/ton.

Table 16. Statistics for Peak Demand per Ton in CZ03

Statistical Descriptors, units	Baseline Case	Post-measure Case	Savings
Mean, kW/ton	0.783	0.718	0.065
Median, kW/ton	0.783	0.717	n/a
Mode, kW/ton	0.731	0.643	n/a
Standard Deviation, kW/ton	0.080	0.068	0.105
Minimum, kW/ton	0.513	0.492	n/a
Maximum, kW/ton	1.039	0.964	n/a
Mean Standard Error, kW/ton	0.001	0.001	0.001

Figure 12 and Table 17 provide the distribution of the natural gas consumption per cooling ton and associated statistical descriptors, respectively, for both the baseline and the post-measure cases in Climate Zone 3. While it is unusual to see natural gas savings reported per cooling ton, this is how the units for the UES were established in the workpaper.

Figure 12. Natural Gas Consumption per Ton in CZ03

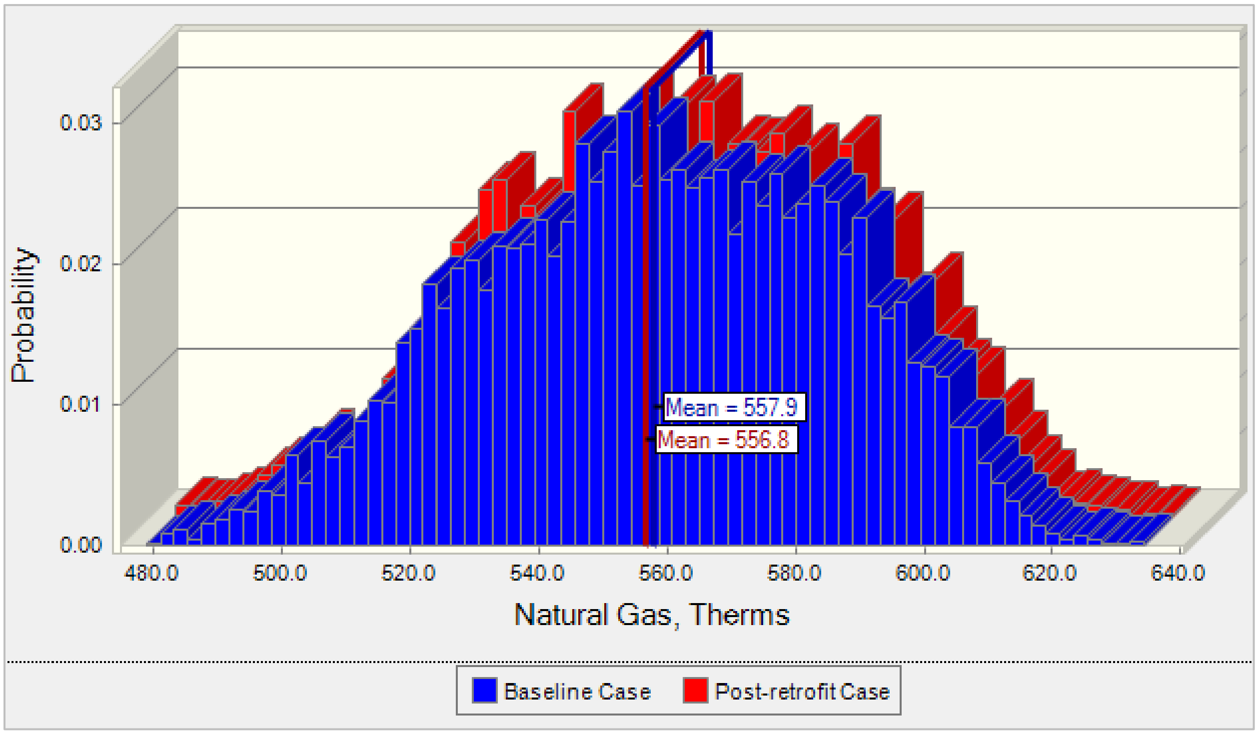


Table 17. Statistics for Natural Gas Energy Consumption in CZ03

Statistical Metrics, units	Baseline Case	Post-measure Case	Resulting Savings
Mean, therms/ton	557.9	556.8	1.10
Median, therms/ton	558.4	557.5	n/a
Mode, therms/ton	534.0	533.5	n/a
Standard Deviation, therms/ton	28.0	27.8	39.4
Coefficient of Variation	0.050	0.050	n/a
Minimum, therms/ton	470.5	469.9	n/a
Maximum, therms/ton	646.0	642.3	n/a
Mean Standard Error, therms/ton	0.3	0.3	0.4

Figure 13, Figure 14, and Figure 15 show a comparison of the ex ante savings reported in the PG&E workpaper and the simulated savings forecasted by Crystal Ball for annual electric energy savings per ton, peak demand savings per ton, and natural gas savings per ton, respectively. The annual electric energy estimates are within 25% of the ex ante savings in all climate zones except CZ12. For peak demand, the simulated savings and ex ante savings in all climate zones except for Climate Zone 1 are within 25%. For natural gas energy, however, the ex ante savings are significantly higher than the simulated savings. DNV GL was not able to determine a reason for this difference and request consultation with the workpaper group.

Figure 13. Simulated and Ex Ante Annual Electric Energy Savings per Ton

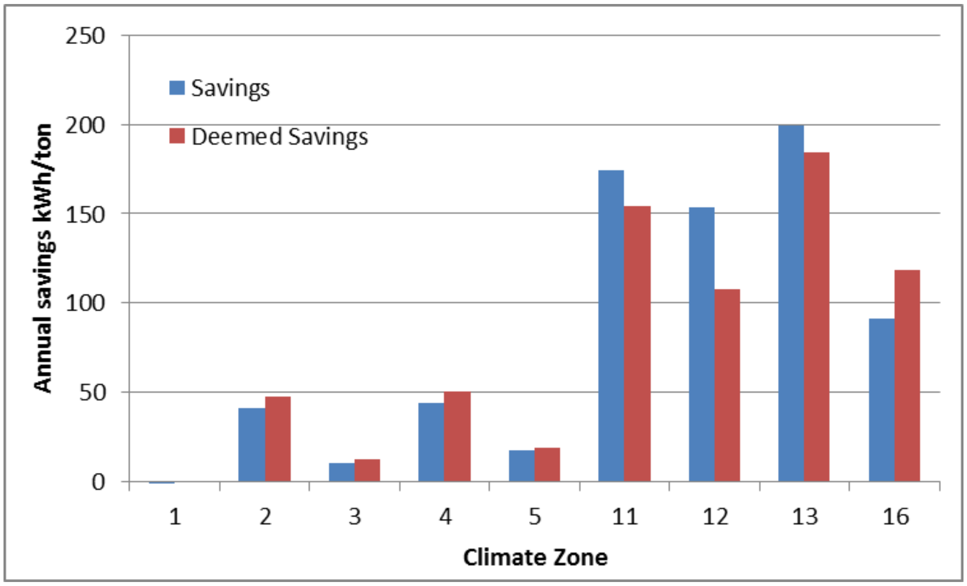


Figure 14. Simulated and Ex Ante Peak Demand Savings per Ton

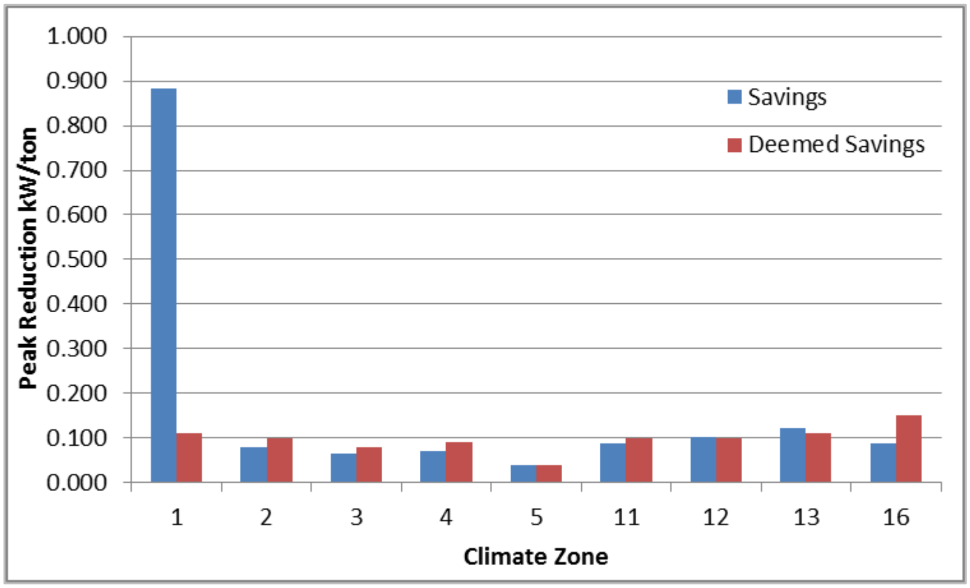
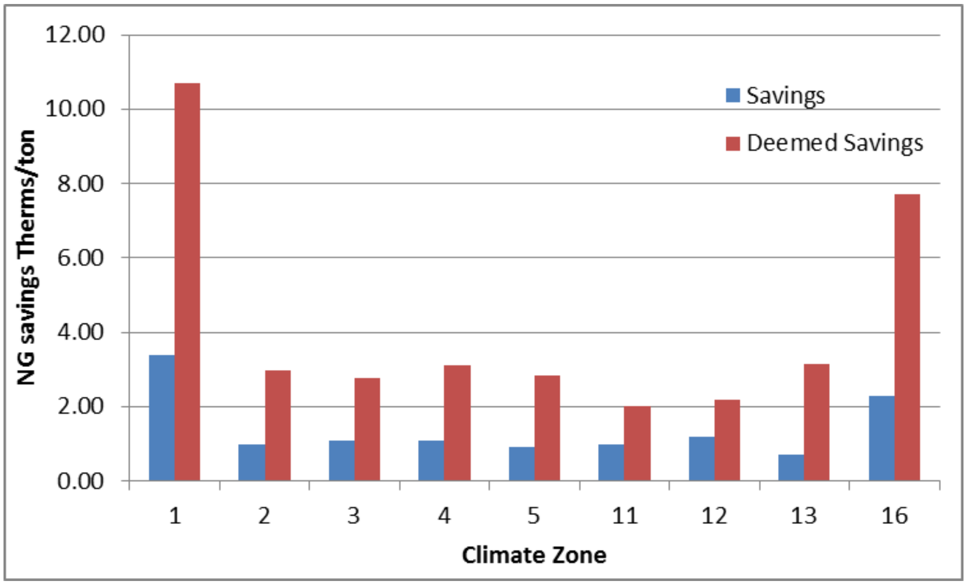


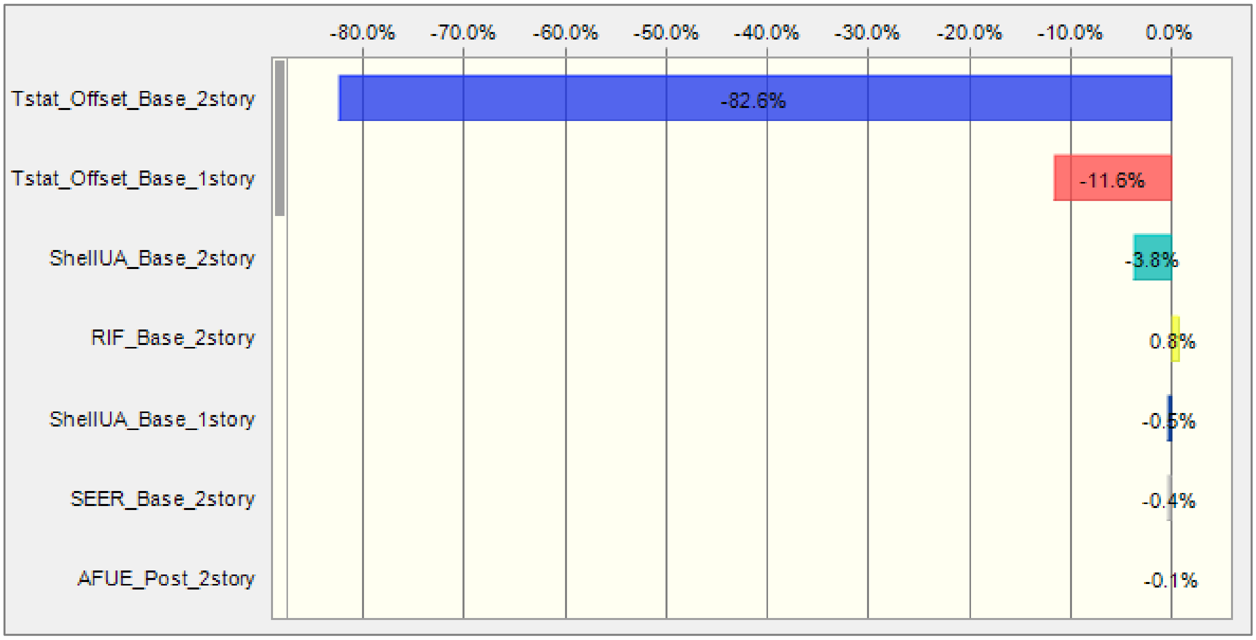
Figure 15. Simulated and Ex Ante Natural Gas Savings per Ton



4.4.2 Input Parameter Sensitivities

Climate zone 03 is also used as an example to assess the sensitivities of the baseline and post-measure energy consumption for annual electric energy, peak demand, and natural gas. Figure 16 shows the sensitivities of the simulated annual electric energy for the baseline where T-stat offset contributes nearly 95% of the consumption uncertainty; the post-measure sensitivities are nearly identical. For the baseline case, the most uncertainty is contributed by the T-stat offset at 2-story homes, followed by the T-stat Offset at the 1-story homes. Overall, the T-stat offset contributes nearly 95% of the uncertainty for the baseline peak demand. Similarly, the T-stat Offset contributes nearly 95% of the uncertainty for the post-measure annual electric energy consumption.

Figure 16. Sensitivities of Baseline Annual Electric Energy Consumption



As shown in Figure 17, T-stat offsets account for approximately 75% of the baseline peak demand consumption uncertainty whereas RIF accounts for just over 15%. For the post-measure case, T-stat offsets accounted for nearly 95% of the peak demand consumption uncertainty (see Figure 18).

Figure 17. Sensitivities of Baseline Peak Demand

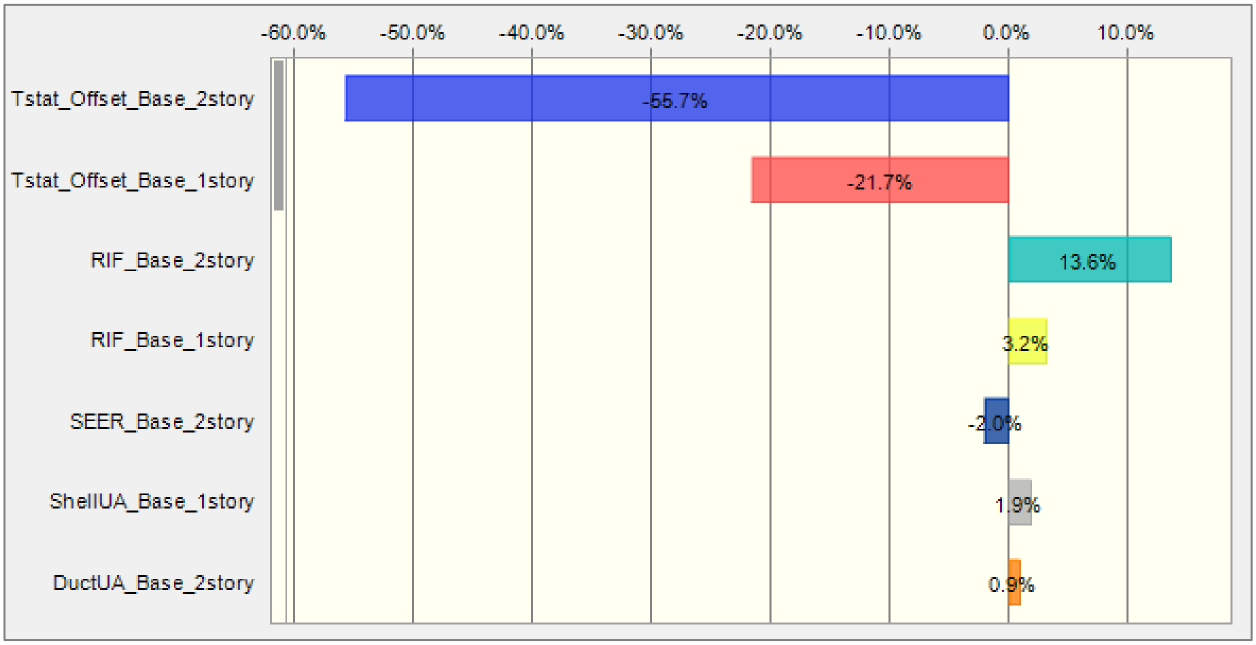
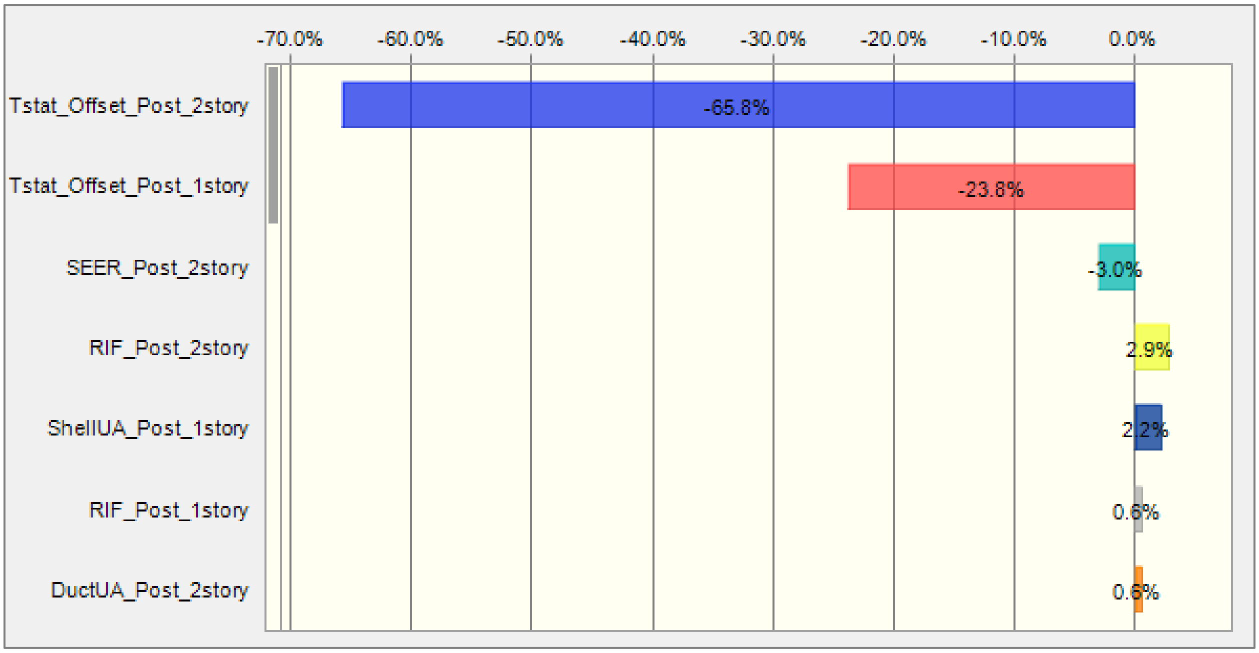
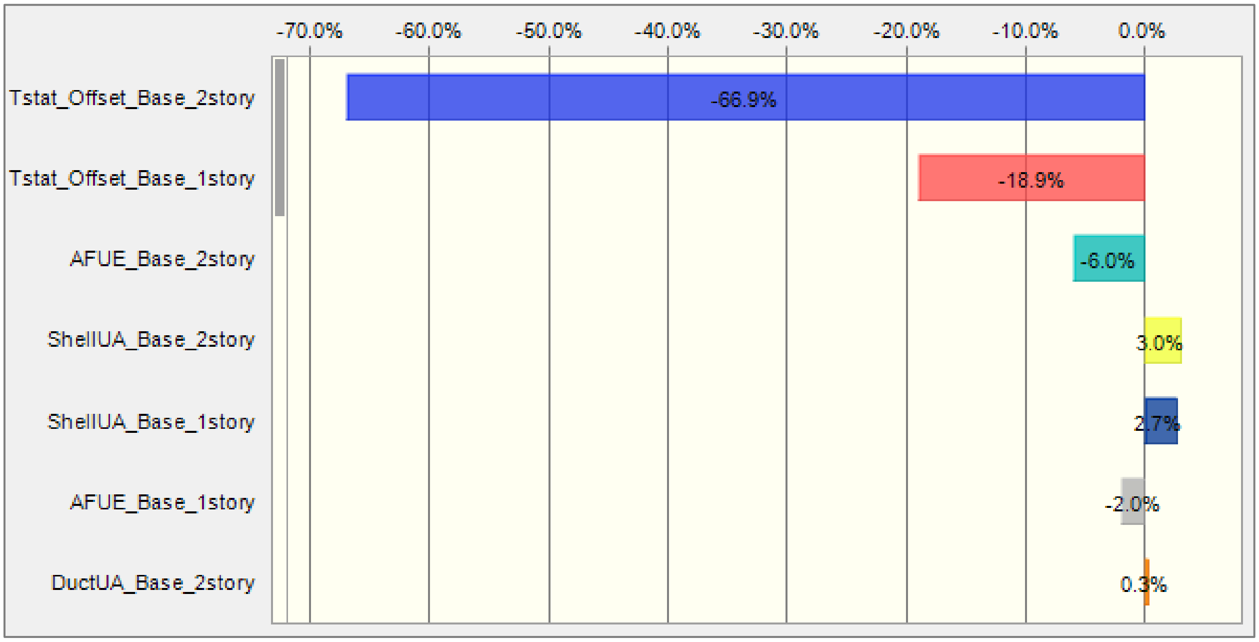


Figure 18. Sensitivities of Post-Measure Peak Demand



As shown in Figure 19, T-stat offset accounts for more than 85% of the uncertainty for the baseline natural gas consumption; AFUE accounts for about 6 percent. The results for the post-measure case were nearly identical.

Figure 19. Sensitivities of Baseline Annual Natural Gas Consumption



The baseline and post-measure consumption simulation results as well as the sensitivity analysis results for each climate zone are included in Appendix C. For annual electric energy consumption, the greatest contributor to the uncertainty is the T-stat offset at all PG&E climate zones with the exception of CZ01. In Climate Zone 1, UA contributes the greatest degree of uncertainty to the energy consumption.

For peak demand savings, the sensitivity analysis shows different results for the baseline case and the post-measure case in Climate Zones 11, 12, 13, and 16. For example, in Climate Zone 13, the greatest uncertainty comes from RIF and building shell UA for the baseline case whereas, for the post-measure case, the greatest uncertainty comes from the T-stat offset and the nominal SEER values.

For natural gas savings, the thermostat usage offsets, the building shell UA, and the AFUE contribute the greatest uncertainty to the energy consumption estimates, in decreasing order.

4.4.3 Information Gaps

There were no available datasets from studies to use to evaluate the baseline and post-measure distributions for duct UA and furnace AFUE values in PG&E territory. Presently, the duct UA distribution is based on an informed estimate and the furnace AFUE is based on assuming a normal distribution. Further studies should be conducted to survey the distributions of these two input parameters for each climate zone and to “true up” the results of the deemed energy savings.

Another major assumption made for this study is that the distribution of the influence factors in the QM program participant population is identical to the distribution of these factors in individual studies or surveys. It is very conceivable that the QM program participants would occupy somewhat older homes than those of the general population.

As previously indicated, in Climate Zones 1, 5, and 16, there were insufficient data to generate weights associated with building shell UAs. For the purposes of this study, the weights from adjacent zones were used.

4.5 Recommendations

Based on the results of the preceding analysis of the residential QM measures, our recommendations are as follows:

1. For annual electric energy and demand savings, the greatest uncertainty is contributed by the T-stat offsets. Therefore, update the thermostat offset values and weights for each climate zone based on the thermostat usage bins yielded by the 2009 RASS. Considering the wide range of thermostat usage patterns expected by climate zone, such an update could reduce deemed savings uncertainty significantly. Given that the thermostat usage bins were established more than 10 years ago, revisiting these values is overdue. In addition to updating the thermostat usage bins, the 2009 RASS may also include data to inform updated T-stat offsets, too.
2. Given their contributions to the variance of the energy consumption (although not the dominant input parameter), we recommend gathering data to study the distributions of duct UAs and AFUEs in each climate zone.
3. Building shell UAs and their associated weights contribute a significant portion of uncertainty to peak demand consumption and natural gas consumption. We recommend gathering building shell UAs in Climate Zones 1, 5, and 16 to bridge to improve and update the associated weights. Since the discrepancy was greatest for the oldest building vintages, these should be targeted for study, first.
4. For those ex ante natural gas savings in Climate Zone 1 that differ dramatically from the output of the Monte Carlo simulations, we recommend a working session with the PG&E workpaper authors to identify the source of the discrepancy.
5. Verify that the distributions of the input parameters in the residential QM program participant population align with those used in the workpaper. Where differences are identified, “true up” the distribution.

5. Mini-Split & Variable Refrigerant Flow Systems

Mini-Split & Variable Refrigerant Flow (VRF) Systems are delivered to IOU customers by “upstream” programs. These programs provide incentives to upstream market actors (distributors) who sell qualifying high-efficiency equipment to contractors to install at commercial projects. Mini-split and VRF systems were identified as having high savings uncertainty by the Energy Savings Performance Incentive (ESPI) Commission Decision. The team considered these measures important to review due to the ESPI decision and anticipated continued growth of their implementation. The mini-split & VRF system measure group includes the following:

- Mini-split and multi-split units that consist of ductless split systems having less than 65 kBtuh of cooling capacity. To qualify for the measure category, the replacement system must achieve a seasonal energy efficiency ratio (SEER) rating of between 16 SEER and 22 SEER.
- Units having VRF capability provided by built-in, inverter-driven compressors. By building in the capability to vary the refrigerant flow, the energy efficiency is improved when operating in part-load conditions. This component can be incorporated into systems of single- and multi-zone configurations.
- Fan coil units with electronically commutated motors (ECM) that offer the capability to vary the fan speed as the load varies in the building zone it serves.
- Heat recovery configurations that offer the capability of capturing the heat removed from zones being cooled (from inverter waste heat) and diverting the captured heat to zones that are being heated.

The study team identified three relevant workpapers as shown inTable 18. The first SCE workpaper pertains to the first measure listed above (ductless mini-split and multi-split heat pump units under 65 kBtuh), and the other two workpapers pertain to the second measure (VRF systems).

Table 18. Workpaper and Measure Descriptions

IOU	Workpaper Title	Measure Description
SCE	Ductless Mini-Split and Multi-Split Heat Pump units under 65 kBtuh. May 30, 2012.	Covers single- and multi-zone configurations, <65 kBtuh
SCE	Variable Refrigerant Flow Commercial Heat Pumps & Heat Recovery Systems >65 kBtu/h. May 25, 2012.	Covers single and multi-zone configurations, both with and without heat recovery, >65 kBtuh
PG&E	Variable Refrigerant Flow Nonresidential Systems. August 28, 2012.	Covers all VRF system sizes with single- or multi-zone configurations

Since the two major measures in this measure group are addressed by separate workpapers, this chapter is into two subsections to address each major measure.

5.1 Ductless Mini-Split and Multi-Split Heat Pump Units

This section contains a review of the methodology used by the workpapers to determine the ex ante savings for ductless mini- and multi-split heat pump units, a review of secondary sources, an assessment of the methods and secondary sources, and our recommendations for improvements.

5.1.1 Review of Workpapers

The first workpaper listed in Table 18 describes the methodology used by SCE to determine the ex ante savings yielded by the installation of mini-split and multi-split heat pumps of <65 kBtuh capacity at commercial applications. For this measure, the following baseline assumptions are used:

- The baseline equipment is 13 SEER package units that have comparable capacity to the <65 kBtuh replacement units. The determination of the baseline equipment is based on the assumption that—in the absence of the upstream incentives—the replacement equipment would only be as efficient as required by Title 20 and Title 24 building code requirements, set forth in California.
- The baseline equipment was replaced-on-burnout (ROB).

Through the upstream programs, the measures are promoted at three levels of efficiency: 16 SEER, 19 SEER, and 22 SEER. The energy savings yielded by any of the three efficiency levels equal the sum of the following two terms:

1. The first term represents the savings yielded by the improved efficiency rating. It is determined by the following equation:

$$Comm\_Savings_{\mathrm{PAC(Repl\_SEER)}} = F_{\mathrm{PAC(Repl\_SEER)}} \times Comm\_Savings_{\mathrm{PAC(14\_SEER)}}$$

where,

$Comm\_Savings_{\mathrm{PAC(14\_SEER)}}$ *is the DEER savings for a 14 SEER package AC system at a commercial application. In fact, 14 SEER is the only efficiency level represented in DEER for commercial applications.*

$\mathrm{Comm\_Savings}_{\mathrm{PAC(Repl\_SEER)}}$ is the estimated savings for a replacement package AC system at a commercial application of one of the three efficiency levels of ductless mini- and multi-split heat pump units offered through the program, represented by subscript Repl_SEER.

and,

$\mathrm{F}_{\mathrm{PAC(Repl\_SEER)}}$ is a scalar factor determined by the following equation:

$$F_{\mathrm{PAC(Repl\_SEER)}} = \frac{SFM\_Savings_{\mathrm{A|C(Repl\_SEER)}}}{SFM\_Savings_{\mathrm{A|C(14\_SEER)}}}$$

where,

$\mathrm{SFM\_Savings}_{\mathrm{A|C(14\_SEER)}}$ is the DEER savings for a 14 SEER split AC system at a single family home prototype.

$\mathrm{SFM\_Savings}_{\mathrm{P|C(Repl\_SEER)}}$ is the DEER savings for a split AC system, at a single family home prototype, of one of the three efficiency levels of ductless mini- and multi-split heat pump units offered through the program.

(Note: For the 22 SEER measure, SCE uses the DEER savings for a 21 SEER split AC unit at single family home prototype because there is no DEER savings value for a 22 SEER split AC unit at a single family home prototype.)

2. The second term represents the savings yielded by installing a ductless system (replacement case) instead of a ducted system (baseline case). SCE draws from three studies regarding the energy savings for sealing existing ductwork to determine the value of this term.

Due to the limited scope of Year 1 of this study, we were limited to reviewing the secondary sources cited by the workpaper. Our comments and recommendations for improvements are provided thereafter.

5.1.2 Review of Secondary Sources

Since the ex ante savings estimate for ductless mini- and multi-split heat pump units consisted of two terms, each from different sources, our review of the secondary sources is also provided in two parts:

1. To determine the portion of ex ante savings due to the improved SEER efficiency level relative to that of the baseline equipment (represented by the first term described above), SCE relied entirely on DEER savings. We acknowledge that there are insufficient data to inform the determination of the savings yielded by refraining from installing equipment of the minimum SEER level required by building codes and, instead, installing equipment of a higher SEER level promoted by the program. We have several concerns about this approach, however.
    a. The validity of the scaling factor used to estimate savings for replacement equipment of a higher SEER than required by code at commercial applications depends upon the validity of the following relationship:

    $$\frac{Comm\_Savings_{\mathrm{PAC(Repl\_SEER)}}}{Comm\_Savings_{\mathrm{PAC(14\_SEER)}}} = \frac{SFM\_Savings_{\mathrm{A|C(Repl\_SEER)}}}{SFM\_Savings_{\mathrm{A|C(14\_SEER)}}}$$

    No secondary sources were provided in the workpaper to support the validity of this relationship.

    b. Presuming that each DEER savings value has an associated error (albeit unavailable and indeterminate)—represented in the expression below by the terms preceded by a δ—these errors in the data propagate through the calculations to produce error in the result. For independent data quantities that are multiplied or divided, the relative error of the result may be as high as the sum of the relative errors of each data quantity as shown:

    $$\frac{\delta Comm\_Savings_{\mathrm{PAC(Repl\_SEER)}}}{Comm\_Savings_{\mathrm{PAC(Repl\_SEER)}}} \le \frac{\delta Comm\_Savings_{\mathrm{PAC(14\_SEER)}}}{Comm\_Savings_{\mathrm{PAC(14\_SEER)}}} + \frac{\delta SFM\_Savings_{\mathrm{A|C(Repl\_SEER)}}}{SFM\_Savings_{\mathrm{A|C(Repl\_SEER)}}} + \frac{\delta SFM\_Savings_{\mathrm{A|C(14\_SEER)}}}{SFM\_Savings_{\mathrm{A|C(14\_SEER)}}}$$

2. To determine the fraction of the ex ante savings that represent the difference in energy consumption due to replacing ducted units with ductless ones, SCE referenced three studies pertaining to duct sealing outcomes. These studies describe the improved system efficiency that results from greatly reducing duct leakage by sealing the ductwork,

thereby reducing the conditioned air lost to unconditioned spaces. The studies reported annual energy savings of between 10% and 18% and demand savings of 20% from duct sealing services. While we have little reason to doubt the savings realized by sealing ducts at ducted systems, their relevance to this measure is dubious for several reasons:

a. Duct sealing yields savings by reducing the amount of conditioned air that is lost to unconditioned spaces, thereby reducing return air temperature and unit runtime.

b. Moving conditioned air across long distances via ductwork is much more energy-intensive than moving refrigerant the same distance (as is done with ductless mini- and multi-split systems). Due to the resulting fan load reduction, ductless systems typically use smaller fans.

c. The decreased blower energy consumption that results from reducing duct leakage is quite different from the decrease that results from using a significantly smaller blower when eliminating ductwork (as with ductless mini- and multi-split heat pump units).

5.1.3 Recommendations

Given the concerns expressed in the preceding "Review of Secondary Sources," our recommendations are as follows:

1. Further study is needed to verify whether the increased energy savings that go hand-in-hand with an improved SEER rating scale up at the same rate when installed at commercial applications as they do at residential ones. As discussed above, SCE's measure savings for ductless mini- and multi-split heat pump units start by using commercial DEER savings for a 14 SEER package AC system that is then scaled by the ratio of two residential DEER savings quantities for split AC systems. The relative error of the resulting ex ante measure savings may be as high as the sum of the relative errors of each of the three DEER savings quantities used.
2. Further investigation is warranted to determine whether the energy savings that result from the elimination of ductwork equal those that result from duct sealing treatments.
3. Consideration should be given to creating models for building simulations consistent with DEER prototypes. Doing so would require incorporating performance maps that are tailored to the measure equipment, but use modified inputs to account for duct losses.

5.2 Variable Refrigerant Flow Systems

This section contains a review of the methodology used by the workpapers to determine the ex ante savings for VRF systems, a review of secondary sources used by the workpapers, an assessment of the methods and secondary sources, and our recommendations for improvements.

5.2.1 Review of Workpapers

Since 2011 DEER does not provide savings for VRF measures, the savings are established within the latter two workpapers listed in Table 18, by PG&E and SCE. Both workpapers establish the savings for two cases: 1) commercial VRF units or systems with heat recovery and 2) commercial VRF units or systems without heat recovery. Alternatively, VRF systems may be comprised of a combination of ducted and ductless fan coil units.

Depending upon the type of VRF unit or system selected, the Title 24-compliant baseline equipment is assumed to be either: 1) single-zone package direct expansion (DX) AC units with gas heating, or 2) multi-zone package DX variable air volume (VAV) AC units with reheat and separate gas heat. Again, it is assumed that the baseline equipment was replaced-on-burnout.

Both workpapers determined the ex ante savings by running EnergyPro® v5.1 building simulations using building models for small and large office buildings in each climate zone. The models were based upon two key assumptions:

- The equipment was manufactured by either Daikin or Mitsubishi, the two largest manufacturers of VRF equipment.
- Half of the zones in the building models were served by ducted systems and the other half by ductless units. This assumption was based on the sales proportions provided during interviews with Daikin and Mitsubishi representatives.

As indicated for the preceding measure, it would have been ideal if the methodology in the workpaper had used deterministic equations. This would have allowed us to produce a model and perform Monte Carlo simulations. We reviewed the secondary sources cited by the workpaper and provided comments and recommendations in the section that follows.

5.2.2 Review of Secondary Sources

Neither of the VRF workpapers cited published secondary sources. The only secondary source mentioned was the result of interviews of representatives of the two biggest manufacturers of ductless mini- and multi-split heat pump units: Daikin and Mitsubishi. Given that this market is likely changing rapidly, the results may quickly become outdated.

It is impossible to compare the measure savings generated by EnergyPro to DEER savings estimates since both the load and the baseline performance curves differ. While EnergyPro allows the use of a high efficiency performance curve that might reasonably be used to represent VRF systems, there is no performance curve that is specific to them.

There are numerous case studies available that highlight the benefits of VRF systems, but there are no empirical ex post evaluation data sets available to verify the estimated savings. Such data would be of great value to improving the industry's knowledge regarding the energy savings for VRF measures.

5.2.3 Recommendations

Based on our review of the workpapers listed in Table 18, we recommend the following:

1. The building simulations used to determine claimed savings assume that half of the zones are ducted and half are ductless. This assumption—based on interviews with representatives of the two largest manufacturers of VRF equipment—could be validated or improved upon by collecting field or telephone survey data regarding standard practices. The HVAC-1 evaluation offers an opportunity to gather data regarding the following:
    a. The distribution of zones that are ducted and zones that are ductless,
    b. The distribution of the quantities of zones, and
    c. The quantities of and typical lengths of duct runs.
2. Since the building simulations are based upon the average savings, by climate zone, reported by two manufacturers of VRF equipment, there would be a lot of value in gathering field or laboratory data to learn more. For instance, it would be helpful to understand equipment selection trends for a wide range of buildings. Additional research may be warranted to identify:
    a. The range of performance ratings of currently available equipment,
    b. Distribution of binned performance ratings at commercial installations by climate zones, and
    c. Projected changes in the part-load performances through the next program cycle.
3. Since only small and large office building types are presently modeled in EnergyPro, the resulting savings may not be representative of the population of commercial building types nor comparable to DEER. It would be worthwhile to revisit the approach to better represent the full range of commercial building types, occupancy types, and associated load profiles. Alternatively, since the tracking data do not contain consistent building type fields, improving the tracking of participant building types would greatly facilitate the identification of building simulation models that would be worthwhile to produce.

6. Key Findings & Recommendations

6.1 Year 1 Deemed Measure Findings

Of the three measures selected for assessment, the Monte Carlo uncertainty analysis could only be conducted in Year 1 for the residential furnace with VSM (assessment of electric energy savings) and for the maintenance and blower motor retrofit (electric energy savings only). The uncertainty analysis in Year 1 was restricted to those measures for which the deemed savings were determined using relatively simple mathematical equations.

Below we present key findings related to our analysis of the three selected HVAC measures.

6.1.1 Residential Furnaces

The workpapers for the two studied residential furnace measures draw annual natural gas savings estimates directly from the 2011 DEER database. We were able to perform Monte Carlo simulations for the electric savings yielded by retrofitting the blower fan with a variable speed motor. This work led the the following findings and recommendations:

1. The building vintage bins contribute the most uncertainty to electric energy savings estimates. In most cases, building vintage accounted for the majority of the variance (70% or more). Currently, the vintage weights rely on 2003 RASS data. However, it is unclear whether the RASS data is representative of the measure population. We recommend that the IOU programs begin to include building vintage in their respective tracking databases to improve future ex ante savings and to facilitate improved resolution for future evaluations.
2. After vintage weights, the thermostat usage bins contribute the most uncertainty to electric energy savings estimates. This is due to the large differences in savings across thermostat usage bins. Again, these weights are drawn from 2003 RASS data. Thermostat usage patterns and behaviors may have changed since this study was conducted. An update to these weights should be pursued. A consideration for year two or three of this study would be to estimate the degree to which the thermostat usage bin uncertainty propagates to the residential HVAC savings.
3. The workpapers draw on secondary sources to establish baseline fan motor power in furnaces with VSM fans. However, these studies provide inconsistent values, do not address the fact that blower power would be expected to vary depending upon whether the coils were wet or dry, and/or they do not provide sufficient detail to facilitate the correlation of the motor power to the weather conditions for each climate zone. Motor power draw estimates that were used in the savings calculations lacked substantial

support in the secondary sources cited by the workpaper. Since other programs rely on these values, too, much would be gained by further study.

6.1.2 Residential Quality Maintenance and Blower Motor Retrofit

While we were unable to conduct Monte Carlo simulations and uncertainty analyses for the blower motor retrofits, the workpaper methodology for the QM measures were modeled for Monte Carlo simulations. The results of this anlysis lead us to the following recommendations:

1. For annual electric energy and demand consumption, the greatest uncertainty is contributed by the T-stat offsets. Update the thermostat offset values and weights for each climate zone based on the 2009 RASS database. Given that the thermostat usage bins were established more than 10 years ago, revisiting these values is overdue.
2. Given their contributions to the variance of the energy consumption (although not the dominant input parameter), we recommend gathering data to study the distributions of duct UAs and AFUEs in each climate zone.
3. Building shell UAs and their associated weights contribute a significant portion of uncertainty to peak demand consumption and natural gas consumption. We recommend gathering building shell UAs in Climate Zones 1, 5, and 16 to bridge to improve and update the associated weights. Since the discrepancy was greatest for the oldest building vintages, these should be targeted for study, first.
4. For those ex ante natural gas savings in Climate Zone 1 that differ dramatically from the output of the Monte Carlo simulations, we recommend a working session with the PG&E workpaper authors to identify the source of the discrepancy.
5. Verify that the distributions of the input parameters in the residential QM program participant population align with those used in the workpaper. Where differences are identified, “true up” the distribution.

6.1.3 Mini-Split & Variable Refrigerant Flow Systems

We were not able to conduct Monte Carlo uncertainty analysis for these measures during Year 1 because the workpapers either relied on building simulations or DEER savings estimates.

1. For mini- and multi-split systems:
    a. Savings estimates were determined by scaling residential DEER savings data because DEER does not include savings for commercial applications of 16 SEER, 19 SEER, and 22 SEER equipment. Further study is needed to verify whether the increased energy savings that go hand-in-hand with an improved SEER rating scale up at the same rate when installed at commercial applications as they do at residential ones. The approach used is not well supported and much more work is necessary. This is a growing measure and the basis for the savings must be well understood.

    b. An additional component is arithmetically added to savings estimates to account for savings associated with converting from a ducted system to a ductless system. These incremental savings are determined based on three studies about the energy savings that result from sealing ductwork. This approach may not be appropriate, given that moving to a ductless system is very different from sealing ductwork in a ducted system, and given that these incremental savings may already be embedded in the mini- and multi-split systems' higher SEER ratings. Further study is necessary.

2. For the variable refrigerant flow systems:
    a. The building simulations used to determine claimed savings were set up by assuming that half of the zones are ducted and half are ductless. This assumption was based on interviews with representatives of the two largest manufacturers of VRF equipment, but should be substantiated using additional sources.
    b. The building simulations are based upon the average savings, by climate zone, reported by two manufacturers of VRF equipment, but their bias is self-evident. The savings by climate zone need to be substantiated by other means.
    c. Since only small and large office building types are presently modeled, the resulting savings may not be representative of the population of commercial building types. At some point in the future, it will make sense to product additional commercial building prototypes. More easily identify which building simulation models should be produced by implementing consistent building type fields in the tracking data for these measures.
    d. To improve mini- and multi-split system savings estimates, consider creating models for building simulations that would allow for inputting partial-load performance curves, much like chiller manufacturers provide.
    e. Improve ex ante savings estimates for VRF systems by conducting field or laboratory research to supplement the "average savings by climate zone" information reported by Mitsubishi and Daikin, which currently feeds into building simulations for VRF system measures.
    f. Improve ex ante savings estimates for VRF systems by creating additional models to better represent the full range of commercial building types, occupancy types, and associated load profiles.

6.2 Recommendations for Year 2

Based on our findings in Year 1—and in order to facilitate a more nuanced comparison of the ex post impacts to the ex ante savings—we recommend the following activities for Year 2 of this study. Note that the uncertainty analysis approach we used should work ideally for non-weather dependent measures, but for HVAC measures propogation of error analysis and Monte Carlo simulation will require additional simulation sensitivity analyses to provide input distributions.

1. Review the 2014 tracking data to identify any new trends and insights to inform future efforts.
2. Consider analyzing measures that were identified as good candidates based on 2013 tracking data, but were not reviewed in Year 1.
    a. Among natural gas measures, HVAC boiler measures have considerable savings, and IOUs have expressed interest in exploring these further.
    b. Among electric measures, fan VFDs, and HVAC controls measures accounted for significant savings in the 2013 data. Also Deemed refrigeration measures are currently not the subject of planned evaluations, but are assigned to the HVAC Roadmap and could be considered.
3. Gather the underlying data for the parametric runs for measures whose deemed savings estimates were drawn directly from DEER in order to facilitate running Monte Carlo simulations and uncertainty analyses for residential furnaces. Once the data are available, Monte Carlo simulations could be executed with relatively little effort since the existing model for the annual electric savings simulations would serve as a template. The sensitivity analysis used for lighting interactive effects provides a useful framework and some results that are directly applicable.[42]
4. Further support the mini-split ESPI measure evaluation by coordinating with the Upstream Impact Evaluation and doing the following within the Deemed Year 2 study.
    a. To improve mini- and multi-split system savings estimates, consider building simulations that input performance maps, rather than using scaling factors and assumptions.
    b. Improve ex ante savings estimates for VRF systems by conducting field or laboratory research to supplement the “average savings by climate zone” information reported by Mitsubishi and Daikin, which currently feeds into building simulations for VRF system measures.
    c. Improve ex ante savings estimates for VRF systems by creating additional models to better represent the full range of commercial building types, occupancy types, and associated load profiles.

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[42] A Study of the Sensitivity of DEER HVAC Interactive Effects Factors to Modeling Parameters. 2012. ftp://deeresources.com/HVACInteractiveEffects/IE_Sensitivity_Report_Draft_Mar_2012.pdf

5. More easily identify which building simulation models should be produced by implementing consistent building type field assignments in the tracking data for deemed HVAC measures.

6.2.1 Data Collection Opportunities for Other HVAC Projects

We identified two opportunities for other HVAC Roadmap projects to gather data that would help to reduce savings uncertainties:

1. Collect field data or conduct telephone surveys to validate or improve the assumption, used in ex ante savings estimates for VRF systems that half of the zones are ducted and half are ductless. Key data could be collected as part of the HVAC-1 evaluation. This should be added to the existing survey instrument which only surveyed 2010-12 installations.
2. For mini- and multi-split systems, further investigation is warranted to determine whether the energy savings that result from eliminating ductwork are already fully accounted for by the increased SEER ratings of mini- and multi-split heat pumps. If no supporting research can be identified, this data could be gathered in a laboratory setting, perhaps via added funding to HVAC-5.

Appendices

A. Appendix A: 2013 HVAC Roadmap Tracking Data Details

A.1 Mini-Split and VRF Measures in 2013 Tracking

Table 19. Frequency of Mini-Split and VRF Measures in 2013 Tracking

Mini-Split and VRF	Rows in Tracking
<24 kBtu/hr 16 SEER Ductless AC DX Equipment replacing 13 SEER AC	35
<24 kBtu/hr 19 SEER Ductless AC DX Equipment replacing 13 SEER AC	139
<65 kBtu/hr 16 SEER Mini-Split Heat Pump DX Equipment replacing Split System AC	28
<65 kBtu/hr 16 SEER Multi-Split Heat Pump DX Equipment replacing Split System AC	7
<65 kBtu/hr 19 SEER Mini-Split Heat Pump DX Equipment replacing Split System AC	76
<65 kBtu/hr 22 SEER Mini-Split Heat Pump DX Equipment replacing Split System AC	6
>= 65 kBtu/hr VRF Heat Pump DX Equipment replacing Single Zone Package AC	41
>= 65 kBtu/hr VRF Heat Recovery DX Equipment replacing Package Variable Air Volume	3
>= 65 kBtu/hr VRF Heat Recovery DX Equipment replacing Single Zone Package AC	61
HVAC_VARIABLE_REFRIG_FLOW_HEAT_PUMP >=_ 80_TONS	33
HVAC_VARIABLE_REFRIG_FLOW_HEAT_PUMP_<_80_TONS	129
HVAC_VARIABLE_REFRIG_FLOW_HEAT_RECOVERY_ >=_ 80_TONS	318
HVAC_VARIABLE_REFRIG_FLOW_HEAT_RECOVERY_<_80_TONS	210
Grand Total	**1,086**

A.2 Furnace Measures in 2013 Tracking

Table 20. Frequency of Furnace Measures in 2013 Tracking

Measure Name	Rows in Tracking
95 PCT AFUE FURNACE - WITHOUT BUILT-IN VSM	1
AFUE >= 94% < 96% GAS FURNACE ONLY	1,067
AFUE >= 94% < 96% GAS FURNACE WITH BUILT-IN VSM	100
AFUE >= 96% GAS FURNACE ONLY	1,313
AFUE >= 96% GAS FURNACE WITH BUILT-IN VSM	262
Central Gas Energy Star 92% AFUE	30
Central Gas Furnace 95% AFUE	562
CENTRAL NATURAL GAS FURNACE - 95% AFUE WITH VSM	2
CENTRAL NATURAL GAS FURNACE - 95% AFUE WITHOUT VSM	7
CENTRAL NATURAL GAS FURNACE - 97% AFUE WITHOUT VSM	1
Furnace - Energy Star Central Gas (AFUE>=95%)	87
Residential Furnaces and Boilers	36
Unit Heaters and Duct Furnaces	36
Grand Total	**3,504**

B. Appendix B: Furnace Analysis Details

This appendix provides a summary of the values used for the furnace uncertainty analysis and the results of the uncertainty analysis. These values are based on workpaper values that are derived from DEER. The results include comparison across climate zones for three dwelling categories: single family homes (SFM), multi-family housing (MFM), and detached mobile homes (DMO).

B.1 95 AFUE Weights & Savings from Workpaper for Single Family Homes (SFM) in CZ 11

Table 21. Thermostat Usage Bin Weights for SFM in CZ11

T-stat Bin	Weights by Building Vintage				
	Before 1978	1978 - 1992	1993 - 2001	2002 - 2005	After 2005
T1	0.20	0.20	0.20	0.15	0.45
T2	0.20	0.25	0.35	0.35	0.35
T3	0.20	0.25	0.25	0.25	0.10
T4	0.30	0.10	0.15	0.15	0.05
T5	0.10	0.20	0.05	0.10	0.05

Table 22. Baseline Annual Electric Energy Consumption, 1 Story SFM in CZ11

T-stat Bin	Annual Electric Energy Consumption, kWh				
	Before 1978	1978 - 1992	1993 - 2001	2002 - 2005	After 2005
T1	553.0	617.0	664.0	842.5	741.0
T2	643.0	597.0	627.0	518.5	441.0
T3	638.0	687.0	529.0	555.0	500.0
T4	299.0	642.0	574.0	502.0	909.0
T5	442.0	491.5	349.0	520.0	489.0

Table 23. Baseline Annual Electric Energy Consumption, 2 Story SFM in CZ11

T-stat Bin	Annual Electric Energy Consumption, kWh				
	Before 1978	1978 - 1992	1993 - 2001	2002 - 2005	After 2005
T1	1,109.0	1362.0	1,419.0	1607.0	1,437.0
T2	1,230.0	1307.5	1,340.0	1008.5	878.0
T3	1,216.0	1480.5	1,137.0	1076.5	989.0
T4	636.0	1399.5	1,234.0	983.5	895.0
T5	831.0	1074.5	826.0	1015.5	968.0

Table 24. Post-Retrofit Annual Electric Energy Consumption, 1 Story SFM in CZ11

T-stat Bin	Annual Electric Energy Consumption, kWh				
	Before 1978	1978 - 1992	1993 - 2001	2002 - 2005	After 2005
T1	311.0	346.5	373.0	473.0	416.0
T2	361.0	335.0	352.0	291.0	248.0
T3	358.0	385.5	297.0	312.0	281.0
T4	168.0	360.5	322.0	282.0	253.0
T5	248.0	276.0	196.0	292.0	275.0

Table 25. Post-Retrofit Annual Electric Energy Consumption, 2 Story SFM in CZ11

T-stat Bin	Annual Electric Energy Consumption, kWh				
	Before 1978	1978 - 1992	1993 - 2001	2002 - 2005	After 2005
T1	623.0	765.0	797.0	902.5	807.0
T2	691.0	734.0	752.0	566.5	493.0
T3	683.0	831.5	639.0	604.5	556.0
T4	357.0	786.0	693.0	552.5	503.0
T5	467.0	603.5	464.0	570.5	544.0

Table 26. Story & Vintage Weights for SFM in CZ11

Building Vintage	1-Story Weight	2-Story Weight	Vintage Weight
Before 1978	0.74	0.26	0.43
1978 - 1992	0.77	0.23	0.27
1993 - 2001	0.60	0.40	0.16
2002 - 2005	0.60	0.40	0.09
After 2005	0.60	0.40	0.05

B.2 95 AFUE Furnace Simulation Savings at Single Family Homes (SFM)

Figure 20. Distributions of Annual Electric Energy Savings at SFM

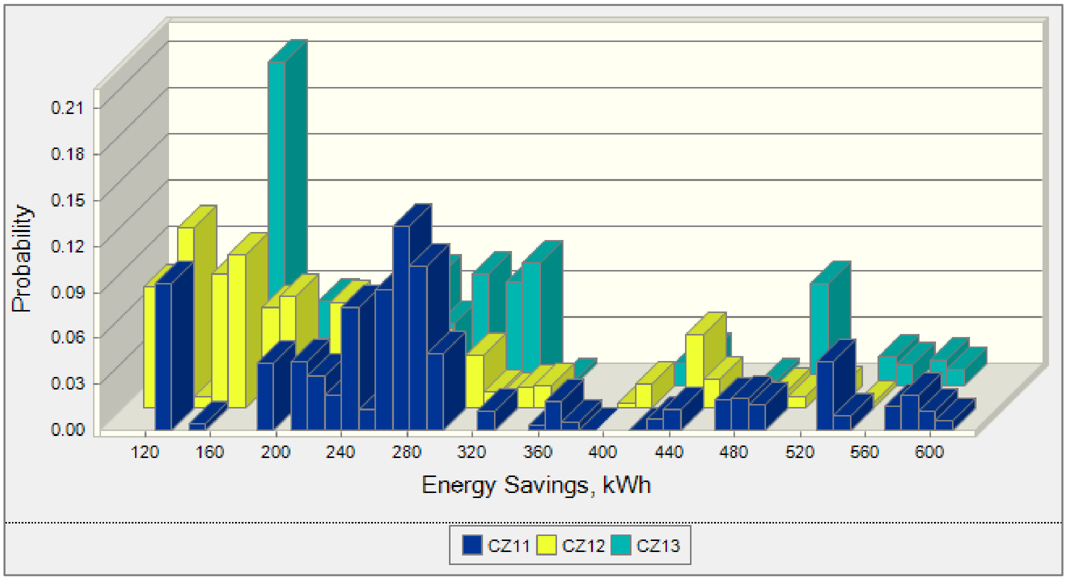


Table 27. Statistics for Annual Electric Energy Savings

Statistics	CZ11	CZ12	CZ13
Mean, kWh	318	223	299
Median, kWh	280	194	263
Mode, kWh	131	162	171
Standard Deviation, kWh	141	108	134
Coefficient of Variation	0.44	0.48	0.45
Minimum, kWh	131	85	149
Maximum, kWh	705	547	675
Range Width, kWh	574	462	526
Mean Standard Error, kWh	1.41	1.08	1.34

Figure 21. Sensitivities of Annual Electric Energy Savings for SFM in CZ 11

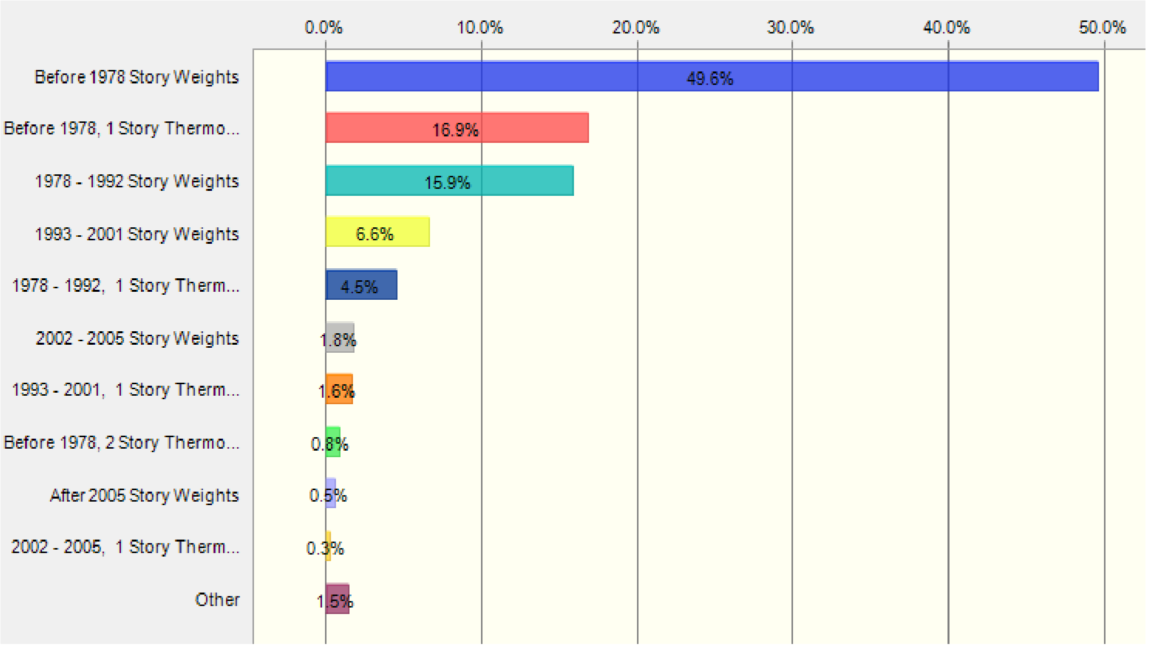


Table 28. Sensitivities of Annual Electric Energy Savings for SFM in CZ 11

Assumptions	Contribution to Variance	Rank Correlation
Before 1978 Story Weights	50%	0.42
Before 1978, 1 Story Thermostat Weight	17%	0.24
1978 - 1992 Story Weights	16%	0.24
1993 - 2001 Story Weights	7%	0.15
1978 - 1992, 1 Story Thermostat Weight	5%	0.13
2002 - 2005 Story Weights	2%	0.08
1993 - 2001, 1 Story Thermostat Weight	2%	0.08
Before 1978, 2 Story Thermostat Weight	1%	0.05
After 2005 Story Weights	1%	0.04
2002 - 2005, 1 Story Thermostat Weight	0%	0.03
Other	1%	

Figure 22. Sensitivities of Annual Electric Energy Savings at SFM, in CZ 12

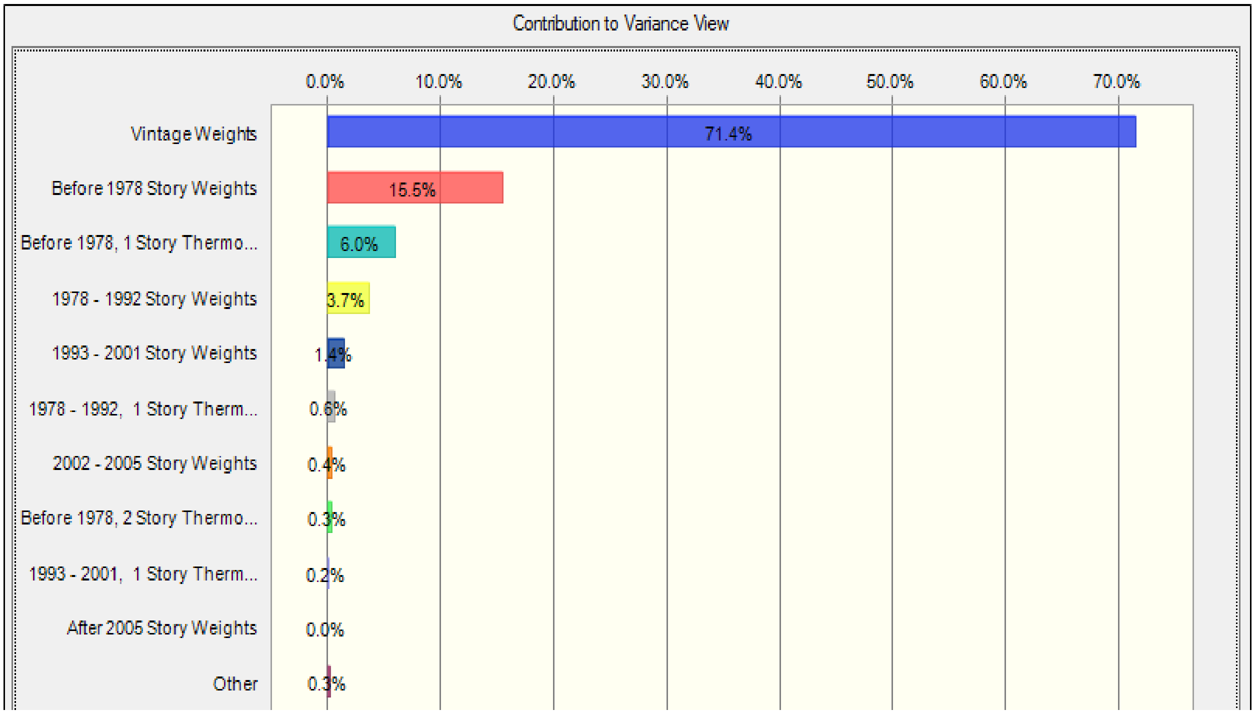


Table 29. Sensitivities of Annual Electric Savings of SFM, CZ 12

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	71%	1.00
Before 1978 Story Weights	15%	0.47
Before 1978, 1 Story Thermostat Weight	6%	0.29
1978 - 1992 Story Weights	4%	0.23
1993 - 2001 Story Weights	1%	0.14
1978 - 1992, 1 Story Thermostat Weight	1%	0.09
2002 - 2005 Story Weights	0%	0.08
Before 1978, 2 Story Thermostat Weight	0%	0.07
1993 - 2001, 1 Story Thermostat Weight	0%	0.05
After 2005 Story Weights	0%	0.03
Other	0%	

Figure 23. Sensitivities of Annual Electric Savings of SFM, CZ 13

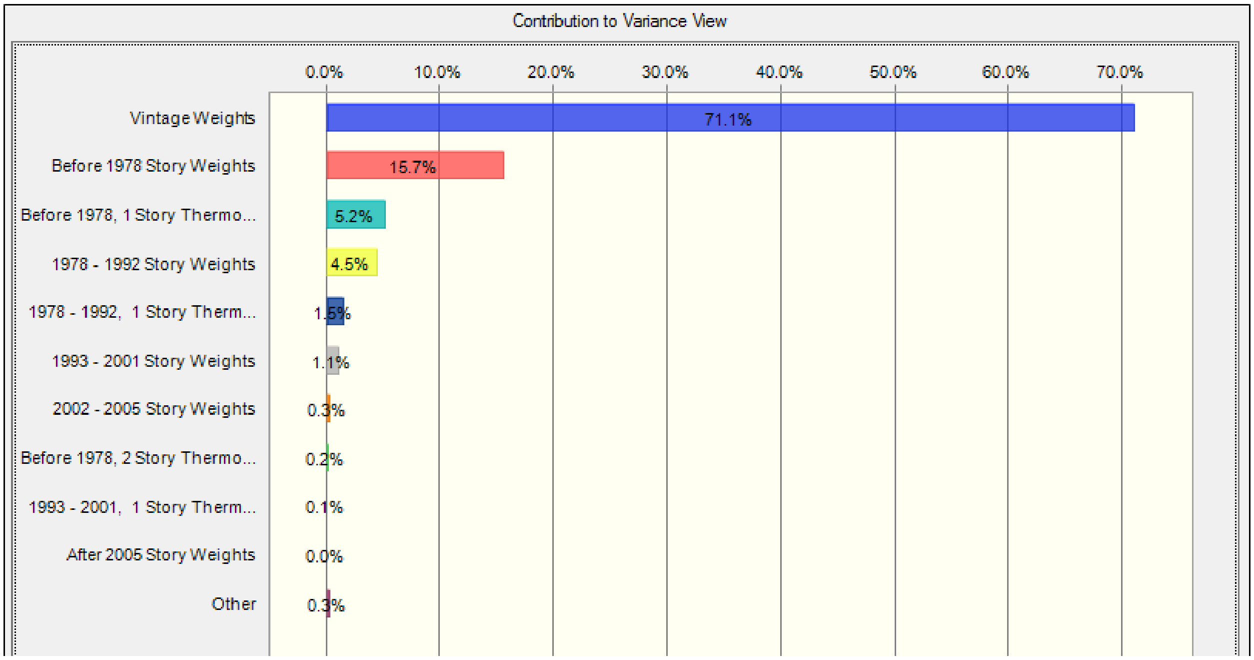


Table 30. Sensitivities of Annual Electric Savings of SFM, CZ 13

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	71%	1.00
Before 1978 Story Weights	16%	0.47
Before 1978, 1 Story Thermostat Weight	5%	0.27
1978 - 1992 Story Weights	5%	0.25
1978 - 1992, 1 Story Thermostat Weight	2%	0.15
1993 - 2001 Story Weights	1%	0.12
2002 - 2005 Story Weights	0%	0.06
Before 1978, 2 Story Thermostat Weight	0%	0.05
1993 - 2001, 1 Story Thermostat Weight	0%	0.04
After 2005 Story Weights	0%	0.02
Other	0%	

B.3 95 AFUE Furnace Monte Carlo Simulation Results at Multi-family Housing (MFM)

Figure 24. Distributions of Annual Electric Energy Savings at MFM

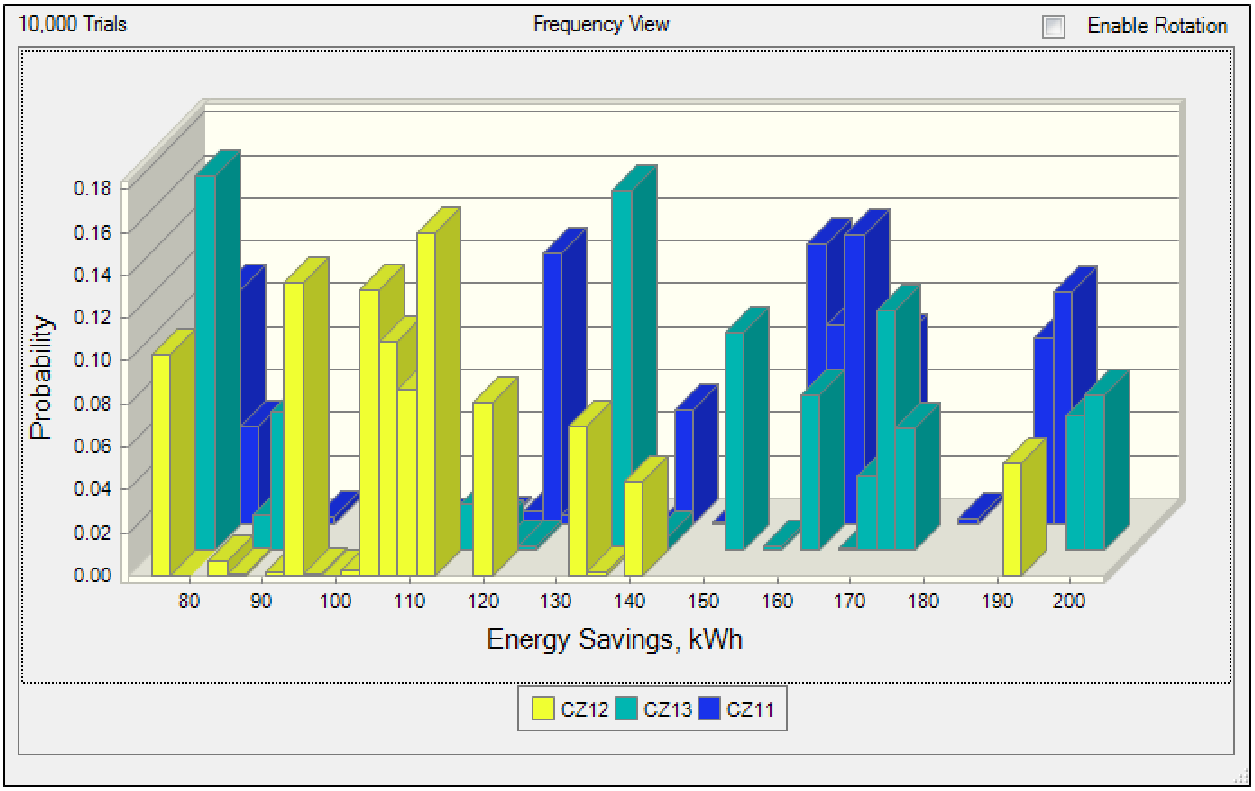


Table 31. Statistics for Annual Electric Energy Savings at MFM, kWh

Statistics	CZ11	CZ12	CZ13
Mean	148	110	139
Median	160	108	151
Mode	163	112	79
Standard Deviation	36	25	42
Coefficient of Variation	0.24	0.23	0.30
Minimum	75	30	44
Maximum	227	191	201
Range Width	151	161	157
Mean Standard Error	0.36	0.25	0.42

Figure 25. Sensitivities of Annual Electric Savings at MFM, CZ 11

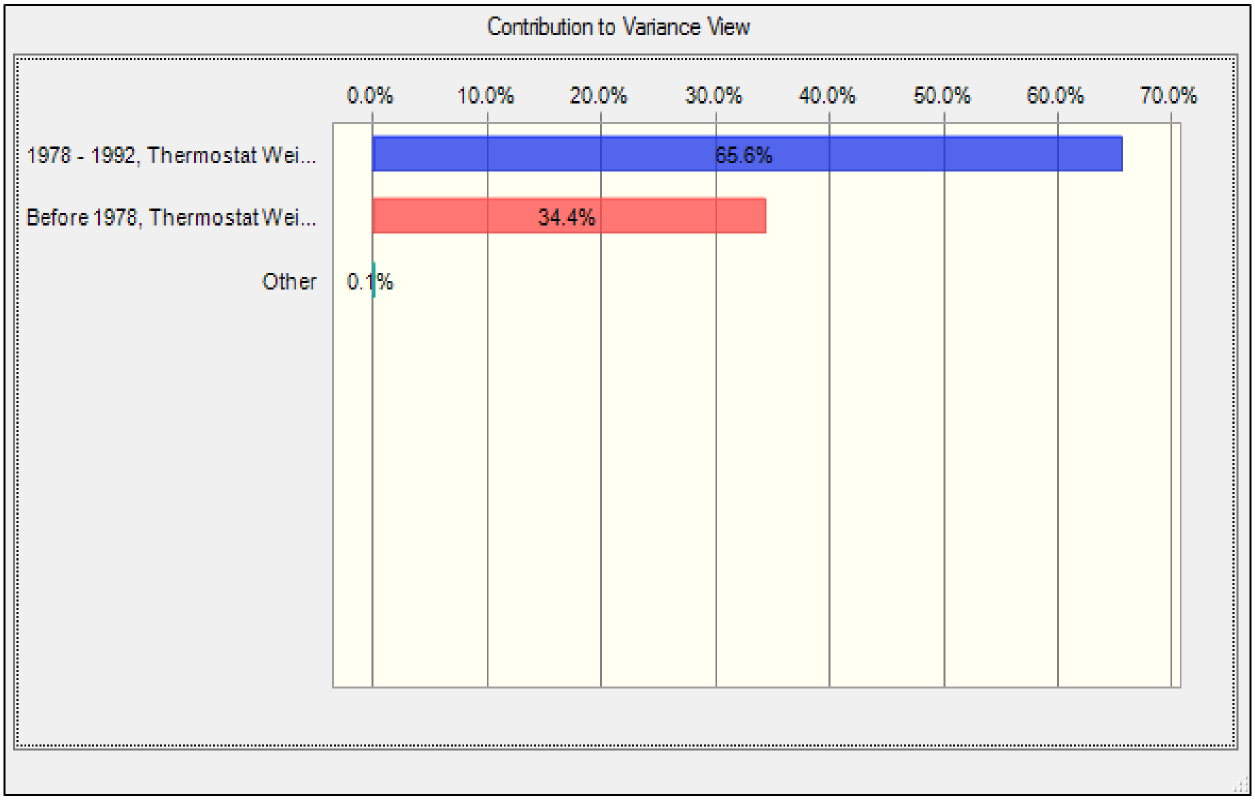


Table 32. Sensitivities of Annual Electric Savings at MFM, CZ 11

Assumptions	Contribution to Variance	Rank Correlation
1978 - 1992, Thermostat Weights	66%	0.56
Before 1978, Thermostat Weights	34%	0.40
Other	0%	

Figure 26. Sensitivities of Annual Electric Savings at MFM, CZ 12

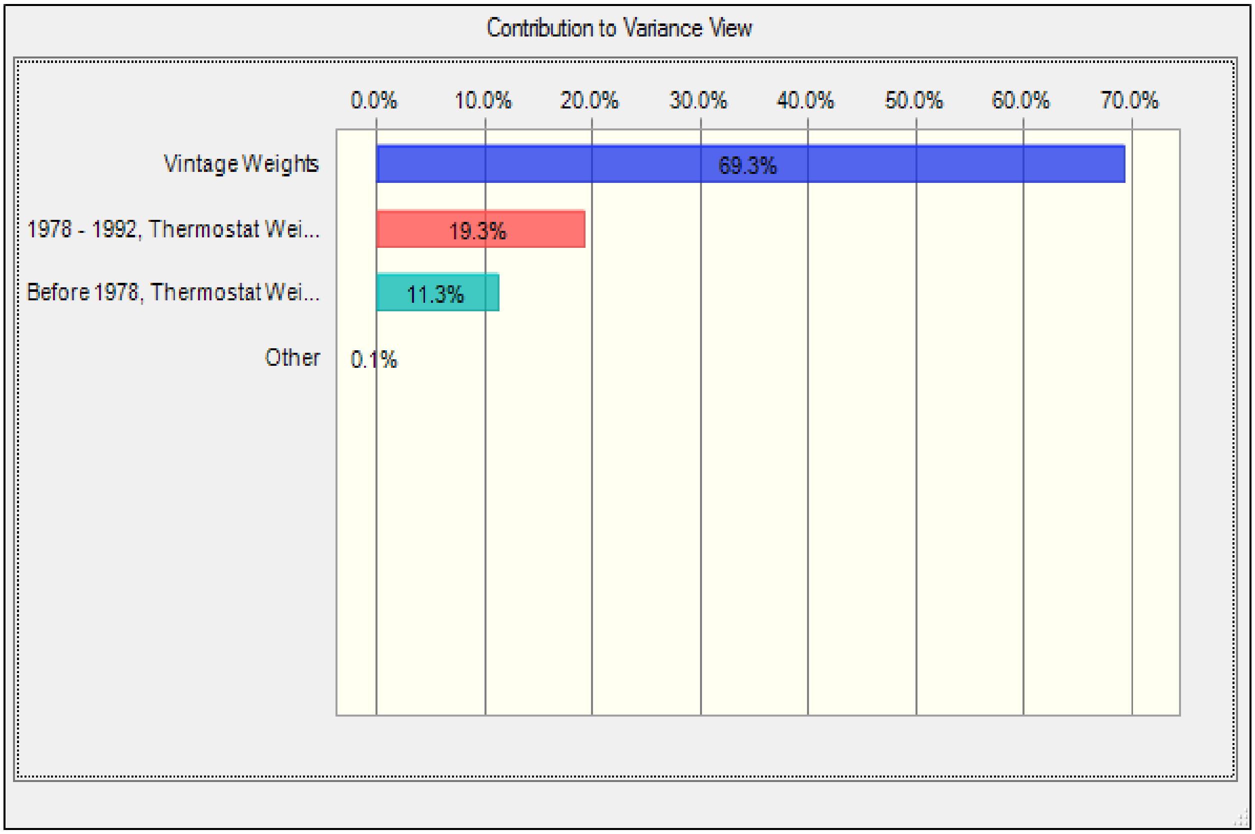


Table 33. Sensitivities of Annual Electric Savings at MFM, CZ 12

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	69%	1.00
1978 - 1992, Thermostat Weights	19%	0.53
Before 1978, Thermostat Weights	11%	0.40
Other	0%	

Figure 27. Sensitivities of Annual Electric Energy Savings at MFM, CZ 13

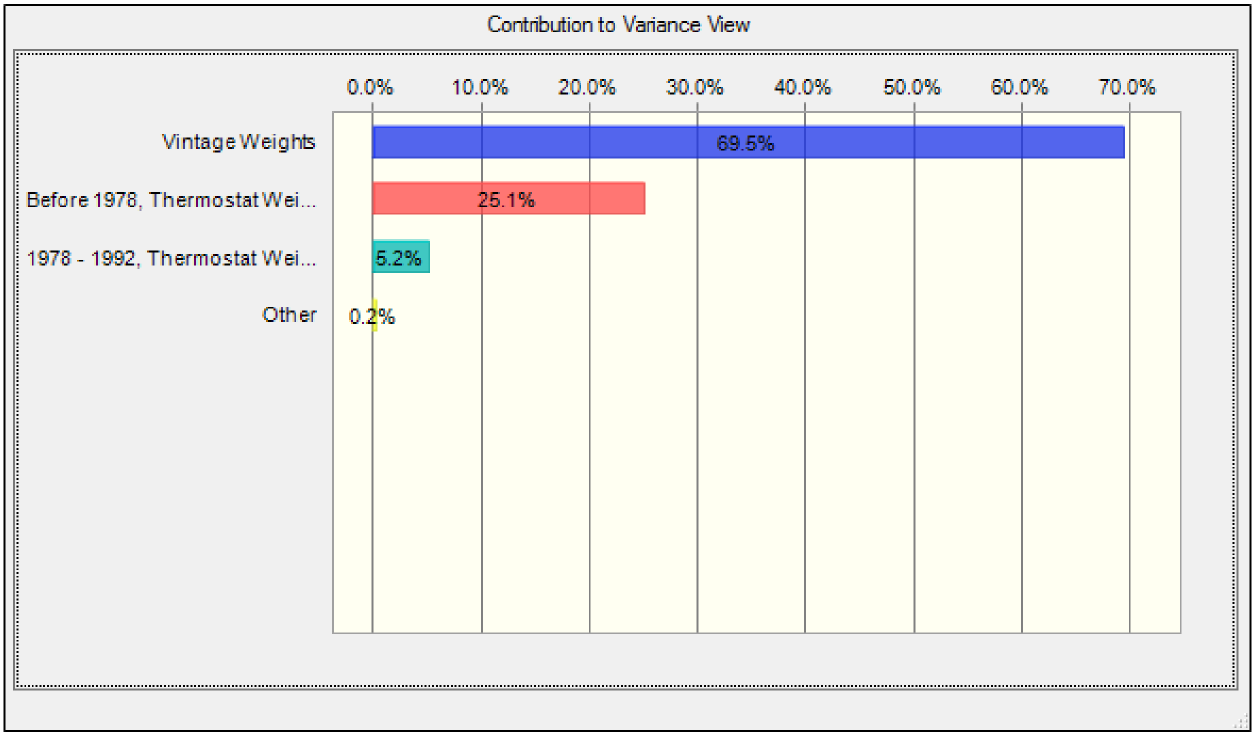


Table 34. Sensitivities of Annual Electric Savings at MFM, CZ 13

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	70%	1.00
Before 1978, Thermostat Weights	25%	0.60
1978 - 1992, Thermostat Weights	5%	0.27
Other	0%	

B.4 95 AFUE Furnace Monte Carlo Simulations Results at Detached Mobile Homes (DMO)

Figure 28. Distribution of Annual Electric Energy Savings at DMO, kWh

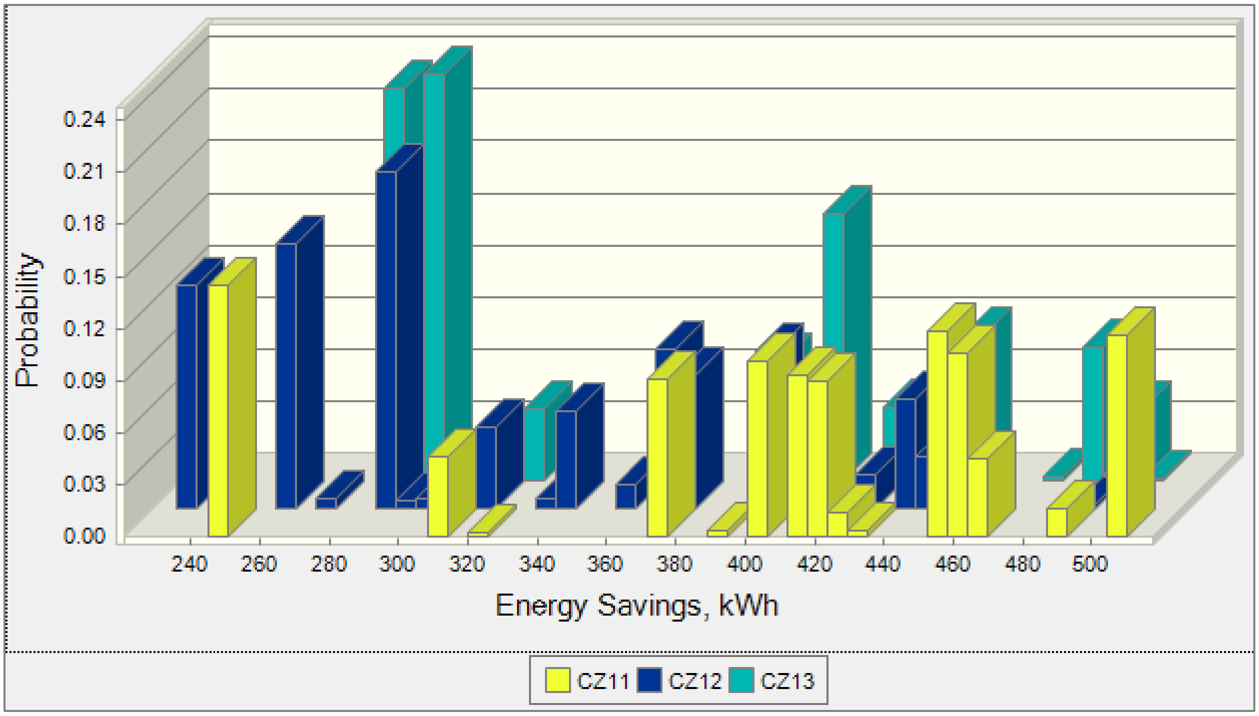


Table 35. Statistics for Annual Electric Energy Savings at DMO, kWh

Statistics	CZ11	CZ12	CZ13
Mean, kWh	407	324	366
Median, kWh	420	316	321
Mode, kWh	247	287	297
Standard Deviation, kWh	81	69	81
Coefficient of Variation	0	0	0
Minimum, kWh	247	228	280
Maximum, kWh	590	490	526
Range Width, kWh	343.00	262.00	245.50
Mean Standard Error, kWh	0.81	0.69	0.81

Figure 29. Sensitivities of Annual Electric Savings at DMO in CZ 11

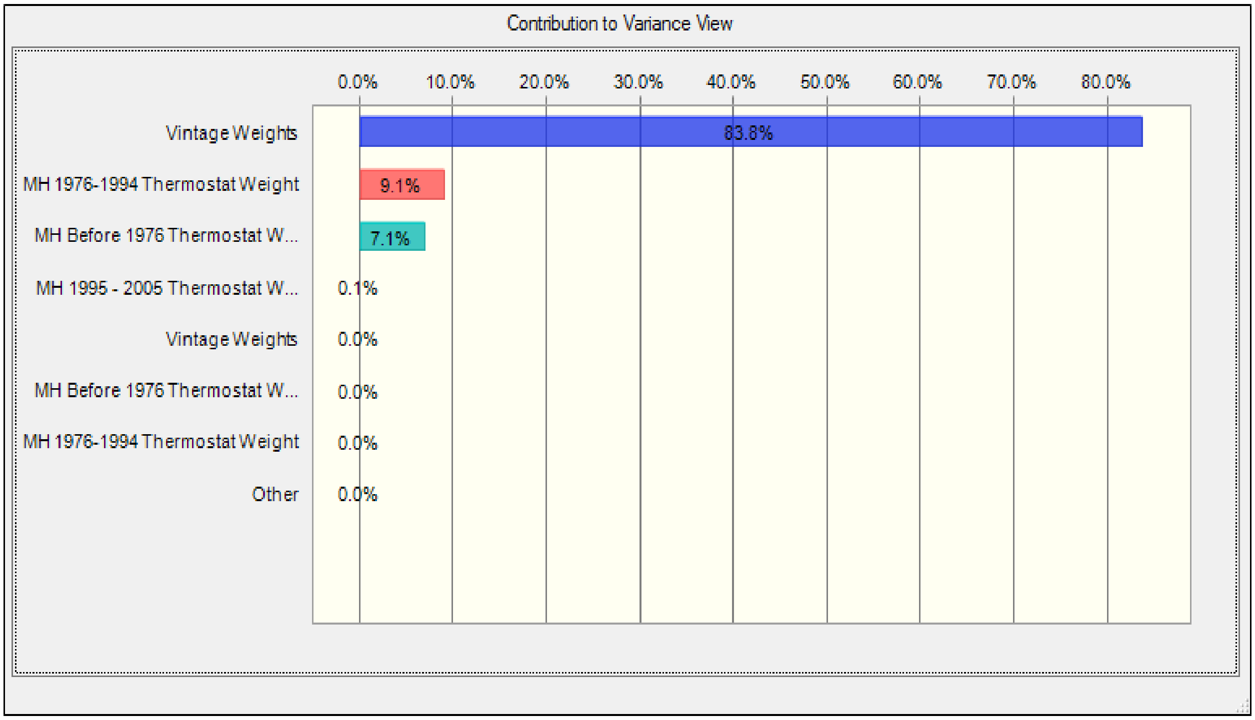


Table 36. Sensitivities of Annual Electric Savings at DMO in CZ 11

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	83.8%	1.00
MH 1976 - 1994 Thermostat Weight	9.1%	0.33
MH Before 1976 Thermostat Weight	7.1%	0.29
MH 1995 - 2005 Thermostat Weight	0.1%	0.03
Vintage Weights	0.0%	0.02
MH Before 1976 Thermostat Weight	0.0%	0.01
MH 1976 - 1994 Thermostat Weight	0.0%	-0.01
Other	0.0%	

Figure 30. Sensitivities of Annual Electric Savings at DMO in CZ 12

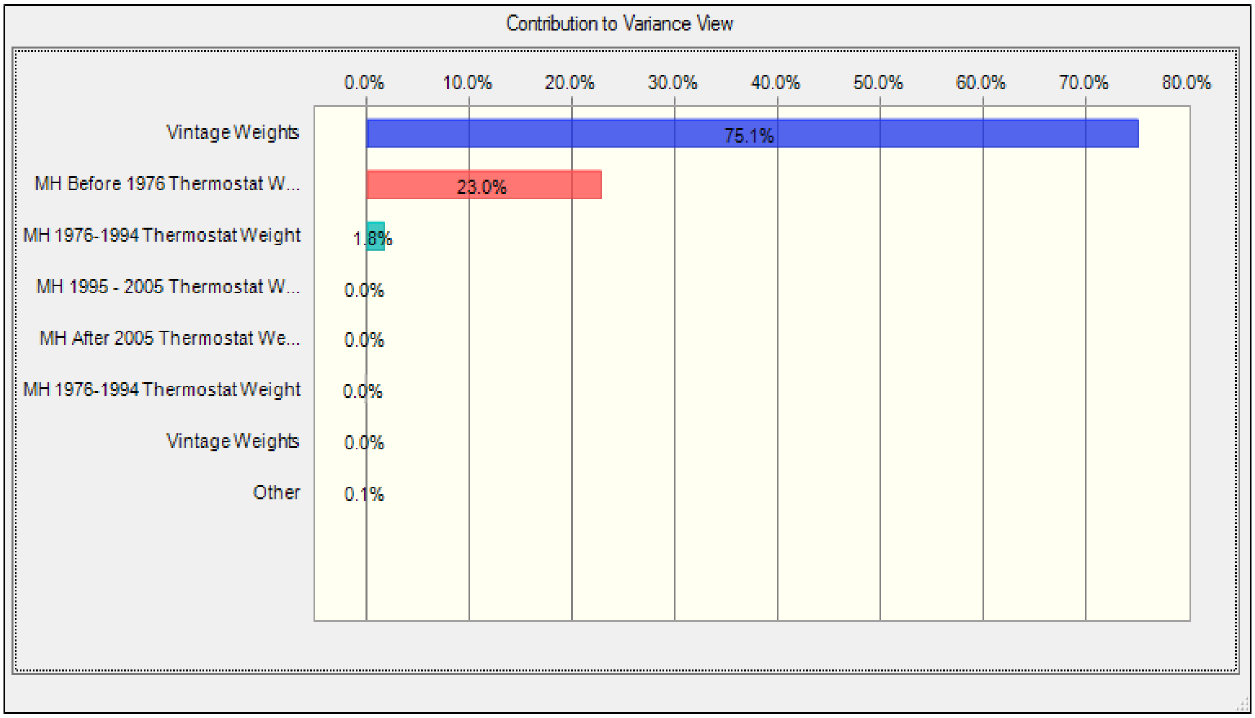


Table 37. Sensitivities of Annual Electric Savings at DMO in CZ 12

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	75%	1.00
MH Before 1976 Thermostat Weight	23%	0.55
MH 1976 - 1994 Thermostat Weight	2%	0.15
MH 1995 - 2005 Thermostat Weight	0%	0.02
MH After 2005 Thermostat Weight	0%	0.02
MH 1976 - 1994 Thermostat Weight	0%	-0.02
Vintage Weights	0%	0.02
Other	0%	

Figure 31. Sensitivities of Annual Electric Energy at DMO in CZ 13

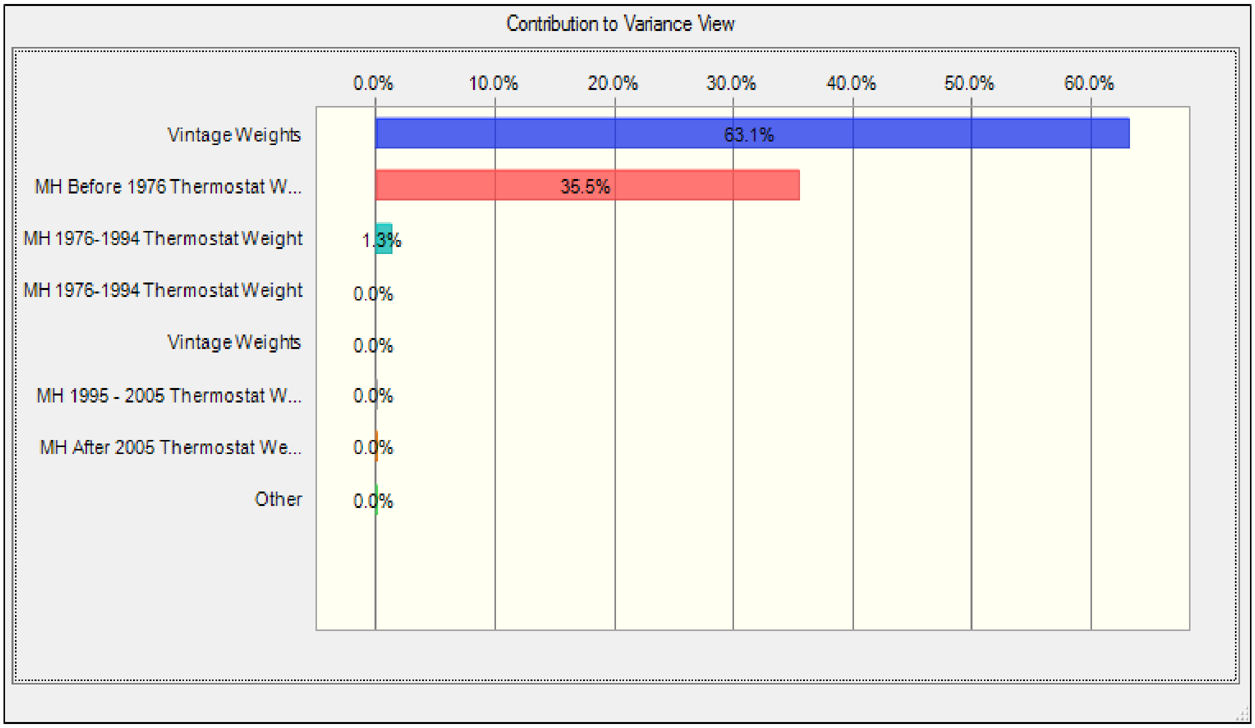


Table 38. Sensitivities of Annual Electric Savings at DMO in CZ 13

Assumptions	Contribution to Variance	Rank Correlation
Vintage Weights	63%	1.00
MH Before 1976 Thermostat Weight	36%	0.75
MH 1976 - 1994 Thermostat Weight	1%	0.14
MH 1976 - 1994 Thermostat Weight	0%	-0.02
Vintage Weights	0%	-0.01
MH 1995 - 2005 Thermostat Weight	0%	0.01
MH After 2005 Thermostat Weight	0%	0.01
Other	0%	

C. Appendix C: Residential Quality Maintenance

This section presents uncertainty analysis results for each climate zone, including distribution of annual savings, statistics, sensitivies of baseline consumption, and sensitivities of the post-treatment consumption for kWh/ton, kW/ton, therms/ton, respetively. The primary and secondary sources of uncertainty are summaized in the following tables. For kWh/ton, the primary source is Tstat_Offset_ 2story and the secondary source is Tstat_Offset_ 1story for most climate zones. For kW/ton, the most primary and secondary sources are still Tstat_Offset_ 2story, but SEER, ShellUA, and RIF emerge, too. For therms/ton, the primary source is still Tstat_Offset_ 2story and the secondary source could be either Tstat_Offset or ShellUA.

Table 39. Chief Sources of Uncertainty for Annual Electric Energy Consumption

Climate Zone	Baseline Case		Post-treatment Case	
	Primary Source	Secondary Source	Primary Source	Secondary Source
CZ01	ShellUA_Base_2story	Tstat_Offset_Base_2story	ShellUA_Post_2story	Tstat_Offset_Post_2story
CZ02	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ03	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ04	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ05	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ11	Tstat_Offset_Base_2story	RIF_Base_2story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ12	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ13	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ16	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story

Table 40. Chief Sources of Uncertainty for Peak Demand Consumption

Climate Zone	Baseline Case		Post-treatment Case	
	Primary Source	Secondary Source	Primary Source	Secondary Source
CZ01	Tstat_Offset_Base_2story	RIF_Base_2story	Tstat_Offset_Post_2story	RIF_Post_2story
CZ02	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ03	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ04	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ05	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ11	ShellUA_Base_2story	SEER_Base_2story	ShellUA_Post_2story	SEER_Post_2story
CZ12	ShellUA_Base_2story	SEER_Base_2story	Tstat_Offset_Post_2story	ShellUA_Post_2story
CZ13	RIF_Base_2story	ShellUA_Base_2story	Tstat_Offset_Post_2story	SEER_Post_2story
CZ16	RIF_Base_2story	Tstat_Offset_Base_2story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story

Table 41. Chief Sources of Uncertainty for Natural Gas Consumption

Climate Zone	Baseline Case		Post-treatment Case	
	Primary Source	Secondary Source	Primary Source	Secondary Source
CZ01	Tstat_Offset_Base_2story	ShellUA_Base_2story	Tstat_Offset_Post_2story	ShellUA_Post_2story
CZ02	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ03	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ04	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ05	Tstat_Offset_Base_2story	Tstat_Offset_Base_1story	Tstat_Offset_Post_2story	Tstat_Offset_Post_1story
CZ11	Tstat_Offset_Base_2story	ShellUA_Base_2story	Tstat_Offset_Post_2story	ShellUA_Post_2story
CZ12	Tstat_Offset_Base_2story	ShellUA_Base_2story	Tstat_Offset_Post_2story	ShellUA_Post_2story
CZ13	Tstat_Offset_Base_2story	ShellUA_Base_2story	Tstat_Offset_Post_2story	ShellUA_Post_2story
CZ16	Tstat_Offset_Base_2story	ShellUA_Base_1story	Tstat_Offset_Post_2story	ShellUA_Post_1story

C.1 Climate Zone 1

Figure 32. Distributions of Annual Electric Energy in CZ01, kWh/ton

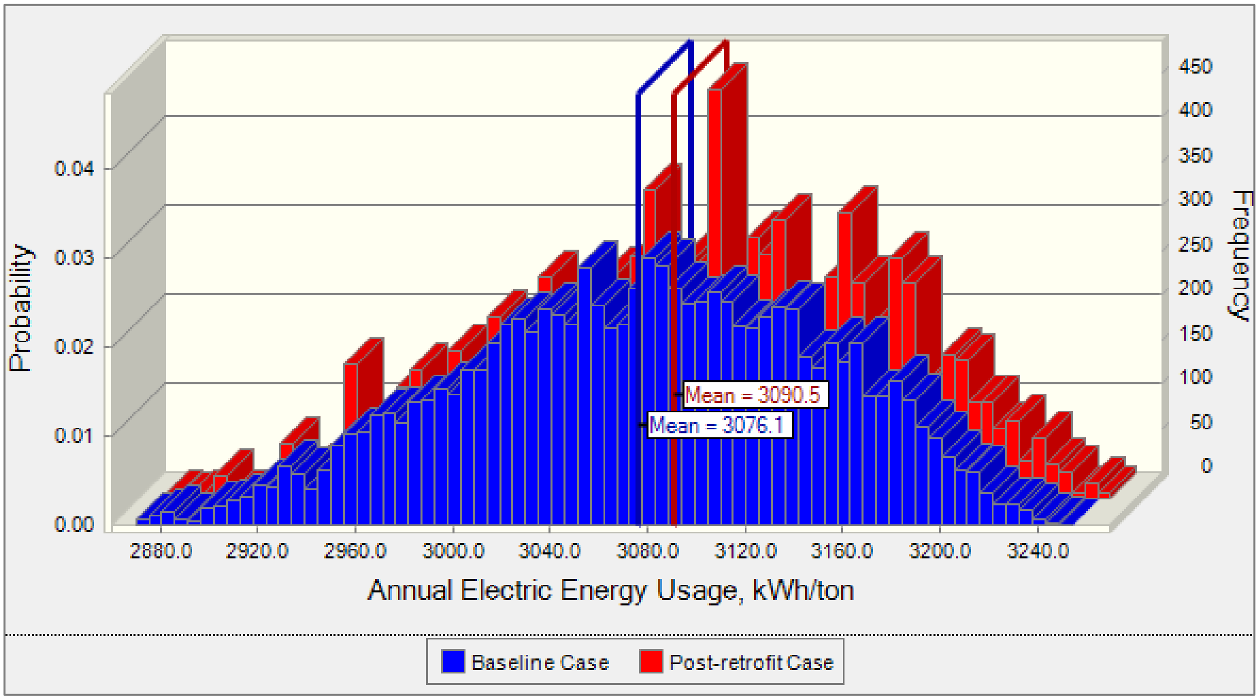


Table 42. Statistics for Annual Electric Energy in CZ01, kWh/ton

Statistical Metric	Baseline Case	Post-treatment Case
Mean	3,076	3,091
Median	3,080	3,095
Mode	2,902	2,946
Standard Deviation	73.7	73.5
Coefficient of Variation	0.0239	0.0238
Minimum	2,832	2,859
Maximum	3,250	3,259
Mean Standard Error	0.7	0.7

Figure 33 Sensitivities of Baseline Annual Electric Energy in CZ01

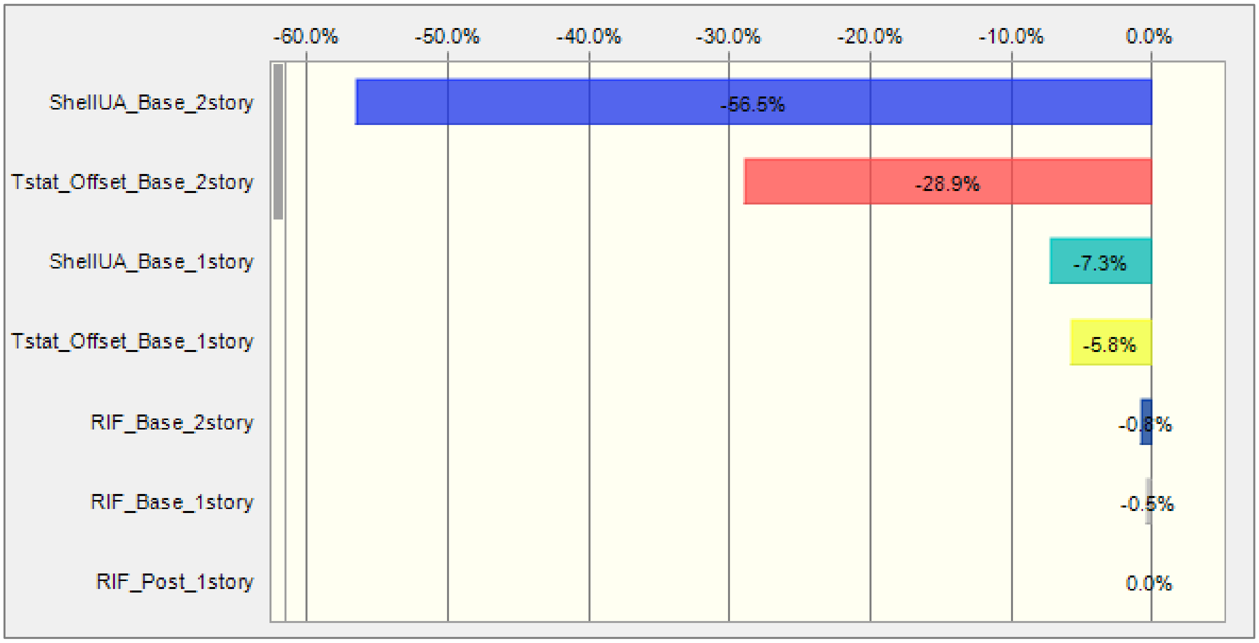


Figure 34 Sensitivities of Post-Retrofit Annual Electric Energy in CZ01

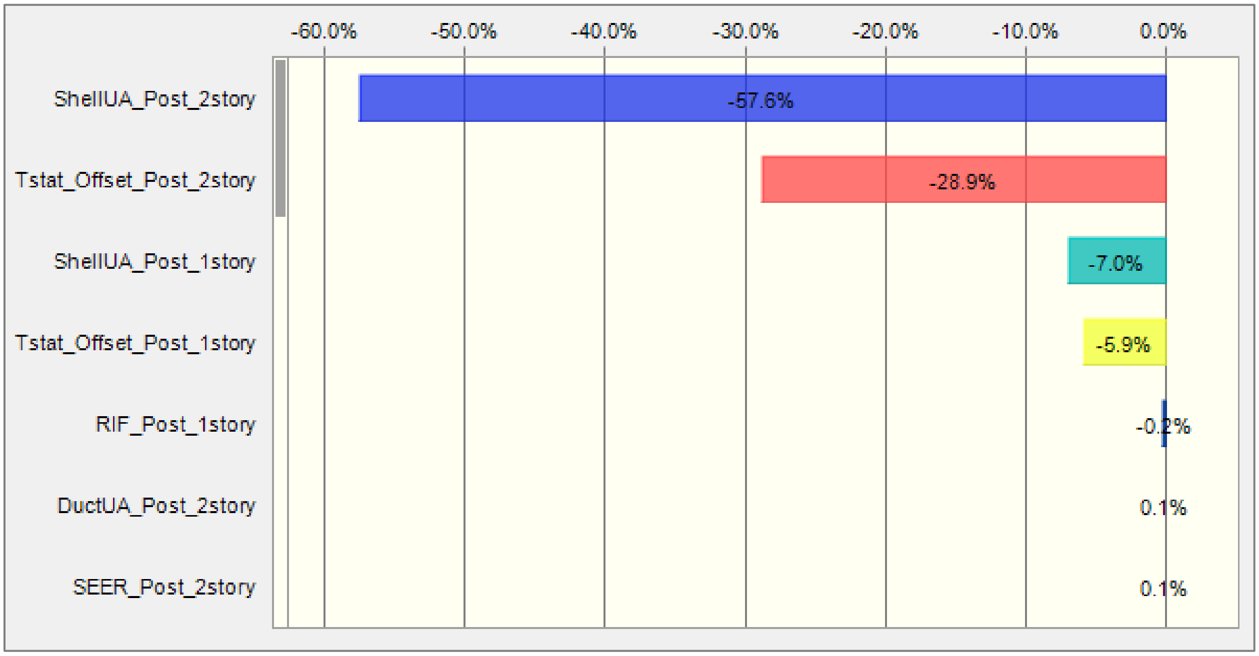


Figure 35. Distributions of Peak Demand in CZ01, kW/ton

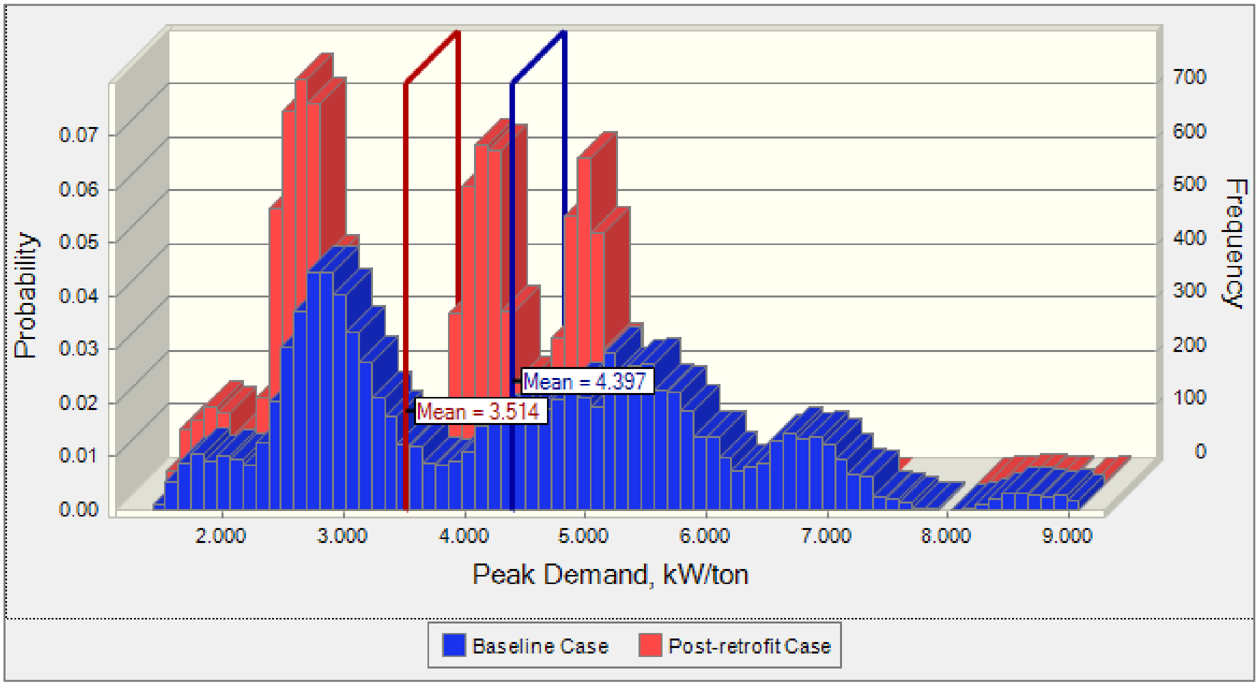


Table 43. Statistics for Peak Demand in CZ01, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean, kW/ton	4.397	3.514
Median, kW/ton	4.375	3.787
Mode, kW/ton	1.944	2.322
Standard Deviation, kW/ton	1.673	1.173
Coefficient of Variation	0.380	0.334
Minimum, kW/ton	1.442	1.312
Maximum, kW/ton	9.887	9.143
Mean Standard Error, kW/ton	0.017	0.012

Figure 36. Sensitivities of Baseline Peak Demand, CZ01

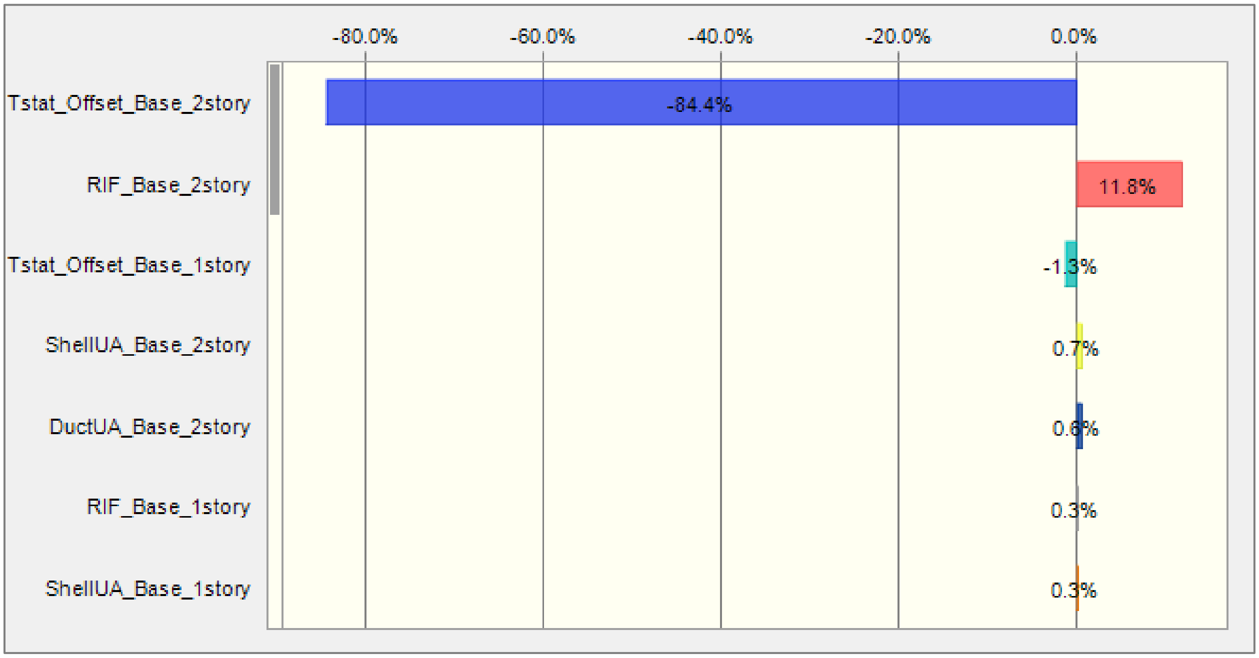


Figure 37. Sensitivities of Post-Retrofit Peak Demand, CZ01

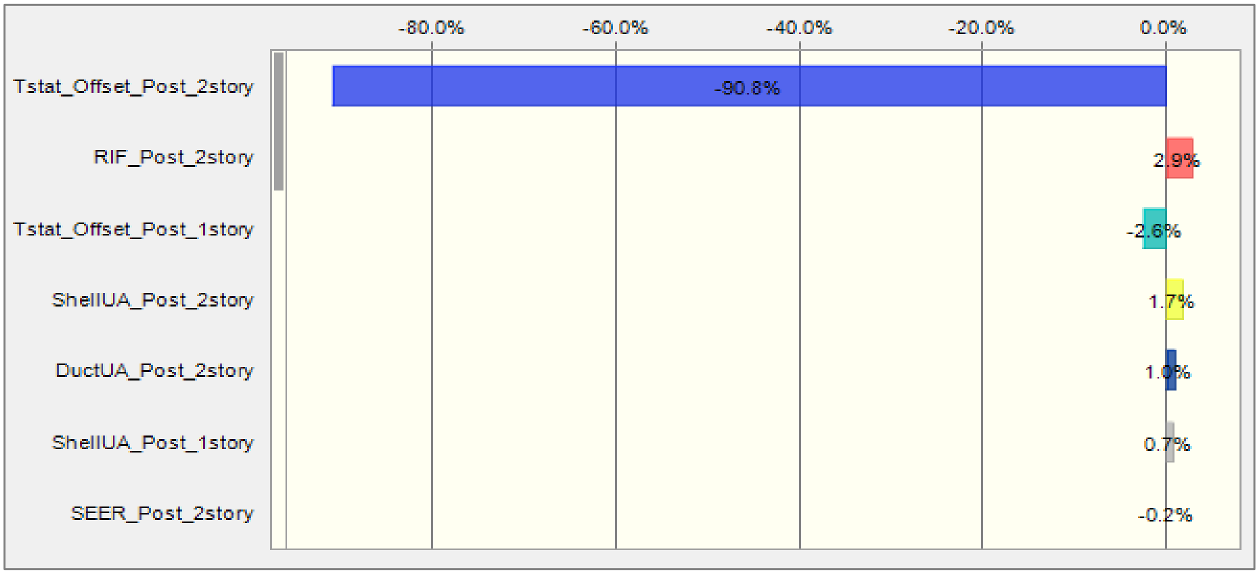


Figure 38. Distributions of Natural Gas Consumption in CZ01, therm/ton

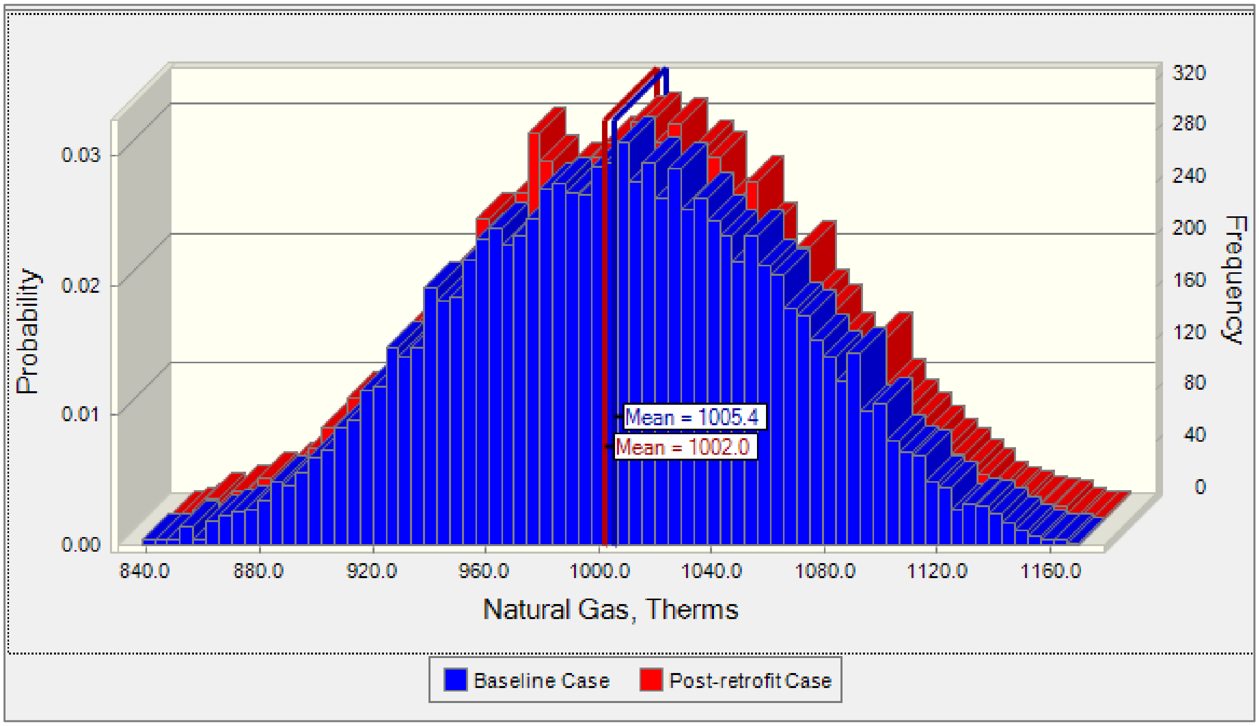


Table 44. Statistics for Natural Gas Consumption CZ01, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	1,005.400	1,002.000
Median	1,005.900	1,002.600
Mode	980.300	959.000
Standard Deviation	58.800	58.500
Coefficient of Variation	0.059	0.058
Minimum	819.900	811.100
Maximum	1,187.400	1,182.800
Mean Standard Error	0.600	0.600

Figure 39. Sensitivities of Baseline Natural Gas Consumption in CZ01

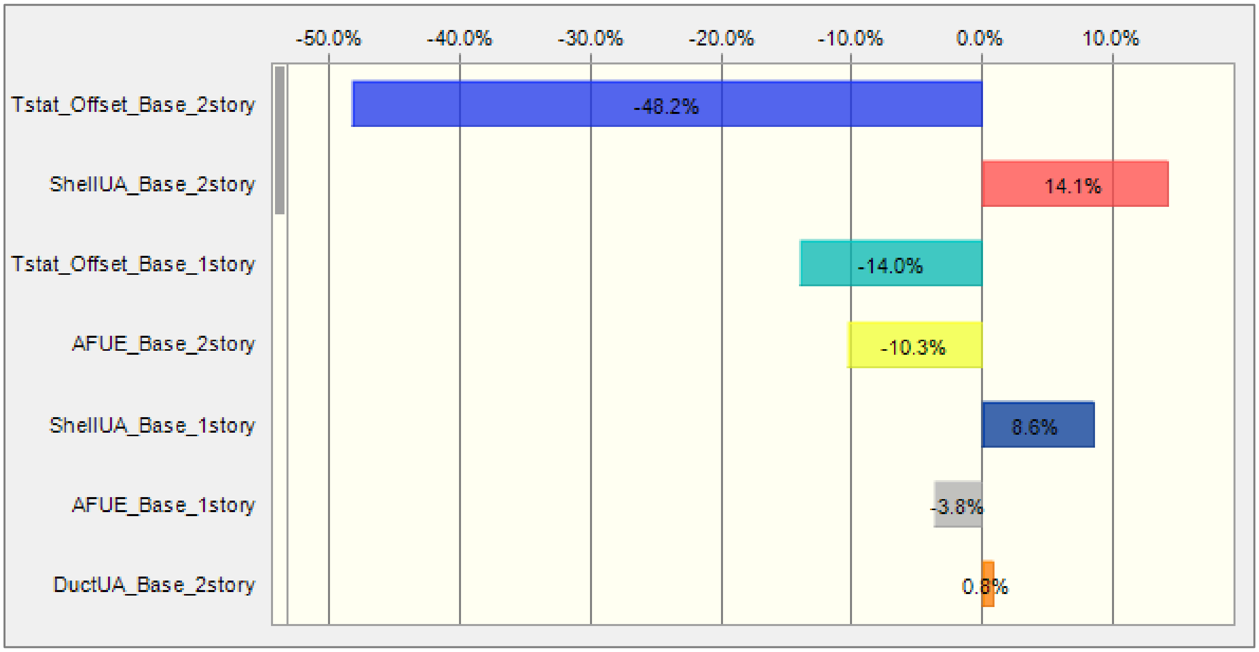
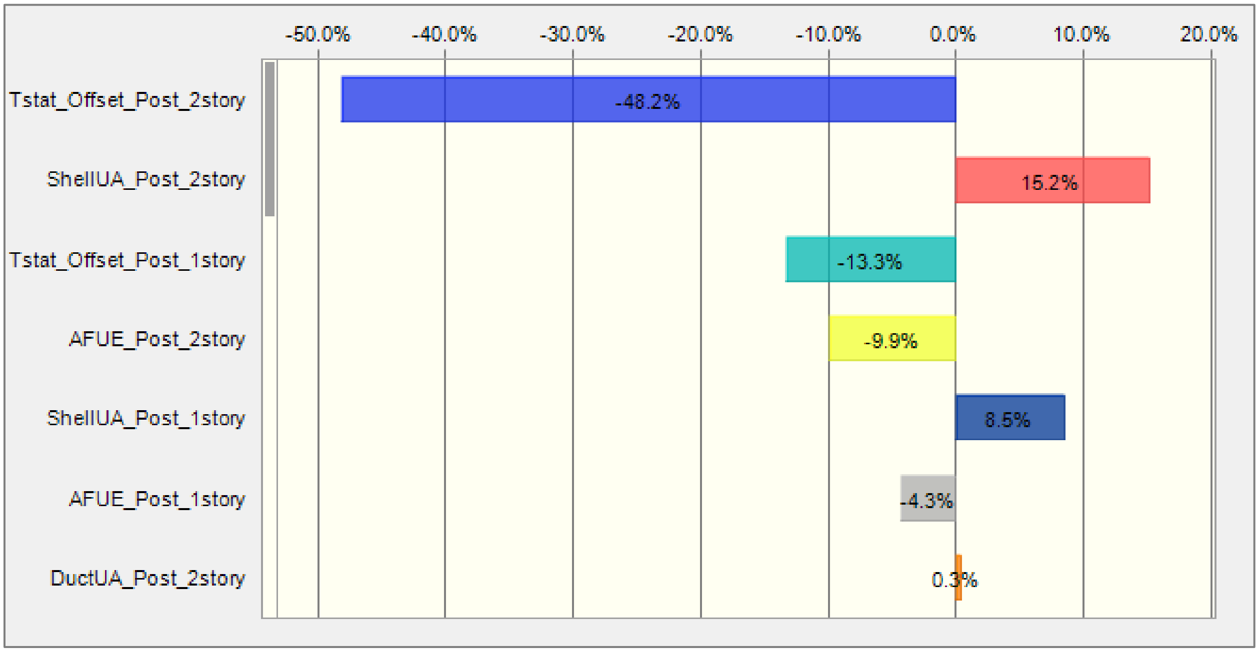


Figure 40. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ01



C.2 Climate Zone 2

Figure 41. Distributions of the Annual Electric Energy in CZ02. kWh/ton

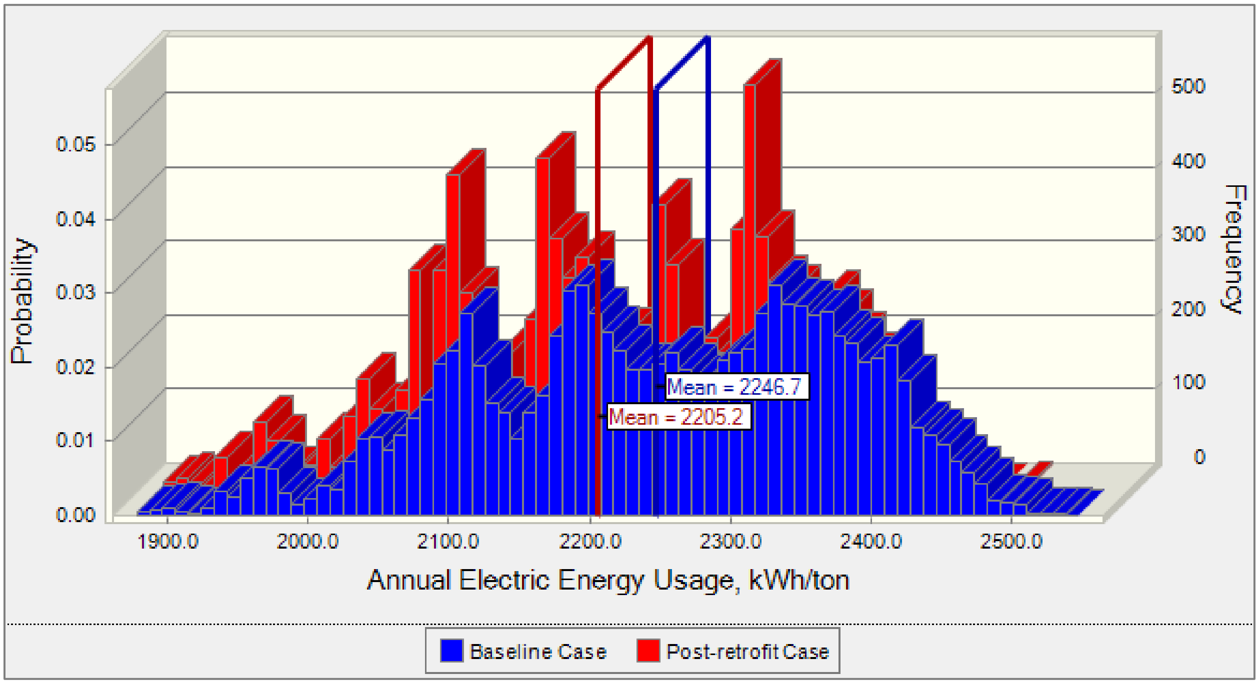


Table 45. Statistics for Annual Electric Energy in CZ02, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	2,247	2,205
Median	2,254	2,216
Mode	1,934	2,076
Standard Deviation	128.2	116.8
Coefficient of Variation	0.0571	0.053
Minimum	1,861	1,850
Maximum	2,547	2,486
Mean Standard Error	1.3	1.2

Figure 42 Sensitivities of Baseline Annual Electric Energy in CZ02

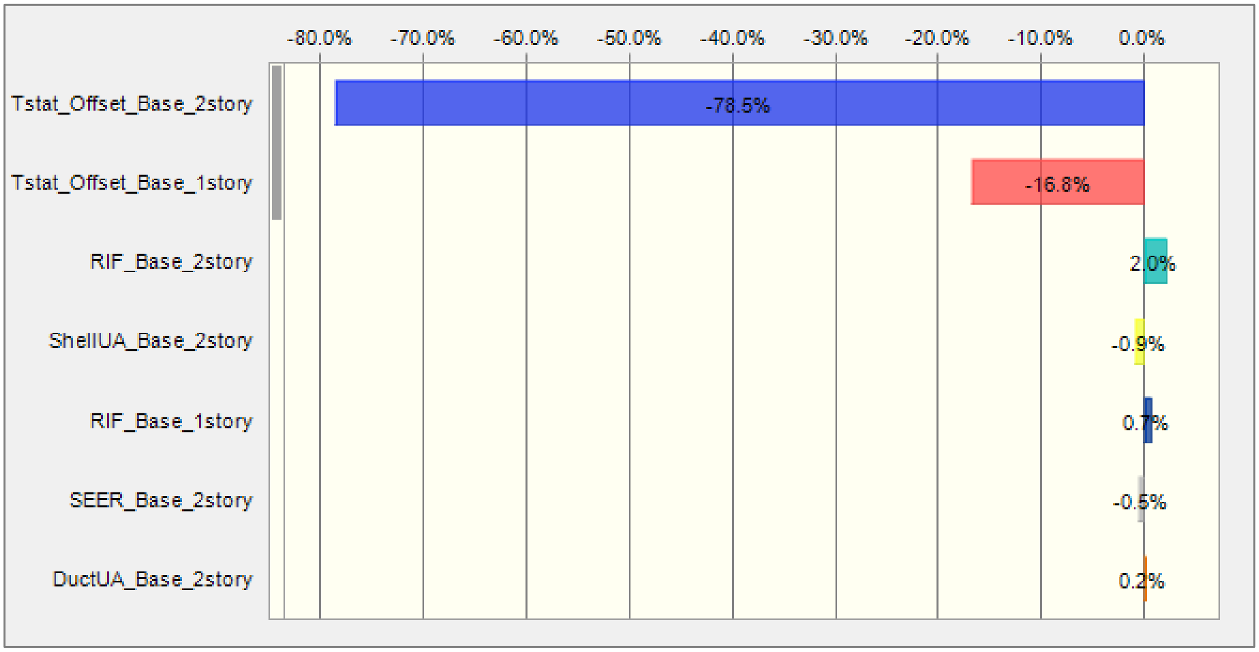


Figure 43 Sensitivities of Post-Retrofit Annual Electric Energy in CZ02

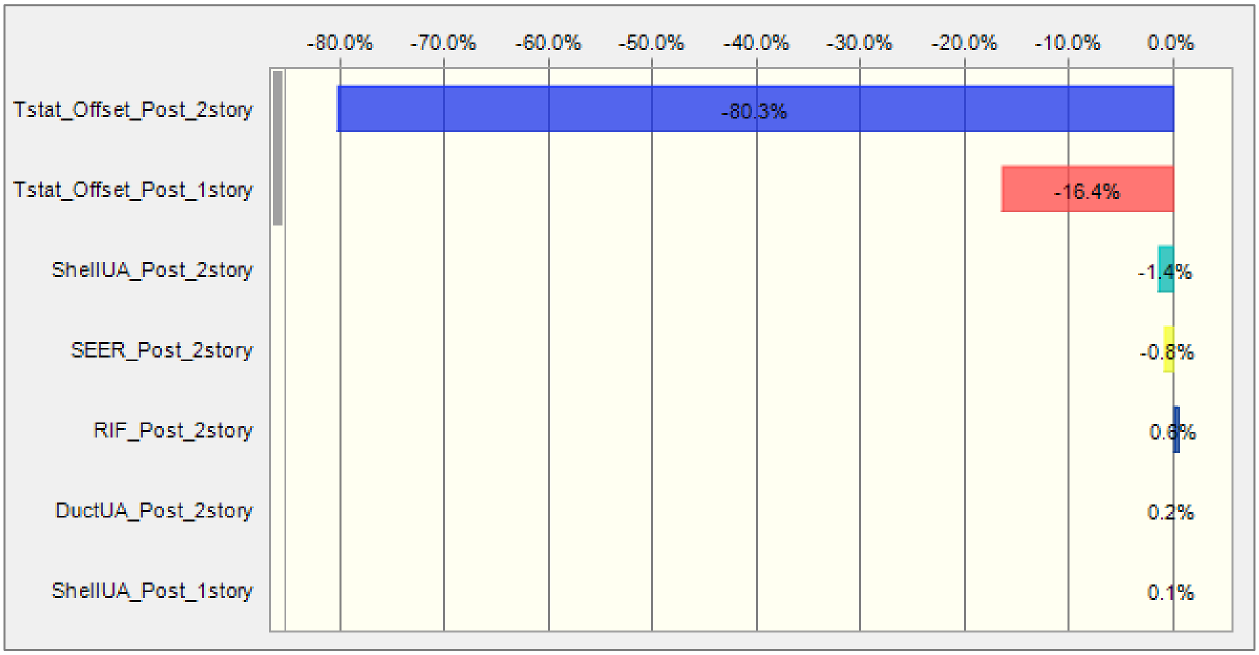


Figure 44. Distributions of Peak Demand in CZ02, kW/ton

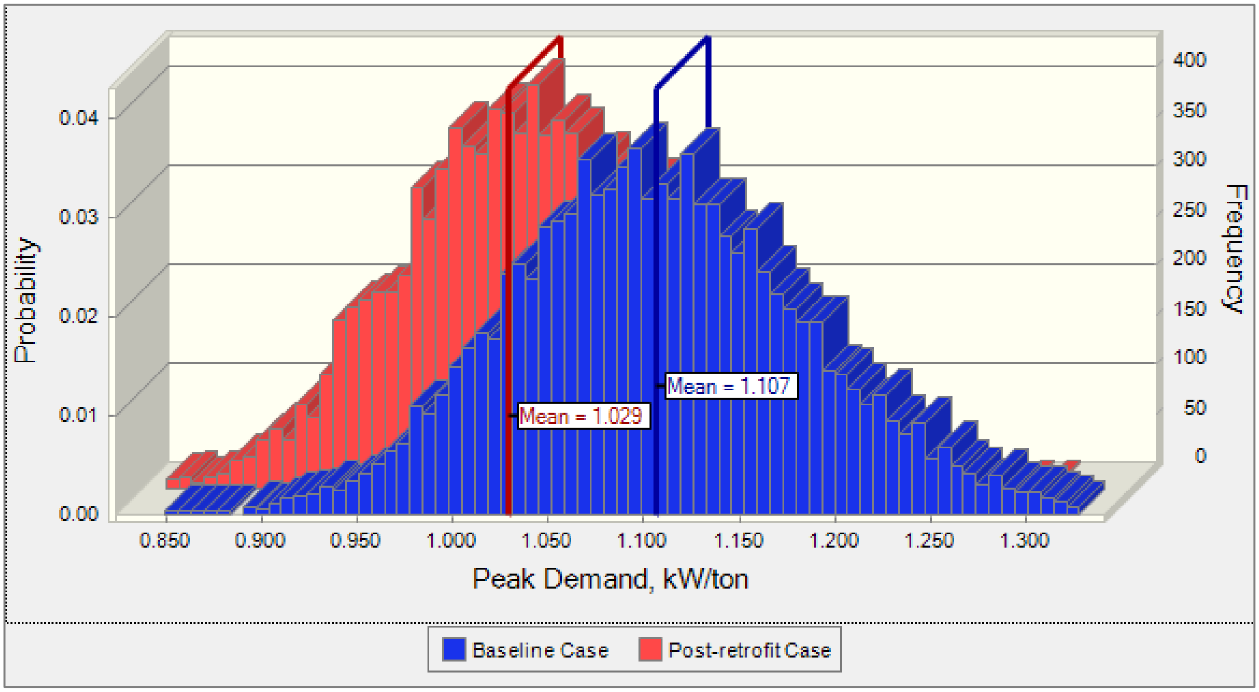


Table 46. Statistics for Peak Demand in CZ02, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Base Case	1.148	1.148
Mean	1.107	1.029
Median	1.103	1.028
Mode	0.981	0.956
Standard Deviation	0.079	0.069
Coefficient of Variation	0.071	0.067
Minimum	0.829	0.778
Maximum	1.428	1.297
Mean Standard Error	0.001	0.001

Figure 45. Sensitivities of Baseline Peak Demand in CZ02

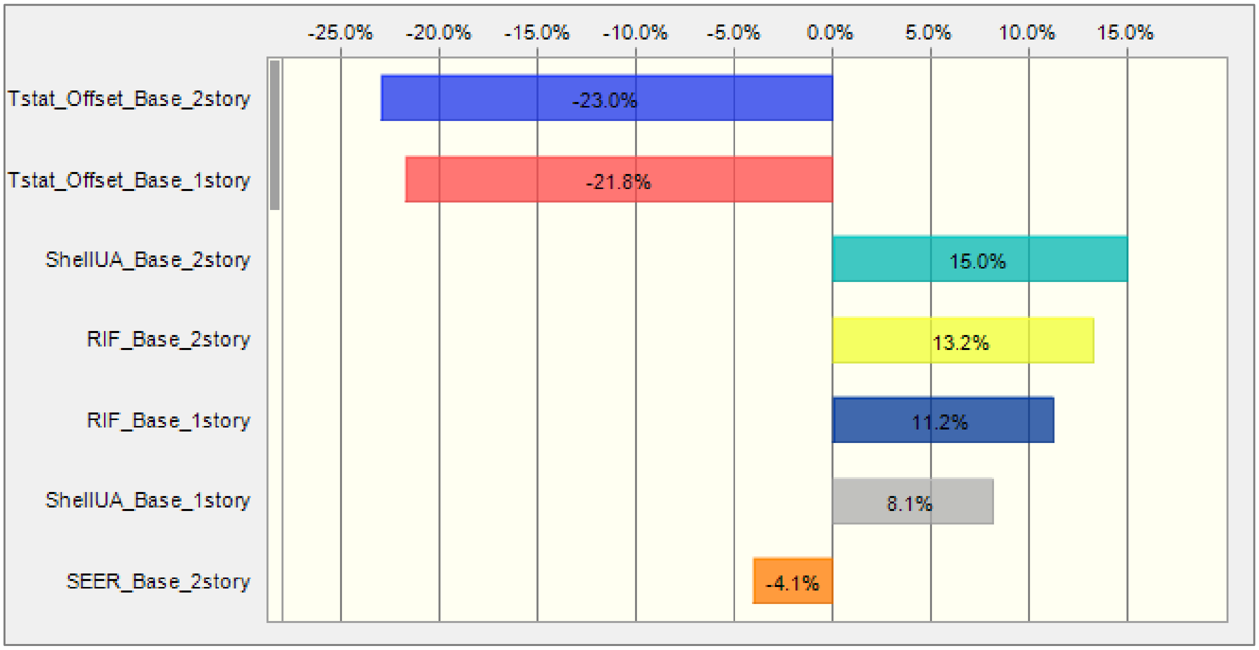


Figure 46 Sensitivities of Post-Retrofit Peak Demand in CZ02

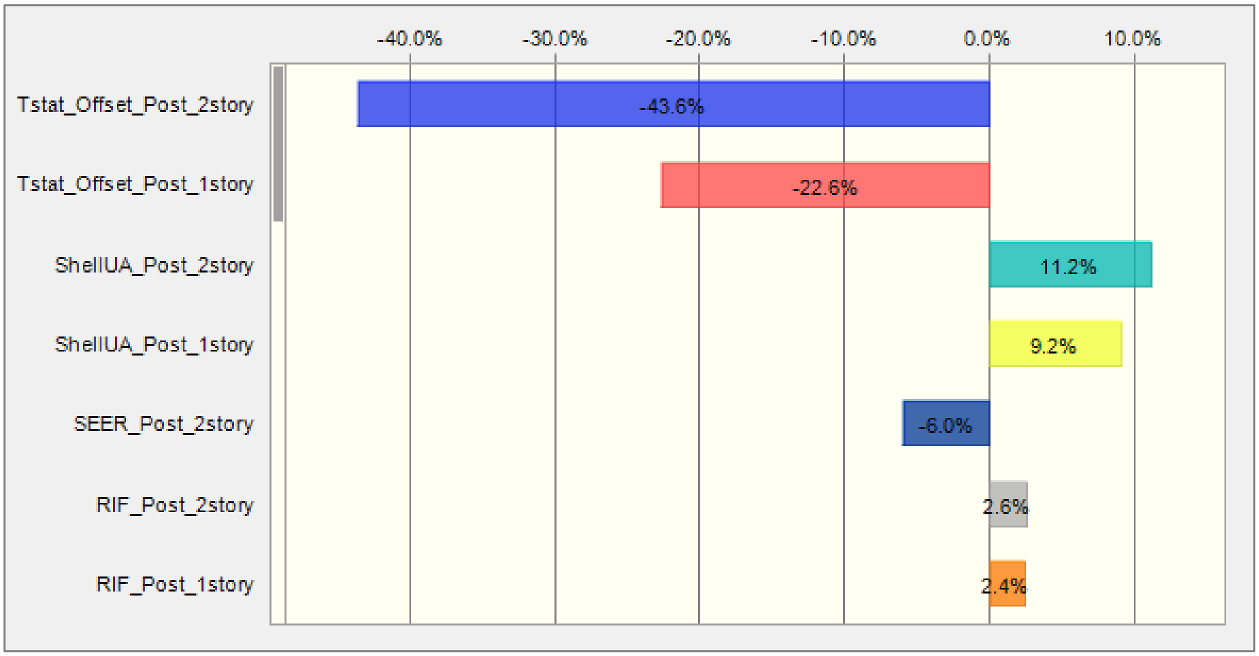


Figure 47. Distributions of Natural Gas Consumption in CZ02, therm/ton

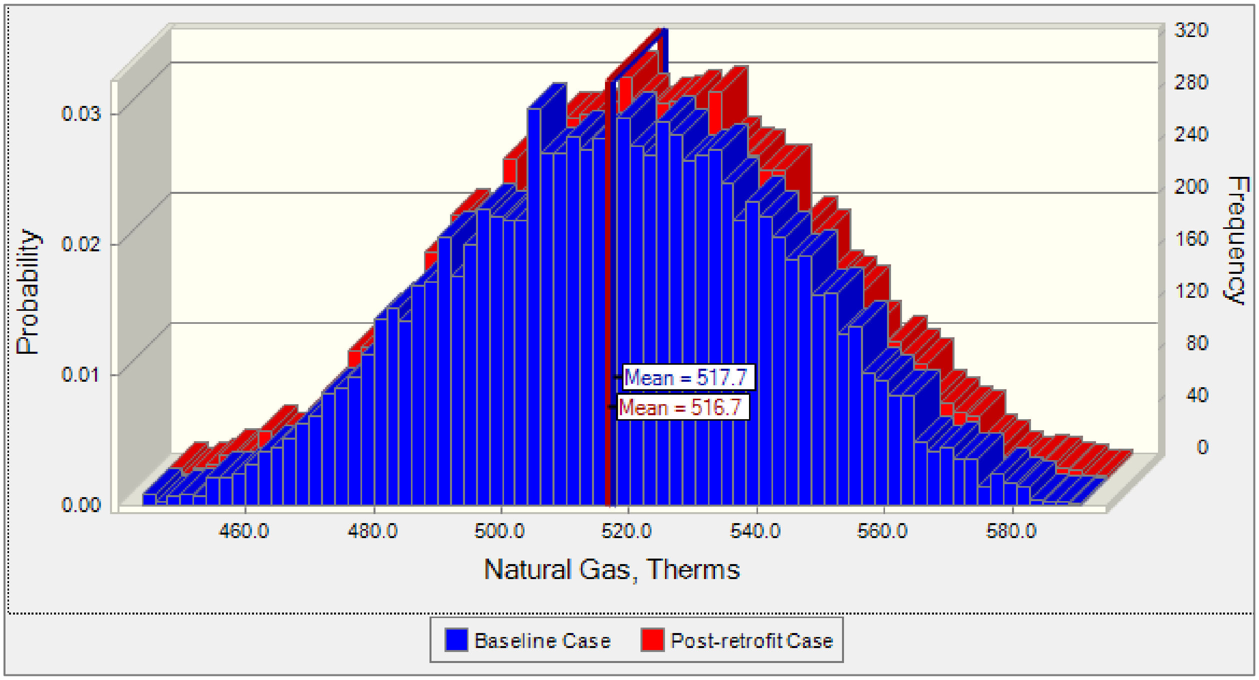


Table 47. Statistics for Natural Gas Consumption in CZ02, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	517.700	516.700
Median	518.200	517.000
Mode	493.500	492.900
Standard Deviation	26.100	26.000
Coefficient of Variation	0.050	0.050
Minimum	434.900	434.200
Maximum	592.500	595.100
Mean Standard Error	0.300	0.300

Figure 48. Sensitivities of Baseline Natural Gas Consumption in CZ02

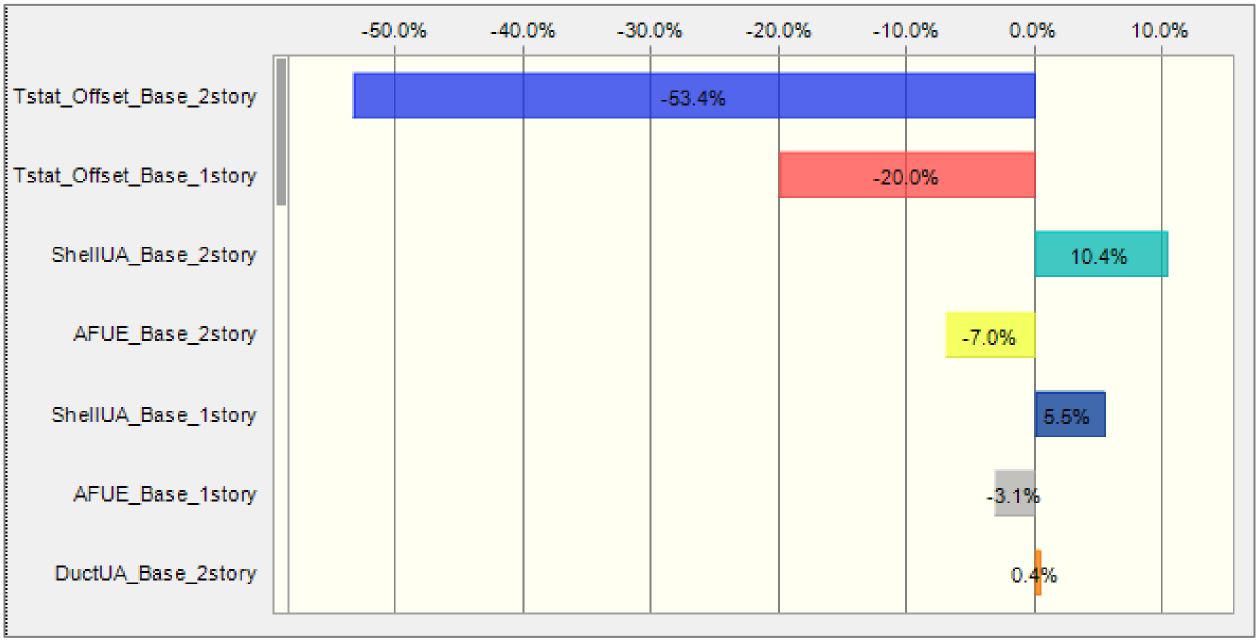
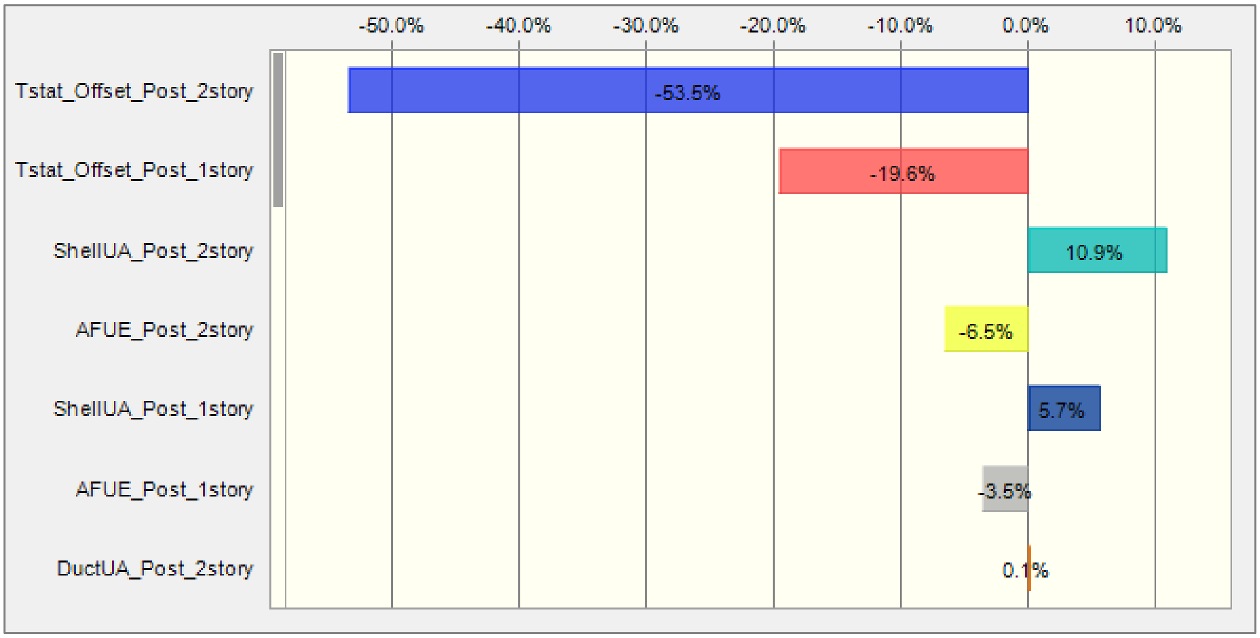


Figure 49. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ02



C.3 Climate Zone 3

Figure 50. Distributions of Annual Electric Energy Consumption per Ton, CZ03

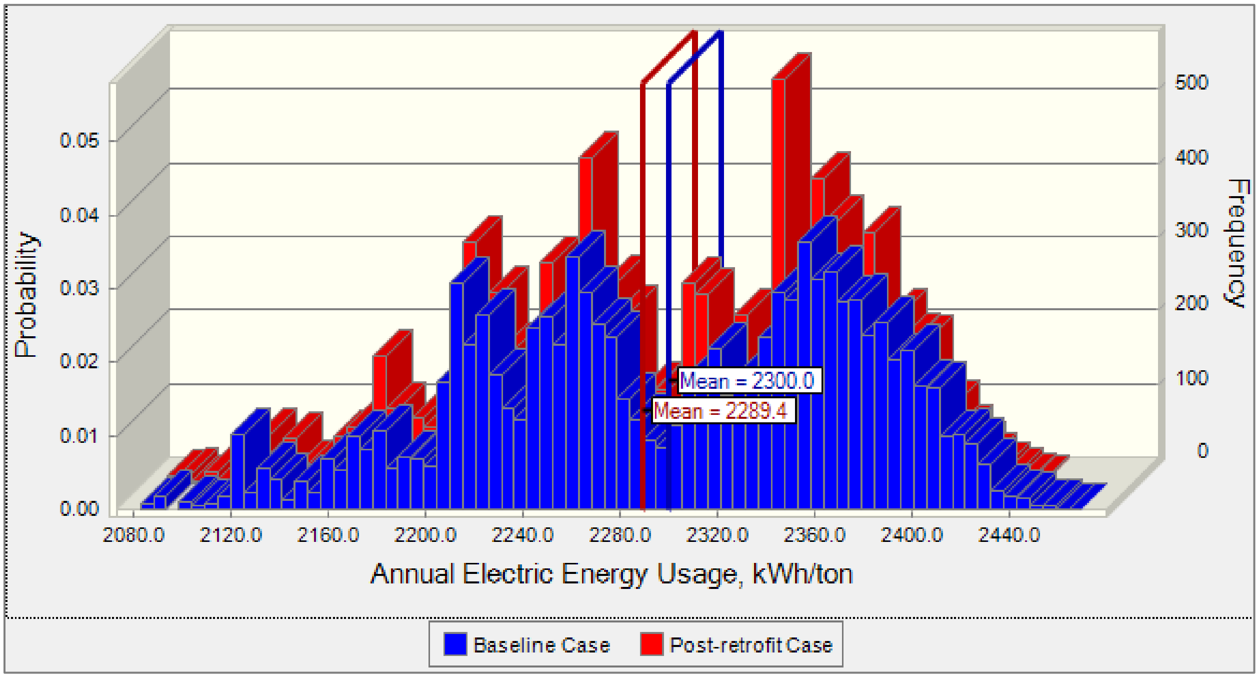


Table 48. Statistics for Annual Electric Energy Consumption per Ton, CZ03

Statistic	Baseline Case	Post-Retrofit Case
Mean	2,300	2,289
Median	2,310	2,299
Mode	2,215	2,205
Standard Deviation	77.5	73.3
Coefficient of Variation	0.0337	0.032
Minimum	2,050	2,048
Maximum	2,470	2,443
Mean Standard Error	0.8	0.7

Figure 51. Sensitivities of Baseline Annual Electric Energy in CZ03

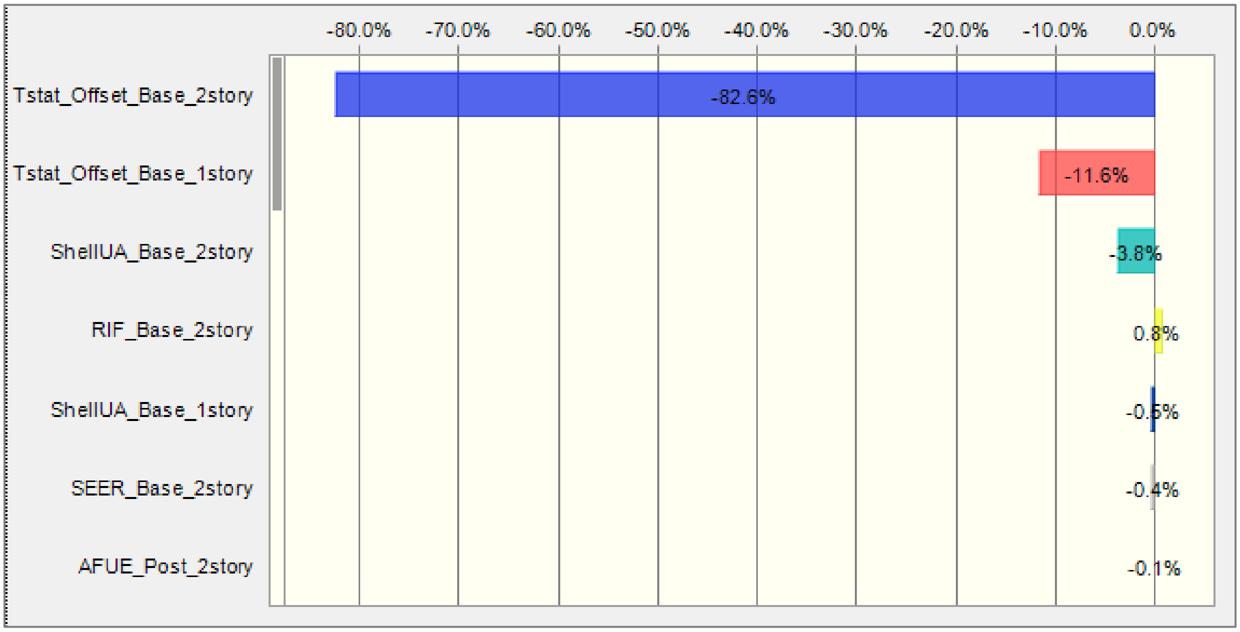


Figure 52. Sensitivities of Post-Retrofit Annual Electric Energy in CZ03

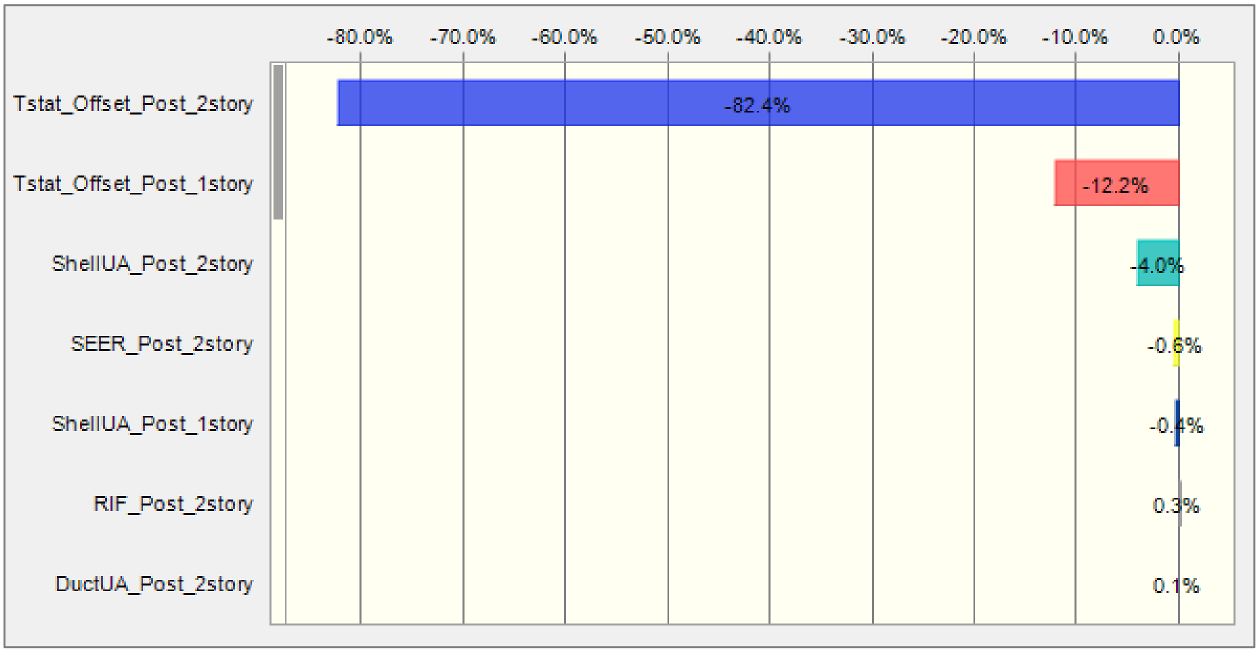


Figure 53. Distributions of Peak Demand in CZ03, kW/ton

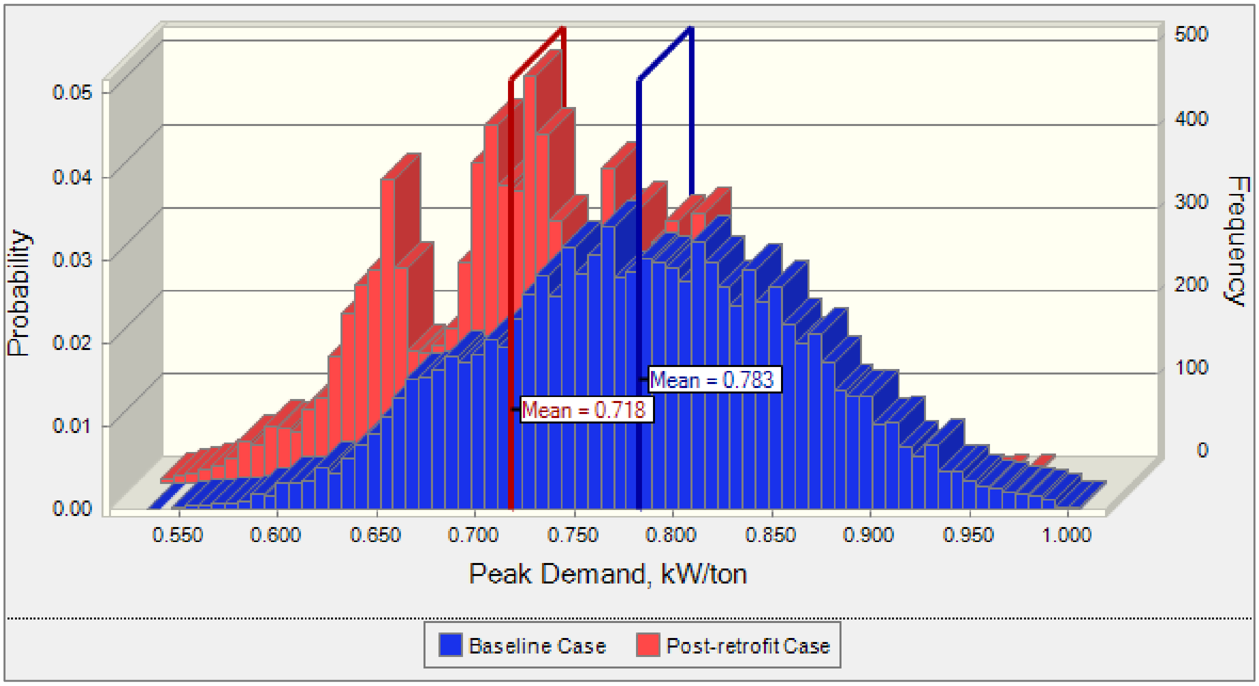


Table 49. Statistics for Peak Demand in CZ03, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	0.783	0.718
Median	0.783	0.717
Mode	0.731	0.643
Standard Deviation	0.080	0.068
Coefficient of Variation	0.102	0.095
Minimum	0.513	0.492
Maximum	1.039	0.964
Mean Standard Error	0.001	0.001

Figure 54 Sensitivities of Baseline Peak Demand in CZ03

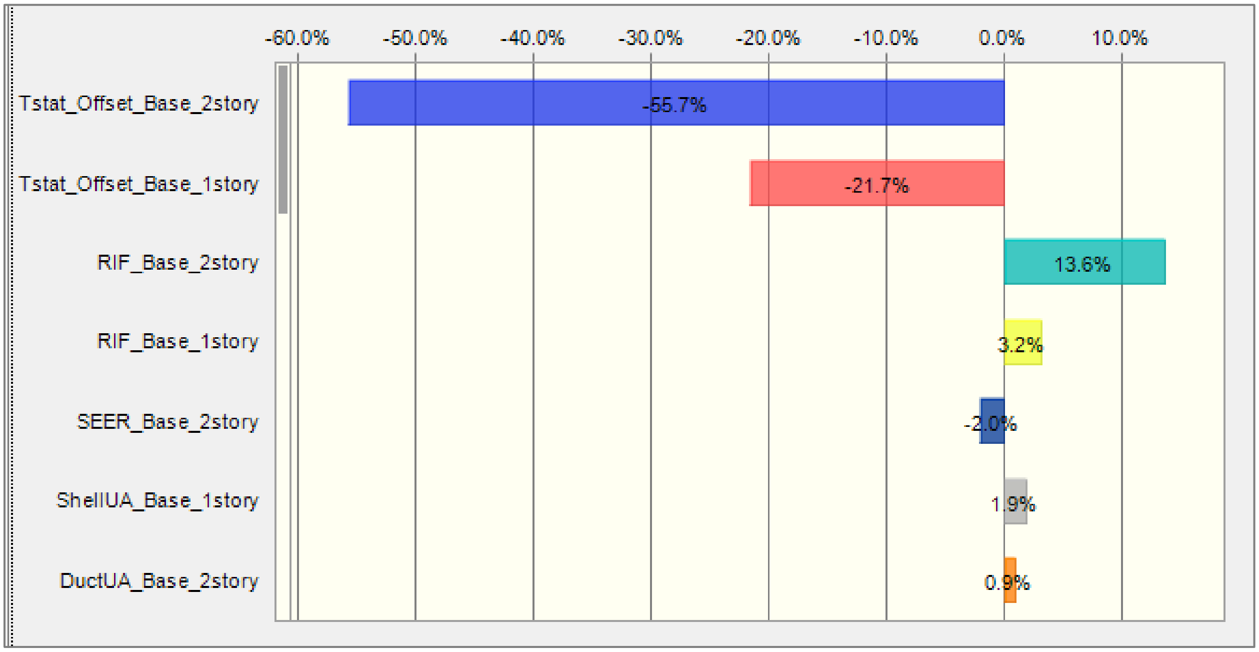


Figure 55 Sensitivities of Post-Retrofit Peak Demand in CZ03

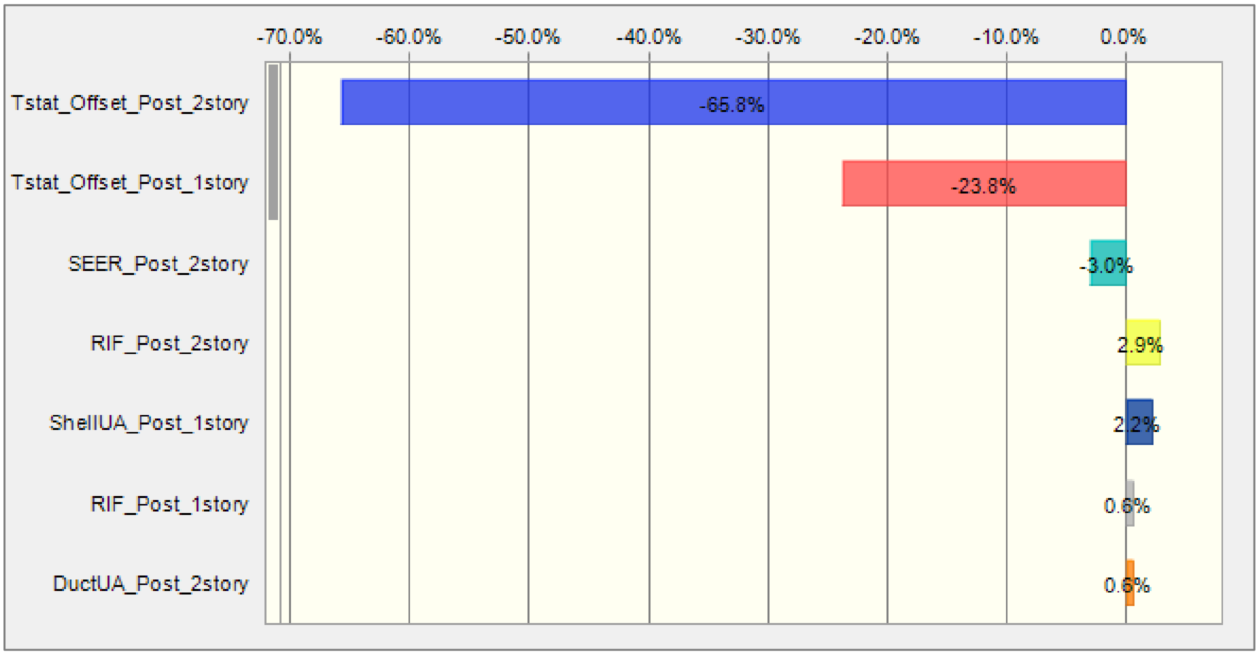


Figure 56. Distributions of Natural Gas Consumption in CZ03, therm/ton

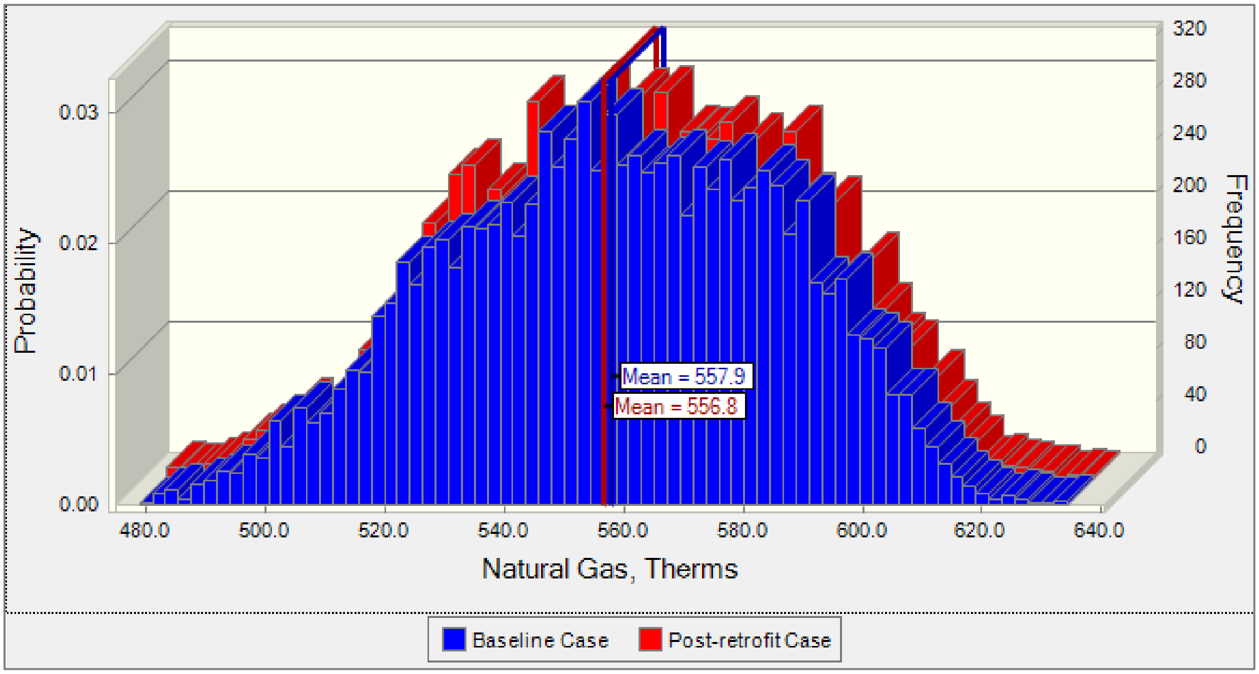


Table 50. Statistics for Natural Gas Consumption in CZ03, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	557.900	556.800
Median	558.400	557.500
Mode	534.000	533.500
Standard Deviation	28.000	27.800
Coefficient of Variation	0.050	0.050
Minimum	470.500	469.900
Maximum	646.000	642.300
Mean Standard Error	0.300	0.300

Figure 57. Sensitivities of Baseline Natural Gas Consumption in CZ03

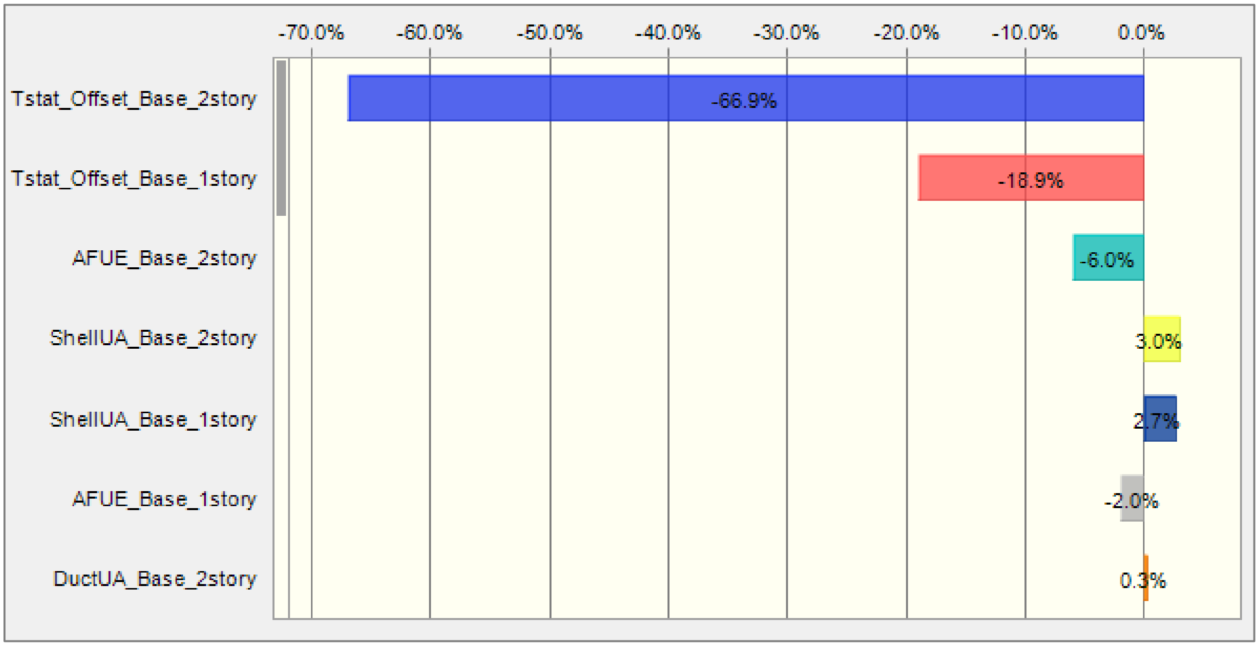
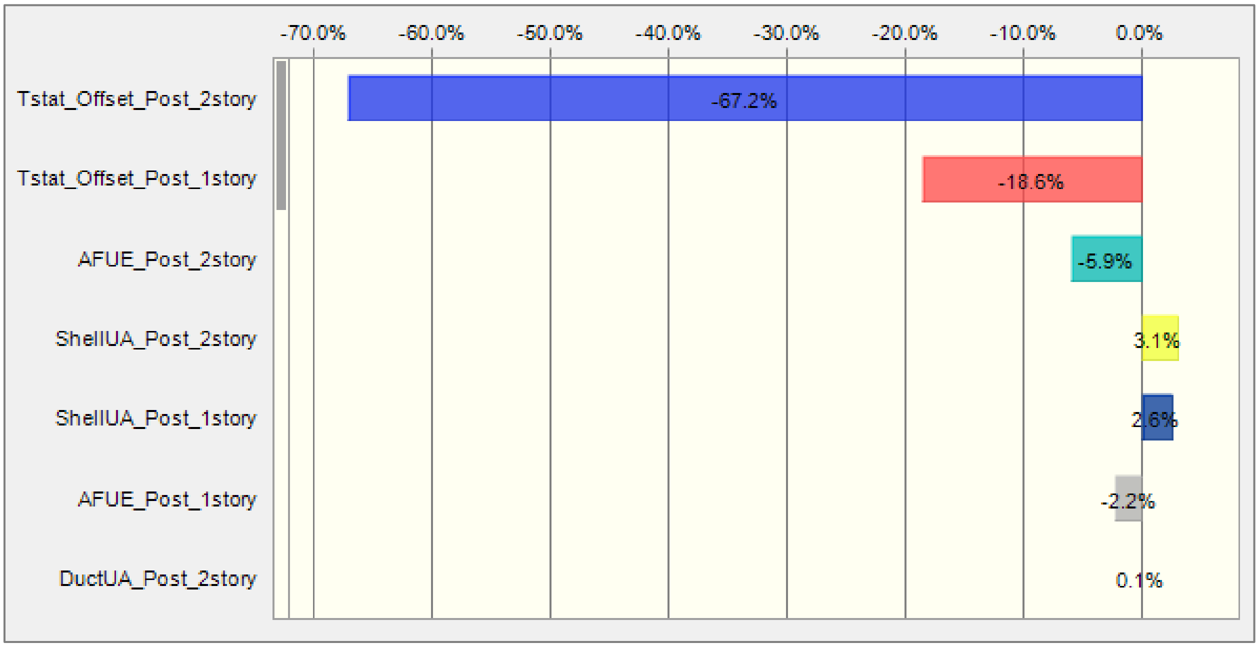


Figure 58. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ03



C.4 Climate Zone 4

Figure 59. Distributions of Annual Electric Energy in CZ04, kWh/ton

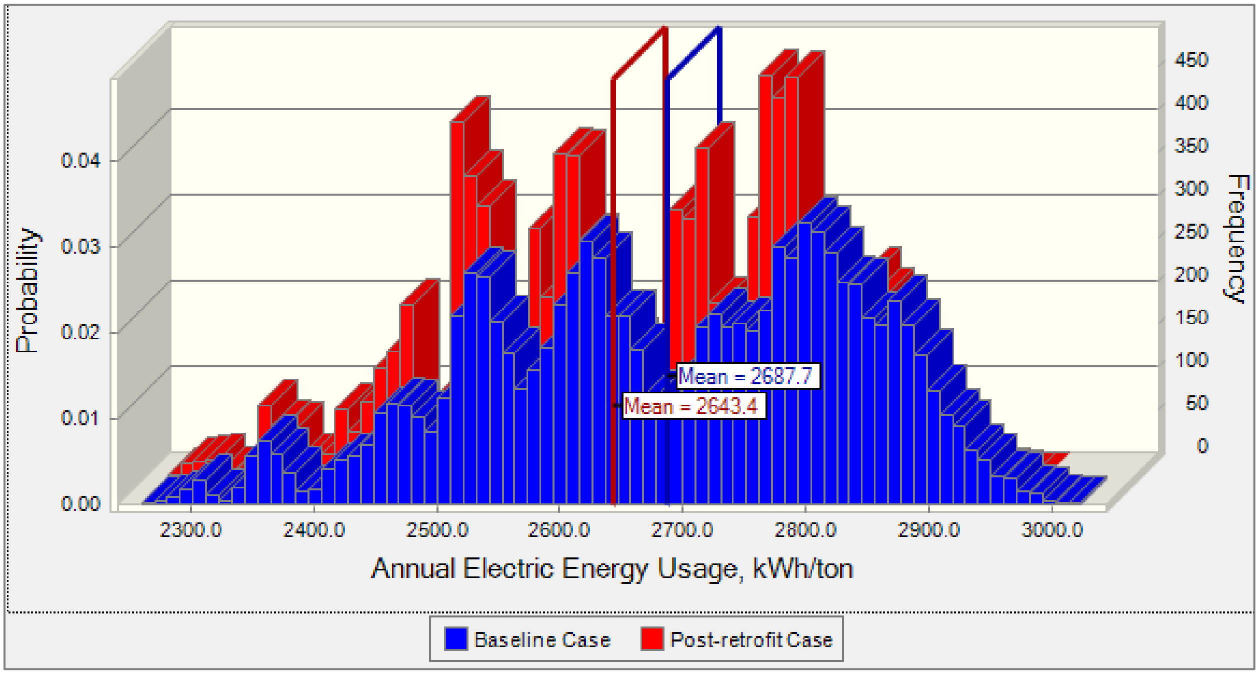


Table 51. Statistics for Annual Electric Energy in CZ04, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	2,688	2,643
Median	2,705	2,669
Mode	2,527	2,494
Standard Deviation	150.7	137
Coefficient of Variation	0.0561	0.0518
Minimum	2,230	2,233
Maximum	3,024	2,966
Mean Standard Error	1.5	1.4

Figure 60. Sensitivities of Baseline Annual Electric Energy in CZ04

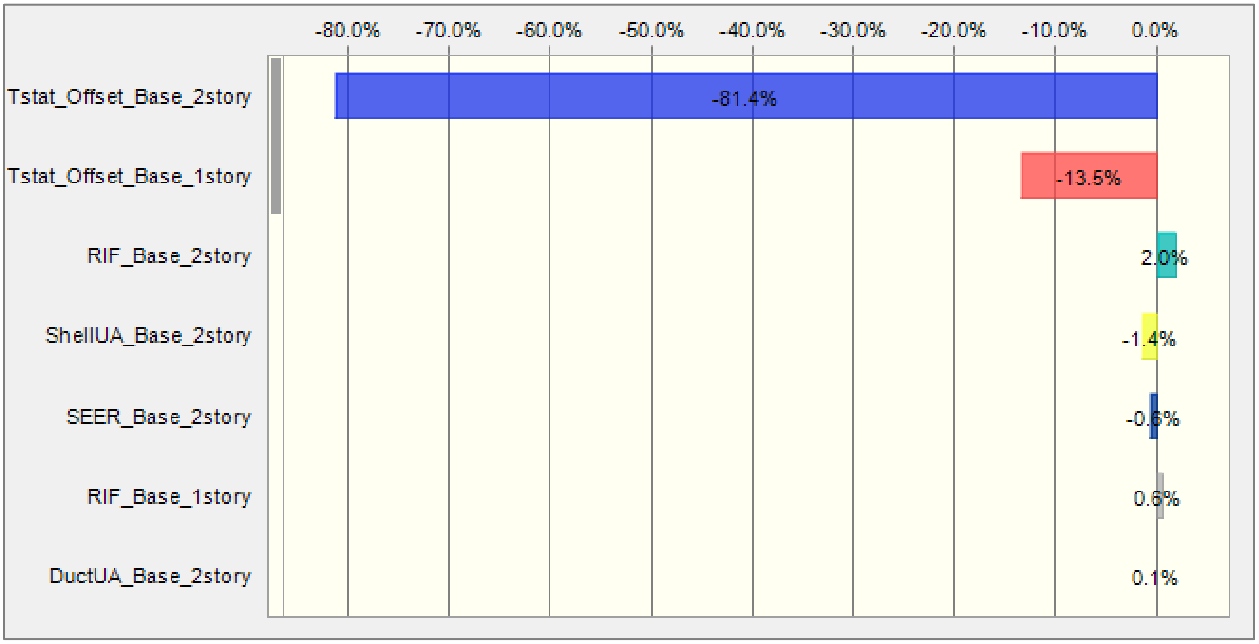


Figure 61 Sensitivities of Post-Retrofit Annual Electric Energy in CZ04

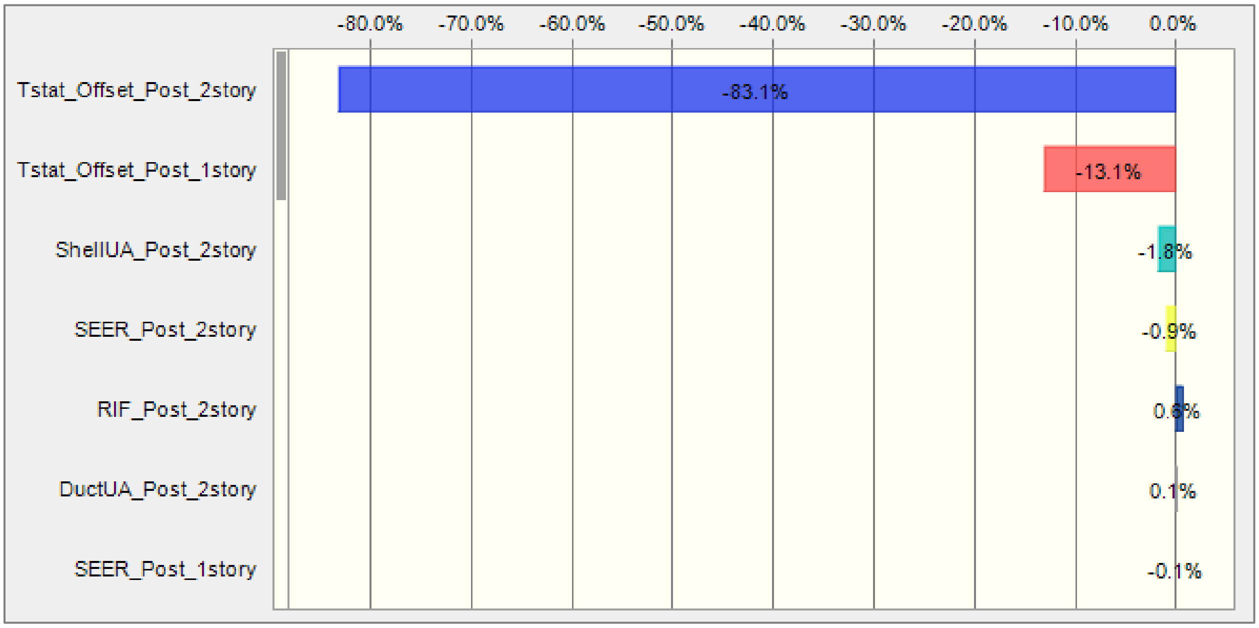


Figure 62. Distribution of Peak Demand in CZ04, kW/ton

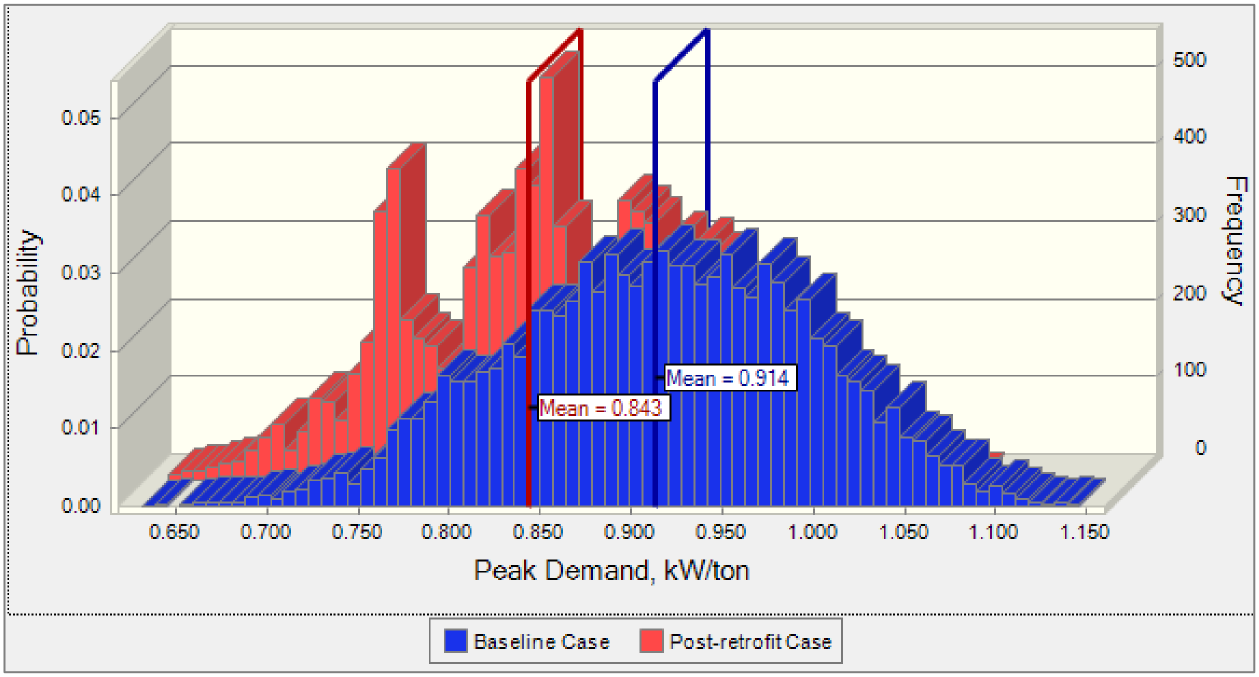


Table 52. Statistics for Peak Demand in CZ04, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	0.914	0.843
Median	0.916	0.842
Mode	0.829	0.754
Standard Deviation	0.083	0.076
Coefficient of Variation	0.091	0.090
Minimum	0.636	0.579
Maximum	1.165	1.074
Mean Standard Error	0.001	0.001

Figure 63. Sensitivities of Baseline Peak Demand in CZ04

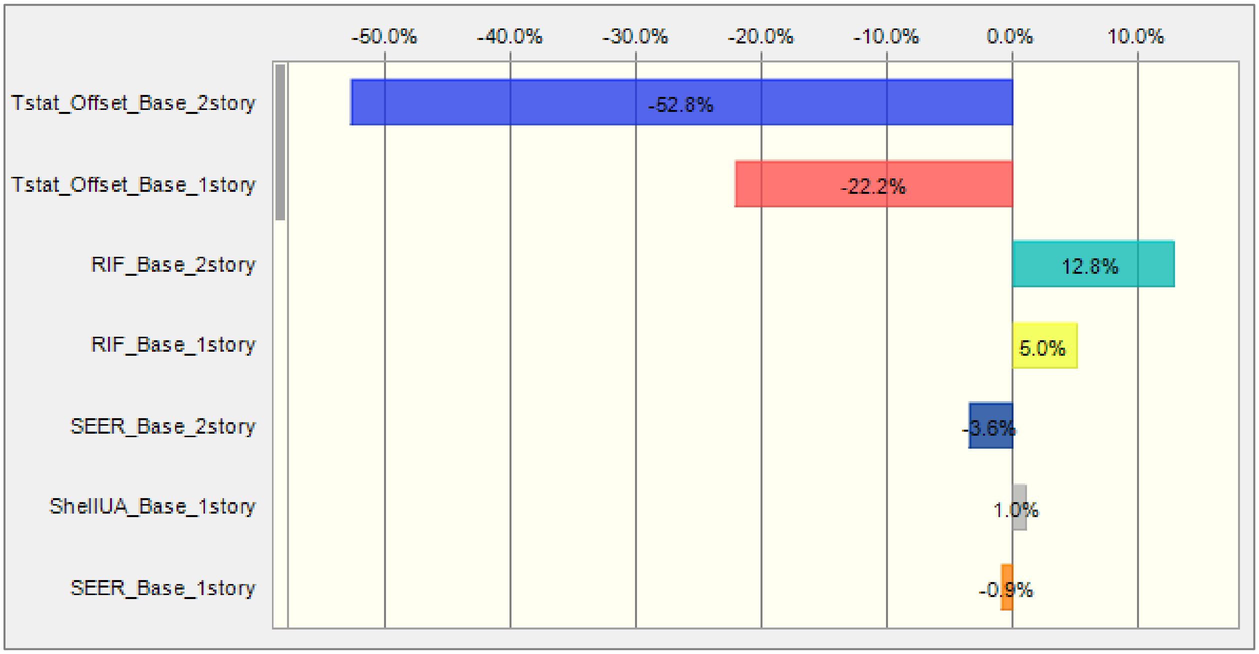


Figure 64. Sensitivities of Post-Retrofit Peak Demand in CZ04

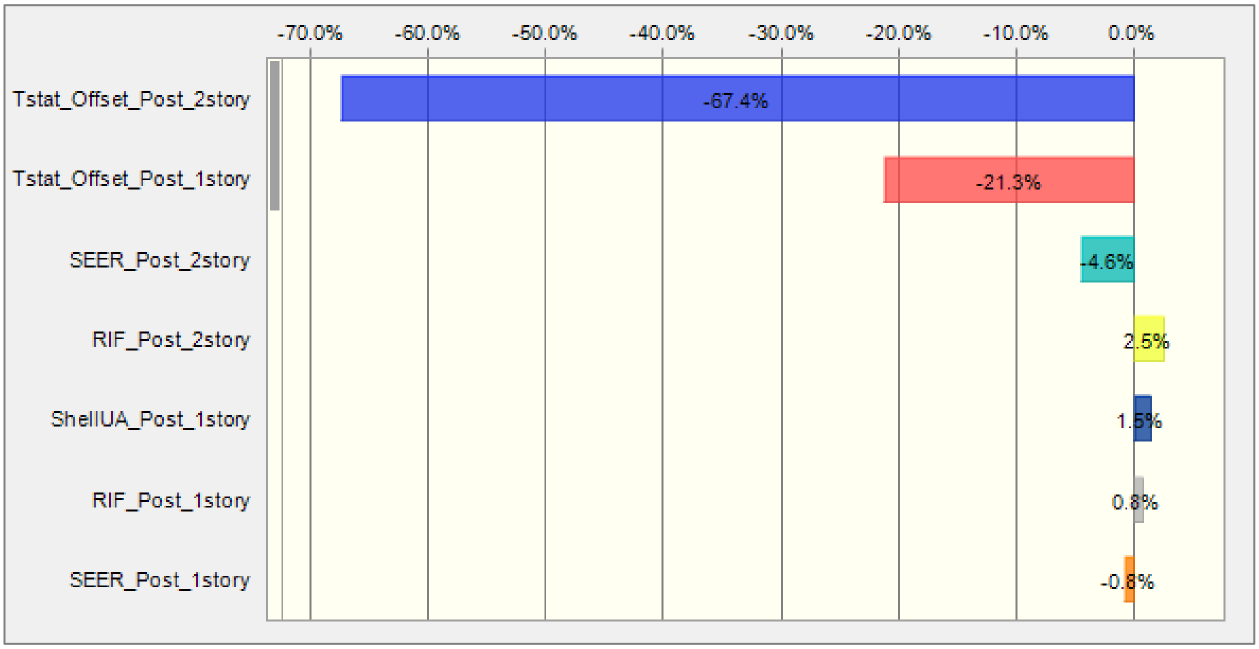


Figure 65. Distribution of Natural Gas Consumption in CZ04, therm/ton

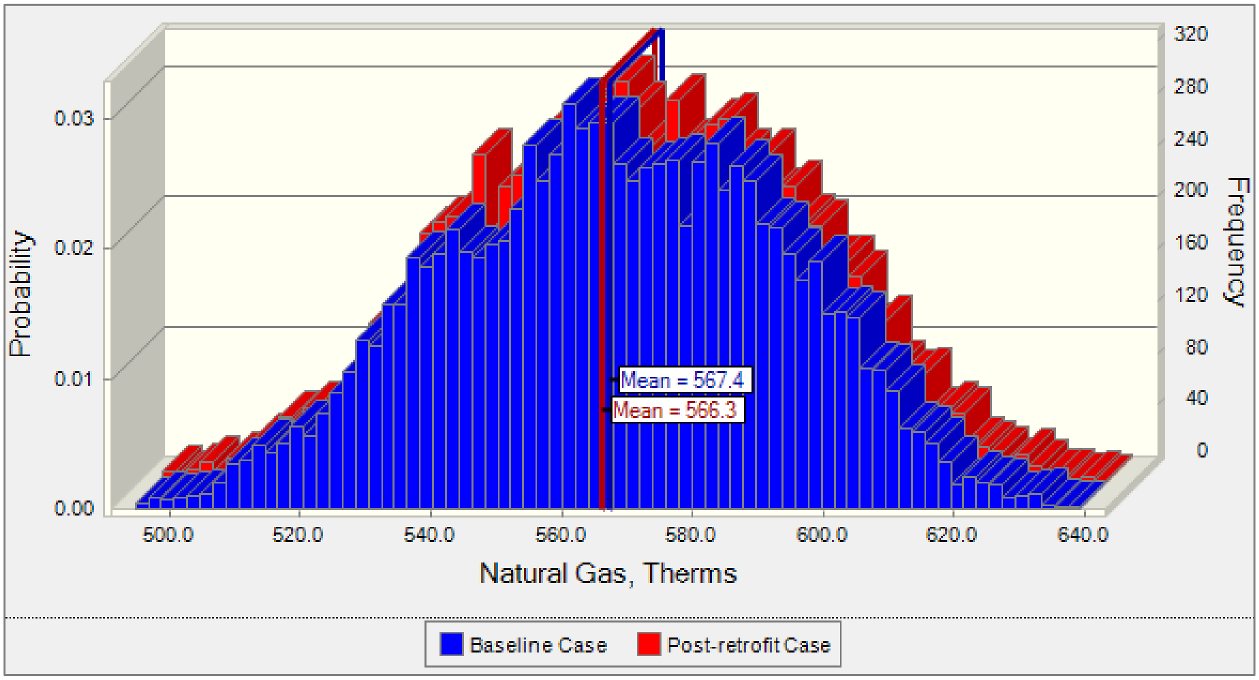


Table 53. Statistics for Natural Gas Consumption in CZ04, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	567.400	566.300
Median	567.600	566.400
Mode	542.900	542.300
Standard Deviation	25.700	25.500
Coefficient of Variation	0.045	0.045
Minimum	486.500	487.300
Maximum	646.200	648.200
Mean Standard Error	0.300	0.300

Figure 66. Sensitivities of Baseline Natural Gas Consumption in CZ04

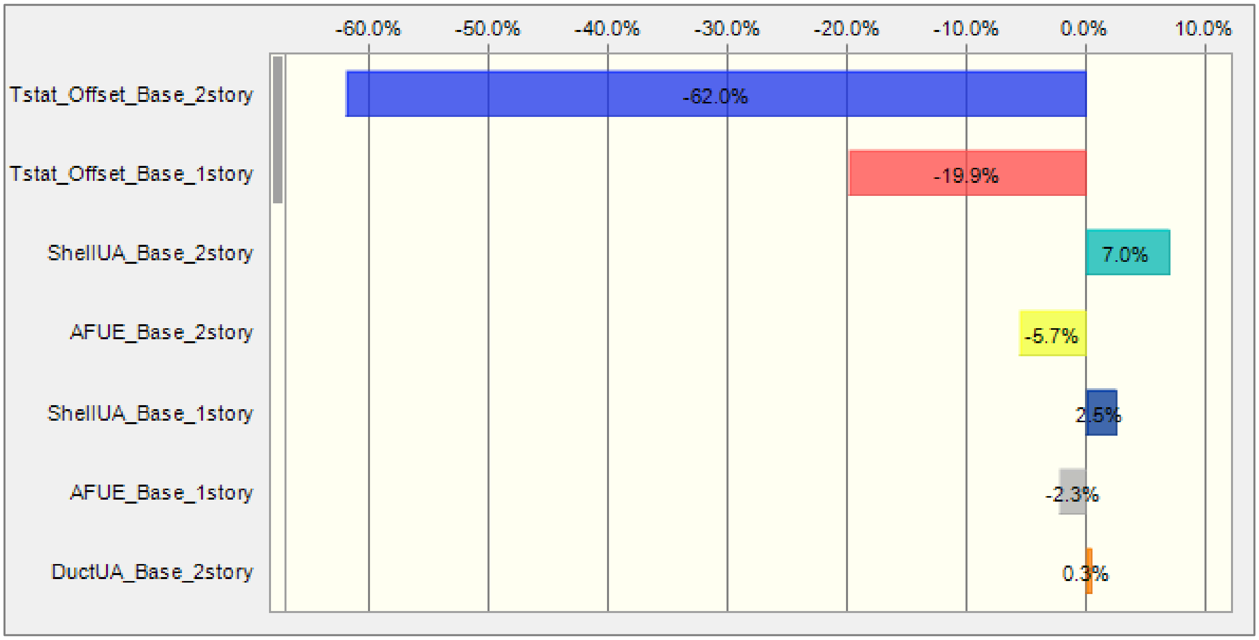
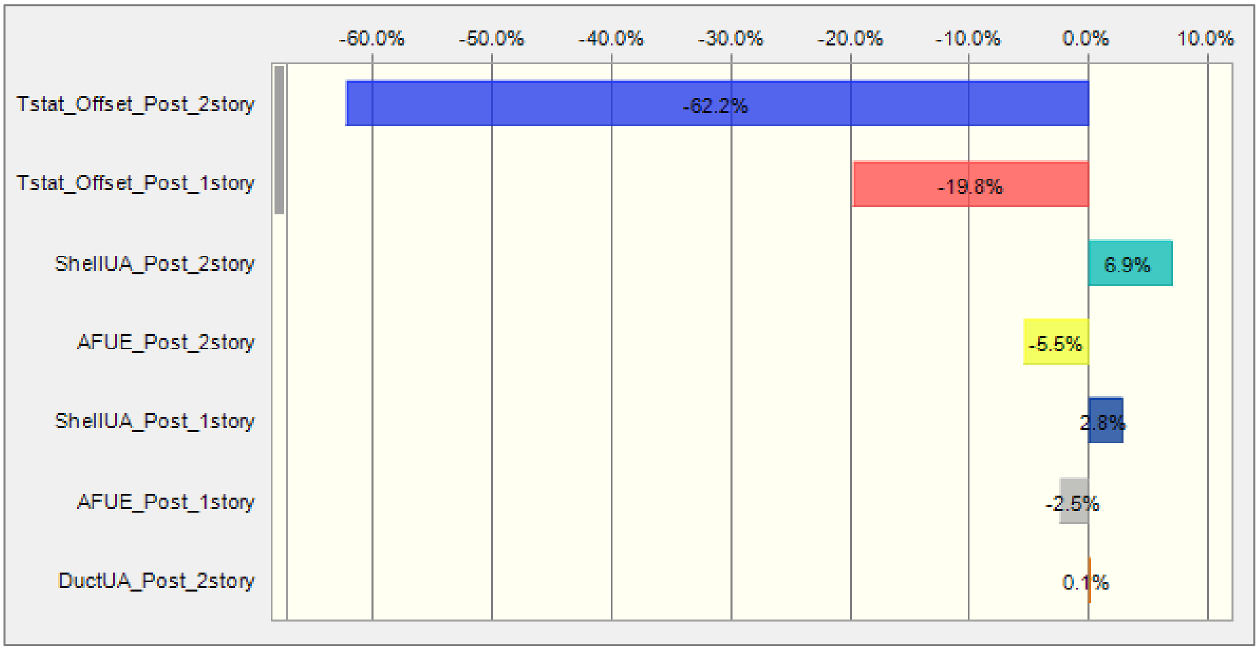


Figure 67. Sensitivities of Post-Retrofit Natural Gas Energy Consumption in CZ04



C.5 Climate Zone 5

Figure 68. Distributions of Annual Electric Energy in CZ05, kWh/ton

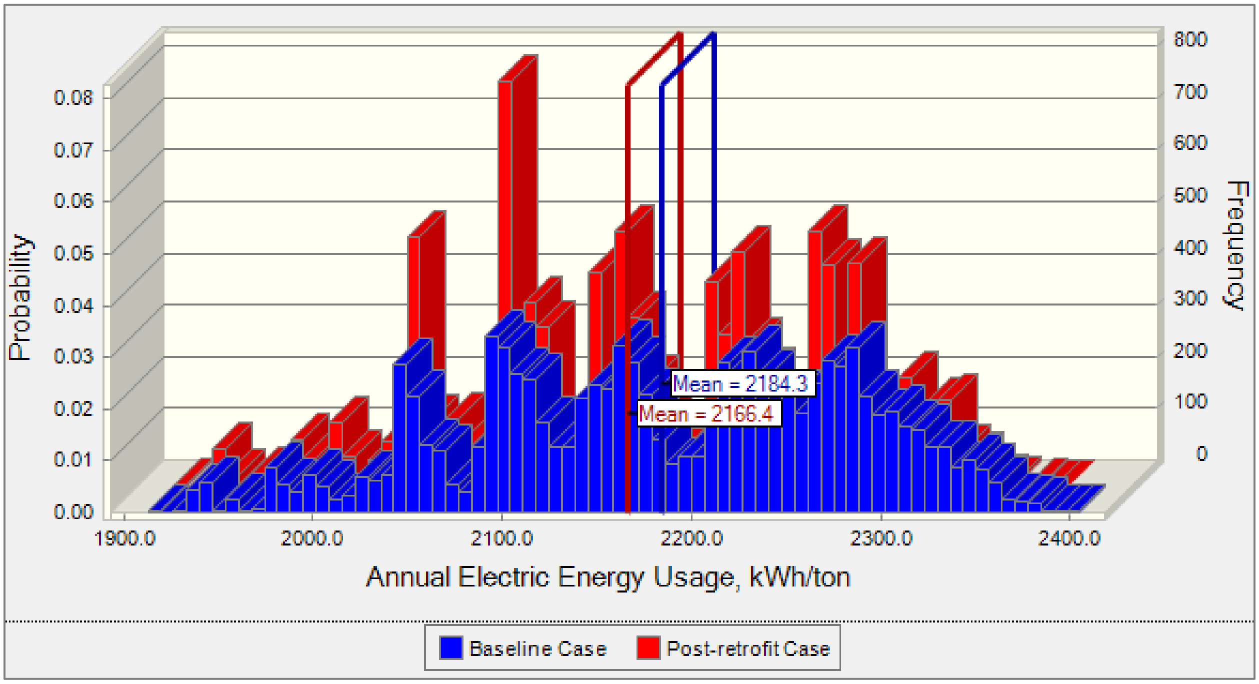


Table 54. Statistics for Annual Electric Energy in CZ05, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	2,184	2,166
Median	2,185	2,165
Mode	2,052	2,039
Standard Deviation	99.4	92.3
Coefficient of Variation	0.0455	0.0426
Minimum	1,890	1,893
Maximum	2,405	2,381
Mean Standard Error	1	0.9

Figure 69. Sensitivities of Baseline Annual Electric Energy in CZ05

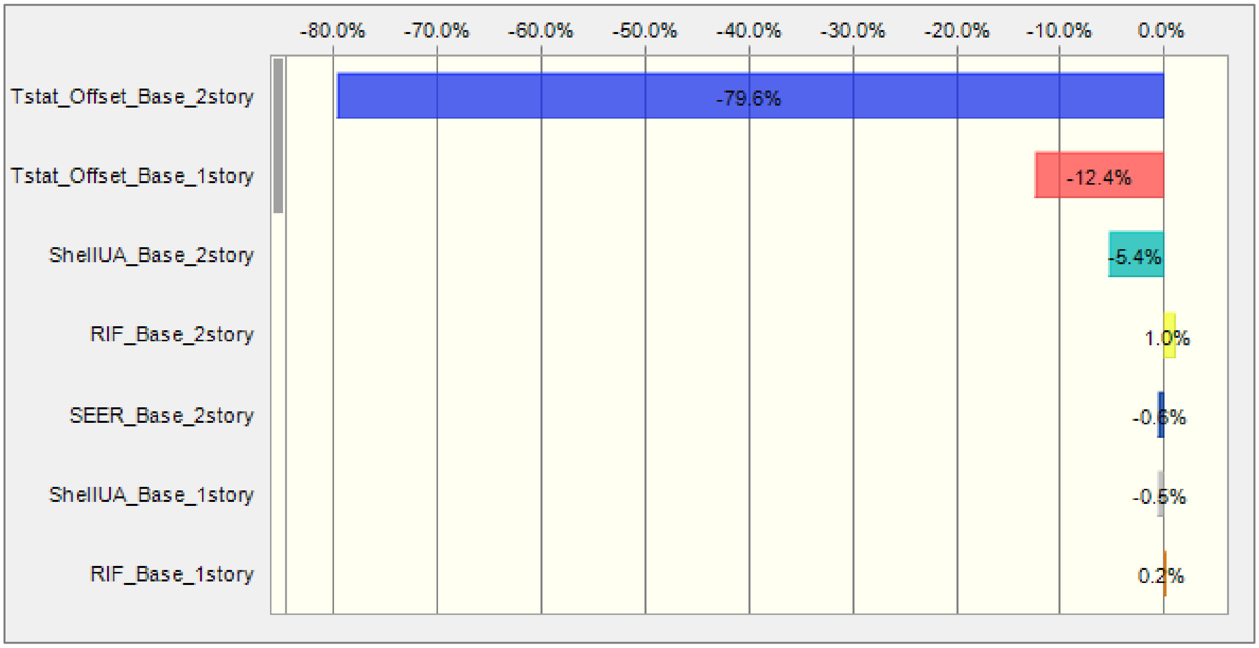


Figure 70. Sensitivities of Post-Retrofit Annual Electric Energy in CZ05

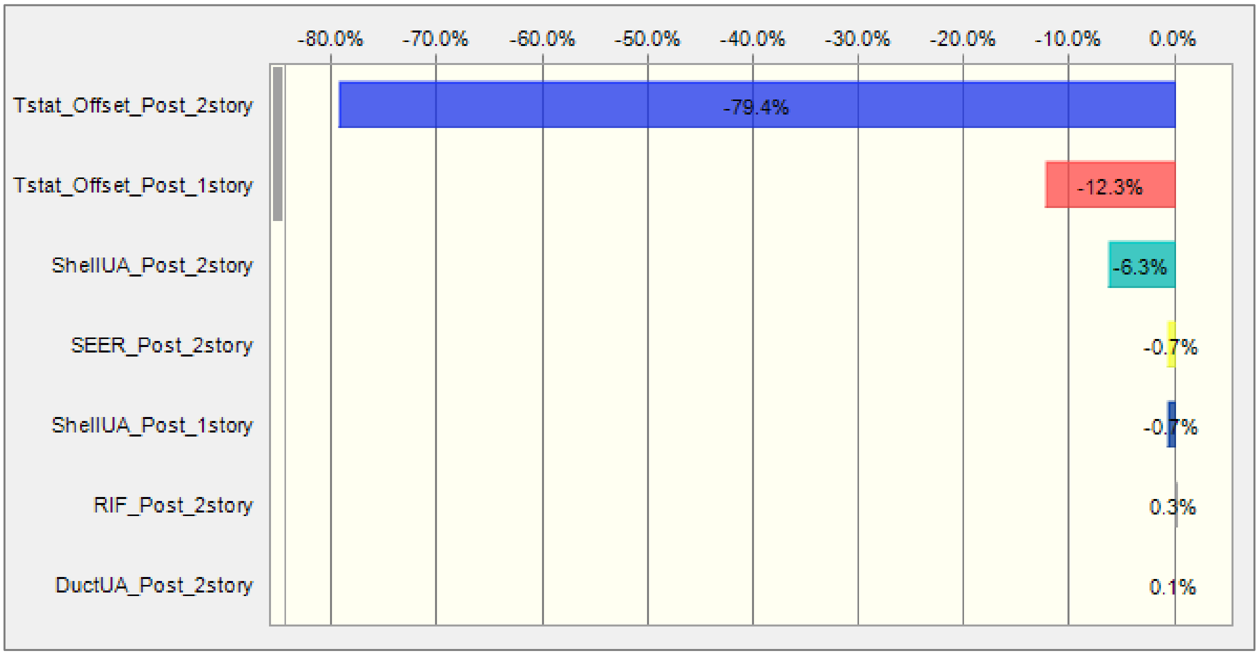


Figure 71. Distributions of Peak Demand in CZ05, kW/ton

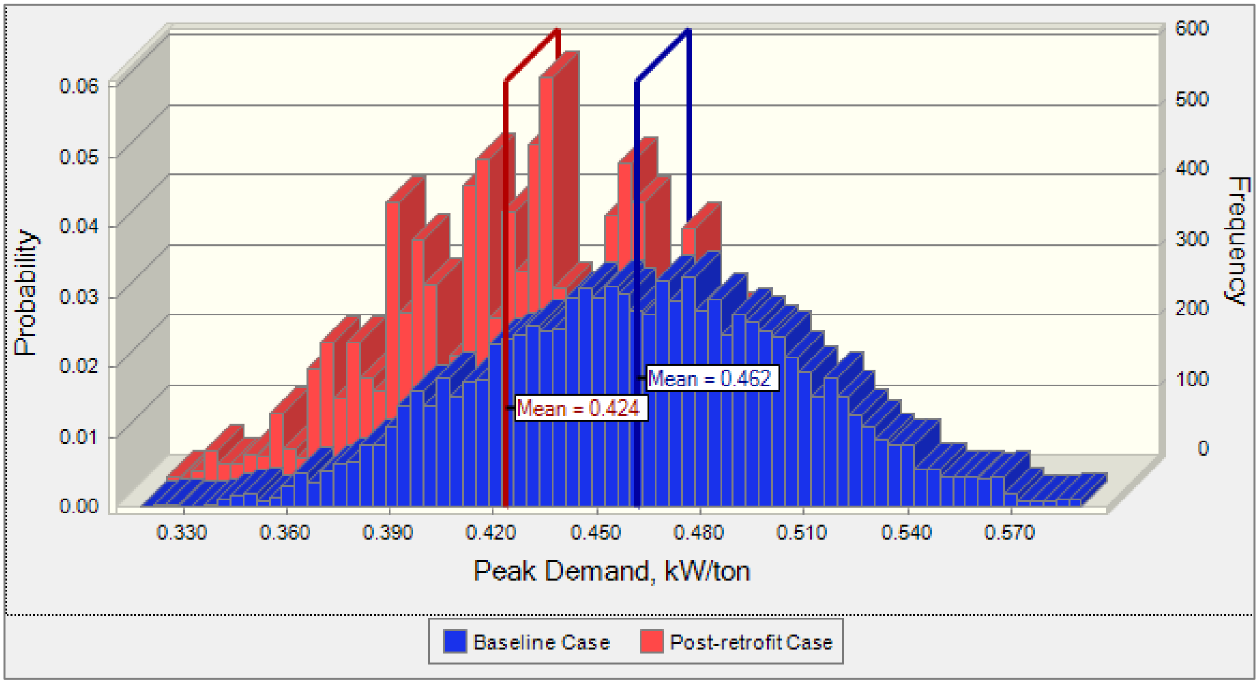


Table 55. Statistics for Peak Demand in CZ05, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	0.462	0.424
Median	0.462	0.425
Mode	0.428	0.391
Standard Deviation	0.046	0.038
Coefficient of Variation	0.100	0.089
Minimum	0.304	0.303
Maximum	0.618	0.556
Mean Standard Error	0.000	0.000

Figure 72. Sensitivities of Baseline Peak Demand in CZ05

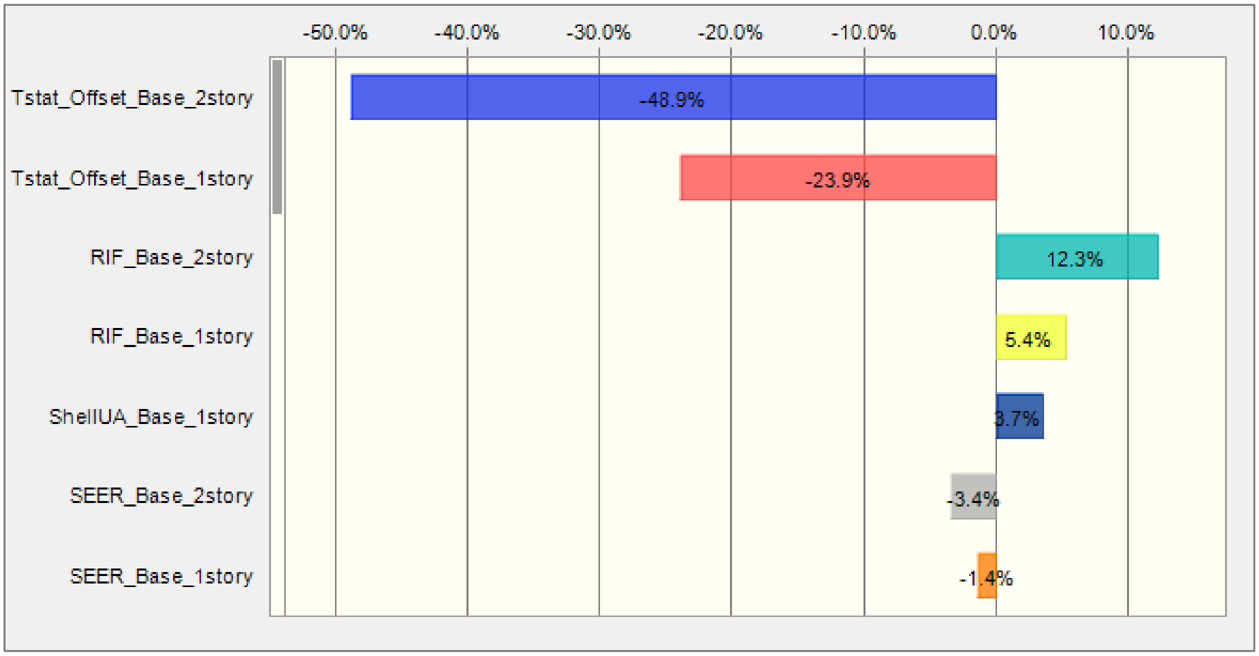


Figure 73. Sensitivities of Post-Retrofit Peak Demand in CZ05

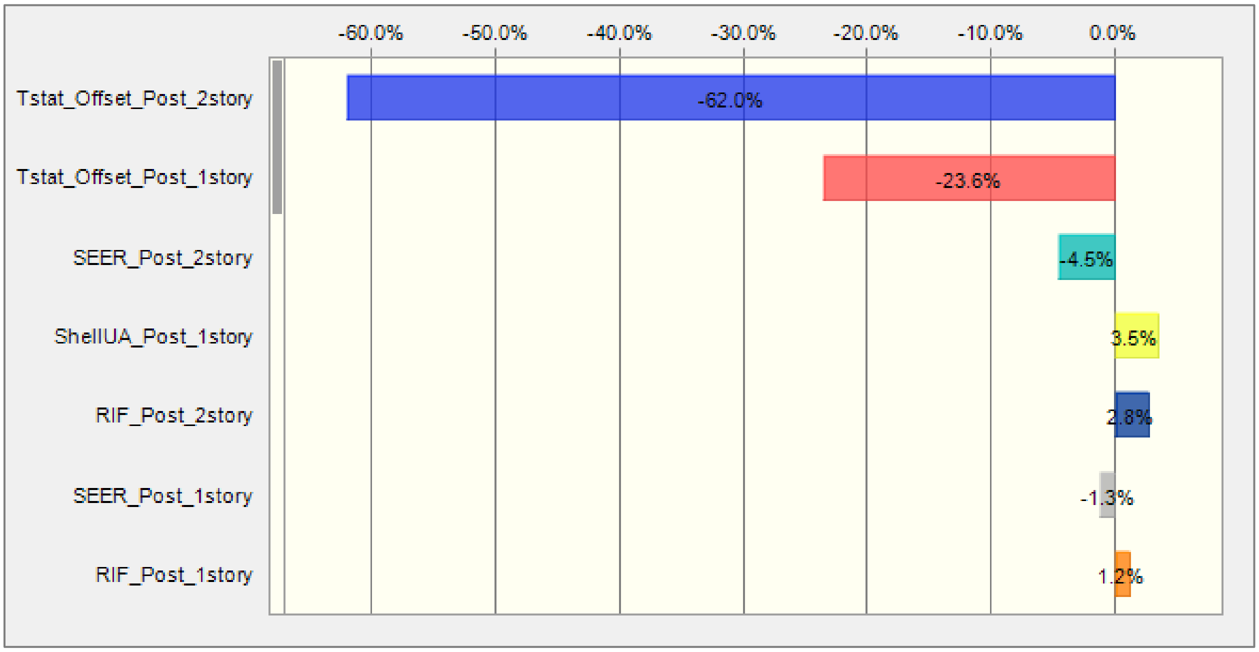


Figure 74. Distributions of Natural Gas Consumption in CZ05, therm/ton

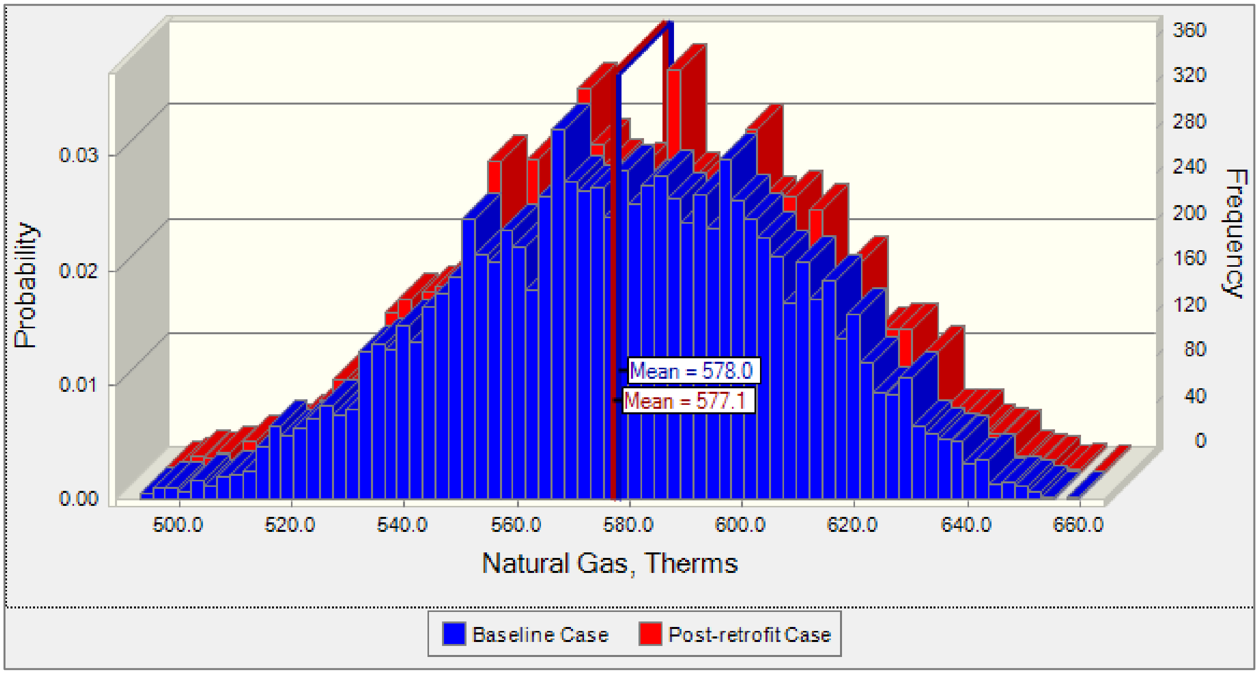


Table 56. Statistics for Natural Gas Consumption in CZ05, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	578.000	577.100
Median	578.800	577.600
Mode	565.000	556.000
Standard Deviation	30.100	30.000
Coefficient of Variation	0.052	0.052
Minimum	481.900	481.600
Maximum	659.800	659.500
Mean Standard Error	0.300	0.300

Figure 75. Sensitivities of Baseline Natural Gas Consumption in CZ05

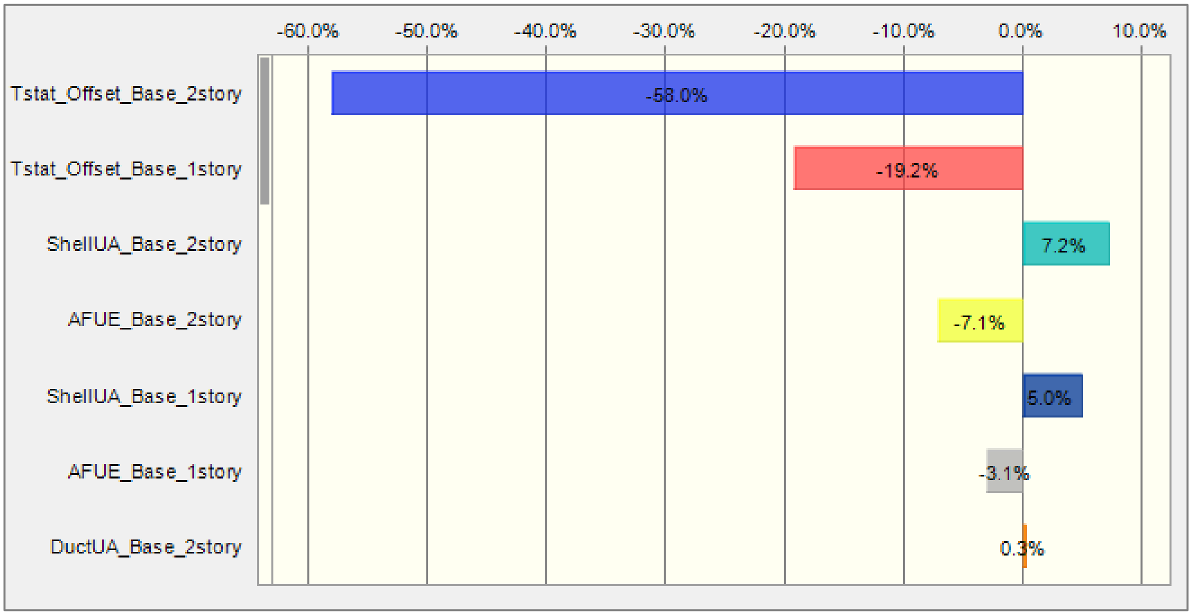
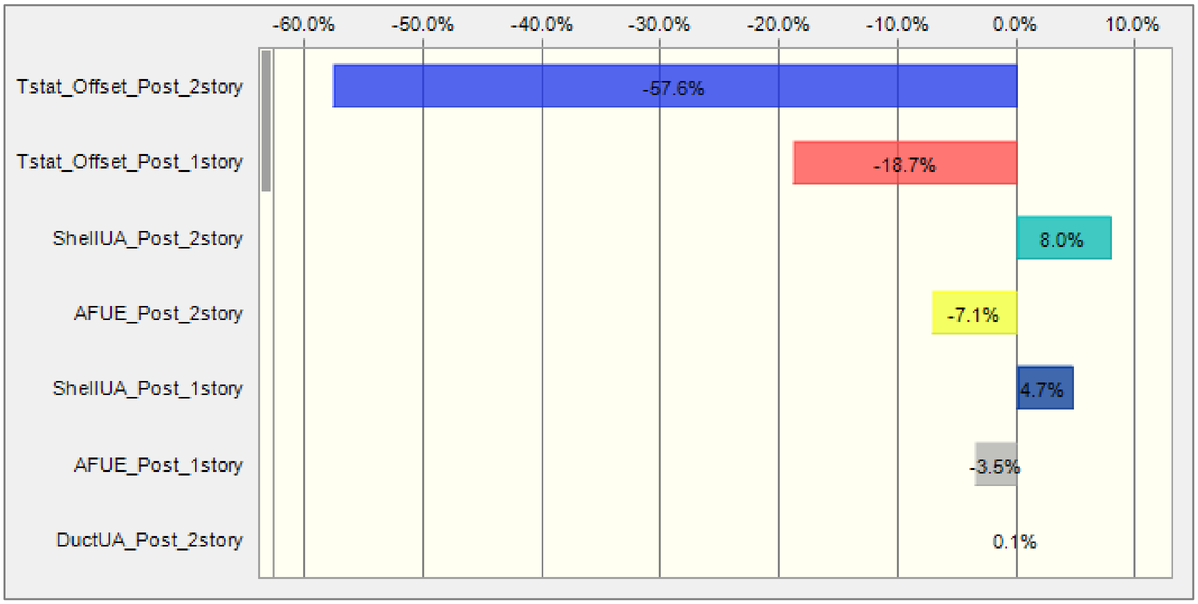


Figure 76. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ05



C.6 Climate Zone 11

Figure 77. Distributions of Annual Electric Energy in CZ11, kWh/ton

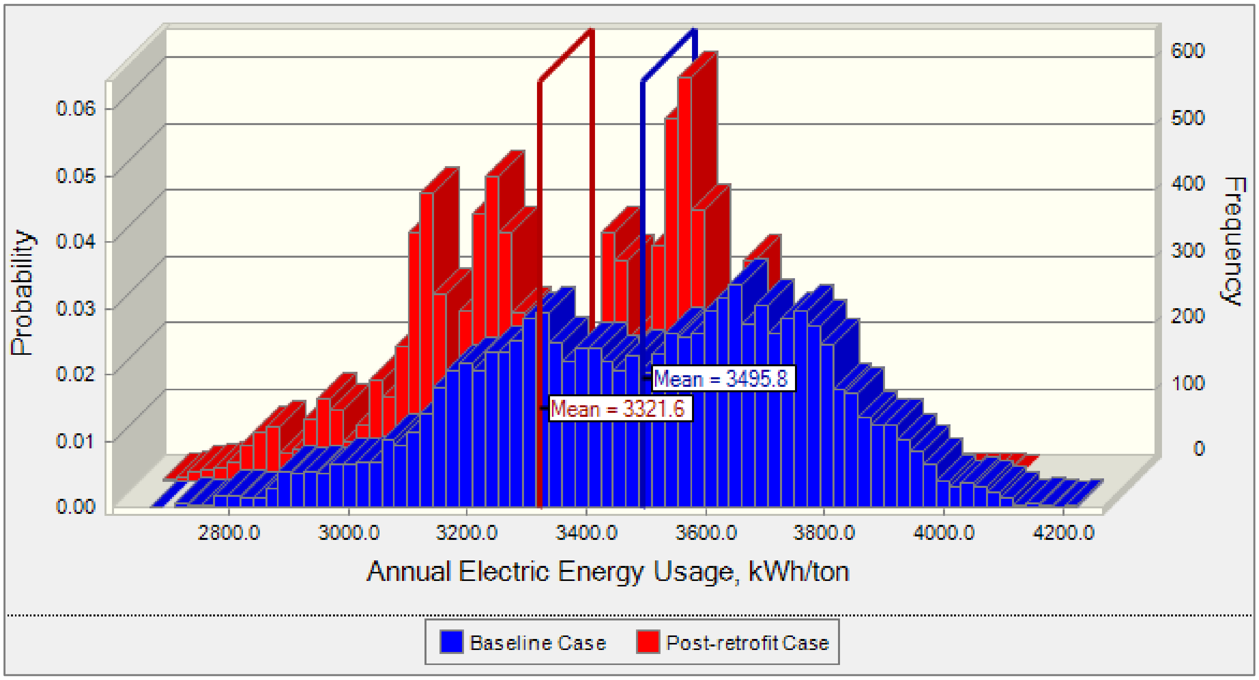


Table 57. Statistics for Annual Electric Energy in CZ11, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	3,496	3,322
Median	3,518	3,358
Mode	2,897	3,080
Standard Deviation	272.2	241.7
Coefficient of Variation	0.0779	0.0728
Minimum	2,674	2,596
Maximum	4,225	4,052
Mean Standard Error	2.7	2.4

Figure 78. Sensitivities of Baseline Annual Electric Energy in CZ11

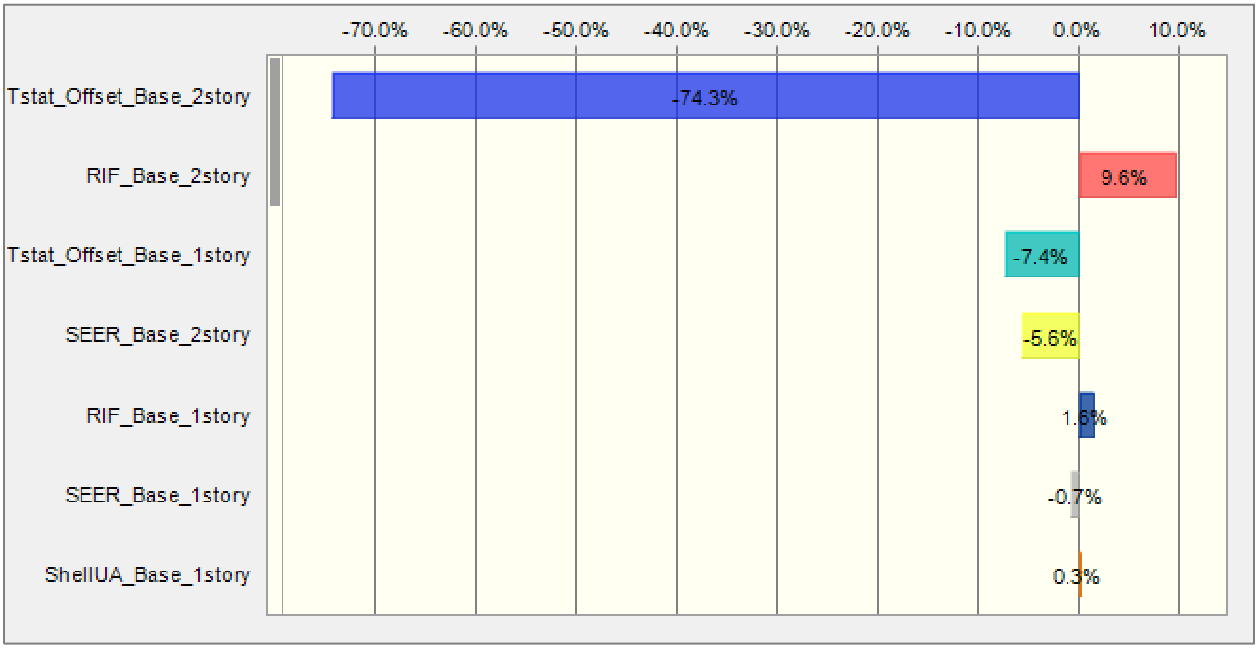


Figure 79. Sensitivities of Post-Retrofit Annual Electric Energy in CZ11

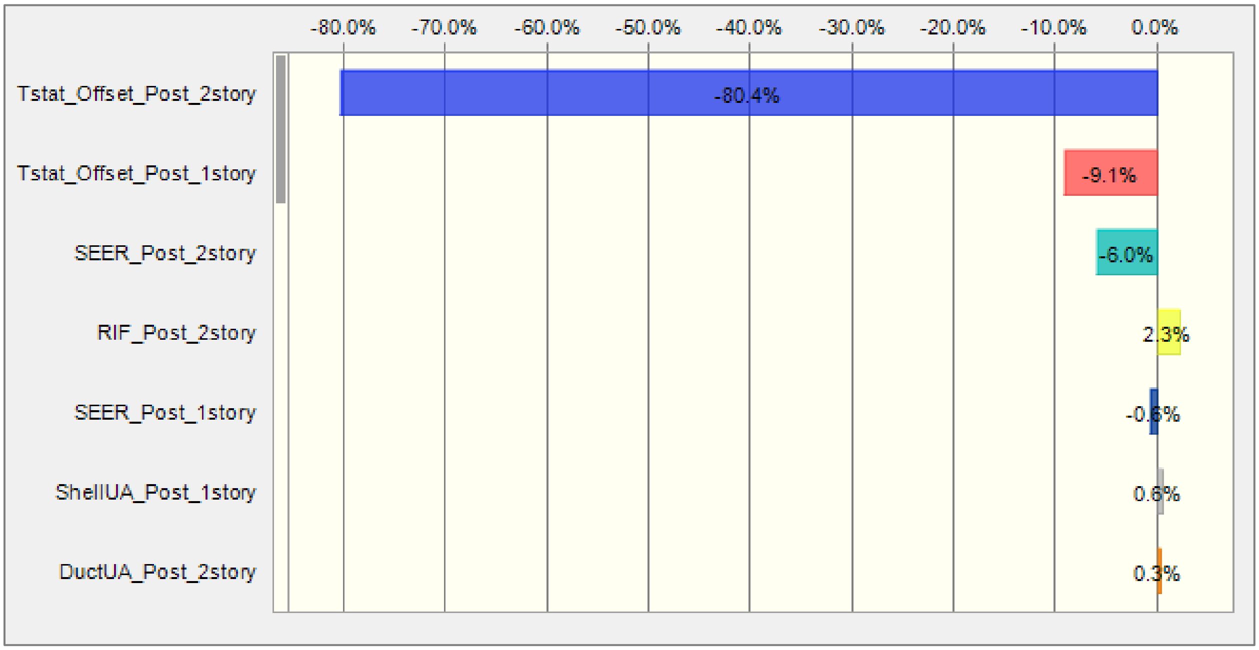


Figure 80. Distributions of Peak Demand in CZ11, kW/ton

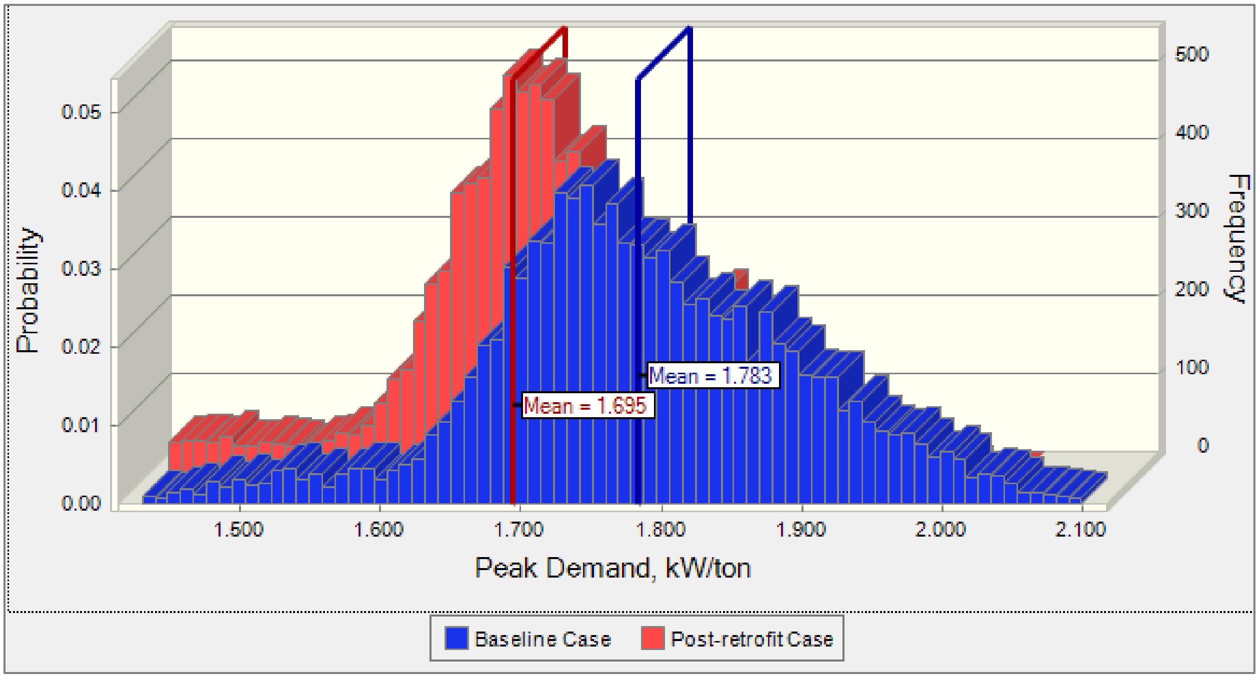


Table 58. Statistics for Peak Demand in CZ11, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	1.783	1.695
Median	1.775	1.695
Mode	1.701	1.718
Standard Deviation	0.113	0.094
Coefficient of Variation	0.063	0.056
Minimum	1.377	1.326
Maximum	2.146	2.034
Mean Standard Error	0.001	0.001

Figure 81. Sensitivities of Baseline Peak Demand in CZ11

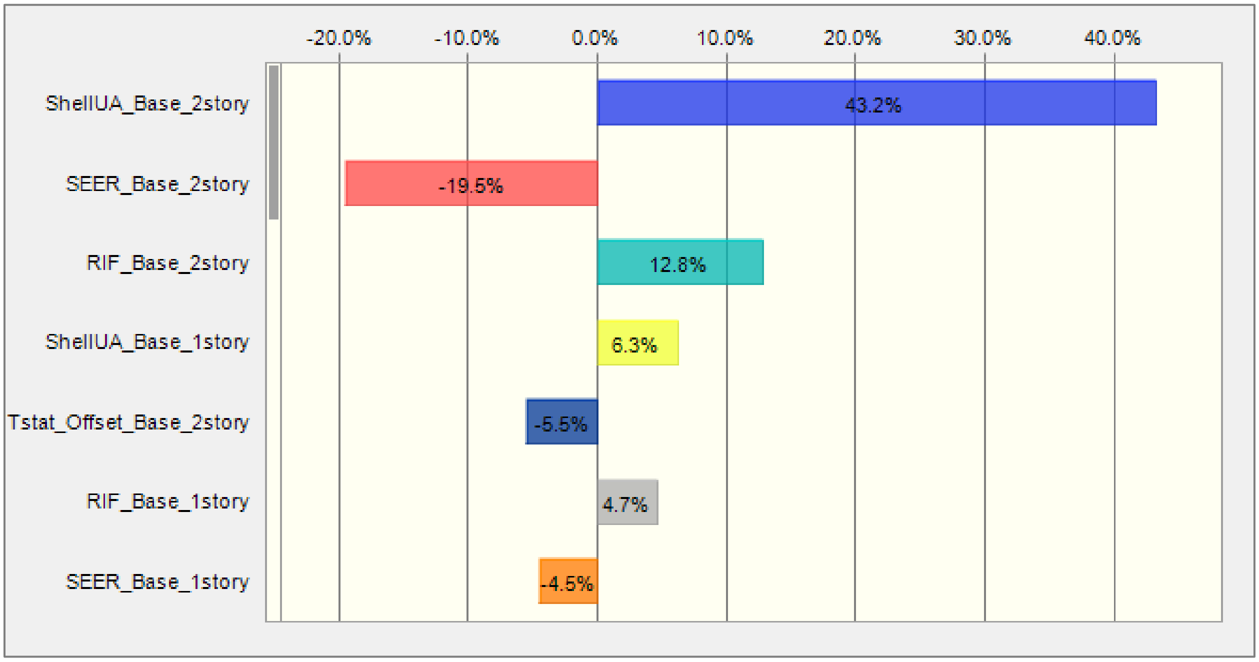


Figure 82. Sensitivities of Post-Retrofit Peak Demand in CZ11

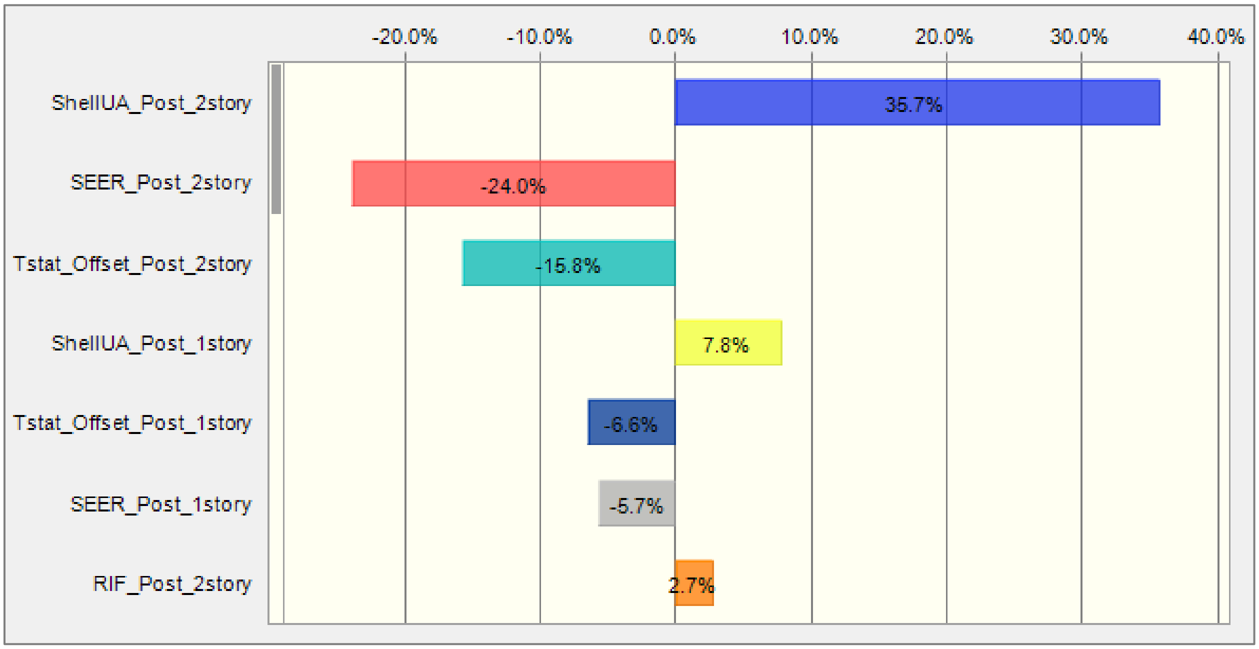


Figure 83. Distributions of Natural Gas Consumption in CZ11, therm/ton

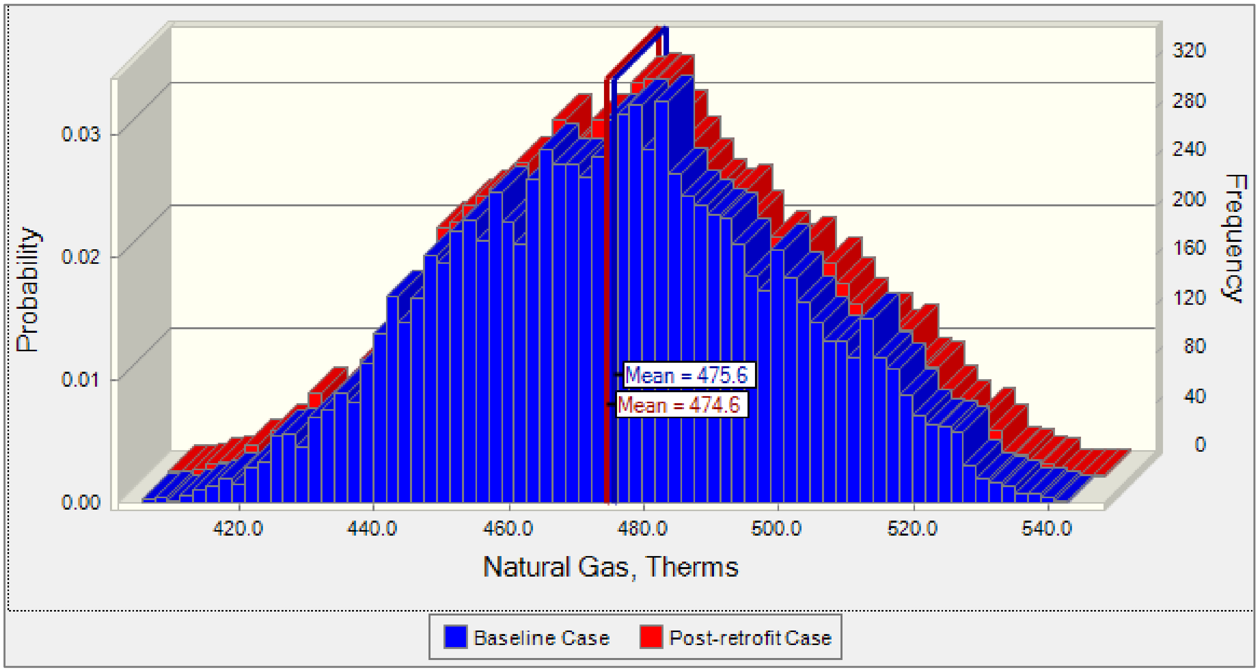


Table 59. Statistics for Natural Gas Consumption in CZ11, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	475.600	474.600
Median	475.700	474.500
Mode	476.900	502.700
Standard Deviation	24.600	24.700
Coefficient of Variation	0.052	0.052
Minimum	401.800	401.100
Maximum	544.800	543.000
Mean Standard Error	0.200	0.200

Figure 84. Sensitivities of Baseline Natural Gas Consumption in CZ11

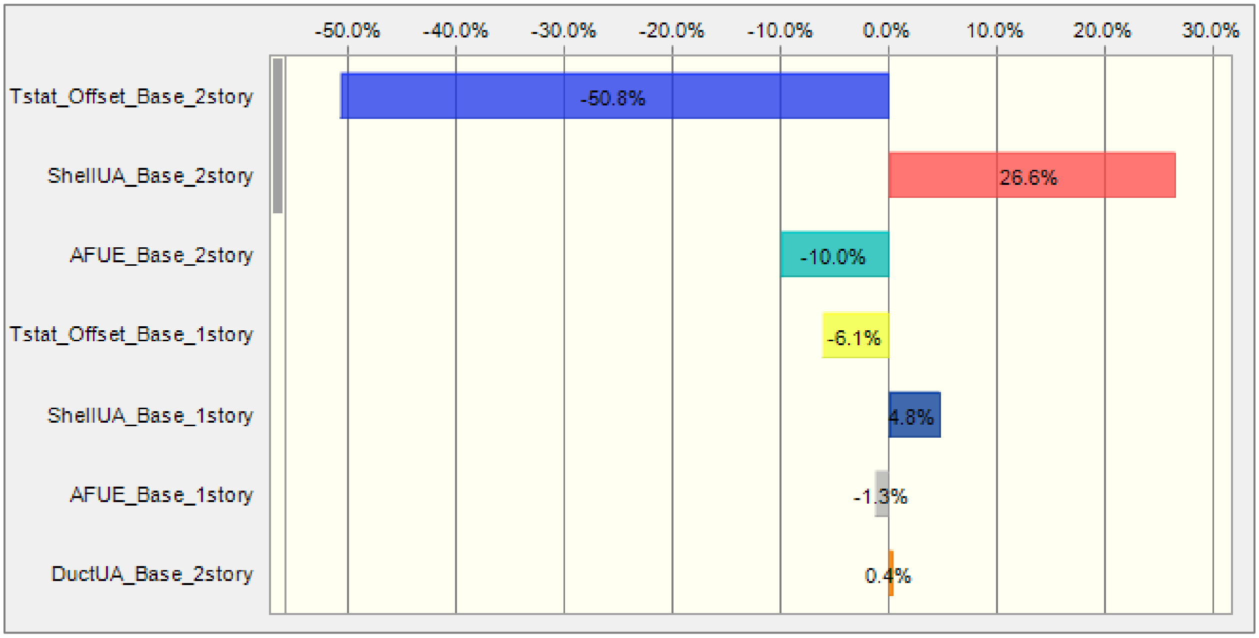
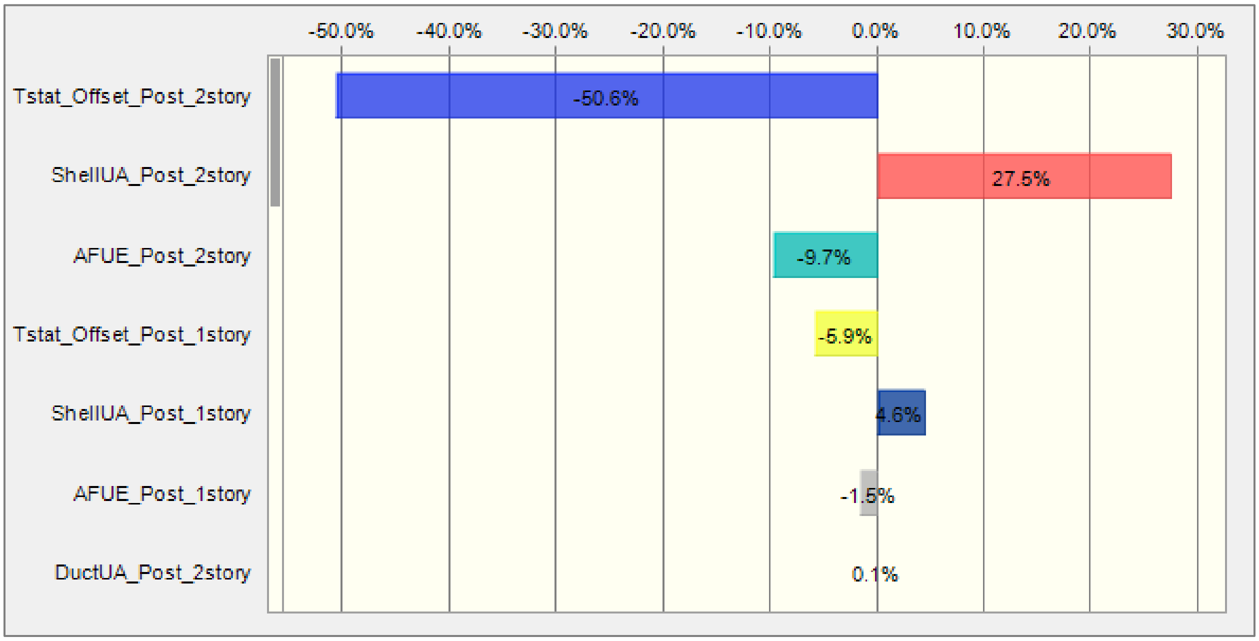


Figure 85. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ11



C.7 Climate Zone 12

Figure 86. Distributions of Annual Electric Energy in CZ12, kWh/ton

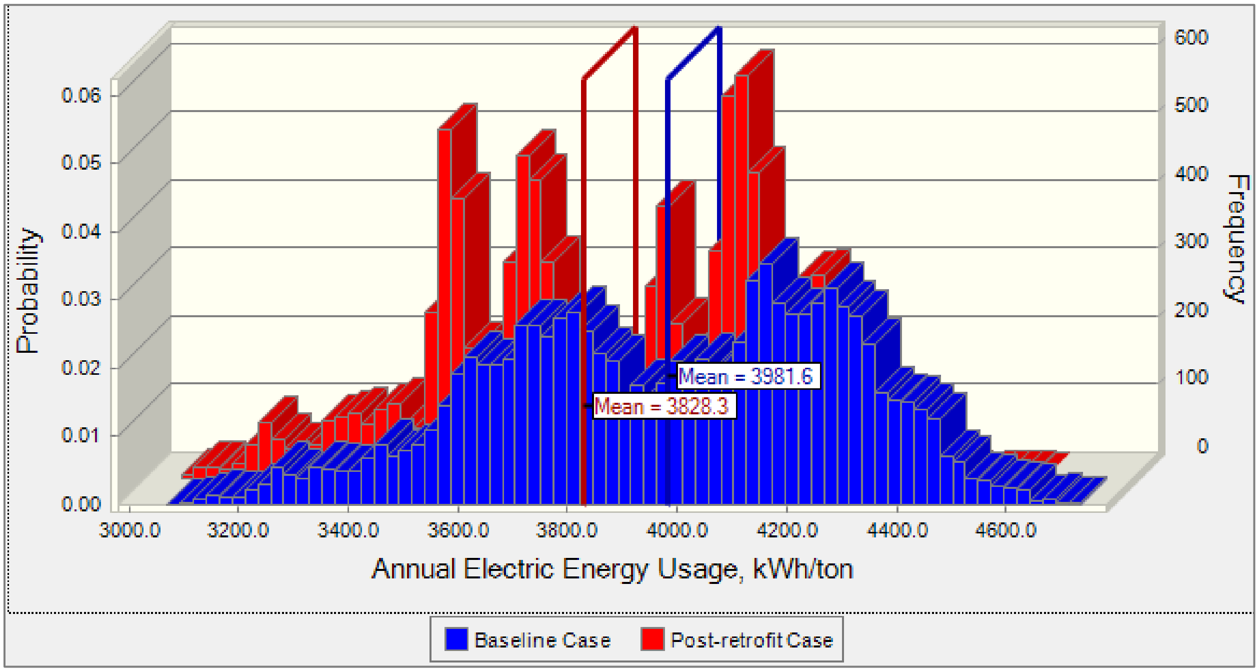


Table 60. Statistics for Annual Electric Energy in CZ12, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	3,982	3,828
Median	4,010	3,880
Mode	4,117	3,533
Standard Deviation	314.8	287.3
Coefficient of Variation	0.0791	0.0751
Minimum	3,087	2,993
Maximum	4,737	4,599
Mean Standard Error	3.1	2.9

Figure 87. Sensitivities of Baseline Annual Electric Energy in CZ12, kWh/ton

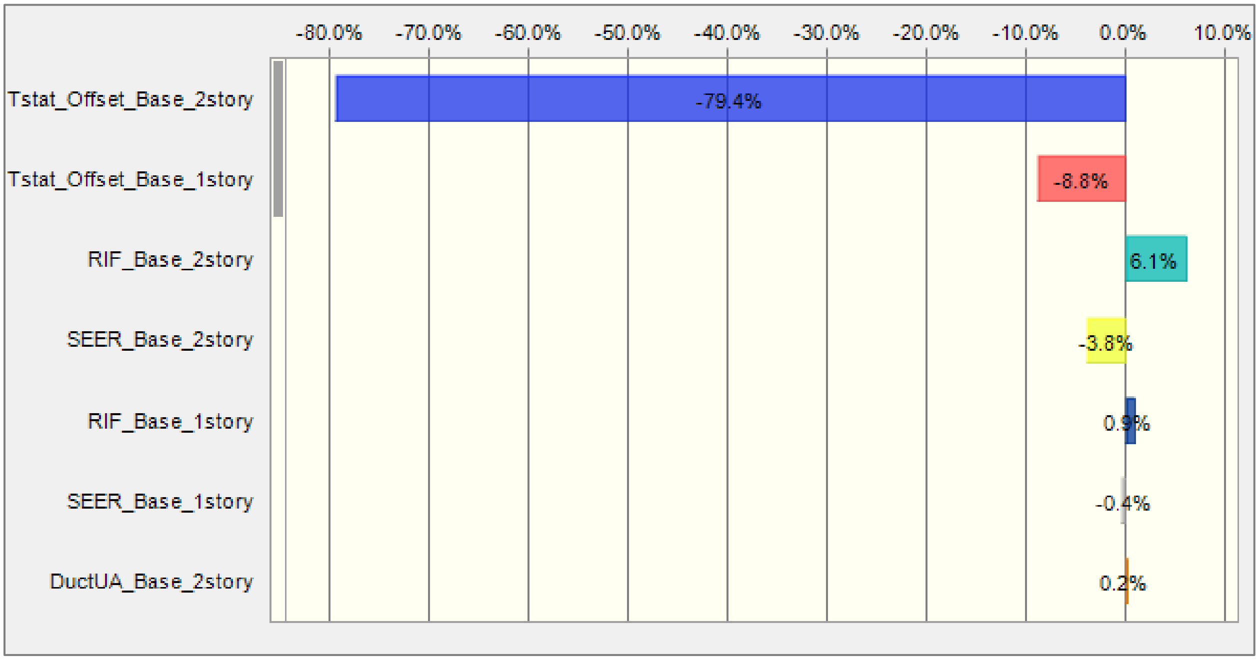


Figure 88. Sensitivities of Post-Retrofit Annual Electric Energy in CZ12, kWh/ton

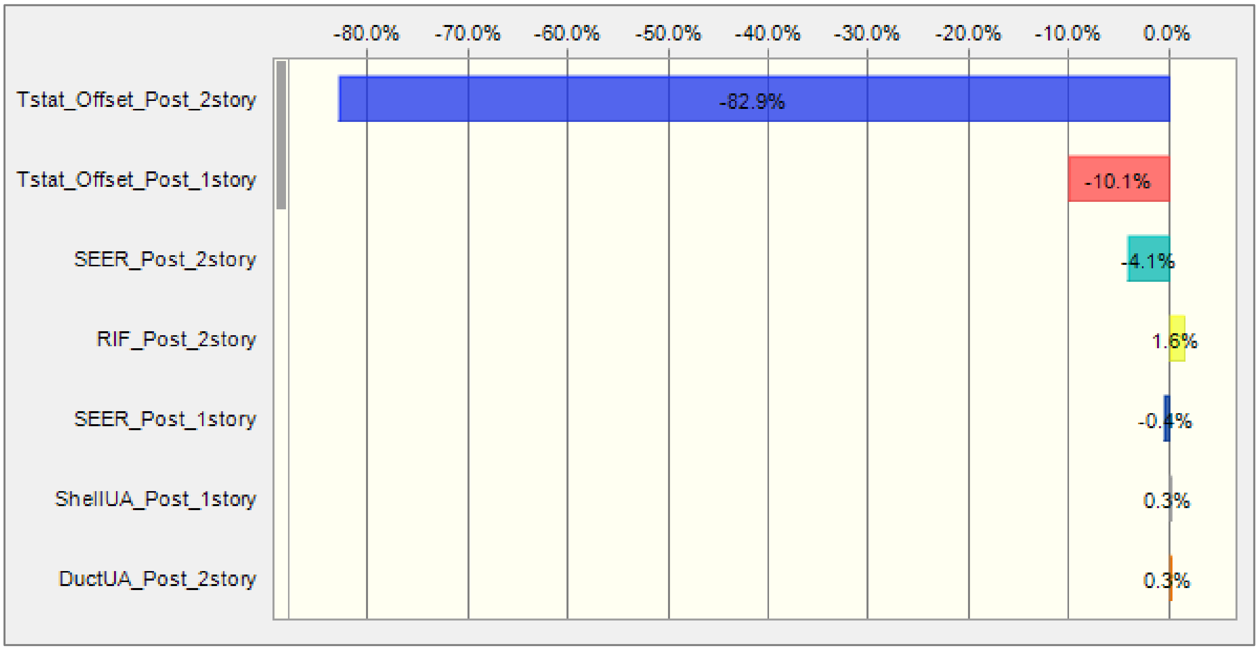


Figure 89. Distributions of Peak Demand in CZ12, kW/ton

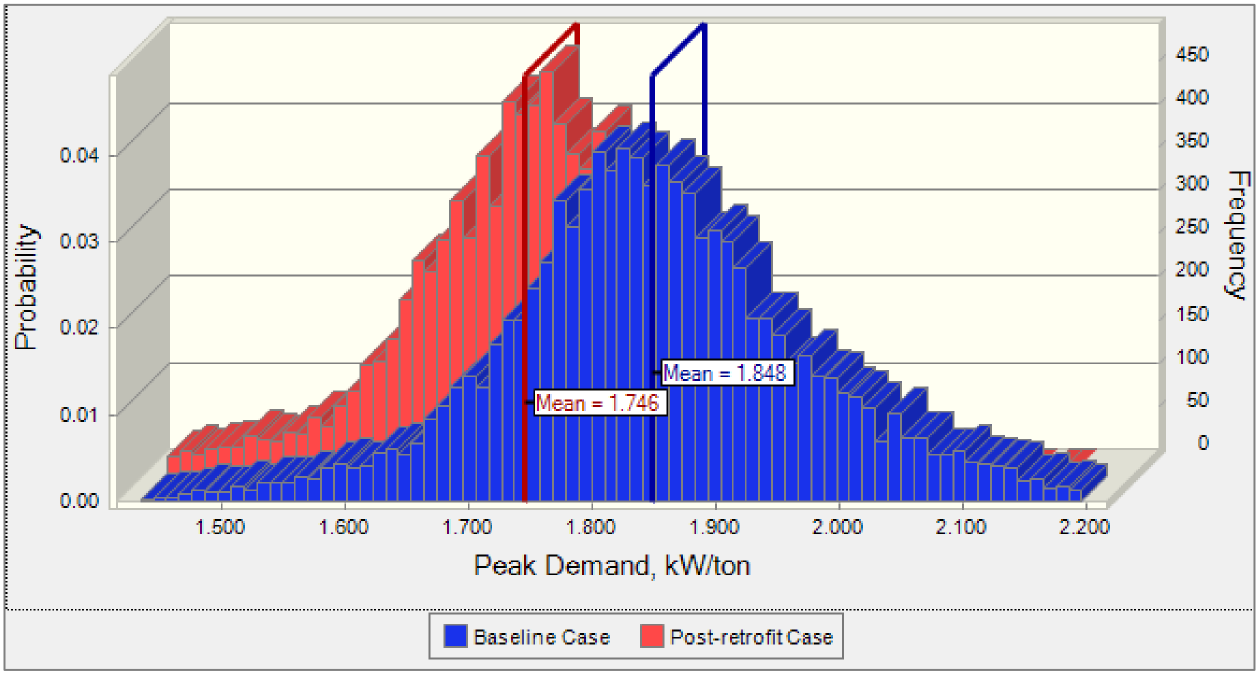


Table 61. Statistics for Peak Demand in CZ12, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	1.848	1.746
Median	1.843	1.745
Mode	1.851	1.664
Standard Deviation	0.124	0.111
Coefficient of Variation	0.067	0.064
Minimum	1.372	1.340
Maximum	2.305	2.160
Mean Standard Error	0.001	0.001

Figure 90. Sensitivities of Baseline Peak Demand in CZ12

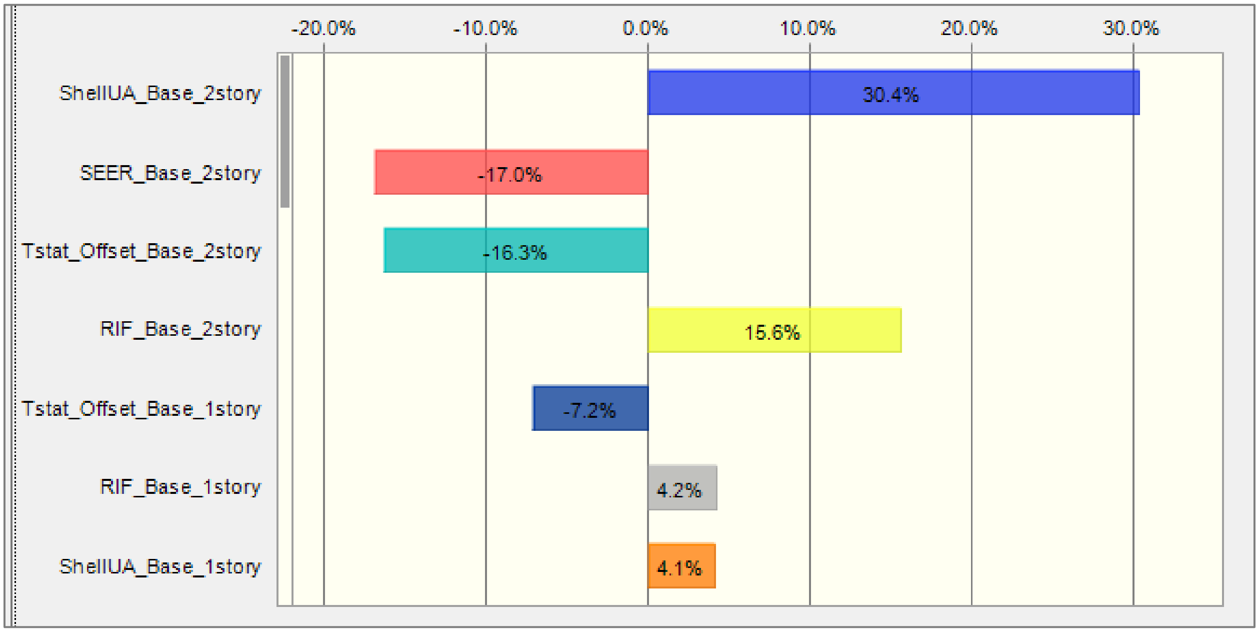


Figure 91. Sensitivities of Post-Retrofit Peak Demand in CZ12

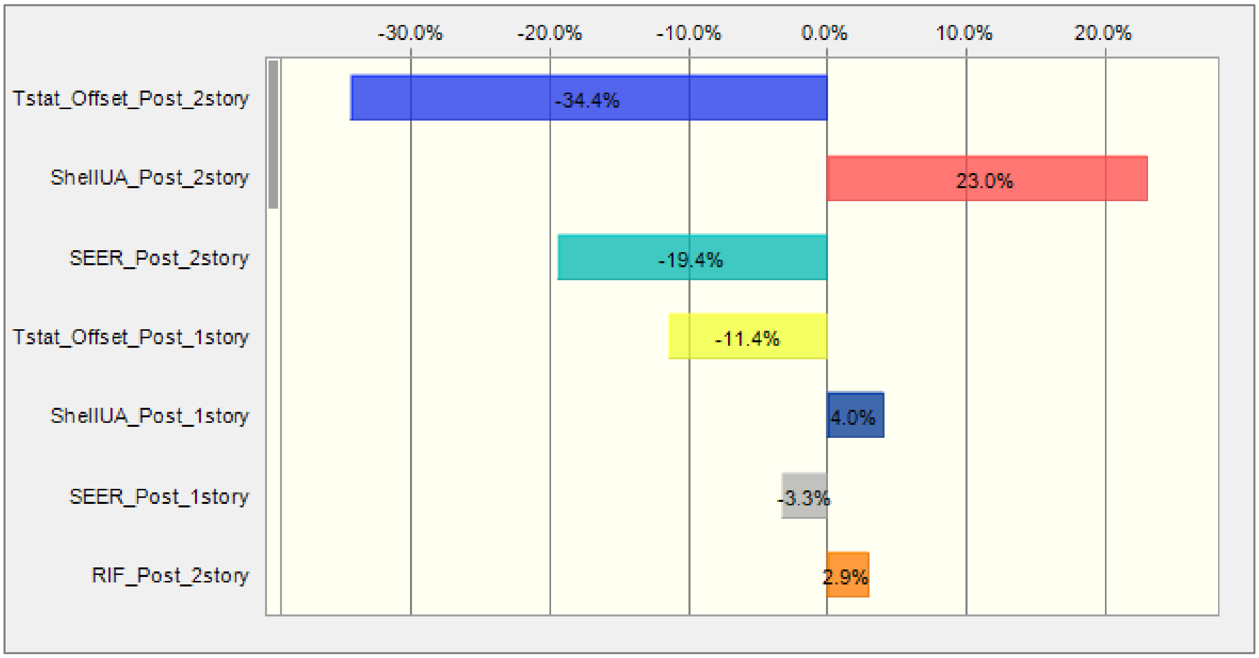


Figure 92. Distributions of Natural Gas Consumption in CZ12, therm/ton

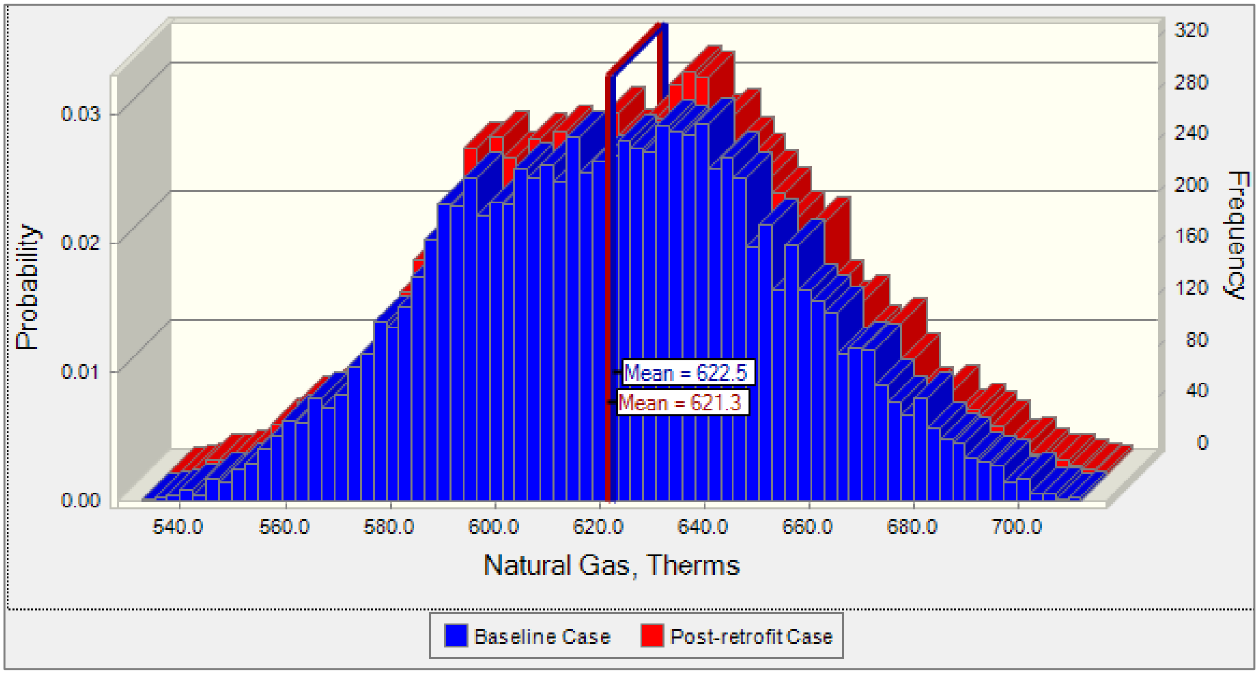


Table 62. Statistics for Natural Gas Consumption in CZ12, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	622.500	621.300
Median	622.800	621.900
Mode	595.400	580.100
Standard Deviation	31.900	31.700
Coefficient of Variation	0.051	0.051
Minimum	529.400	528.600
Maximum	715.700	717.000
Mean Standard Error	0.300	0.300

Figure 93. Sensitivities of Baseline Natural Gas Consumption in CZ12

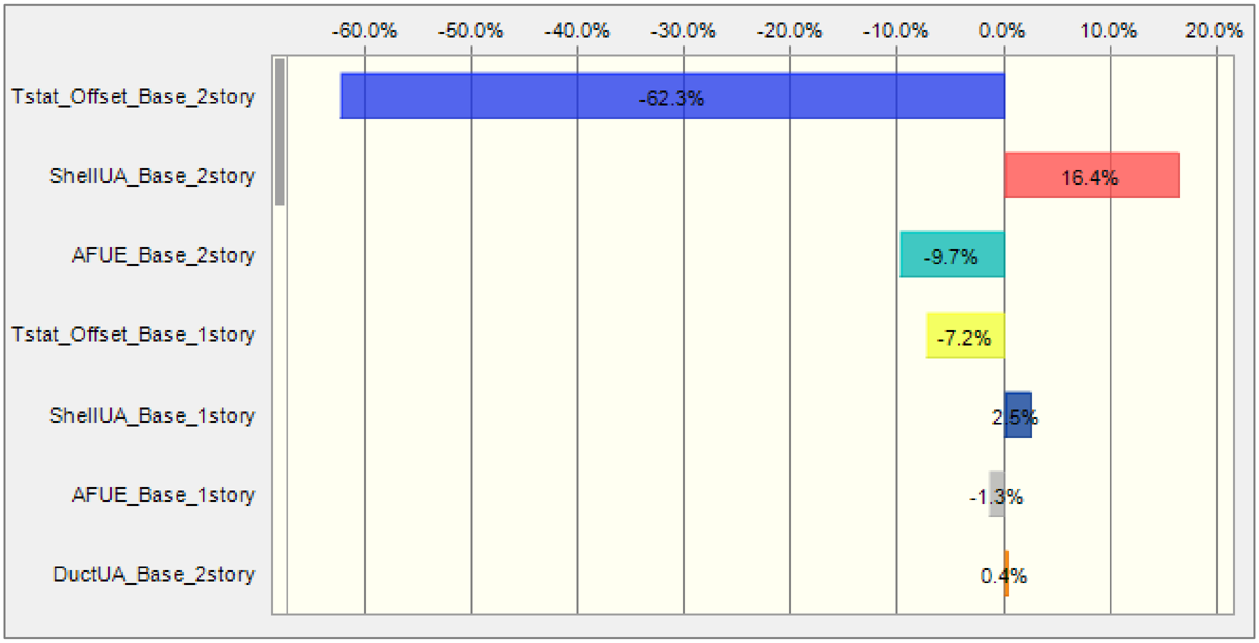
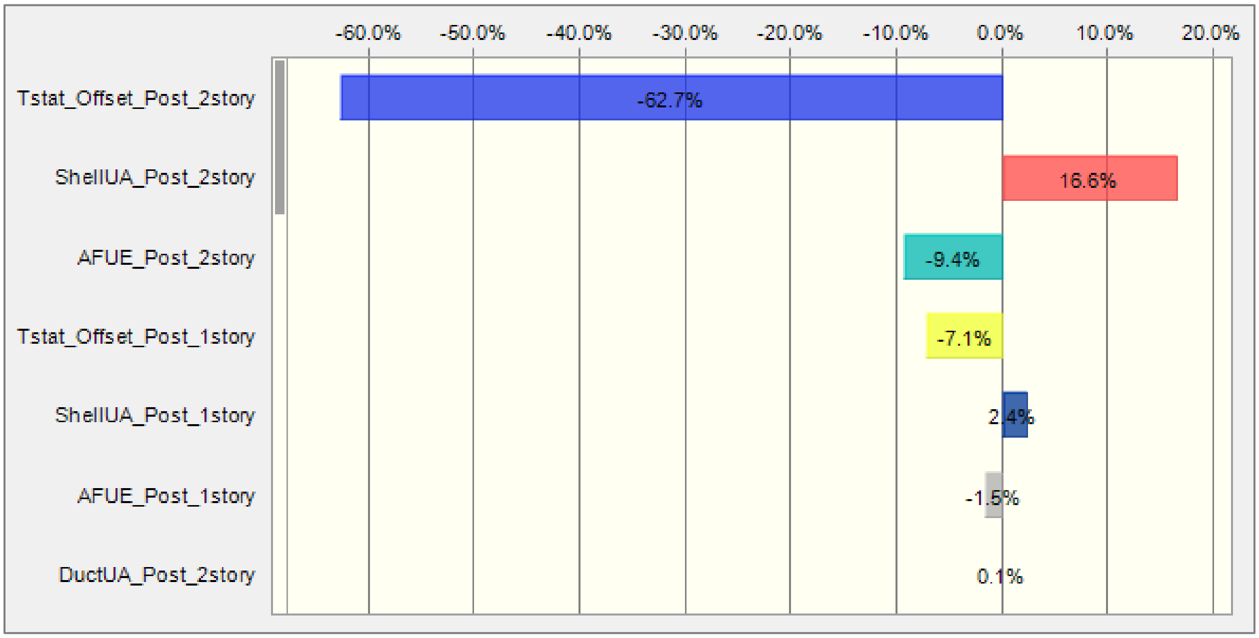


Figure 94. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ12



C.8 Climate Zone 13

Figure 95. Distributions of Annual Electric Energy in CZ13, kWh/ton

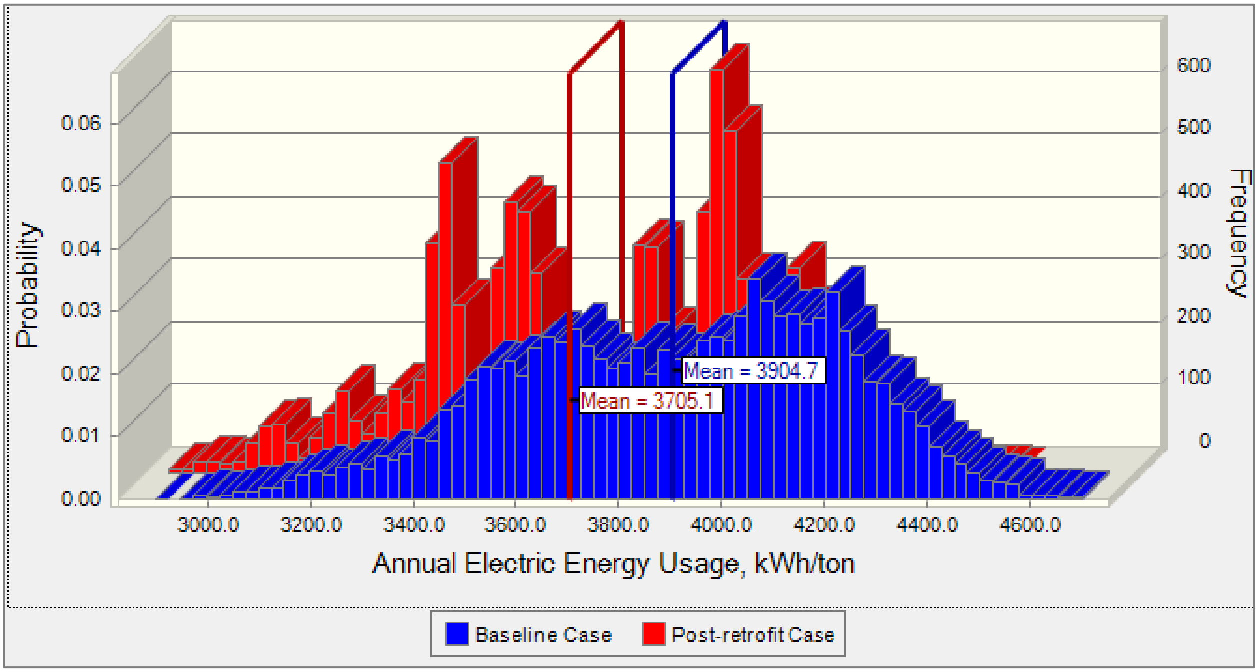


Table 63. Statistics for Annual Electric Energy in CZ13, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	3,904.7	3,705.1
Median	3,934.8	3,758.2
Mode	3,198.9	3,404.2
Standard Deviation	315.5	297.6
Coefficient of Variation	0.0808	0.0803
Minimum	2,921.6	2,786.5
Maximum	4,703.4	4,503.0
Mean Standard Error	3.2	3.0

Figure 96. Sensitivities of Baseline Annual Electric Energy in CZ13

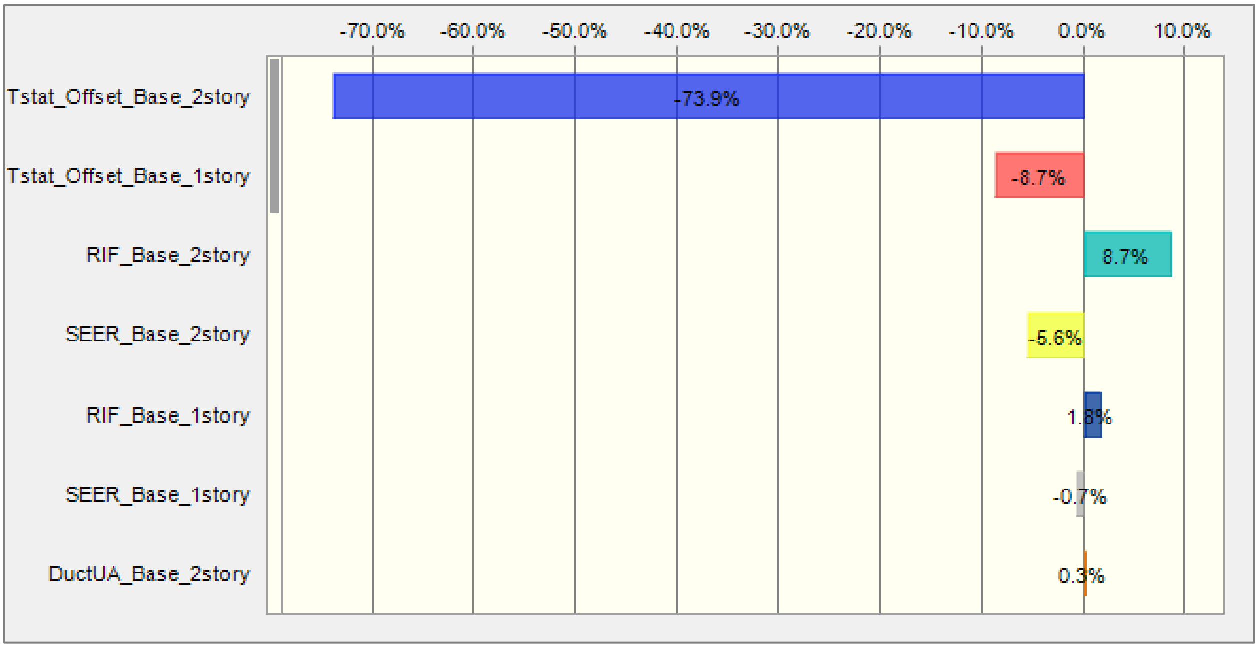


Figure 97. Sensitivities of Post-Retrofit Annual Electric Energy in CZ13

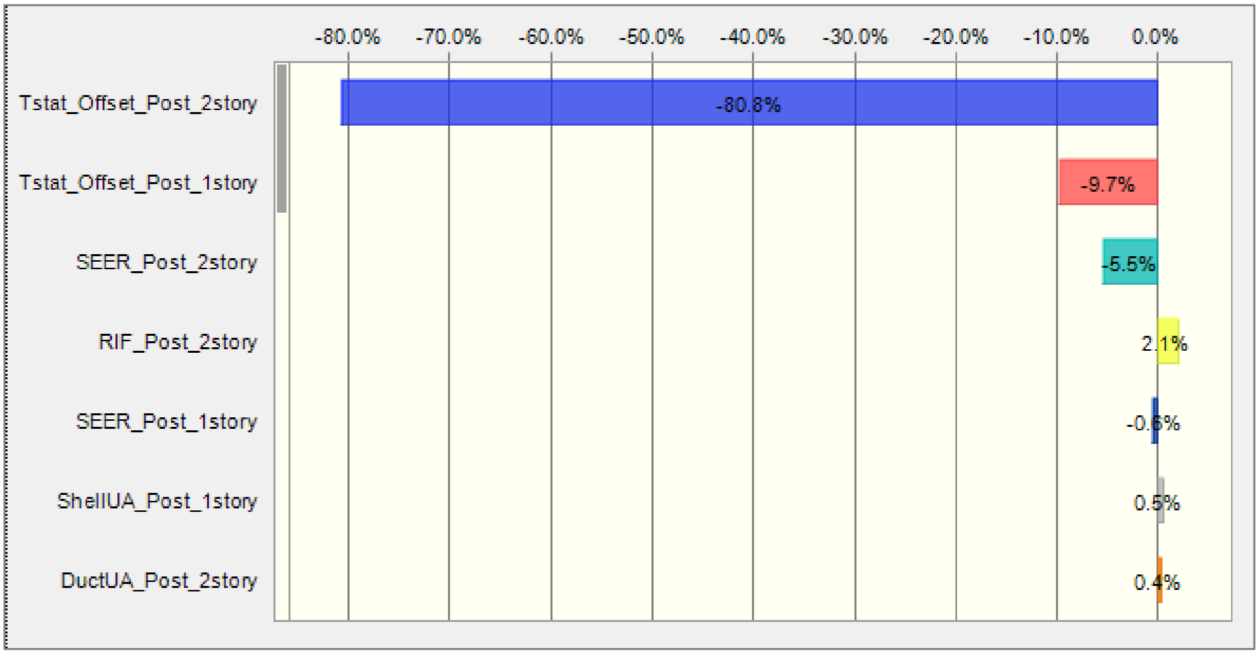


Figure 98. Distributions of Peak Demand in CZ13, kW/ton

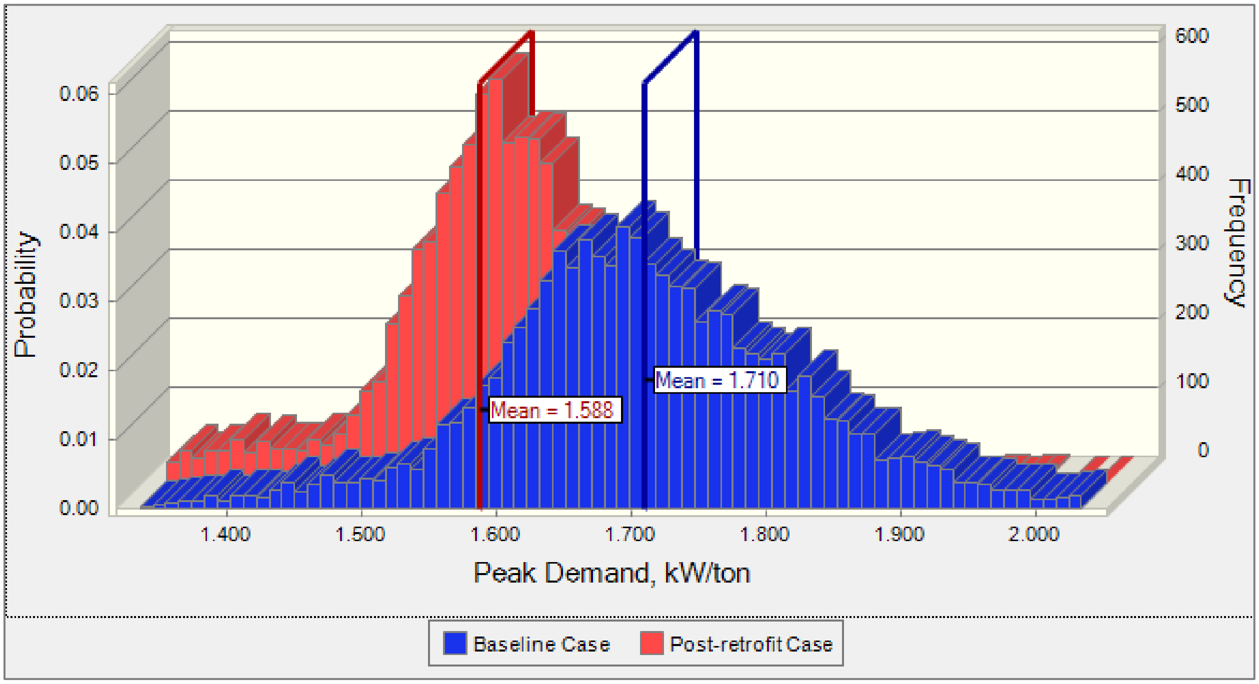


Table 64. Statistics for Peak Demand in CZ13, kW/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	1.710	1.588
Median	1.703	1.587
Mode	1.626	1.540
Standard Deviation	0.116	0.090
Coefficient of Variation	0.068	0.057
Minimum	1.279	1.254
Maximum	2.147	2.033
Mean Standard Error	0.001	0.001

Figure 99. Sensitivities of Baseline Peak Demand in CZ13

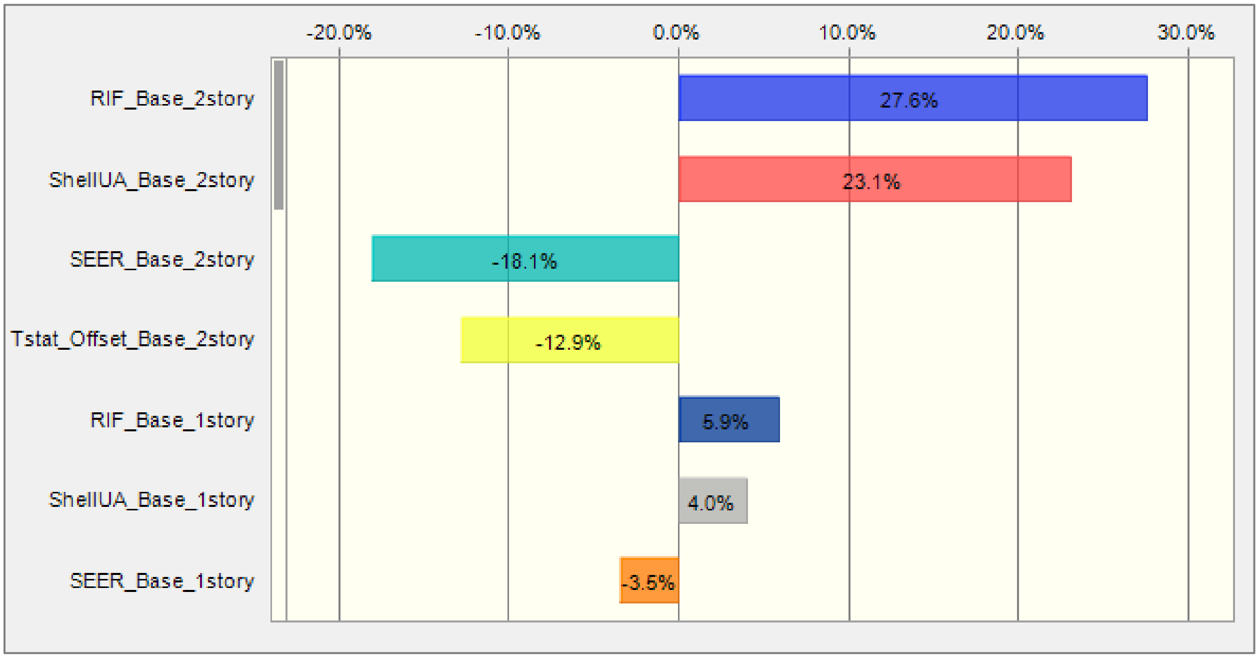


Figure 100. Sensitivities of Post-Retrofit Peak Demand in CZ13

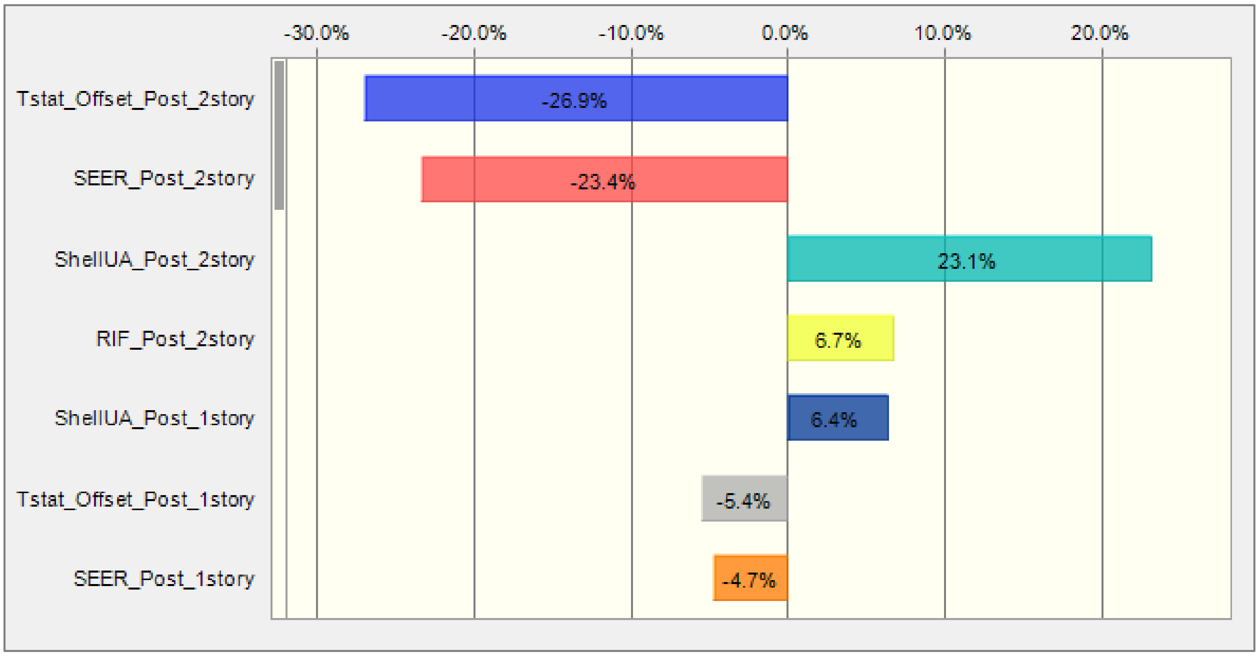


Figure 101. Distributions of Natural Gas Consumption in CZ13, therm/ton

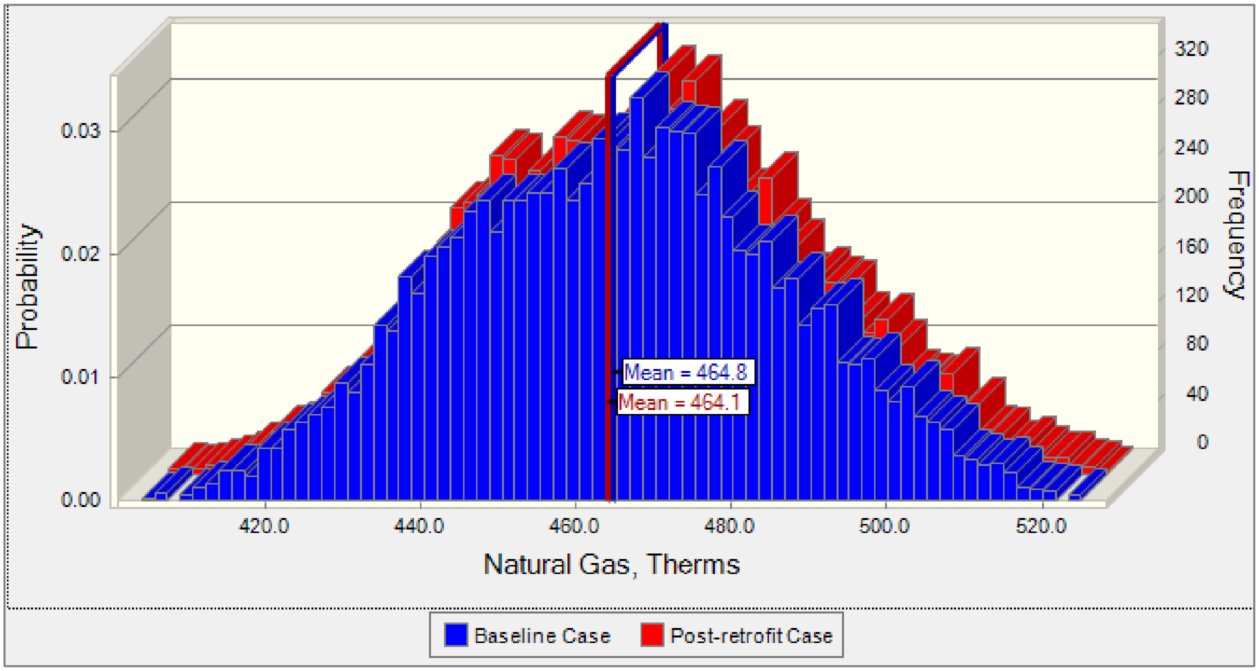


Table 65. Statistics for Natural Gas Consumption in CZ13, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	464.800	464.100
Median	465.100	464.200
Mode	442.500	444.900
Standard Deviation	21.500	21.500
Coefficient of Variation	0.046	0.046
Minimum	400.900	400.400
Maximum	526.900	527.900
Mean Standard Error	0.200	0.200

Figure 102. Sensitivities of Baseline Natural Gas Consumption in CZ13

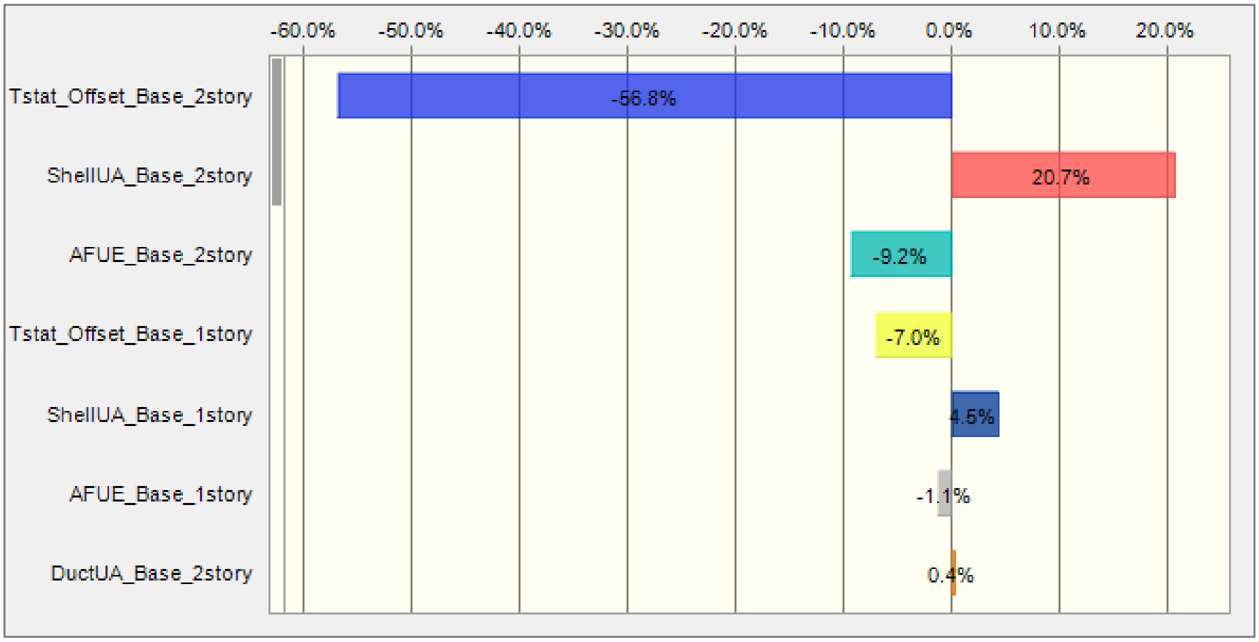
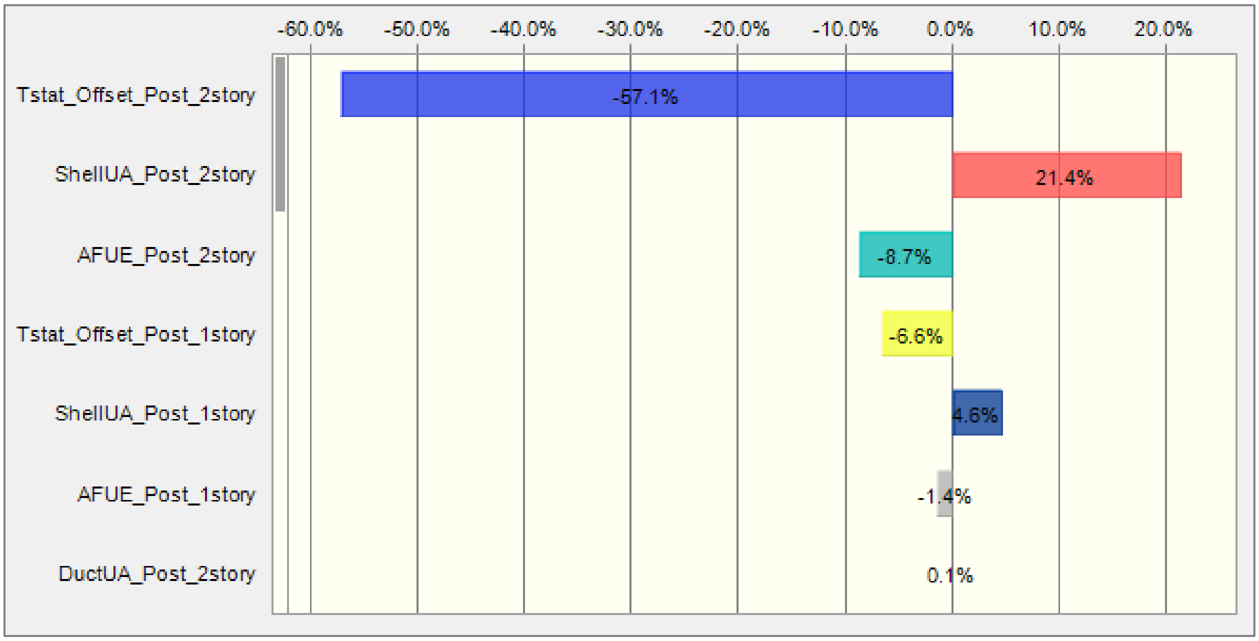


Figure 103. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ13



C.9 Climate Zone 16

Figure 104. Distributions of Annual Electric Energy in CZ16, kWh/ton

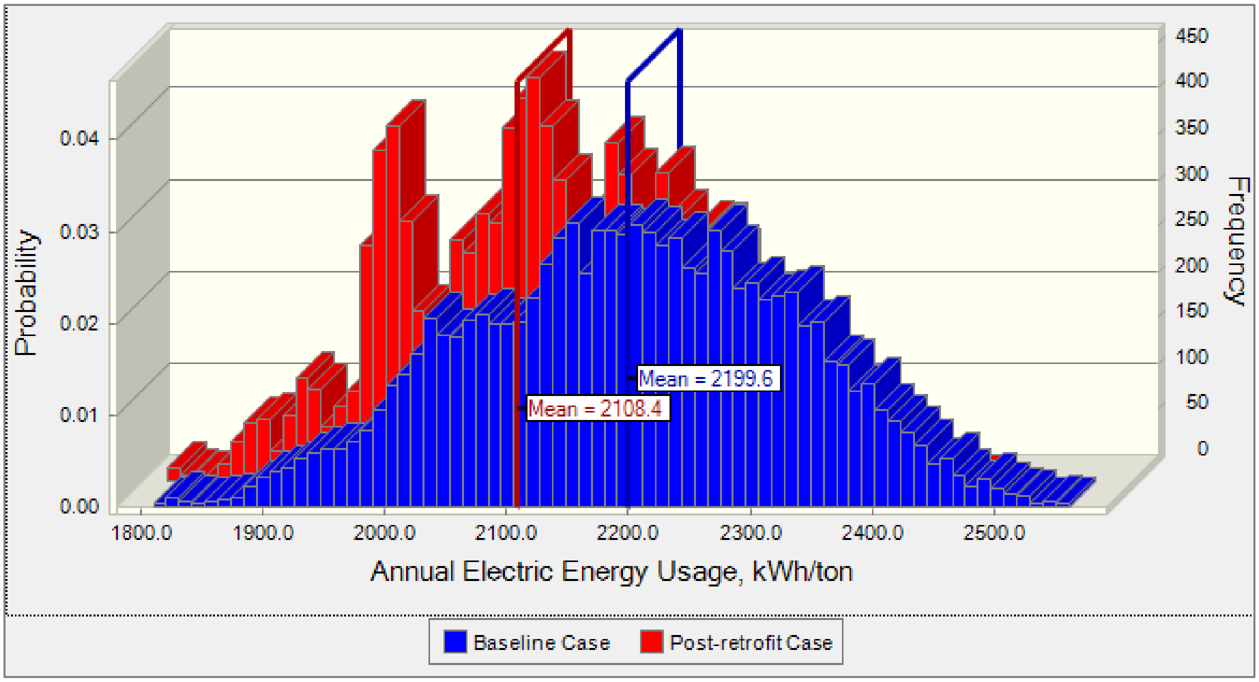


Table 66. Statistics for Annual Electric Energy in CZ16, kWh/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	2,200	2,108
Median	2,202	2,110
Mode	1,904	1,981
Standard Deviation	133	110
Coefficient of Variation	0.06	0.05
Minimum	1,798	1,767
Maximum	2,620	2,458
Mean Standard Error	1	1

Figure 105. Sensitivities of Baseline Annual Electric Energy in CZ16

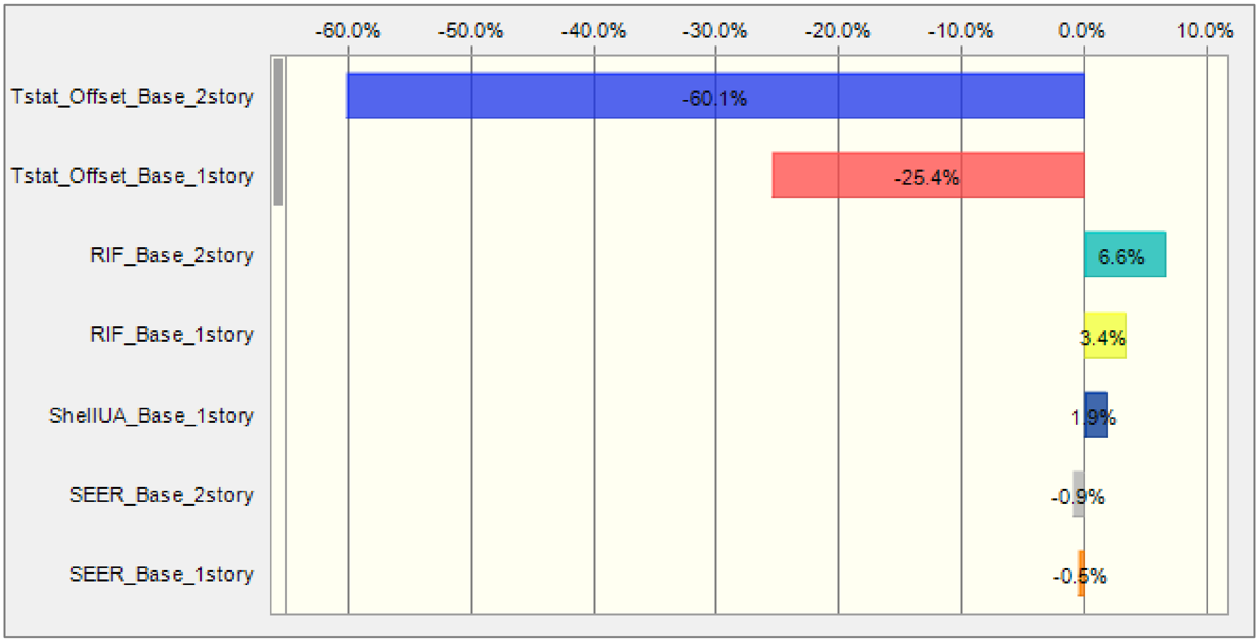


Figure 106. Sensitivities of Post-Retrofit Annual Electric Energy in CZ16

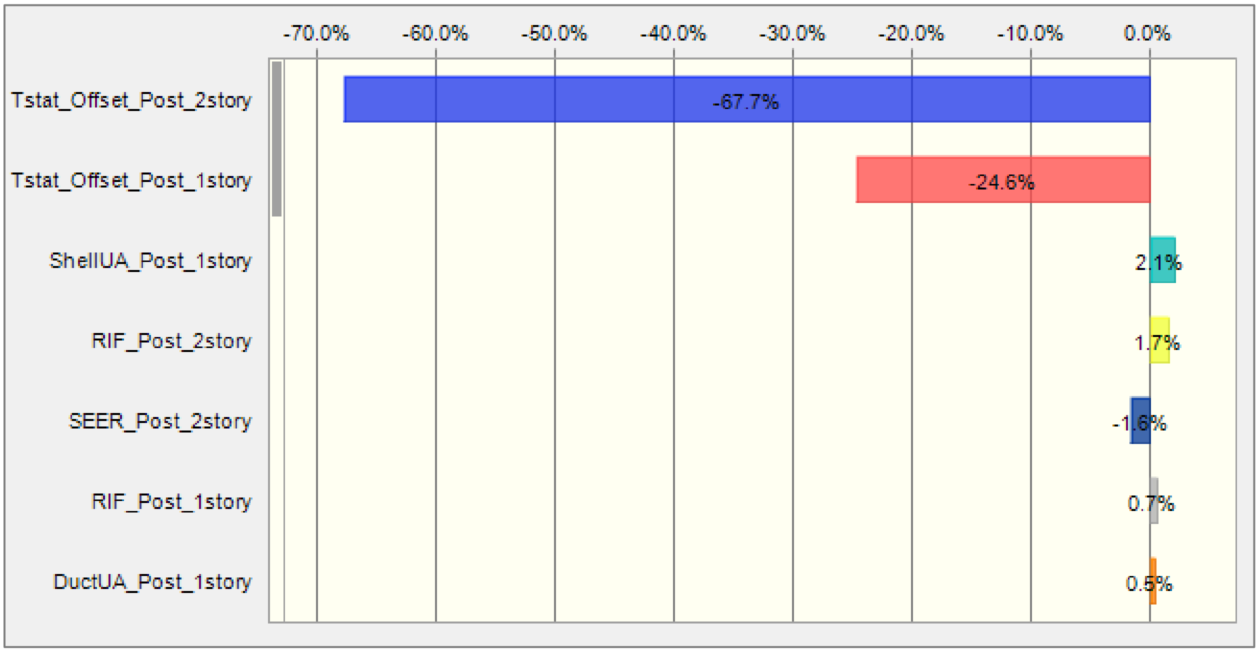


Figure 107. Distributions of Peak Demand in CZ16, kW/ton

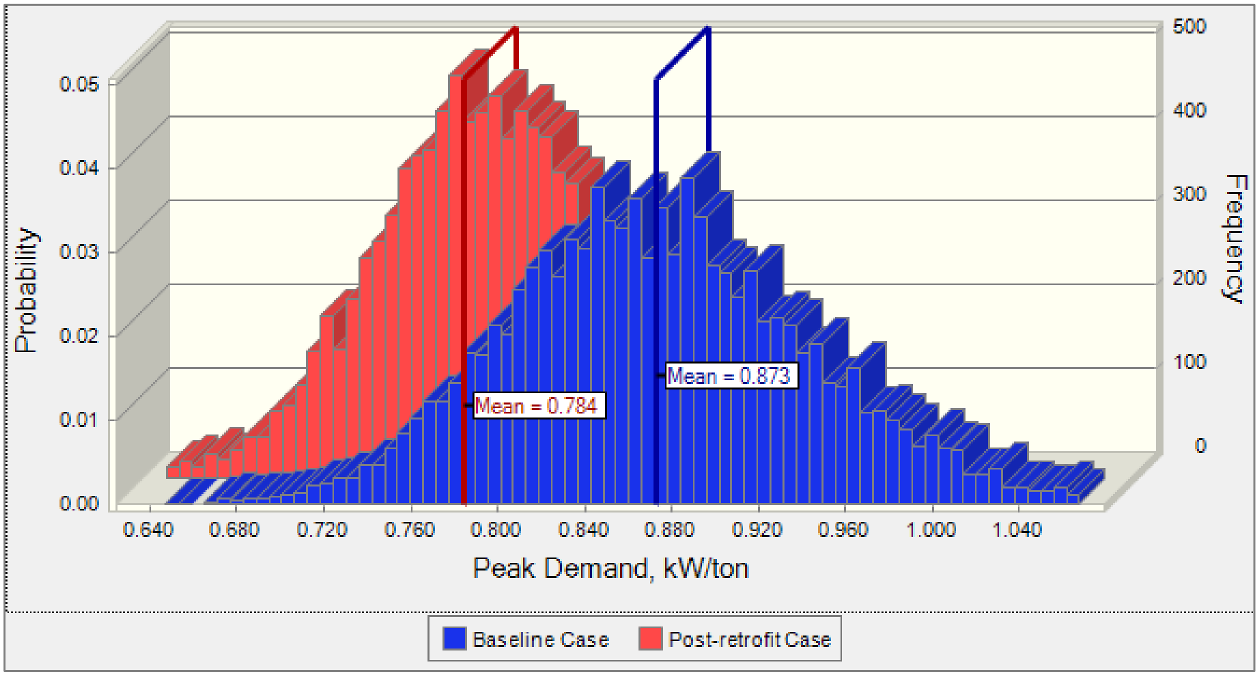


Table 67. Statistics for Peak Demand per Ton, CZ16

Statistic	Baseline Case	Post-Retrofit Case
Mean	0.873	0.784
Median	0.870	0.783
Mode	0.778	0.740
Standard Deviation	0.070	0.053
Coefficient of Variation	0.080	0.068
Minimum	0.630	0.571
Maximum	1.147	1.003
Mean Standard Error	0.001	0.001

Figure 108. Sensitivities of Baseline Peak Demand in CZ16

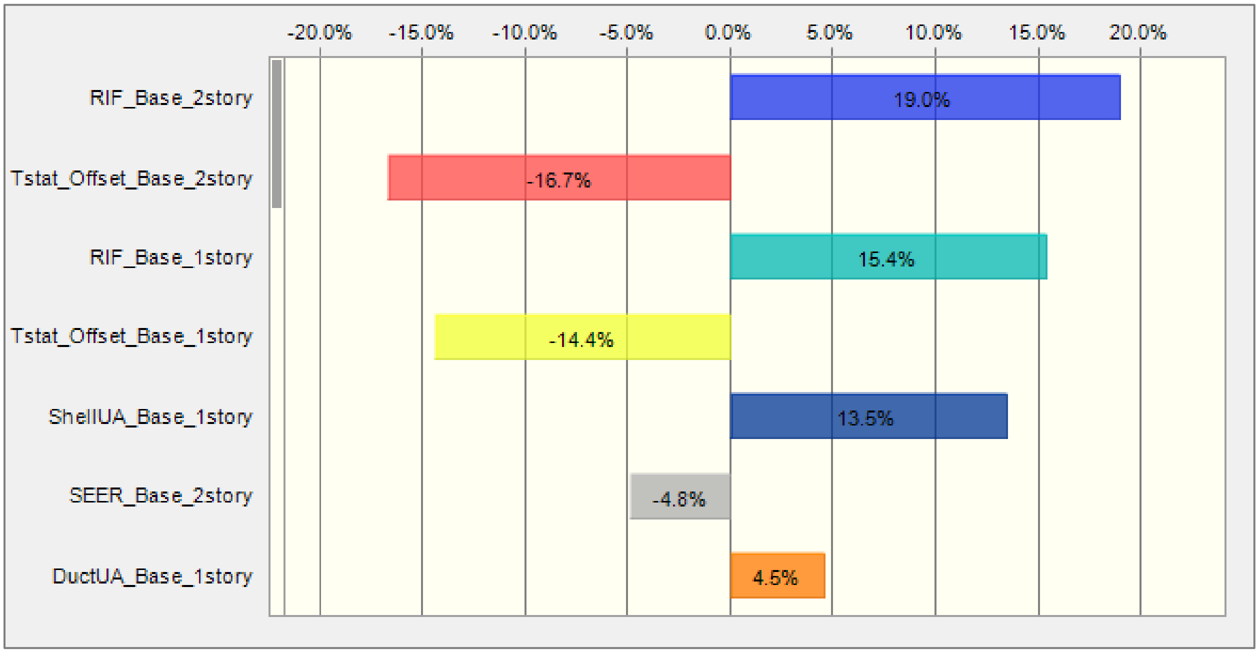


Figure 109. Sensitivities of Post-Retrofit Peak Demand in CZ16

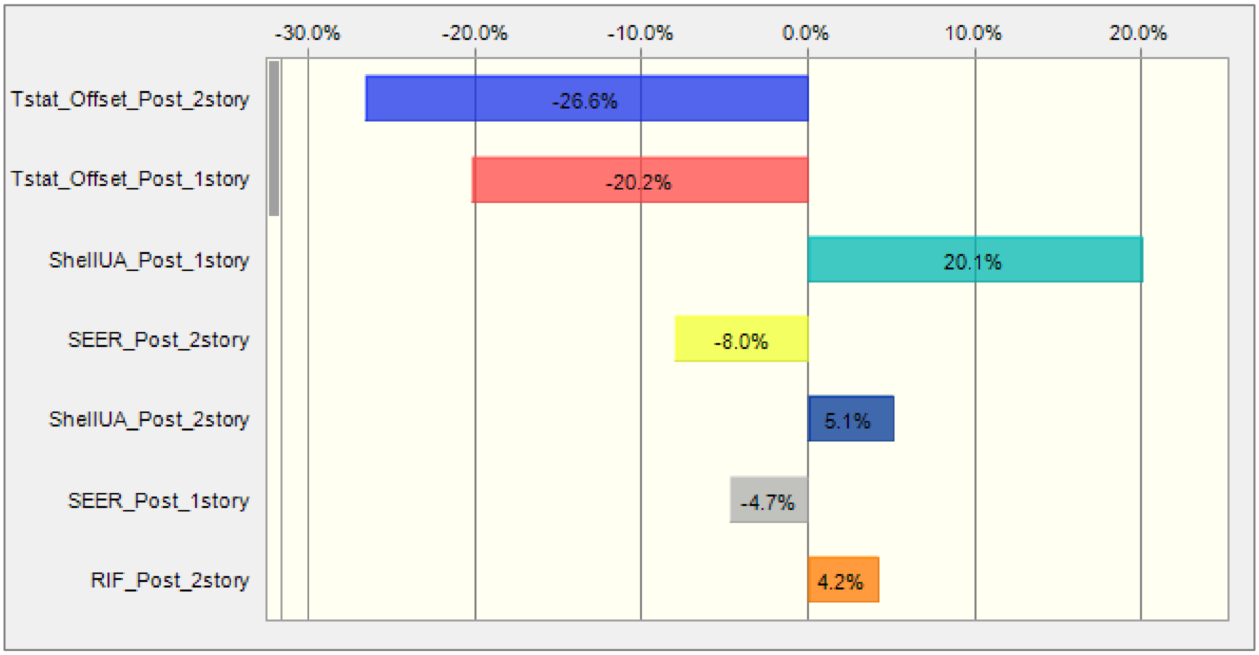


Figure 110. Distributions of Natural Gas Consumption in CZ16, therm/ton

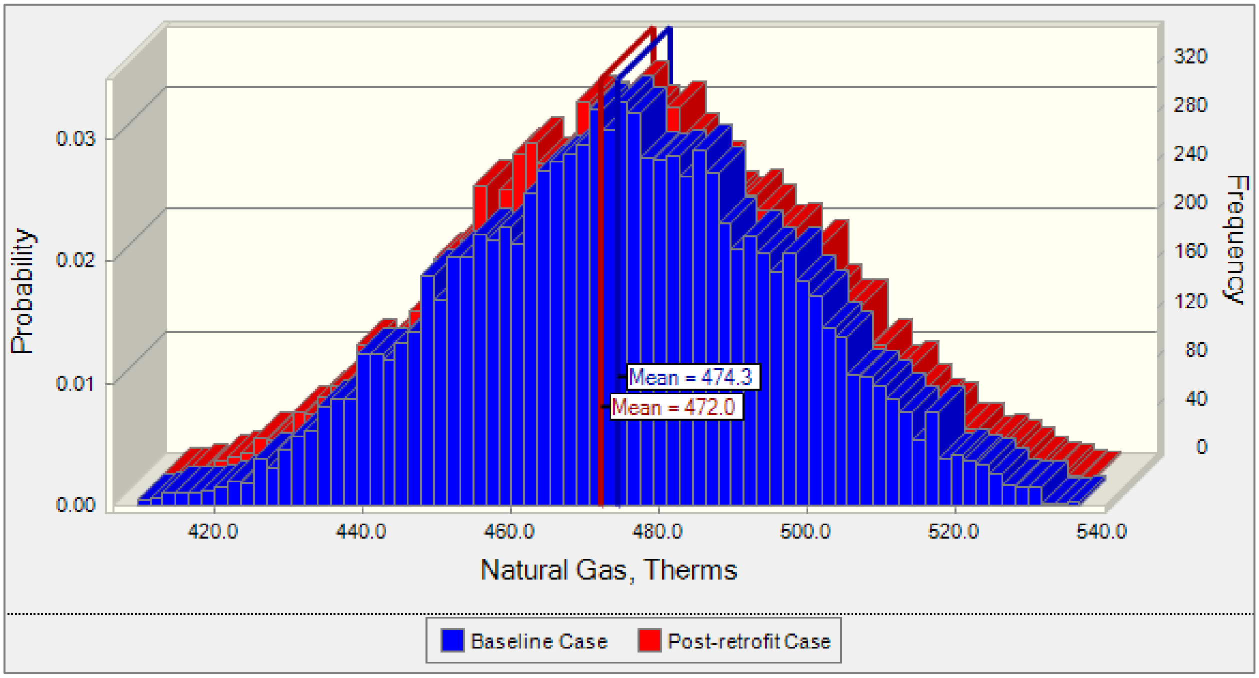


Table 68. Statistics for Natural Gas Consumption in CZ16, therm/ton

Statistic	Baseline Case	Post-Retrofit Case
Mean	474.300	472.000
Median	474.400	472.000
Mode	473.200	456.100
Standard Deviation	22.400	22.400
Coefficient of Variation	0.047	0.047
Minimum	401.500	398.700
Maximum	539.300	534.600
Mean Standard Error	0.200	0.200

Figure 111. Sensitivities of Baseline Natural Gas Consumption in CZ16

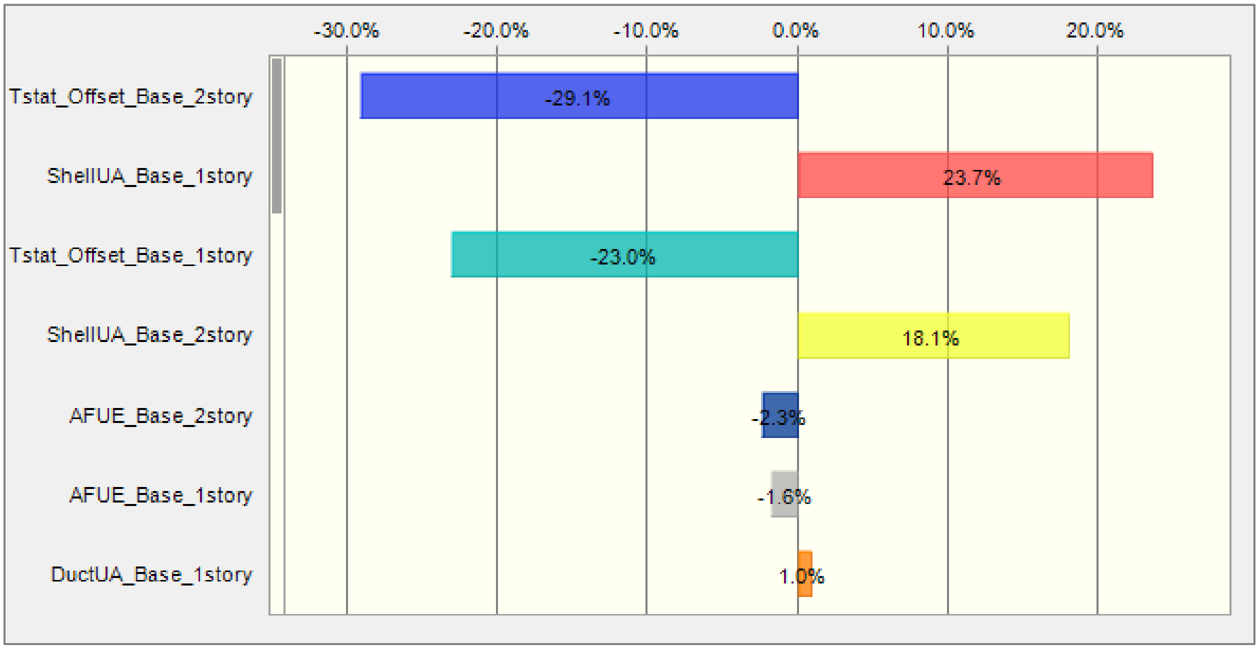
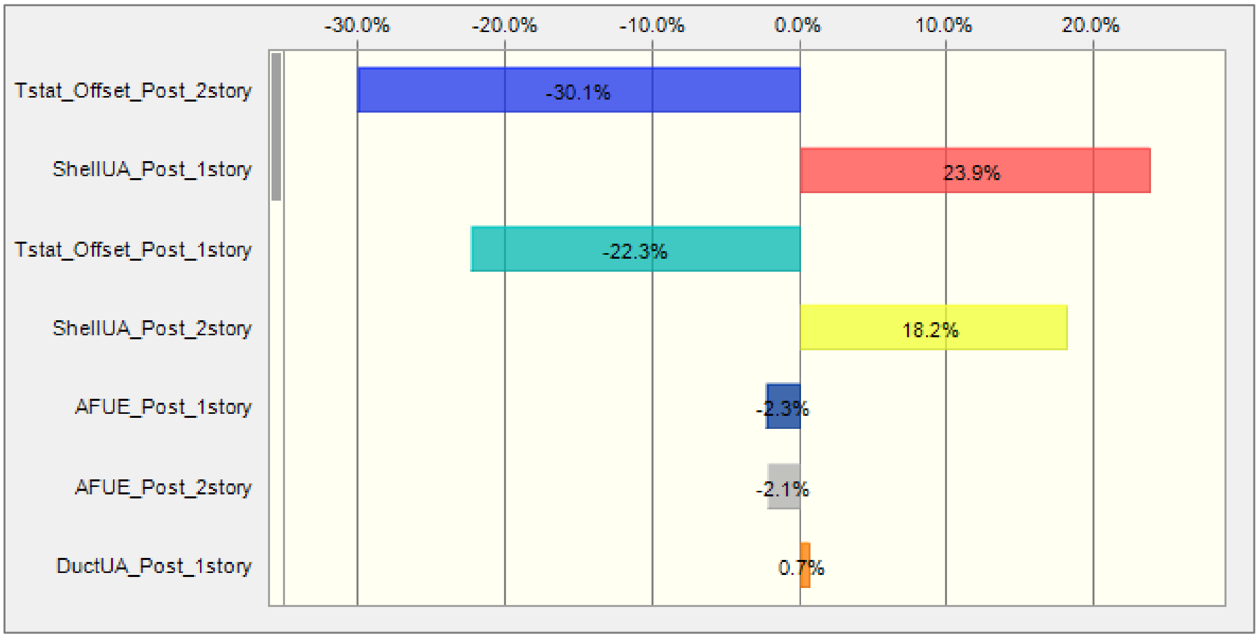


Figure 112. Sensitivities of Post-Retrofit Natural Gas Consumption in CZ16



D. Public Comments and Responses

Commenter	Organization	Comment	DNV GL Response to Comment
Ron Jarnagin	Western HVAC Performance Alliance (WHPA)	Members of the WHPA were invited to a webinar on the HVAC3 plan [sic], which we appreciate. However, the closing dates for comment occur only 3 days after the webinar. This allows precious little time to craft comments supported by documentation. You should allow additional time for receiving written comments.	While the comment addresses the brief comment period available between the HVAC3 plan webinar and the close of the commenting period, we assume that it is included here in reference to the HVAC 4 report. While we acknowledge the brevity of the intervening period, the report was publically available two weeks before the close of the commenting period. Furthermore, it is typically challenging to schedule a webinar time that is agreeable to all stakeholders.
Abram Conant	Proctor Engineering	The findings of this study are presented as representing uncertainty in the savings estimates for IOU HVAC programs, but would be more accurately portrayed as representing the variability that can be achieved within the building simulation models. The accuracy and responsiveness of the models themselves is a very significant source of uncertainty. It has never been proven that the models accurately predict energy use representative of CA buildings, and it is even less certain that the models respond in a realistic way to input changes. Since the current trend seems to be to force all workpapers to be developed through these unproven simulation models, an informative future study might be an investigation of how well the models are able to represent energy efficiency measures (including level of effort to customize the models and uncertainty associated with the customization process), how well the models are able to represent a wide range of building characteristics, and how the model results correlate to real world data. A comparison of simulation model based estimation methods to estimates derived through engineering calculations would be particularly useful.	This is a great point. Year 2 of this study may shed some light on the sensitivity of the simulation outputs to the various input parameters. Comparing simulation models to engineering calculations would be interesting, but falls outside the current scope of project.

Commenter	Organization	Comment	DNV GL Response to Comment
Abram Conant	Proctor Engineering	It would be helpful if workpapers associated with the measures being evaluated could be provided when these reports/plans are posted for comment. While some workpapers are available on deerresources.com, they aren't necessarily the current version or the version that describes the programs being evaluated.	We, too, would benefit from improved access to workpapers.
Abram Conant	Proctor Engineering	Section 5.1.3 recommends "Further investigation is warranted to determine to what extent the energy savings that result from the elimination of ductwork are already accounted for by the higher SEER ratings of ductless mini- and multi-split heat pumps." There seems to be some confusion regarding duct losses. Possibly the workpapers aren't clear on the subject. In any event, it shouldn't be necessary to allocate resources to investigate the relationship between two totally unrelated topics. The standard rating tests apply to the HVAC unit only. They do not consider any losses that occur externally to the unit, such as in the ducts. Therefore, duct leakage and heat conduction losses are not accounted for in the efficiency ratings. Eliminating the duct losses by eliminating the ducts will save energy (when a ducted system with ducts in unconditioned space is replaced with a ductless system). There are a multitude of studies by DOE and others documenting the effects of duct losses.	We have revised the recommendation to: "Further investigation is warranted to determine whether the energy savings that result from the elimination of ductwork equal those that result from duct sealing treatments." The decreased blower energy consumption that results from reducing duct leakage is quite different from the decrease that results from using a significantly smaller blower when eliminating ductwork (as with ductless mini- and multi-split heat pump units).
Abram Conant	Proctor Engineering	The latest CEC research casts doubt on the reliability of energy savings estimates based on the standard efficiency ratings for variable speed mini and multi split systems. We recommend coordinating with the CEC to incorporate the current research into savings estimates. Potential issues include: differences in system behavior and energy use characteristics when the complex controls for these systems are configured for the rating test vs. the field installed configurations, rating test procedures that do not specify that variable speed units be operating at maximum speed, and challenges verifying proper field assembly and commissioning.	This is useful information for all stakeholders to be aware of, but is not within the scope of this project. We agree that further coordination and research is warranted.

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