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Determining Energy Use Volatility for Commercial Mortgage Valuation

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Disclaimer

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Executive Summary

Commercial mortgage contracts currently do not fully account for the risks inherent in the level and volatility of energy use in commercial buildings. As a result, energy efficiency is not explicitly included in the valuation process for commercial mortgage underwriting. In particular, there is limited if any consideration of the volatility of energy use and price, which is critical to evaluate the impact of extreme events and default risk. Explicit inclusion of energy use and volatility in commercial mortgage underwriting can send a strong "price signal" that financially rewards and values energy efficiency in commercial properties. This report presents the results of a technical analysis of and a proposed protocol to assess energy use volatility for the purposes of commercial mortgage valuation.

Current practice to determine energy use for mortgage valuation varies widely. In particular, there appears to be little, if any, consideration of volatility due to variations in weather, operational practices, and vacancy level over the course of a mortgage term, as distinct from any changes in a building's construction and equipment. Parametric energy simulations were used to analyze the range and relative impacts of these volatilities for large, medium, and small prototypical office buildings in four different climates.

Weather volatility was analyzed in terms of the variation in annual site energy using actual year weather data relative to annual site energy using "typical" year weather data. The variation is mostly within ±4% except in the cool and mixed-humid climates, where the site energy variation for small offices is in the range of -8% to 6%. Warm-marine climate shows the least variation, with a range of -1% to 3%. In the warm, mixed and cool-humid climates, the small office presents slightly larger variation than large and medium offices, due to its larger skin-to-volume ratio and lower thermal mass.

For the analysis of volatility due to operational practices, three levels of practice – good, average, poor – for various operational parameters were defined based on expert opinion from building commissioning practitioners and researchers. In general, the reduction in energy use from average to good practice is much less than the increase in energy use due to poor practice. The results for large offices show that an individual parameter can affect overall building energy use by -5% to +15%. The parameters with the largest variations are lighting control, plug load controls, VAV minimum ratio settings, and supply air temperature reset. This trend generally holds for medium offices as well. Large offices located in warm-marine climate present less energy volatility than large offices located in cool, mixed and warm-humid climates, which demonstrate similar energy volatilities. Energy volatilities for medium offices across four climates are comparable. Small offices exhibit the least energy volatilities among the three office building sizes. Similar to the results for large and medium offices, plug load and lighting control show the highest variation in annual site energy use. The combined effect of good or poor practice across multiple parameters is significant – for large offices, it ranges from -17% to 87% for the combination of all parameters and -9% to 82% for the combination of HVAC parameters. It is notable that these variations are just due to the effect of operational practices, and not differences in fixed asset characteristics.

Finally, this report outlines a protocol to determine energy use and volatility in the context of mortgage valuation. The protocol utilizes actual operating data and ASTM E2797 whenever appropriate, complemented by simulation and other methods, based on data availability and the desired level of rigor.

1 Introduction

Commercial mortgage contracts currently do not fully account for the risks inherent in the level and volatility of energy use in commercial buildings. As a result, energy efficiency is not explicitly included in the valuation process for commercial mortgage underwriting. In particular, there is limited if any consideration of the volatility of energy use and price, which is critical to evaluate the impact of extreme events and default risk. Explicit inclusion of energy use and volatility in commercial mortgage underwriting can send a strong "price signal" that financially rewards and values energy efficiency in commercial properties.

The U.S. Department of Energy Building Technologies Program commissioned a research project to analyze and develop a commercial mortgage underwriting protocol that uses energy efficiency metrics to evaluate energy-related usage risks across building types, building qualities, and tenanting structures. This project was conducted by Lawrence Berkeley National Laboratory (LBNL), in collaboration with the Haas School of Business and the Civil and Environmental Engineering Department at the University of California, Berkeley. This project's major objectives were to:

1. Review current best practice use of efficiency metrics for mortgage underwriting.
2. Analyze existing datasets to evaluate relationship between efficiency and financial value.
3. Develop an Energy Use Volatility (EUV) protocol using simulation-based and empirical energy benchmarking to produce technical metrics for use in the mortgage valuation process.
4. Develop Target Value Design (TVD) and delivery protocol to produce energy efficiency cost metrics for use in the mortgage valuation process.
5. Develop a mortgage valuation protocol tool for underwriting energy efficiency investments and evaluating the cost effectiveness of corrective energy efficiency investments.

This report presents the results of objective 3 i.e. technical analysis of and a proposed protocol to assess energy use volatility for the purposes of commercial mortgage valuation.

Section 2 describes the state of current practice and its limitations. This section also describes potential enhancements to current practice, including the use of energy simulations.

Section 3 describes a technical analysis of energy use volatility based on parametric energy simulations of prototype benchmark models for office buildings.

Section 4 proposes a protocol to assess energy use volatility, using a tiered approach that allows for different levels of accuracy depending upon data availability.

2 Energy Metrics in Mortgage Valuation: Current Practice

2.1 Energy use and Net Operating Income

The key metric used in commercial mortgage valuation is the Net Operating Income (NOI) of the property. The NOI is calculated as the gross revenues (e.g. from rents) less the operating expenses, which includes energy costs. Energy costs are a function of energy use (volume) and price. Accordingly, energy-related risk analysis can be disaggregated into four components:

- Energy use i.e. average use over the course of the mortgage term.
- Energy use volatility i.e. variability in energy use
- Energy price i.e. forward curves for electricity, natural gas, and other fuels
- Energy price volatility i.e. volatility of forward curves

The focus of this task is on energy use and volatility. A separate report [Jaffee et al. 2011] presents the results of combining this analysis with the analysis of energy prices and incorporates the resulting energy cost metrics into the mortgage valuation process.

To varying degrees, current practice nominally accounts for average energy use in the NOI calculation via total energy cost. However, there is limited if any consideration of the volatility of use i.e. unintended or unexpected changes in use. Furthermore, there is a range of rigor in how the average energy use is determined. From a risk management perspective, volatility is often of greater interest than the average use because volatility can be used to evaluate the impact of extreme events and default risk. Volatility in use generally results from three sources:

- Weather. Year to year weather variations will naturally cause changes in energy use from year to year.
- Operational practices. Buildings with similar assets (walls, windows, heating and cooling equipment) can have very different levels of energy use based on how they are operated. This includes factors controlled by facilities personnel (e.g. HVAC controls) as well those controlled by occupants (e.g. turning off lights and computers when not in use). This explains why sometimes just a change in facilities staff may have an impact on how effectively the building is operated, and therefore its energy use.
- Vacancy levels. Higher vacancy levels should cause a decrease in energy use, although the degree to which this happens is a function of the thermal and lighting control in vacant spaces.

There are different methods to estimate energy use and volatility in the context of commercial mortgage valuation. The applicability of these methods varies for existing buildings and new construction. In this context, an existing building is one that has been in operation under normal occupancy conditions for at least one year and for which for which there is at least one year of energy and operational data. If an existing building is expected to be significantly retrofitted or operated differently in the future, historical energy use data may have little relevance for estimating future energy use and volatility and this case may necessitate using methods applicable to new construction.

2.2 Methods to determine energy use and volatility

Unadjusted historical energy use data

In existing buildings, average use is typically determined using data from prior years (e.g. from utility bills). The simplest and crudest approach is to use the data from the most recent twelve months – and this may well be adequate if the weather and vacancy level was normal, and the operational practices are likely to be unchanged. A slight improvement is to compute the average use over several years – to the extent that there were no significant changes in asset or use characteristics over those years, e.g. it would not be appropriate to use data preceding a major renovation or change of use. Deviation from the average use provides a crude estimate of volatility, although it is not possible to disaggregate the volatility due to weather, vacancy levels and operational characteristics.

Normalized historical energy use data

A more rigorous approach would be to normalize the historical data to account for variations in weather, vacancy levels and operational practices. The most common way to do this is to use a regression model to fit the historical data with these factors as dependent variables and predict the average energy use (dependent variable) for expected values of typical weather, operational characteristics, and occupancy levels (independent variables). The regression model can then be used to determine the volatility by varying the input factors and analyzing the resulting variation in average energy use.

ASTM released standard E2797 Standard Practice for Building Energy Performance Assessment for a Building Involved in a Real Estate Transaction [ASTM 2011] defines a practice for conducting a *building energy performance assessment* (BEPA) on a building involved in a commercial real estate transaction and provides a methodology for the collection, compilation, analysis, and reporting of building energy performance information in the context of real estate transactions. As the standard is relatively new, we do not have any data on its application. Nonetheless, as a standard developed through the ASTM consensus process, it offers insight into current industry practices and recommendations, and is highly relevant to this effort as it directly addresses energy use and volatility for real estate transactions.

The standard requires that the building's total annual site energy use shall be estimated for a reasonable lower limit, a reasonable upper limit, and average case conditions. The standard specifies a calculation procedure using regression analysis to relate the building energy use (dependent variable) to various independent variables that significantly impact energy use. The average annual site energy use is calculated by using the average value of the independent variables over the time period for which data were collected. The upper limit site energy use is calculated using the 75th percentile values of the independent variables and the lower limit is calculated using the 25th percentile values of the independent variables.

The ability to conduct such regression analysis is naturally dependent on the availability of data for the variables of interest. Energy use and weather data are, in most cases, easily obtained. Likewise, vacancy levels should be readily available in most tenanted properties, although they are less likely to be available in owner-occupied buildings. Reliable data for most operational parameters are typically more difficult to obtain, with the possible exception of operation hours.

There are many commercially available tools to do regression analysis. Several Energy Information Systems (EIS) also have normalization features built into them [Granderson et al. 2009].

Simulation

For new buildings or buildings that will undergo major retrofit and for which there are no historical data, average use is typically determined by using an energy simulation tool. This requires detailed data on building asset and expected operational characteristics, some of which may not be known and therefore have to be assumed. For mortgage valuation, a major concern with the use of energy simulation tools is the gap between model predictions and actual performance. This gap can be due to various reasons, including: a) modeling limitations of simulation tools; b) building not being constructed as designed; c) building not being occupied and operated as intended (differences in occupant loads, plug loads, operational hours, control strategies, etc.). Therefore, the quality of the modeling results are highly dependent on the model input assumptions, the expertise of the modeler, and the algorithms of the modeling tool. These issues notwithstanding, a major advantage of simulation-based analysis is that it provides a rich amount of information such as energy use for various end uses (lighting, HVAC, plug loads) and parametric data on the relative impact of various asset and operational characteristics.

While simulation is most commonly used to evaluate energy efficiency options for design decision-making, interviews with stakeholders did not yield any information on current practice vis-à-vis the use of simulated energy data for mortgage valuation. As discussed later in sections 3 and 4, simulation-based approaches may be able to complement empirical approaches and address some of the gaps in current practice.

Energy benchmarking tools

Finally, we consider the role of energy benchmarking tools in mortgage valuation. Energy benchmarking tools are primarily used to compare a building's energy use to its peers to identify and screen buildings for potential efficiency opportunity. Benchmarking tools typically use a metric such as energy use per unit area, and most benchmarking tools also normalize the energy efficiency metric for other significant variables such as weather and operation hours. Methods used to normalize range from simple filtering of the dataset (i.e. selecting a sub set of peer buildings in a similar location and with similar characteristics) to regression-based methods as described earlier. ENERGYSTAR Portfolio Manager, one of the most widely used benchmarking tools, uses a regression-based approach, normalizing for building area, weather, operation hours, and other building-type specific characteristics such as number of computers, etc.

As such, data on how a building compares to its peers are not a direct input into the NOI and mortgage valuation itself – although it may be of interest to the stakeholders for other reasons, most importantly to identify potential efficiency opportunities. In situations where there are no historical energy use data or if it's not possible or too burdensome to run a simulation, energy benchmarking tools could potentially be used as a last resort to estimate energy use based on building type, location, etc.

2.3 Summary and limitations of current practice

There is a range current practice to determine energy use for mortgage valuation. In particular, there appears to be little, if any, consideration of volatility due to variations in weather, operational practices, and vacancy level over the course of a mortgage term, as distinct from any changes in its construction and equipment. Table 1 qualitatively summarizes the applicability and characteristics of the three major methods discussed earlier.

Table 1. Summary of current methods to determine energy use and volatility

Characteristics	**Unadjusted historical data**	**Normalized historical data (e.g. ASTM 2797)**	**Energy Simulation**
Applicability to existing buildings	●	●	○
Applicability to new construction			●
Assess variability due to weather		●	●
Assess variability due to vacancy levels		●	●
Assess variability due to operational practices		○	●
Ease of use vis-à-vis level of effort	●	◐	○
Ease of use vis-à-vis required expertise	●	◐	○

●*high* ◐*medium* ○*low*

The ASTM Standard E2797 is notable in that it provides a standard way to determine and report energy use for real estate transactions. It also requires assessment of volatility due to weather, vacancy level, and operation hours. However, it does not address the volatility of use due to operational practices such as equipment control settings. A simulation-based analysis allows for a fine-grained parametric analysis that is not possible to do empirically due to the heterogeneity of buildings and lack of any dataset with detailed data on operational characteristics and energy use. It can therefore potentially complement empirical methods based on measured data. Section 3 presents a simulation-based analysis of weather, vacancy and operational parameters that highlights the relative impacts of these different drivers of volatility. Section 4 proposes a protocol that utilizes existing tools and methods, extending them where appropriate to address gaps in current practice.

3 Technical Analysis of Energy Use Volatility

3.1 Approach

The energy use volatility due to weather, operational practices and vacancy levels in a given building will depend on the unique characteristics and context of that building. The intent of the analysis presented in this section is to illustrate the range of these volatilities for prototypical buildings in different climates, using parametric energy simulation analysis. LBNL also considered using an empirical approach but was unable to identify and obtain a dataset[1] that would afford such an analysis. Parametric energy simulation is well-suited for this analysis in that it can easily isolate the relative impacts of individual parameters.

U.S. DOE reference models [DOE 2011] were modified in compliance with ASHRAE 90.1-2007 and were used for the analysis. These models were developed to support whole building energy analysis using the EnergyPlus simulation software [EnergyPlus 2012] and represent approximately 70% of the commercial building energy use based on the 2003 Commercial Building Energy Consumption Survey (CBECS) [EIA 2005]. The models have also been peer-reviewed to increase confidence in their use [Winiarski et al. 2008].

Three building models were used for this study – large, medium, and small office. The buildings were modeled for four climatic regions represented by San Francisco (warm marine), Chicago (cool-humid), Baltimore (mixed humid) and Atlanta (warm humid). The models for each building and climate was parametrically varied for a range of operational practices, vacancy levels, and weather years, as described in the following sections.

Figure 1, 2 and 3 show the building geometry and typical floor thermal zones for large, medium and small office respectively. The key characteristics of the building geometry and HVAC type for each building are listed in Table 2. These characteristics generally correspond to new construction.

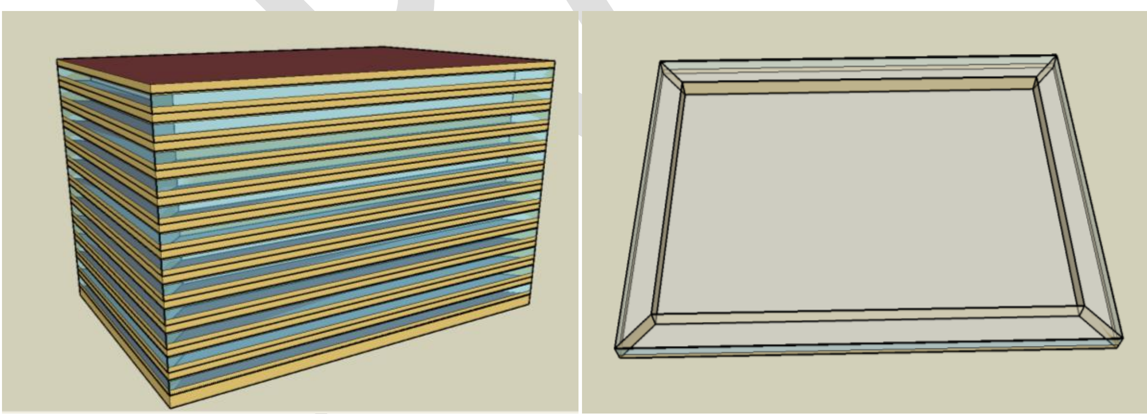

Figure 1. Large office building geometry model and thermal zones

[1] The dataset for empirical analysis would, at a minimum, need to include energy use, occupancy information, building size and key asset and operational characteristics. While there are several efforts underway to build such datasets, none were available for this analysis.

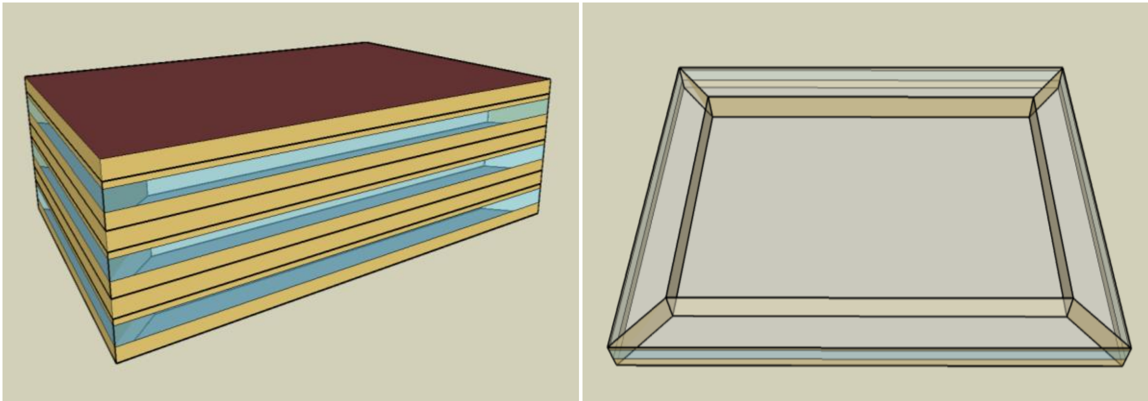

Figure 2. Medium office building geometry model and thermal zones

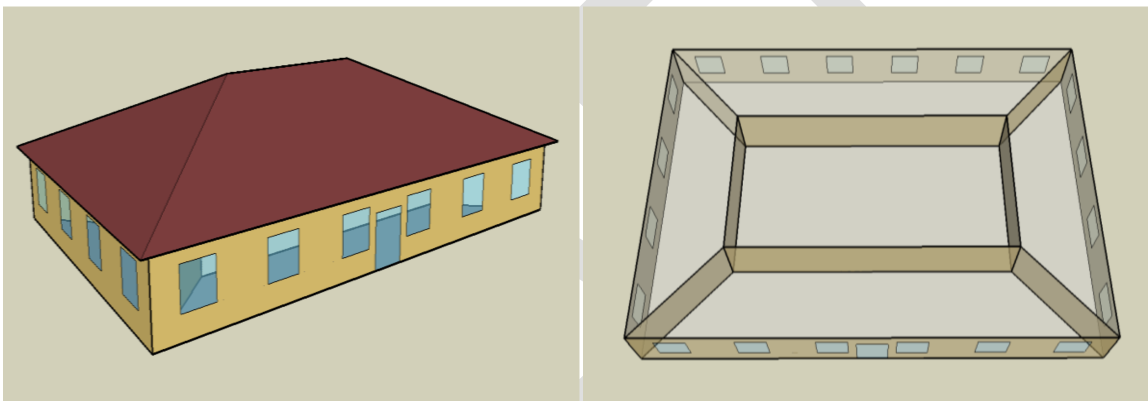

Figure 3. Small office building geometry model and thermal zones

Table 2. Building characteristics for large, medium and small offices

Building Characteristic	**Large**	**Medium**	**Small**
Total Floor Area (ft^2)	498,584	53,626	5,500
Occupant density (ft^2/per)	400 for basement and 200 for the rest	200	200
Lighting load (W/ft^2)	1	1	1
Plug load (W/ft^2)	1	1	1
Building Shape	Rectangle	Rectangle	Rectangle
Aspect Ratio	1.5	1.5	1.5
Number of Floors	12 plus basement	3	1
Window Fraction (Window to Wall Ratio)	0.38	0.33	0.212 (total); 0.244 (S), 0.198 (N,E,W)
Thermal Zoning	core zone with four perimeter zones on each floor	core zone with four perimeter zones on each floor	core zone with four perimeter zones
Floor to Ceiling Height (ft)	9.0	8.8	10.2
Floor to Floor Height (ft)	13.0	13.1	N/A

Building Characteristic	Large	Medium	Small
Roof type	Built-up flat roof, insulation entirely above deck	Built-up flat roof, insulation entirely above deck	Attic
Exterior Wall Type	Mass wall	Steel frame	Mass wall
Exterior Walls – Gross Area (ft^2)	124,754	21,291	3,030
Exterior Walls – Net Area (ft^2)	74,852	14,553	2,390
Wall to Skin Ratio	0.77	0.54	0.32
Roof Construction Type	IEAD	IEAD	Attic
Roof - Total Area (ft^2)	38,352	17,879	6,445
Roof to Skin Ratio	0.24	0.46	0.68
Window Total Area (f^2)	49,901.5	7,026.7	600.6
Infiltration (ACH)	0.10	0.20	0.45
HVAC System Type [1]	Multi-zone VAV	Multi-zone VAV	Packaged Single Zone
Heating Type	Gas boiler	Gas furnace and electric reheat	Gas furnace
Cooling Type	2 water cooled chillers	PACU	Unitary DX
Fan Control	Variable	Variable	Constant volume
Ventilation (L/s·per)	10	10	10
Service Water Heating Type	boiler	gas water heater	gas water heater
Fuel	gas	gas	gas
Thermal Efficiency (%)	80	80	80
Temperature Setpoint (ºF)	60	60	60
Water Consumption (L^3)	1,504,130	174,590	17,630

[1] Equipment sizing for each office size was determined based on average operational practice conditions.

3.2 Volatility due to weather

The methodology used by [Crawley and Huang 1997] was adopted to model volatility due to weather, using actual weather data from 1995 to 2010, except for Atlanta which uses data from 1999 to 2010. The actual weather data were obtained from a commercial weather data vendor. The key parameters including dry bulb temperature, dew point temperature, relative humidity, wind speed, wind direction and sky cover were obtained directly based on hourly recorded weather parameters from weather stations in each city and hourly direct solar radiations and diffuse solar radiations were calculated and provided by the data provider.

The basecase building model representing average operational practice (discussed in section 3.3) was used for the weather analysis, with HVAC equipment sizing based on design conditions at 99.6% annual heating condition based on dry bulb temperature and 0.4% annual cooling condition based on wet bulb temperature [ASHRAE 2005]. Figures 4 to 7 show the annual site energy using actual year weather data as well as Typical Meteorological Year (TMY) weather data for San Francisco, Atlanta, Chicago and Baltimore respectively.

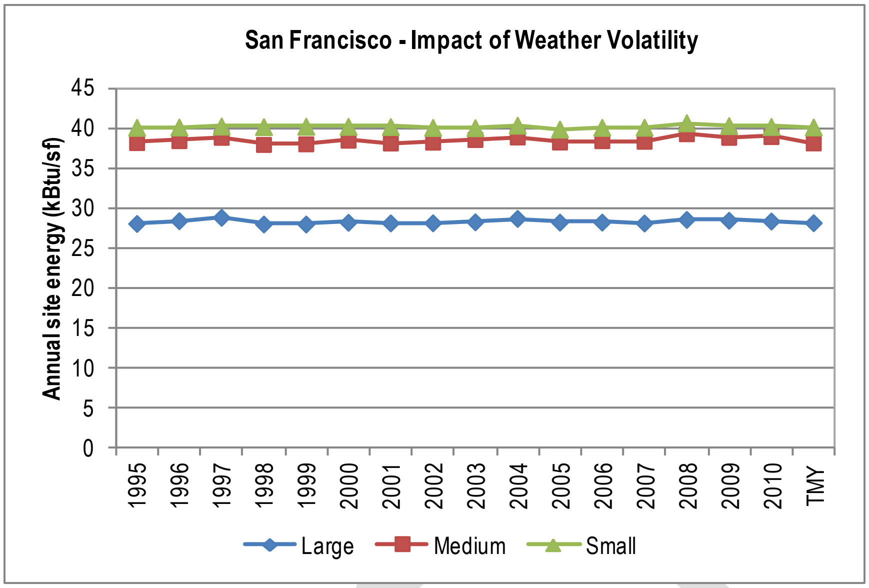

Figure 4. Annual site energy using actual year weather data and TMY weather data for San Francisco.

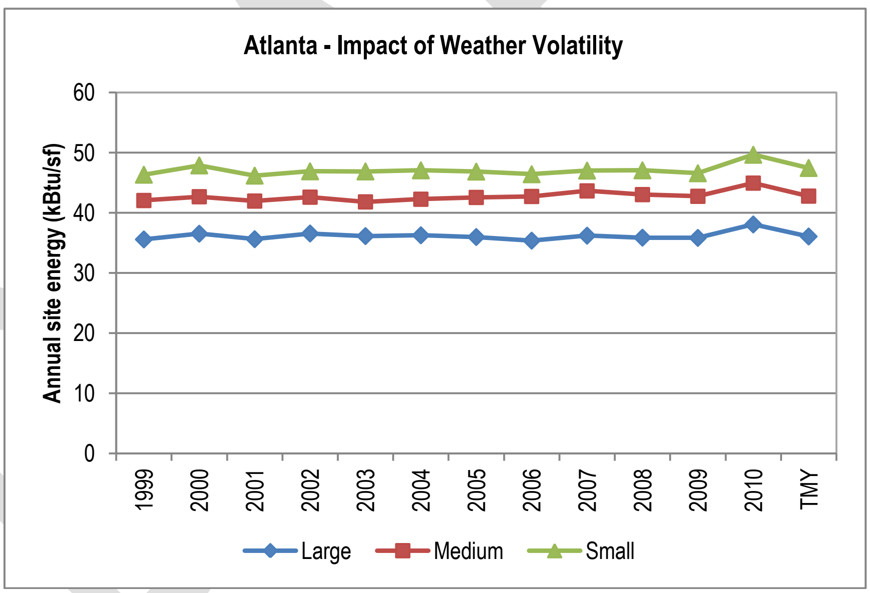

Figure 5. Annual site energy using actual year weather data and TMY weather data for Atlanta

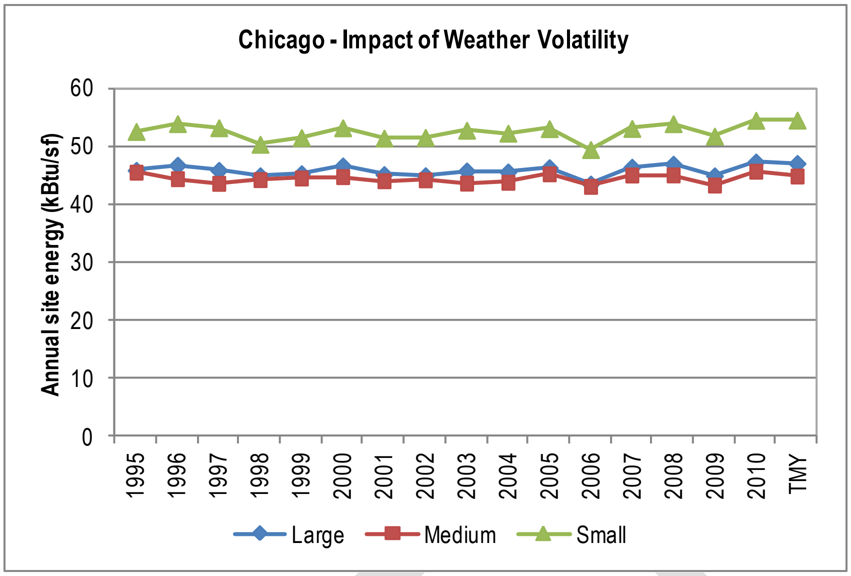

Figure 6. Annual site energy using actual year weather data and TMY weather data for Chicago

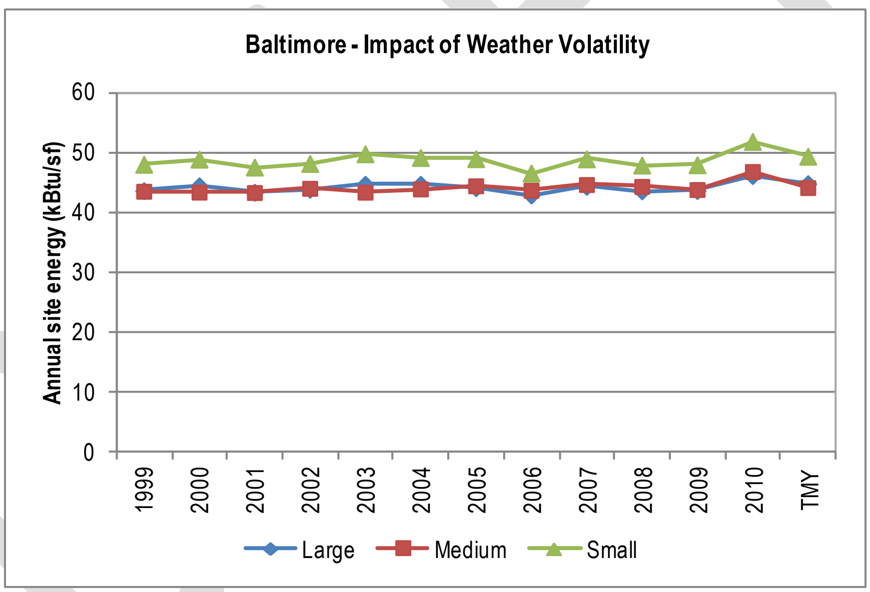

Figure 7. Annual site energy using actual year weather data and TMY weather data for Baltimore

Figure 8 summaries the simulation results for all climates and building sizes in terms of the variation in annual site energy using actual year weather data relative to annual site energy using TMY weather data. The variation is mostly within ±4% except in the cool and mixed-humid climates, where the site energy variation for small offices is in the range of -8% to 6%. The warm-marine climate represented by San Francisco shows the least variation, with a range of -1% to 3%. This could be attributed to the fact that the climate in San Francisco is relatively mild and requires less heating and cooling than other climates. In the warm, mixed and cool-humid climates, the small office presents slightly larger variation than large and medium offices, due to its larger skin-to-volume ratio and lower thermal mass.

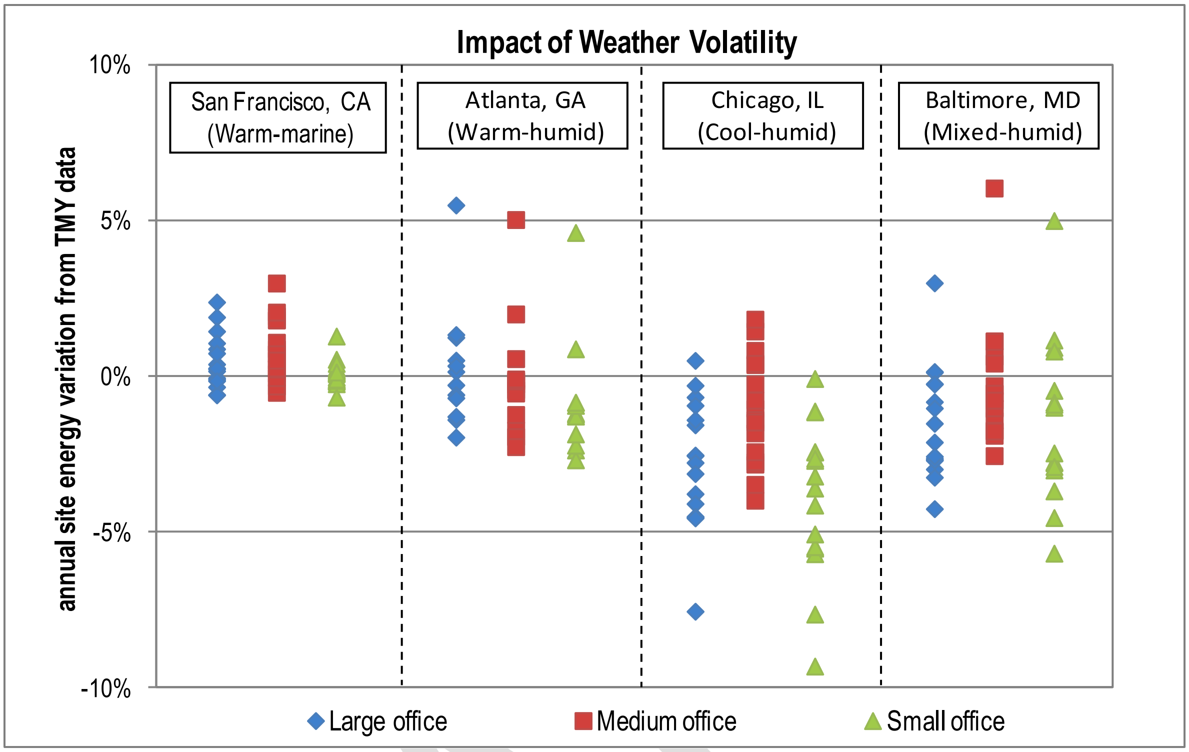

Figure 8. Changes in annual site energy using actual weather data relative to annual site energy using TMY weather data.

3.3 Volatility due to operations

The quality of building operational practice varies widely and is difficult to characterize and categorize, especially given the heterogeneity of buildings. For this analysis, three levels of practice – good, average, poor – for various operational parameters were defined based on expert opinion from building commissioning practitioners and researchers. The intent of this analysis is to illustrate the range of impacts due to different operational practices and it should be noted that the range of impacts for any given building will depend on the specific characteristics of that building.

Table 3 summarizes the range of practice modeled for various operational parameters. Good practice represents design intent or optimal performance of the building. For average practice and poor practice, the analysis assumes the building has the capability to run at the good practice level, but runs less efficiently due to poorer facility management.

The list of operations parameters modeled is not comprehensive and there are several other operational parameters that affect energy use but were not part of this analysis, due to modeling limitations or scope (e.g. maintenance, static pressure reset for air side and water side, building pressure control).

Further descriptions of the operations parameters are provided below.

Table 3. *Range of practice for various operations parameters*

Operations Parameters	Range of Practice			Building Size *
	Good Practice	**Average Practice**	**Poor Practice**	
Lighting control	Dimming control with minimum point w/ occupancy control.	Only occupancy sensor	No lighting control	L,M,S
Plug load control	Turn off when occupants leave	Sleep mode by itself	No energy saving measures	L,M,S
HVAC operation schedule	6am to 8pm and one hour warm-up period	6am to 10pm and one hour warm-up period	5am to midnight and two hours warm-up period	L,M,S
Night setback	55°Ffor heating set point and 85°Ffor cooling set point for unoccupied hours	60°Ffor heating set point and 85°F for cooling set point for unoccupied hours	65°Ffor heating set point and 80°Ffor cooling set point for unoccupied hours	L,M,S
Room temp. setpoints for occupied hours	68°F for heating and 77°F for cooling	70°Ffor heating and 75°F for cooling	71.6°F for heating and 73.4°F for cooling	L,M
VAV box minimum flow setting	15% of design flow rate.	30% of design flow rate.	50% of design flow rate.	L,M
Supply air temperature reset	SAT reset base on warmest zones	SAT reset based on the stepwise function of outdoor air temperature	Constant supply air temperature	L,M
Economizer control	Differential Enthalpy	Differential Dry bulb temperature	No economizer	L,M
Chilled water supply temperature reset	Reset chilled water temperature based on cooling demand.	Linear relationship with outside air temp (OAT).	No reset with constant year-round.	L
Condenser water temperature reset	Reset based on OA wetbulb temperature.	reset based on OAT with narrow range.	No reset.	L
Chiller sequencing	Kick on the lag chiller when the lead chiller reaches its peak efficiency.	Kick on the lag chiller when the chilled water temperature cannot be maintained.	Kick on the lag chiller based on OAT.	L
Hot water supply temperature reset	Reset the hot water supply temperature according to heating load.	Linear relationship with OAT.	No reset with constant year-round.	L
Boiler sequencing	Kick on the lag boiler when lead boiler reaches its peak efficiency.	Kick on the second boiler based on OAT.	no sequencing and always running two boilers.	L

* L- Large office building, M- Medium office building, S- Small office building.

Lighting control

In good practice, electric lighting dims continuously as the daylight illuminance increases. The illuminance set point is 50 footcandles. For average practice, occupancy sensors automatically switch the lighting resulting in an operation schedule as shown in Figure 9. In poor practice, occupants keep the lights turned on throughout occupancy hours as shown in Figure 10.

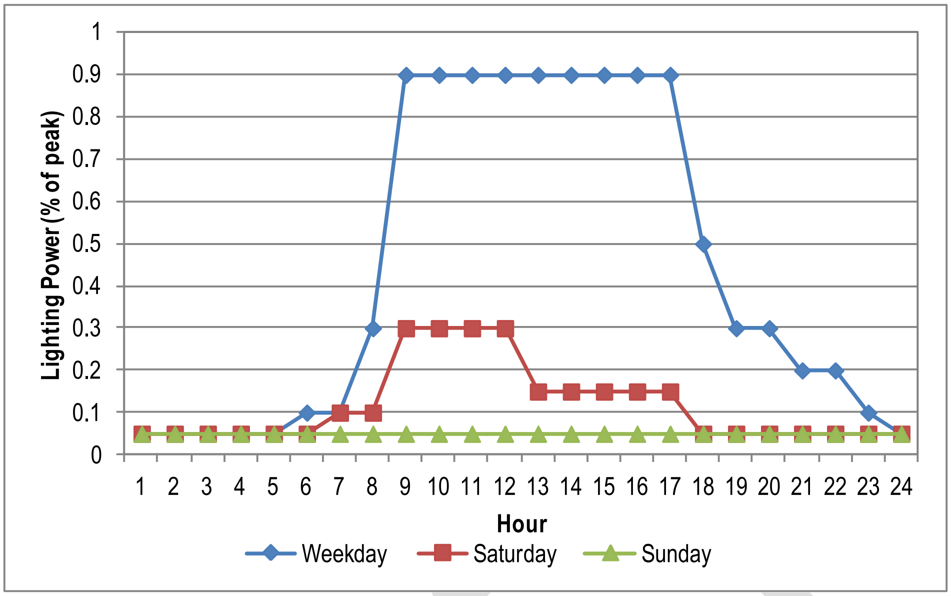

Figure 9. Lighting schedule with occupant sensor control

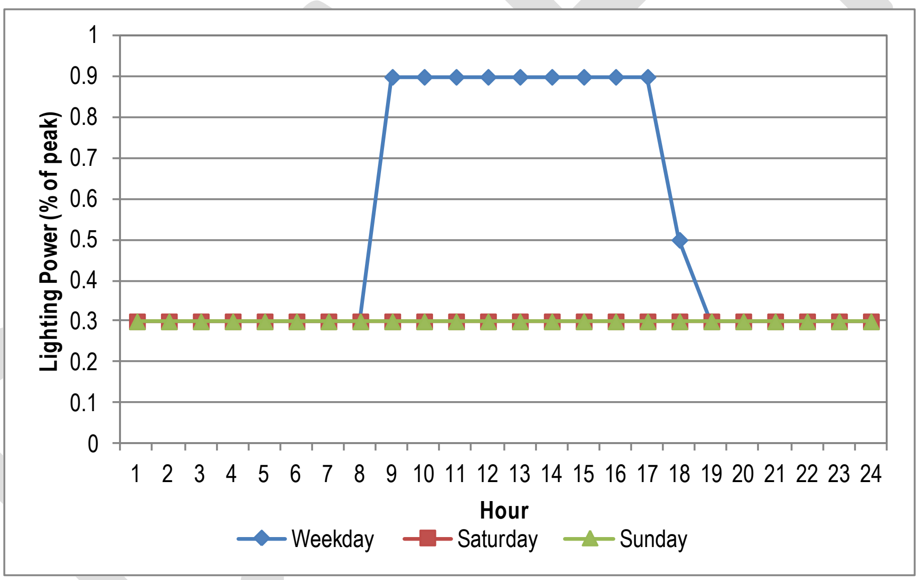

Figure 10. Lighting schedule with manual controls

Plug load control

The levels of practice correspond to the degree to which plug loads are turned off at night. Figure 11 shows the weekday plug load schedule for the ranges of practice.

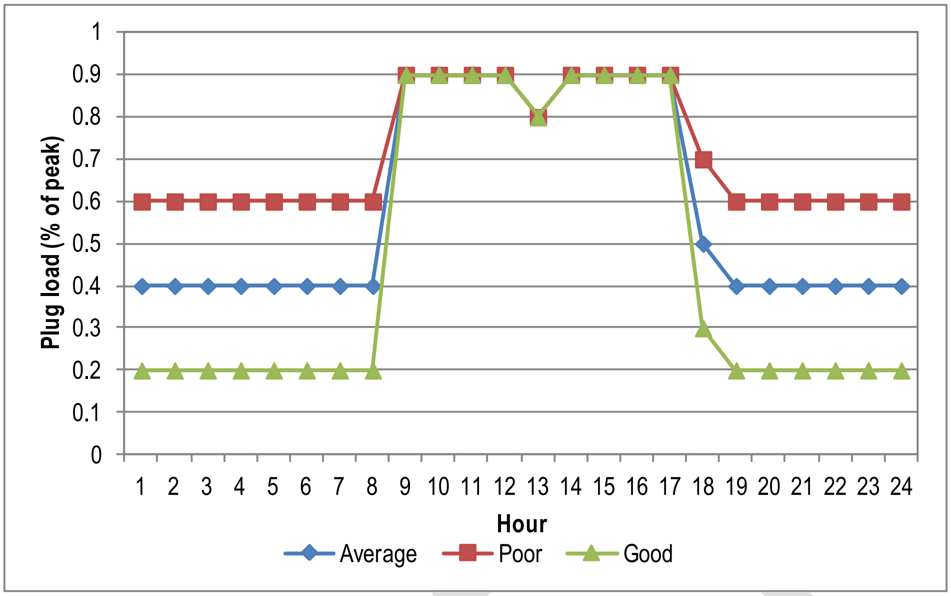

Figure 11. Plug load weekday schedule range of practice

HVAC operation schedule

The HVAC operation schedule is set to enable the HVAC equipment to provide comfort conditions for a given occupancy schedule. The range of practice for HVAC operation schedules used in this analysis is shown in Figure 12. The HVAC operation schedule in the benchmark model is considered as average practice. Poor practice represents the case where the building operator sets the HVAC to operate much longer than the occupancy schedule. Good practice represents a case where the building operator carefully tracks the occupancy schedule and sets the HVAC schedule as close to it as possible without sacrificing comfort.

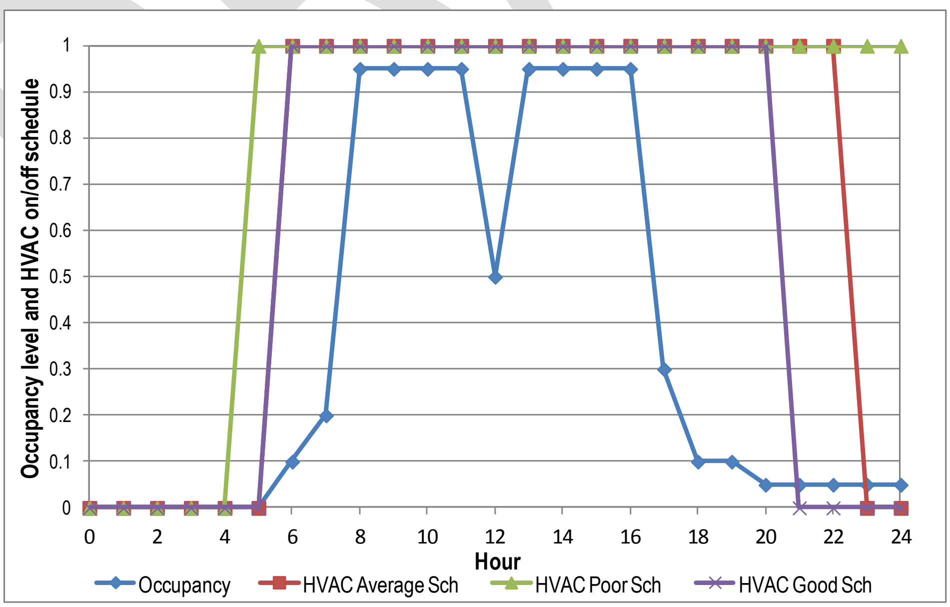

Figure 12. HVAC operation schedules range of practice

Night setback

Setting the heating set point a few degrees lower and cooling set point a few degrees higher at night can significantly reduce heating and cooling energy. The night setback profiles are shown in Figures 13 and 14. The range of practice is based on a literature review [Szydlowski et al. 1992, FEMP 2004, Williamsburg-James City County Public Schools]. The period for night setback is from 10:00 pm to 5:00 am. The cooling and heating setpoints for the period of night setback for the range of practice are summarized in Table 1. There is about a 6°F temperature difference for cooling setpoint and 10°F temperature difference for heating setpoint across the good, average and poor practice setpoints for night setback.

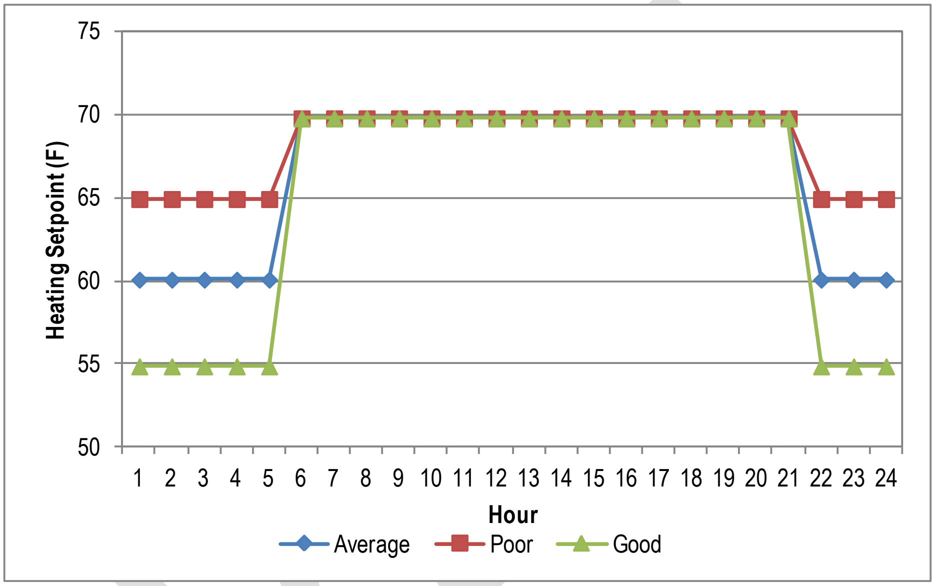

Figure 13. Heating setpoint night setback range of practice

Figure 14. Cooling setpoint night setback range of practice

Room temperature setpoints for occupied hours

The room temperature setpoint has a significant impact on the building energy use. Occupant behavior, e.g. dressing appropriate for the current season, can lead to higher cooling set point and lower heating set point so as to reduce energy use. For good practice, the room temperature setpoint is decreased by 2°F for heating and increased by 2°F for cooling. For poor practice, the room temperature setpoint is increased by 2°F for heating and is decreased by 2°F for cooling. The profiles of the temperature setpoints for the range of practice are shown in Figures 15 and 16.

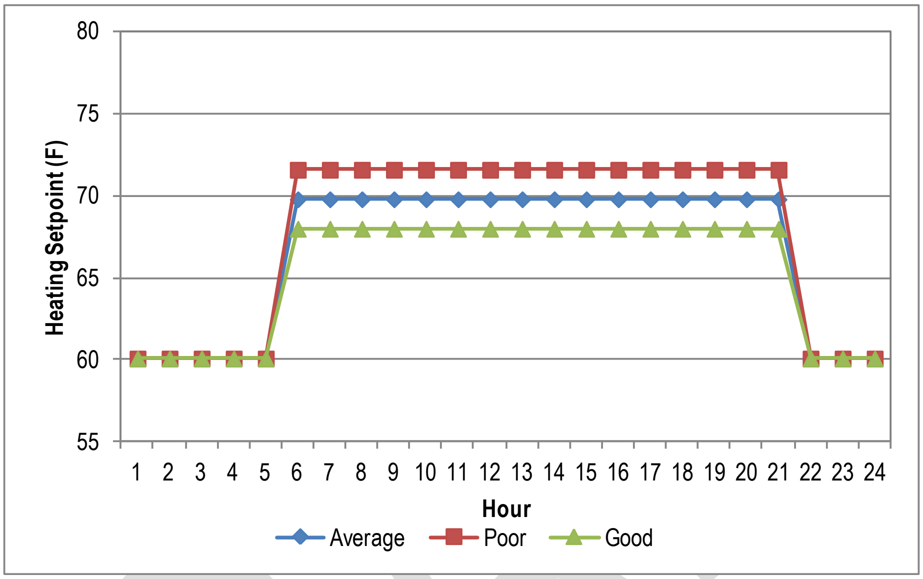

Figure 15. Heating setpoint schedules range of practice

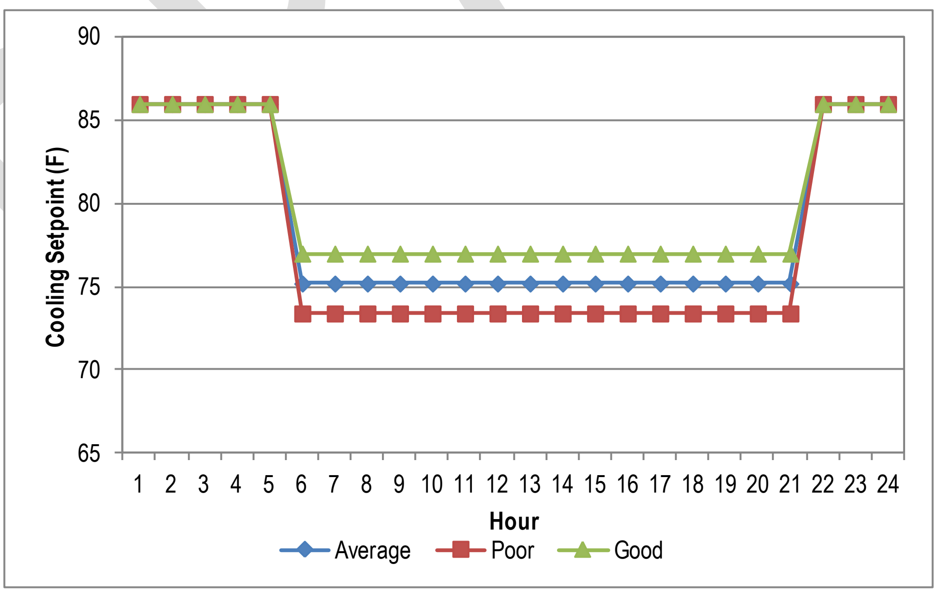

Figure 16. Cooling setpoint schedules range of practice

VAV box minimum flow setting

Variable air volume (VAV) terminal boxes modulate the supply air flow and reheat valve (if equipped) in sequence to maintain the zone temperature set points. In cooling mode, the supply air flow is modulated between its maximum and minimum settings to maintain the zone cooling set point. In heating mode, the supply air flow is typically set to minimum and the reheat valve is modulated to maintain the zone heating set point. Setting of the minimum air flow is tricky as there is a trade-off between indoor comfort and energy use. Higher minimum air flow setting can provide better ventilation in the space but at the expense of high fan power as well as extra heating and cooling energy use due to simultaneous heating and cooling. Minimum air flow fractions of 15%, 30% and 50% of the maximum air flow are used to represent the range of practice in this parametric study.

Supply air temperature reset

In poor practice, the supply air temperature is kept as a constant temperature at 55˚F for a single duct VAV system. In average practice, the supply air temperature is reset based on outdoor air temperature, in order to minimize simultaneous heating and cooling. Note that fan energy use could increase when the supply air temperature is reset to a higher temperature. The stepwise function of the supply air temperature reset is shown in Figure 17. The cooling loads for the core zones in an office building may not vary with outdoor air temperature. In good practice the supply air temperature is reset based on the cooling demands of the warmest zone.

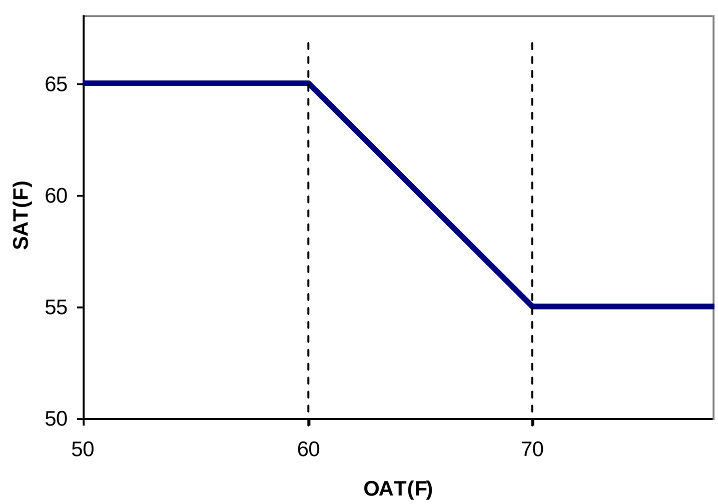

Figure 17. Stepwise function for supply air temperature reset based on outdoor air temperature

Economizer control

Economizers are one of the most important features to reduce energy use for buildings when outdoor air conditions are favorable for "free cooling". For this study, a scenario with an inoperative economizer represents poor practice. In the average scenario the economizer is controlled by differential temperature between outdoor air and return air. Differential enthalpy is applied to control the economizer operation for the good practice scenario. Theoretically, enthalpy is a better parameter to determine whether the outdoor air condition is favorable as humidity ratio of the air is considered. However, differential enthalpy algorithm is not common in practice due to the lack of accuracy in relative humidity measurement.

Chilled water supply temperature reset

For average practice, the chilled water supply temperature has a reset logic based on outside air temperatures as shown in Figure 18. Good practice is to reset the chilled water supply temperature to the cooling load in the system as shown in Figure 19 [Liu et al. 2002]. The chilled water supply temperatures can rise above the design chilled water supply temperature when outdoor air temperatures decrease or the cooling load is less than the design loads. Consequently, chiller efficiency is increased by lowering the compressor head and reducing the amount of work it has to do. The air handling unit (AHU) fans will compensate for the corresponding elevated supply air temperature (SAT) as needed, but the total energy is use is lower.

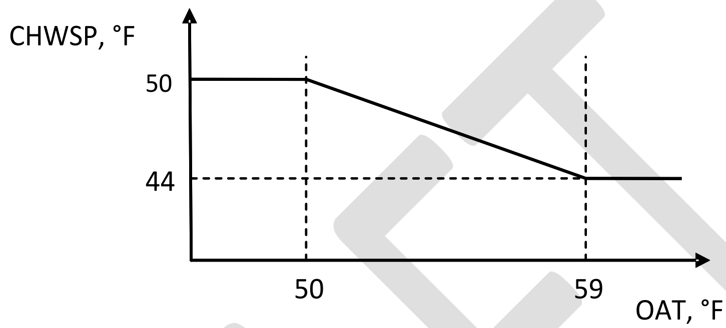

Figure 18. Chilled water supply temperature reset based on outdoor air temperatures

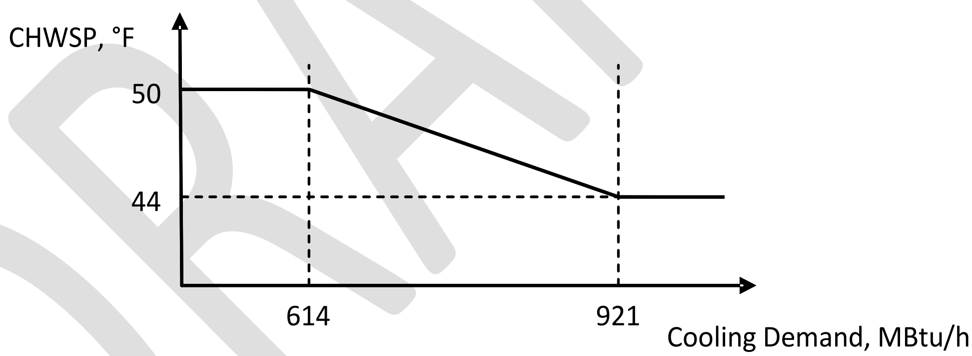

Figure 19. Chilled water supply temperature reset based on cooling demands

Condenser water temperature reset

Resetting the condenser water temperature lower can decrease the chiller electricity use. On the other hand, lowering the condenser water temperature increases cooling tower fan energy use because the cooling tower fans have to run harder to achieve the lower condenser water temperature. The energy savings by reduced condenser water temperature may be offset by extra amount of fan energy. Therefore, the optimization of the condenser water temperature is important for energy savings. Good practice is to reset the condenser water temperature based on outdoor air wet bulb [Liu et al. 2002]:

The average practice is to reset the condenser water temperature based on outside air dry bulb temperature as shown in Figure 20. In poor practice the condenser water temperature has a constant set point at 84.2°F.

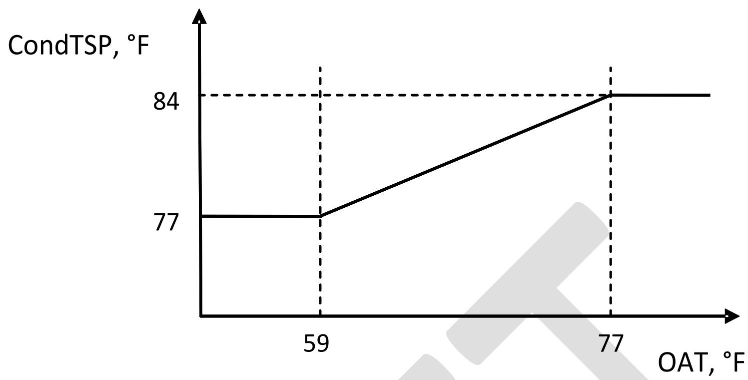

Figure 20. Condenser water temperature reset according to outdoor air temperature

Chiller sequencing

Implementing chiller sequencing control can have a major impact on overall energy efficiency of the chiller plant. In the modified EnergyPlus models of the large office building, there are two identical chillers for sequencing arrangement. Each of them can provide 50% of design loads. The best efficiency of the selected chiller is reached when the system cooling load is around 80% of chiller capacity [Liu et al. 2002]. In poor practice, the lead and lag chiller are loaded based on outdoor air temperature. In average and good practice, the lag chiller is loaded when the lead chiller reaches full load and 80% of full load respectively.

Hot water supply temperature reset

The hot water supply temperature should be sufficiently high for large amount of heating loads under severe cold ambient temperature. Under moderate heating loads or mild weather conditions, hot water supply temperature should be reset to a low temperature to reduce the heat losses through pipes, increase boiler efficiency, and avoid boiler frequent cycling. Hot water supply temperature is kept as constant for poor practice. Hot water supply temperature is reset based on outdoor air temperature or heating demands for average and good practice respectively [Liu et al. 2002] (Figures 21 and 22).

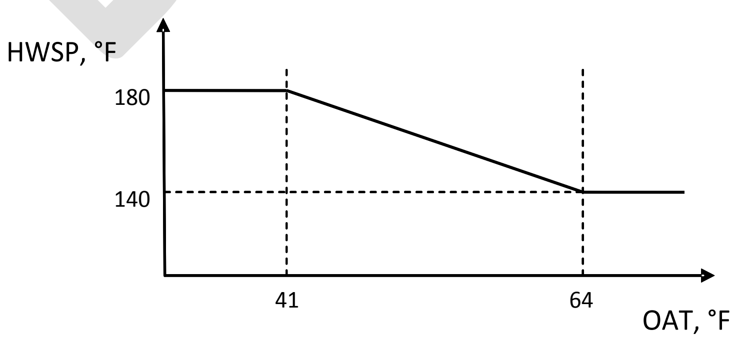

Figure 21. Hot water temperature reset according to outdoor air temperature

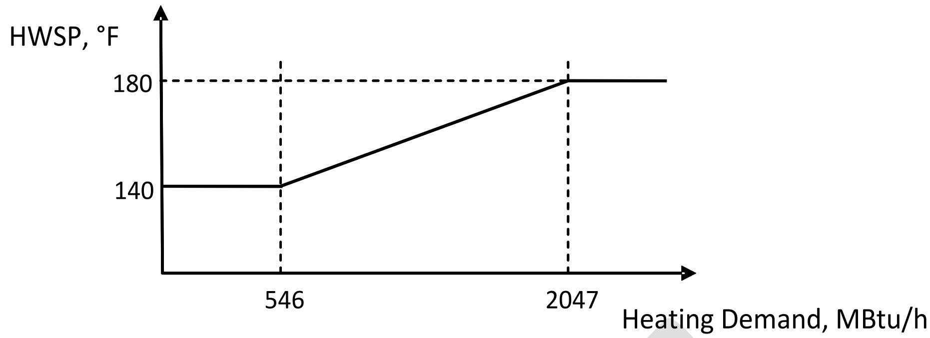

Figure 22. Hot water temperature reset according to heating demands

Boiler sequencing

If more than one boiler is installed then a boiler sequencing control will be used to designate one boiler as a lead and one or more as a lag boiler. There are two identical boilers in the current heating plant loop. In poor practice, both of the boilers are running when heating is demanded. In average practice, the lag boiler is loaded based on the outdoor air temperature. In good practice, the lead boiler will be enough to heat the building in times of smaller heating demand and the lag boiler(s) will be switched off until the lead boiler reaches full capacity.

Results

Figures 23, 24, and 25 show the annual site energy variation due to the range of practice for each operational parameter, in all four cities for large, medium, and small offices respectively. The figures show the percentage change in annual site energy for good and poor practice relative to average practice, with negative numbers indicating a reduction in energy use and positive numbers indicating an increase in energy use. For each parameter that was set to poor or good practice, all other parameters were set at the average practice. Therefore the change shown for each parameter represents the impact of poor or good practice for that parameter alone.

Figure 26 shows the combined effect of having good or poor practice across multiple parameters in two scenarios: 1) good or poor practice in all HVAC parameters, keeping lighting and plug load parameters at average practice, and 2) good or poor practice in all parameters i.e. HVAC, lighting and plug loads. The numbers are indicative of the range of variation when all or most parameters are in good or poor practice.

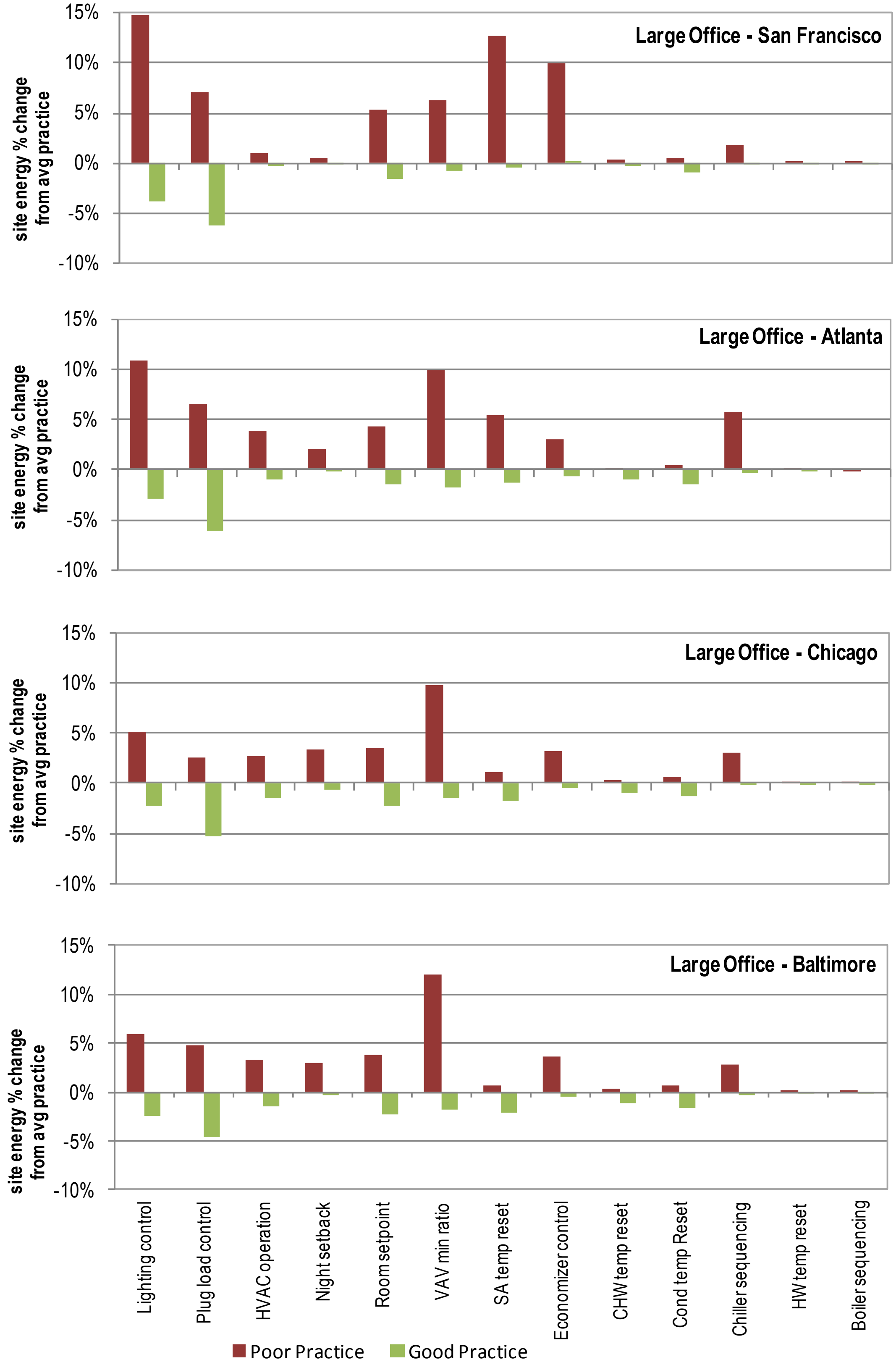

Figure 23. Annual site energy variation due to operational practices for large offices

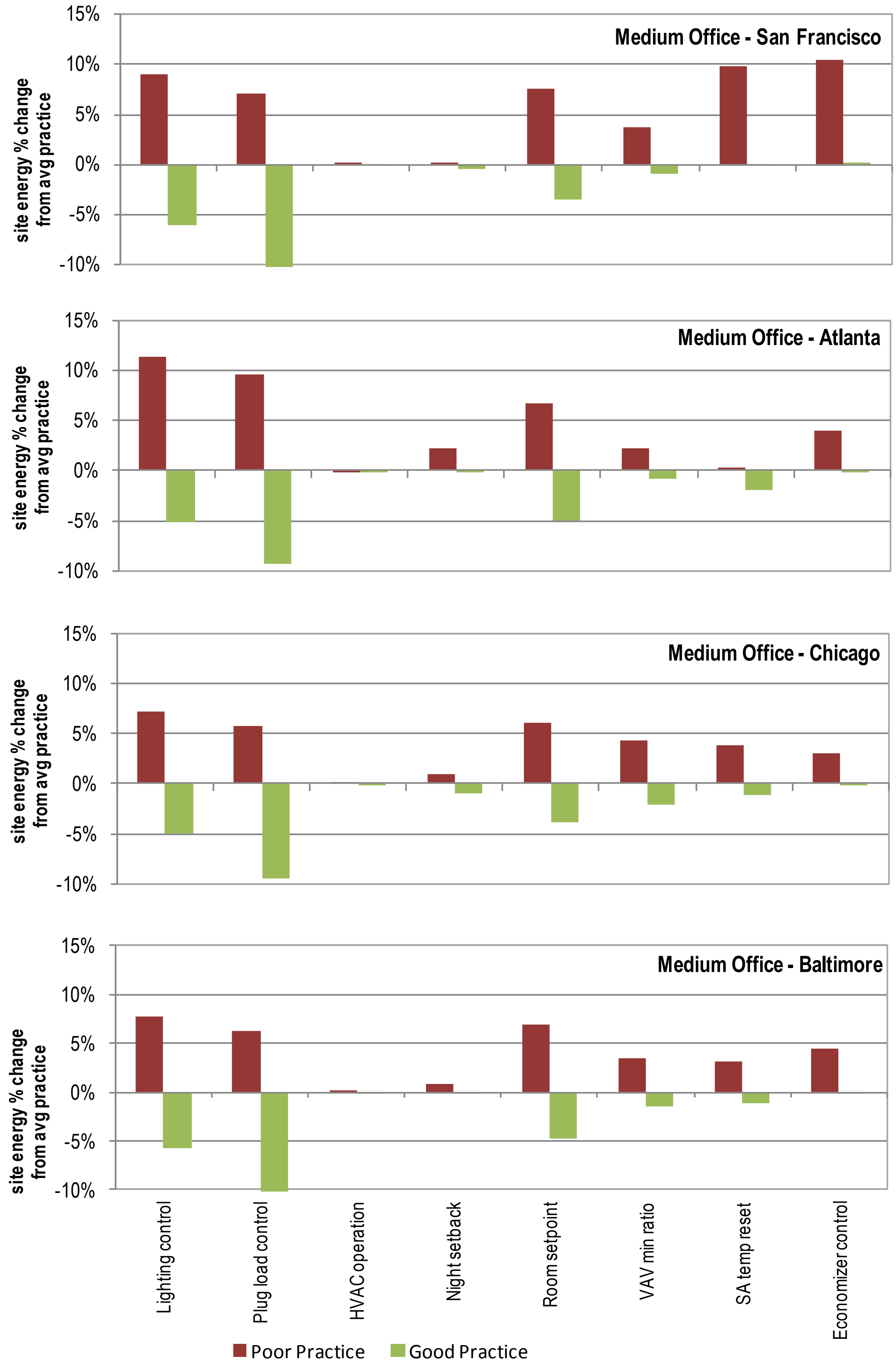

Figure 24. Annual site energy variation due to operational practices for medium offices

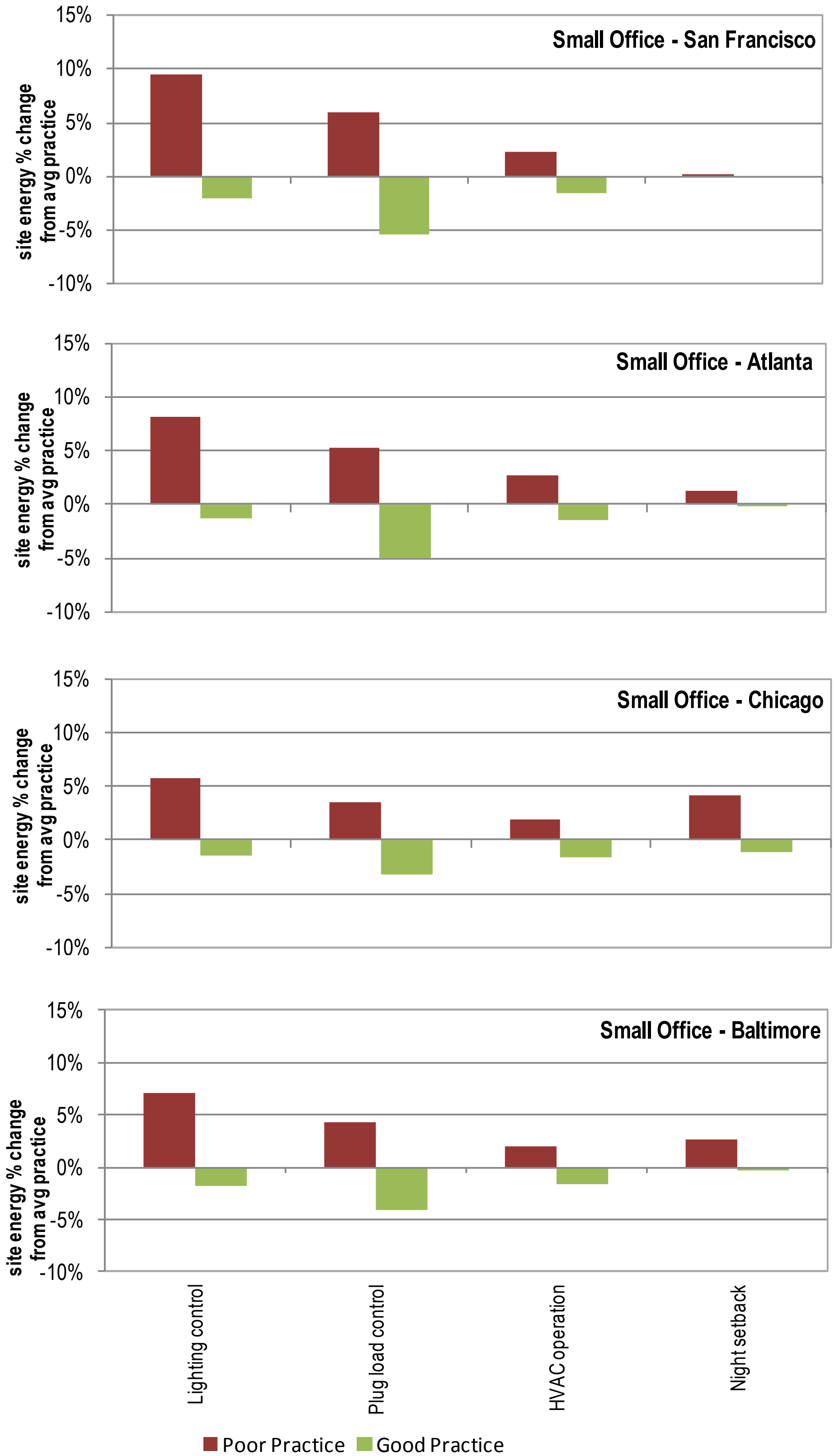

Figure 25. Annual site energy variation due to operational practices for small offices

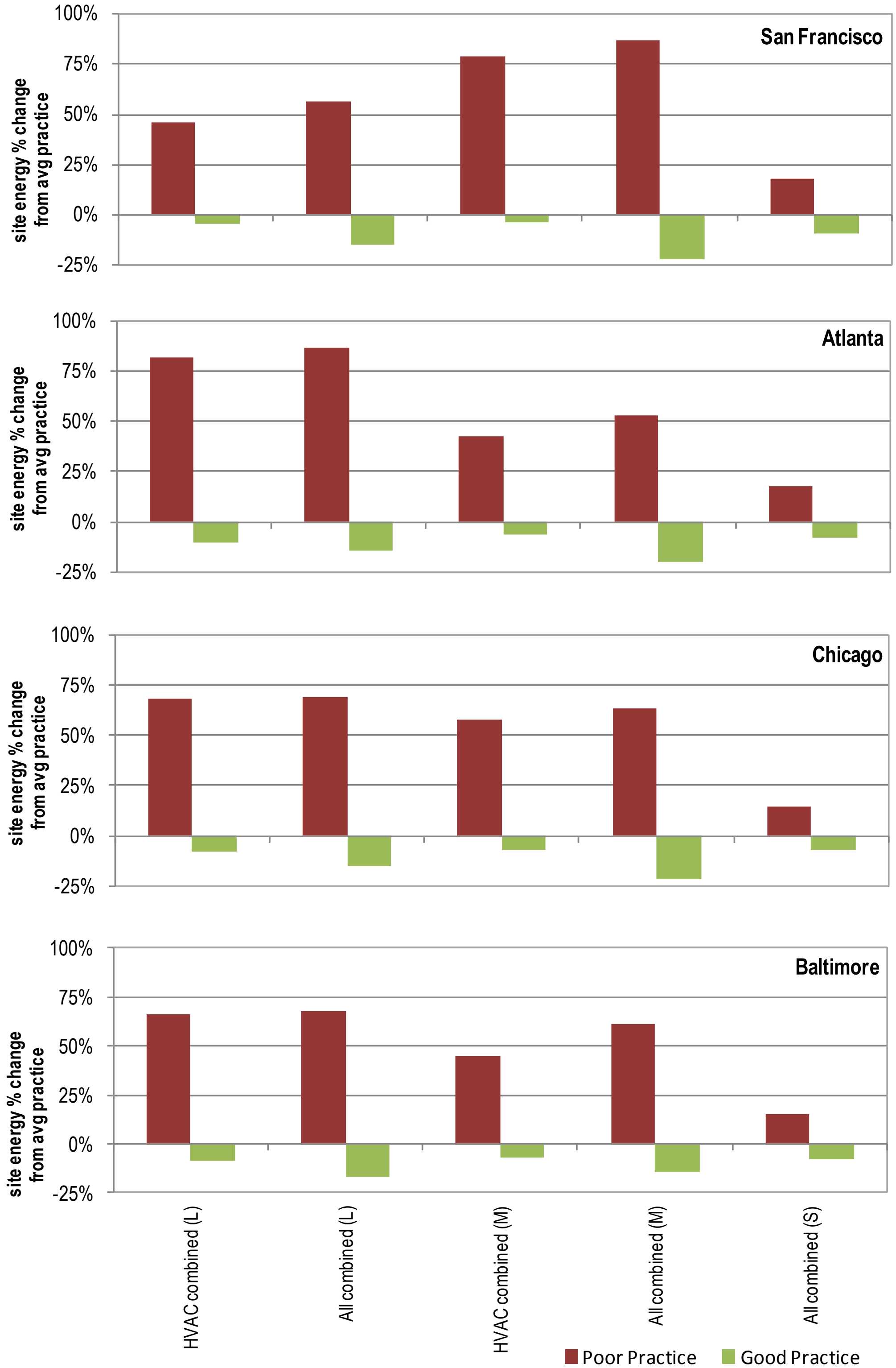

Figure 26. Annual site energy variation due to the combined effects of operational practices for large (L), medium (M) and small (S) offices. 'HVAC Combined' implies good or poor practice across all HVAC parameters. 'All combined' implies good or poor practice across all parameters (HVAC, lighting and plug loads)

In general, the reduction in energy use from average to good practice is much less than the increase in energy use due to poor practice. The results for large offices show that an individual parameter can affect overall building energy use by -5% to +15%. The parameters with the largest variations are lighting control, plug load controls, VAV minimum ratio settings, and supply air temperature reset. This trend generally holds for medium offices as well. (However, medium offices show very low volatility due to HVAC operation schedule variation. This is because medium offices utilized a different modeling assumption wherein the temperature setpoint schedules were kept constant and therefore the poor and good practice cases were very similar to the average case with night cycle control.) Large offices located in warm-marine climate present less energy volatility than large offices located in cool, mixed and warm-humid climates, which demonstrate similar energy volatilities. Energy volatilities for medium offices across four climates are comparable.

Only four parameters were analyzed for small office buildings operation, as some of the other parameters are not relevant to smaller buildings. Small offices exhibit the least energy volatilities among the three office building sizes. Similar to the results for large and medium offices, plug load and lighting control show the highest variation in annual site energy use. Energy volatilities for small offices across the four climates are comparable.

As figure 26 shows, the combined effect of good or poor practice across multiple parameters is significant – for large offices, it ranges from -17% to 87% for the combination of all parameters and -9% to 82% for the combination of HVAC parameters. The combined effect of poor practices across all HVAC parameters is larger than the impacts of the sum of individual effects for each HVAC parameter. Again, note that these variations are just the effect of operational practices, and not differences in fixed asset characteristics. That is, two identical buildings with the same building construction and equipment can show wide variation in energy use just due to their operational practices.

3.4 Volatility due to vacancy level

Two vacancy levels are considered in this study: 10% and 20% of total floor area. For each level, the good practice assumes that in the vacant space the HVAC set point is set back as 55°F for heating and 90°F for cooling, lights are turned off and there are no plug loads. Poor practice assumes that in the vacant space, the HVAC and lights have the same operation schedule as occupied spaces, and there are no plug loads. These vacancy levels were modeled for large and medium offices.

The annual site energy savings of good practice compared to poor practice is illustrated in Figure 28. Good practice results in 3.4%-9.5% of annual energy savings compared to poor practice, with no significant differences across the four climates. The annual energy savings with good practice in large office buildings is greater than those in medium office buildings.

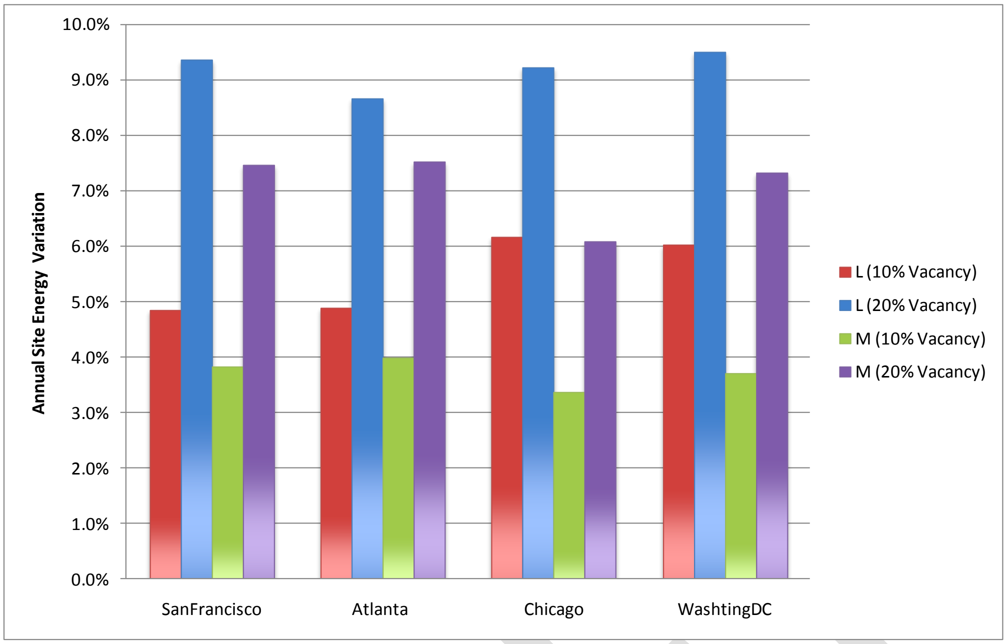

Figure 27. Annual site energy savings of good practice compared to poor practice conditions in vacant spaces, for two different vacancy levels.

4 Proposed Approach for Energy Use Volatility Protocol

To determine energy use and volatility in the context of mortgage valuation, we propose an approach that utilizes actual operating data and ASTM E2797 whenever appropriate, complemented by simulation and other methods, based on data availability and desired level of rigor.

Broadly, the process can be divided into two parts: 1) determine average energy use; and 2) determine energy use volatility. The overall approach is indicated in figures 28 and 29. Sections 4.1 and 4.2 provide more information on the numbered steps in part 1 and 2 respectively.

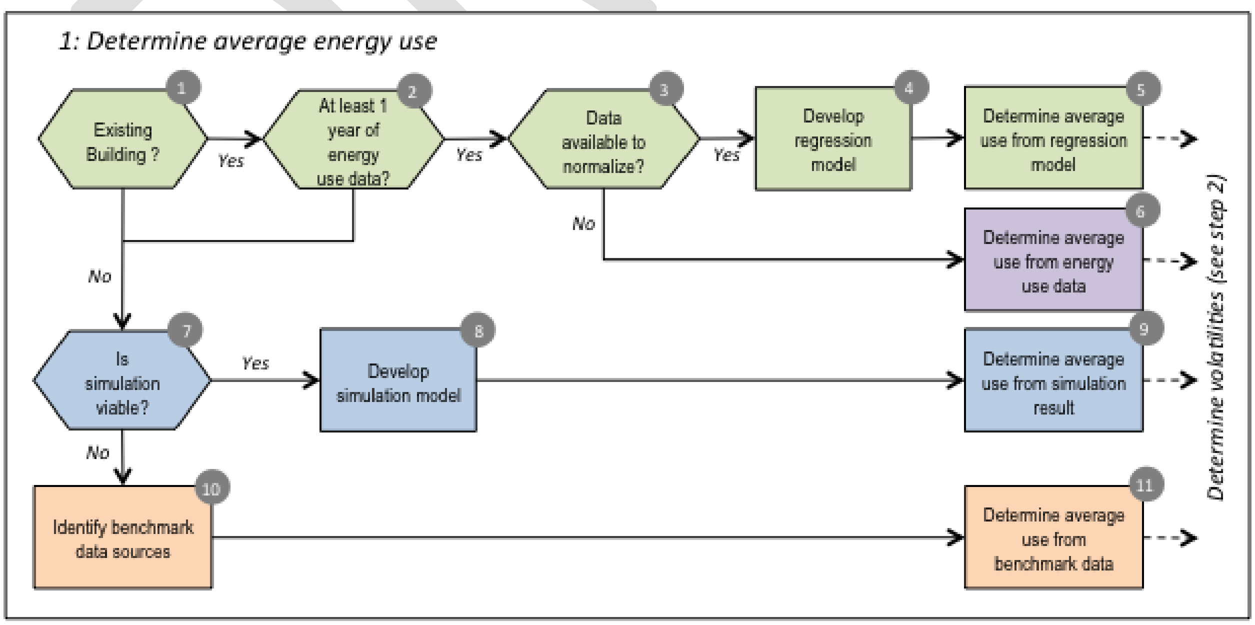

Figure 28. Overall process to determine average energy use.

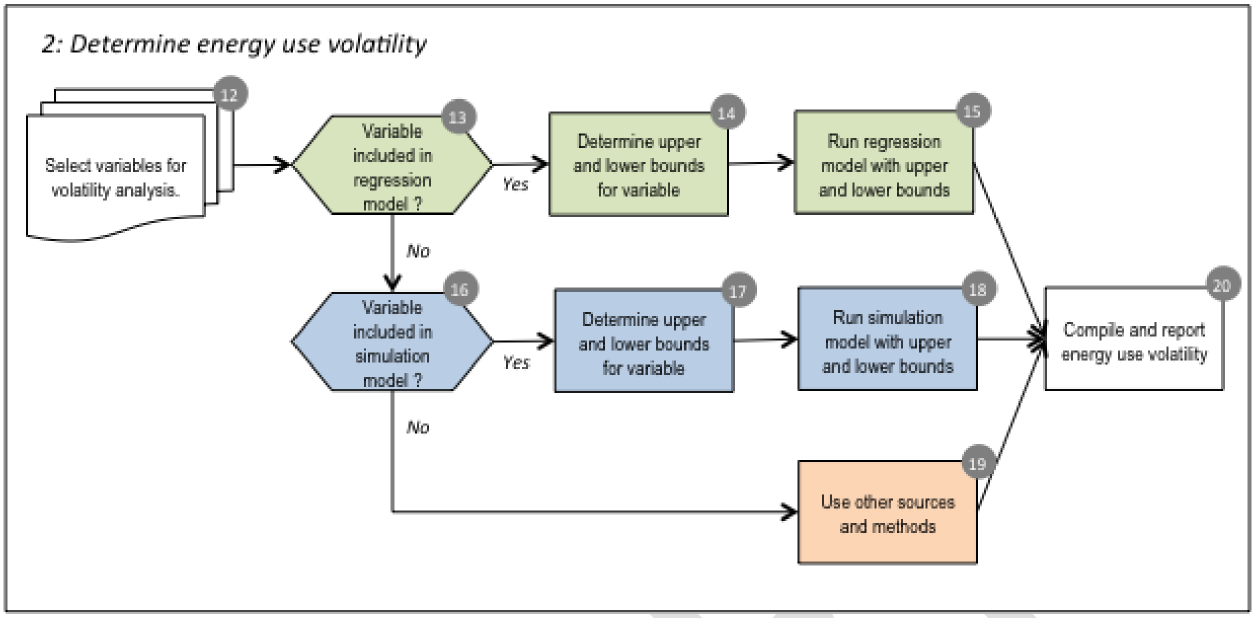

Figure 29. Overall process to determine energy use volatility

4.1 Determine average energy use

To determine average energy use, refer to figure 28 for the overall sequence. Note that these steps are not necessarily sequential and depending on decision points, some steps will be by-passed or not applicable.

1. *Existing building?*

Is this an existing building or new construction? In this context, an existing building is one that has been in operation under normal occupancy conditions for at least one year.

2. *At least one year of energy use data?*

Is there at least one year of measured monthly energy use data for all energy types i.e. electricity, natural gas, fuel oil, etc.? If data are not available, go to step 7.

3. *Data available to normalize?*

Are adequate data available on the independent variables to normalize historical energy use data using regression analysis? (If data are not available, go to step 6.) Consider using ASTM E2797 as a guideline for this step (particularly section 11.4). The independent variables include weather, vacancy levels, and any operational characteristics that significantly affect energy use. For weather, heating degree-day and cooling degree-day data are usually used as independent variables and are available from weather files (e.g. TMY stations). Operations hours and vacancy levels may be obtained from building operations records.

4. *Develop regression model*

Develop a regression model that relates the energy use (dependent variable) to the independent variables. A separate regression model should be developed for each energy type. Most statistics packages available today have the capability to conduct multiple regression. Consider using ASTM E2797 as a guideline for this step (particularly section 11.4).

5. Determine average use from regression model

Calculate the average energy use by running the regression model for each energy type with average values for the independent variables. The average values for the independent variables may be determined either from the historical data or expected values for the mortgage term. As in steps 3 and 4, consider using ASTM E2797 as a guideline for this step (particularly section 11.4).

6. Determine average use without normalization

If step 3 determined that there were inadequate data to normalize historical energy use, simply calculate the average the historical data for multiple prior years. If there is only data for one year, use those data.

7. Is simulation viable?

The two major considerations to determine if simulation is viable are: 1) data availability; and 2) personnel skill and availability.

Development of a simulation model requires fairly detailed data on building geometry, construction, equipment characteristics, occupancy characteristics and operation schedules. In the case of new construction these data are usually readily available in construction drawings and specifications. In fact, simulation models may have already been developed to explore energy efficiency options or for LEED certification. In existing buildings, if drawings and specifications are not available or are not current, data collection may be too burdensome and therefore simulation may not be a viable option for this particular purpose.

The development of a simulation model also requires specialized expertise – and the cost or unavailability of such expertise may preclude the use of simulation.

8. Develop simulation model

Several different simulation tools are available. If the building has unusual construction or equipment, it is important to ensure that the simulation tool can effectively model these features. There is unfortunately no standard way to use simulation tools and quality control is a key issue. The COMNET protocol [COMNET 2010] could be used to reduce uncertainty in modeling assumptions. For existing buildings, the model should preferably be calibrated to actual performance, although this usually requires significant effort.

9. Determine average use from simulation result

Simulation tools provide detailed results and annual energy use is a standard output.

10. Identify benchmark data sources

If neither regression nor simulation are viable, benchmark data may provide a “last resort” option for estimating average energy use. This approach should be used with caution because benchmarking tools are used to compare a building’s energy use to its peers, not to estimate the energy use of the building itself. However, to the extent that the peer buildings have similar characteristics, the average energy use of the peer buildings may be a proxy for the subject building. Several benchmark data sources are available, including the Commercial Building Energy Consumption Survey (CBECS) and the California Commercial End Use Survey (CEUS). Some organizations such as property management companies may also use their own portfolio data as a benchmark data set.

11. Determine average use from benchmark data

For example, Figure 30 shows the energy use intensity (energy per unit area) distribution for office buildings of a certain size, vintage, and location from the EnergyIQ tool (EnergyIQ.lbl.gov). The energy intensity would be multiplied by the area of the subject building to determine average energy use.

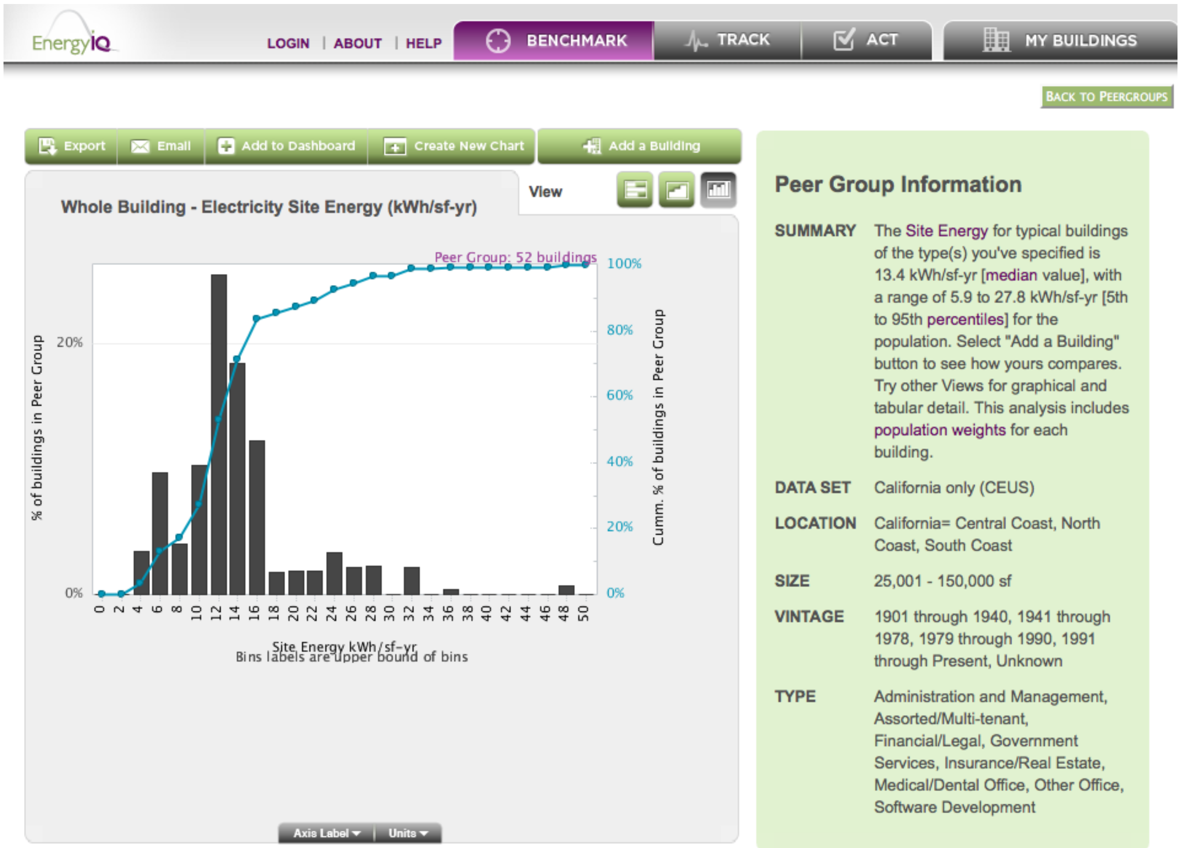

Figure 30. Example of benchmark data from EnergyIQ

4.2 Determine energy use volatility

Refer to figure 29 for the overall sequence. Note that these steps are not necessarily sequential and depending on decision points, some steps will be by-passed or not applicable.

12. Select variables for volatility analysis

The variables for volatility analysis generally fall into three categories: weather, vacancy levels, and operational practices. The list of variables may include the independent variable(s) used for normalizing average energy use (step 3,4) as well as additional variables. Volatility may be determined separately for each variable or in combination, depending on the risk analysis and management objectives.

13. Variable included in regression model?

If a regression model was developed in step 4, was this variable included? For example, weather variables, vacancy levels and operation hours may have been included in the regression model and their impacts on energy use volatility could be assessed using the regression model.

14. Determine upper and lower bounds for variable

Determine upper and lower bounds for the variable. For example, this may be the minimum, 5^{th} or 25^{th} percentile for lower bound, and maximum, 95^{th} or 75^{th} percentile for the upper bound. The selection of these bounds should be driven by the risk analysis and management objectives. ASTM E2797 recommends using the 25^{th} and 75^{th}percentiles for weather (HDD, CDD), vacancy levels, and operation hours.

15. Run regression model with upper and lower bounds

Perform multiple runs of the regression model to obtain the energy use with upper and lower bounds for each variable separately, as well as with upper and lower bounds for all variables together i.e. to evaluate the impact of upper and lower bounds for each variable separately as well as in combination.

16. Included in simulation model?

If a simulation model was developed in step 8, can this variable be parametrically analyzed with the simulation model?

Simulation models allow for parametric analysis of a wide range of operational characteristics for which empirical data may not be available. Indeed, for most operational practices, simulation is the only viable means to analyze volatility.

17. Determine upper and lower bounds for variable

See guidance in step 14. If empirical data are not available for determining upper and lower bounds, as is likely to be the case for most operational practices variables, they may be determined based on expert opinion and experience from current practice.

18. Run simulation model with upper and lower bounds

Perform parametric simulation runs with upper and lower bounds for variables separately and in combination, as desired for risk analysis and management.

19. Use other sources and methods

For variables that were not analyzable by regression modeling or simulation, options for estimating volatility include the following:

- Use prototype simulation models: As demonstrated in technical analysis in section 3, prototype models such as the DOE reference models can be used to determine the volatility for a prototype case (e.g. large office building in Chicago climate). The relative volatility ranges for the prototype could then be applied to the average use to obtain volatilities for the subject building. A hybrid approach would be to make selected modifications to the prototype simulation models to reflect the subject building's characteristics.
- Case studies: Retro-commissioning (RCx) case studies may offer a good source of data to estimate volatility due to operational practices i.e. many RCx measures are in fact corrections to poor operational practices and therefore the savings from these measures area crude proxy for the range of energy use volatility for that practice.
- Analysis from similar buildings. The relative volatility ranges from regression or simulation analysis of similar buildings could be applied to the average use to obtain volatilities for the subject building.

20. Compile and report energy use volatility

Compile and report the energy use volatility in a manner appropriate for input to the mortgage valuation process. The data should include the following:

- Average energy use for each fuel type – annual and monthly values.
- Modeling approach and assumptions used to calculate average energy use, including (as applicable):
    - Regression equation used to normalize average energy use
    - Simulation tool and input values
    - Benchmarking tool and input values (if benchmarking was used)
- List of variables for which volatility was determined, and their upper and lower bounds.
- Energy use volatility (upper and lower bound values of energy use) for each variable and combination.
- Modeling approach and assumptions for each variable, including (as applicable):
    - Regression equation
    - Simulation tool and input values
    - Other methods and sources

5 Conclusions

This report presented current practice for estimating energy use volatility for commercial mortgage valuation (section 2); a simulation analysis to demonstrate the relative volatility due to weather, vacancy levels and operational practices (section 3); and a proposed energy use volatility (EUV) protocol (section 4) that applies empirical and simulation-based methods to determine energy use volatility metrics for application in commercial mortgage valuation.

A companion report for this project [Jaffee et al. 2011] documents the results of incorporating energy cost risks into mortgage valuation. An analysis of loans with different mortgage contract structures and locations showed that the inclusion of the energy channels generates mortgage values that are on average about 8.89% below the value of the mortgages using the traditional modeling approach (which ignores the energy channel in valuing the embedded default options). A 20% reduction in energy use resulted in 1.3% average increase in mortgage value. The size of these elasticities varies importantly across buildings, mortgage contract structures, and regions. Overall, the reductions in energy consumption appear to benefit the higher loan-to-value ratio mortgages and larger buildings. This result, admittedly based on a very small sample, suggests that energy efficiency should affect the mortgage cost of capital.

Future work may include additional analysis of the impact of operational parameters, risk management methods to reduce the volatility of operational parameters, and the development of a detailed protocol for EUV.

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