Efficiency and Demand Flexibility in Large Office Buildings

Detailed Methodology

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This document details the methodology and tools used to estimate changes to large office building load patterns, customer utility bills, operating costs for utilities and associated grid emissions across a range of efficiency and demand flexibility measures. This document is supplementary information. The background and results of the implementation of this methodology is provided in the main report:

McLaren, Joyce; Thomas Bowen, Chioke Harris. 2023. *Efficiency and Demand Flexibility in Large Office Buildings.* National Renewable Energy Laboratory: NREL/TP-7A40-83552.

Associated data and full results are available in the NREL Data Catalog at: https://data.nrel.gov/submissions/205.

Figure 1 summarizes the methodological workflow described in this documentation, which is organized as followed:

Section 1.1 discusses the tools and datasets employed in the study.
Section 1.2 discusses the measures analyzed, how the load patterns were developed, and the changes in load patterns associated with each measure.
Section 1.3 discusses how the impacts of the measures on customer bill savings were calculated.
Section 1.4 discusses how the impacts of the measures on grid operating costs and CO_2 emissions were calculated.

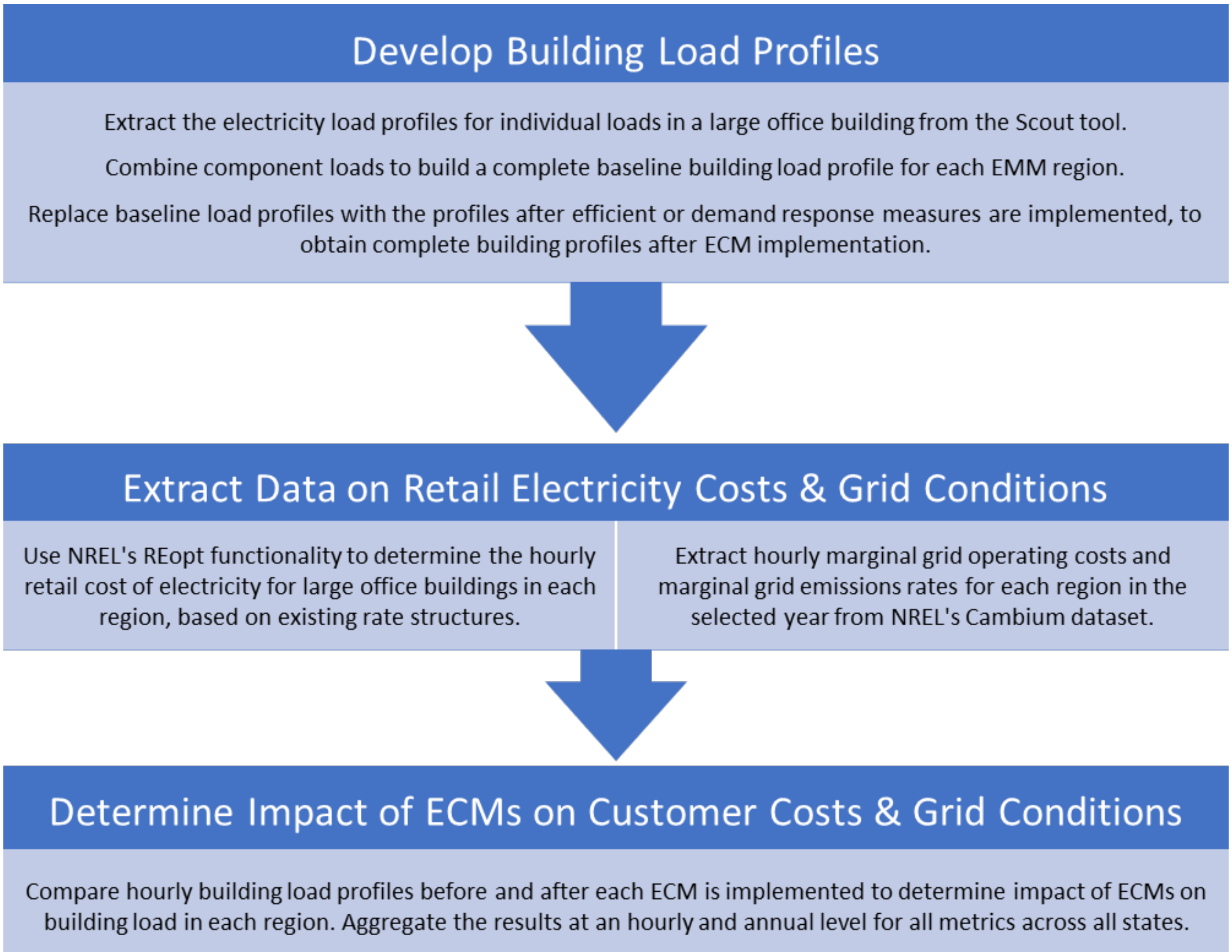

Figure 1: Methodological workflow for the analysis

1.1 Tools and Datasets

This study relies on several tools and datasets to estimate the impacts of various energy efficiency and demand flexibility measures on customers and the power system. Table 1 outlines the tools, summarizes how each was used in the analysis, and lists the geographic granularity inherent within each tool or dataset.

Table 1: Tools and datasets used in the analysis

Tool / Dataset	General Use	Analytical Outputs Used in this Study	Geographic Granularity
Scout	Models the impact of implementing a variety of measures in residential and commercial buildings.	Building load profiles before and after measures. (See Section 1.2 for additional detail)	EIA Energy Market Module Region
REopt	Optimizes energy systems for buildings, campuses, communities,	Processing of electricity bills based on sample large office building	100 km^2

	microgrids, and other load centers. Recommends the optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings, resilience, and energy performance goals.	location, tariff and load patterns associated with given measure. (See Section 1.3 for additional detail)	
Cambium	Data sets of simulated hourly cost and operational data for a variety of U.S. electricity sector futures (aligned with NREL's Standard Scenarios)	Data on the marginal conditions of the power system in each region, including: • Short run marginal operating costs and capacity costs • Long run marginal emissions rates (See Section 1.4 for additional detail)	ReEDs Balancing Areas

The tools outlined in Table 1 are leveraged to identify the individual impact of energy conservation measures on customer bills and the power system more broadly. However, these tools and datasets are not currently interlinked, which limits the ability to derive holistic insights and relationships between the metrics.[1]

Significant effort was taken to ensure that the datasets could be appropriately aligned at a uniform geographic and temporal resolution, but several assumptions had to be made when 'merging' the datasets. The specific challenges of interlinking these tools, as well as the assumptions and the risks they introduce to the analysis are discussed below. Overall, it should be noted that this study relies on exogenously comparing various datasets and that, in practice, the actual interactions between the variety of electricity system components may drive different results.

1.2 Calculating load reductions from efficiency and demand response measures

The impact of measures on a building load in each state were calculated by comparing a 'baseline' load profile with an 'efficient' load profile, which represent the building load before and after the measures are implemented. The DOE Scout tool was used to generate these load profiles, starting from the DOE commercial prototype Large Office building profile (2004 vintage).

Scout applies measures to individual components of building loads; each component is associated with specific energy uses in the building. Combined, the component building loads

[1] For example, Scout provides information on building load patterns based on maintaining occupancy comfort levels. In practice, however, building owners must also consider utility bill affordability. Under different tariffs, a building owner might modify their load through measures differently to balance comfort and affordability. Furthermore, Cambium provides information on marginal grid conditions; however, significant changes to building load patterns enabled by measures could, if widely adopted, alter system load enough to create new marginal grid conditions.

form a complete building load profile. Examples of component building loads in large office buildings include:

- Commercial Refrigeration
- Commercial Miscellaneous Electrical Loads (MELs), i.e., plug loads
- Commercial Electric Heat Pump/Water Heater
- Commercial cooling
- Commercial Lighting

For each of the component building loads, there is a baseline scenario (representing the energy use prior to measure implementation), and one or more efficient scenarios (representing the load after measure implementation). In applying the measures, Scout considers the building type, vintage, climate zone, and measure technology. Scout outputs the component loads before and after the measure is applied.

We then create a complete baseline load profile, by combining individual components of a large office building's energy use from Scout. We create a complete building load profile for an individual, representative office building within each state for the year 2023. This baseline is compared with the load profile after one or more measures is deployed. Only the component load impacted by the measure changes. For example, the lighting load component is altered through efficiency and demand response. Scout provides information on component building load profiles for a wide range of building types and a wide range of measures. Additional information on the individual load components can be found on the Scout documentation.

Some measures interact with one another when they are implemented at the same time. Often interactions are complex, and these must be considered during the modeling and interpretation of the results. For example, increasing the efficiency of a cooling system typically reduces the amount of load that can be shed during peak periods (a demand response measure). Scout models this combined effect of multiple measures, and so these interactions are accounted for in the results presented below.

The measures modeled in this study include lighting energy efficiency to simulate occupancy controls, lighting demand response to reduce load during peak hours, cooling upgrades to increase efficiency, cooling demand response to simulate global temperature adjustments, and precooling to reduce load during peak hours. Due to the nature of the measures, *either* cooling demand response *or* pre-cooling are implemented, but never together. Table 2 defines how each of the measures studied are deployed in the model.

Table 2: Definition of Energy Conservation Measures studied in the Analysis

Measure(s)	Definition
Lighting EE	Lighting efficiency measures follow ASHRAE's Advanced Energy Design Guidelines. Lighting power density is reduced by an additional 15% from the base lighting schedule as a proxy for occupancy controls (per AEDG modeling guidance). Daylighting controls in the perimeter zones are set at 300 lux setpoint.

Lighting DR	Reduces lighting load during peak hours by 30% for occupied spaces and 60% for unoccupied spaces. Thresholds maintain comfort and safety (e.g. stairwells, hallways).
cooling EE	This measure makes upgrades the existing water-cooled centrifugal chiller with 5.5 COP (co-efficient of performance) to a chiller of the same type with 7.0 COP.
cooling DR	A global temperature adjustment (GTA) measure that adjusts zone temperatures during the peak hours. In summer the set point temperature increases from 75ºF to 80ºF GTA during the peak period, maintaining a comfort range of 73ºF–80ºF based on ASHRAE Standard 55-2017. In winter the set point temperature decreases from 70ºF to 68ºF GTA during the peak period to maintain a comfort range of 68ºF–78ºF based on ASHRAE Standard 55-2017.
cooling Pre-cooling	Adjusts zone cooling temperatures downwards for the 4 hours preceding the peak period. (No pre-heating is assumed in winter since the risk of discomfort at 68ºF is low, particularly given that the peak period begins in the evening hours, when most commercial buildings have low occupancy.)

1.2.1 Developing Individual, State-level Load Profiles

From a geographic perspective, the Scout load profiles were each associated with one of the 22 U.S. EIA Electricity Market Module (EMM) regions as outlined in the 2019 Annual Energy Outlook and shown in Figure 2 (EIA 2019; Scout documentation).[2,3] Some states have area in multiple EMM regions. When calculating the impact of measures on marginal grid conditions such states are assigned to the EMM region that covered the most area. When calculating the impact of measures on customer bills, multiple EMM regions could be assigned to a state, so that load variations across the state could be captured. The appendix in the main report provides the mapping between state and EMM region.[4]

[2] Since the development of this analysis, EIA EMM regions have been modified in Scout. To see the current EIA EMM regions, please reference the Scout Documentation: https://scout-bto.readthedocs.io/en/stable/measure_reference.html#eia-electricity-market-module-emm-regions.

[3] There are a total of 22 U.S. EIA EMM regions, but only 21 regions were considered in this study due to difficulties in merging datasets. The MROE (MRO East) and parts of the RFCW (RFC West) regions in Wisconsin and the Upper Peninsula of Michigan were merged into the MROW (MRO West) region.

[4] To scale the building load from a EMM region to a single building, we used the total building footprint associated with an average large office building (498, 588 ft^2), and the total regional building footprint associated with each EMM region (see appendix in main report for EMM region to building square footage mapping).

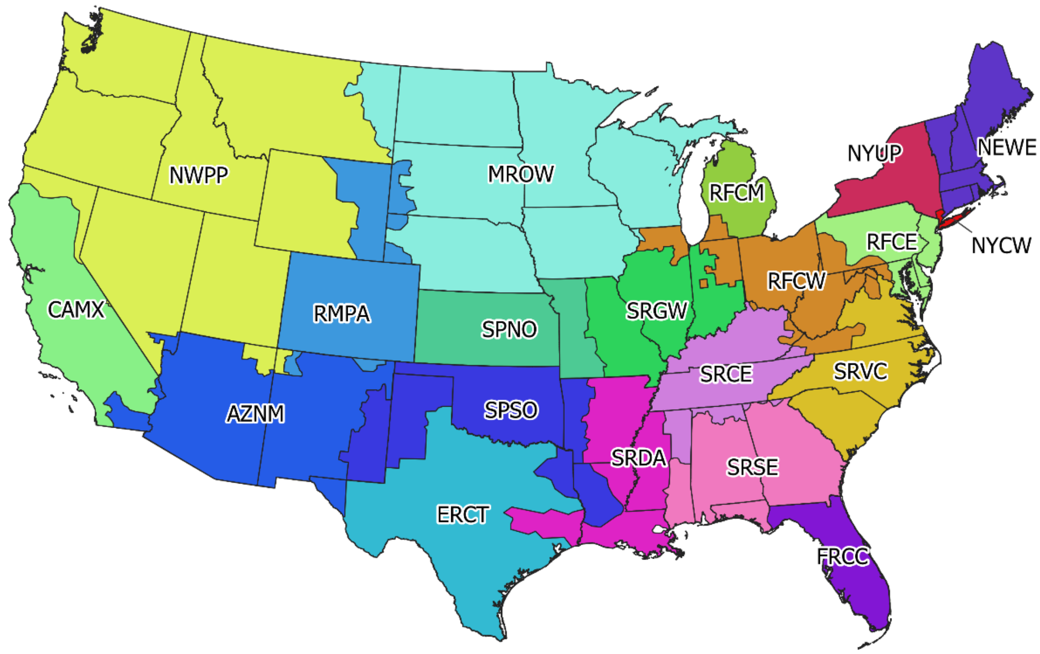

Figure 2: Map of EMM Regions Considered in this Analysis

1.2.2 Assigning a year to load profiles

Hourly data from Scout is not associated with a particular year (2022, 2023, etc.) but the weekly and diurnal load patterns are based on a standard year (no leap-days) starting on a Sunday (e.g. 2017, 2023, 2034), and the time zone associated with the data is based on a local time zone occurring for the majority of the EMM region. That is, the data is agnostic to time zones, and is associated with whichever local time zone the theoretical office building is located in. For this study, we assigned a time zone to each state, based on the time zone that covers much of the state, and assumed a starting year of 2023.[5]

1.3 Calculating customer bill savings

To determine the approximate customer bill savings, the desktop version of NREL's Renewable Energy Optimization Tool (REopt) was used to both identify appropriate rate tariffs and to calculate customer bills. Typically, REopt is used to evaluate the economic viability, optimized system size, and dispatch strategies of distributed solar PV, wind, battery energy storage, combined heat and power and thermal energy storage technologies. In this analysis, we suppressed the deployment of any accompanying generation or storage technologies, and calculated customer utility bills for customer load profiles taken directly from Scout for each measure, and each scenario, at significant geographic granularity.

[5] While not critical for the hourly load data by itself, these assumptions on 'absolute' time periods as opposed to Scout's native 'relative' time periods become increasingly important when merging with other datasets associated with absolute times, such as Cambium.

REopt draws from the [Utility Rate Database (URDB)]() for the identification and characterization of qualifying commercial retail tariffs. For each scenario, the retail tariff(s) were identified that are applicable to a large office building in the given geographic location, given the electricity demand of the building and the customer class. For each relevant rate tariff, hourly rate profiles (the cost of electricity during each hour of the year) were constructed using the data from the URDB on the hourly weekday and weekend rates (energy charge, demand charge, and fixed costs) for each qualifying retail tariff. These rate profiles were then compared to a building load profile to estimate electricity bills for customers representing large office buildings. For each measure baseline and efficient scenario explored, the tariff associated with the lowest electricity bill was then down-selected.

To calculate the customer bill savings for a measure, we compared the electricity bills (calculated using the above process) before and after the measure was implemented. In a few cases, the least expensive tariff differed for the before measure scenario and the post-measure scenario, and the results include these tariff changes. This aligns with our expectations that the energy manager of a large office building would switch to a new tariff after implementing a measure, if doing so would reduce electricity costs.

While load profiles varied by EMM region, large office building electricity bills were calculated for qualifying retail tariffs for each 100 sq. km. block in a grid spanning the continental United States, based on the available granular spatial resolution of utility service territories. The cheapest tariff for each 100 sq. km block was identified using a module within REopt that initiates requests and organizes responses to and from the URDB. Figure 3 shows how the continental United States was broken down into 100 sq. km. blocks and information on retail tariff rates were identified for each block using the URDB.

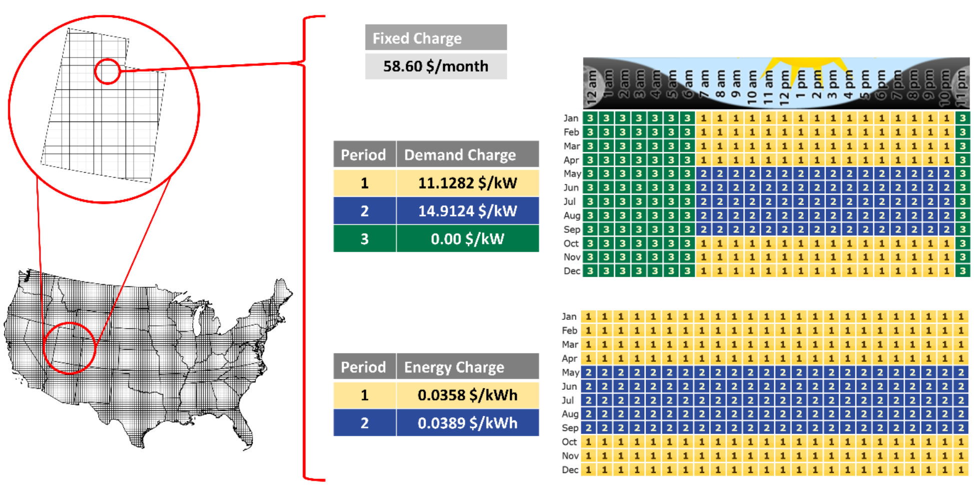

Figure 3: Retails tariffs are assigned at a sub-state granularity to estimate customer bill savings associated with measures.

The example utility rate shown here contains common commercial tariff components, including a fixed charge, time-varied demand charge, and seasonal energy charge.

It should be noted that the measure measures in Scout are deployed generically based on an understanding of how building occupants might use measures to maintain heating, cooling, and lighting comfort levels. The measures do *not* capture how customers or energy managers would deploy given measures in response to a particular retail tariff rate. In practice, a building energy manager might adjust demand response measures to take advantage of local retail tariffs. For instance, if a large office building was on a time-of-use rate (either demand charge or volumetric energy charge) the energy manager might time a pre-cooling period for a cooling system with a low-cost period to avoid consumption in a more expensive period. Since the Scout measure load patterns were exogenously compared to the retail tariffs these factors could not be considered, and therefore the load patterns are not optimized to reduce bills. *Thus, the bill savings estimated here may not capture the full potential of a measure.*

1.4 Calculating Impacts on the Bulk Power System

Cambium is a dataset that provides information on the conditions of the bulk power system for the continental United States (Gagnon, 2020).[6] Cambium relies on a capacity expansion model, the Regional Energy Deployment System (ReEDS) model, and a production cost model (PLEXOS) to generate information on future operational and cost characteristics of the grid for the United States. The Cambium dataset was used in this study to provide estimates for the impact on the bulk power system due to changes in load patterns caused by various energy efficiency and demand response measures. The two main sets of metrics explored to estimate 'impact' were changes in the costs of operating the power system and changes to emissions from the power system.

The Cambium dataset provides information on the power system in hourly increments for every other (even) year out to 2050, and can be aggregated to different geographic levels, including at the state-level, which was used in this study. Depending on the local time zone for a given state, the Cambium data for 2022 was shifted such that the day of the week and the hour matched that of the Scout data (which is time zone agnostic but based on a standard year). This is critical as both grid conditions and office building load have both intraday (e.g., morning vs. evening) and inter-day (e.g., weekday vs. weekend) patterns, in addition to seasonal patterns. To determine the impact of a given measure on the power system, the hourly difference in load between the baseline and efficient measure scenarios was compared with the equivalent hourly Cambium value for either grid operating costs or emissions. For an additional discussion on the limitations of using Cambium in this study see the appendix in the main report.

[6] Since the development of the model used in this analysis, the Cambium model and associated data have been updated (compare Gagnon et al. [2020] and Gagnon et al. [2021]). Updates in the latest version of Cambium have been made to how marginal grid emissions are calculated. Future work in this space could take advantage of these new data as well as new Cambium scenarios to develop a better indication of the potential for measures to reduce grid emissions (see the Conclusion for additional suggestions for future work).

1.4.1 Calculating reductions in grid operating costs

To calculate the impact of certain measures on the operating costs of the power system, the energy, capacity, and policy Cambium metrics were combined into a single hourly 'grid value' metric that tracked overall cost impacts to the system (excluding ancillary services).[7]

Notably these costs do not capture all the costs associated with building and operating the electricity system, and do not capture all the costs that targeted changes in load could feasibly influence, particularly costs around the distribution system.

1.4.2 Calculating CO2 emissions reductions

When a particular measure can consistently reduce demand within a given period (e.g. summer afternoons), the impacts to emissions from the power sector are two-fold: (1) there are immediate changes to the dispatch of generators (because less load is being served), and (2) assuming that this load is consistently reduced at a particular time in the year, there are structural changes due to lower load over the long-term (e.g. there will be smaller investments in certain generation technologies). Cambium's long-run marginal emission rate (LRMER) (*co2_lrmer_enduse*) captures both impacts to the system's hourly emissions rate.

Because the LRMER is meant to capture more structural changes that occur over longer periods of time and our interest includes near-term changes, we did not use the LRMER values directly from Cambium. Instead, we normalized the values over 15 years, which is assumed to be the standard lifetime of the technologies applicable to the energy efficiency and demand response measures in this study. To normalize the values, individual 'raw' values for each hour and location in the Cambium dataset were taken starting with 2022 and going out to 2037, with the values for the previous even-numbered year used for odd-numbered years. For each of these future values, a discount rate of 6.4% was used to generate an 8,760 hourly array of the net present value of long-run marginal emission rates for each state. The normalized LRMER values were then applied to the changes in load to estimate the impact of load reductions on power system emissions.

Citations

Gagnon,Pieter; Will Frazier; Elaine Hale; Wesley Cole. November 2020. *Cambium Documentation: Version 2020*. National Renewable Energy Laboratory NREL/TP-6A20-78239. https://www.nrel.gov/docs/fy21osti/78239.pdf

Gagnon, Pieter; Will Frazier; Wesley Cole; Elaine Hale. December 2021. *Cambium Documentation: Version 2021*. NREL/TP-6A40-81611. https://www.nrel.gov/docs/fy22osti/81611.pdf

Energy Information Administration. 2019. *Annual Energy Outlook 2019. https://www.eia.gov/todayinenergy/detail.php?id=38112*.

[7] For additional information see 'energy_cost_enduse,' 'capacity_cost_enduse,' and 'policy_cost_enduse' metrics in the Cambium documentation (https://www.nrel.gov/docs/fy21osti/78239.pdf).