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California Energy Commission

CONSULTANT REPORT

California Building Decarbonization Case Study

Prepared for: **California Energy Commission**
Prepared by: **Qualus and ENERlite Consulting**

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California Energy Commission

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ABSTRACT

This report presents three detailed case studies — a large commercial office building, a big-box retail store, and a multifamily residential community — to evaluate practical pathways for decarbonization. The study applies a structured modeling approach, including calibrated baseline energy simulations and parametric analysis of electrification, energy efficiency, and renewable energy strategies. The project team used economic assessments to estimate the total capital and utility costs over a 25-year horizon, excluding incentives, to provide a baseline estimate of building upgrade costs.

Findings indicate that all three buildings can fully decarbonize and reduce energy use intensity by 2045 through cost-effective measures such as heat pumps, heat recovery chillers, advanced controls, and on-site solar generation. Bundled strategies consistently outperform single measures, delivering greater savings and resilience benefits. While upfront investments vary, total costs are modest compared to long-term utility expenditures, and many scenarios yield savings. Lessons learned emphasize the importance of aligning upgrades with equipment replacement cycles, addressing electrical service capacity early, and prioritizing efficient equipment.

Keywords: Decarbonization, Energy Efficiency, Senate Bill 48 (Becker, Chapter 378, Statutes of 2023)

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EXECUTIVE SUMMARY

Study Purpose

The California Energy Commission commissioned this case study to examine real-world pathways for building decarbonization focusing on costs, benefits, and practical challenges. This study will provide policy makers and stakeholders with actionable insights into how existing buildings can eliminate the consumption of fossil fuels while maintaining affordability and reliability to support a statewide strategy for buildings to meet California's midcentury policy goals.

Methods

The authors developed a *decarbonization strategy framework* and applied the 6R Resilient Retrofit Framework (review, reduce, recover, repair, replace, regenerate) to each building in the study. Each case study began with detailed data collection and development of calibrated baseline energy models for each building using the United States Department of Energy EnergyPlus® engine. Multiple EnergyPlus building simulations evaluated electrification, energy efficiency, and renewable energy strategies. Economic analysis converted capital and utility costs to net present values over a 25-year horizon (2035–2060). The studies excluded incentives and tax credits to provide a baseline view of building upgrade costs that do not depend upon future economic policy.

Buildings Studied

The authors contacted building owners and property managers to participate in the study. Three building owners participated in the study and provided the authors with access to their buildings:

- **Large office building** — 700,000 square feet (ft²) high-rise in the San Francisco Bay Area with complex heating, cooling, and ventilation systems and high heating loads.
- **Large retail space** — 57,000 ft² big-box store in Santa Clara County with rooftop packaged units and minimal domestic hot water demand.
- **Multifamily community** — 59-unit garden-style apartment complex in Yolo County with gas-fired space and water heating, in-house and shared laundry, and on-site solar photovoltaic (PV).

General Findings

The analysis of all three case studies revealed trends that can guide technical and policy decisions. While each building presented unique challenges, several overarching conclusions emerged about feasibility, cost, and performance.

- **Cost-effective measures exist for all buildings**: Each building had viable strategies — such as heat pumps, heat recovery chillers, advanced heating, cooling, ventilation, and lighting controls — that reduced energy use and emissions cost-effectively. The authors also investigated measures that are not cost-effective today but could become cost effective under different energy cost scenarios, with technological advances, incentives, or tax credits.

- **Onsite renewable generation**: In alignment with the federal ENERGY STAR® Portfolio Manager definition, onsite renewables such as solar photovoltaic systems and wind turbines reduce the net energy purchased from the grid, but do not affect the site energy use intensity of the buildings. All energy consumed, regardless of generation source, was counted toward the energy consumption of the buildings. While cost-effective decarbonization pathways were achievable for all buildings without relying on onsite solar generation, rooftop solar photovoltaic (PV) was included to demonstrate opportunities for further cost reduction.
- **Full decarbonization is achievable**: With long-term planning and end-of-life equipment replacement, all three buildings can decarbonize fully by 2045.
- **Energy-use intensity is reduced**: Modeled bundles of measures lowered site energy-use intensity by 15–50 percent, depending on building type.
- **Costs are manageable**: Bundled strategies often deliver lifetime utility cost reductions beyond their incremental costs over baseline equipment, even without incentives. However, initial investment costs can be high, which highlights the importance of long-term planning and budgeting.
- **Benefits include grid resilience**: Measures such as battery storage and heat recovery chillers reduce peak demand and demand-related utility charges, and support grid reliability.

Lessons Learned

Beyond the quantitative results, the case studies provided valuable insights into implementation challenges and opportunities. These lessons highlight considerations that building owners, policy makers, and program designers should keep in mind when planning for statewide decarbonization.

- **Bundling measures maximizes value**: Integrated packages of building measures outperform single measures by reducing oversizing and leveraging system interactions.
- **Electrical service capacity may need optimization**: Panel and wiring upgrades may be required for full decarbonization through electrification, especially in multifamily buildings. The multifamily building was the only case requiring electrical service upgrades to achieve full decarbonization, and the panel and wiring upgrades were found to be cost-effective when bundled with other measures. On the other hand, the nonresidential buildings studied had adequate service capacity and did not exhibit significant electric demand increases associated with decarbonization. Careful analysis of service capacity and measure bundling is necessary to avoid the cost of unnecessary service upgrades.
- **Aligning investments with replacement cycles helps reduce costs**: Aligning decarbonization upgrades with normal equipment replacement cycles (replacing equipment at the end of useful life) minimizes incremental costs. Each case study identified several cost-effective measures that can be staged over time to manage capital flow.
- **Premium efficiency equipment pays off**: High-efficiency heat pumps and advanced controls outperformed standard options in life-cycle cost analysis.

- **Operational constraints matter**: Occupant disruption and space limitations can influence measure selection, the timing of upgrades, and can increase project costs.
- **Decarbonization economics are highly sensitive to electricity and gas rates**: While the lifetime net cost or benefit of most decarbonization measures are small relative to the energy costs over the same period, long-term decarbonization costs would decrease substantially if the cost of electricity were lower relative to gas compared to present-day cost ratios. Current electricity rates include significant infrastructure costs, in addition to generation and demand charges, that undermine the cost-effectiveness of decarbonization. Efforts to increase affordability of electricity will also boost the cost-effectiveness of decarbonization measures that depend on electrification. New approaches may be necessary to simultaneously promote energy efficiency and decarbonization.
- **Market-specific opportunities and challenges exist:** While all three buildings can decarbonize cost-effectively by 2045, the pathways differ substantially. The high-rise office building faces constraints in generating adequate hot water for its hot-water circulation loops used for space heating, without relying on large electric resistance boilers that are impractical due their substantial electricity needs. This constraint makes heat-recovery strategies from space cooling, process cooling, and refrigeration more valuable for decarbonization. Although replacing the 200° F hydronic distribution system is complex and would require careful planning and project timing to minimize tenant disruption, the upgrade would be required by 2045 even in a business-as-usual scenario. The fact that the costs associated with the distribution system replacement would be incurred in baseline and decarbonization scenarios drives the cost-effectiveness of decarbonization for this building. Other factors that promote cost-effectiveness include the stacking of energy efficiency measures before full decarbonization, which allows the specification of lower capacity heat recovery chillers than the existing gas boilers.

  The retail building benefits from ample rooftop area for solar PV, modest space- and water-heating loads, and straightforward packaged heating, ventilation, air-conditioning (HVAC) systems. As a result, decarbonization for this building is the most straightforward of the three case studies.

CHAPTER 1: Introduction

The *California Building Decarbonization Case Study* explores the real-world opportunities and challenges to advancing energy efficiency and decarbonization in three large buildings.[1] The central goal of the study is to develop a model compliance plan consistent with potential legislation that creates standards for the energy performance and operation of existing buildings. While the details of such legislation are not known, the authors have assumed that the legislation would require large reductions to on-site greenhouse gas (GHG) emissions achievable through building electrification primarily, as well as technically feasible reductions in on-site energy-use intensity (EUI) by 2045.

The California Energy Commission (CEC) has retained Qualus LLC (Qualus), ENERlite Consulting, and Davenergy Solutions (the team) to conduct the study. Participants in the study provided building data to the team on a voluntary and confidential basis. The team conducted building energy modeling, engineering, and economic analysis to develop model compliance plans. The plans were developed using in-depth interviews with participants and address specific opportunities and constraints in each building.

This report presents case studies of real-world buildings in different sectors, including large commercial offices, retail spaces, and multifamily communities. Each case study applies a structured decarbonization framework to evaluate technical feasibility, economic impacts, and operational challenges. The analysis integrates detailed building energy models, calibrated to actual utility data, with multiple scenario-based simulations of electrification, energy efficiency, and renewable energy strategies. These strategies are assessed for the energy and emissions performance and cost-effectiveness under current and projected utility rate structures.

The findings highlight opportunities and barriers to improving energy performance of existing buildings. Opportunities include leveraging end-of-life equipment replacement cycles to minimize incremental costs, bundling decarbonization measures to optimize system interactions, and deploying on-site renewable generation and storage to enhance resilience to high peak demand charges or disruptions in electrical service. Barriers include limitations in electrical service capacity, high upfront costs for certain technologies, high electricity rates relative to gas rates, and operational constraints in occupied buildings. By documenting these real-world conditions, this report aims to guide policy development that supports building owners considering practical and cost-effective net-zero carbon building operations.

These case studies provide a roadmap for policymakers and stakeholders to understand the connections between technology, economics, and implementation. The case studies underscore the importance of flexible compliance pathways, targeted incentives, and

1 The study focuses on "Covered Buildings" specifically in the context of the Building Energy Savings Act (Senate Bill 48, Becker, Chapter 378, Statutes of 2023): commercial buildings more than 50,000 ft^2 in floorspace and multifamily buildings with at least 17 units and more than 50,000 ft^2 in aggregate floorspace.

integrated planning to ensure that California's building sector can meet decarbonization goals while maintaining affordability and reliability.

CHAPTER 2: Method

The team developed a structured Decarbonization Strategy Framework, illustrated in Figure 1, to ensure that the team evaluated decarbonization opportunities with realistic and data-driven engineering and economic assumptions. The Decarbonization Strategy Framework begins with comprehensive data collection of building geometry, space-use schedules, utility billing histories, documentation of mechanical and electrical systems, renewable energy systems, and past retrofits. The strength of any building energy model is tied directly to the completeness and accuracy of these inputs. A more detailed dataset provides more reliable and defensible analysis.

For each building studied, the team developed a preliminary baseline model in the DesignBuilder™ building simulation software suite, which uses the United States Department of Energy (U.S. DOE) EnergyPlus® engine. The baseline model represented existing conditions of each building studied. Since baseline accuracy determines the credibility of any decarbonization scenario, the team applied its proprietary ENERtune™ calibration module to refine building envelope, lighting, plug loads, and mechanical and operational schedules to match utility gas and electricity usage from the building for at least twelve months. All baseline models passed the metrics for acceptable calibration according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 14.[2]

After validating the model, the team simulated several decarbonization strategies, which were tailored for each building's characteristics. The hourly and annual energy results were processed through the National Renewable Energy Laboratory System Advisor Model (SAM)[3] and the team's custom utility cost engine to quantify electricity and gas cost impacts under current rate structures. SAM was also used to simulate the performance of solar PV and battery storage configurations, enabling an integrated assessment of building- and site-level decarbonization pathways.

Finally, the team compiled all outputs (for example, energy, cost, load profiles, carbon impacts, and PV-storage potential) into a spreadsheet to compare strategies and identify the most effective decarbonization roadmap for each building. Gas-related GHG impacts were calculated using an emissions factor of 0.0053 metric tons of carbon dioxide (CO_2) per therm.[4]

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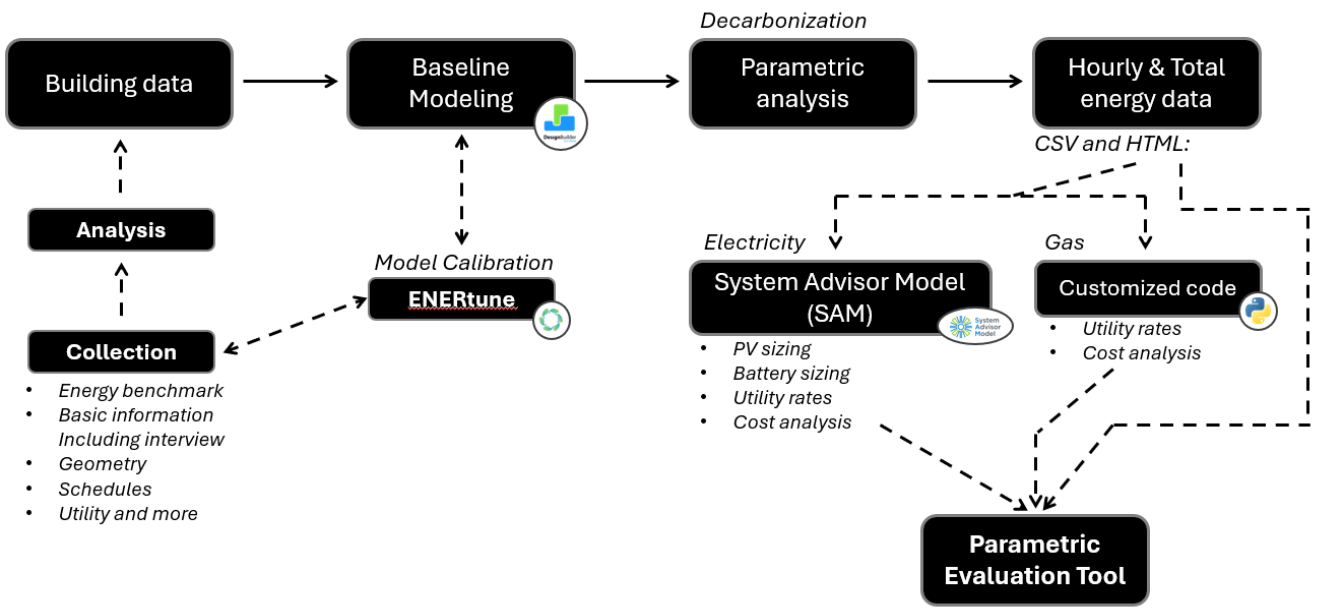
2 ASHRAE. (2014/2023). *Guideline 14-2014: Measurement of Energy, Demand, and Water Savings*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, https://www.conuee.gob.mx/transparencia/nuevaestrategia/docs/1.3.%20ASHRAE%20Guideline%2014-2014.pdf. This guideline includes calibration precision recommendations for building simulation, such as ±10% matching of energy usage for each month. www.ashrae.org

3 National Laboratory of the Rockies (NLR). 2025. "System Advisor Model (SAM) Version 2025.4.16," https://sam.nlr.gov/download/78-sam-2025-4-16-for-windows.html.

4 Environmental Protection Agency staff. "Greenhouse Gas Equivalencies Calculator — Calculations and References," https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references.

GHG impacts related to electricity generation were not considered since Senate Bill 100 (De León, Chapter 312, Statutes of 2018) requires a carbon-free grid by 2045.

Figure 1: Decarbonization Strategy Framework



Credit: ENERlite Consulting

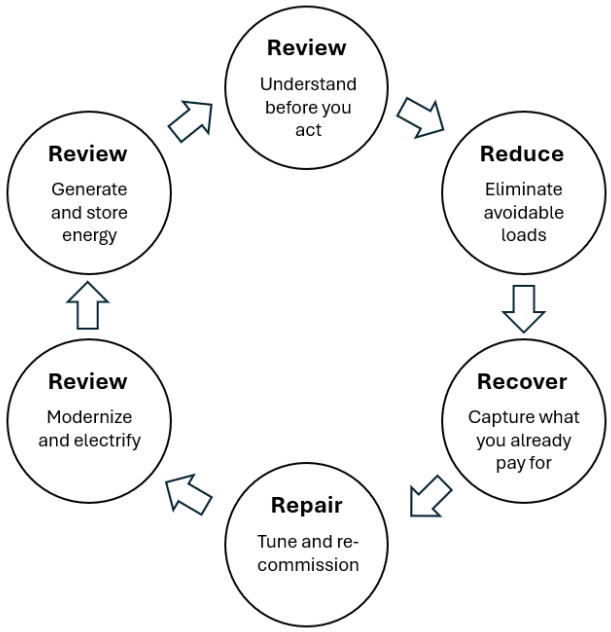
The "6R" Resilient Retrofit Framework

Decarbonizing an existing building cannot be accomplished through any single measure. Building decarbonization is a process that unfolds over time, aligns with budgets, and reflects aging air conditioning and heating systems, occupant needs, and capital planning constraints. To guide this process in a logical, cost-effective, and resilience-driven manner, the team used the 6R Resilient Retrofit Framework shown in Figure 2: Review, Reduce, Recover, Repair, Replace, and Regenerate. The 6R Framework provides a structured, sequential approach to evaluating and implementing building decarbonization, electrification, and resilience strategies while maintaining operational and financial feasibility.

The 6R framework is ordered intentionally from Review, Reduce, Recover, and Repair, which are stages that require low-cost actions before the Replace and Regenerate decarbonization strategies, which involve significant capital investments.

This sequencing aligns with how building owners naturally plan capital projects one step at a time within available budgets, while prioritizing actions that have the largest immediate impact with the lowest cost.

Figure 2: The 6R Resilient Retrofit Framework



Credit: ENERlite Consulting

Review — Understand Before You Act

The process begins with gaining a clear understanding of the current performance of the building including energy use, envelope characteristics, heating, ventilation, and air conditioning (HVAC) operation, controls, and past retrofits. This step ensures decisions are grounded in data with a focus on developing a complete understanding of the existing building and the operational context before proposing solutions. Activities in this stage may include:

- Virtual or on-site building audits.
- Review of architectural, mechanical, and controls documentation.
- Evaluation of past retrofit measures.
- Analysis of benchmarking and utility data.
- Discussions with building operations managers to understand system issues, constraints, and priorities.

The Review stage includes interviews with building operations managers to identify realistic and feasible decarbonization pathways given the operational constraints of the building and real-world challenges.

Reduce — Eliminate Avoidable Loads

In this step, the priority is minimizing overall energy demand of the building ahead of investing significant capital in new equipment. Minimizing building energy demand includes reducing envelope losses, eliminating simultaneous heating and cooling, improving ventilation

schedules, and addressing operational inefficiencies. Reducing energy loads can lead to cost-savings associated with capacity reductions during HVAC replacement.

This step targets demand-side reductions that lower the overall heating, cooling, and electrical loads. Measures typically include:

- Building envelope improvements (glazing, insulation, air sealing).
- Light-emitting diode (LED) lighting upgrades.
- Occupancy and daylighting sensors.
- Plug-load management.

Recover — Capture What You Already Pay For

Buildings can waste a significant amount of energy through heat rejection, exhaust air, and unoptimized processes. This step captures and reuses waste heat or other recoverable energy streams such as heat recovery from exhaust air, data rooms, refrigeration systems, or process loads. Recovering energy further reduces the size and cost of subsequent upgrades.

This step focuses on reusing waste heat and maximizing the efficiency of air-side systems. Typical measures include:

Air-side heat recovery: It is often necessary to exhaust conditioned air from within the building and replace it with fresh outside air to maintain indoor air quality. Air-side heat recovery is a way to reduce energy use by reusing heating or cooling from already conditioned air before it is exhausted to the outside. Instead of bringing in hot or cold outdoor air and conditioning it from scratch, these systems transfer heat (and sometimes moisture) from exhaust air to the incoming fresh air. By helping warm the air in winter and cool it in summer before it reaches heating or cooling equipment, air-side heat recovery lowers energy demand and improves overall building efficiency.

Economizers: An economizer is a control strategy that reduces air conditioner usage by using outdoor air when conditions allow.

During this study, the team also discussed advanced recovery methods, such as capturing heat from data centers, on-site server rooms, or refrigeration systems.

Repair — Tune, Fix, and Recommission

Many buildings operate far below the intended efficiency because of faulty controls, sensors that have drifted out of calibration, heating and cooling temperature setpoints or lighting and fan operation scheduled that are not optimally aligned with building occupancy, and deferred maintenance. The process of addressing these issues to optimize building performance is known as retrocommissioning (RCx) or recommissioning. Fine-tuning existing controls and associated instrumentation can substantially improve performance with minimal cost. Repairing the "operational backbone" of the building prevents unnecessary energy waste.

RCx activities typically include:

- Checking and correcting sensor calibration.
- Reviewing equipment data to identify wasteful operation patterns.

- Optimizing control sequences of operations.
- Establishing fault detection and diagnostics to support ongoing maintenance.

RCx focuses on restoring systems to optimal performance, addressing calibration issues, improving schedules, and ensuring that HVAC systems operate efficiently based on building usage patterns.

Replace — Modernize and Electrify Efficiently

After minimizing loads through the previous steps, the framework moves to replacing outdated systems. Because previous steps lower the building's energy loads, the new systems can be smaller, less costly, and more efficient.

This step evaluates replacement of major systems with modern, efficient, and low-carbon technologies such as:

- Replacing gas-fired heating equipment with heat pumps.
- Installing heat-recovery chillers to reduce or replace gas boiler use.
- Installing heat-pump water heaters.
- Installing high-efficiency gas boilers (if necessary and appropriate for the site).
- Replacing gas-fueled food service and laundry equipment with electric equipment.
- Choosing high-efficiency electric equipment at the time of replacement.

Regenerate — Produce Clean Energy and Store It

The final stage is to add on-site renewable energy systems and storage, such as solar PV and batteries or thermal storage. This step builds long-term resilience, reduces dependence on the grid, and supports carbon-free building operation. Regeneration is most effective after all earlier steps have minimized and optimized energy needs.

Measures include:

- Rooftop and façade-integrated solar PV panels.
- On-site battery energy storage systems.
- Thermal energy storage and heat-battery technologies.
- Demand flexibility and grid-interactive efficient building strategies.

This step ensures the building reduces and optimizes energy demand and contributes to grid resiliency while lowering carbon emissions and operational costs.

Bundled Rs Analysis

Building decarbonization rarely succeeds through single measures implemented in isolation. In this study, individual measures were integrated into "bundled" packages. In a bundled scenario, measures deliver greater total savings, reduce system oversizing, and can offset electrification-related load growth through efficiency and load flexibility. This approach reflects

real-world retrofit planning, where owners must weigh multisystem interactions, capital sequencing, and operational impacts rather than focusing on single-measure benefits.

Economic Analysis

This section describes the scope, method, and key assumptions used to evaluate the economic implications of energy efficiency and decarbonization measures. The analysis focuses on long-term costs and benefits associated with building investments, energy use, and equipment replacement decisions over time. The following subsections outline which costs and benefits were included, the economic assumptions applied, and how the timing of investments was handled in the modeling framework.

Costs and Benefits Considered

Energy efficiency and decarbonization project cost estimates include labor and materials. Benefits include utility gas and electricity savings. Byproducts such as improved comfort, safety, or reduced emissions are not assigned a dollar value. This analysis does not account for other potential costs and benefits such as incentives from utility energy efficiency or demand response programs, tax credits, depreciation, or compliance costs with potential codes and standards. The team made the choices above to reflect only the long-term change in building investment, operation, and maintenance costs associated with decarbonization.

Field Study Planning Assumptions

The team made planning assumptions on the following parameters that describe the time value of money.

Evaluation time frame: The economic analysis covered the years 2035 to 2060. In all cases, the first energy efficiency or decarbonization investment occurs in 2035, and the last investment occurs in 2045. There is an assumption that long-term strategic planning for decarbonization happens before 2035. For example, if a gas furnace is planned to be replaced by a heat pump on or around 2035, the building owner would not replace that gas furnace with a new gas furnace prior to that year.

A single integrated economic system: This analysis evaluates net impacts across owners and tenants as one combined system. The overall costs and benefits are considered for the combined system. This analysis does not make any findings or recommendations related to the "split incentive," where owners typically make capital and maintenance decisions and expenditures, while tenants typically pay the utility bills.

General inflation rate: The team used a 2.5 percent general inflation rate for labor and materials, which aligns with the 20-year historical average inflation rate.

Energy escalation rates: The team used a 3 percent annual escalation rate (starting with 2026) for electricity and a 4 percent rate for gas. These values were not taken from any single source but reflected the team's agreement on electricity and gas escalation rates. The team considered historical price trends, and long-term price forecasts, and the fact that electricity has more generation, delivery, and storage sources than gas, some of which are expected to decline in price over the next decades.

Net present value: Net present value (NPV) was used as the primary metric for evaluating the cost-effectiveness of individual measures and measure bundles. NPV represents the sum of all project costs and benefits over the evaluation period, discounted to a common base year to account for the time value of money. A positive NPV indicates that the present value of benefits exceeds the present value of costs, while a negative NPV indicates the present value of costs exceeds the present value of benefits.

Discount rate: The team applied a discount rate to reflect the opportunity cost of capital. In a single-stakeholder analysis, the discount rate would likely default to the opportunity cost of capital for that stakeholder. Decarbonization involves multiple stakeholders such as building owners, tenants, and, given the broader policy context, the public, each of whom would apply a different discount rate. To represent multiple stakeholders, cost-effectiveness tests in California use a range of discount rates such as a 3 percent societal discount rate, or specific borrowing costs for utilities, building owners or operators, and tenants.

In keeping with the cost and benefit terms discussed above, this analysis considers tenants and building owners together when evaluating costs and benefits. This analysis assumed that a portion of decarbonization project costs can be passed through to tenants, particularly when energy bill savings will accrue to tenants rather than owners. Passing some of the costs to tenants, especially over an extended period as part of rent payments, reduces the owner's overall financial commitment and has a similar effect to reducing interest rates associated with financing energy efficiency and decarbonization projects. Accordingly, the team applied a discount rate lower than a conventional borrowing cost (for example, 8 percent). A 5.5 percent discount rate was selected to reflect this tenant-landlord cost-sharing arrangement.

Timing of Investments

The previous section on the "6R" Resilient Retrofit Framework addressed the sequencing of investments and emphasized that low-cost measures — particularly those that reduce heating or cooling loads — should be implemented before upgrades with higher capital costs. The timing of investments was also a key consideration.

In the economic modeling, the team deferred most investments until the existing equipment was at or near the end of service life. At that point, the building owner would likely need to make a comparable replacement investment to maintain the service provided by the original equipment. Basing the analysis on deferring investments until equipment end of life shifts the focus from the full stand-alone cost of a measure to the incremental cost relative to a baseline replacement scenario.

To simplify computations, and enable direct comparisons of relative cost-effectiveness, the team modeled most individual and bundled measures as occurring in the same year. However, the findings would remain unchanged if owners timed investments to align with naturally occurring replacement cycles. For example, results would be similar if three investments modeled for 2035 were spread across 2034–2041.

CHAPTER 3:
Case Study — A Large Office Building

This chapter presents a case study of a large office building to illustrate key considerations for building decarbonization in practice. It describes the building's characteristics, heating and air conditioning systems, and operating conditions, and summarizes the data and modeling approach used in the analysis. The case study highlights technical and economic challenges and opportunities common to large, occupied commercial office buildings.

Building Characterization

The large office building in this study was constructed around 1970 in the San Francisco Bay Area and has a floorspace of about 700,000 square feet (ft^2), more than 80 percent of which is occupied. The property holds Leadership in Energy and Environmental Design (LEED) Platinum certification and has been continuously ENERGY STAR®-certified for over a decade. The building consists primarily of office space and includes two restaurants (about 4,000 ft^2 in total), a bank (10,000 ft^2), and a server room and data center (6,500 ft^2). The building energy use intensity, at about 32 kilo-British thermal units per square foot ($kBtu/ft^2$), is 44 percent lower than the national median for office buildings, and 15 percent lower than the median for similar large office buildings that have reported to the United States Environmental Protection Agency's ENERGY STAR Portfolio Manager in California. Space heating is the main source of gas energy use and presents the largest decarbonization opportunity.

This large office building posed the most complex technical, economic, and contractual challenges in the study. The property owner has a strong sustainability program and a track record of continuous improvements in energy efficiency and GHG reductions across their portfolio and at this site.

However, despite this commitment, the owner has not identified a market-ready solution to decarbonize the building fully. The primary barrier is replacing two large, aging gas boilers in the central plant[5] that supply 200°F water to zonal variable air volume (VAV) terminal units (VAV boxes) for space heating. Current heat pump technologies cannot deliver 200°F water at the required capacity. A full HVAC system overhaul within the next several years is cost-prohibitive and would cause prolonged tenant disruption. However, if the retrofits are conducted in phases near the end of life of the current VAV boxes, then decarbonization is financially viable.

Data Collection

The building owner provided the team with mechanical drawings and architectural floor plans. The building has undergone several modernization efforts. In 2017, the chillers were upgraded with variable-speed drives, enabling more precise control of power use and improving central

5 A central plant is a centralized facility that produces heating, cooling, and possible water heating or energy for one or more buildings from a single location. Many large multistory buildings or campuses employ central plants with chillers and boilers rather than many independent HVAC units.

plant efficiency. In 2022, the building automation system was upgraded, incorporating demand-response controls for the VAV terminal boxes to enhance operational flexibility and load management.

A member of the team conducted a site visit and solar heat gain analysis. A solar heat gain analysis calculates the amount of solar radiation that enters a building through windows, walls, and roofs, crucial for optimizing energy efficiency, heating and cooling loads, and occupant comfort. In this case, the analysis reveals a significant effect from the shading from adjacent buildings, which prevents solar heat gain and increases heating demand for the building.

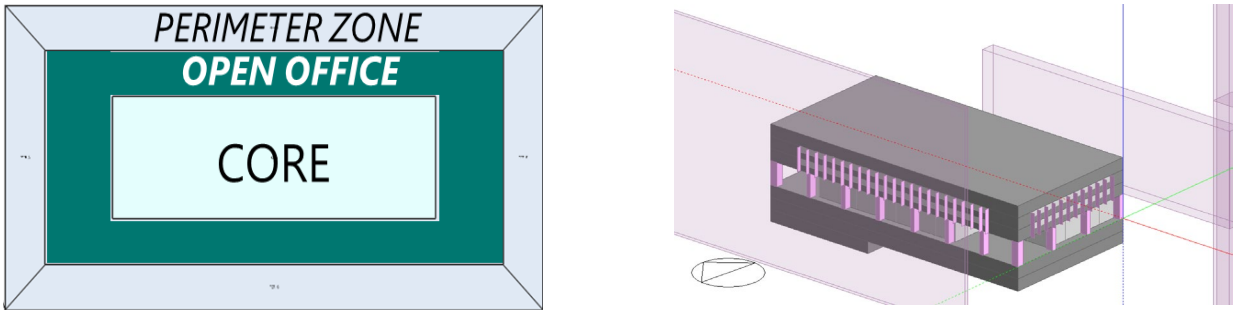
Geometry and Building Envelope

The building has 37 stories, including 36 rentable floors, and a mechanical penthouse level. In addition, there is an underground garage that accommodates 140 vehicles. A typical office floor footprint is 20,000 ft², with interior floor-to-floor heights of about 10 ft, and overall building dimensions of 200 ft by 100 ft.

The window-to-wall ratio is 38 percent, opaque, decorative panels compose 38 percent of the exterior surface, and concrete composes 24 percent of the exterior surface. The windows' thermal conductance (U-value)[6] was estimated to be 0.65 Btu/hr·ft²·°F –0.75 Btu/hr·ft²·°F, and solar heat gain coefficient (SHGC) is about 0.65. The spandrel panels have no insulation, and the R-value[6] is between R-2 to R-5. In addition, the R-value of the concrete without interior finishes ranges from 1.2 hr·ft²·°F/Btu to 1.35 hr·ft²·°F/Btu.

Figure 3 shows a typical floor composition in the energy model. The model isolates perimeter zones which are influenced by conduction and solar heat gain more acutely than the core zone.

Figure 3: Building Energy Model Depiction



Typical Office floors in DesignBuilder (left) and a simplified depiction of the building exterior with about 40 floors of offices represented by a single floor (right).
Credit: ENERlite Consulting

6 Thermal conductance is a measure of how readily heat flows through a material. It represents the rate of heat transfer per unit surface area for a given temperature difference between the two sides of the material. Thermal conductance is commonly expressed as a U-value, which is the inverse of the R-value used to describe insulation effectiveness. In U.S. customary units, thermal conductance is measured in British thermal units per hour per square foot per degree Fahrenheit (Btu/hr·ft²·°F). R-values for insulators (R stands for resistance while there is no linguistic associated for the U in U-value) have the inverse units, hr·ft²·°F/Btu.

HVAC System

The main building is served by boilers, chillers, cooling towers, and air handling units with VAV boxes utilizing 200°F water heated by two 53-year-old original boilers, with 8,370 kBtu/hr capacity per boiler. The total capacity of the boilers is 16,740 kBtu/hr. In addition, a tenant tower provides dedicated cooling for certain tenant spaces, including the 6,500 ft^2 data center.

Domestic Hot Water

There is a gas boiler providing domestic hot water (DHW) for bathrooms in common areas. Individual tenants provide their own small water electric heaters as needed for bathrooms and breakrooms.

Equipment and Internal Loads

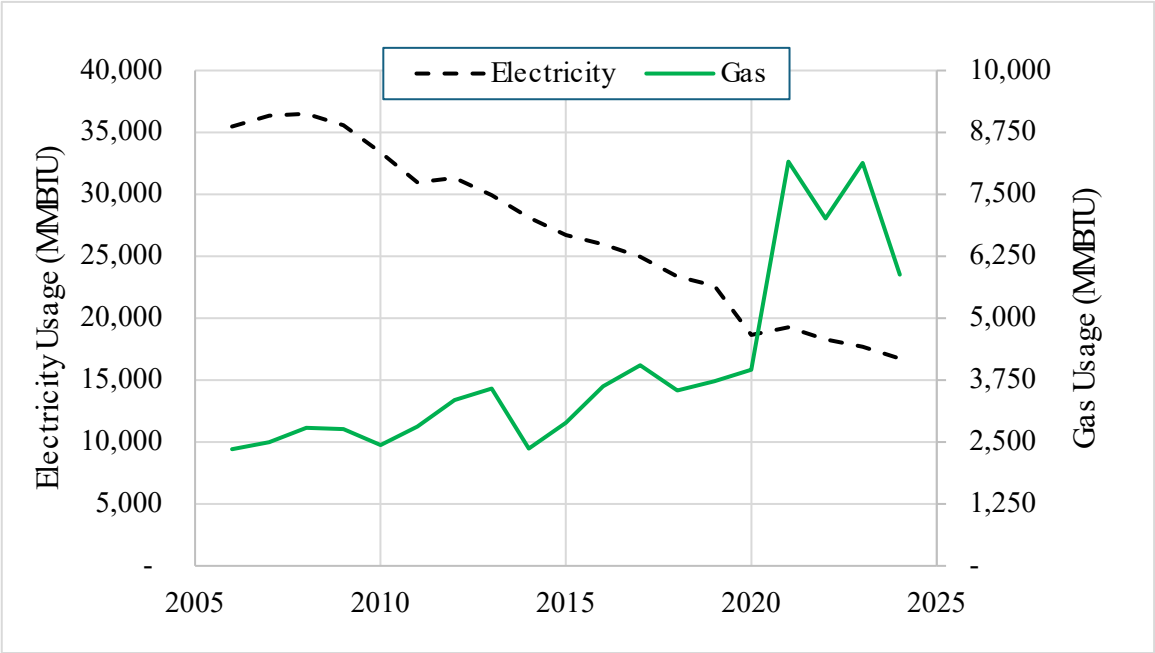
ENERlite created a baseline building model using information provided by the study participant. The model follows inputs from the building prototype "Large Office Post-1980" in U.S. DOE Commercial Refence Buildings[7] Occupancy, ventilation rates, infiltration, heating and cooling setpoints, interior lightings, interior equipment, and other inputs are based on data collected from the building or follow the default values in the "Large Office Post-1980" model template. These parameters are tuned during the model calibration process.

Notably, through years of energy efficiency upgrades, the building electric energy usage in 2024 was about half of the usage in 2006 or 2007, yet the gas usage has more than doubled, as shown in Figure 4. Some of the increase in gas usage is explained by the decreasing electricity usage. More efficient lighting, for example, produces less "waste heat," and thus the heater must work harder to maintain space temperature in winter.

The marked increase in gas usage in the years after the coronavirus disease (COVID-19) pandemic is also noteworthy. This increase can be attributed to increased ventilation rates because of guidelines during the pandemic. Anecdotally, the researchers observed this trend across much of the commercial sector in the CEC Commercial End-Use Survey (CEUS). Reduced occupancy in the post-COVID period ironically increases the heating energy usage due to reduced body heat. At full occupancy, the body heat of occupants accounts for about 2,500 million British thermal units (MMBtu) of "free" heating.

7 U.S. Department of Energy. 2011. *Commercial Reference Building Models of the National Building Stock.* National Laboratory of the Rockies (NLR). Technical Report NREL/TP-5500-46861. https://docs.nlr.gov/docs/fy11osti/46861.pdf.

Figure 4: Historical Gas and Electricity Usage



Annual electricity usage (dashed black profile, left axis) and gas usage (solid green profile, right axis) in units of MMBTU/year from 2006 to 2024. The heating load increases as electricity usage decreases.
Credit: Anonymous building owner

Utility Data Analysis

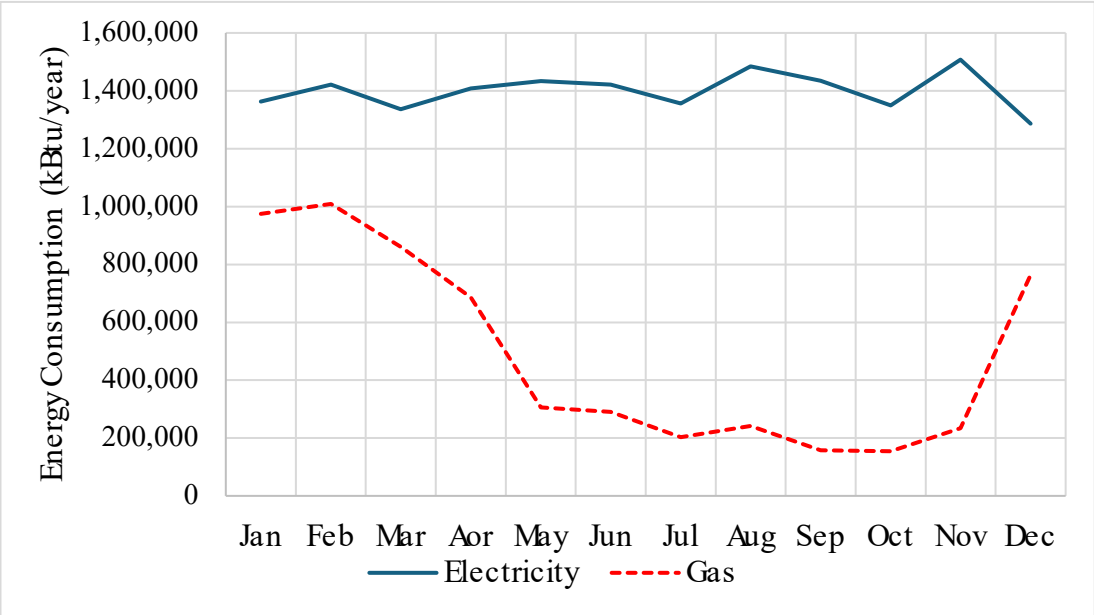
The team analyzed utility consumption data spanning 2006 to 2024 to establish an appropriate baseline for the building energy modeling effort. To analyze utility data, the team set two criteria described below:

- The baseline must reflect current operational conditions.
- Meter data reliability must be verified to avoid errors in the model.

Calendar year 2024 was selected as the benchmark year for the modeling and calibration process.

In 2024, the building total energy use was 22,906,289 kBtu, composed of 6,122,900 kBtu of gas and 16,783,389 kBtu of electricity shown in Figure 5. Gas exhibits the expected seasonal swing, with high consumption in winter months reflecting space-heating demand and minimal use during the rest of the year. In contrast, electricity consumption remains stable throughout the year, indicating that the primary sources of electricity usage are lighting, computing, and ventilation, typical of large commercial office buildings in the region. The calculated site EUI is 29.2 kBtu/ft^2.

Figure 5: The Building Monthly Utility Data in 2024



Credit: Building owner (anonymous)

Utility Costs and Economic Analysis

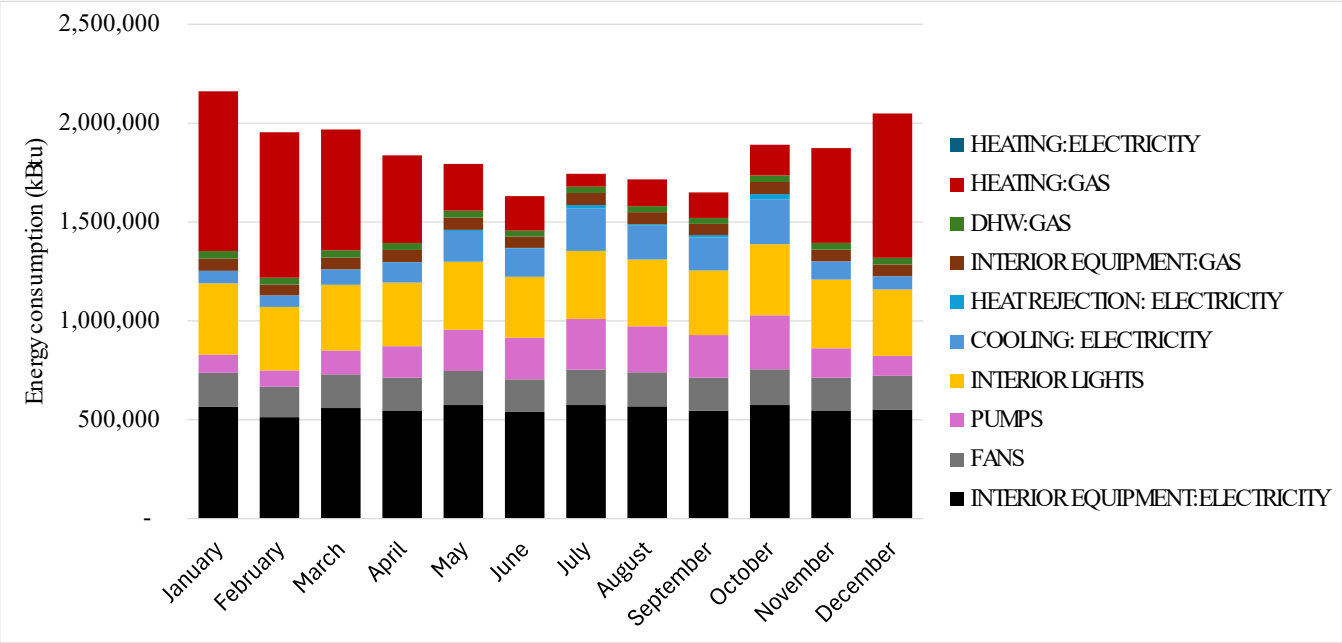
The team conducted utility cost analysis using the B-20 time-of-use (TOU) and G-NR2 gas rates[8] from Pacific Gas and Electric Company (PG&E). The gas rate is a declining block schedule, where usage more than 4,000 therms per month is billed at a rate about 33 percent lower than the rate for the initial 4,000 therms. The electricity rate is a TOU rate with small fixed monthly costs and six TOU periods ranging from $0.04 per kilowatt-hour (kWh) to $0.18 per kWh, as well as coincident and noncoincident demand charges that vary with times of the day and year.

Baseline Model Results

Figure 6 shows the end-use energy consumption of the calibrated building energy model by month and fuel type. The annual end-use with electricity is 16,446,247 kBtu and 5,819,085 kBtu with gas. The electricity consumption is 2.8 times higher than the gas consumption. The interior equipment accounts for the largest portion as 30 percent (6,664,268 kBtu) followed by the heating with gas, which accounts for 21 percent (4,702,295 kBtu) shown in Figure 6. Domestic water heating (DWH) is among the lowest categories for gas spent and used at 401,077 kBtu per year. Energy consumption is higher during winter than in summer, dominated by heating energy. This energy consumption is consistent with the building owner's account that economizers limit chiller runtime to about 600 hours per year.

8 The B-20 and G-NR2 electricity and gas rates are typical utility rates for large buildings in PG&E service territory. The B-20 TOU rate has variable pricing for various pre-defined periods of the day and year. Please see Appendix B for more information on electricity rates.

Figure 6: Baseline Model Building Energy Breakdown by Month, End Use, and Fuel



Credit: ENERlite Consulting

Energy Efficiency and Decarbonization Measures

This section discusses potential retrofit solutions applied within the 6R Resilient Retrofit Framework. This section describes how each step is executed using targeted strategies for the building, offering a clear and practical roadmap to achieve resilient, cost-effective building upgrades. Quantitative costs and impacts are discussed later in this report.

Bundled Package

For this building, the team developed a bundled scenario that combines key decarbonization and efficiency strategies. The bundle represents a cost-effective decarbonization pathway and includes:

- Adjusted mechanical schedules.
- Demand-controlled ventilation.
- Heat-recovery chiller (with thermal storage and accelerated replacement of VAV boxes).
- Heat pump water heater.

This bundle represents the 6R approach to decarbonization and starts with a review of candidate measures such as demand-controlled ventilation to reduce energy usage — particularly the heating load caused by outside air. Adjusting the mechanical schedules involves repairing potential faulty or out-of-calibration sensors and optimizes HVAC operation for the anticipated shift in costs from gas to electricity, associated with decarbonization. Aging water heating systems, including boilers, the gas water heater, and the aging fan coils are replaced which enables the new chiller to recover waste heat from the building and ambient air through the cooling tower.

Bundled Package With Solar and Battery Storage

Adding a solar PV and battery system to the bundle allows power regeneration and provides load flexibility — an important consideration that will benefit the building owner and address local grid capacity issues that electrification might cause. Individual measures in the bundled package are described below.

Building Energy Management System (BMS) Optimization — Schedule Optimization

In this scenario, the HVAC availability schedule is modified to reduce peak demand slightly by setting the cooling and heating schedules to earlier parts of the day. While this is one way to model the impacts of BMS optimization, the implementation may be more nuanced, and schedule set points and changes can vary between floors or zones.

Demand Control Ventilation

Demand control ventilation (DCV) reduces energy use by adjusting outdoor air ventilation rates in real-time based on the number of occupants or building interior CO_2 levels instead of operating at a constant air flow rate. DCV reduces fan energy and conditioning loads by lowering the volume of outside air that requires heating, cooling, humidifying, or dehumidifying to just the amount needed to maintain air quality based on occupancy. This targeted ventilation strategy improves operational efficiency and reduces emissions directly by minimizing unnecessary HVAC energy consumption.

In the baseline model, the minimum outdoor air (OA) ventilation is fixed and does not vary with occupancy. The office space is modeled with an occupancy density of 200 ft^2 per person. In the updated DCV model, ventilation is changed from a fixed, area-based rate to a variable outdoor air rate based on actual occupancy. A CO_2 sensor is modeled in the air handler unit (AHU) return air duct, with a DCV setpoint strategy of:

- Minimum (lower) threshold: 800 parts per million (ppm).
- Target setpoint: 900 ppm.
- Upper threshold (maximum): 1000 ppm.

The outside air brought into the building is continually adjusted to maintain the desired CO_2 levels.

Heat Pump Water Heater

Air source heat pumps for domestic hot water (DHW) reduce energy use by taking heat from the surrounding air and delivering it to the water to be heated, rather than generating the required heat by means of a gas-fueled fire or electric resistance heating element. The efficiency for heat pumps is often stated as a coefficient of performance (COP). The COP is the ratio of useful heating or cooling delivered by the heat pump to the energy required to provide that heating or cooling.

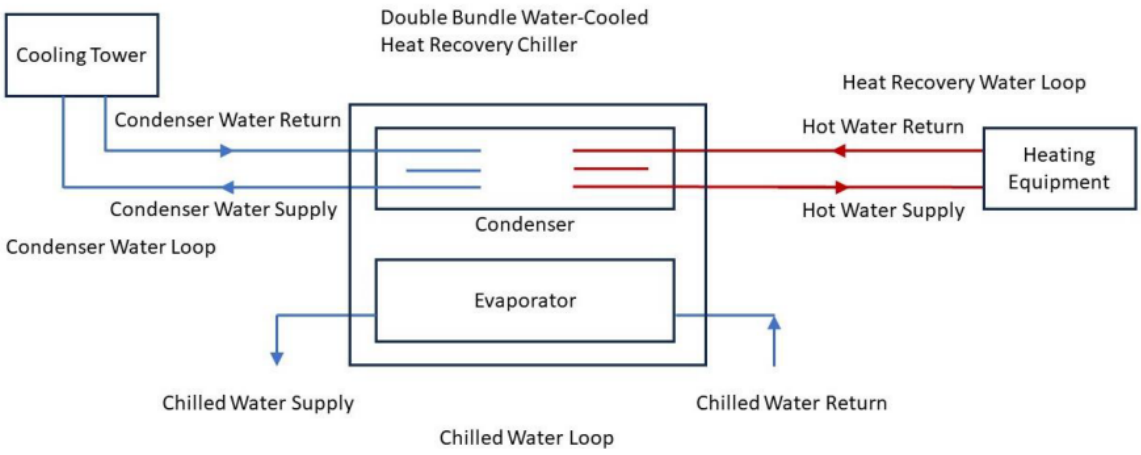
Heat pump water heaters have COPs ranging from 3.0 to 5.0, while even the most efficient electric resistance or gas water heaters are nearing their theoretical maximum efficiencies of 1.0. Because air source heat pumps eliminate onsite combustion and operate on clean

electricity, they deliver immediate and sustained reductions in operational GHG emissions. Air source heat pumps also reduce peak gas demand, support load shifting with thermal storage, and create a scalable, all-electric pathway for building decarbonization in multifamily and commercial buildings. However, this replacement is not as effective for most office buildings because office buildings consume DHW sparingly.

Heat Recovery Chiller

A heat recovery chiller (HRC) produces chilled water and high-grade heating at the same time by capturing condenser heat that would otherwise be rejected outdoors as shown in Figure 7. This configuration provides two flow paths through the condenser. One flow path rejects excess heat to a cooling tower via a conventional condenser-water loop, while the second path delivers useful hot water to the heat-recovery loop. In buildings with overlapping heating and cooling loads, common in commercial office buildings, data center floors, and large interior zones, an HRC reduces boiler operation by providing "free" recovered heat at a high COP while still meeting cooling demands. By displacing gas heating with efficient electric heat recovery, the system delivers substantial energy savings, reduces peak gas consumption, and supports whole-building decarbonization.

Figure 7: Heat Recovery Chiller Schematic



Credit: ENERlite Consulting

It is common practice to combine one or more heat recovery chillers with a conventional cooling-only chiller. In the large office building in this study, for example, two heat recovery chillers are paired with one standard chiller. The conventional chiller provides additional capacity during peak summer cooling conditions, supplementing the HRCs when cooling loads exceed capacity. In the EnergyPlus model, the chiller operation sequence is configured so that the heat recovery chillers operate first, maximizing heat recovery potential, followed by the conventional chiller as secondary capacity.

As previously mentioned, the building relies sparsely on mechanical cooling, which may limit the applicability of an HRC. However, the following strategies are available for allowing the chiller to supply most or all the necessary heating.

- **Strategy 1:** Reduce or eliminate economizer usage when heating and cooling are needed at the same time. While reducing economizer usage increases the energy usage associated with cooling, it also provides "free" heating and offsets use of the boiler.
- **Strategy 2:** Install thermal energy storage to reduce peak demand and increase availability of heat recovery on days with overlapping heating and cooling loads.
- **Strategy 3:** Use the heat recovery chiller as the primary cooling source for the 6,500 ft^2 server room while maintaining a backup cooling source for this space. This strategy could potentially provide a base level of year-round heating capacity. In an interview, the building owner expressed concern that there are no guarantees that the tenant data center will remain in the building for the foreseeable future. This is a valid and material consideration.
- **Strategy 4:** Use the cooling tower as a heat sink. During the heating season it is not necessary to reject heat in through the cooling tower as all the heat can be rejected into the heating loop. A key challenge is that the chilled water loop needs a heat sink or else it would freeze quickly. With some modification, the cooling tower can serve as the heat sink. The chilled water can be coupled to the cooling tower like the condenser water. Some additional controls and a supplementary heater would be needed to avoid freezing when the outdoor temperature drops below about 38˚F.

In addition to the strategies listed above, the cost for this measure assumes that half of the fan coils and VAV boxes are replaced in 2035. The original replacement schedule in the baseline scenario has half of the VAV boxes replaced in 2040, and the other half in 2045. The actual replacement schedule can vary based on operational budgets, market conditions, and potential tenant disruptions. However, the team selected 2040 and 2045 as two representative years for the end-of-life replacement of the VAV boxes in the economic model. The heat recovery chiller can supply water hotter than the air-to-water heat pump, but still lower than 200°F. To avoid heating capacity degradation, approximately half of the VAV boxes, those in zones with higher heating loads, will be replaced in 2035, coincident with the heat recovery chiller installation.

Onsite PV

Onsite PV generation offsets grid electricity with clean, locally produced power. By producing zero-carbon electricity during peak daytime hours, PV lowers operational emissions, reduces utility costs, and mitigates peak-load impacts on the grid. When paired with electrification measures such as heat pumps or heat-pump water heaters, on-site PV is a decarbonization strategy that enables a long-term transition away from fossil fuels. To implement on-site PV, the team reviewed the options and concluded the roof top PV is the practical choice. About 200,000 kWh can be generated annually if 35 percent of the walkable space on the rooftop is used for a solar array.

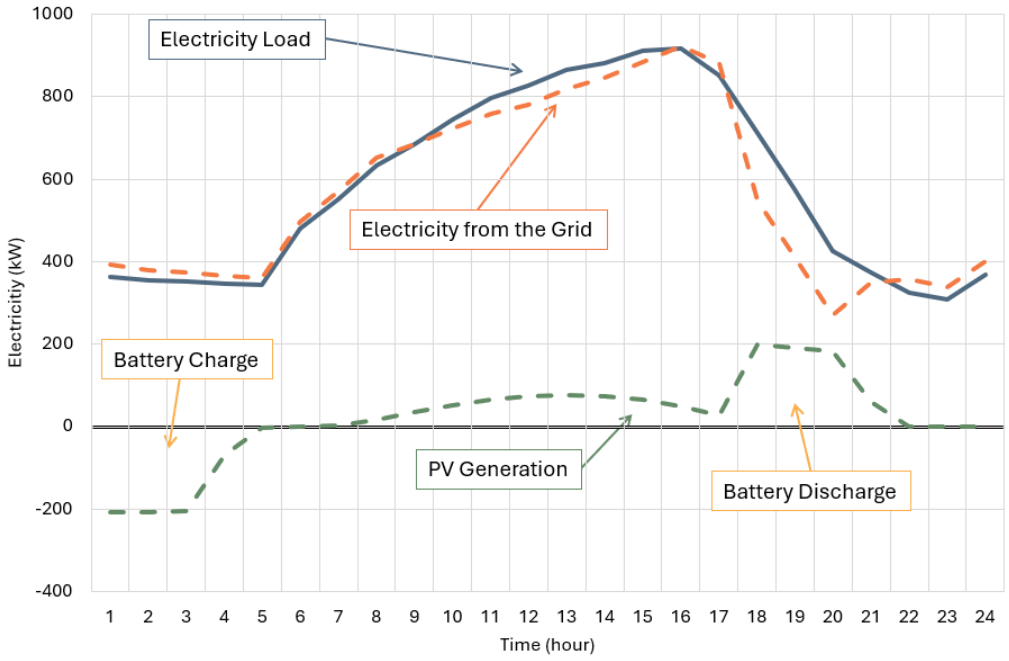
Battery Energy Storage System

The study found that battery storage can complement other efficiency and onsite generation measures, add load flexibility, and reduce peak demand charges. The team modeled a 1,000-kWh battery, discharging from 4 pm to 9 pm, which is a period associated with the highest

energy and demand costs for this building. In this case, about 60 percent of bill reductions from battery installation are caused by reduced demand charges, and the remaining 40 percent are caused by reduced energy charges.

Figure 8 shows the hourly performance of the solar PV and battery system on a typical day in the peak cooling season. The peak electric load is 920 kW in this scenario. The dashed green curve that crosses the horizontal axis shows reduced grid electricity purchases due to the solar PV and battery system. At the bottom left of the plot, from midnight to 3 a.m., the curve is negative because the battery is being charged with grid-purchased electricity at that time. During the day the battery continues to be charged by solar power, yet solar power also offsets building electricity load. The battery discharges in the afternoon, from 5 p.m. to 9 p.m. in this example.

Figure 8: Battery Charge/Discharge Energy Patterns for a Typical Summer Day



Credit: ENERlite Consulting

Decarbonization Parametric Study Results

Table 1, Table 2, and Table 3 below compare multiple decarbonization strategies by showing annual electricity consumption in kWh, peak demand in kW, annual gas consumption in kBtu, along with site GHG emissions in metric tons and the corresponding energy use intensity in units of kBtu/ft². The site GHG emissions are from gas only, since Senate Bill 100 (De León, Chapter 312, Statutes of 2018) requires a carbon-free grid by 2045. The peak demand is measured in the "Summer Peak" period of the B-20 TOU rate,[9] but noncoincident or absolute peaks trended very similarly. All measures shown in Table 2 below, except for the heat pump water heater, reduce coincident and noncoincident peak demand. As a result, they support

9 Please see Appendix B for detailed descriptions of electric rates.

systemwide capacity needs while also reducing stress on local transformers and improving grid resilience.

Note that the values in the table do not reflect a small amount of gas usage for food service equipment in two restaurants that are excluded from this study. Decarbonization is possible for food service as electric options are available, but it is not expected to require material modifications to the building or the building systems.[10] Table 1 presents the baseline energy use of the building, derived from energy simulation models calibrated to utility bills.

Table 1: Building Energy Use Baseline

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Baseline	**4,820,118**	**1,365**	**5,099,965**	**270**	**31**

Source: ENERlite Consulting

Table 2 summarizes modeled electric and gas energy usage, site GHG emissions, and energy use intensity for the building under different retrofit scenarios. The impacts for each measure are listed individually, and the "Combined Bundle" reflects the combined impact of all listed measures.

Table 2: Modeled Building Energy Usage and Site GHG for Various Measures

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Schedule Optimization	**4,830,142**	**1,338**	**5,095,717**	**270**	**31**
Demand Control Ventilation (DCV)	**4,824,220**	**1,353**	**3,941,692**	**209**	**29**
Heat Pump Water Heater	**4,892,283**	**1,380**	**4,699,474**	**249**	**31**
Heat Recovery Chiller	**5,178,709**	**1,365**	**399,782**	**21**	**26**
Combined Bundle	**5,265,821**	**1,338**	**0**	**0**	**26**

Source: ENERlite Consulting

10 Under ENERGY STAR Portfolio Manager guidance, small individually-metered restaurants may be excluded from the benchmarking process.

Table 3 presents the modeled results of onsite solar energy generation, a battery system designed to optimize building load to minimize costs, and a combined bundle of the modeled measures from Table 2 above and the modeled solar plus battery storage systems.

Table 3: Modeled Energy Generation and Storage Measures

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Solar	**4,619,848**	**1,336**	**5,099,965**	**270**	**31**
Battery	**4,854,045**	**1,215**	**5,099,965**	**270**	**31**
Bundle w/Solar + Battery	**5,105,015**	**1,139**	**0**	**0**	**26**

Source: ENERlite Consulting

Table 4, Table 5, and Table 6 provides results of the economic analysis. Table 4 presents the baseline operating costs of the building. The first column shows the net present value of the incremental investment cost relative to the baseline scenario. For the baseline scenario, this value is zero, but it's important to note that even the baseline scenario includes some costs that are expected to be incurred over the study period including:

- Replacement of one of two boilers in 2040, for a cost of $323,000 in 2026 dollars.
- Replacement of half of the VAV boxes in 2040, for a cost of $1.3 million in 2026 dollars.
- Replacement of half of the VAV boxes in 2045, for a cost of $1.3 million in 2026 dollars.
- Replacement of at least one chiller in 2045, for a cost of $0.8 million in 2026 dollars.

These expenses have a combined net present value of $3.4 million in 2035.[11] The second, third, and fourth columns of the tables show the net present cost of electricity, gas, and combined investment and utility costs from 2035 to 2060 in 2026 dollars. The final column shows the net present value of the savings or the cost (costs shown as negative) associated with the investments. For the baseline scenario, the value is zero since all costs and savings are presented as relative to the baseline.

11 All costs incurred between 2035 and 2060 are discounted to 2035 dollars, so the stated total is different than the sum of the costs listed above.

Table 4: Net Present Value of Baseline Utility Costs (25-Year Analysis Period)

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Baseline	**0**	**34,113,125**	**2,877,603**	**36,990,728**	**0**

Source: ENERlite Consulting

Table 5 shows the incremental costs above the baseline scenario, as well as the electricity and gas costs over the study period, the total cost, which is the sum of utility and incremental investment costs, and the savings associated with each measure (if a measure results in additional cost rather than savings, then they are shown with a negative value as negative savings in the last column). The costs previously described for the baseline case are common to the controls optimization, demand control ventilation, heat pump water heater, solar panels, and battery energy storage measures. The heat recovery chiller and bundle scenarios do not incur costs to replace the boiler, accelerate the VAV box retrofit, and defer the chiller replacement in 2045, since the heat recovery chiller should have service life left. Appendix A provides an explanation of the costing process for this case study.

The cost impacts for each measure are listed individually, and the "Combined Bundle" reflects the combined cost impact of all listed measures.

Table 5: Investment Costs, Utility Costs, and Savings for Various Measures

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Schedule Optimization	**80,507**	**33,939,143**	**2,875,633**	**36,895,282**	**95,446**
Demand Control Ventilation (DCV)	**562,684**	**33,344,892**	**2,334,537**	**36,242,114**	**748,614**
Heat Pump Water Heater	**16,277**	**34,568,560**	**2,669,366**	**37,254,203**	**-263,475**
Heat Recovery Chiller	**1,294,631**	**35,182,557**	**254,738**	**36,731,927**	**258,801**
Combined Bundle	**1,954,099**	**34,538,130**	**0**	**36,492,229**	**498,498**

Source: ENERlite Consulting

Table 6 presents the modeled results of onsite solar energy generation, a battery system designed to optimize building load to minimize costs, and a combined bundle of the modeled measures from Table 5 above and the modeled solar plus battery storage systems.

Table 6: Costs and Savings for Generation and Storage Measures

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Solar	**339,278**	**32,887,401**	**2,877,603**	**36,104,282**	**886,446**
Battery	**512,942**	**32,837,960**	**2,877,603**	**36,228,505**	**762,222**
Bundle w/Solar + Battery	**2,806,319**	**32,214,159**	**0**	**35,020,478**	**1,970,250**

Source: ENERlite Consulting

This analysis does not account for other potential costs and benefits such as incentives from utility energy efficiency or demand response programs, tax credits, depreciation, or compliance costs with potential codes and standards.

Table 7 shows the costs and savings (in green) and impacts (in blue) associated with sequential application of the bundled measures. Because the measures are applied cumulatively, each row reflects the combined effect of all measures listed up to that point. The "Combined Bundle" row represents the final bundle of measures from Schedule Optimization through the Heat Recovery Chiller. Since no additional measure is added between the preceding row and the Combined Bundle row, the values are identical. In contrast, the "Bundle w/Solar + Battery" scenario includes a battery system in addition to the measures included in the previous scenario, resulting in further changes to costs, savings, and building performance metrics.

Table 7: Costs and Impacts of Sequential Application of Bundled Measures

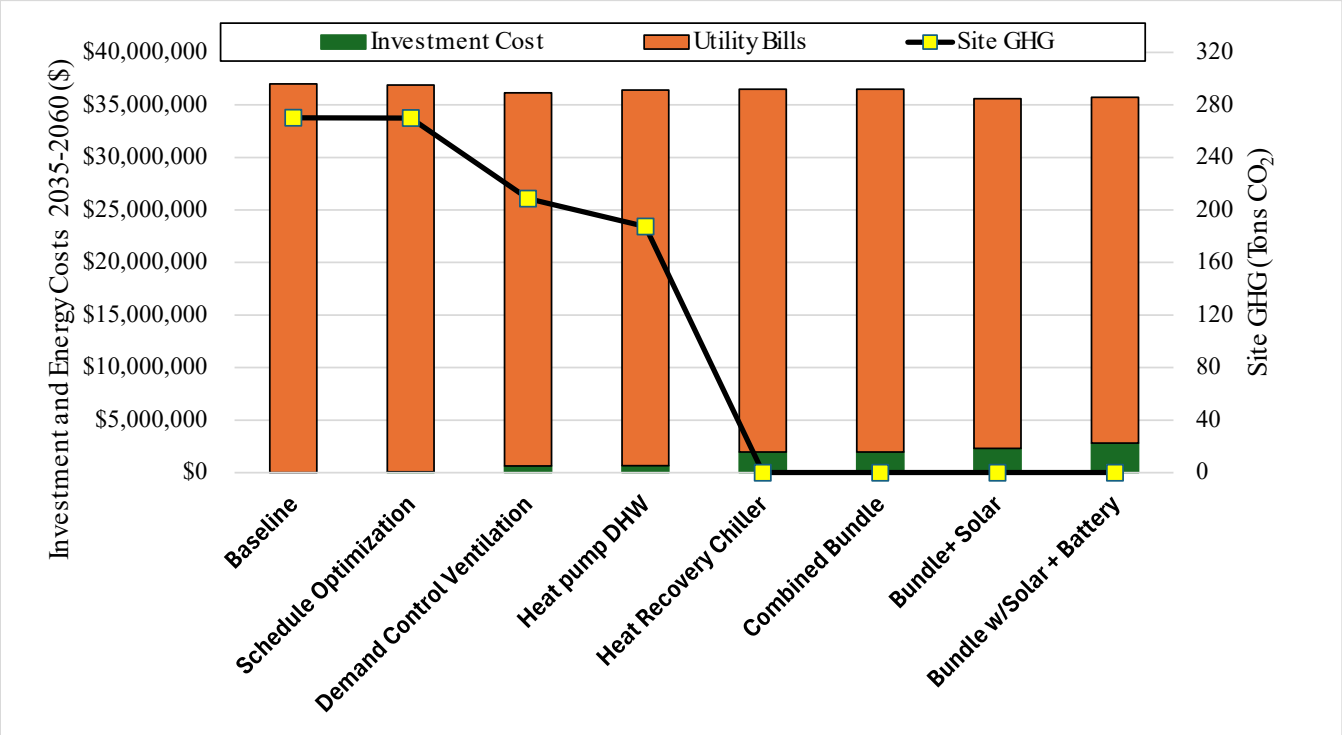
Measure	Incremental Cost ($)	Utility Cost ($)	Total Savings ($)	Annual Grid-Purchased Electricity Usage (kWh)	Peak Demand (kW)	Annual Gas Usage (kBtu)	Site GHG (tons CO_2)
Baseline	**0**	**36,990,728**	**0**	**4,820,118**	**1,365**	**5,099,965**	**270**
Schedule Optimization	**80,507**	**36,814,775**	**95,446**	**4,830,142**	**1,338**	**5,095,717**	**270**
Demand Control Ventilation (DCV)	**643,191**	**35,503,477**	**844,060**	**4,834,244**	**1,326**	**3,937,444**	**209**
Heat Pump Water Heater	**659,468**	**35,750,675**	**580,584**	**4,906,409**	**1,341**	**3,536,954**	**187**
Heat Recovery Chiller	**1,954,099**	**34,538,130**	**498,498**	**5,265,821**	**1,338**	**0**	**0**
Combined Bundle	**1,954,099**	**34,538,130**	**498,498**	**5,265,821**	**1,338**	**0**	**0**

Bundle + Solar	**2,293,377**	**33,312,406**	**1,384,944**	**5,065,551**	**1,308**	**0**	**0**
Bundle w/Solar + Battery	**2,806,319**	**32,214,159**	**1,970,250**	**5,105,015**	**1,139**	**0**	**0**

Source: ENERlite Consulting

Figure 9 shows the sequential changes (from left to right) in total investment and energy costs as each measure is applied to the building, combined with all previous measures. The overall costs are shown using stacked bars, with the dark green portion representing incremental investment costs above the baseline scenario, and the orange portion representing utility bills associated with energy purchases. The site GHG emissions are shown with a black line and yellow markers.

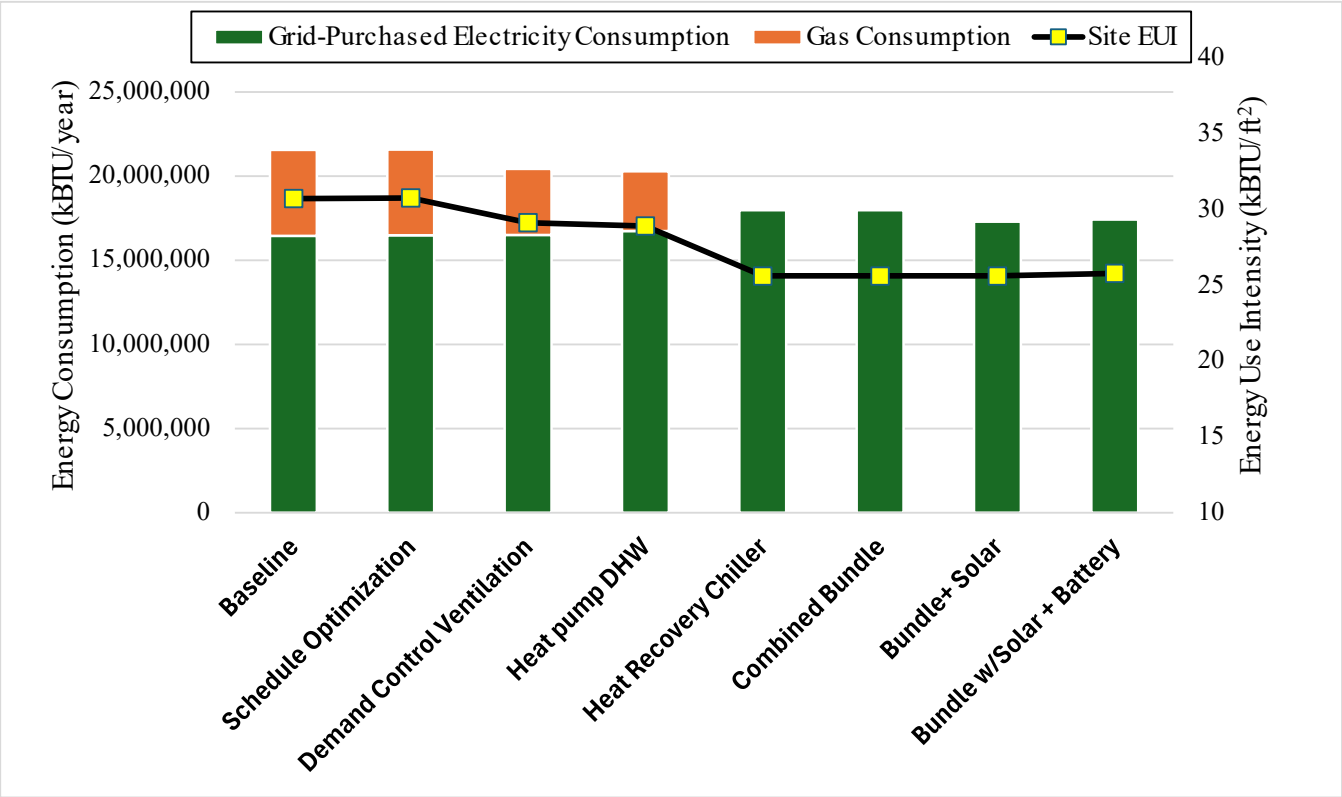
Figure 9: Sequential Development of Utility Plus Investment Costs and Site GHG



Credit: ENERlite Consulting

Figure 10 shows the sequential changes (from left to right) in total purchased energy consumption as each measure is applied to the building. The overall energy consumption, in units of kBtu/year, is represented with stacked bars. The dark green portion of the bars represents grid-purchased electricity consumption, and the orange portion of the bars represents gas consumption. The site EUI emissions are shown with the black line and yellow markers. Note that the solar PV does not reduce the site EUI since the EUI is calculated as the total purchased and self-generated energy, divided by the floorspace.

Figure 10: Sequential Development of Utility-Purchased Energy and Site EUI



Credit: ENERlite Consulting

Other Considered Measures

The team considered additional energy efficiency and decarbonization measures. Two notable measures are discussed below.

Gas-Supplemented Air-to-Water Heat Pumps

Air-to-water heat pumps reduce building energy use by replacing combustion-based boilers with a high-efficiency electric system that delivers three to five times more useful heat per unit of energy than gas-fired equipment. These systems enable efficiency gains when paired with envelope upgrades, controls, and thermal storage, which reduce peak loads and lower annual energy consumption. By shifting heating demand to clean electricity rather than onsite fossil fuel combustion, air-to-water heat pumps reduce operational GHG emissions directly and accelerate whole-building decarbonization. However, as previously mentioned, the heat pump must operate at reduced supply temperatures (for example, about 140°F instead of 180°F–200°F), which limits the ability to fully replace high-temperature boiler loads.

According to interviews with the building owner, fan coil replacements would be necessary to operate with a hot water temperature of 140°F. Given the age of the building, fan coil replacements are likely to be necessary in the next 20 years. This strategy, however, accelerates decarbonization by offering a partial-decarbonization approach. The heat pump will supply water at 140°F to the existing boiler. The boiler will boost the water to increase temperature to 180°F–200°F (it is likely that certain zones will have adequate capacity with 180°F hot water supply temperature). When it is time to replace the fan coils and VAV boxes

(in the economic modeling the team assumes that half of them would need replacement in 2040, and the other half in 2045), then it may be possible to add heat pump capacity, remove the boilers, and operate the building with 140°F hot water. The building has sufficient electrical capacity to power the heat pumps in winter, given that the historical electricity usage was twice the current usage.

Higher-Efficiency Boilers

High-efficiency boilers reduce energy consumption by converting a larger amount of fuel into useful heat. The existing 53-year-old boilers have an efficiency of 70–73 percent while high-efficiency boilers have an efficiency of 85 percent. Replacing existing boilers with new boilers lowers annual gas use, reduces operating costs, and cuts combustion-related emissions without requiring major changes to existing hydronic distribution systems. While not a full decarbonization measure, upgrading to high-efficiency boilers provides an immediate step toward reducing the carbon footprint of the building.

Table 8 shows electricity and gas energy usage, peak electric demand, as well as site GHG emissions and EUI for each measure.

Table 8: Energy Usage and Intensity, Demand, and Emissions for Various Scenarios

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Baseline	**4,820,118**	**1,365**	**5,099,965**	**270**	**30.7**
Efficient Boiler	**4,820,118**	**1,365**	**4,436,555**	**235**	**29.8**
Air to Water Heat Pump (Gas Boost)	**5,268,134**	**1,353**	**1,689,013**	**90**	**28.1**

Source: ENERlite Consulting

Table 9 shows equipment and installation costs, total utility costs over the study period, and cost savings over the study period for each measure. Any overall cost increases are shown as negative amounts in the last column.

Table 9: Net Present Value of Investment Costs, Utility Costs, and Savings

Measure	Investment Costs (above Baseline) ($)	Electricity Costs ($)	Gas Costs ($)	Total Costs ($)	Savings ($)
Baseline	**0**	**34,113,125**	**2,877,603**	**36,990,728**	**0**
Efficient Boiler	**91,208**	**34,113,125**	**2,564,940**	**36,769,272**	**221,456**
Air to Water Heat Pump (Gas Boost)	**1,351,339**	**35,920,181**	**1,074,545**	**38,346,064**	**-1,355,337**

Source: ENERlite Consulting

CHAPTER 4:
Case Study — A Large Retail Space

Building Characterization

The retail building studied for this report is a big box retail store in Santa Clara County with about 57,000 ft^2 of floor area, constructed in 2006. The building is typical of large single-story retail spaces in shopping centers. The building's energy-use intensity, at 34 $kBtu/ft^2$, is about 25 percent lower than the national median for retail centers and 25 percent lower than the median for similar large retail buildings that have reported to ENERGY STAR Portfolio Manager in California. Space heating is the main source of gas energy usage and presents the largest decarbonization opportunity.

Data Collection

The building owner provided utility billing data, floor plans, and documentation on the quantity, types, and age of the HVAC systems to the team. Members of the team also surveyed the building in 2019 as part of the CEC CEUS survey. The building does not have energy-intensive commercial food service or refrigeration equipment or server rooms; therefore, lighting and HVAC account for most of the energy usage.

Geometry and Building Envelope

The retail building, located in California Climate Zone 4 and built under the 2001 Energy Code, used R-22.7 (U-0.044) insulation for low-sloped roofs and R-16.2 (U-0.062) cavity insulation for exterior walls after calibration. Glazing materials met Energy Code requirements, with a U-factor of 0.36, SHGC of 0.55, and a visual transmittance of 0.7 for vertical fenestration. For modeling purposes, the building consists of the following five zones:

- Back space
- Core retail
- Front entry
- Front retail
- Point of sales

Lighting

Lighting fixtures are 2 foot by 4 foot linear fluorescent fixtures retrofitted with LED lamps. The lighting power density is estimated at 0.7 watts per ft^2 (W/ft^2) for the sales floor and 0.45 W/ft^2 for storage, receiving, and other "back of house" areas of the building.

HVAC System

The HVAC system consists of packaged rooftop units (RTUs) primarily, as illustrated in Figure 11. The rooftop units have direct expansion cooling coils, gas heating coils, and economizers. The back of the retail building has a gas-fired space heater to provide additional heating when needed. The RTUs are 20 years old as of 2026. Therefore, the RTUs will be replaced in the

coming years. Outside air for the building is regulated by outdoor air dampers in the exterior cabinets of the RTUs, and the economizer controllers allow the RTUs to cool the building using outside air in favorable weather conditions, instead of running the air conditioners.

Figure 11: An Array of RTUs (left) and a Gas Space Heater (right).



Equipped HVAC systems in San Jose Market Center: (a) RTU and (b) space heater
Credit: Building owner (anonymous)

Domestic Hot Water

This retail store has a minimal DHW load (comparable to a single-family home) due to the lack of hot water-intensive activities such as laundry or commercial food service. Hot water serves only restrooms, the breakroom, and janitorial needs. The facility has 50-gallon storage electric water heaters.

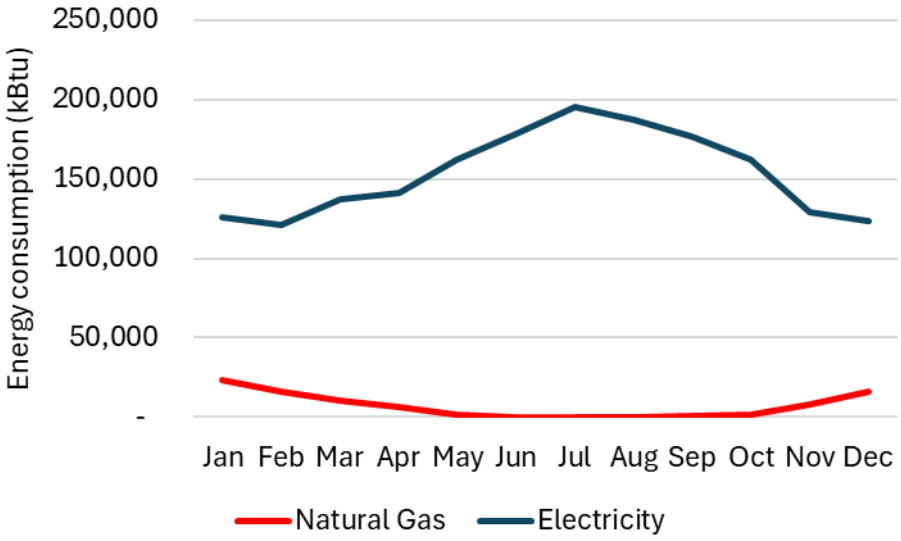
Internal Loads

The retail building operates daily from 8 a.m. to 11 p.m. Occupants' heat gain and cash registers comprise the main nonlighting internal loads.

Utility Data Analysis

Figure 12 below represents the utility data for the retail building in 2024. The dark blue line represents monthly electric use for the building, and the red line represents gas use. The total electricity consumption was 1,840,465 kBtu and the total gas consumption was 83,034 kBtu. The total energy consumption was 1,923,499 kBtu, and the EUI was 33.85 kBtu per square foot per year, which is about 34 percent lower than the national median for retail buildings and 25 percent lower than the median for similar retail buildings that have reported to ENERGY STAR Portfolio Manager in California. The overall energy usage of the building is typical of medium-to-large retail stores of similar construction vintage and within similar climates in California. Space heating is the main source of gas energy usage and presents the largest decarbonization opportunity, although the building has a relatively small heating load of just 1,000 therms per year, or the equivalent of three single-family homes in the same climate zone.

Figure 12: Monthly Electricity and Gas Consumption for the Building



Credit: Building owner (anonymous)

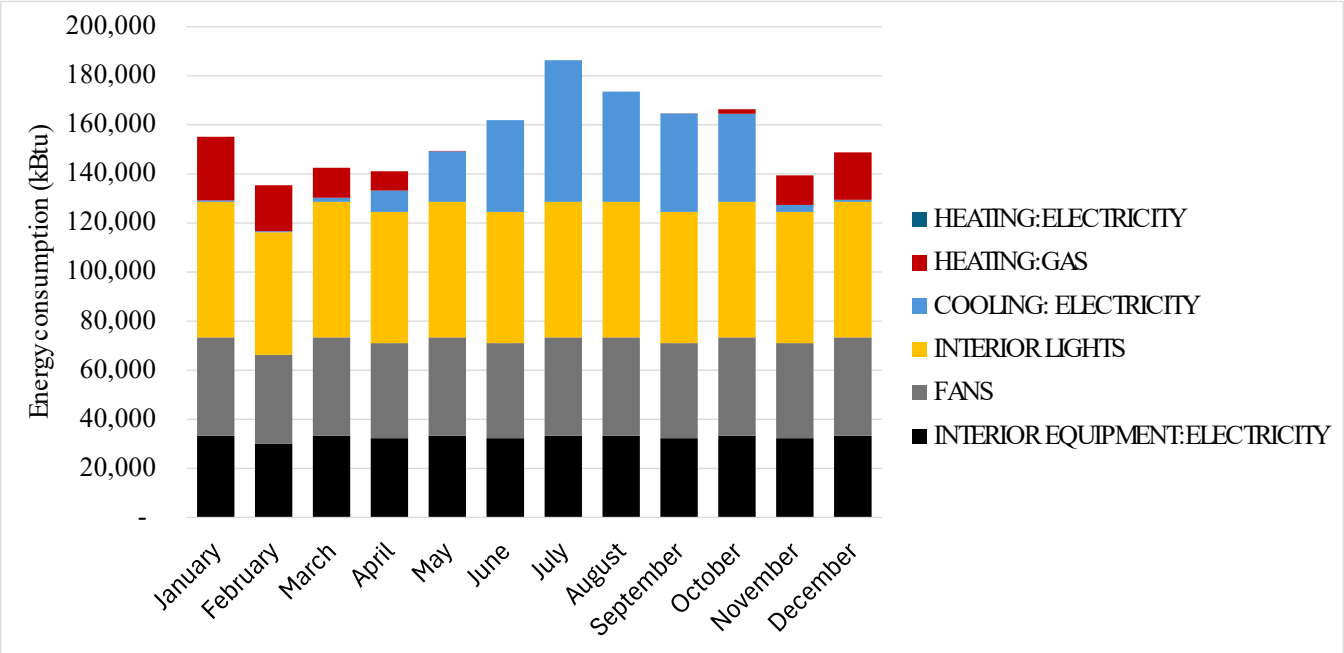
Utility Costs and Economic Analysis

The team analyzed utility cost using the B-19 TOU and G-NR1 gas rates from PG&E. The gas rate is a declining block schedule, where usage above 4,000 therms per month is billed at a rate about 33 percent lower than the rate for the initial 4,000 therms. This customer does not approach the 4,000-therm threshold and uses gas in winter only, so the gas rate is fixed at one price per therm. The electricity rate is a TOU rate with approximately $1,620 of fixed monthly costs (amounting to approximately 28% of total electricity costs) and six TOU periods ranging from $0.04 to $0.18 per kWh, as well as both coincident and non-coincident demand charges that vary with times of the day and year.

Baseline Model Results

Figure 13 shows the end-use energy consumption of the calibrated model. The annual electricity consumption is 1,814,862 kBtu and gas consumption is 98,401 kBtu. Electricity consumption accounts for 95 percent of building energy usage. The interior lights make up the biggest portion as 35 percent (650,750 kBtu) followed by fans which make up 25 percent (471,359 kBtu), and interior equipment, which make up 21 percent (392,345 kBtu). Cooling accounts for 24% of building electricity usage from May to October.

Figure 13: Baseline Model Building Energy Breakdown by Month, End Use and Fuel



Credit: ENERlite Consulting

Energy Efficiency and Decarbonization Measures

This section discusses potential retrofit solutions applied within the 6R Resilient Retrofit Framework. This section describes how each step is executed using targeted strategies for the building, offering a clear and practical roadmap to achieve resilient, cost-effective building upgrades. Quantitative costs and impacts are discussed later in this report.

Bundled Package

For this building, the team developed a bundled scenario that integrates key decarbonization and efficiency strategies. The bundle represents a cost-effective decarbonization pathway and includes:

- Advanced rooftop controls.
- Roof insulation upgrade.
- Network lighting controls.
- Heat pump water heaters.
- Air source heat pumps.

This bundle represents the 6R approach to decarbonization and starts with a review of measures. Measures such as network lighting controls and advanced rooftop controls reduce energy usage. Roof insulation repairs the thermal boundaries of the building. HVAC systems and water heaters are replaced at the end of life. The heat pumps also recover heat from ambient air rather than burning fossil fuels to generate heat.

Bundled Package With Additional Solar and Battery Storage

The solar system allows for regeneration of power from sunlight on the rooftop and provides the final "R" of the 6R approach to decarbonization. Battery storage provides additional load flexibility and maximizes the payback from solar panels by discharging during peak electricity price periods.

Individual measures within the bundled package are described below.

Advanced Rooftop Controls

This scenario combines variable-speed drives, economizers, and demand-controlled ventilation (DCV) to achieve energy savings. Advanced rooftop controllers achieve savings by reducing fan speeds during fan-only operation mode when no heating or cooling is required, by lowering fan speeds during heating, and reducing the need for ventilation when occupancy rates are low in the retail store.

Roof Insulation

This measure involves adding 6-inch rigid insulation boards to the underroof insulation.

Network Lighting Controls

Network lighting controls act as a comprehensive energy management system for store lighting, combining the benefits of daylighting and occupancy sensors and *high-end trimming*. With high-end trimming, the store can dim the lights slightly to meet adequate lighting levels but avoid overlighting spaces.

Heat Pump Water Heaters

The retail store has hot water needs comparable to a home. As such, 50-gallon storage heat pump water heaters can replace the existing water heaters. Heat pump water heaters are about 300 percent more efficient than electric resistance water heaters and 400 percent more efficient than gas water heaters.

Air Source Heat Pumps

Air source heat pumps are a simple and effective decarbonization solution for this building. Heat pump retrofits would have minimal incremental investment costs if conducted at or near the end of service life for the existing gas-heated packaged HVAC units. The team modeled one-for-one replacements of air source heat pumps for gas-heated packaged HVAC units.

Solar Panels

Large single-story retail buildings have ample space on rooftops for solar panels, as is the case with this building. The team modeled about 110 kW of solar panels with a south-southwest orientation.

Batteries

The team modeled a 250-kWh battery storage system which charges when electricity rates are low (and when solar energy is plentiful) and discharges to reduce electricity purchases during peak periods that have high energy and coincident demand costs. In this case, about 75 percent of bill reductions from battery installation are caused by reduced demand charges, and the remaining 25 percent are caused by reduced energy charges.

Decarbonization Parametric Study Results

Table 10, Table 11, and Table 12 compare decarbonization strategies by showing annual electricity consumption in kWh, peak demand in kW, annual gas consumption in kBtu, and site GHG emissions (from gas only, since SB 100 will require a carbon-free grid by 2045) in metric tons and the corresponding energy use intensity in units of kBtu/ft². The peak demand is measured in the "Summer Peak" period of the B-19 TOU rate, but noncoincident or absolute peaks trended similarly. Thus, the measures shown below that reduce peak demand tend to enhance local grid resilience as well as offer systemwide capacity benefits. Table 10 presents the baseline energy use of the building, derived from energy simulation models calibrated to utility bills.

Table 10: Building Energy Use Baseline

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft²)
Baseline	**531,905**	**155**	**98,335**	**5.2**	**34**

Source: ENERlite Consulting

Table 11 summarizes modeled electric and gas energy usage, site GHG emissions, and energy use intensity for the building under different retrofit scenarios. The impacts for each measure are listed individually, and the bolded values in the row labeled "Combined Bundle" reflect the combined impact of all bundled measures.

Table 11: Modeled Building Energy Usage and Site GHG for Various Measures

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft²)
Advanced Rooftop Control	**451,693**	**155**	**79,086**	**4.2**	**29**
Roof Insulation	**500,681**	**142**	**98,351**	**5.2**	**32**
Lighting Controls	**488,460**	**146**	**109,134**	**5.8**	**31**
Heat Pump Water Heaters	**530,905**	**156**	**99,615**	**5.3**	**34**
Rooftop HP for Heating	**532,801**	**148**	**0**	**0.0**	**32**
Combined Bundle	**400,547**	**128**	**0**	**0.0**	**24**

Source: ENERlite Consulting

Table 12 presents the modeled results of onsite solar energy generation, a battery system designed to optimize building load to minimize costs, and a combined bundle of the modeled measures from Table 11 above and the modeled solar plus battery storage systems.

Table 12: Modeled Energy Generation and Storage Measures

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Solar	**307,749**	**138**	**98,335**	**5.2**	**34**
Battery Storage	**537,380**	**125**	**98,335**	**5.2**	**34**
Bundle w/Solar + Battery	**181,866**	**84**	**0**	**0.0**	**24**

Source: ENERlite Consulting

Table 13, Table 14, and Table 15 provide results of the economic analysis. Appendix A explains the costing process for this case study. Table 13 presents the baseline operating costs of the building. The first column shows the net present value of the investment cost relative to the baseline scenario. For the baseline scenario, this value is zero since incremental costs are defined as costs beyond baseline expenditures. The second, third, and fourth columns show the net present cost, of electricity, gas, and combined investment and utility costs from 2035 to 2060 in 2026 dollars. The final column shows the net present value of the savings of the investments, which are zero for the baseline scenario.

Table 13: Net Present Value of Baseline Utility Costs (25-Year Analysis Period)

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Baseline	**0**	**4,195,866**	**63,523**	**4,259,389**	**0**

Source: ENERlite Consulting

Table 14 shows the incremental costs above the baseline scenario, as well as the electricity and gas costs over the study period, the total cost, which is the sum of utility and incremental investment costs, and the savings associated with each measure (if a measure results in additional cost rather than savings, then they are shown with a negative value as negative savings in the last column). The cost impacts for each measure are listed individually, and the "Combined Bundle" reflects the combined impact of all listed measures.

Table 14: Investment Costs, Utility Costs, and Savings for Various Measures

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Advanced Rooftop Control	**80,415**	**3,863,380**	**51,088**	**3,994,884**	**264,505**
Roof Insulation	**205,263**	**3,901,363**	**63,533**	**4,170,160**	**89,229**
Lighting Controls	**114,369**	**3,901,700**	**70,499**	**4,086,568**	**172,821**
Heat Pump Water Heaters	**2,318**	**4,192,106**	**64,349**	**4,258,773**	**616**
Rooftop HP for Heating	**136,114**	**4,107,948**	**0**	**4,244,061**	**15,328**
Combined Bundle	**546,520**	**3,283,054**	**0**	**3,829,574**	**429,815**

Source: ENERlite Consulting

Table 15 presents the modeled results of onsite solar energy generation, a battery system designed to optimize building load to minimize costs, and a combined bundle of the modeled measures from Table 14 above and the modeled solar plus battery storage systems.

Table 15: Costs and Savings for Generation and Storage Measures

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Solar	**263,050**	**3,121,770**	**63,523**	**3,448,343**	**811,046**
Battery Storage	**146,206**	**3,988,882**	**63,523**	**4,198,611**	**60,778**
Bundle w/Solar + Battery	**955,776**	**1,857,043**	**0**	**2,812,819**	**1,446,570**

Source: ENERlite Consulting

This analysis does not account for other potential costs and benefits such as incentives from utility energy efficiency or demand response programs, tax credits, depreciation, or compliance costs with potential codes and standards.

Table 16 shows the costs and savings (in green) and impacts (in blue) associated with sequential application of the bundled measures. Because the measures are applied cumulatively, each row reflects the combined effect of all measures listed up to that point. The "Combined Bundle" row represents the final bundle of measures from Advanced Rooftop Controls through Rooftop Heat Pumps. Since no additional measure is added between the preceding row and the Combined Bundle row, the values are identical. In contrast, the "Bundle w/Solar + Battery" scenario includes a battery system in addition to the measures included in the previous scenario, resulting in further changes to costs, savings, and building performance metrics.

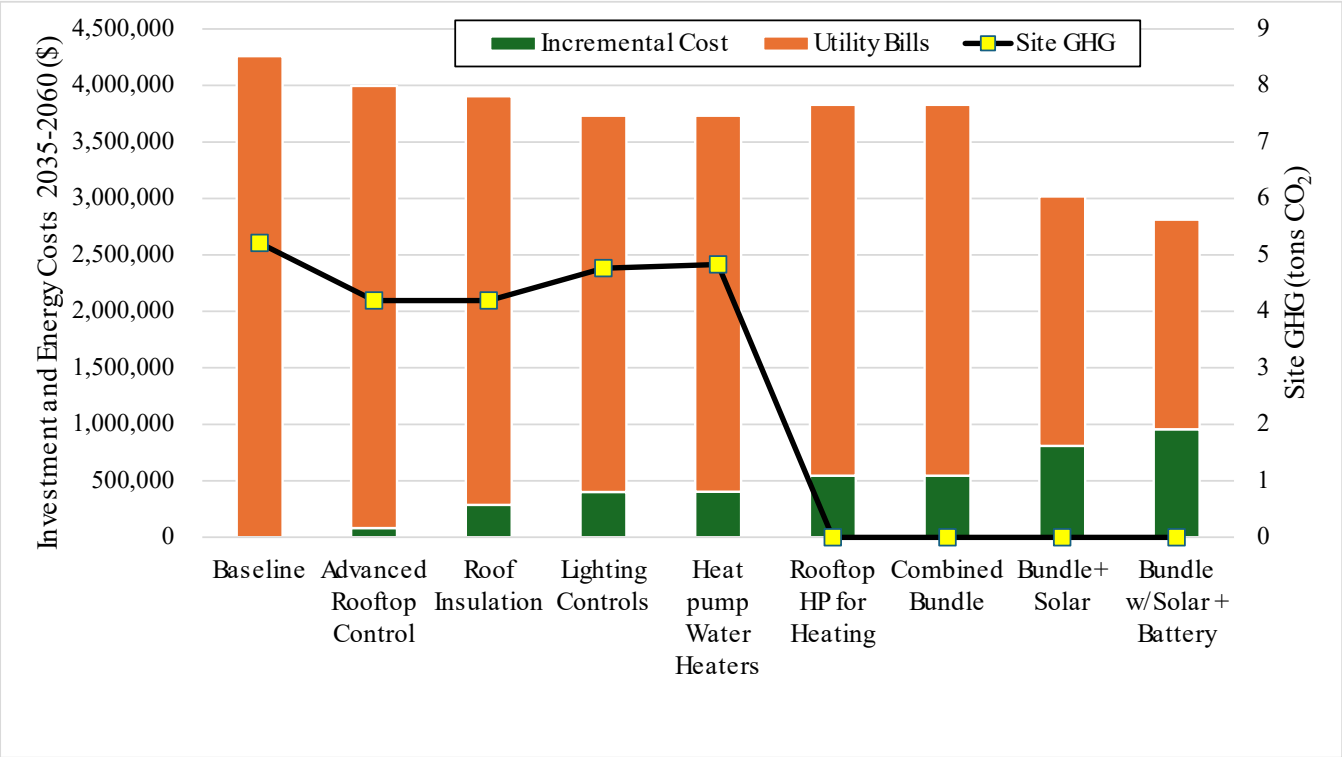
Table 16: Costs and Impacts of Sequential Application of Bundled Measures

Measure	Incremental Cost ($)	Utility Cost ($)	Total Savings ($)	Annual Grid-Purchased Electricity Usage (kWh)	Peak Demand (kW)	Annual Gas Usage (kBtu)	Site GHG (tons CO_2)
Baseline	**0**	**4,259,389**	**0**	**531,905**	**155**	**98,335**	**5**
Advanced Rooftop Control	**80,415**	**3,914,468**	**264,505**	**451,693**	**155**	**79,086**	**4**
Roof Insulation	**285,678**	**3,619,976**	**353,735**	**420,468**	**142**	**79,102**	**4**
Lighting Controls	**400,047**	**3,332,786**	**526,556**	**377,023**	**134**	**89,901**	**5**
Heat Pump Water Heaters	**402,365**	**3,329,852**	**527,172**	**376,023**	**135**	**91,181**	**5**
Rooftop HP for Heating	**546,520**	**3,283,054**	**429,815**	**400,547**	**128**	**0**	**0**
Combined Bundle	**546,520**	**3,283,054**	**429,815**	**400,547**	**128**	**0**	**0**
Bundle + Solar	**809,570**	**2,208,958**	**1,240,861**	**176,391**	**114**	**0**	**0**
Bundle w/Solar + Battery	**955,776**	**1,857,043**	**1,446,570**	**181,866**	**84**	**0**	**0**

Credit: ENERlite Consulting

Figure 14 shows the sequential changes (from left to right) in total investment and energy costs as each measure is applied to the building, combined with all previous measures. The overall costs are shown using stacked bars, with dark green portions representing incremental investment costs above the baseline scenario, and orange portions showing utility bills associated with energy purchases. The site GHG emissions are shown with a black line and yellow markers.

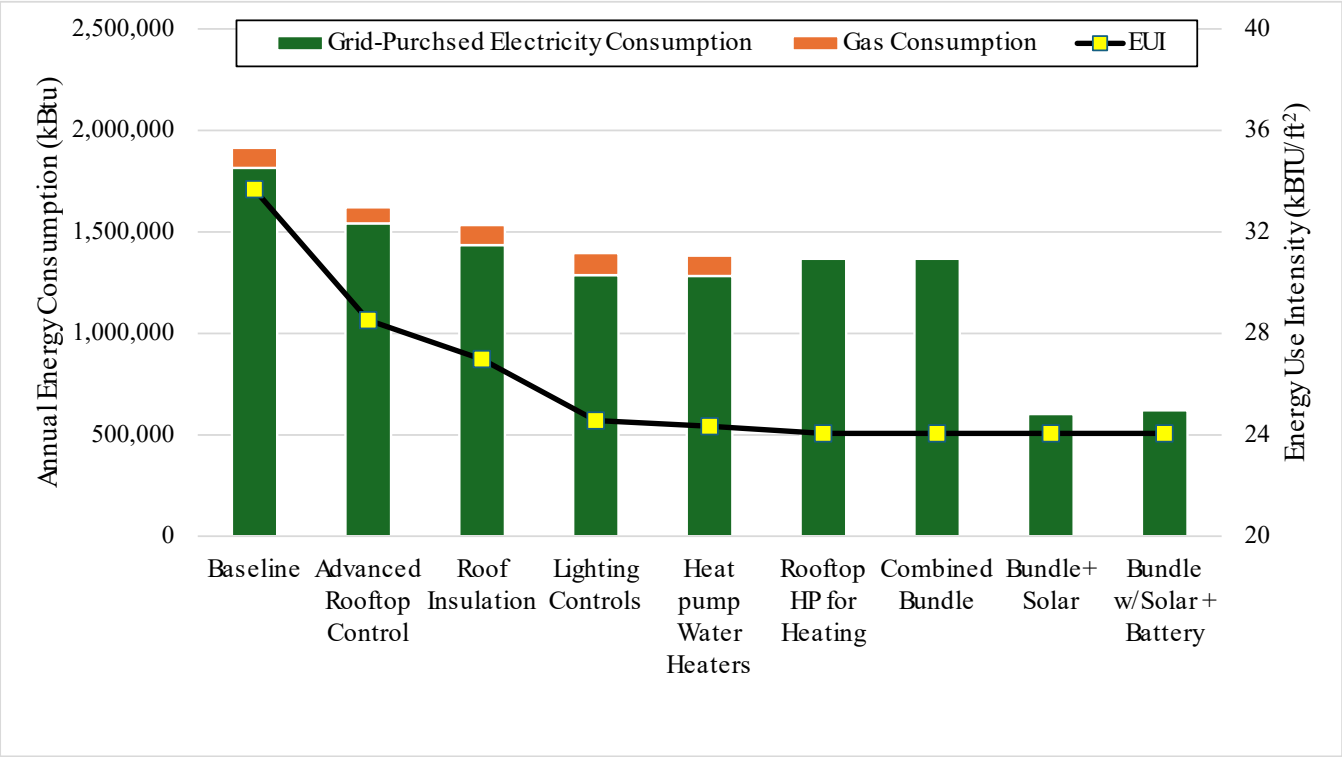
Figure 14: Sequential Development of Utility Plus Investment Costs and Site GHG



Credit: ENERlite Consulting

Figure 15 shows the sequential changes in total purchased energy consumption as each measure is applied to the building. The overall energy consumption, in units of kBtu/year, are represented using stacked bars with the dark green portion representing grid-purchased electricity consumption and the orange portion representing gas consumption. The site EUI emissions are shown with the black line and yellow markers. Note that solar power does not reduce the site EUI since the EUI is calculated as the total purchased and self-generated energy, divided by the floorspace.

Figure 15: Sequential Development of Utility-Purchased Energy and Site EUI



Credit: ENERlite Consulting

Other Considered Measures

The team considered additional energy efficiency and decarbonization measures. Three of these measures are discussed below.

Window Replacement

The team considered two replacement cases for the storefront windows. The first case involved an upgrade to a high-performance glazing system with 50 percent lower solar heat-gain and thermal conductance compared to the baseline. The second case also involved more efficient windows, but with higher solar heat gain to help reduce heating loads in the winter.

Window Film

Window film costs less than window replacement. Applying a thin film to storefront windows reduces solar heat gain by 30 percent and reduces thermal conductance by 7 percent. The improvements are not as significant as window replacement, but the measure has just one tenth the cost of window replacement.

Heat Recovery

The team modeled heat recovery for the RTUs, with an ability to recover about 75 percent of the heat from exhausted air across all units.

Table 17 shows electricity and gas energy usage, peak electric demand, as well as site GHG emissions and EUI for each measure.

Table 17: Energy Usage and Intensity, Demand, and Emissions for Various Scenarios

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Baseline	**531,905**	**155**	**98,335**	**5.2**	**33.7**
Window Replacement	**529,301**	**154**	**100,262**	**5.3**	**33.5**
Window Film	**530,576**	**155**	**99,685**	**5.3**	**33.6**
Heat Recovery	**531,221**	**151**	**75,539**	**4.0**	**33.2**

Source: ENERlite Consulting

Table 18 shows equipment and installation costs, total utility costs over the study period, and cost savings over the study period for each measure. Any overall cost increases are shown as negative amounts in the last column.

Table 18: Net Present Value of Investment Costs, Utility Costs, and Savings

Measure	Investment Costs (above Baseline) ($)	Electricity Costs ($)	Gas Costs ($)	Total Costs ($)	Savings ($)
Baseline	**0**	**4,195,866**	**63,523**	**4,259,389**	**0**
Window Replacement	**120,077**	**4,172,939**	**64,768**	**4,357,784**	**-98,395**
Window Film	**10,086**	**4,184,844**	**64,395**	**4,259,325**	**64**
Heat Recovery	**232,894**	**4,144,846**	**48,797**	**4,426,538**	**-167,149**

Source: ENERlite Consulting

CHAPTER 5:
Case Study — A Multifamily Community

Building Characterization

This garden-style multifamily community in Yolo County was constructed in 2005 with 59 residential units, including 17 one- and two-bedroom units, and 25 three-bedroom units. There are three communal buildings — a recreation building with a kitchen and computer room, laundry building, and maintenance building. The total floor area is 66,334 ft^2. The community has solar panels on most roofs, totaling 115 kW. The community's energy-use intensity, 46 $kBtu/ft^2$, is about 29 percent lower than the national median for multifamily communities but is near the median for similar large multifamily communities in California that have reported to ENERGY STAR Portfolio Manager.

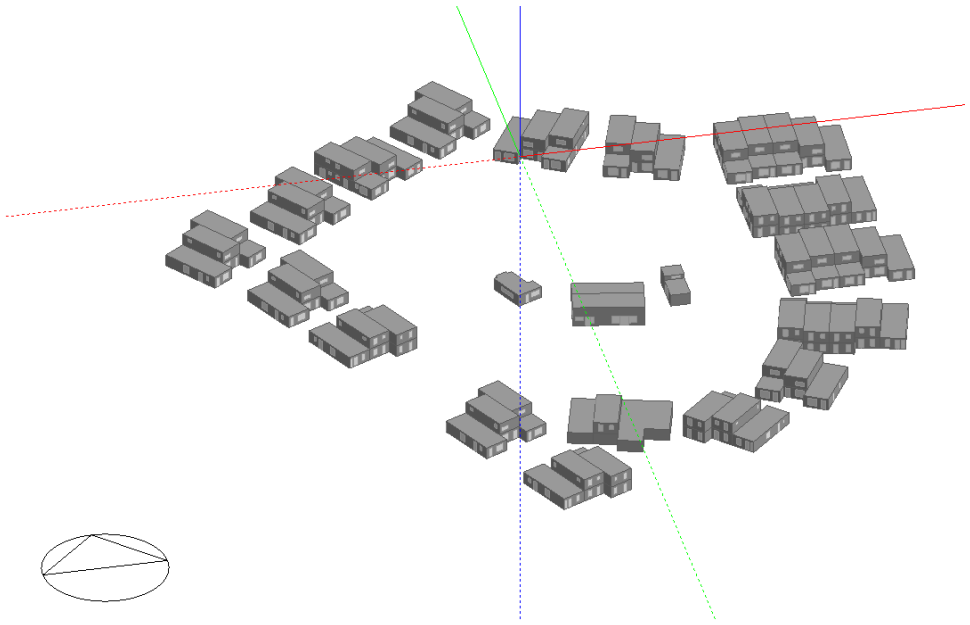
Data Collection

The building owner provided the team with utility billing data, floor plans, construction drawings, and documentation on the HVAC systems and other equipment.

Geometry and Building Envelope

After reviewing the community outlay and building geometry, the team modeled typical one-, two-, and three-bedroom units. Each unit in the model is located at the exact position as in the real community, as shown in Figure 16 below.

Figure 16: A Depiction of the Energy Simulation Model Representing the Community



Credit: ENERlite Consulting

Most building walls in the community are wood framed with R-17.8. The tenant unit attics are adequately insulated, with R-37 insulation. The windows are also high-performance windows, with low solar heat gain coefficients and low thermal conductance.

Lighting

The recreation building was upgraded to LED fixtures. The kitchen has T8 linear lighting fixtures, and the restrooms have CFL sconces. The dwelling units were specified originally with fluorescent lighting, but according to the building owner, the lighting in some units has been changed to LEDs. Socket-based general service lamps are mostly LEDs. Exterior lighting is sparse, with some pole-mounted LED fixtures lighting parking areas and walkways illuminated mostly by wall sconces and porch lights.

HVAC System

All dwelling units have single-zone HVAC units and gas furnaces. The HVAC units are rated at seasonal energy efficiency ratio (SEER) 14, which is typical for air conditioners installed 20 years ago. The common areas have air conditioners with gas furnaces and two heat pumps.

Water Heating

Domestic hot water is provided by gas furnaces to all buildings. Dwelling units have 40-gallon residential units while the common area has a larger, 200 kBtu/hr commercial gas water heater.

Laundry

The two-bedroom and three-bedroom units have washers and gas dryers. There are 17 one-bedroom units that share a common laundry room with six pairs of washers and gas dryers. The electrical design of the dwelling units assumes a maximum 2.5 kilovolt-ampere draw from dryers and specifies 30-amp breakers, which is sufficient for electric heat pump dryers.

Cooking

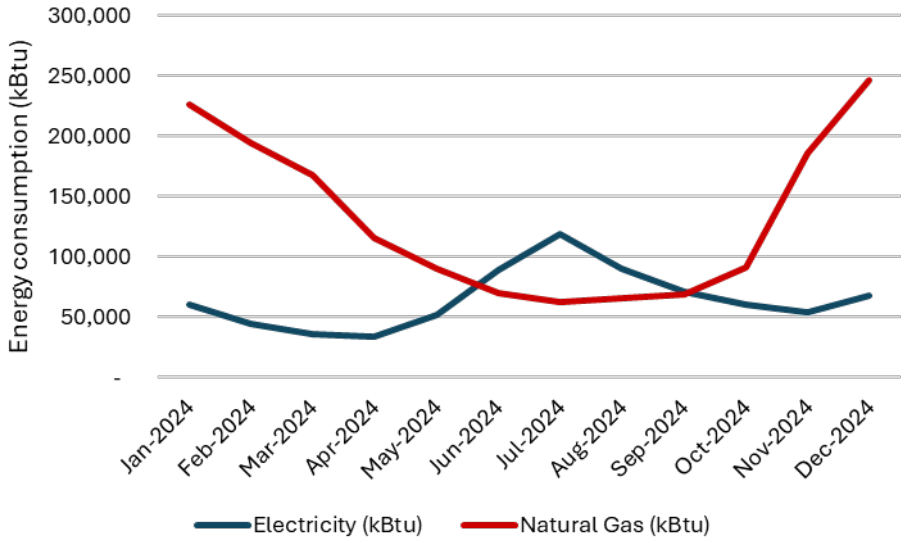
All dwelling units are equipped with gas ranges. The kitchen also has a gas range. The gas ranges are a challenge for decarbonization since the dwelling units have limited electrical service capacity (100-amp panels) which may not be enough to support heat pumps, electric dryers, and electric ranges together. Panel upgrades can be avoided for some buildings by using circuit-sharing devices, 120-volt appliances, smart load controls, and other load management technologies.

Utility Data Analysis

Figure 17 represents the utility data for the retail building in 2024. The total grid electricity consumption was 775,437 kBtu (with 676,102 kBtu supplied by solar panels) and the total gas consumption was 1,584,383 kBtu. The total energy consumption is 3,071,953 kBtu (inclusive of generation from existing solar panels), and the EUI is about 46 kBtu per square foot per year, which is about 12 percent lower than the national median for garden-style multifamily properties and 11 percent lower than the median for similar garden-style multifamily properties in California that have reported to ENERGY STAR Portfolio Manager. Note that the grid-purchased electricity usage appears to be low because of the on-site solar generation,

which is about 200,000 kWh per year. The property is otherwise typical in terms of gas and electricity usage. Monthly electric usage is shown with the blue line, and gas usage is shown with the red line.

Figure 17: Monthly Electricity and Gas Consumption for the Building



Credit: Building owner (anonymous)

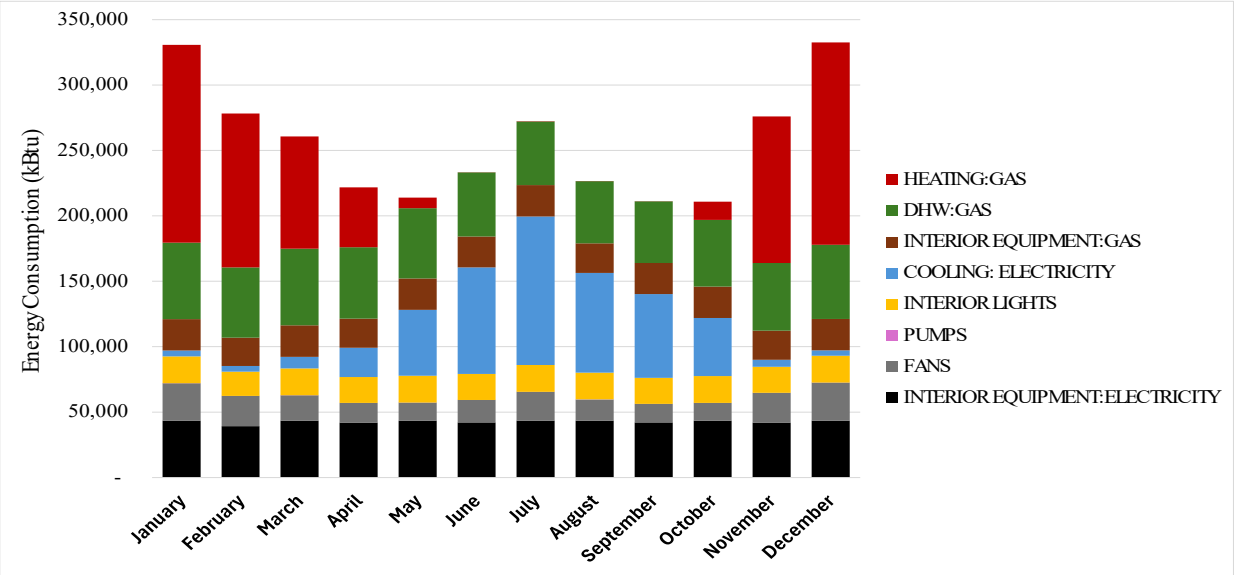
Utility Costs and Economic Analysis

The team used the E-TOU-C and GSL gas rates from PG&E to analyze utility costs. The electricity rate is a TOU rate with fixed monthly costs and four TOU periods ranging from $0.29 per kWh to $0.44 per kWh.

Baseline Model Results

Figure 18 shows the end-use energy consumption of the calibrated model. The annual electricity consumption is 1,472,372 kBtu and gas consumption is 1,599,581 kBtu. The modeled electricity usage is higher than the utility bills because the simulation reflects the building's total energy consumption, while the utility bills show only the electricity purchased from the utility after on-site solar production is deducted.

Figure 18: Baseline Model Building Energy Breakdown by Month, End Use, and Fuel



Credit: ENERlite Consulting

Energy Efficiency and Decarbonization Measures

This section discusses potential retrofits applied within the 6R Resilient Retrofit Framework. This section describes how each step is executed using targeted strategies for the building, offering a clear and practical roadmap to achieve resilient, cost-effective building upgrades. Quantitative costs and impacts are discussed later in this report.

Bundled Package

For this building, the team developed a bundled scenario that combines key decarbonization and efficiency strategies. The bundle represents a cost-effective decarbonization pathway and includes:

- Smart thermostats.
- Attic insulation upgrade.
- Air sealing.
- High-efficiency heat pumps.
- Heat pump water heaters.
- Heat pump dryers.
- Electric ranges.
- Electrical panel and wiring upgrades necessary to increase service capacity in units.

This bundle represents the 6R approach to decarbonization and starts with a review of measures such as smart thermostats, window film, and attic insulation that reduce energy usage. Air sealing repairs gaps and cracks in the building walls, floors, and roof, helping keep heated or cooled air inside the building. HVAC systems, water heaters, dryers, and ranges are replaced at the end of life. The new heat pump dryers and water heaters recover heat from

ambient air. The existing solar system allows for power regeneration. Note that LED lighting is not considered in the bundle because the building will likely be fully equipped with LEDs by 2035, which is when the decarbonization investments are modeled to start.

Bundled Package With Additional Solar and Battery Storage

The bundled package with additional solar and battery storage adds 116 kW of solar panels and a 425-kWh battery to the bundle described above. Individual measures within the bundled package are described below.

Smart Thermostats

The team modeled smart thermostats by altering HVAC setpoints in the simulation models. The overall energy savings are consistent with average per-unit energy savings that evaluation, measurement, and verification studies have measured through billing analyses.

Attic Insulation

This measure consists of increasing the attic insulation from R-35 to R-45.5.

Air Sealing

This measure involves applying sealants to wall-to-roof joints and other openings in walls and sealing window frames. The team simulated the effects of air sealing by reducing the air-exchange rate in the simulation model.

Air Source Heat Pumps

This measure involves replacing furnace-air conditioner units at or near the end of service life with air source heat pumps. Standard efficiency and premium efficiency heat pumps were modeled to explore trade-offs between higher initial cost and higher bill savings.

Heat Pump Clothes Dryers

This measure involves replacing gas dryers at or near the end of service life with efficient heat pump dryers. Most heat-pump dryers would need a 240-volt, 30-ampere dedicated circuit, which, based on the site electrical plans provided by the study participant, are specified for clothes dryers in the dwelling units.

Heat Pump Water Heaters

This measure involves replacing gas water heaters at or near the end of service life with heat pump water heaters. Most heat-pump water heaters would need a 240-volt, 30-ampere dedicated circuit. The dwelling units have one circuit only, reserved for the clothes dryers. The cost of electrical upgrades is considered in the bundled list of measures, since it would be shared among several electrification measures.

Electric Range Conversion

This measure involves replacing gas ranges at or near the end of service life with standard electric ranges. Induction ranges were not selected for the study because of the high cost and low gains compared to standard electric units. The electric ranges would need an added 240-volt, 40-ampere dedicated circuit and may require panel upgrades when coupled with other electrification measures such as water heaters and dryers. The cost of electrical upgrades is

considered in the bundled list of measures, since it would be shared among several electrification measures.

Additional Solar Power

Using space available in car ports and on the recreation building can double the solar generation capacity of the community. The team modeled an additional 116 kW of solar power added on site.

Battery Storage

The team modeled a 425-kWh battery storage system which charges when electricity rates are low (and when solar energy is plentiful) and discharges to reduce electricity purchases during high-cost peak periods.

Decarbonization Parametric Study Results

Table 19, Table 20, and Table 21 compare decarbonization strategies by showing annual electricity consumption in kWh, peak demand in kW, annual gas consumption in kBtu, and site GHG emissions (from gas only as well as combined with secondary emissions from electricity generation) in metric tons, and the corresponding EUI in units of kBtu/ft². The peak demand is measured in the "Summer Peak" period of the E-TOU-C rate, but noncoincident or absolute peaks trended similarly. Thus, the measures shown below that reduce peak demand tend to enhance local grid resilience as well as offer systemwide capacity benefits. Table 19 presents the baseline energy use of the building, derived from energy simulation models calibrated to utility bills.

Table 19: Building Energy Use Baseline

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Baseline	**233,373**	**276**	**1,599,581**	**85**	**46**

Source: ENERlite Consulting

Table 20 summarizes modeled electric and gas energy usage, site GHG emissions, and energy use intensity for the building under different retrofit scenarios. The impacts for each measure are listed individually, but the bolded values in the row labeled "Combined Bundle" reflects the combined impact of all bundled measures.

Table 20: Modeled Building Energy Usage and Site GHG for Various Measures

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Smart Thermostat	**228,161**	**275**	**1,466,840**	**78**	**44**
Attic Insulation	**217,993**	**271**	**1,590,629**	**84**	**45**
Air Sealing	**216,833**	**266**	**1,478,989**	**78**	**44**
High Efficiency Heat Pump	**233,473**	**214**	**910,414**	**48**	**36**
Heat Pump Clothes Dryer	**245,794**	**278**	**1,431,444**	**76**	**44**
Electrical Upgrades	**233,373**	**276**	**1,599,581**	**85**	**46**
Heat Pump Water Heater	**280,479**	**285**	**969,393**	**51**	**39**
Electric Range	**250,838**	**278**	**1,487,490**	**79**	**46**
Combined Bundle	**279,975**	**214**	**0**	**0**	**25**

Source: ENERlite Consulting

Table 21 presents the modeled results of onsite solar energy generation, a battery system designed to optimize building load to minimize costs, and a combined bundle of the modeled measures from Table 20 above and the modeled solar plus battery storage systems.

Table 21: Modeled Energy Generation and Storage Measures

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Solar	**37,358**	**276**	**1,599,581**	**85**	**46**
Battery	**242,110**	**198**	**1,599,581**	**85**	**47**
Bundle w/Solar + Battery	**92,696**	**136**	**0**	**0**	**25**

Source: ENERlite Consulting

Table 22, Table 23, and Table 24 show the results of the economic analysis. Appendix A provides an explanation of the costing process for this case study. Table 22 presents the baseline operating costs of the building. The first column shows the net present value of the

investment cost relative to the baseline scenario. For the baseline scenario, this value is zero since incremental costs are defined as costs beyond baseline expenditures. The second, third, and fourth columns show the net present cost, of electricity, gas, and combined investment and utility costs from 2035 to 2060 in 2026 dollars. The final column shows the net present value of the savings of the investments, which are zero for the baseline scenario.

Table 22: Net Present Value of Baseline Utility Costs (25-Year Analysis Period)

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Baseline	**0**	**2,234,502**	**1,153,164**	**3,387,667**	**0**

Source: ENERlite Consulting

Table 23 shows the incremental costs above the baseline scenario, as well as the electricity and gas costs over the study period, the total cost, which is the sum of utility and incremental investment costs, and the savings associated with each measure (if a measure results in additional cost rather than savings, then they are shown with a negative value as negative savings in the last column). The cost impacts for each measure are listed individually, and the "Combined Bundle" reflects the combined impact of all listed measures.

Table 23: Investment Costs, Utility Costs, and Savings for Various Measures

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Smart Thermostat	**16,698**	**2,202,745**	**1,057,469**	**3,276,912**	**110,755**
Attic Insulation	**124,139**	**2,126,008**	**1,146,711**	**3,396,858**	**-9,191**
Air Sealing	**64,210**	**2,113,060**	**1,066,228**	**3,243,497**	**144,169**
High-Efficiency Heat Pump	**200,540**	**2,260,264**	**656,333**	**3,117,136**	**270,531**
Heat Pump Clothes Dryer	**18,850**	**2,316,962**	**1,031,952**	**3,367,764**	**19,902**
Electrical Upgrades	**148,253**	**2,234,502**	**1,153,164**	**3,535,919**	**-148,253**
Heat Pump Water Heater	**104,175**	**2,559,048**	**698,852**	**3,362,075**	**25,592**
Electric Range	**0**	**2,350,593**	**1,072,356**	**3,422,950**	**-35,283**
Combined Bundle	**676,864**	**2,581,061**	**0**	**3,257,925**	**129,741**

Source: ENERlite Consulting

Table 24 presents the modeled results of onsite solar energy generation, a battery system designed to optimize building load to minimize costs, and a combined bundle of the modeled measures from Table 23 above and the modeled solar plus battery storage systems.

Table 24: Costs and Savings for Generation and Storage Measures

Measure	Incremental Cost ($)	Electricity Cost ($)	Gas Cost ($)	Total Cost ($)	Savings ($)
Solar	**488,089**	**1,714,248**	**1,153,164**	**3,355,501**	**32,165**
Battery	**222,852**	**2,018,833**	**1,153,164**	**3,394,850**	**-7,183**
Bundle w/Solar + Battery	**1,387,805**	**1,573,718**	**0**	**2,961,523**	**426,143**

Source: ENERlite Consulting

Table 25 shows the costs and savings (in green) and impacts (in blue) associated with sequential application of the bundled measures. Because the measures are applied cumulatively, each row reflects the combined effect of all measures listed up to that point. The "Combined Bundle" row represents the final bundle of measures from Smart Thermostats through the Electric Ranges. Since no additional measure is added between the preceding row and the Combined Bundle row, the values are identical. In contrast, the "Bundle w/Solar + Battery" scenario includes a battery system in addition to the measures included in the previous scenario, resulting in further changes to costs, savings, and building performance metrics.

Table 25: Costs and Impacts of Sequential Application of Bundled Measures

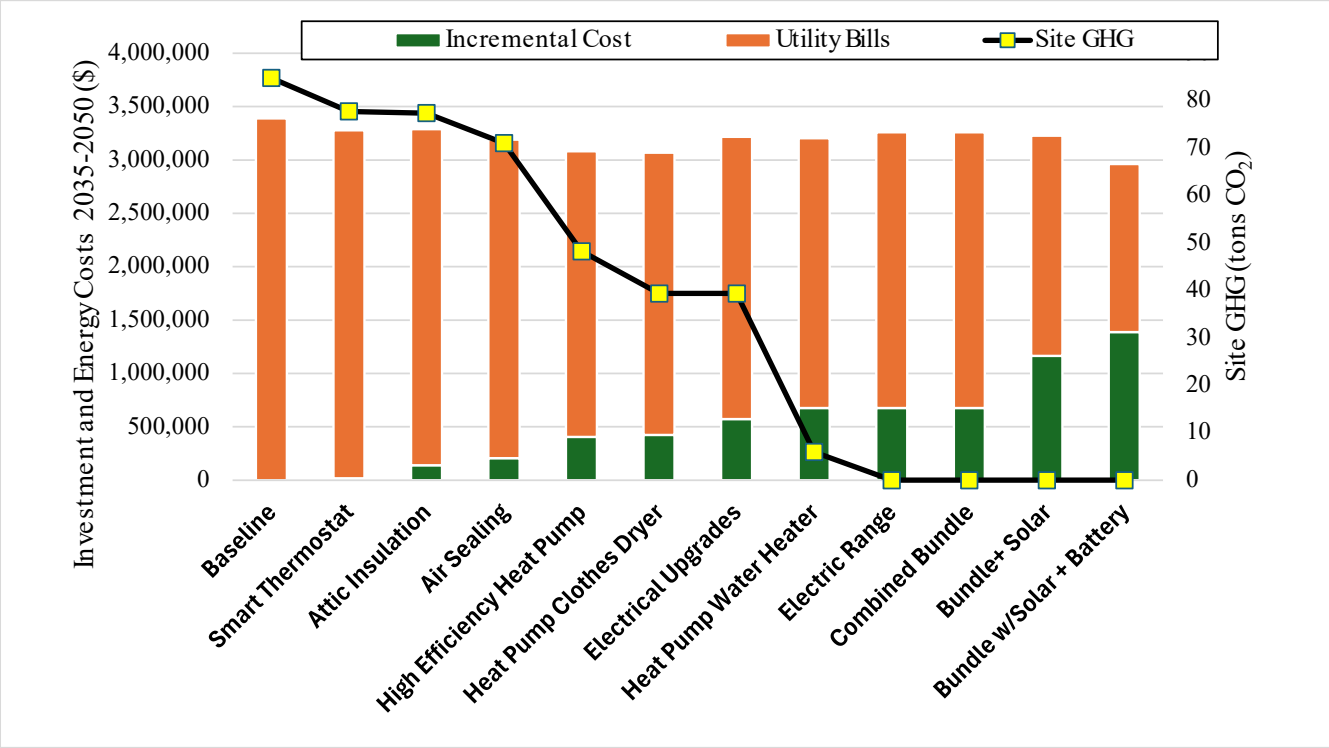
Measure	Incremental Cost ($)	Utility Cost ($)	Total Savings ($)	Annual Grid-Purchased Electricity Usage (kWh)	Peak Demand (kW)	Annual Gas Usage (kBtu)	Site GHG (tons CO_2)
Baseline	**0**	**3,387,667**	**0**	**233,373**	**276**	**1,599,581**	**85**
Smart Thermostat	**16,698**	**3,260,214**	**110,755**	**228,161**	**275**	**1,466,840**	**78**
Attic Insulation	**140,836**	**3,146,471**	**100,359**	**213,504**	**270**	**1,459,614**	**77**
Air Sealing	**205,046**	**2,984,475**	**198,146**	**202,900**	**260**	**1,340,589**	**71**
High Efficiency Heat Pump	**405,586**	**2,674,961**	**307,120**	**202,985**	**205**	**910,414**	**48**
Heat Pump Clothes Dryer	**424,436**	**2,642,988**	**320,243**	**215,405**	**206**	**742,278**	**39**
Electrical Upgrades	**572,689**	**2,642,988**	**171,990**	**215,405**	**206**	**742,278**	**39**
Heat Pump Water Heater	**676,864**	**2,527,130**	**183,672**	**262,510**	**214**	**112,090**	**6**
Electric Range	**676,864**	**2,581,061**	**129,741**	**279,975**	**214**	**0**	**0**
Combined Bundle	**676,864**	**2,581,061**	**129,741**	**279,975**	**214**	**0**	**0**

Bundle + Solar	**1,164,953**	**2,060,807**	**161,907**	**99,339**	**214**	**0**	**0**
Bundle w/Solar + Battery	**1,387,805**	**1,573,718**	**426,143**	**92,696**	**136**	**0**	**0**

Source: ENERlite Consulting

Figure 19 shows the sequential changes (from left to right) in total investment and energy costs as each measure is applied to the building, combined with all previous measures. The overall costs are represented in the graph using stacked bars. The green portion of the bars represents incremental investment costs above the baseline scenario, and the orange portion of the bars represents utility bills associated with energy purchases. The site GHG emissions are shown with a black line and yellow markers.

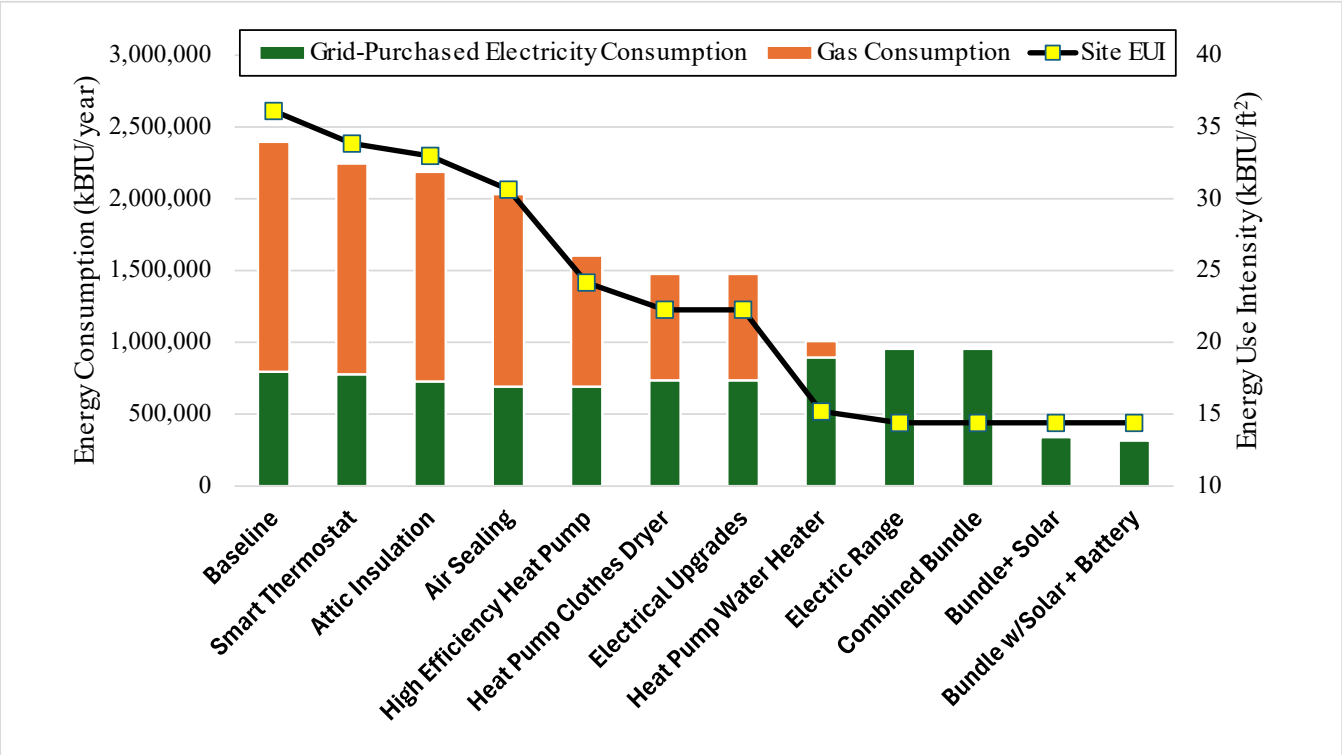
Figure 19: Sequential Development of Utility Plus Investment Costs and Site GHG



Credit: ENERlite Consulting

Figure 20 shows the sequential changes (from left to right) in total purchased energy consumption as each measure is applied to the building. The overall energy consumption, in units of kBtu/year, are shown with stacked bars. The green portion of the bars represents grid-purchased electricity consumption, and the orange portion of the bars represents gas consumption. The site EUI emissions are shown with the black line and yellow markers. The solar power does not reduce the site EUI since the EUI is calculated as the total purchased and self-generated energy, divided by the floorspace.

Figure 20: Sequential Development of Utility-Purchased Energy and Site EUI



Credit: ENERlite Consulting

Other Considered Measures

The team considered other energy efficiency and decarbonization measures. Some notable measures are discussed below.

Window Replacement

This measure involves an upgrade to a high-performance glazing system with significantly lower solar heat-gain and thermal conductance compared to the baseline.

Window Film

Window film costs less than window replacement. Applying a thin film to windows reduces solar heat gain by 30 percent and reduces thermal conductance by 7 percent. The improvements are not as significant as window replacement, but the measure provides costs just one tenth as much as window replacement. In this case window film was not cost-effective due to the labor costs involved with applying film to many relatively small windows.

Wall Insulation

This measure adds R-4.2 rigid insulation to exterior-facing walls.

Lighting Controls

Occupancy sensor controls in dwelling units were modeled by adjusting lighting utilization schedules in the building simulation. The simulation used a low controlled wattage to acknowledge that LEDs are the prevalent lighting source in the community. This measure was

marginally cost-effective but wasn't considered as a deep energy efficiency or decarbonization strategy.

Air Source Heat Pumps

Both standard efficiency and premium efficiency heat pumps were modeled to explore trade-offs between higher initial cost and higher bill savings. While both types of heat pumps were found to be cost effective, the higher efficiency models were found to be more cost effective than standard models.

Table 26 shows electricity and gas energy usage, peak electric demand, as well as site GHG emissions and EUI for each measure.

Table 26: Energy Usage and Intensity, Demand, and Emissions for Various Scenarios

Measure	Annual Grid-Purchased Electricity Consumption (kWh)	Peak Demand (kW)	Annual Gas Consumption (kBtu)	Site GHG (tons CO_2)	Site EUI (kBtu/ft^2)
Baseline	**233,373**	**276**	**1,599,581**	**85**	**46.3**
Window Film	**224,477**	**274**	**1,631,197**	**86**	**46.3**
Window Replacement	**221,997**	**273**	**1,611,311**	**85**	**45.9**
Wall Insulation	**230,018**	**274**	**1,573,359**	**83**	**45.7**
Lighting Controls	**232,413**	**276**	**1,599,420**	**85**	**45.7**
Standard Heat Pump	**275,791**	**250**	**910,414**	**48**	**38.1**

Source: ENERlite Consulting

Table 27 shows equipment and installation costs, total utility costs over the study period, and cost savings over the study period for each measure. Any overall cost increases are shown as negative amounts in the last column.

Table 27: Net Present Value of Investment Costs, Utility Costs, and Savings

Measure	Investment Costs (above Baseline) ($)	Electricity Costs ($)	Gas Costs ($)	Total Costs ($)	Savings ($)
Baseline	**$0**	**$2,234,502**	**$1,153,164**	**$3,387,667**	**$0**
Window Film	**$74,341**	**$2,172,900**	**$1,175,957**	**$3,423,198**	**($35,532)**
Window Replacement	**$657,269**	**$2,154,731**	**$1,161,620**	**$3,973,620**	**($585,954)**

Wall Insulation	**$187,416**	**$2,208,224**	**$1,134,260**	**$3,529,901**	**($142,234)**
Lighting Controls	**$2,967**	**$2,230,911**	**$1,153,049**	**$3,386,927**	**$739**
Standard Heat Pump	**$52,376**	**$2,555,565**	**$656,333**	**$3,264,274**	**$123,393**

Source: ENERlite Consulting

CHAPTER 6: Conclusions

Office Building

The study found that the lifetime net benefits for the bundle of measures ranged from 1 percent (without solar and battery) to 6 percent (with solar and battery) of the total utility bills from 2035 to 2060. The team found the recommended bundle of measures is cost-effective and can decarbonize the building, provided that the restaurant tenants also replace cooking equipment with electric options. A lower first-cost alternative, which may still reduce site GHG emissions by more than 70 percent if bundled with other measures such as demand-control ventilation or electric food service equipment, is to supplement an air-to-water heat pump with an existing gas boiler. The recommended bundle of measures reduces the site EUI by 16 percent, which is noteworthy since the building is already efficient.

The economic analysis is most sensitive to the difference between gas and electricity costs. Decarbonization project cost-effectiveness would improve under utility rate structures that distinguish fixed costs from variable costs more clearly, so that the cost of electricity usage, particularly in off-peak times, were lower.

The team noted the following lessons learned from this case study.

Electrical Service Capacity

Building decarbonization often involves adding to the connected electrical load of the building. This building likely has ample spare capacity because it uses less than half the electricity than it did at the turn of the century. It is reasonable to assume that older buildings were designed with sufficient capacity to power inefficient HVAC systems, motors, lighting, and appliances from decades ago. Moreover, heating and cooling have little overlap, so the air-to-water heat pump scenario studied for this report would likely not cause increases in actual load. Heat-recovery chillers are advantageous under constrained electrical capacity conditions, since they can provide heating and cooling at the same time without adding to the connected load.

Boiler Replacement

Replacement of fossil fuel boilers with electric alternatives can be a complex and costly undertaking. The team could not find straightforward, ready-to-implement solutions or one-for-one boiler replacement options. The air distribution system of the building poses the greatest challenge, since it is designed to work with 200°F water. Heat-recovery chillers or heat pumps with adequate capacity are available, but they cannot heat water to 200°F. A second challenge is limited available space for the heat exchanger. Heat pumps and chillers must have a source of heat or adequate cooling loads during times of heating.

One way to solve the problem that heat recovery chillers and heat pumps cannot heat water to 200°F is to run tandem gas and electric heaters. In the air-to-water heat pump scenario, the heat pump produced 140°F water which was fed into the boiler for heating to 200°F. This approach reduced space heating gas consumption by about 70 percent without requiring VAV box replacement. The heat-recovery chiller offered a more complete solution, but at the cost

of replacing half of the VAV boxes earlier than otherwise scheduled. Optimization steps such as assigning the heat-recovery chiller to the server room, reducing economizer usage if needed during periods of simultaneous heating and cooling, and using the cooling tower as a heat exchanger in winter, will allow the heat recovery chiller to serve the full heating load of the building.

Retail Building

The study found that the lifetime net benefits of the bundle of measures ranged from ten percent (without solar and battery) to 34 percent (with solar and battery) of the total utility bills from 2035 to 2060. The high potential for savings in this case is driven by the ample capacity for solar panels.

The parametric energy modeling results indicate that all measures considered, other than window replacements and heat recovery, have a positive net present value, indicating that they reduce overall building maintenance costs during the period of the study. The energy savings for heat recovery were modest for this building, and the team suspects the main reason is that the building brings in close to the minimum recommended amount of outside air during the heating season.

Envelope improvements such as window upgrades, window film, and wall insulation yield modest savings, confirming that internal loads and HVAC operation — rather than envelope performance — are the dominant drivers of energy use in big box retail buildings.

On-site solar PV generation provides the largest overall reduction in grid-purchased energy use, followed by advanced rooftop controls. The air source heat pump retrofit is the main measure for reducing site GHG emissions. Other measures may result in more source decarbonization in the next few years, but as California's electricity grid decarbonizes, electrification measures will result in greater incremental decarbonization over the next three decades. While heat pumps are essential for decarbonization, many other measures can yield savings and reduce EUI by up to 30 percent.

Electrical Service Capacity

Building decarbonization often involves adding to the connected electrical load of the building. Technically, air source heat pumps increase connected loads because they are equipped with auxiliary heating coils. Auxiliary electric heating coils are large electric resistance coils inside rooftop heat pump units that automatically provide extra heat when outdoor temperatures are too cold for the heat pump to supply all the heating by itself. However, heat pumps are not expected to rely on heating coils given the mild, above-freezing temperatures in Santa Clara County.

Multifamily Community

The study found that the lifetime net benefits of the bundle of measures ranged from four percent (without solar and battery) to 13 percent (with solar and battery) of the total utility bills from 2035 to 2060. Air sealing, smart thermostats, and efficient heat pumps were among the most cost-effective measures. Although some measures such as electric ranges and battery storage were not cost-effective, when combined with other measures they created a cost-effective bundle that could achieve full site decarbonization. The electrical upgrades

accounted for 22 percent of recommended bundle costs, but 11 percent for the more costly bundle with solar and battery. Despite these costs, however, both decarbonization bundles were cost-effective.

Electrical Service Capacity

Building decarbonization often involves adding to the connected electrical load of the building. Inspection of current panel layouts at this multifamily community suggests that costly electrical upgrades are needed to achieve full decarbonization. While the electrical upgrades will not generate energy or bill savings by themselves, they unlock other cost-effective decarbonization. Despite the additional costs associated with electrical upgrades, the decarbonization bundle (with solar and battery storage) is expected to generate utility cost savings of more $400,000 (net present value in 2026 dollars) during the service life.

Premium Efficiency Equipment

Premium efficiency heat pumps were a better choice than standard heat pumps. The accumulated bill savings over time were greater than the initial cost of the more efficient equipment.

Summary of Conclusions

This section summarizes the key findings of the decarbonization analysis across the three study buildings. Overall, the results indicate that decarbonization pathways can be both technically feasible and economically viable when measures are implemented strategically and aligned with normal equipment replacement cycles. The conclusions also highlight how building characteristics, load profiles, utility rate structures, and future energy price trends influence cost-effectiveness, with implications for how similar buildings may approach long-term decarbonization planning.

Decarbonization Was Technically and Economically Viable

The study found that decarbonization was technically and economically viable for all three buildings provided that the highest capital cost investments are timed to align with equipment replacement schedules. All buildings had a mix of low-cost and high-cost measures that could be stacked into cost-effective decarbonization bundles.

Building Representativeness

All three buildings selected for the study were typical but were also more efficient than the average building of that type. Poorer performing buildings may have more potential for energy efficiency measures and thus may have more cost-effective pathways to decarbonization.

Load Flexibility

Battery storage was economically viable for all three buildings. However, the economics were far more favorable for the nonresidential buildings because of the higher charges related to demand in the utility tariffs. As discussed in Appendix B, if current trends in charges related to demand continue then battery storage will become cost-effective in the commercial buildings sector.

Factors Impacting Cost-Effectiveness

This study used current electricity and gas rates and escalated them by 3 percent to 4 percent during the study period, reflecting the current relationship between gas and electricity prices. The results are highly sensitive to this price ratio in which lower electricity costs relative to gas would improve decarbonization cost effectiveness. The study also assumes that the long time frame allows capital investments to align with natural equipment replacement cycles, reducing incremental costs compared to early replacement of functional equipment. An assumption is that building owners would choose carbon-free equipment if replacement is necessary sooner than expected.

GLOSSARY

BATTERY ENERGY STORAGE SYSTEMS — A system of large rechargeable batteries with controls that integrate with the electrical system of a building, allowing energy to be stored when it is inexpensive or abundant and used during periods of high cost or grid stress.

ENERTUNE A proprietary software application that integrates with building simulation engines to automate the building model calibration process.

HEAT EXCHANGER — A device that transfers heat from one fluid (air or liquid) to another without the two fluids mixing. Heat exchangers are commonly used to heat, cool, or recover heat in building and mechanical systems.

HEAT-RECOVERY CHILLER — A chiller is a device that cools water, usually to between 40 and 50 degrees Fahrenheit for eventual use in cooling air. In the process of cooling water, chillers typically reject heat that was taken away to the water back into the atmosphere. A heat recovery chiller is a variant that rejects the heat back into a separate water source that can be applied for space heating. This increases the combined heating and cooling efficiency during periods of simultaneous heating and cooling.

INTERNAL LOADS — Internal loads refer to sources of heat, such as lighting, computers, refrigerator, and people within a building. Internal loads are typically expressed as a power density, like watts per square foot.

PHOTOVOLTAICS (PV) — Technology that converts sunlight directly into electricity using semiconductor materials, commonly deployed in solar panels.

RETROCOMMISSIONING (RCX) — A systematic process for evaluating and improving the performance of existing building systems to ensure they operate efficiently and as intended, often identifying low-cost operational improvements.

ROOFTOP UNIT (RTU) — A rooftop unit is a packaged HVAC system that is commonly used in low-rise retail buildings.

SEASONAL ENERGY EFFICIENCY RATIO (SEER) — The total cooling output of a central air conditioning unit in Btus during its normal usage period for cooling divided by the total electrical energy input in watt-hours during the same period, as determined using specified federal test procedures.

SOLAR HEAT GAIN COEFFICIENT (SHGC) — The ratio of solar heat gain through a specific glazing system to the total solar heat gain through a single layer of clear, double-strength glass.

VARIABLE AIR VOLUME SYSTEM (VAV SYSTEM) — A mechanical HVAC system capable of serving multiple zones which controls the temperature maintained in a zone by controlling the amount of heated or cooled air supplied to the zone by a variable air volume terminal unit, also known as a VAV box.

VARIABLE SPEED DRIVE — An electronic device that controls the speed and torque of an alternating current electric motor by varying the frequency and voltage of the power supplied to it.

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APPENDIX A:
Investment Cost Estimates

The economic analysis considered equipment upgrade and replacement costs between 2035 and 2060. Any upgrades are assumed to occur no earlier than 2035 and no later than 2045. Staff from Qualus, ENERlite Consulting, and Davenergy Solutions (the team) used several sources to estimate costs for the energy efficiency and decarbonization measures considered in this study. These sources included publicly available databases such as the California eTRM,[12] the Pennsylvania Act 129 Incremental Measure Cost Database[13] (PA Incremental Cost DB), online literature and wholesaler price lists, and invoices submitted with rebate applications for energy efficiency programs that Qualus evaluates across the country.

Costs for solar power are taken from the United States Department of Energy Better Buildings Initiative,[14] and battery cost projections for 2035 are taken from the National Renewable Energy Laboratory (NREL) Annual Technology Baseline study.[15] While the team endeavored to provide realistic cost estimates, the scope of the study precluded the solicitation of quotes for equipment and services.

Costing assumptions for each case study are summarized below. The costs reported below are normalized to 2026 dollars. The costs are escalated at 3 percent annually until the year that they are incurred.

Large Office Building

This section describes the assumptions, methods, and data sources used to estimate the costs of energy efficiency and decarbonization measures for large office building.

Baseline Scenario

The baseline scenario represents "business as usual" but includes costs that are expected to be incurred as existing equipment needs to be replaced. The first is a boiler replacement, which is assumed to occur in 2040. The second is the gradual replacement of the VAV boxes and heating coils in the building. VAV boxes and heat exchangers have long, but finite lifespans, and at some point, the building will likely need to move away from requiring 200°F water for space heating. In the baseline scenario the team assumed that half of the coils are replaced by or around 2040, and the other half in 2045. At least one of the chillers is assumed to be replaced in 2045. The team determined present-day costs for equipment and labor and

12 California Technical Forum. 2024. "California eTRM Online Database," https://www.caetrm.com/login/?next=.

13 Pennsylvania Act 129 Statewide Evaluator Staff. 2025. "Pennsylvania Act 129 2026 Incremental Measure Cost Database," https://www.puc.pa.gov/filing-resources/issues-laws-regulations/act-129/total-resource-cost-test.

14 United States Department of Energy. 2016. *Solar Photovoltaic Panels: Industrial Applications,* https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Solar_Photovoltaic_Panels_Industrial_Applications.pdf.

15 National Laboratory of the Rockies. 2021. "2021 Annual Technology Baseline," https://atb.nlr.gov/electricity/2021/commercial_battery_storage.

then escalated them to the year in which they are assumed to be incurred using a 3 percent inflation rate.

The team estimated boiler replacement cost using the average of two online estimates and the California eTRM. Only one boiler replacement is considered in this study, which is a conservative assumption given the age of the boilers. The team assumed a capacity of 8,400 kilo-British thermal units per hour (kBtu/hr), which is smaller than the existing boilers. The main reason for this assumed capacity is that the utility bills and energy simulations did not show that higher capacity was needed.

The team obtained two cost estimates for VAV box retrofits ($3,500 per unit and $4,000 per unit) through online literature review and used the average cost per unit and a quantity of 700 units to estimate the cost of VAV box retrofits.

The team estimated the replacement chiller cost in the baseline scenario from the California eTRM at about $690 per ton of cooling. However, costs associated with required rigging and cranes, controls integration, and labor and commissioning doubled this cost for a 600-ton water-cooled chiller.

The estimated costs (in 2026 dollars) for the baseline scenario are $1,635,622 to replace one boiler and half of the VAV boxes in 2040, $1,312,500 to replace the remaining VAV boxes in 2045, and $842,334 to replace a chiller in 2045.

Air-to-Water Heat Pump

The team estimated costs for the air-to-water heat pump installation using the average of an estimate from literature and the California Electronic Technical Reference Manual (eTRM).

The air-to-water heat pump will feed 140°F water into an existing boiler. In addition to the heat pump, the team considered installation-related costs such as rigging and crane costs, new piping, isolation valves, strainers and insulation, controls and sensors, and labor and commissioning. These costs, along with the heat pump, were estimated through online literature review. As a second data source, the team used a large heat pump water heater from the California eTRM as a proxy for an air-to-water heat pump. The eTRM cost was about 20 percent lower than the cost found in online review.

The estimated costs for the air-to-water heat pump scenario are $1,174,980 to install and integrate the heat pump in 2035, $1,635,622 to replace one boiler and half of the VAV boxes in 2040, $1,312,500 to replace the remaining VAV boxes in 2045, and $842,334 to replace a chiller in 2045.

Heat Recovery Chiller

The overall cost for the heat recovery chiller includes labor and equipment costs, integration costs such as piping and controls, removal costs, and costs associated with replacing 700 fan coils which are designed to operate with 200°F incoming water. There are market-available heat recovery chillers that can supply condenser water approaching 160°F. The lower hot water temperature could result in significant capacity loss without fan coil retrofits. While it is quite likely that some areas with high heating needs would need immediate upgrades, the team assumed that half of the fan coils would be replaced in 2035 and the rest in 2040.

The eventual need to replace aging fan coils is also reflected in the baseline scenario, but five years later.

The estimated costs for the heat recovery chiller scenario are $2,577,500 to install and integrate the heat recovery chiller and to replace half of the VAV boxes in 2035, $323,122 to replace one boiler in 2040, and $1,312,500 to replace the remaining VAV boxes in 2045. The chiller replacement cost in 2045 is taken to be half of the nominal $842,334, since the heat recovery chiller would have half of the service life remaining at that time presumably.

Schedule Optimization and Demand Control Ventilation

The team used online literature review to determine costs for schedule optimization and demand control ventilation. The cost for schedule optimization is about $70,000, or $0.10 per square foot, which is less than for full retro-commissioning. The cost for demand-controlled ventilation (DCV) is estimated at $489,250 which is an average of two methods — one that builds costs based on floorspace and another that builds costs based on outside air flow. The schedule optimization and DCV costs are assumed to be incurred in 2035. All the costs incurred in the baseline scenario are also incurred in these scenarios.

Boiler Replacement

The team estimated costs for boiler replacement using the average of two online estimates and the California eTRM. The average of the two costs was $359,024. This scenario also incurs all other costs in the baseline scenario except for the standard boiler replacement in 2040, since the efficient boiler is assumed to be installed in 2035.

Heat Pump Water Heater

The team estimated costs for the heat pump water heater at $14,153 using the CA eTRM. This scenario also incurs all other costs in the baseline scenario. The cost for the heat pump water heater is taken as the incremental cost, above what it would cost to replace the existing gas water heater at the end of life.

Solar Panels

The team estimated costs for solar panels at $2,000 per kilowatt (kW), plus $75,000, which is half of the expected crane and rigging cost. To save on costs, the solar panels are assumed to be installed at the same time as the battery energy storage system. The total cost for the 110-kW system is $295,000, to be incurred in 2035.

Batteries

The team used two sources to estimate the cost for battery energy storage installation. One source was a recent case study for an installation on a comparable building in New York, New York. The other source was a cost projection for the year 2035 from NREL, plus $75,000, which is half of the expected crane and rigging cost since the installation is assumed to occur at the same time as the solar installation. The assumed installed cost for the 1,000 kWh battery array is $446,000.

Total Bundle Cost

The cost of the bundle is constructed from the costs of individual components discussed above.

Large Retail Space

The team used 2035 as a convenient point in time to model all investments, but the results of the economic analysis would not change if the investments were phased over a long period of time. Table A-1 lists the cost of the efficient and baseline equipment (in 2026 dollars), as well as the normalization units and data sources used to determine costs. The costs include labor and material costs, except for cases where labor costs for standard and efficient equipment are expected to be the same (for example, a heat pump installed instead of an air conditioner and furnace).

Table A-1: Multifamily Community Efficient and Baseline Investment Costs

Measure	Investment Cost	Baseline Equipment Cost	Normalization Unit	Source
Baseline	**$0.00**	**$0.00**	**$0.00**	**N/A**
New Windows	**$125.00**	**$0.00**	**One ft² of window**	**Online research**
Window Film	**$10.50**	**$0.00**	**One ft² of window**	**Online research**
Advanced Rooftop Control	**$5,826.72**	**$0.00**	**per unit (12 units for site)**	**PA Incremental Cost DB**
Roof Insulation	**$3.93**	**$0.00**	**One ft² of ceiling area**	**Online research**
Lighting Controls	**$4.40**	**$0.00**	**One ft² of floorspace**	**Online research**
Rooftop HP for Heating	**$2,653.11**	**$1,754.55**	**One ton of cooling**	**CA eTRM**
Heat Recovery	**$16,875.00**	**$0.00**	**One heat recovery unit**	**Online research**
Heat Pump Water Heaters	**$2,555.28**	**$1,547.71**	**One water heater**	**CA eTRM**
Solar	**$1,906.00**	**$0.00**	**One kW direct current**	**Online research**
Battery Storage	**$508.50**	**$0.00**	**One kWh storage**	**Online research**

Source: Qualus, ENERlite Consulting, and Davenergy Solutions

Multifamily Community

All investments for the multifamily community are assumed to occur in 2035. By 2035, heating, ventilation, and air conditioning (HVAC) systems, water heaters, dryers, and ranges that have not been replaced will be at or near the end of life. The team used 2035 as a convenient point in time to model these investments, but the results of the economic analysis would not change if the investments were phased over a long period. Table A-2 lists the cost of efficient and baseline equipment (in 2026 dollars), as well as the normalization units and data sources used to determine costs. The costs include labor and material costs, except for

cases where labor costs for standard and efficient equipment are expected to be the same (for example, a heat pump installed instead of an air conditioner and furnace).

The team also conducted online research to estimate the cost of electrical upgrades needed to support full decarbonization. The team estimated a cost of $2,500 per unit, with 59 dwelling units and one common area, for a total cost of $150,000. The team assigned zero incremental cost to two measures. The first measure is light-emitting diode (LED) lighting upgrades, since LED lighting is the standard lighting technology used in most buildings and costs about the same as other lighting technologies. For this reason, the measure was not considered in the bundle. The second measure with zero incremental investment cost is standard electric ranges, which, at the time of replacement, are expected to cost about the same or less than comparable gas ranges.

Table A-2: Multifamily Community Efficient and Baseline Investment Costs

Measure	Investment Cost	Baseline Equipment Cost	Normalization Unit	Source
Baseline	**$0.00**	**$0.00**	**N/A**	**N/A**
Window Film	**$10.50**	**$0.00**	**One ft^2 floorspace**	**Online Research**
Window Replacement	**$92.83**	**$0.00**	**One ft^2 floorspace**	**Online Research**
Attic Insulation	**$1.74**	**$0.00**	**One ft^2 floorspace**	**CA eTRM (SWBE006)**
Wall Insulation	**$1.70**	**$0.00**	**One ft^2 floorspace**	**CA eTRM (SWBE007)**
Air Sealing	**$0.90**	**$0.00**	**One ft^2 floorspace**	**PA Incremental Cost DB**
LED Lights	**$11.25**	**$11.25**	**One luminaire**	**Online Research**
Lighting Controls	**$40.75**	**$0.00**	**One controller**	**PA Incremental Cost DB**
Standard Heat Pump	**$2,194.11**	**$1,767.82**	**One ton cooling**	**CA eTRM**
High Efficiency Heat Pump	**$3,400.03**	**$1,767.82**	**One ton cooling**	**CA eTRM**
Heat Pump Water Heater	**$2,491.50**	**$1,127.03**	**One water heater**	**CA eTRM**
Smart Thermostat	**$252.23**	**$0.00**	**One thermostat**	**CA eTRM**
Heat Pump Clothes Dryer	**$3,204.27**	**$1,649.93**	**One dryer**	**CA eTRM**
Electric Range	**$813.00**	**$813.00**	**One range**	**CA eTRM**
Battery	**$467.5**	**$0.00**	**One kWh storage**	**Online Research**

Solar	**$3,750**	**$0.00**	**One kW direct current**	**Online Research**
Electrical Upgrades	**$2,500**	**0**	**One residence unit**	**Online Research**

Source: Qualus, ENERlite Consulting, and Davenergy Solutions

APPENDIX B:
Utility Commercial Rates Review

California Energy Commission staff asked the authors to review commercial rates that include charges related to utility demand for non-residential electric rates with explicit demand charges, as well as energy charges. The authors reviewed demand charges for the five largest electric utilities in California: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas & Electric (SDG&E), Sacramento Municipal Utility District (SMUD), and Los Angeles Department of Water and Power (LADWP). The utility commercial tariffs have the following common elements:

- Most rates include a charge related to maximum noncoincident demand, typically defined as the highest 15-minute measured demand during the billing month. Utilities refer to this as a facilities charge, infrastructure charge, or maximum demand charge.
- Many rates also include coincident peak demand charges, defined as the highest 15-minute demand occurring within specified time-of-use (TOU) periods (for example, 4 p.m. to 9 p.m. during summer weekdays).
- Noncoincident demand charges are similar across months typically, while coincident peak demand charges are often higher during summer months.
- Many rates also have "part-peak" periods, typically adjacent to peak periods.

In addition to demand charges, rates also have variable energy costs for defined TOU periods, different for summer and winter, as well as monthly or daily fixed charges that are often associated with each utility meter.

Recent Trends in Electric Bill Components

Between 2020 and 2025, increases in electricity costs across the utilities reviewed were driven primarily by growth in demand charges and fixed charges rather than by energy charges. For large commercial customers, fixed charges increased most substantially under PG&E and SMUD rates, where monthly fixed charges are typically on the order of hundreds to several thousand dollars per meter, depending on demand tier. In contrast, fixed charges under LADWP A rates generally remain below $100 per meter per month.

Demand charges increased significantly for PG&E, SCE, and SDG&E, with summer peak demand rates commonly increasing by roughly 70 to 100 percent over the study period, while energy charges increased more gradually — often by less than 30 percent.[16] SMUD relies most heavily on fixed infrastructure charges, whereas SCE and SDG&E rely more heavily on kW-based demand charges. LADWP exhibits the lowest overall fixed charges and the slowest rate

16 There is considerable variation by utility, as indicated in tables that follow in this section.

escalation among the utilities reviewed; however, the authors were unable locate historical data going back to 2020 for LADWP.

Illustrative Ranking of Electricity Bill Components

The proportion of a customer's electricity costs attributable to demand, energy, and fixed charges depends on total electricity use and the timing of that use. However, trends in utility rate structures shown indicate that utilities have shifted cost recovery toward fixed charges and demand charges. More than 10 years ago, a larger share of utility cost recovery for commercial customers came from volumetric energy charges ($/kWh). The impact of higher demand favors electrification if peak coincident and noncoincident loads can be managed through energy efficiency, electrification, and load-shifting measures.

Two of the three buildings evaluated in this study were served under time-of-use (TOU) rates. For these buildings, the authors used hourly energy simulation data to estimate annual utility bills and to disaggregate those bills into fixed (per-meter), demand (per-kilowatt), and energy (per-kilowatt-hour) components, as summarized below.

Office building: Demand charges associated with the B-20 TOU rate accounted for about 58 percent of total electricity costs, energy charges accounted for 39 percent, and fixed charges accounted for 3 percent.

Retail building: Demand charges associated with the B-19 TOU rate accounted for about 38 percent of total electricity costs, energy charges accounted for 52 percent, and fixed charges accounted for 11 percent.

Review of Selected Utility Rate Schedules

Demand, energy, and fixed charges are summarized below for each of the five studied electric utilities.

A Note on Time Convention

In the tables that follow, times are expressed using a 24-hour clock and refer to the hour ending. For example, 17 to 21 represents the hours ending 17:00 through 21:00, corresponding to 4:00 p.m. through 9:00 p.m.

PG&E

The authors reviewed three common time-of-use (TOU) rates for PG&E. The three TOU rates correspond to customers with the following maximum peak demands:

- B-10: 499 kW
- B-19: 999 kW
- B-20 1000 kW or more

Each rate has one or more type of peak demand charge. Table B-1 shows the TOU rates, the eligible peak demand ranges for each rate, and the definition of various peak periods.

Table B-1: PG&E Time-of-Use Demand Charge Descriptions

Attribute	B-10	B-19 and B-20
Demand Range	**0–499 kW**	**500–999 kW for B-19, >= 1000 kW for B-20**
Summer Peak	**N/A**	**Jun-Sep 17 to 21 all days**
Summer Part-Peak	**N/A**	**Jun-Sep 15 to 16 and 22 to 23 all days**
Winter Peak	**N/A**	**Oct-May 17 to 21 all days**
Summer Maximum Demand	**Jun-Sep Max 15-minutes**	**Jun-Sep Max 15-minutes**
Winter Maximum Demand	**Oct-May Max 15-minutes**	**Oct-May Max 15-minutes**

Source: PG&E

Table B-2 shows the demand charges from 2020 to 2025 for the selected TOU rates in dollars per kW ($/kW).

Table B-2: PG&E Time-of-Use Demand Charges

Rate	Demand Charge	2020 ($/kW)	2021 ($/kW)	2022 ($/kW)	2023 ($/kW)	2024 ($/kW)	2025 ($/kW)
B-10	Summer Max	13.59	14.31	17.47	19.44	20.76	22.71
B-10	Winter Max	13.59	14.31	17.47	19.44	20.76	22.71
B-19	Summer Peak	25.79	26.56	32.9	38.75	47.26	55.76
B-19	Summer Part Peak	5.30	5.59	6.81	8.11	10.42	12.21
B-19	Summer Max	21.44	22.77	26.07	30.20	36.35	40.90
B-19	Winter Peak	1.77	1.72	2.22	2.53	2.65	3.20
B-19	Winter Max	21.44	22.77	26.07	30.20	36.35	40.90
B-20	Summer Peak	25.74	26.38	30.06	35.58	42.92	50.19
B-20	Summer Part Peak	5.31	5.57	6.13	7.34	9.34	10.81
B-20	Summer Max	21.41	22.81	28.04	33.08	38.81	43.05
B-20	Winter Peak	1.86	1.80	2.24	2.57	2.66	3.22
B-20	Winter Max	21.41	22.81	28.04	33.08	38.81	43.05

Source: PG&E

Table B-3 shows the energy charges from 2020 to 2025 for the selected TOU rates in dollars per kW ($/kW).

Table B-3: PG&E Time-of-Use Energy Charges

Rate	Energy Charge	2020 ($/KWh)	2021 ($/KWh)	2022 ($/KWh)	2023 ($/KWh)	2024 ($/KWh)	2025 ($/KWh)
B-10	Summer Peak	0.27	0.27	0.31	0.34	0.36	0.37
B-10	Summer Part-Peak	0.21	0.21	0.25	0.28	0.30	0.31
B-10	Summer Off-Peak	0.18	0.18	0.22	0.24	0.27	0.27
B-10	Winter Peak	0.20	0.19	0.24	0.26	0.28	0.29
B-10	Winter Off-Peak	0.16	0.16	0.20	0.23	0.25	0.26
B-10	Winter Super Off-Peak	0.13	0.12	0.17	0.19	0.21	0.22
B-19	Summer Peak	0.17	0.16	0.20	0.22	0.22	0.22

Rate	Energy Charge	2020 ($/KWh)	2021 ($/KWh)	2022 ($/KWh)	2023 ($/KWh)	2024 ($/KWh)	2025 ($/KWh)
B-19	Summer Part-Peak	0.14	0.13	0.16	0.17	0.17	0.16
B-19	Summer Off-Peak	0.11	0.11	0.13	0.14	0.14	0.13
B-19	Winter Peak	0.15	0.14	0.17	0.19	0.19	0.18
B-19	Winter Off-Peak	0.11	0.11	0.13	0.14	0.14	0.13
B-19	Winter Super Off-Peak	0.07	0.07	0.08	0.08	0.08	0.05
B-20	Summer Peak	0.16	0.15	0.19	0.21	0.21	0.21
B-20	Summer Part-Peak	0.13	0.12	0.15	0.17	0.17	0.16
B-20	Summer Off-Peak	0.11	0.10	0.13	0.14	0.13	0.12
B-20	Winter Peak	0.14	0.13	0.17	0.18	0.18	0.18
B-20	Winter Off-Peak	0.11	0.10	0.13	0.14	0.13	0.12
B-20	Winter Super Off-Peak	0.07	0.06	0.07	0.08	0.07	0.04

Source: PG&E

Table B-4 shows the fixed charges from 2020 to 2025 for the selected TOU rates in dollars per meter per day ($/meter/day).

Table B-4: PG&E Time-of-Use Fixed Charges

Rate	Fixed Charge	2020	2021	2022	2023	2024	2025
B-10	$/Meter/Day	4.60	5.48	6.42	7.65	10.74	12.20
B-19	$/Meter/Day	24.78	27.58	31.55	38.23	54.66	63.11
B-20	$/Meter/Day	45.09	50.05	58.30	71.71	102.20	115.81

Source: PG&E

SCE

The authors reviewed four common TOU rates for SCE. The four common TOU rates correspond to customers with the following maximum peak demands:

- TOU-GS-1: 20 kW
- TOU-GS-2: 200 kW
- TOU-GS-3 500 kW
- TOU-8: 501 kW or more of

Customers are placed on higher demand schedules when their maximum demand exceeds the applicable threshold in 3 of the previous 12 months typically. Customers may move to a lower schedule if their demand remains below the threshold for an extended period, 12 consecutive months typically. Table B-5 shows the rates, the eligible peak demand ranges for each rate, and the definition of various peak periods.

Table B-5: SCE Time-of-Use Demand Charge Descriptions

Attribute	TOU-GS-1	TOU-GS-2 / GS-3	TOU-8
Demand Range	**0-20**	**20-200 (GS-2); 200-500 (GS-3)**	**500+**
Summer Peak	**Jun-Sep 16 to 21 weekdays**	**Jun-Sep 17 to 21 weekdays**	**Jun-Sep 17 to 21 weekdays**
Winter Mid- Peak	**N/A**	**Oct-May 17 to 21 all days**	**Oct-May 17 to 21 all days**
Summer Max Demand	**N/A**	**Jun-Sep Max 15-minutes**	**N/A**
Winter Max Demand	**N/A**	**Oct-May Max 15-minutes**	**N/A**

Source: SCE

Table B-6 shows the demand charges from 2020 to 2025 for the selected TOU rates.

Table B-6: SCE Time-of-Use Demand Charges

Rate	Demand Charge	2020 ($/kW)	2021 ($/kW)	2022 ($/kW)	2023 ($/kW)	2024 ($/kW)	2025 ($/kW)
TOU-GS-1	**Facilities Charge**	**8.96**	**14.92**	**14.32**	**16.3**	**18.18**	**19.91**
TOU-GS-1	**Summer Peak**	**2.76**	**3.46**	**4.5**	**3.7**	**4.4**	**5.18**

Rate	Demand Charge	2020 ($/kW)	2021 ($/kW)	2022 ($/kW)	2023 ($/kW)	2024 ($/kW)	2025 ($/kW)
TOU-GS-1	Winter Mid-Peak	N/A	N/A	N/A	N/A	N/A	N/A
TOU-GS-2	Facilities Charge	10.54	13.55	17.04	20.97	22.97	24.86
TOU-GS-2	Summer Peak	8.82	11.87	14.83	13.37	15.85	17.07
TOU-GS-2	Winter Mid-Peak	3.17	4.26	5.32	2.16	2.57	2.76
TOU-GS-3	Facilities Charge	11.48	14.63	18.47	19.78	21.61	23.89
TOU-GS-3	Summer Peak	9.4	12.45	15.57	14.52	17.38	18.81
TOU-GS-3	Winter Mid-Peak	3.18	4.22	5.28	2.58	3.09	3.34
TOU-8	Facilities Charge	11.78	14.98	18.97	21.22	23.28	26.44
TOU-8	Summer Peak	9.18	12.11	15.17	15.9	19.09	21.46
TOU-8	Winter Mid-Peak	3.08	4.07	5.1	2.73	3.27	3.68

Source: SCE

Table B-7 shows the energy charges from 2020 to 2025 for the selected TOU rates.

Table B-7: SCE Time-of-Use Energy Charges

Rate	Energy Charge	2020 ($/kWh)	2021 ($/kWh)	2022 ($/kWh)	2023 ($/kWh)	2024 ($/kWh)	2025 ($/kWh)
TOU-GS-1-D	Summer On-Peak	0.15	0.17	0.19	0.22	0.21	0.19
TOU-GS-1-D	Summer Mid-Peak	0.15	0.16	0.18	0.20	0.19	0.18
TOU-GS-1-D	Summer Off-Peak	0.09	0.10	0.11	0.14	0.13	0.12
TOU-GS-1-D	Winter Mid-Peak	0.15	0.16	0.19	0.21	0.20	0.18
TOU-GS-1-D	Winter Off-Peak	0.10	0.11	0.12	0.15	0.14	0.13
TOU-GS-1-D	Winter Super-Off-Peak	0.08	0.09	0.10	0.11	0.11	0.10
TOU-GS-2-D	Summer On-Peak	0.13	0.14	0.16	0.19	0.18	0.17
TOU-GS-2-D	Summer Mid-Peak	0.12	0.13	0.15	0.17	0.17	0.16
TOU-GS-2-D	Summer Off-Peak	0.09	0.10	0.11	0.12	0.13	0.12
TOU-GS-2-D	Winter Mid-Peak	0.11	0.11	0.12	0.14	0.14	0.13
TOU-GS-2-D	Winter Off-Peak	0.10	0.10	0.12	0.14	0.14	0.13
TOU-GS-2-D	Winter Super-Off-Peak	0.08	0.08	0.09	0.09	0.10	0.10
TOU-GS-3-D	Summer On-Peak	0.12	0.13	0.15	0.18	0.17	0.15
TOU-GS-3-D	Summer Mid-Peak	0.11	0.12	0.14	0.17	0.16	0.14
TOU-GS-3-D	Summer Off-Peak	0.09	0.09	0.10	0.13	0.12	0.12
TOU-GS-3-D	Winter Mid-Peak	0.10	0.11	0.12	0.14	0.13	0.13
TOU-GS-3-D	Winter Off-Peak	0.09	0.10	0.11	0.14	0.13	0.13
TOU-GS-3-D	Winter Super-Off-Peak	0.07	0.08	0.09	0.09	0.09	0.09
TOU-8	Summer On-Peak	0.12	0.12	0.12	0.17	0.17	0.15
TOU-8	Summer Mid-Peak	0.11	0.11	0.12	0.16	0.15	0.14
TOU-8	Summer Off-Peak	0.08	0.09	0.09	0.12	0.12	0.11
TOU-8	Winter Mid-Peak	0.10	0.10	0.10	0.13	0.13	0.12
TOU-8	Winter Off-Peak	0.09	0.09	0.09	0.13	0.13	0.12
TOU-8	Winter Super-Off-Peak	0.07	0.07	0.08	0.09	0.09	0.09

Source: SCE

Table B - 8 shows the fixed charges from 2020 to 2025 for the three TOU rates in dollars per meter per day ($/meter/day) or dollars per meter per month ($/meter/month).

Table B-8: SCE Time-of-Use Fixed Charges

Rate	Fixed Charge	2020	2021	2022	2023	2024	2025
TOU-GS-1-D	$/Meter/Day	0.37	0.46	0.60	0.47	0.47	0.47
TOU-GS-2-D	$/Meter/Month	133.31	158.61	188.51	184.07	228.13	227.55
TOU-GS-3-D	$/Meter/Month	320.99	383.59	496.89	541.81	664.03	658.51
TOU-8	$/Meter/Month	479.29	571.13	716.13	349.79	434.84	447.44

Source: SCE

SDG&E

The authors reviewed three common TOU rates for SDG&E, the TOU-A, TOU-A-2, and AL-TOU rates. TOU-A and TOU-A-2 apply to commercial customers whose maximum demand remains below about 20 kW generally. Customers with higher demand are placed on the AL-TOU schedule typically, which includes demand charges based on kW. If a customer's demand exceeds either threshold, they are moved to the AL-TOU rate. The TOU-A rate includes a tiered monthly facilities charge that increases with the customer's maximum demand, rather than a strictly proportional $/kW demand charge. The TOU-A-2 and AL-TOU rates were introduced as part of the SDG&E commercial rate restructuring in 2021 and include explicit $/kW demand charges. Table B-9 shows the rates, the eligible peak demand ranges for each rate, and the definition of various peak periods.

Table B-9: SDG&E Time-of-Use Demand Charge Descriptions

Attribute	TOU-A	TOU-A-2	AL-TOU
Demand Range	Not over 20 kW for 12 consecutive months and not over 200 kW for two consecutive months	Not over 20 kW for 12 consecutive months and not over 200 kW for two consecutive months	Over 20 kW for 12 consecutive months or over 200 kW for two consecutive months
Summer Peak	N/A	Jun-Oct 17 to 21 weekdays	Jun-Oct 17 to 21 weekdays
Winter Mid- Peak	N/A	Nov-May 17 to 21 weekdays	Nov-May 17 to 21 weekdays
Summer Max Demand	Depending on kW range	Jun-Oct Max 15-minutes	Jun-Oct Max 15-minutes

Winter Max Demand	**Depending on kW range**	**Nov-May Max 15-minutes**	**Nov-May Max 15-minutes**

Source: SDG&E

Table B-10 shows the demand charges from 2020 to 2025 for the three SDG&E rates discussed above. Note, rates TOU A-2 and AL-TOU were updated in late 2021, and data for those rates are shown only for years 2022 and later.

Table B-10: SDG&E Time-of-Use Demand Charges

Rate	Demand Charge	2020 ($/Month)	2021 ($/Month)	2022 ($/kW)	2023 ($/kW)	2024 ($/kW)	2025 ($/kW)
TOU-A	**Facilities Charge 0 — 5 kW**	**10.00**	**10.00**	**10.70**	**11.45**	**11.45**	**11.45**
TOU-A	**Facilities Charge 5 — 20 kW**	**16.00**	**16.00**	**17.12**	**18.32**	**18.32**	**18.32**
TOU-A	**Facilities Charge 20 — 50 kW**	**30.00**	**30.00**	**32.10**	**34.35**	**34.35**	**34.35**
TOU-A	**Facilities Charge 50 kW or more**	**75.00**	**75.00**	**80.25**	**85.87**	**85.87**	**85.87**
TOU-A-2	**Facilities Charge**	**N/A**	**N/A**	**18.63**	**20.57**	**15.89**	**20.67**
TOU-A-2	**Summer Peak**	**N/A**	**N/A**	**26.81**	**39.06**	**26.36**	**33.18**
TOU-A-2	**Winter Mid-Peak**	**N/A**	**N/A**	**1.12**	**1.28**	**1.05**	**1.31**
TOU-A-2	**TOU Demand**	**N/A**	**N/A**	**34.20**	**34.27**	**39.05**	**46.18**
AL-TOU	**Facilities Charge**	**N/A**	**N/A**	**31.32**	**33.38**	**30.43**	**37.86**
AL-TOU	**Summer Peak**	**N/A**	**N/A**	**39.98**	**48.04**	**45.22**	**52.50**
AL-TOU	**Winter Mid-Peak**	**N/A**	**N/A**	**28.74**	**28.83**	**32.46**	**38.53**
AL-TOU	**TOU Demand**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

Source: SDG&E

Table B-11 shows the energy charges from 2020 to 2025 for the three SDG&E rates discussed above. Note, rates TOU A-2 and AL-TOU were updated in late 2021, and data for those rates are shown only for years 2022 and later.

Table B-11: SDG&E Time-of-Use Energy Charges

Rate	Energy Charge	2020 ($/kWh)	2021 ($/kWh)	2022 ($/kWh)	2023 ($/kWh)	2024 ($/kWh)	2025 ($/kWh)
TOU-A	Summer On-Peak	0.36	0.41	0.45	0.61	0.49	0.54
TOU-A	Summer Off-Peak	0.26	0.30	0.34	0.43	0.37	0.41
TOU-A	Summer Super Off-Peak	N/A	N/A	N/A	N/A	N/A	N/A
TOU-A	Winter On-Peak	0.23	0.25	0.35	0.44	0.38	0.42
TOU-A	Winter Off-Peak	0.21	0.24	0.27	0.34	0.30	0.34
TOU-A	Winter Super Off-Peak	N/A	N/A	N/A	N/A	N/A	N/A
TOU-A-2	Summer On-Peak	N/A	N/A	0.17	0.31	0.21	0.22
TOU-A-2	Summer Off-Peak	N/A	N/A	0.10	0.20	0.14	0.14
TOU-A-2	Summer Super Off-Peak	N/A	N/A	0.10	0.17	0.12	0.12
TOU-A-2	Winter On-Peak	N/A	N/A	0.20	0.32	0.22	0.24
TOU-A-2	Winter Off-Peak	N/A	N/A	0.12	0.19	0.14	0.14
TOU-A-2	Winter Super Off-Peak	N/A	N/A	0.09	0.16	0.11	0.11
AL-TOU	Summer On-Peak	N/A	N/A	0.19	0.28	0.23	0.24
AL-TOU	Summer Off-Peak	N/A	N/A	0.12	0.19	0.15	0.15
AL-TOU	Summer Super Off-Peak	N/A	N/A	0.11	0.15	0.13	0.13
AL-TOU	Winter On-Peak	N/A	N/A	0.22	0.29	0.24	0.26
AL-TOU	Winter Off-Peak	N/A	N/A	0.13	0.18	0.15	0.15
AL-TOU	Winter Super Off-Peak	N/A	N/A	0.10	0.14	0.12	0.12

Source: SDG&E

Table B-12 shows the fixed charges from 2020 to 2025 for the three TOU rates in dollars per meter per day ($/meter/day).

Table B-12: SDG&E Time-of-Use Fixed Charges

Rate	Fixed Charge	2020	2021	2022	2023	2024	2025
TOU-A	$/Meter/Day	4.60	5.48	6.42	7.65	10.74	12.20
TOU-A-2	$/Meter/Day	24.78	27.58	31.55	38.23	54.66	63.11
AL-TOU	$/Meter/Day	45.09	50.05	58.30	71.71	102.20	115.81

Source: SDG&E

LADWP

The team reviewed three common TOU rates for LADWP. The general rate definitions and structure are available on LADWP's website, but the authors were unable to locate historical rates for LADWP. Instead, the authors used the US Utility Rate Database[17] for historical energy and demand charges and found records for 2023 to 2025.

The A-1 rate is reserved for customers with peak demands below 30 kW. Customers with demands more than 30 kW are placed on the A-2 or A-3 rates depending on the voltage level of service, typically 4.8 kV for A-2 and 34.5 kV for A-3. The A-2 and A-3 rates include summer peak, summer part-peak, and winter peak charges as well as a facilities charge that is based on noncoincident peak demand, while the A-1 rate includes the facilities charge only. Table B-13 shows the three rates, the eligible peak demand ranges for each rate, and the definition of various peak periods.

Table B-13: LADWP Time-of-Use Demand Charge Descriptions

Attribute	A-1	A-2	A-3
Demand Range	0 kW-30 kW	30 kW or more (4.8kV)	30 kW or more (34.5kV)
Summer Peak	N/A	Jun-Sep 16 to 21 all days	Jun-Sep 16 to 21 all days
Summer Part-Peak	N/A	Jun-Sep 14 to 16 and 21 to 23 all days	Jun-Sep 14 to 16 and 21 to 23 all days
Winter Peak	N/A	Oct-May 16 to 21 all days	Oct-May 16 to 21 all days
Facilities Charge	Highest 15-minute kW in trailing 12 months	Highest 15-minute kW in trailing 12 months	Highest 15-minute kW in trailing 12 months

17 The US Utility Rate Database (https://apps.openei.org/USURDB) is maintained by the National Laboratory of the Rockies and used as a database of utility rates by software such as the System Advisor Model and EnergyPlus, both used by the authors for building and solar panel energy simulations.

Source: LADWP and US Utility Rate Database

Table B - 14 shows the demand charges from 2021 to 2025 for the LADWP rates discussed above above.

Table B-14: LADWP Time-of-Use Demand Charges

Rate	Demand Charge	2023 ($/kW)	2024 ($/kW)	2025 ($/kW)
A-1	Facilities Charge	9.17	9.48	9.651
A-1	Summer Part-Peak	N/A	N/A	N/A
A-1	Summer Peak	N/A	N/A	N/A
A-1	Winter Peak	N/A	N/A	N/A
A-2	Facilities Charge	9.17	9.48	9.651
A-2	Summer Part-Peak	4.75	4.75	4.75
A-2	Summer Peak	10	10	10
A-2	Winter Peak	3.75	3.75	3.75
A-3	Facilities Charge	8.37	8.68	8.851
A-3	Summer Part-Peak	4.3	4.3	4.3
A-3	Summer Peak	9.7	9.7	9.7
A-3	Winter Peak	3.3	3.3	3.3

Source: LADWP and US Utility Rate Database

Table B-15 shows the energy charges from 2023 to 2025 for the three LADWP rates discussed above.

Table B-15: LADWP Time-of-Use Energy Charges

Rate	Energy Charge	2023 ($/kWh)	2024 ($/kWh)	2025 ($/kWh)
A-1	Summer High Peak	0.29	0.30	0.31
A-1	Summer Low Peak	0.24	0.25	0.26
A-1	Summer Base	0.21	0.22	0.23
A-1	Winter High Peak	0.24	0.25	0.26
A-1	Winter Low Peak	0.24	0.25	0.26
A-1	Winter Base	0.21	0.22	0.23
A-2	Summer High Peak	0.20	0.21	0.22
A-2	Summer Low Peak	0.19	0.20	0.21
A-2	Summer Base	0.17	0.18	0.19
A-2	Winter High Peak	0.19	0.20	0.22
A-2	Winter Low Peak	0.19	0.20	0.22
A-2	Winter Base	0.18	0.19	0.20
A-3	Summer High Peak	0.19	0.20	0.21
A-3	Summer Low Peak	0.18	0.20	0.21
A-3	Summer Base	0.16	0.17	0.18
A-3	Winter High Peak	0.19	0.20	0.21
A-3	Winter Low Peak	0.19	0.20	0.21
A-3	Winter Base	0.17	0.18	0.19

Source: LADWP and US Utility Rate Database

Table B-16 shows the fixed charges from 2023 to 2025 for the three LADWP TOU rates in dollars per meter per day ($/Meter/Day).

Table B-16: LADWP Time-of-Use Fixed Charges

Rate	Fixed Charge	2023	2024	2025
A-1	$/Meter/Month	7.00	7.00	7.00
A-2	$/Meter/Month	28.00	28.00	28.00
A-3	$/Meter/Month	75.00	75.00	75.00

Source: LADWP and US Utility Rate Database

SMUD

The authors reviewed four common TOU rates for SMUD that correspond to customers with maximum peak demands:

- CI TOD-1: 299 kW
- CI TOD-2: 499 kW
- CI TOD-3: 999 kW
- CI TOD-4: more than 999 kW

Each rate includes a noncoincident infrastructure demand charge based on the customer's maximum monthly demand, and a summer peak demand charge. Table B-17 shows the rates, the eligible peak demand ranges for each rate, and the definition of the peak periods.

Table B-17: SMUD Time-of-Use Demand Charge Descriptions

Attribute	CI TOD-1	CI TOD-2	CI TOD-3	CI TOD-4
Demand Range	21 kW — 299 kW	300 kW – 499 kW	500 kW – 999 kW	1000 kW or more
Summer Peak	Jun-Sep 16 to 21 weekdays	Jun-Sep 16 to 21 weekdays	Jun-Sep 16 to 21 weekdays	Jun-Sep 16 to 21 weekdays
Infrastructure Charge	Max 15-minutes in month	Max 15-minutes in month	Max 15-minutes in month	Max 15-minutes in month

Source: SMUD

Table B-18 shows the demand charges from 2021 to 2025 for the four SMUD rates discussed above.

Table B-18: SMUD Time-of-Use Demand Charges

Rate	Demand Charge	2021 ($/kW)	2022 ($/kW)	2023 ($/kW)	2024 ($/kW)	2025 ($/kW)
CI-TOD-1	Infrastructure Charge	7.93	8.05	7.57	6.62	6.99
CI-TOD-1	Summer Peak	1.68	1.71	3.47	7.32	7.73
CI-TOD-2	Infrastructure Charge	4.36	4.43	4.60	5.01	5.29
CI-TOD-2	Summer Peak	9.44	9.58	9.88	10.66	11.25
CI-TOD-3	Infrastructure Charge	3.61	3.66	4.15	5.25	5.54
CI-TOD-3	Summer Peak	9.07	9.21	9.73	11.00	11.61
CI-TOD-4	Infrastructure Charge	4.63	4.70	4.88	5.25	5.54
CI-TOD-4	Summer Peak	3.35	3.40	6.94	11.00	11.61

Source: SMUD

Table B-19 shows the energy charges from 2021 to 2025 for the four SMUD rates discussed above.

Table B-19: SMUD Time-of-Use Energy Charges

Rate	Energy Charge	2021 ($/kWh)	2022 ($/kWh)	2023 ($/kWh)	2024 ($/kWh)	2025 ($/kWh)
CI-TOD-1	Non-Summer Peak	0.11	0.12	0.12	0.13	0.14
CI-TOD-1	Non-Summer Off-Peak	0.11	0.11	0.12	0.12	0.14
CI-TOD-1	Non-Summer Off-Peak Saver	0.11	0.11	0.11	0.12	0.10
CI-TOD-1	Summer Peak	0.19	0.19	0.19	0.20	0.23
CI-TOD-1	Summer Off-Peak	0.11	0.11	0.11	0.12	0.12
CI-TOD-2	Non-Summer Peak	0.12	0.12	0.12	0.13	0.14
CI-TOD-2	Non-Summer Off-Peak	0.09	0.10	0.10	0.10	0.11
CI-TOD-2	Non-Summer Off-Peak Saver	0.09	0.10	0.10	0.10	0.10
CI-TOD-2	Summer Peak	0.21	0.22	0.22	0.23	0.24
CI-TOD-2	Summer Off-Peak	0.13	0.13	0.14	0.14	0.14
CI-TOD-3	Non-Summer Peak	0.12	0.12	0.12	0.13	0.14

Rate	Energy Charge	2021 ($/kWh)	2022 ($/kWh)	2023 ($/kWh)	2024 ($/kWh)	2025 ($/kWh)
CI-TOD-3	Non-Summer Off-Peak	0.09	0.10	0.10	0.10	0.12
CI-TOD-3	Non-Summer Off-Peak Saver	0.09	0.09	0.09	0.10	0.08
CI-TOD-3	Summer Peak	0.20	0.21	0.21	0.22	0.23
CI-TOD-3	Summer Off-Peak	0.12	0.13	0.13	0.14	0.11
CI-TOD-4	Non-Summer Peak	0.12	0.12	0.12	0.13	0.14
CI-TOD-4	Non-Summer Off-Peak	0.10	0.10	0.10	0.11	0.12
CI-TOD-4	Non-Summer Off-Peak Saver	0.09	0.09	0.10	0.10	0.08
CI-TOD-4	Summer Peak	0.19	0.19	0.19	0.20	0.24
CI-TOD-4	Summer Off-Peak	0.12	0.12	0.12	0.13	0.12

Source: SMUD

Table B-20 shows the fixed charges from 2021 to 2025 for the three TOU rates in dollars per meter per day ($/meter/day).

Table B-20: SMUD Time-of-Use Fixed Charges

Rate	Fixed Charge	2021	2022	2023	2024	2025
CI-TOD-1	$/Meter/Month	293.39	301.24	309.29	317.56	326.05
CI-TOD-2	$/Meter/Month	882.34	905.93	930.15	955.02	980.55
CI-TOD-3	$/Meter/Month	2,105.17	2,161.46	2,219.25	2,278.58	2,339.50
CI-TOD-4	$/Meter/Month	3,507.03	3,600.80	3,697.07	3,795.91	3,897.40

Source: SMUD

Recent Trends in Gas Costs

The authors also reviewed five prevalent gas rate schedules for large commercial customers in California. The gas utility commercial tariffs have the following common elements:

- Like many commercial electric rates, the gas rates have fixed monthly charges. These charges are billed on a per-meter, per-day basis. The fixed charges range from $8 to $150 per month, and these charges will account for a relatively small portion of the overall gas bill for most large commercial buildings.
- All gas tariffs include separate gas procurement and gas transport charges.

- The procurement charge tends to be more volatile and track with the SoCal Citigate[18] and PG&E Citygate prices for Southern and Northern California respectively.
- Over the 2020–2025 period the procurement charge ranged from under 25 cents per therm in the summer of 2024 to more than $3 per therm in the winter of 2023 in Southern California.
- Transportation charges are often the largest component of the gas bill.
- Transportation charges typically follow a tiered schedule based on usage.
- Transportation costs decrease for higher-usage tiers, reflecting economies of scale.

Over the 2020–2025 period, transportation costs have increased by about 70 percent. This spike represents a steeper increase than the volumetric energy charges for electricity but is less than the observed rate of increase for demand-based electric charges. Procurement costs, while volatile, have generally increased more slowly than volumetric electricity costs. For example, the per-therm procurement cost in the winter of 2025 was only about 19 percent higher than the same cost in 2020, as averaged over PG&E, SDG&E, and SCG.

Illustrative Ranking of Gas Bill Components

The proportion of a customer's gas costs attributable to procurement, distribution, and fixed charges depends on total gas use and the prevailing gas procurement price.

Each of the three buildings evaluated in this study were served gas by PG&E. For these buildings, the authors used hourly energy simulation data to estimate annual utility bills and to disaggregate those bills into fixed (per-meter), and volumetric (per-therm), components, as summarized below.

Office building: Transportation charges associated with the GN-2 rate accounted for about 77 percent of total gas costs. Gas procurement accounted for 22 percent, and fixed charges accounted for 2 percent.

Retail building: Transportation charges associated with the GN-1 rate accounted for about 41 percent of total gas costs. Gas procurement accounted for 12 percent, and fixed charges accounted for 47 percent. Fixed costs were unusually high for this building due to low volumetric usage.

Multifamily community: Transportation charges associated with the GS residential rate for tenants accounted for about 79 percent of total gas costs. Gas procurement accounted for 18 percent, and fixed charges accounted for 3 percent.

Review of Selected Utility Gas Rate Schedules

Transportation, procurement, and fixed charges are summarized below for each of the five studied electric utilities.

Fixed Charges

18 The PG&E and SoCal Citygates are regional delivery points where natural gas enters the Northern and Southern California distribution systems, respectively, and where wholesale market prices are established.

The authors reviewed the G-NR1 and G-NR2 gas rates for PG&E, the GN-10 gas rate for SCG, and the GN-3 rate for SDG&E. Table B-21 shows the fixed charges from 2020 to 2025 for the selected TOU rates in dollars per kW ($/kW). The fixed monthly charges have not changed since 2020.

Table B-21: Fixed Monthly Charges for Gas Tariffs

Utility	Rate	Attribute	2020 -2025 Rate ($/Meter-Day)
PG&E	G-NR1	Facility Charge - Under 5 Therms/day	0.27
PG&E	G-NR1	Facility Charge - 5 - 16 Therms/day	0.52
PG&E	G-NR1	Facility Charge - 16 - 41 Therms/day	0.95
PG&E	G-NR1	Facility Charge - 41 -123 Therms/day	1.66
PG&E	G-NR1	Facility Charge - Over 123 Therms/day	2.15
PG&E	G-NR2	Facility Charge - All Customers	4.96
SCG	GN-10	Connection Charge - All Customers	0.49
SDG&E	GN-3	Connection Charge - All Customers	0.33

Source: PG&E, SCG, and SDG&E

Volumetric Charges

Transportation charges feature lower per-therm rates applied at higher usage tiers. Table B-22 shows the upper limits of the first and second tiers. The two PG&E rates have two tiers, while the SCG and SDG&E rates have three tiers.

Table B-22: Monthly Usage Limits for Tiered Pricing

Utility	Rate	Tier 1 Upper Limit (therms/month)	Tier 2 Upper Limit (therms/month)
PG&E	G-NR1	4,000	N/A
PG&E	G-NR2	4,000	N/A
SCG	GN-10	250	4,167
SDG&E	GN03	1,000	21,000

Source: PG&E, SCG, and SDG&E

Procurement charges reflect fluctuating natural gas market commodity prices and vary monthly. In the tables below, the winter season is defined as November through March, and the summer season is defined as April through October. Procurement costs shown for each season represent the averages over those months.

Table B-23 lists procurement and transportation charges are shown for the summer and winter seasons of 2020 to 2025 for the PG&E G-NR1 and G-NR2 rates.

Table B-23: PG&E G-NR1 and G-NR2 Procurement and Transportation Charges

Rate	Year	Season	Procurement ($/therm)	Tier 1 Transportation ($/therm)	Tier 2 Transportation ($/therm)
G-NR1	2025	Winter	0.47	1.63	0.94
G-NR1	2025	Summer	0.30	1.39	0.80
G-NR1	2024	Winter	0.54	1.43	0.90
G-NR1	2024	Summer	0.29	1.24	0.79
G-NR1	2023	Winter	1.03	1.04	0.65
G-NR1	2023	Summer	0.32	0.89	0.56
G-NR1	2022	Winter	0.78	1.08	0.67
G-NR1	2022	Summer	0.68	0.91	0.57
G-NR1	2021	Winter	0.53	0.92	0.55
G-NR1	2021	Summer	0.29	0.80	0.48
G-NR1	2020	Winter	0.42	0.88	0.51
G-NR1	2020	Summer	0.27	0.76	0.44
G-NR2	2025	Winter	0.43	1.63	0.94
G-NR2	2025	Summer	0.26	1.39	0.80
G-NR2	2024	Winter	0.50	1.43	0.90
G-NR2	2024	Summer	0.25	1.23	0.79
G-NR2	2023	Winter	1.02	1.04	0.65
G-NR2	2023	Summer	0.27	0.89	0.56
G-NR2	2022	Winter	0.74	1.08	0.67
G-NR2	2022	Summer	0.64	0.91	0.57
G-NR2	2021	Winter	0.49	0.92	0.55
G-NR2	2021	Summer	0.25	0.80	0.48
G-NR2	2020	Winter	0.38	0.88	0.51
G-NR2	2020	Summer	0.23	0.76	0.44

Source: PG&E

Table B-24 lists procurement and distribution charges are shown for the summer and winter seasons of 2020 to 2025 for the SCG G-10 rate.

Table B-24: SCG G-10 Procurement and Transportation Charges

Rate	Year	Season	Procurement ($/therm)	Tier 1 Transportation ($/therm)	Tier 2 Transportation ($/therm)	Tier 3 Transportation ($/therm)
G-10	2025	Winter	0.43	1.17	0.70	0.39
G-10	2025	Summer	0.32	1.68	0.95	0.47
G-10	2024	Winter	0.49	1.13	0.66	0.35
G-10	2024	Summer	0.25	1.13	0.66	0.35
G-10	2023	Winter	1.70	1.11	0.64	0.33
G-10	2023	Summer	0.43	1.07	0.60	0.29
G-10	2022	Winter	0.66	1.07	0.60	0.30
G-10	2022	Summer	0.76	1.07	0.60	0.30
G-10	2021	Winter	0.37	0.99	0.53	0.26
G-10	2021	Summer	0.37	0.99	0.53	0.26
G-10	2020	Winter	0.29	0.78	0.43	0.19
G-10	2020	Summer	0.24	0.78	0.43	0.19

Source: SCG

Table B-25 lists procurement and distribution charges are shown for the summer and winter seasons of 2020 to 2025 for the SCG G-10 rate.

Table B-25: SDG&E GN-3 Procurement and Transportation Charges

Rate	Year	Season	Procurement ($/therm)	Tier 1 Transportation ($/therm)	Tier 2 Transportation ($/therm)	Tier 3 Transportation ($/therm)
GN-3	2025	Winter	0.43	1.17	0.70	0.39
GN-3	2025	Summer	0.32	1.68	0.95	0.47
GN-3	2024	Winter	0.49	1.13	0.66	0.35
GN-3	2024	Summer	0.25	1.13	0.66	0.35
GN-3	2023	Winter	1.70	1.11	0.64	0.33
GN-3	2023	Summer	0.43	1.07	0.60	0.29
GN-3	2022	Winter	0.66	1.07	0.60	0.30
GN-3	2022	Summer	0.76	1.07	0.60	0.30

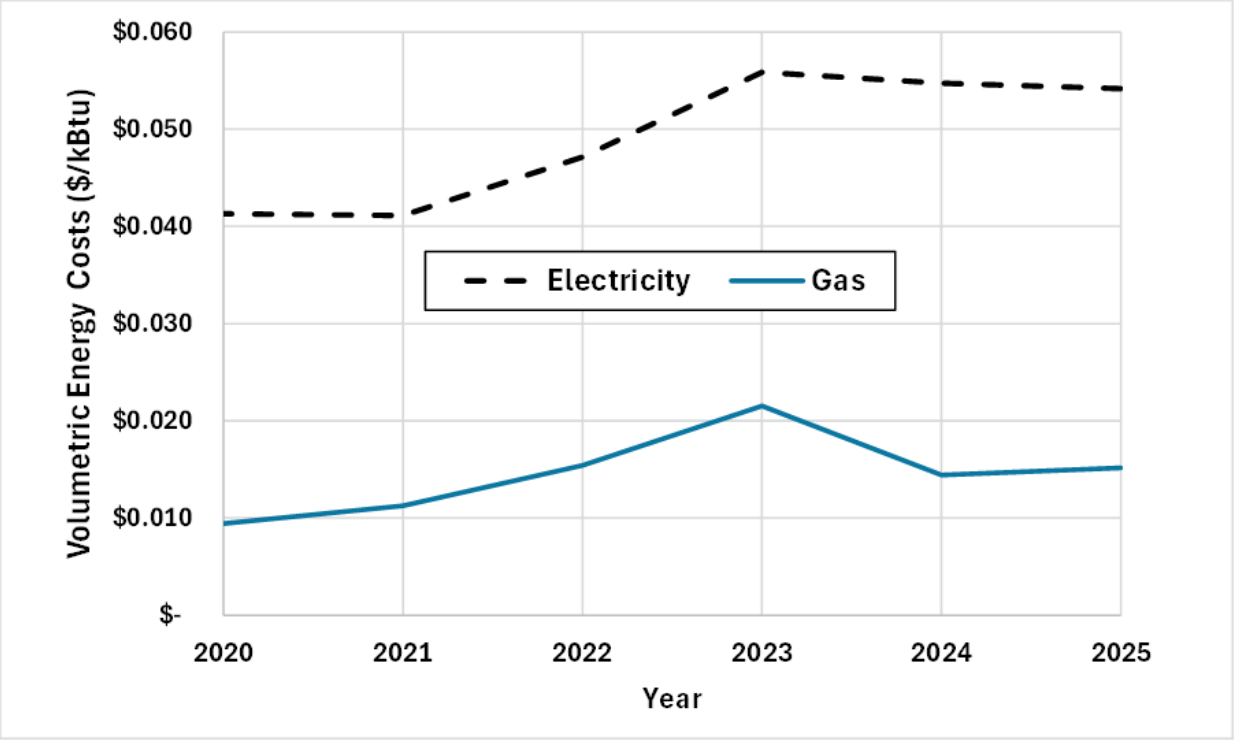
GN-3	**2021**	**Winter**	**0.37**	**0.99**	**0.53**	**0.26**
GN-3	**2021**	**Summer**	**0.37**	**0.99**	**0.53**	**0.26**
GN-3	**2020**	**Winter**	**0.29**	**0.78**	**0.43**	**0.19**
GN-3	**2020**	**Summer**	**0.24**	**0.78**	**0.43**	**0.19**

Source: SDG&E

Comparison of Gas Price Increases With Electricity Price Increases

Over the 2020–2025 period, gas transportation costs have increased by about 70 percent. This spike represents a steeper increase than the volumetric energy charges for electricity (about 25 percent). However, it is lower than the 70–100 percent increase observed for electricity fixed charges and demand-based charges. Figure 21 shows historical gas and electricity volumetric prices for California commercial customers from 2020 to 2025. The electricity costs shown include the demand and energy-based components, weighted to estimate marginal bill impacts from decarbonization measures. Likewise, gas costs shown also weigh procurement and tiered transportation costs to estimate bill impacts from decarbonization measures. Both electricity and gas costs shown exclude fixed costs. Electricity is more expensive per kBtu, one kBtu of electricity can provide roughly the same useful heat as four kBtu of gas because heat pumps operate at higher efficiency.

Figure 21: Average Commercial Gas and Electricity Costs From 2001 to 2025



Credit: LADWP, PG&E, SCE, SCG, SDG&E, and SMU