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Optimized Retrofit Strategies Final Report (02/07/23)

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PREFACE

Project Overview

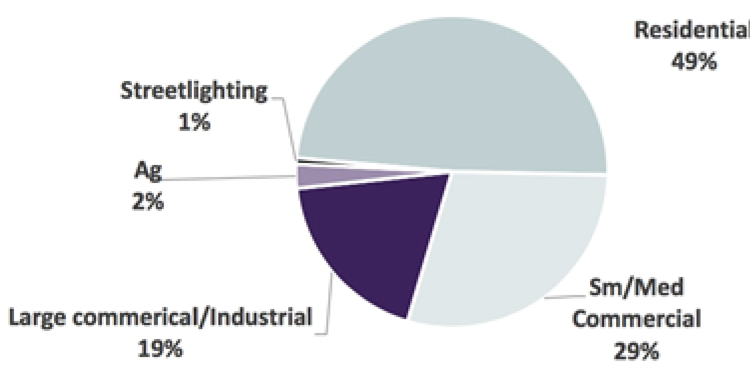
Sonoma Clean Power's (SCP) "Lead Locally" project, funded through the California Energy Commission's (CEC) GFO-17-304 aims to identify strategies and technologies that can assist with the State's goals of doubling the efficiency of existing buildings by 2030. The Project includes applied research and technology deployment activities, each of which will propose innovations that could stimulate the energy efficiency market. With the applied research work, the team is investigating a series of innovative technologies that have the potential to be integrated into existing program models. Lessons learned from the applied research projects will be funneled directly to consumers, contractors, real estate professionals, and building officials through SCP and its local partner organizations. The technology deployment work is driven in part through the SCP Advanced Energy Center (AEC), a physical storefront where consumers can directly procure energy efficient products and services. The AEC has the potential to speed deployment of energy efficiency, make energy efficiency programs more accessible to all customers, and increase customer knowledge of energy efficiency and energy code requirements.

About Sonoma Clean Power and its Customers

SCP is a public power provider operating as a Community Choice Aggregator (CCA) and is the default electricity provider for Sonoma and Mendocino Counties. SCP exists to provide broad public benefits relating to affordability, reliability, climate change and sustainability, coordination with local agencies, customer programs, and to support the local economy. The default service for SCP customers is CleanStart, which provides customers with 45% renewable power and 87% carbon free power (2017 Climate Registry certified values). SCP customers also have the option to select EverGreen service, which is 100% renewable power produced entirely within the SCP service area.

SCP serves just over 220,000 accounts, of which 86% are residential accounts. On an annual basis, SCP's load is comprised of about 50% residential energy use as shown in Figure P-1.

Figure P-1. SCP Customer Load for 2017



SCP, its employees, agents, contractors, and affiliates maintain the confidentiality of individual customers' names, service addresses, billing addresses, telephone numbers, email addresses, account numbers, and electricity consumption, except where reasonably necessary to conduct SCP's business or to provide services to customers as required by the California Public Utilities Commission (CPUC). SCP shall not, under any circumstance, disclose customer information for third-party telemarketing, e-mail, or direct mail solicitation. Aggregated data that cannot be traced to specific customers may be released at SCP's discretion.

Any questions or concerns regarding the collection, storage, use, or distribution of customer information, or those who wish to view, inquire about, or dispute any customer information held by SCP or limit the collection, use, or disclosure of such information, may contact Erica Torgerson, Director of Customer Service, via email at etorgerson@sonomacleanpower.org.

Project Team, Roles and Responsibilities

The applied research team was comprised of the following parties (referenced in this document as the Team), with roles and responsibilities outlined below.

Sonoma Clean Power served as the prime coordinator with the CEC, and was responsible for identifying project sites, initial outreach to customers, and reporting Project progress to the CEC.

Frontier Energy's lead roles were management of the applied research activities and associated subcontractors, execution of laboratory testing, installation of instrumentation at test sites, analysis of monitored data, energy modeling, technology demonstration and deployment, and technical reporting.

DNV provided independent Evaluation, Measurement, and Verification (EM&V) for the Project, specified required measurement points and accuracy levels for the instrumentation package, and evaluated performance relative to the metrics for success.

ABSTRACT

This report documents the results of a modeling research project to evaluate and compare the energy performance and cost-effectiveness of various retrofit measures on single family and office buildings in both inland and coastal Sonoma and Mendocino County, California. The project was part of Lead Locally, an initiative managed by Sonoma Clean Power and funded primarily by the California Energy Commission. This research project integrated a large-scale modeling exercise with data from technology demonstrations to make recommendations with the intent to accelerate the adoption of building retrofits and achieve deeper energy savings. 30 residential measures and 14 commercial measures were evaluated to identify those that maximize cost, electricity, and greenhouse gas savings. This analysis identified cost-effective retrofit measures for homes and commercial buildings based on characteristics such as location and existing conditions.

Keywords: (modeling, retrofit measures, envelope, HVAC, water heating, lighting, appliances, existing buildings, single family, office, Lead Locally, Sonoma Clean Power)

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EXECUTIVE SUMMARY

Background

The Lead Locally Grant is an innovative programmatic approach to existing buildings research, development and demonstration that includes a range of innovative technologies, program features, and market strategies to engage new customers in energy efficiency upgrades and deliver benefits to California's electric ratepayers. The Grant is led by Sonoma Clean Power (SCP) under funding by the California Energy Commission (CEC) through the Electric Program Investment Charge (EPIC) program. SCP offers Community Choice Aggregation, providing electricity to 189,000 residential and 31,000 commercial customers in Sonoma and Mendocino Counties. This robust existing building initiative also serves to complement current fire recovery efforts in Sonoma and Mendocino Counties, enabling SCP programs to have impact far beyond the scope of this project.

The Optimized Retrofit Strategies project was led by Lead Locally partner Frontier Energy. The objective of this research project was to use hourly building simulations to identify optimal energy efficiency measures targeted at SCP customers based on existing building type, building characteristics, and climate zone. These technological solutions, when combined with customer targeting and marketing strategies, can be used to overcome key market barriers to large-scale retrofits. This work integrates a large-scale modeling exercise with data from technology demonstrations to make recommendations with the intent to accelerate the adoption of building retrofits and achieve deeper energy savings.

The work focused on the SCP service territory, located in Northern California Climate Zones 1 and 2. Measures were evaluated to identify those that maximize cost, electricity, and greenhouse gas savings and included technologies evaluated in the applied research and technology demonstration phases of this project, as well as common off-the-shelf retrofit measures. Building types covered were single-family residential and small office commercial occupancy.

Key questions that this research aimed to answer are provided below.

- Which cost-effective measures produce the greatest electricity and greenhouse gas savings?
- Which measures result in the greatest net present value (NPV) over the analysis period?
- What are the lowest cost approaches to reach 10% and 20% electricity savings in both residential and commercial buildings?
- What are the optimal efficiency and electrification measures for SCP to target to maximize greenhouse gas savings across the SCP service territory?

Methodology

This study evaluated 30 residential measures and 14 commercial measures. Two climate regions were defined for the analysis. The largest is the inland region represented by California

Climate Zone (CZ) 2. The coastal region is represented by CZ1.[1] The residential analysis covered both CZs while the commercial analysis focused on Climate Zone 2 only.

The residential analysis covered single family buildings and utilized NREL's ResStock Analysis Tool[2] to develop prototype buildings and analyze energy measures. ResStock is a versatile tool that performs extensive residential energy analysis to achieve granularity and accuracy in modeling the diversity of the existing housing stock. ResStock creates a broad distribution of archetype building models that are defined by a particular combination of building characteristics, such as vintage, number of stories, foundation type, and heating fuel. A base dataset of 6,000 building models was established to represent the estimated 150,543 single family homes in Sonoma and Mendocino counties. Each upgrade was simulated by taking the ResStock base dataset and applying the upgrade to the applicable models. The upgrade was only applied to a subset of the base dataset that meets certain defined criteria to ensure that only relevant upgrades were analyzed. The basecase for each measure varied for most cases and was dependent on the existing conditions of the particular home in the base dataset. The exception are the HVAC and water heating equipment replacement measures which were always assumed to be replaced at the end of their useful life and therefore the basecase was a new minimum efficiency piece of equipment.

The commercial building analysis used DOE's OpenStudio tool to evaluate a small office prototype. Two vintages of the office prototype were evaluated, one built under the first Title 24, Part 6 energy code of 1978 and another under the 1998 energy code.

A customer-based lifecycle cost (LCC) approach was used to determine cost-effectiveness that values energy based upon estimated site energy usage and customer utility bill savings using today's electricity and natural gas utility tariffs and estimating total savings over the analysis period accounting for discount of future costs and energy cost inflation. NPV is calculated as the present value of the benefit, which are based on utility savings in this analysis, less the present value of the incremental cost.

Results

Table ES-1 presents average NPV, electricity savings, and greenhouse gas (GHG) savings of each residential measure for the homes where it was found to be cost-effective. Also reported is the percent of total cases evaluated that were found to be cost-effective. Grey highlighted cells represent the top 10 measures for each metric. There were seven measures in the top 10

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1 This map hosted by the California Energy Commission provides an easy lookup reference to determine what regions fall within what California Climate Zone: https://caenergy.maps.arcgis.com/apps/webappviewer/index.html?id=5cfefd9798214bea91cc4fddaa7e643f

2 https://www.nrel.gov/buildings/resstock.html

for three of the four metrics. These measures were mini-split heat pump (MSHP) installations, replacing electric furnaces with heat pumps, R-49 attic insulation, R-13 wall insulation, and LED lighting. The measures that resulted in the highest kWh savings were heat pumps replacing electric furnaces, MSHPs replacing standard split heat pumps, and new energy efficient windows. The measures that resulted in the highest GHG savings were heat pump installations replacing either gas or electric resistance space heating or water heating equipment. The measures that were generally found to be cost-effective were measures that affected older homes with inefficient envelopes and mechanical equipment, as well as homes with higher use patterns (for example higher loads due to higher occupant densities, higher heating thermostat setpoints, or lower cooling thermostat setpoints.) Newer homes or homes that have implemented efficiency upgrades usually already had fewer measures that were cost-effective because the smaller increase in efficiency did not outweigh the cost of the measures in most cases.

Table ES-1: Average Annual Savings per Residential Measure

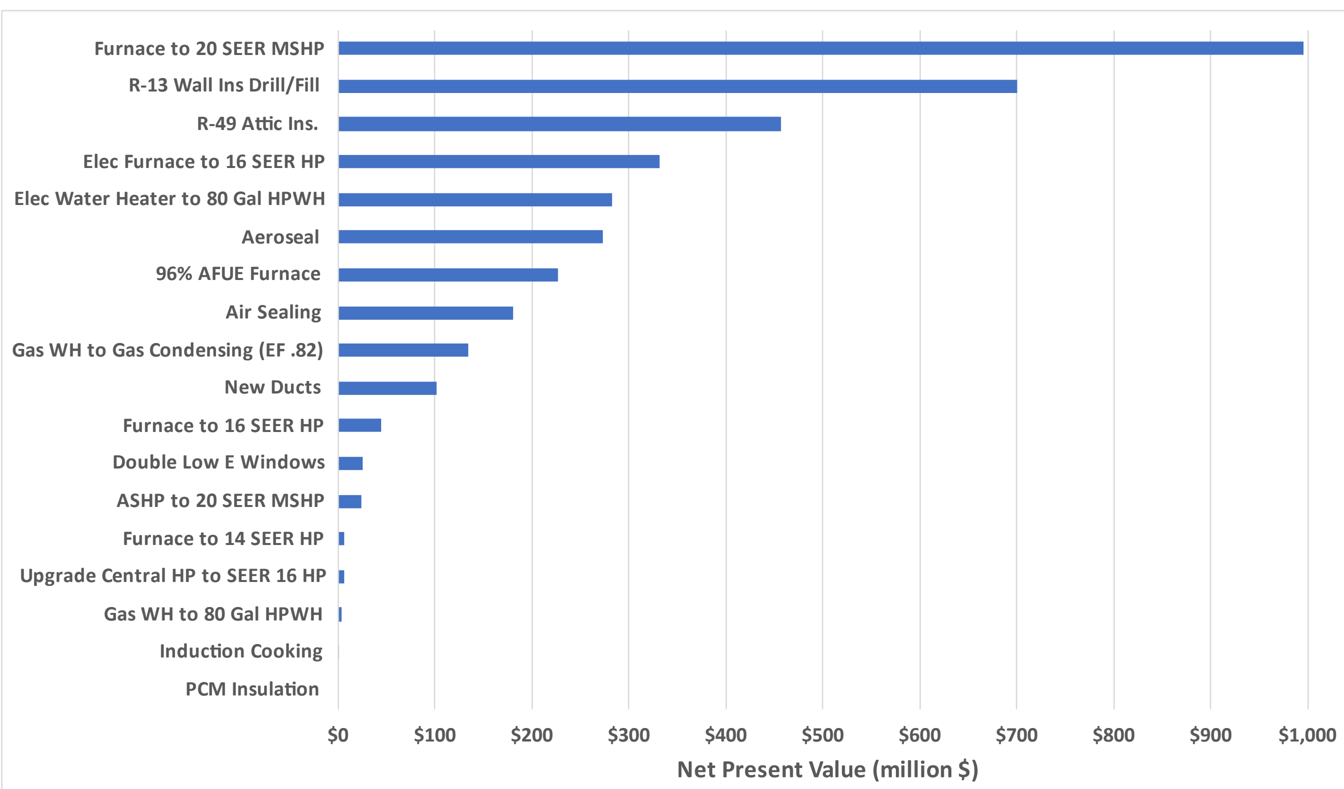
Measure	% Cost-Effective	Average NPV	Average Electricity Savings (kWh)	Average GHG Savings (lbs CO2e)
SEER 14 to 16 HP	100%	$3,777	531	182
SEER 14 heat pump to MSHP	100%	$15,989	2,263	774
LED lighting	100%	$4,283	612	127
Low flow fixtures	100%	$2,840	174	357
Electric furnace to SEER 14 HP	100%	$60,530	7,075	2,421
Electric furnace to SEER 16 HP	100%	$65,095	7,653	2,618
ENERGY STAR clothes dryer	99%	$2,099	291	93
Gas furnace to MSHP	99%	$13,138	-827	4,165
ENERGY STAR refrigerator	95%	$979	168	23
ENERGY STAR clothes washer	93%	$1,704	188	220
80% to 96% AFUE furnace	90%	$3,316	2	826
Electric WH to HPWH	89%	$8,081	1,496	328
0.60 to 0.82 EF gas WH	83%	$1,699	-5	773
R-13 wall insulation	83%	$10,754	653	1,930
SEER 14 to 16 AC	72%	$576	138	49
Air sealing – manual	59%	$2,044	144	528
Duct sealing	57%	$1,490	158	217
R-49 attic insulation	56%	$6,004	515	952
R-60 attic insulation	52%	$5,940	541	979
Hot water pipe insulation	48%	$40	8	6
Air sealing – Aerobarrier	40%	$4,622	452	1,397
ENERGY STAR dishwasher	32%	$473	73	65
Gas furnace to SEER 16 HP	26%	$2,228	-3,125	4,539
New ducts	25%	$2,792	487	741
SEER 14 to 18 AC	13%	$1,131	473	160

New windows	9%	$2,406	1,353	864
Gas furnace to SEER 14 HP	9%	$914	-3,585	4,759
Gas WH to HPWH	2%	$1,240	-982	2,070
Induction stove	0%	$242	-386	248
PCM	0%	n/a	n/a	n/a

Figure ES-1 presents total potential NPV savings across the SCP territory if a measure was applied in all homes where it was found to be cost-effective. While such a large magnitude of upgrades is unlikely, this analysis does indicate where the largest opportunities lie. The measures which resulted in the highest NPV were replacing gas furnaces with MSHPs, wall and attic insulation, and replacing electric furnaces with heat pumps. The same measures also captured the greatest electricity savings, except for the gas furnace replacement which increased electricity consumption but had the highest GHG savings potential. The next highest GHG savings measures were R-13 wall insulation, replacing gas furnaces with heat pumps, Aerobarrier air sealing, and R-60 attic insulation.

Measure impacts are not always independent of one another, and as a result the savings cannot always be considered additive. For example, in some homes replacing the gas furnace with either a standard split heat pump or a MSHP was cost-effective. The impacts of both scenarios were captured in the results. Also, interactive effects of measures were not accounted for. For example, improving the building envelope decreased the heating and cooling loads and therefore reduced the savings from HVAC equipment upgrade measures.

Figure ES-1: Total NPV Across All Cost-Effective Residential Measures



Of the 14 commercial office building measures evaluated, six of them were found to be cost-effective. Table ES-2 summarizes NPV only for the measures that were found to be cost-effective. The base conditions differed for each of the two prototypes. For example, the 1978 code prototype was assumed to have single pane, metal windows while the 1998 prototype dual pane metal framed windows. Measures that reduced lighting and fan energy use were found to be the most cost-effective and resulted in the greatest savings. The largest end-use for both office vintages was interior equipment. This analysis covered envelope, HVAC, lighting, and water heating measures only and did not consider measures that target office equipment or other miscellaneous interior equipment loads.

Table ES-2: Results Summary for Cost-Effective Commercial Measures

Measure	NPV for the 1978 Prototype	NPV for the 1998 Prototype
LED lighting	$59,357	$27,098
RTU fan motor replacement	$18,851	$13,906
Occupancy controls	$7,342	$2,404
High-efficiency RTU	$4,754	n/a
New windows	$2,828	n/a
Skylights & daylighting	$1,859	n/a

Conclusions & Recommendations

Table ES-3 and ES-4 summarizes the measure level recommendations found from this study for residential buildings and commercial buildings, respectively.

The residential measures that provided the greatest electricity savings were replacing electric furnaces with heat pumps, heat pump upgrades to MSHPs, and replacing electric resistance water heaters with heat pump water heaters. The lowest cost approach to meet 10 percent savings are LED lighting and ENERGY STAR refrigerators. The most cost-effective residential measures with an average net present value greater than $10,000 were replacing electric furnaces with heat pumps, MSHPs installations, and R-13 wall insulation. The residential measures that resulted in the greatest GHG savings were gas furnace upgrades to heat pumps and gas water heater upgrades to heat pump water heaters. Across SCP territory the top three measures for territory-wide GHG reductions were replacing gas furnaces with MSHPs or standard heat pumps and R-13 wall insulation.

Fewer commercial measures were found to be cost-effective. The LED replacement and daylighting measures resulted in the greatest electricity and GHG savings. The LED replacement measures was found to be the most cost-effective, followed by the RTU fan motor replacement. None of the individual measures meet the 20% savings target for commercial buildings. While measure bundles weren’t evaluated as part of this study, some combination of measures may result in the 20% savings target.

This analysis and others have identified cost-effective retrofit measures for residential homes and commercial buildings based on existing building characteristics and location. These results can be useful for selecting technologies that receive incentives or promotion through SCP's Advanced Energy Center. However, customized analyses based on actual building conditions and operations would better inform recommendations for a particular building. Even when this information is available, retrofit programs across the United States have been challenged with significant uptake unless incentives are high. Measures may be proven to be cost-effective over their lifetime; however, owners and occupants often have limited options to finance projects and may not resonate with a cost-effectiveness justification based on a longer time period than they may own the building. To achieve large-scale energy retrofits across the entire building stock, creative solutions are needed, such as the on-bill financing approach developed by SCP for Lead Locally customers, which avoids out-of-pocket costs for building owners as long as the expected savings is achieved.

Table ES-3: Residential Recommendations

Measure	Recommendation
Wall Insulation	Recommended in homes with uninsulated walls.
Attic Insulation	Recommend either R-49 or R-60 in homes with R-19 attic insulation or less. Combine with sealing of the ceiling plane between the home and the attic whenever possible.
PCM	Not recommended, too costly.
Windows	Not recommended as an energy efficiency upgrade on its own because it is very costly. However, there are other significant benefits of upgrading single-pane windows, particularly if they are metal framed, such as reduction of noise and drafts and increased comfort. When a window upgrade is already planned a dual or triple pane product is recommended with a U-factor 0.30 or lower. A low solar heat gain coefficient (SHGC) is recommended in inland climates ($\leq$0.23) and a high SHGC is recommended in coastal climates ($\geq$0.35).
Air Sealing	The cost-effectiveness of this depends on the existing sealing level (>10 ACH50), but where testing is not already planned this measure can be recommended in homes built before 1980 where occupants experience drafts. Aerobarrier may be more expensive but is expected to provide more consistent results and should be considered when the service is available.
Upgrade Air Conditioner	Recommend upgrading to a SEER 16 air conditioner in the inland climate when the air conditioner is being replaced.
Upgrade Gas Furnace	Recommend upgrading to a condensing gas furnace when the gas furnace is being replaced.

Upgrade Heat Pump	Recommend upgrading to a 16 SEER, 9 HSPF heat pump or higher and consider a mini-split heat pump product to provide higher efficiencies.
Replace Furnace with Heat Pump	Recommend upgrading to a mini split heat pump when replacing an existing gas or electric furnace and air conditioner. Conduct load calculations to properly size the equipment. Evaluate the duct system to determine if the existing system is adequate for a heat pump, if not replace the ducts with a properly sized system. Where possible combine this with envelope upgrades to reduce building loads.
Nighttime Ventilation	Recommended as a low-cost alternative to installing air conditioning for small homes with central heating systems where the air handling unit is in the attic. Where possible combine this with envelope upgrades to reduce building loads improving the effectiveness of a nighttime ventilation system.
HVAC Ducts	Recommend inspecting ductwork as part of any retrofit project and sealing them whenever leaks are found. Consider Aeroseal when that service is available. Consider a new duct system if the existing system is 20 years old or if an entirely new HVAC systems is being installed, particularly if an existing gas furnace is replaced with a heat pump.
Upgrade Gas Water Heater	Recommend upgrading to a condensing water heater when the water heater is being replaced.
Replace Gas Water Heater with HPWH	Recommend upgrading to a heat pump water heater when replacing an existing gas water heater if incentives are available.
Replace Electric Water Heater with HPWH	Recommend upgrading to a heat pump water heater when replacing an existing electric storage water heater.
Pipe Insulation	Recommend insulating hot water pipes that are easily accessible and are not already insulated.
Low Flow Fixtures	Recommend CalGREEN compliant showerheads and faucets wherever they don't already exist.
Appliances	Recommend upgrading to ENERGY STAR rated refrigerators, clothes washers, and clothes dryers when replacing the existing appliances. Consider induction cooktops as an alternative to electric resistance cooktops to provide performance benefits. While not cost-effective today, as more induction products are developed it's expected costs will decline improving cost effectiveness improve.
Lighting	Recommend replacing existing incandescent and CFL lightbulbs with LED lightbulbs.

Table ES-4: Commercial Recommendations

Measure	Recommendation
LED lighting	Recommend replacing linear fluorescent tubes with LED tubes.
Replace RTU fan motor	For packaged units with PSC fan motors that have not reached the end of their life recommend replacing the fan motor with a brushless permanent magnet motor.
Occupancy controls	Recommend occupancy controls be installed in all spaces.
High-efficiency RTU	Recommend upgrading to a high-efficiency RTU furnace when the furnace is being replaced for offices for buildings 1980 or older or buildings with single pane windows and minimal insulation.
New windows	Recommend upgrading existing single-pane, metal framed windows to a dual or triple pane product with a U-factor 0.30 or lower. A low SHGC is recommended in inland climates (≤0.23) and a high SHGC is recommended in coastal climates (≥0.35).
Tubular skylights & daylighting controls	For buildings 1980 or older in spaces with limited daylighting recommend tubular skylights in conjunction with daylighting controls. For spaces with a reasonable amount of daylighting from existing windows and/or skylights, recommend daylighting controls be connected to the existing lighting system for a significantly lower cost.

CHAPTER 1: Introduction

1.1: Background

The Lead Locally Grant is an innovative programmatic approach to existing buildings research, development and demonstration that includes a range of innovative technologies, program features, and market strategies to engage new customers in energy efficiency upgrades and deliver benefits to California's electric ratepayers. The Grant is led by Sonoma Clean Power (SCP) under funding by the California Energy Commission (CEC) through the Electric Program Investment Charge (EPIC) program. SCP offers Community Choice Aggregation, providing electricity to 189,000 residential and 31,000 commercial customers in Sonoma and Mendocino Counties. This robust existing building initiative also serves to complement current fire recovery efforts in Sonoma and Mendocino Counties, enabling SCP programs to have impact far beyond the scope of this project.

1.2: Objectives

The objective of this research project was to identify optimal retrofit efficiency measures targeted at customers based on building type, existing building characteristics, and climate zone. These technological solutions, when combined with customer targeting and marketing strategies, can be used to overcome key market barriers to large-scale retrofits. This work integrates a large-scale modeling exercise with data from technology demonstrations to make recommendations with the intent to accelerate the adoption of building retrofits.

The work focused on the SCP service territory and the Northern California climate regions of California Climate Zones 1 and 2. Measures were selected to maximize cost, electricity, and greenhouse gas savings and include technologies evaluated in the applied research phase of this project and technologies solicited through the Advanced Energy Center (AEC), as well as common off-the-shelf retrofit measures. Building types covered were single-family residential and small office commercial occupancy.

Key questions that this research aimed to answer are provided below. In this study cost-effectiveness was defined using a customer-based lifecycle cost (LCC) approach which compared measure incremental cost to utility bill cost savings.

- Which cost-effective measures produce the greatest electricity and greenhouse gas savings?
- Which measures result in the greatest net present value over the analysis period?
- What are the lowest cost approaches to reach 10% and 20% electricity savings?
- What are the optimal measures for SCP to target to maximize greenhouse gas savings across the SCP service territory?

CHAPTER 2: Technical Approach

2.1: Approach Overview

The analysis covered the following two primary building types:

- Single family homes
- Small commercial office buildings

Multifamily buildings were not directly evaluated; however, many of the recommendations and conclusions made for single family are applicable to typical multifamily construction in SCP territory. Low-rise multifamily buildings often have similar construction and system types as single family buildings, aligning the potential and feasible upgrades.

Similar analysis approaches were applied for both occupancy types, even though the approaches were implemented very differently for single family homes compared to the small office. The major steps are described below.

1. *Define prototypes*: Research identified, to the extent possible, the characteristics of the existing building stock including building type, vintage, floor area, and number of stories, construction type (foundation and attic type, construction material), space heating and water heating fuel and system type, and space cooling system type where present. For the commercial analysis, a representative prototype was defined based on this data to represent most of the existing buildings within SCP's service territory as well as those where the greatest savings opportunities exist. The residential analysis used a different approach leveraging a large-scale energy analysis that resulted in hundreds of prototypes in both coastal (Climate Zone 1) and in-land (Climate Zone 2) climates. The commercial building analysis covered Climate Zone 2 only where most of the commercial building stock resides.

   Energy related building characteristics, such as insulation levels, were determined by cross referencing the building vintage with the relevant Title 24, Part 6 code that was in place at the time of building construction or survey data sources such as the CEC's Residential Appliance Saturation Study (RASS) ((DNV, 2010) (DNV, 2022)). For older buildings constructed before the energy code was enacted, typical construction practices were applied based on the experience of the Team.
2. *Identify retrofit measures*: A review of potential retrofit measures was conducted and included the technologies evaluated in the applied research and technology demonstration phases of this project and various common off-the-shelf retrofit measures. Selected measures were based on a high-level evaluation of technical feasibility, availability in the market, cost-effectiveness, and the ability to be evaluated within the defined analysis processes. Measures that primarily reduce the use of natural gas, including gas appliance efficiency improvements, as well as fuel substitution or electrification measures were included in the analysis for completeness but were not the primary focus of the study.

3. *Measure costing*: Retrofit measure costs are highly variable dependent on existing conditions, project region (labor costs), contractor comfort with measures and contractor manufacturer/distributor relationships, among other factors, and are very difficult to accurately estimate for an average hypothetical project. Often, optimization analysis results are more sensitive to cost input assumptions than other modeling assumptions.

   The Team conducted a costing exercise to estimate costs for the retrofit measures as accurately as possible. Costs were estimated from various sources such as data from other research and programmatic activities in which the Lead Locally research team is involved, the National Renewable Energy Laboratory's (NREL's) National Residential Efficiency Measures Database, R.S. Means, and costs from projects under the applied research and technology demonstration phases. Estimated costs were derived using the Team's best judgment; in some cases, costs were averaged across various datapoints, in other cases a single datapoint may have been used where there is more confidence in that cost compared to others. Sources and assumptions are documented in this report.
4. *Parametric analysis*: A dataset of energy simulations in the coastal and inland climates was created using the selected simulation tool for each building type including existing basecase models and individual measure upgrades.
5. *Life cycle costs*: Lifecycle cost (LCC) effectiveness was calculated based on comparing the present value (PV) of the incremental cost of the measure (first cost, replacement costs and maintenance costs) relative to the PV of the benefit of the measure (utility cost savings). Net present value (NPV) was calculated as the difference between the PV of the benefit less the PV of the cost and accounted for discounting of future savings and costs, and energy escalation. The evaluation period was over a 30-year lifetime for the residential analysis and 15-year for the commercial analysis, consistent with the approach used by the CEC for Title 24, Part 6 code development.

   For equipment upgrade measures the analysis evaluates replacement at end-of-life. Equipment lifetimes were based on industry standards such as the CPUC's Database for Energy Efficient Resources (DEER). Envelope measures were assumed to last for the entire evaluation period.
6. *Measure review and recommendations*: Based on results of the LCC analysis the most promising measures were identified based on the following criteria.
   - Greatest electricity and greenhouse gas savings while still cost-effective.
   - Most cost-effective independent of electricity savings.
   - Lowest cost way to reach 10% electricity savings for residential buildings and 20% electricity savings for commercial buildings.

Appendix A provides a summary of software tools that were considered for this analysis.

2.2: Prototype Buildings, Measure Selection, and Modeling

Methods

Single Family Homes

Modeling Process

The single family analysis utilized NREL's ResStock Analysis Tool[3] to develop prototype buildings and analyze energy measures. ResStock is a versatile tool that performs extensive residential energy analysis to achieve granularity and accuracy in modeling the diversity of the existing housing stock. It uses DOE's OpenStudio platform and the EnergyPlus energy simulation engine and is provided free for the public to download and customize to represent local analysis needs. This feature allowed the Team to leverage a validated housing stock model developed by NREL resulting in greater coverage of the existing residential building stock in SCP's service area. In development of ResStock, NREL conducted a housing stock characterization for the single family detached housing stock that defines more than 100 components of a building using large public and private data from 11 sources. NREL's statistical sampling identified a representative sample of 350,000 homes across the United States on which detailed sub-hourly building simulations were run. Validation was conducted by NREL by comparing the results against the U.S. Energy Information Administration's Residential Energy Consumption Survey. (National Renewable Energy Laboratory, 2021)

ResStock creates a broad distribution of archetype building models that are defined by a particular combination of building characteristics, such as vintage, number of stories, foundation type, and heating fuel. Within ResStock the probability of a given building characteristic value is defined according to various dependences such as location, building type, etc. NREL used numerous data sources to define housing characteristic distributions for California as a whole. The Team reviewed data sources specific to SCP's service territory, including the 2009 RASS (DNV, 2010) and census data (U.S. Census Bureau, 2012), in order to identify where NREL's housing characteristic probabilities for the whole of California might differ from the housing characteristics of buildings in the SCP service territory. Adjustments were then made to the housing characteristic probabilities to create a more representative building stock for the SCP service territory. ResStock also applies a distribution to occupant behavior, represented by general usage level of appliances as well as thermostat setpoints, which adds an element of realism. The ResStock assumptions for usage were applied in this analysis. ResStock version 2.2.4 was used in tandem with version 2.9.1 of Openstudio's Parametric Analysis Tool and version 9.2 of Energyplus to perform the modeling for the residential measures.

3 https://www.nrel.gov/buildings/resstock.html

Two climate regions were defined for the analysis. The largest is the inland region represented by California Climate Zone (CZ) 2 and covering Santa Rosa, Sonoma, Cloverdale, Cotati, Rohnert Park, Petaluma, Windsor, Sebastopol, Willits and other inland regions of Sonoma and Mendocino counties. The coastal region is represented by CZ1 and covers Fort Bragg, Point Arena, and other coastal regions of Sonoma and Mendocino counties.[4] Modeling used the typical meteorological year 3 (TMY)[5] weather files of Santa Rosa for CZ2 and Arcata for CZ1.

ResStock references data tables for each of the 100+ covered building components that characterize the likelihood of any particular building characteristic value appearing in a single family home. As an example, Table 1 shows the data table for wall insulation which establishes the probability of a home having various levels of insulation in the walls. Most building characteristics, as in this example, were also dependent on the vintage of the home, meaning for each vintage a separate probability breakdown of the building characteristic values are provided. The wall insulation characteristics shown in Table 1 were based on the ResStock California data tables with some adjustments to reflect more California typical insulation practices. Some building characteristics were dependent on the climate region, as was the case for heating system type. Further details on the resultant characterizations and how they were defined can be found in Appendix B.

Table 1: Wall Insulation Probability Breakdown by Vintage

Dependency: Vintage	Wood Stud, Uninsulated	Wood Stud, R-11	Wood Stud, R-13	Wood Stud, R-15	Wood Stud, R-19
<1950	1	0	0	0	0
1950s	1	0	0	0	0
1960s	1	0	0	0	0
1970s	0.5	0.5	0	0	0
1980s	0.01	0.02	0.9	0	0.06
1990s	0	0	0.69	0.08	0.24
2000s	0	0	0.47	0.02	0.51

To estimate the total number of single family homes within SCP territory, the Lead Locally team used the building stock within Sonoma and Mendocino counties as a proxy. All customers living in either Sonoma or Mendocino counties are eligible for SCP service except for customers

4 This map hosted by the California Energy Commission provides an easy lookup reference to determine what regions fall within what California Climate Zone: https://caenergy.maps.arcgis.com/apps/webappviewer/index.html?id=5cfefd9798214bea91cc4fddaa7e643f

5 https://nsrdb.nrel.gov/data-sets/tmy

in the cities of Ukiah and Healdsburg, which have municipal power programs. Census data for all of California provided by NREL and used in ResStock was used to estimate total housing counts (U.S. Census Bureau, 2012). The data was formatted to provide total single family housing counts by census tract. The census tracts within Mendocino and Sonoma counties were segregated and mapped to zip codes and then climate region (CZ1 or CZ2 based on data provided by the California Energy Commission). The resulting total counts are presented in Table 2.

Table 2: Single Family Home Counts

	Coastal (CZ1)	Inland (CZ2)	Total
# Single Family Homes	11,585	138,958	150,543
Percent	8%	92%	100%

A base dataset of 6,000 building models was established to represent the 150,543 single family homes. The ratio of about 25 homes per simulation (or 4 percent, 6,000/150,543) was selected based on recommendations by NREL to balance accuracy and simulation time. Once the building characteristic information was updated in the ResStock data tables, ResStock was used to simulate the 6,000 building models applying the base case building characteristics. The simulation results, referred to as the ResStock base dataset, describe the energy use by end use for each of the 6,000 models. These results can be scaled up to the population it represents by multiplying the results for each individual case by 25. Retrofitting the entire housing stock may be unrealistic, but it is useful for evaluating the maximum technical and savings potential of each measure.

Each upgrade was simulated by taking the ResStock base dataset and applying the upgrade to the applicable models. The upgrade was only applied to a subset of the base dataset that meets certain defined criteria to ensure that only relevant upgrades were analyzed. ResStock simulations were conducted using Amazon Web Services, which allowed for significantly reduced runtimes versus conducting the simulations using local computer resources.

Measures

More than 50 efficiency upgrade measures were defined in ResStock. Measures covered insulation upgrades, window replacements, air sealing, and equipment upgrades. In addition to these measures, the Team identified additional efficiency upgrades that are applicable to existing homes covered within this evaluation. To apply measures in the ResStock analysis, measures must be either already available as a ResStock upgrade, created by editing an existing ResStock upgrade, or applied as an OpenStudio or EnergyPlus Measure. The Team leveraged other measures that were already developed within OpenStudio, for example residential measures from NREL's BEopt™ (Building Energy Optimization Tool) software that have been converted to OpenStudio.

In some cases, the applied research and technology demonstration measures could not be directly modeled within ResStock. The following describes the approach for evaluation of each measure.

- Aerosol envelope sealing (Aerobarrier): This was modeled directly in ResStock as a 60% reduction in overall building ACH50 based on test data from four single family homes tested in the technology demonstration phase of Lead Locally.
- Phase change material (PCM): This could not be directly modeled within ResStock. The Team developed an EnergyPlus measure to apply the PCM to the relevant subset of the ResStock base models. Performance specifications in the energy model were based on manufacturer data for the PCM products installed at the technology demonstration sites using a 77 °F melting point. The PCM was modeled under attic insulation (instead of above) because this configuration was found to be most effective in previous modeling.
- Mini-split heat pumps: Mini-split heat pumps were directly modeled within ResStock. Performance specifications were based on manufacturer data for the Fujitsu heat pumps installed at Lead Locally test homes.
- Induction cooking: This was modeled directly in ResStock. Performance specifications were confirmed with data from the products installed at Lead Locally test sites. Evaluated stovetop Energy Factors were 0.84 for induction, 0.74 for electric resistance, and 0.40 for gas and propane.

The following measures were not modeled directly within this study due to modeling limitations but are considered as part of the recommendations.

- Hydronic heating & cooling: Hydronic delivery with air-to-water heat pumps cannot be easily modeled with ResStock or with an OpenStudio Measure. This measure was not evaluated as part of this project. However, it is discussed as an alternative to air-to-air heat pumps.
- Nighttime ventilation: This measure uses the heating system fan to flush the home with cool outdoor air at night, reducing indoor air temperatures throughout the day and delaying the time the air conditioner has to turn on. It cannot be directly modeled within ResStock and was not evaluated as part of this project. However, it is discussed as an alternative to installing air conditioning in homes that don't currently have a mechanical cooling system.
- Grid integrated heat pump water heater (HPWH): HPWHs were directly modeled within ResStock. However, the grid integration functionality (primarily in the form of load shifting) cannot be easily modeled in ResStock and was not evaluated as part of this project. However, the benefits of grid integration are discussed along with the HPWH results.
- Aerosol duct sealing (Aeroseal): For the technology demonstration this was evaluated in only one single family home and 2 multifamily homes, and the measured impact was highly variable across the three test sites. As a result, it wasn't straightforward to determine the appropriate savings value for this measure. Consequently, aerosol duct sealing was not directly modeled in this study but is discussed as an alternative to traditional manual duct sealing.

See Table 3 for a list of the measures evaluated. The table provides a description of each measure, the existing home characteristics necessary for application of the measure, and whether the baseline differed in any way from the base case simulation. Applied research and technology demonstration measures are highlighted in blue. The *characteristics of homes evaluated* column describes which homes from the ResStock base dataset were selected to receive the measure upgrade. For example, the attic insulation upgrade to R-49 was applied to all homes with a vented attic with R-30 existing insulation or less. This upgrade was not evaluated for homes with R-38 existing insulation because the Team's experience has shown that cost-effectiveness of additional insulation is limited if existing insulation already meets a minimum standard. The *baseline condition* column describes what reference case the savings and costs were evaluated against. The ResStock base dataset was used as the baseline for all cases except equipment replacement measures. Since equipment replacement was only considered to be viable at the end of the useful life of existing equipment, the baseline included replacement equipment that meets current minimum DOE efficiency standards.

For hot water pipe insulation, low flow fixtures, and appliance and lighting measures, there was insufficient data to determine which subset of the building stock would be candidates for the upgrades. The baseline set of building models are representative of homes with vintages spanning from pre 1950s to 2000s and it was not known how many homes already have upgraded to ENERGY STAR appliances or CALGreen compliant low flow fixtures. Due to this constraint, results for these measures are presented based on the potential for homes that do not already have these upgrades, and do not try to represent the impact across the SCP territory.

Table 4 presents measure costs for each of the evaluated measures. Costs are presented as total incremental lifecycle costs over a 30-year analysis period, discounted at 3% per year. Replacement costs were assumed for all equipment measures in both the baseline and upgrade cases. The lifetimes for the heat pump, furnace, and air conditioner were based on the Database for Energy Efficient Resources (DEER) (California Public Utilities Commission, 2021b). In DEER, heat pump and air conditioner measures were assigned an effective useful lifetime (EUL) of 15 years and furnace measures are assigned an EUL of 20 years. The heating and cooling system components are typically replaced at the same time when one reaches the end of its life and the other is near it. Therefore, a 17.5 EUL, halfway between 15 and 20 years, was assumed for the furnace and air conditioner measures. Other appliances EULs were based on data from the Beopt tool. Future cost reductions were assumed where appropriate to account for a maturing market.

Table 3: Single Family Measure List

Name	Description	Characteristics of Homes Evaluated	Baseline Condition
THERMAL ENVELOPE			
Air sealing – manual	Air sealing by weatherstripping & caulking – 25% reduction in ACH50	5-20 ACH50	ResStock base dataset
Air sealing – aerosol	60% reduction in ACH50 per test home data	5-20 ACH50	ResStock base dataset
R-49 attic insulation	Upgrade to R-49 blown-in cellulose or fiberglass to attic floor	Vented attic R-0 to R-30 attic ins.	ResStock base dataset
R-60 attic insulation	Upgrade to R-60 blown-in cellulose or fiberglass to attic floor	Vented attic R-0 to R-38 attic ins.	ResStock base dataset
R-13 wall insulation	Add R-13 cavity insulation to uninsulated wood frame walls using drill and fill technique.	R-0 2x4 walls	ResStock base dataset
New windows	Replace windows with double-pane Low-E model (0.30 U-factor, 0.23 Solar heat gain coefficient (SHGC))	Single-pane/double-pane (non low-e) windows	ResStock base dataset
PCM	Per applied research testing	R-19 or greater attic insulation	ResStock base dataset
HVAC			
Duct sealing	Seal ducts in unconditioned space to 10% total leakage	>=15% duct leakage	ResStock base dataset
New ducts	Replace existing ductwork with new R-8 ducts, 5% total leakage	>=10% duct leakage	ResStock base dataset
SEER 14 to 16 AC	Upgrade central AC to SEER 16 (single stage) (at wear out)	Existing central A/C	SEER 14 central AC
SEER 14 to 18 AC	Upgrade central AC to SEER 18, 14 EER (two-stage) (at wear out)	Existing central A/C	SEER 14 central AC
80% to 96% gas furnace	Upgrade gas furnace to ENERGY STAR 96% AFUE (at wear out)	Existing central gas furnace	80% gas furnace
Electric furnace to SEER 14 heat pump	Replace electric furnace with SEER 14, HSPF 8.2 split heat pump (at wear out)	Existing central electric furnace	Electric furnace, SEER 14 AC

Electric furnace to SEER 16 heat pump	Replace electric furnace with SEER 16, HSPF 9.0 split heat pump (at wear out)	Existing central electric furnace	Electric furnace, SEER 14 AC
Gas furnace to SEER 14 heat pump	Replace gas furnace with SEER 14, HSPF 8.2 split heat pump (at wear out)	Existing central gas furnace	80% gas furnace, SEER 14 AC
Gas furnace to SEER 16 heat pump	Replace gas furnace with SEER 16, HSPF 9.0 split heat pump (at wear out)	Existing central gas furnace	80% gas furnace, SEER 14 AC
SEER 14 to 16 heat pump	Upgrade split heat pump to SEER 16, HSPF 9.0 split heat pump (at wear out)	Existing central heat pump	SEER 14, HSPF 8.2 heat pump
SEER 14 heat pump to MSHP	Upgrade conventional heat pump to 20 SEER, 11.5 HSPF ducted MSHP (at wear out)	Existing central heat pump	SEER 14, HSPF 8.2 heat pump
Gas furnace to MSHP	Replace furnace with 20 SEER, 11.5 HSPF ducted MSHP (at wear out)	Existing central gas furnace	80% gas furnace, SEER 14 AC
WATER HEATING			
Electric water heater to HPWH	Upgrade .92 EF electric water heater to HPWH (80 gal, 2.4 COP) (at wear out)	Existing electric storage water heater	Electric resistance storage water heater
0.60 to 0.82 EF gas WH	Upgrade gas water heater to condensing unit EF 0.82 (at wear out)	Existing gas storage water heater	0.60 EF storage water heater
Gas water heater to HPWH	Upgrade gas water heater to HPWH (80 gal, 2.4 COP) (at wear out)	Existing gas storage water heater	0.60 EF storage water heater
Hot water pipe insulation	Insulate all accessible hot water pipes with R-3 pipe insulation, assumes 10% of pipes are accessible.	All homes	ResStock base dataset
Low flow fixtures	Upgrade sink and shower fittings to meet current CALGreen requirements of 1.8 gpm for showerheads and 1.2 gpm for faucets. Assumes a 14% reduction for showerheads (down from 2.1 gpm) and 45% reduction for faucets (down from 2.2 gpm)	All homes	ResStock base dataset

	(DeOreo, Mayer, Dziegielewski, & Kiefer, 2016).		
APPLIANCS & LIGHTING			
ENERGY STAR clothes washer	Upgrade clothes washer to ENERGY STAR (at wear out)	Homes without EnergyStar Clothes Washer	ResStock base dataset
ENERGY STAR electric clothes dryer	Upgrade electric clothes dryer to ENERGY STAR (at wear out)	All homes with existing electric clothes dryers	ResStock base dataset
ENERGY STAR dishwasher	Upgrade dishwasher to ENERGY STAR (at wear out)	All homes	ResStock base dataset
ENERGY STAR refrigerator	Upgrade refrigerator to ENERGY STAR (at wear out). Assumes 18 ft^3 top freezer product.	All homes	ResStock base dataset
Induction stove	Per tech demo testing	All homes	ResStock base dataset
LED lighting	Replace 95% of lamps with LED (80 lumens per watt)	All homes	ResStock base dataset

Table 4: Single Family Measure Costs: Single Family Measure Incremental Costs

Name	Cost Multiplier	Lifecycle Cost Per Unit ($Present Value)	Source
THERMAL ENVELOPE			
Air sealing – manual	Conditioned floor area	$0.89/sqft	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021)
Air sealing – aerosol	Conditioned floor area	$3.14/sqft	Technology demonstration projects
R-49 attic insulation	Unfinished attic area	$1.71/sqft – from uninsulated attic $1.54/sqft – from R-7 & R-12 attic $1.43/sqft – from R-19 attic $1.11/sqft – from R-30 attic	2022 CASE report on residential additions and alterations (Statewide CASE Team, 2020).
R-60 attic insulation	Unfinished attic area	$1.99/sqft – from uninsulated attic $1.81/sqft – from R-7 & R-13 attic $1.71/sqft – from R-19 attic $1.39/sqft – from R-30 attic $0.98/sqft – from R-38 attic	2022 CASE report on residential additions and alterations (Statewide CASE Team, 2020).
R-13 wall insulation	Above grade wall area	$2.14/sqft	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021)

Name	Cost Multiplier	Lifecycle Cost Per Unit ($Present Value)	Source
New windows	Window area	$45/sqft	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021)
PCM	Unfinished attic area	$6.59/sqft	Applied research projects
HVAC			
Duct sealing	Conditioned floor area	$0.25/sqft – from 15% leakage, $0.30/sqft – from 20% leakage, $0.41/sqft – from 30% leakage,	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021)
New ducts	Conditioned floor area	$2.39/sqft	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021)
SEER 14 to 16 AC (at wear out)	Per home	$531	AC Wholesalers[6] cost research, reflects material costs only, assuming no incremental labor costs. Assumes replacement at 17.5 years for furnaces/AC and 15 years for heat pumps.
SEER 14 to 18 AC (at wear out)	Per home	$2,632	
80% to 96% gas furnace (at wear out)	Per home	$840	
SEER 14 to 16 heat pump (at wear out)	Per home	$460	
Electric furnace to SEER 14 heat pump (at wear out)	Per home	$1,487	2022 CASE report on residential additions and alterations (Statewide CASE Team, 2020). 16 vs 14 SEER costs based on AC Wholesalers cost research. Assumes replacement at 17.5 years for furnaces and 15 years for heat pumps.
Electric furnace to SEER 16 heat pump (at wear out)	Per home	$1,987	
Gas furnace to SEER 14 heat pump (at wear out)	Per home	$501	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). Includes cost to provide 240V electrical service to the air

6 https://www.acwholesalers.com/

Name	Cost Multiplier	Lifecycle Cost Per Unit ($Present Value)	Source
Gas furnace to SEER 16 heat pump (at wear out)	Per home	$962	handler. 16 vs 14 SEER costs based on AC Wholesalers cost research. Assumes replacement at 17.5 years for furnaces and 15 years for heat pumps.
SEER 14 heat pump to MSHP (at wear out)	Per home	$2,070	Base systems costs from 2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). MSHP costs based on technology demonstration projects with certain line-items removed to align cost components between the base and upgrade system costs. Assumes replacement at 17.5 years for furnaces and 15 years for heat pumps.
Gas furnace to MSHP (at wear out)	Per home	$2,571	
WATER HEATING			
Electric water heater to HPWH (at wear out)	Per home	$2,747	HPWH costs based on 2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). Electric water heater costs based on Home Depot cost research. Assumes replacement at 15 years.
0.69 to 0.82 EF condensing gas WH (at wear out)	Per home	$2,147	SupplyHouse and Ferguson online costs. Assumes replacement at 15 years.
Gas water heater to HPWH (at wear out)	Per home	$2,994	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). Includes cost to provide 240V electrical service to the HPWH location and condensate drain. Assumes replacement at 15 years.
Hot water pipe insulation	Conditioned floor area	$0.03/sqft	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). Assumes only 10% of the pipes are accessible and insulated. Costs assume that a contractor is onsite providing other related services, or the insulation is installed by the occupant. Hiring a contractor just to provide this service would be much more costly.
Low flow fixtures	Number of bedrooms	1 Bed - $72 2 Bed - $99 3 Bed - $126	Extrapolated from 2019 single family and multifamily retrofit reach code studies to differentiate costs based on number of bedrooms

Name	Cost Multiplier	Lifecycle Cost Per Unit ($Present Value)	Source
		4 Bed - $153 5 Bed - $179	((Statewide Reach Code Team, 2021), (Statewide Reach Code Team, 2022)).
APPLIANCES & LIGHTING			
ENERGY STAR clothes washer (at wear out)	Per home	$611	2022 RS Means, standard versus ENERGY STAR qualified, front loading, minimum cost basis. Assumes replacement at 14 and 28 years.
ENERGY STAR clothes dryer (at wear out)	Per home	$186	Home Depot cost research. Assumes replacement at 13 and 26 years.
ENERGY STAR dishwasher (at wear out)	Per home	$320	2022 RS Means, standard versus ENERGY STAR qualified products, minimum cost basis. Assumes replacement at 11 and 22 years.
ENERGY STAR refrigerator (at wear out)	Per home	$178	Home Depot cost research. Assumes replacement at 17.4 years.
Induction stove (at wear out)	Per home	$772 from electric range $1,192 from gas range	Home Depot cost research based on lowest cost induction stove and traditional gas/electric stove with similar features. Assumes replacement at 13 and 26 years.
LED lighting	Conditioned floor area + garage area	$0.07/sqft relative to CFL $-0.16/sqft relative to incandescent	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). LEDs are assumed to have a 30 year lifetime. CFL baseline assumes replacement at year 10 and 25. Incandescent baseline is more expensive due to frequent replacements every 2 years.

Commercial Buildings

Modeling Process

While NREL has been working on a similar version of ResStock for commercial buildings, called ComStock, it was not available within the timeframe of this project. Therefore, for the commercial building analysis the Team used DOE's OpenStudio tool. OpenStudio is an open-source collection of software tools developed by NREL and DOE that supports whole building energy modeling using EnergyPlus as the simulation engine. Graphical applications within OpenStudio include a SketchUp plug-in for modeling building geometry, the OpenStudio Application for developing mechanical systems and assigning building characteristics, and a ResultsViewer for visualizing results. The Parametric Analysis Tool enables studying the impact of applying multiple combinations of OpenStudio Measures. While OpenStudio can be used for all building types, it is most appropriate for commercial buildings. It is actively maintained and improved upon by NREL and its development team as well as by other software developers who contribute to the open-source code. Version 3.1.0 of OpenStudio and version 9.4 of EnergyPlus were used for the nonresidential modeling.

With the objective of developing one commercial prototype building to evaluate energy efficiency measures, the Team reviewed available data from the City of Santa Rosa Geographical Information System (GIS) website[7] and parcel data from the County of Sonoma website[8] to determine the predominant commercial building types and characteristics within SCP service territory. While the County of Sonoma data has a broader geographic coverage, it does not include building floor area, a critical datapoint to quantify how much total floor area is attributed to various occupancy types. The City of Santa Rosa data covers commercial and business park parcels within Santa Rosa, Cotati, Rohnert Park, Sebastopol, and Windsor and does include building floor area. While these cities do not represent the entirely of SCP territory, this dataset covers a substantial portion of it and is expected to be a reasonable indicator of the rest of the county. As a result, the City of Santa Rosa data was used for this evaluation. The data demonstrated that office buildings, retail buildings, and shopping centers represented roughly one-third of total commercial floor area within these cities. The office building category had the largest representation at 15 percent. Within this category, a little over half was represented by one- and two-story office buildings. Based on these data, a small office building was selected for this analysis. The DOE commercial prototype building models (Pacific Northwest National Laboratory, 2018) were reviewed and the most appropriate model was selected, the small office prototype. The small office prototype is 5,502 square foot, single

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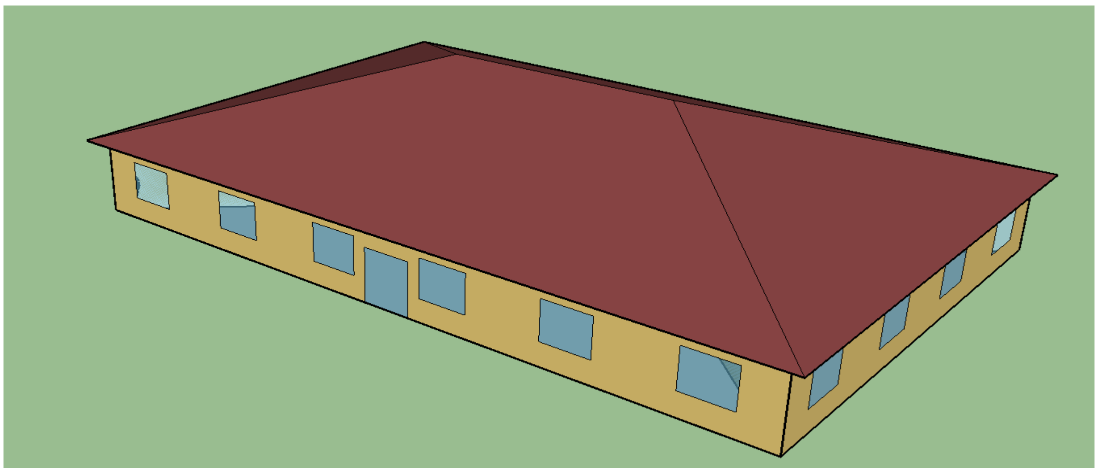
7 https://srcity.org/829/GIS-Maps-Documents

8 https://gis-sonomacounty.hub.arcgis.com/datasets/2202c1cd6708441f987ca5552f2d9659

story. This prototype also matches the small office prototype used by the CEC for Title 24, Part 6 code development. Figure 1 shows a graphical depiction of the prototype building and Figure 1 details key characteristics.

The prototype included five office spaces, one core space and four perimeter spaces. As provided by DOE and CEC, the prototype included five thermal zones and five HVAC systems. The Team evaluated cooling and heating loads and determined that the five zones could be condensed into two and accommodated by two commercial packaged units. The Team considered this a more realistic design than five separate HVAC systems for this size of building.

Figure 1: Small Office Prototype Image



Source: (Pacific Northwest National Laboratory, 2018)

Table 5: Office Building Prototype Base Characteristics

Building Type	Small office
Total Floor Area	5,500 square feet (90.8 ft x 60.5ft)
Number of Floors / Floor Height	Single-story, 10ft ceiling height.
Exterior Wall Framing	Wood framed
Exterior Roof Framing	4:12 pitched roof, wood framing. Suspended ceiling with acoustic tile.
Foundation	Slab on grade
Window Area	24.4% for South and 19.8% for the other three orientations 6.0 ft x 5.0 ft punch windows for all façades
HVAC	(2) 7.5 ton gas-electric packaged rooftop units (RTUs)
Water Heating	Gas storage, 40 gallon, 40,000 Btuh. Located inside.

Due to the large spread in the age of the existing building stock observed in City of Santa Rosa data, base characteristics of insulation level, window types, and equipment efficiencies were developed for two vintages of the office prototypes, one built under the first Title 24, Part 6 energy code of 1978 and another under the 1998 energy code. The building characteristics for the two vintages are listed in Table 6. These were based on design elements for which there was a specific non-residential building Title 24, Part 6 requirement. Otherwise, typical construction practices were assumed. The Team also reviewed the 2001 energy code, the code cycle after the 1998 cycle, and found that the requirements were very similar.

Table 6: Comparison of 1978 and 1998 Non-Residential Title 24, Part 6 Code Requirements

Building Element	1978 Code	1998 Code
Cooling Efficiency	11 EER, 3.84 COP (assumes 1 replacement)	11 EER, 3.84 COP
Economizer	No	Yes, controlled on dry bulb temperature
Heating Efficiency	Gas, 75% thermal efficiency	Gas, 75% thermal efficiency
HVAC Fan Efficiency	PSC fan motor, motor efficiency 60% and total efficiency 39%	PSC fan motor, motor efficiency 60% and total efficiency 39%
Water Heating System	Gas storage, 75% thermal efficiency	Gas storage, 78% thermal efficiency
Roof Insulation	R-11 cavity	R-19 cavity
Roof Type/Properties	Steep-sloped, asphalt roofing product, 0.10 reflectance, 0.85 emittance	Steep-sloped, asphalt roofing product, 0.10 reflectance, 0.85 emittance
Wall Insulation	R-11 cavity	R-15 cavity
Window U-factor / Solar Heat Gain Coefficient (SHGC)	Single pane, metal framed. 1.1 U-factor / 0.85 SHGC	Dual pane, metal framed. 0.77 U-factor / 0.62 SHGC
Lighting Power Density	1.6 W/ft^2	1.2 W/ft^2

Measures

A list of energy efficiency measures was determined for each prototype to determine optimal energy efficiency improvements. Measures were modeled within OpenStudio when possible; however, OpenStudio did not have the capabilities required in all cases and some measures were modeled directly within EnergyPlus. Table 7 summarizes the list of measures analyzed.

Table 7: Commercial Measure Descriptions

Name	Description	Affected Vintages
THERMAL ENVELOPE		

R-10 roof insulation	Apply R-10 above-deck roof insulation at time of roof replacement.	1978 & 1998
PCM	PCM added to top of dropped T-bar ceiling.	1978 & 1998
Wall insulation	R-13 blown-in fiberglass between studs.	1978
New windows	Replace windows with dual-pane Low-E model (0.30 U-factor, 0.23 SHGC).	1978
Low SHGC window film	Apply film to window interior surface, 0.53 SHGC, similar to 3M Prestige product. No change to U-factor.	1978
LIGHTING		
LED lighting	Reduced lighting power density to 0.65 W/ft^2 by replacing linear fluorescent tubes with LED tubes.	1978 & 1998
Occupancy controls	Install occupancy controls in all spaces, assuming 2 for each of the perimeter office zones and 3 for the core zone. Reduce lighting power density by 5% in those spaces.	1978 & 1998
Tubular skylights & daylighting controls	Install Solatube skylights, 0.32 U-factor, 0.25 SHGC, in conjunction with daylighting controls that turn off the indoor lights when sufficient daylighting from the skylights or windows is available. Spaced 10-15ft on center resulting in 24 skylights.	1978 & 1998
HVAC		
High efficiency packaged gas/electric RTU	Replace on burnout with high efficiency unit, 0.80 AFUE heating, 4.37 COP cooling. Base case assumes replacement with a standard efficiency gas/electric RTU, 0.80 AFUE heating, 3.99 COP cooling.	1978 & 1998
Standard efficiency packaged heat pump RTU	Replace on burnout with heat pump, heating COP = 3.3, cooling COP = 3.91. Base case assumes replacement with a standard efficiency gas/electric RTU, 0.80 AFUE heating, 3.99 COP cooling.	1978 & 1998
High efficiency packaged heat pump RTU	Replace on burnout with heat pump, heating COP = 3.5, cooling COP = 4.0. Base case assumes replacement with a standard efficiency gas/electric RTU, 0.80 AFUE heating, 3.99 COP cooling.	1978 & 1998
RTU Fan motor replacement	Replace RTU belt-drive blowers and PSC motors with direct-drive blowers with an electronically commutated motor (ECM). This was evaluated by increasing the motor efficiency to 82% and total efficiency to 53.3%.	1978 & 1998
SERVICE WATER HEATING		
Gas condensing tank EF 0.82	Upgrade gas water heater at burnout to condensing unit with 48 gal tank, 76,000 btu/h input rate, 0.88 UEF, 124 gal first hour rating, and 0.94 thermal efficiency. Base case assumed replacement with a minimum efficiency 50 gal gas water heater, 0.63 UEF.	1978 & 1998
Heat pump water heater	Upgrade gas water heater at burnout with 45 gal heat pump water heater, 3.75 UEF, 67 gal first hour rating. Base case assumed replacement with a minimum efficiency 50 gal gas water heater, 0.63 UEF.	1978 & 1998

Two of the measures are field-applied research and technology demonstration measures, which are highlighted in blue. The Team strived to apply OpenStudio and EnergyPlus modeling approaches that paralleled the way measures were implemented in the field to the maximum extent possible. The PCM measure was directly modeled in EnergyPlus. The PCM layer was applied above the acoustical tile of the dropped ceiling corresponding to the PCM manufacturer's specifications and performance data as well as the approach used at the test sites.

The tubular skylights and daylighting control measure could not be easily evaluated in OpenStudio or EnergyPlus with the existing base small office prototype with the dropped ceiling. This is because the skylight must pass through both the dropped ceiling layer and the roof layer in the model, the geometry for which was challenging to incorporate in the existing prototype. The Team altered the model to reflect a flat roof and eliminate the dropped ceiling. This change was applied to both the baseline and upgrade model for this measure only.

Cool roof coatings were considered but since the lifetime of a typical built-up asphalt roof is about 20 years, nearly all existing roofs would fall under the 2001 or 2005 codes which required an initial reflectance of 0.70, which based on 2008 code revisions equates to an aged reflectance of 0.55, not far below the current 0.63 reflectance requirement.

The dishmachine heat recovery and induction stove technology demonstration measures were also not evaluated for the small office prototype. These measures were not found to be good fits for a small office building because they are uncommon in office buildings, and are not heavily used if present.

Table 8 presents measure costs for each of the evaluated measures. Costs are presented as total incremental lifecycle costs over the 15-year analysis period. None of the measures were assumed to require replacement over this time period, therefore all of the costs presented are first costs.

Table 8: Commercial Measure Incremental Costs

Name	Unit Cost	Total Cost	Cost Sources & Notes
THERMAL ENVELOPE			
R-10 roof insulation	$2.02/ft^2 roof	$13,041	Based on cost research conducted as part of the 2022 CASE report on residential additions and alterations (Statewide CASE Team, 2020). Costs reflect material and labor for polyisocyanurate insulation.
PCM	$4.05/ft^2 ceiling	$22,283	Cost data from Lead Locally technology demonstrations.
Wall insulation	$2.14/ft^2 exterior wall	$6,485	2019 multifamily retrofit reach code report (Statewide Reach Code Team, 2022).
Replacement Low-E Windows	$45/ft^2 window	$27,018	2019 multifamily retrofit reach code study (Statewide Reach Code Team, 2022)
Low SHGC window film	$13.5/ft^2 window	$8,105	ClimatePro quote (3/9/2021) $12-15/ft2
Low SHGC & U-factor window film	$23.5/ft^2 window	$14,109	ClimatePro quote (3/9/2021) $22-25/ft2
LIGHTING			
LED lighting	$91.02 per 2-tube fixture	$8,840	Material cost for Maxlight G13LPNS lamp holder, bulb cost from 1000bulbs.com, ½ hr per fixture, labor rates from RS Means adjusted for location factor and inflation (97 fixtures & 194 bulbs)
Occupancy controls	$138.78 per switch	$1,527	Costs for three Lutron MS-OPS6-DDV-IV, labor costs based on ½ hr. per switch, labor rates from RS Means adjusted for location factor and inflation. 11 switches total.

Tubular skylights & daylighting controls	$2,671	$55,430	Technology Demonstration site, Engine is Red, per unit installed cost. Labor costs were reduced by 40% to reflect a learning curve by the installing contractor that is expected to improve in a mature market.
HVAC			
High efficiency gas/electric RTU	$2,100 per unit	$4,201	2022 RS Means and online cost research. High efficiency equipment costs assumed to be 30% higher than standard efficiency equipment.
Standard efficiency packaged heat pump	$1,051	$2,102	2022 RS Means and online cost research
High efficiency packaged heat pump	$2,888	$5,776	2022 RS Means and online cost research. High efficiency equipment costs assumed to be 30% higher than standard efficiency equipment.
RTU fan motor replacement	$7,810	$15,620	Q-PAC equipment quote plus 6 hours of labor per RTU.
SERVICE WATER HEATING			
Gas condensing tank EF 0.82	$2,147	$2,147	SupplyHouse and Ferguson online costs.
Heat pump water heater	$2,994	$2,994	2019 single family retrofit reach code study (Statewide Reach Code Team, 2021). Includes cost to provide 240V electrical service to the HPWH location and condensate drain.

2.3 Data Analysis

Outputs from the base case and upgrade simulations were used to calculate annual energy impacts including the following metrics

- Annual electricity savings
- Annual natural gas savings
- Annual propane savings (single family only)
- Annual greenhouse gas savings
- First year electricity cost savings
- First year natural gas cost savings
- First year propane cost savings (single family only)
- Present value (PV) of utility costs over the analysis period
- Net present value (NPV) of the upgrade

A customer-based lifecycle cost (LCC) approach was used to determine cost-effectiveness that values energy based upon estimated site energy usage and customer utility bill savings using today's electricity and natural gas utility tariffs and estimating total savings over the analysis period accounting for discount of future costs and energy cost inflation. A 30-year analysis period was applied for the single family buildings and a 15-year analysis period for the small office. These analysis periods follow the CEC's cost-effectiveness methodology for code change proposals to Title 24, Part 6.

To estimate utility impacts, the initial approach was to apply SCP tariffs to hourly energy use results from all the parametric simulations to calculate annual energy and gas utility costs. While hourly calculations were readily available for the small office analysis, it was more difficult to access the hourly energy use files for each simulation within ResStock, and all the intermediate simulation files had to be downloaded. With the large number of simulations, it was problematic to download these files and the Team experienced repeated problems trying to do so. As a result, annual results from the individual simulations were used to estimate utility cost impacts. Average residential tariff $/kWh and $/therm metrics were determined based on dozens of simulations and hourly utility calculations conducted by the Statewide Reach Codes Team as part of the 2019 retrofit reach code analysis (Statewide Reach Code Team, 2021). An average rate was determined separately for the inland and coastal regions, which have different baseline allowances due to different climate conditions. Average electricity rates were based on 2021 PG&E residential time of use (TOU) TOU-C tariff. These were then adjusted to account for energy inflation between 2021 and 2022 of 20% and minor differences between PG&E and SCP tariffs assuming CleanStart. Average natural gas rates, which were also based on 2021 PG&E residential G1 tariff, were adjusted to account for energy inflation of 16% between 2021 and 2022. Propane costs were based on the most recent national average cost data from the U.S. Energy Information Administration (U.S. Energy Informatoin Administration, 2021) from October 2021 through March 2022. Table 9 presents the average residential tariffs used in this study. The impacts of applying CARE rates are also discussed. Based on review of reach code simulations using hourly data to calculate utility costs for standard and CARE rates, the average annual bill impact is 40% lower total cost for both gas and electric using CARE rates.

Table 9: Residential Utility Tariffs

	Inland	**Coastal**
Electricity $/kWh	$0.3781	$0.3442
Natural Gas $/therm	$1.9327	$2.0632
Propane $/gallon	$2.7763	$2.7763

Because of the smaller volume of simulations conducted for the small office, hourly data was used to calculate utility costs. Utility costs for the small office were evaluated using 2022 PG&E/SCP small general service TOU B-1 tariff for electricity and 2022 PG&E small commercial G-NR1 tariff for natural gas. Utility rates were assumed to escalate over time, using assumptions from the California Public Utilities Commission (CPUC) 2021 En Banc hearings on utility costs through 2030 (California Public Utilities Commission, 2021a). Escalation rates through the remainder of the evaluation period were based on the escalation rate assumptions within the CEC's 2022 TDV factors (Energy + Environmental Economics, 2020). The present value (PV) of utility cost savings over the analysis period was calculated assuming these escalation rate assumptions and a discount rate of three percent. Net present value is calculated as the PV of the benefit (utility savings) less the PV of the incremental cost.

Cost-effectiveness is presented using NPV. Equation 1 demonstrates how this was calculated. If the net savings of a measure or package was positive, it was considered cost-effective. Negative savings indicate that the measure does not recoup the initial cost in a timely manner.

Equation 1

- $NPV\ Savings = PV\ of\ lifetime\ benefit - PV\ of\ lifetime\ cost$

The lifetime costs or benefits were calculated according to Equation 2.

Equation 2

$$PV\ of\ lifetime\ cost\ or\ benefit = \sum_{t=0}^{n} \frac{(Annual\ cost\ or\ benefit)_t}{(1+r)^t}$$

Where:

- *n* = analysis term in years. 30-years used for the residential analysis and 15-years for the commercial analysis.
- *r* = discount rate. Real discount of three percent used.
- *t* = year of analysis term from 0 to n

Greenhouse gas impacts were calculated using the CEC's long run marginal emissions factors that have been adopted for the 2022 Title 24, Part 6 code cycle (Energy + Environmental Economics, 2020). These don't differ for the climate regions evaluated in this study. The factors used in this analysis are presented in Table 10.

Table 10: Greenhouse Gas Emission Factors

	Factor
Electricity metric tons CO2-e/kWh	0.342
Natural Gas metric tons CO2-e/therm	12.888
Propane metric tons CO2-e/therm	13.905

CHAPTER 3: Modeling Results

3.1: Single Family Homes

Base Building Stock

The ResStock base dataset simulation results provided annual electricity and gas use by end use in addition to various characteristics of the simulation such as equipment sizing. These results were reviewed to understand the energy use spread and to compare energy use to other data sources. Figure 2 presents annual electricity use across the base dataset. Average and median home consumption were 10,144 kWh and 8,993 kWh, respectively, with 45 percent of the homes estimated to consume between 6,000 and 10,000 kWh annually. Energy use is compared to 2019 RASS data (DNV, 2022) for Climate Zones 1 (coastal) and 2 (inland). RASS data shows a mean annual consumption of 7,221 kWh, lower than the ResStock dataset. One reason the ResStock dataset may be higher is the long tail on the right side of the histogram with 10 percent of homes estimated to use greater than 16,000 kWh annually. The randomized occupant behavior applied in ResStock did not account for occupant intervention when utility bills reach a certain threshold. A typical occupant may compromise comfort by setting back the thermostat or using less hot water, for example, rather than pay a very high utility bill. This behavior is partially reflected in the ResStock approach given that the dataset is weighted towards average usage levels and thermostat setpoints, but not entirely. Seventy percent of the homes with estimated annual electricity use greater than 16,000 kWh had electric resistance heating; the high energy use was a result of high heating electricity use.

Figure 2: Histogram of Annual Electricity Use Across the ResStock Base Dataset

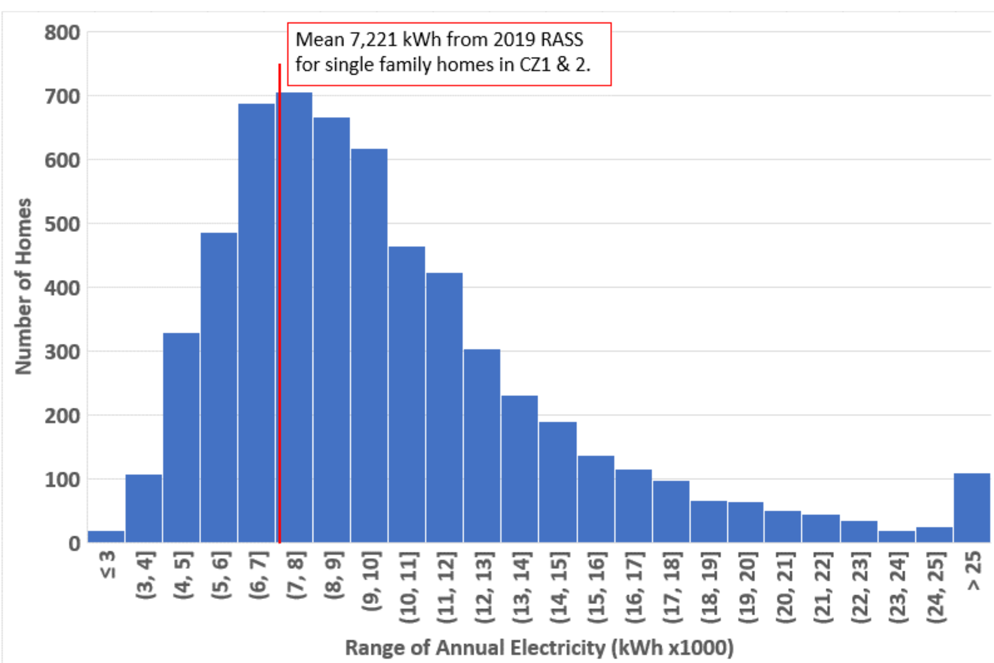
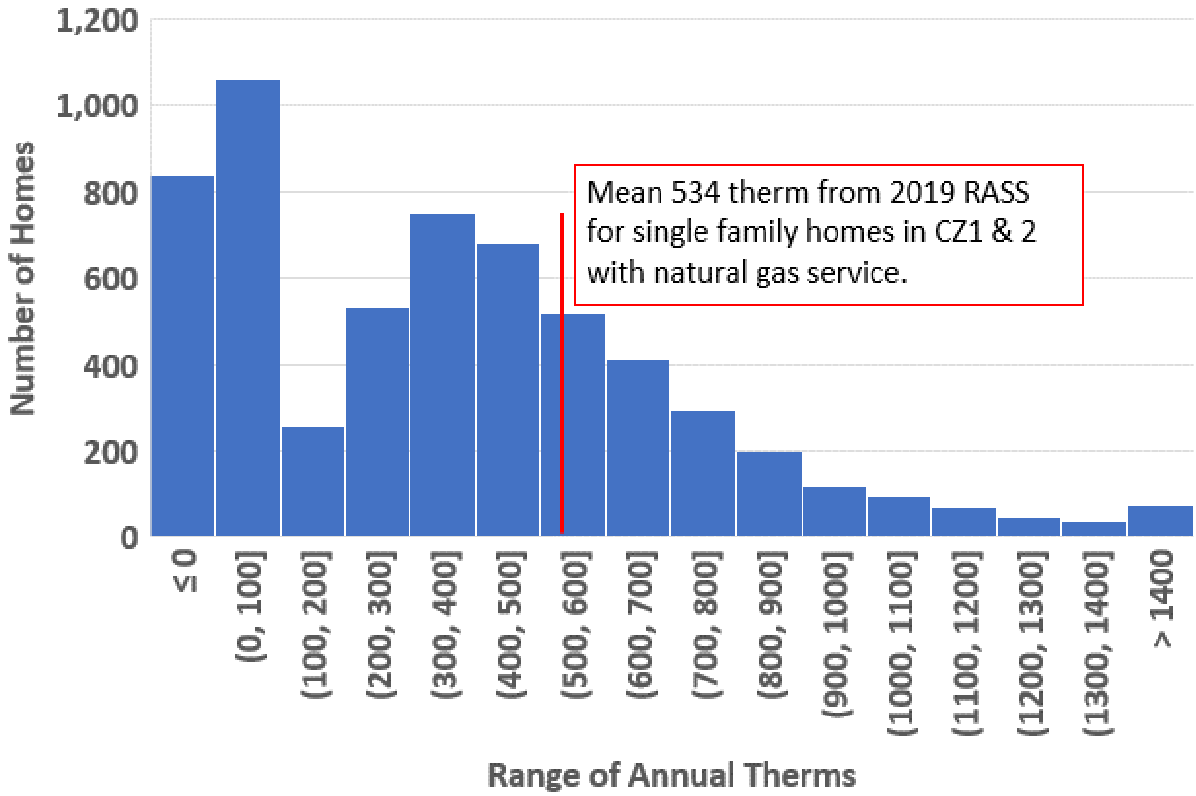


Figure 3 presents a similar comparison for annual natural gas use. Average home consumption from the ResStock base dataset for homes with natural gas service was 439 therms. 14 percent of homes were estimated to not have any gas loads, 18 percent were estimated to use less than 100 therms, and 41 percent were estimated to consume between 200 and 600 therms annually. The 2019 RASS data (DNV, 2022) shows a mean annual consumption of 534 therms, higher than the ResStock dataset.

Figure 3: Histogram of Annual Natural Gas Use Across the 6,000 Home Sample



Individual Measure Analysis

All measures that were applicable to a particular home were evaluated for that home as described in Table 3. This resulted in 10 to 26 measures being applied to each home in the ResStock base dataset. On average, for a given home 10 measures were found to be cost-effective. In general, older homes with inefficient envelopes and mechanical equipment as well as homes with higher use patterns (for example higher loads due to higher occupant densities, higher heating thermostat setpoints, or lower cooling thermostat setpoints) had a greater number of measures that were cost-effective. Newer homes or homes that have implemented efficiency upgrades already generally had fewer measures that were cost-effective. Figure 4 presents a breakdown of the number of measures evaluated and those found to be cost-effective across the ResStock base dataset.

Figure 4: Breakdown of Measures per Home

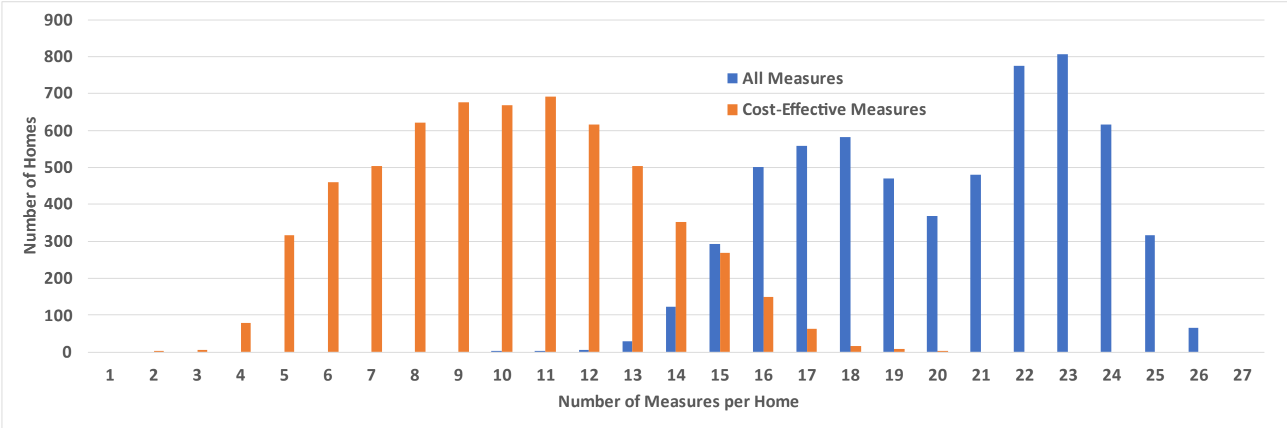


Table 11 summarizes the number homes in which each measure was evaluated and how many of those cases were found to be cost-effective. Ten measures were found to be cost-effective for 90 to 100 percent of the homes in which they were evaluated. These include heat pump upgrades, gas furnace efficiency upgrade, LED lighting, low-flow fixtures, and ENERGY STAR appliances. The worst performers, which were cost-effective in less than 10 percent of evaluated homes, included window upgrades, fuel substitution measures, induction stoves, and PCM.

Table 11: Residential Measure Statistics

Measure	Total Homes Evaluated	# of Cost-Effective Cases	% Cost-Effective
SEER 14 to 16 HP	60	60	100%
SEER 14 heat pump to MSHP	60	60	100%
LED lighting	6,000	5,988	100%
Low flow fixtures	6,000	5,980	100%
Electric furnace to SEER 14 HP	204	203	100%
Electric furnace to SEER 16 HP	204	203	100%
ENERGY STAR clothes dryer	2,520	2,495	99%
Gas furnace to MSHP	3,053	3,018	99%
ENERGY STAR refrigerator	6,000	5,729	95%
ENERGY STAR clothes washer	2,100	1,960	93%
80% to 96% AFUE furnace	3,011	2,717	90%
Electric WH to HPWH	1,571	1,392	89%
0.60 to 0.82 EF gas WH	3,776	3,142	83%
R-13 wall insulation	3,133	2,595	83%
SEER 14 to 16 AC	2,740	1,984	72%
Air sealing – manual	5,907	3,511	59%
Duct sealing	4,441	2,537	57%
R-49 attic insulation	5,440	3,026	56%
R-60 attic insulation	5,968	3,132	52%

Hot water pipe insulation	6,000	2,879	48%
Air sealing – Aerobarrier	5,907	2,354	40%
ENERGY STAR dishwasher	6,000	1,934	32%
Gas furnace to SEER 16 HP	3,053	788	26%
New ducts	5,707	1,446	25%
SEER 14 to 18 AC	2,740	348	13%
New windows	4,719	427	9%
Gas furnace to SEER 14 HP	3,053	273	9%
Gas WH to HPWH	3,776	94	2%
Induction stove	5,925	11	0%
PCM	5,007	0	0%

Table 12 presents average NPV, electricity savings, gas savings, and GHG savings of each measure for the homes where it was found to be cost-effective. These results are reported alongside the percent cost-effective data presented in Table 11. Grey highlighted cells represent the top 10 measures for each metric. There were eight measures that were in the top 10 for three of the four metrics. These measures were MSHP installations, replacing electric furnaces with heat pumps, attic insulation, R-13 wall insulation, and LED lighting. The measures with the highest kWh savings were heat pumps replacing electric furnaces, MSHPs replacing standard split heat pumps, heat pump water heaters replacing electric water heaters, and new windows. The measures with the highest GHG savings were heat pump installations replacing either gas or electric resistance space heating or water heating equipment.

Table 12: Average Annual Savings per Residential Measure

Measure	% Cost-Effective	Average NPV	Average Electricity Savings (kWh)	Average Gas Savings (therm)	Average GHG Savings (lbs CO2e)
SEER 14 heat pump to MSHP	100%	$15,989	2,263	0	774
SEER 14 to 16 HP	100%	$3,777	531	0	182
-5					
LED lighting	100%	$4,283	612	19	127
Low flow fixtures	100%	$2,840	174	0	357
Electric furnace to SEER 16 HP	100%	$65,095	7,653	0	2,618
Electric furnace to SEER 14 HP	100%	$60,530	7,075	0	2,421
345					
ENERGY STAR clothes dryer	99%	$2,099	291	-2	93
Gas furnace to MSHP	99%	$13,138	-827	10	4,165
ENERGY STAR refrigerator	95%	$979	168	64	23
ENERGY STAR clothes washer	93%	$1,704	188	-6	220
80% to 96% AFUE furnace	90%	$3,316	2	60	826
Electric WH to HPWH	89%	$8,081	1,496	109	328

0.60 to 0.82 EF gas WH	83%	$1,699	-5	0	773
R-13 wall insulation	83%	$10,754	653	30	1,930
SEER 14 to 16 AC	72%	$576	138	10	49
Air sealing – manual	59%	$2,044	144	50	528
Duct sealing	57%	$1,490	158	51	217
R-49 attic insulation	56%	$6,004	515	0.2	952
R-60 attic insulation	52%	$5,940	541	74	979
Hot water pipe insulation	48%	$40	8	3	6
Air sealing – Aerobarrier	40%	$4,622	452	435	1,397
ENERGY STAR dishwasher	32%	$473	73	34	65
Gas furnace to SEER 16 HP	26%	$2,228	-3,125	0	4,539
New ducts	25%	$2,792	487	25	741
SEER 14 to 18 AC	13%	$1,131	473	464	160
New windows	9%	$2,406	1,353	187	864
Gas furnace to SEER 14 HP	9%	$914	-3,585	0	4,759
Gas WH to HPWH	2%	$1,240	-982	0	2,070
Induction stove	0%	$242	-386	0	248
PCM	0%	n/a	n/a	n/a	n/a

Table 13 compares results for the three metrics, NPV, electricity savings, and GHG savings, and presents the top five measures for each metric. Measures highlighted in brown represent those that appear in two of the three categories and measures highlighted in blue appear in all three categories. The only measures that appear in all three are heat pump replacements for electric furnace.

Table 13: Top Five Measures Compared for Three Primary Metrics

	NPV	Electricity	GHG
1st	Electric furnace to SEER 16 HP	Electric furnace to SEER 16 HP	Gas furnace to SEER 14 HP
2nd	Electric furnace to SEER 14 HP	Electric furnace to SEER 14 HP	Gas furnace to SEER 16 HP
3rd	SEER 14 heat pump to MSHP	SEER 14 heat pump to MSHP	Gas furnace to MSHP
4th	Gas furnace to MSHP	Electric WH to HPWH	Electric furnace to SEER 16 HP
5th	R-13 wall insulation	New windows	Electric furnace to SEER 14 HP

Table 14 compares the percentage of evaluated homes where each measure was found to be cost-effective and the corresponding average NPV per home for the inland and coastal climates. In general, measures that save heating energy had greater savings in the coastal climate because of the higher heating loads. The coastal climate has very minimal, or no cooling load causing air conditioning measures to be much less cost-effective.

Table 14: Average NPV Savings per Residential Measure and Climate

Measure	Inland Climate (CZ2)	Coastal Climate (CZ1)

	% Cost-Effective	Average NPV	% Cost-Effective	Average NPV
SEER 14 heat pump to MSHP	100%	$14,703	100%	$25,721
SEER 14 to 16 HP	100%	$3,386	100%	$6,736
LED lighting	100%	$4,268	99%	$4,454
Low flow fixtures	100%	$2,776	99%	$3,590
Electric furnace to SEER 16 HP	100%	$59,351	98%	$86,471
Electric furnace to SEER 14 HP	100%	$54,921	98%	$81,401
ENERGY STAR clothes dryer	99%	$2,096	99%	$2,127
Gas furnace to MSHP	99%	$13,108	90%	$17,792
ENERGY STAR refrigerator	96%	$978	86%	$982
ENERGY STAR clothes washer	93%	$1,678	93%	$2,010
80% to 96% AFUE furnace	90%	$3,297	95%	$5,923
Electric WH to HPWH	88%	$7,785	94%	$10,819
0.60 to 0.82 EF gas WH	83%	$1,597	94%	$4,179
R-13 wall insulation	86%	$10,133	47%	$23,887
SEER 14 to 16 AC	78%	$578	5%	$127
Air sealing – manual	60%	$1,869	49%	$4,541
Duct sealing	59%	$1,431	36%	$2,642
R-49 attic insulation	57%	$5,987	41%	$6,278
R-60 attic insulation	54%	$5,921	40%	$6,228
Hot water pipe insulation	48%	$38	51%	$53
Air sealing – Aerobarrier	40%	$4,128	42%	$10,028
ENERGY STAR dishwasher	32%	$467	34%	$544
Gas furnace to SEER 16 HP	26%	$2,133	57%	$8,423
New ducts	25%	$2,584	25%	$5,222
SEER 14 to 18 AC	14%	$1,134	0%	$37
New windows	10%	$2,401	3%	$2,629
Gas furnace to SEER 14 HP	9%	$654	14%	$24,275
Gas WH to HPWH	3%	$1,246	1%	$671
Induction stove	0%	$242	0%	n/a
PCM	0%	n/a	0%	n/a

Table 15 compares the percentage of evaluated homes where the measure was found to be cost-effective and the corresponding average NPV per home for a standard tariff (presented in the tables above) and a CARE tariff. Utility costs under a CARE tariff are on average 40% lower than under standard tariffs. As a result, the NPV under the CARE tariff was lower in all cases and the percent of cases that are cost-effective is similarly lower. There are nuances with the CARE tariff that aren't seen here but would be reflected in hourly bill analysis. Previous analysis has shown that applying CARE tariffs improves cost effectiveness for fuel substitution measures because the gas and electric bills are impacted slightly differently (Statewide Reach Code Team, 2022).

Table 15: Average NPV Savings for CARE Tariff versus non-CARE Tariff

	Standard Tariff		CARE Tariff	
Measure	**% Cost-Effective**	**Average NPV**	**% Cost-Effective**	**Average NPV**
SEER 14 heat pump to MSHP	100%	$15,989	98%	$8,924
SEER 14 to 16 HP	100%	$3,777	95%	$2,196
LED lighting	100%	$4,283	100%	$2,508
Low flow fixtures	100%	$2,840	100%	$1,655
Electric furnace to SEER 16 HP	100%	$65,095	100%	$38,263
Electric furnace to SEER 14 HP	100%	$60,530	100%	$35,723
ENERGY STAR clothes dryer	99%	$2,099	98%	$1,195
Gas furnace to MSHP	99%	$13,138	94%	$7,199
ENERGY STAR refrigerator	95%	$979	78%	$634
ENERGY STAR clothes washer	93%	$1,704	81%	$917
80% to 96% AFUE furnace	90%	$3,316	80%	$1,894
Electric WH to HPWH	89%	$8,081	89%	$4,846
0.60 to 0.82 EF gas WH	83%	$1,699	35%	$1,017
R-13 wall insulation	83%	$10,754	76%	$5,519
SEER 14 to 16 AC	72%	$576	45%	$276
Air sealing – manual	59%	$2,044	36%	$1,171
Duct sealing	57%	$1,490	42%	$884
R-49 attic insulation	56%	$6,004	36%	$4,472
R-60 attic insulation	52%	$5,940	31%	$4,626
Hot water pipe insulation	48%	$40	27%	$22
Air sealing – Aerobarrier	40%	$4,622	17%	$2,944
ENERGY STAR dishwasher	32%	$473	22%	$265
Gas furnace to SEER 16 HP	26%	$2,228	20%	$1,266
New ducts	25%	$2,792	10%	$1,656
SEER 14 to 18 AC	13%	$1,131	3%	$652
New windows	9%	$2,406	1%	$1,137
Gas furnace to SEER 14 HP	9%	$914	5%	$716
Gas WH to HPWH	2%	$1,240	1%	$528
Induction stove	0%	$242	0%	$86
PCM	0%	n/a	0%	n/a

Table 16 presents the percent electricity savings of each measure to evaluate the potential for 10 percent savings within a home. 12 measures were found to achieve a minimum of 10 percent savings in at least 1 percent of the homes where the measure was cost-effective (see grey highlighted cases). Three measures were found to achieve an average savings of 10 percent in almost all homes where the measure was cost-effective (upgrading electric furnaces to heat pumps and upgrading electric resistance water heaters to heat pump water heaters). The lowest cost approach to meet 10 percent savings in homes for which these measures are applicable are LED lighting and ENERGY STAR refrigerators. Such savings for these measures are only available in homes that have not already implemented measures related to these end-uses. For example, homes that already have a certain number of LED lamps will not see 10 percent savings. The next lowest cost way to meet the savings goal is to target homes with an electric furnace and upgrade this to a heat pump.

Table 16: Summary of Percent Electricity Savings by Measure

Measure	Min.	Max.	Average	Percentage >10%	Average Cost
SEER 14 heat pump to MSHP	4%	34%	14%	72%	$2,070
SEER 14 to 16 HP	1%	8%	3%	0%	$460
LED lighting	0%	33%	7%	29%	$161
Low flow fixtures	-1%	16%	1%	0%	$130
Electric furnace to SEER 16 HP	5%	68%	31%	96%	$1,987
Electric furnace to SEER 14 HP	5%	67%	28%	95%	$1,487
ENERGY STAR clothes dryer	0%	12%	3%	0%	$186
Gas furnace to MSHP	-89%	13%	-10%	0%	$2,571
ENERGY STAR refrigerator	0%	25%	2%	3%	$178
ENERGY STAR clothes washer	-1%	9%	2%	0%	$611
80% to 96% AFUE furnace	-1%	2%	0%	0%	$840
Electric WH to HPWH	72%	99%	95%	100%	$2,747
0.60 to 0.82 EF gas WH	-2%	8%	0%	0%	$2,147
R-13 wall insulation	-4%	29%	4%	13%	$3,563
SEER 14 to 16 AC	0%	4%	1%	0%	$531
Air sealing – manual	-1%	11%	1%	0%	$1,675
Duct sealing	-1%	9%	1%	0%	$643
R-49 attic insulation	0%	45%	4%	8%	$2,240
R-60 attic insulation	0%	46%	4%	8%	$2,609
Hot water pipe insulation	0%	0%	0%	0%	$40
Air sealing – Aerobarrier	-4%	25%	3%	7%	$5,733
ENERGY STAR dishwasher	0%	4%	1%	0%	$320
Gas furnace to SEER 16 HP	-156%	2%	-35%	0%	$962
New ducts	0%	14%	4%	2%	$4,224
SEER 14 to 18 AC	1%	8%	4%	0%	$2,632
New windows	3%	24%	10%	38%	$10,550
Gas furnace to SEER 14 HP	-129%	-5%	-36%	0%	$501
Gas WH to HPWH	-24%	-2%	-9%	0%	$2,994
Induction stove	-10%	1%	-4%	0%	$23
PCM	0%	0%	0%	0%	n/a

Table 17 presents average heating and cooling thermostat setpoints for the cases where each measure was found to be cost-effective and those where it was not found to be cost-effective. Highlighted in gray are the cases where the thermostat setpoint appears to be a significant driver of cost-effectiveness with a difference between the two averages greater than or equal to 2°F. Almost all of the envelope and HVAC upgrade measures demonstrated a dependency on thermostat setpoint, where higher heating and cooling loads driven by comfort requirements resulted in greater energy savings and cost-effectiveness. For compliance with the Title 24, Part 6 code via the performance path, the 2019 Residential Alternative Calculation Method (ACM) Reference Manual (CEC, 2019) references a heating setpoint of 68°F (gas furnaces are modeled with a nighttime setback of 65°F). The ACM references a cooling setpoint of 78°F with a daytime setup to between 79°F and 83°F.[9] In general, the setpoints found in this study to yield cost-effective results for measures were lower in cooling and higher in heating than what is assumed for the Title 24, Part 6 code.

Table 17: Average Thermostat Setpoints by Measure

	Average Heating Thermostat Setpoint (°F)			Average Cooling Thermostat Setpoint(°F)		
Measure	**Cost-Effective**	**Not Cost-Effective**	**Diff.**	**Cost-Effective**	**Not Cost-Effective**	**Diff.**
SEER 14 heat pump to MSHP	69	n/a	n/a	73	n/a	n/a
SEER 14 to 16 HP	69	n/a	n/a	73	n/a	n/a
LED lighting	68	70	-1.4	73	74	1.5
Low flow fixtures	68	70	-1.6	73	73	0.2
Electric furnace to SEER 16 HP	69	59	9.8	73	76	3.4
Electric furnace to SEER 14 HP	69	59	9.8	73	76	3.4
ENERGY STAR clothes dryer	68	69	0.0	73	73	0.1
Gas furnace to MSHP	68	60	8.1	73	78	5.4
ENERGY STAR refrigerator	68	71	-2.7	73	73	0.4
ENERGY STAR clothes washer	69	68	0.4	73	73	0.3
80% to 96% AFUE furnace	69	63	6.4	73	74	0.6
Electric WH to HPWH	70	68	1.6	74	76	1.8
0.60 to 0.82 EF gas WH	68	70	-2.2	73	74	1.0
R-13 wall insulation	69	67	1.8	73	73	0.2
SEER 14 to 16 AC	69	68	0.6	72	76	4.7
Air sealing – manual	70	66	3.8	73	73	-0.1
Duct sealing	69	68	1.3	73	73	0.6
R-49 attic insulation	70	67	2.5	73	73	0.0
R-60 attic insulation	70	67	2.7	73	73	0.1
Hot water pipe insulation	68	69	-1.1	73	73	0.8

9 The thermostat cooling setpoint is changing for the 2022 Title 24, Part 6 code to a fixed value of 78°F.

Air sealing – Aerobarrier	71	67	4.0	73	73	-0.4
ENERGY STAR dishwasher	68	68	0.0	73	73	0.2
Gas furnace to SEER 16 HP	68	68	-0.4	71	74	2.3
New ducts	70	68	2.4	72	73	1.0
SEER 14 to 18 AC	68	69	-0.5	69	74	4.7
New windows	71	68	2.3	71	73	2.2
Gas furnace to SEER 14 HP	69	68	1.1	70	73	2.9
Gas WH to HPWH	63	69	-5.2	70	73	2.9
Induction stove	72	68	3.6	74	73	-1.1
PCM	n/a	68	n/a	n/a	73	n/a

Across SCP Territory

Table 18 presents total potential savings across the SCP territory if a measure was applied in all homes where it was found to be cost-effective. While it's not practical to assume such a large magnitude of upgrades is likely, this analysis does indicate where the largest opportunities lie. The measures which resulted in the highest NPV were replacing gas furnaces with MSHPs, wall and attic insulation, and replacing electric furnaces with heat pumps. The same measures also captured the greatest electricity savings except for the gas furnace replacement which increased electricity consumption but had the highest GHG savings potential. The next highest GHG savings measures were R-13 wall insulation, replacing gas furnaces with heat pumps, Aerobarrier air sealing, and R-60 attic insulation.

The measures were not always mutually exclusive of one another and as a result the savings cannot be considered additive. For example, in some homes replacing the gas furnace with either a standard split heat pump or a MSHP was cost-effective. The impacts of both scenarios are captured in the Table 18 results. Also, interactive effects of measures were not accounted for. For example, improving the building envelope decreased the heating and cooling loads and therefore reduces the savings from HVAC equipment upgrade measures.

Recall that hot water pipe insulation, low flow fixtures, and appliance and lighting measures were not evaluated across SCP territory because of limited data on what percent of the population would be impacted by these upgrades.

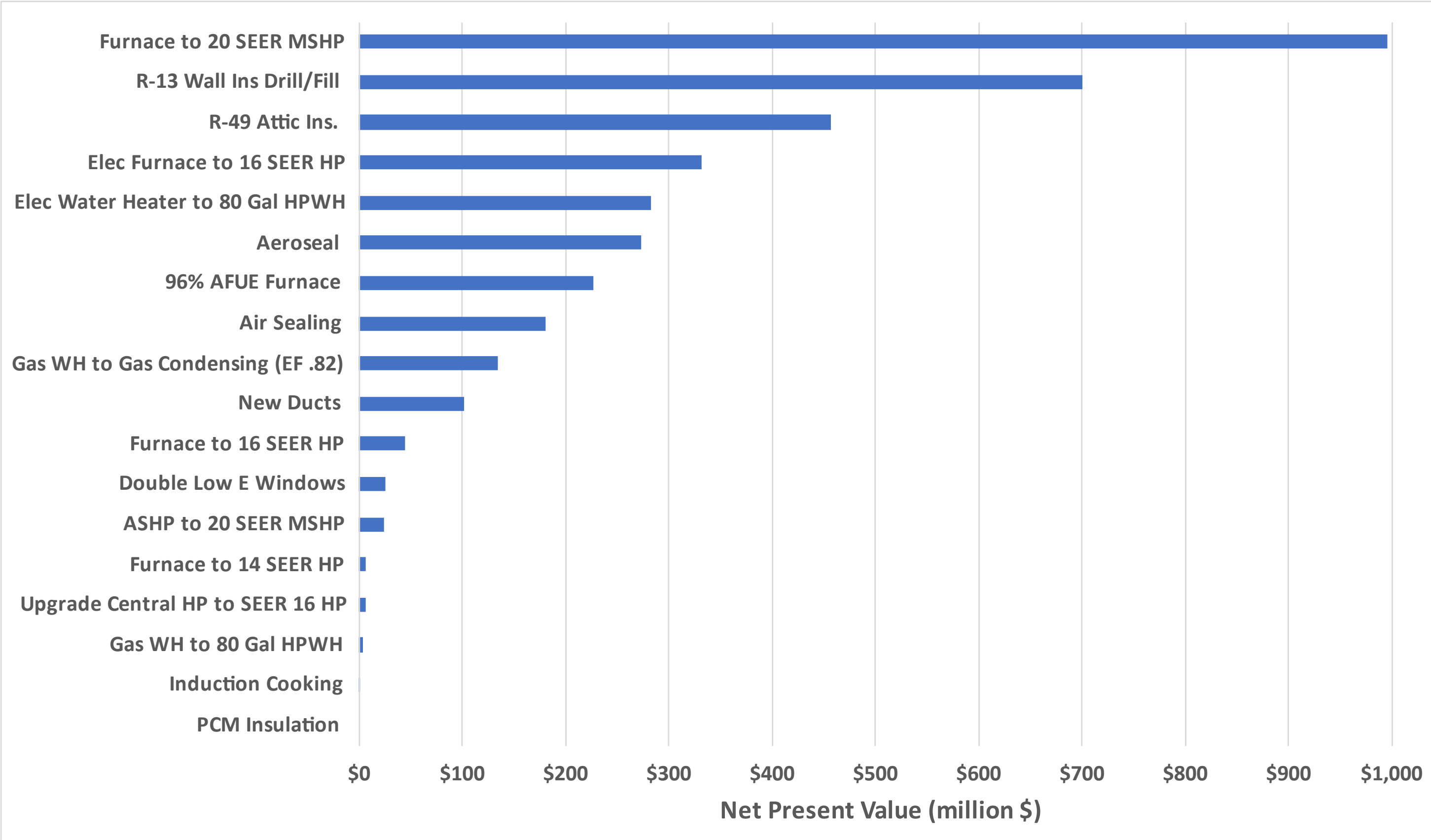
Table 18: Total Savings and Impacts by Measure across SCP Service Territory

Measure	Total NPV (million $)	Electricity Savings (GWh)	Gas Savings (Mbtu)	GHG Savings (metric tons x10^3)	Total Cost (million $)
Gas furnace to MSHP	$994.82	-62.63	104,164	143.10	$194.70
R-13 wall insulation	$700.16	42.50	168,580	57.02	$231.99
R-60 attic insulation	$466.78	42.52	93,433	34.90	$205.02
R-49 attic insulation	$455.87	39.14	87,271	32.80	$170.10
Electric furnace to SEER 16 HP	$331.55	38.98	-1	6.05	$10.12
Electric furnace to SEER 14 HP	$308.30	36.04	-1	5.59	$7.57

Electric WH to HPWH	$282.25	52.25	-26,730	5.20	$95.94
Air sealing – Aerobarrier	$272.99	26.71	137,529	37.44	$338.61
80% to 96% AFUE furnace	$226.05	0.14	17,400	25.55	$57.26
Air sealing – manual	$180.03	12.69	69,144	21.11	$147.59
0.60 to 0.82 EF gas WH	$133.92	-0.41	19,321	27.65	$169.24
New ducts	$101.29	17.67	40,641	12.20	$153.26
Duct sealing	$94.83	10.04	16,474	6.28	$40.95
Gas furnace to SEER 16 HP	$44.06	-61.78	34,288	40.71	$19.02
SEER 14 to 16 AC	$28.65	6.85	194	1.10	$26.45
New windows	$25.78	14.49	7,455	4.20	$113.03
SEER 14 heat pump to MSHP	$24.07	3.41	0	0.53	$3.12
SEER 14 to 18 AC	$9.87	4.13	-4	0.63	$22.98
Gas furnace to SEER 14 HP	$6.26	-24.55	12,679	14.79	$3.43
SEER 14 to 16 HP	$5.69	0.80	0	0.12	$0.69
Gas WH to HPWH	$2.92	-2.31	1,755	2.22	$7.06
Gas WH to 50gal HPWH	$1.71	-0.99	964	1.26	$6.04
Induction stove	$0.07	0.02	53	0.01	$0.21
PCM	$0.00	0.00	0	0.00	$0.00

Figure 5 presents the total NPV results from Table 18 graphically. This visibly demonstrates the potential across the various measures.

Figure 5: Total NPV Across All Measures

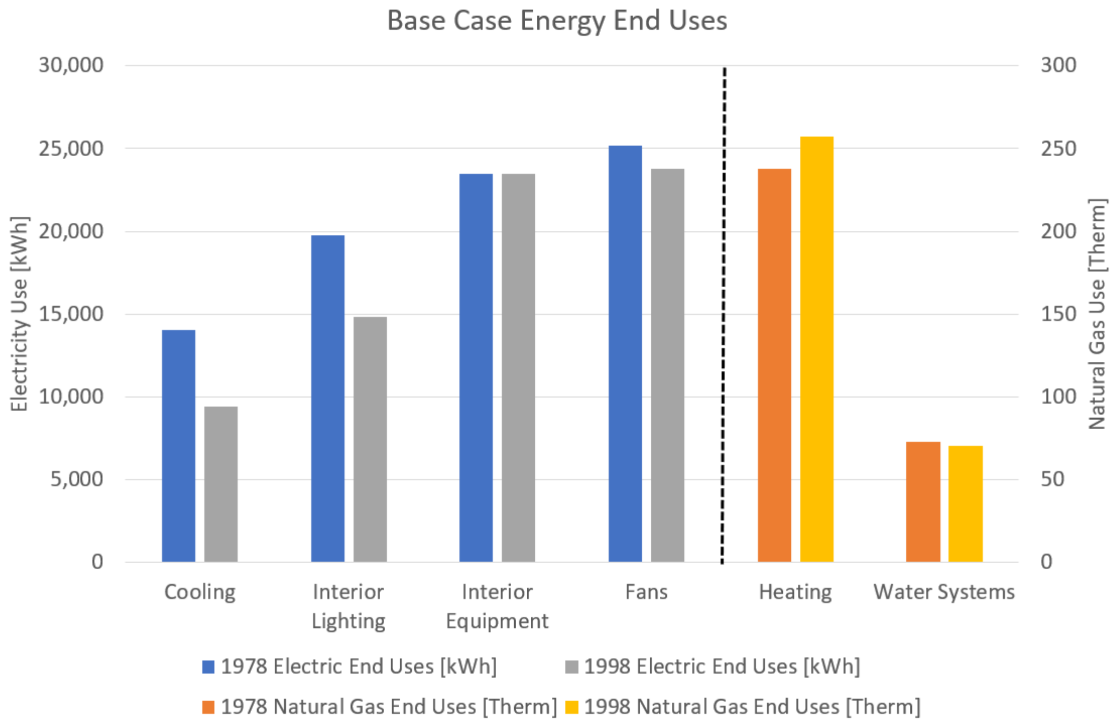


3.2: Commercial Buildings

Baseline Energy Use

Figure 6 presents results of the baseline energy simulation for the two office prototypes comparing electricity and gas by end-use. Total annual energy use is 94,538 kWh and 310 therms for the 1978 prototype and 83,584 kWh and 328 therms for the 1998 prototype.

Figure 6: Office Prototype Annual Base Case Energy Use by End-Use



The Title 24, Part 6 thermostat heating and cooling setpoints for offices were used in the analysis and are described in Table 19. The primary heating setpoint was 70°F and was set back to 60°F overnight and on Sundays and holidays. The primary cooling setpoint was 75°F and was set back to 85°F overnight and on Sundays and holidays. The primary setpoints were maintained through midnight on weekdays which may be realistic for some office buildings, but not all. The Title 24 schedules also have the cooling and heating available year round. The impact of this is cooling energy use in the winter months, which can occur in internally loaded buildings where natural ventilation, or opening of windows, is not or cannot be used.

Table 19: Office Thermostat Setpoint Schedule for Heating and Cooling

Hour	Weekday Temp [°F]		Saturday Temp [°F]		Sunday/Holiday Temp [°F]	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
12am-5am	60	85	60	85	60	85
5am-7pm	70	75	70	75	60	85
7pm-12am	70	75	60	85	60	85

Measure Analysis

Fifteen efficiency measures were evaluated for the office prototype. Table 20 presents results for the envelope measures, including electricity, gas and total utility cost savings, incremental cost, and resultant NPV. The only envelope measure found to be cost-effective was new windows in the older 1978 prototype with existing single pane windows. For both window measures there were electricity savings but an increase in gas use as a result of lower SHGC reducing passive solar gains into the space and consequently increasing heating energy use. The increase in gas use resulted in a slight increase in estimated GHG emissions for the window film measure, while the new window measure still saw a decrease in estimated GHGs due to the measure's higher electricity savings.

After the new windows, the next measure that was closest to being cost-effective was R-13 wall insulation. While gas savings were substantial (45%), cooling electricity use slightly increased. This phenomenon is due to reduced free cooling benefit during cool evenings. In some cases, improving envelope performance in climates such as this inland region (Climate Zone 2), where summer days are warm and evenings are cool, can trap heat from internal gains in buildings with a high density of equipment and people. This can also occur during warmer winter days. This can often be overcome by natural ventilation, i.e. opening of windows by occupants, or be economizer systems. However, the assumptions in the model were conservative and assumed limited window operation. In a building where it's acceptable to open windows, if occupants open them in the mornings when it's cool and during any occupied cool evenings, cooling savings for improved wall insulation may be positive. This behavior could also further improve the already positive GHG savings seen in the insulation measures.

The PCM measure resulted in higher electricity use and gas use, which was observed for a portion of the residential results as well. Office buildings are not an ideal application of PCM, which would likely perform better in applications with large internal gains during the day, such as restaurants.

Table 20: Commercial Envelope Measure Results

Measure	Vintage	Elec Savings (kWh)	Gas Savings (therms)	GHG Savings (lbs CO2e)	Year 1 Utility Cost Savings	Incremental Cost	NPV
R-13 wall	1978	(685)	248	2,964	$222	$6,485	($2,185)
R-10 roof insulation	1978	1,750	27	943	$675	$13,041	($3,815)
	1998	949	44	891	$417	$13,041	($7,192)
PCM	1978	(1,390)	(7)	(572)	($468)	$22,283	($28,627)
	1998	(1,205)	(12)	(571)	($429)	$22,283	($28,125)
Window film	1978	2,760	(74)	(7)	$831	$15,010	($4,211)
	1998	1,049	(31)	(45)	$309	$15,010	($11,008)
New windows	1978	6,587	(29)	1,874	$2,228	$27,018	$2,828
	1998	3,854	(14)	1,133	$1,317	$27,018	($9,354)

Table 21 presents results for the lighting measures. All of the cases were cost-effective with the exception of the skylight and daylighting measure in the 1998 building. Lighting was the third largest electricity end-use in the office building, after interior equipment and fans. Measures that reduce the total lighting load or reduce operating hours result in significant reductions in electricity use for both lighting and cooling. The LED lighting measures had the highest NPV savings across all the measures evaluated in this study. Despite the slight increases in gas use, all lighting measures saw high GHG savings in addition to high NPV savings.

Table 21: Commercial Lighting Measure Results

Measure	Vintage	Elec Savings (kWh)	Gas Savings (therms)	GHG Savings (lbs CO2e)	Year 1 Utility Cost Savings	Incremental Cost	NPV
Occupancy controls	1978	2,103	(31)	326	$671	$1,527	$7,342
	1998	892	(5)	237	$294	$1,527	$2,404
LED lighting	1978	15,614	(115)	3,860	$5,111	$8,840	$59,357
	1998	8,176	(53)	2,119	$2,690	$8,840	$27,098
Skylights & daylighting	1978	12,779	(46)	3,781	$4,273	$55,430	$1,859
	1998	9,935	(46)	2,813	$3,310	$55,430	($11,109)

HVAC measure results are presented in Table 22. Fan electricity was the second largest end-use in the office behind interior equipment. Even though the incremental cost for the ECM motor replacements was high, this measure had a positive NPV over the 15-year analysis period. The high-efficiency RTU was cost-effective for the older vintage prototype but not the newer. Converting from a gas RTU to a standard or high-efficiency heat pump increased electricity use but decreased gas use, resulting in net positive utility cost savings for the 1978 prototype but an increase in utility costs for the 1998 prototype. Neither measure was found to be cost-effective, however both saw high GHG savings as a result of the large drop in gas use. A smaller, but significant decrease in GHG emissions was seen in the two other HVAC measures as well.

Table 22: Commercial HVAC Measure Results

Measure	Vintage	Elec Savings (kWh)	Gas Savings (therms)	GHG Savings (lbs CO2e)	Year 1 Utility Cost Savings	Incremental Cost	NPV
Replace RTU fan motor	1978	7,955	(67)	1,857	$2,587	$15,620	$18,851
	1998	6,886	(70)	1,455	$2,220	$15,620	$13,906
High-efficiency RTU	1978	2,011	(23)	390	$674	$4,201	$4,754
	1998	785	0	269	$292	$4,201	($273)
Heat pump RTU	1978	(1,244)	223	2,450	$43	$2,102	($329)
	1998	(2,184)	257	2,566	($225)	$2,102	($3,753)
High-efficiency heat pump RTU	1978	(750)	223	2,619	$213	$5,776	($1,712)
	1998	(1,899)	257	2,664	($129)	$5,776	($6,135)

Finally, results for the two water heating measures are presented in Table 23. Water heating loads were a small component of total building energy use and neither of these measures were found to be cost-effective. Building types that require more hot water, such as restaurants and motels, would likely yield more favorable results.

Table 23: Commercial Water Heating Measure Results

Measure	Vintage	Elec Savings (kWh)	Gas Savings (therms)	GHG Savings (lbs CO2e)	Year 1 Utility Cost Savings	Incremental Cost	NPV
Gas condensing	1978	0	20	252	$30	$2,147	($1,663)
	1998	0	1	17	$2	$2,147	($2,113)
HPWH	1978	(509)	73	763	($60)	$2,994	($3,474)
	1998	(949)	71	593	($212)	$2,994	($5,528)

CHAPTER 4: Summaries and Recommendations

4.1: Single Family Homes

Measure Summary

Key findings by measures category are discussed below:

Wall Insulation

This measure adds R-13 wall insulation using "drill and fill" techniques to a previously uninsulated wall. For the homes where this measure was evaluated, 83% of the cases were found to be cost-effective, providing a clear signal that in most homes with uninsulated walls this measure is an effective measure to recommend. This measure was found to be similarly impactful in both the inland and coastal climates; the average measure NPV per home is larger in the coastal climate, but the number of affected homes is significantly higher in the inland climate which has a larger population. This measure is only applicable to older homes built before the Title 24, Part 6 code was enacted in 1978 requiring minimum insulation levels in walls. It was estimated based on RASS data that about half of the home population in SCP territory has uninsulated walls, representing a significant opportunity.

Attic Insulation

Adding attic insulation to meet both R-49 and R-60 total levels was evaluated. Across all homes the R-49 and R-60 upgrades were found to be cost-effective 56% and 52% of the time, respectively. Table 24 presents this breakdown based on the existing home attic insulation levels. For homes with existing attic insulation less than R-19 it was found to be cost-effective about three quarters of the time. With R-19 or above the measure cost-effectiveness was more dependent on other factors, such as heating and cooling thermostat setpoints. Results were reasonably consistent across the two climate regions.

Both measures were evaluated on a majority of the ResStock base dataset since many existing homes have inadequate levels of attic insulation. On a hot day, a typical vented attic is hotter than outside and if poorly ventilated the temperature difference between the attic and outdoors can be as high as 45°F (Less, Walker, & Levinson, 2016). Heat loss or gain through the ceiling is a significant portion of total heating and cooling loads in homes with little or no insulation in the attic. Compared to other envelope assemblies in an existing home, such as walls, attics are a relatively accessible area and less expensive to insulate.

Table 24: Percent of Homes Where Attic Insulation is Cost-Effective Based on Existing Attic Insulation Levels

Existing Home Insulation Level	R-49 Upgrade Cost-Effective	R-60 Upgrade Cost-Effective
Uninsulated	90%	90%
Ceiling R-7	88%	87%

Ceiling R-13	77%	74%
Ceiling R-19	60%	57%
Ceiling R-30	26%	29%
Ceiling R-38	n/a	21%

PCM

Adding PCM in contact with the ceiling insulation in the attic was not found to be cost-effective in any case. Energy savings were marginal in most cases and insufficient to overcome the high incremental cost at $6.59 per square foot of ceiling area. The analysis results shows that the cost would need to be reduced significantly to around $0.40 per square foot to be cost-effective in roughly half of the modeled homes that had positive energy savings. PCM has load shifting benefits that aren't captured in this analysis because annual energy use and average utility rates were used to estimate utility bill savings. Annual utility bill savings evaluated on an hourly basis with a time-of-use rate are expected to be higher than what was estimated, but not enough to be cost-effective based on the current costs. In 11% of cases there was a marginal increase in energy use, largely driven by a reduction in free heating from the attic on cold, sunny days. Modeling was done with the PCM located underneath the ceiling insulation; however, the Team expects similar conclusions for PCM located above the ceiling insulation based on the PCM applied research study conducted for Lead Locally.

Windows

This measure installs new windows replacing existing older single and dual pane products. Average electricity savings were 10%. Window replacements are a costly upgrade, and this was only found to be cost-effective on 9% of the homes evaluated. Table 25 presents this breakdown based on the existing window type. The percentage of cost-effective cases increases to 23% when the existing building had poor performing single pane, metal-framed windows. Cost-effectiveness of this upgrade was found to be reasonably dependent on thermostat setpoint with the average difference in setpoints between cases that were and were not cost-effective greater than 2°F for both heating and cooling. This measure did not perform as well in the coastal climate, which may partially be a result of the low SHGC in the measure case. A more appropriate window for this heating dominated climate would likely have a low U-factor and medium to high SHGC, 0.35 to 0.50.

Table 25: Percent of Homes Where New Windows are Cost-Effective Based on Existing Window Type

Existing Home Windows	New Dual, Low-E Windows Cost-Effective
Clear, Single, Metal	23%
Clear, Single, Non-metal	8%
Clear, Double, Metal, Air	9%
Clear, Double, Non-metal, Air	0%

Air Sealing

Manual air sealing and aerosol sealing with Aerobarrier were both evaluated. Average NPV per home for Aerobarrier in cost-effective applications was over twice the value for the manual air sealing. Aerobarrier is more expensive but is expected to achieve more consistent sealing performance. Across all homes the manual air sealing and Aerobarrier upgrades were found to be cost-effective 59% and 40% of the time, respectively. A reduction in air infiltration of 60% was estimated for this study where the manual sealing was estimated to achieve a 20% reduction on average. Table 26 presents the breakdown of how often the two measures were found to be cost-effective based on the existing infiltration level. With very leaky homes 10 ACH50 or above one or both of the two air sealing methods was found to be cost-effective at least half of the time.

Table 26: Percent of Homes Where Air Sealing is Cost-Effective Based on Existing Infiltration Levels

Existing Home Infiltration Level	Manual Cost-Effective	Aerobarrier Cost-Effective
20 ACH50	76%	64%
15 ACH50	72%	53%
10 ACH50	55%	30%
8 ACH50	38%	16%
7 ACH50	32%	15%
6 ACH50	37%	14%
5 ACH50	19%	9%

In both cases average NPV was much higher for the coastal climate than the inland climate. The coastal climate is heating dominated with higher heating loads which result in greater heating energy savings. The inland climate has hot summer days and cool nights. These conditions coupled with air sealing can result in increased energy use due to reduced "free cooling" from air infiltration overnight. This increase in energy use can easily be overcome by occupants opening the windows when it's cooler outside. Additionally, air sealing has many other benefits, including reducing drafts, improving indoor air quality under conditions where outdoor air quality is poor, and improving envelope durability that were not quantified within this analysis, and the measure should be recommended for most homes.

HVAC Equipment

All of the HVAC equipment measures were evaluated at the end of the life of the existing equipment. Five categories of upgrades were evaluated and are individually discussed below.

Upgrade air conditioner (16 and 18 SEER)

These measures upgrade a SEER 14 replacement air conditioner with a higher efficiency product, either 16 or 18 SEER. The 16 SEER upgrade was found to be cost-effective 72% of the time but the 18 SEER only 13% of the time. The cost-effectiveness of this measure was highly dependent on the cooling thermostat setpoint with the average setpoint for the cost-effective scenarios 69°F to 72°F and the average setpoint when not cost-effective 74°F to 76°F. It's also highly dependent on location and is generally not a cost-effective measure in the cooler coastal regions. When the air conditioner is the only piece of equipment that needs to be replaced, in inland regions a SEER 16 air conditioner can be recommended as cost-effective under most scenarios.

Upgrade gas furnace (96 AFUE)

This measure upgrades an 80% AFUE gas furnace to a 96% AFUE condensing gas furnace. This upgrade was found to be cost-effective at least 90% of the time in both the coastal and inland regions. The cost-effectiveness of this measure is highly dependent on the heating thermostat setpoint with the average setpoint for the cost-effective scenarios 69°F and the average setpoint when not cost-effective 63°F. When the furnace and air handler is the only piece of equipment that needs to be replaced, a condensing furnace can be recommended as cost-effective under most scenarios.

Upgrade heat pump (16 SEER split and MSHP)

These measures upgrade a SEER 14, 8.2 HSPF replacement heat pump with a higher efficiency product, either 16 SEER, 9.0 HSPF standard split or a ducted 20 SEER, 11.5 HSPF MSHP. Both upgrades were found to be cost-effective in all cases. When an existing heat pump is being replaced, a higher efficiency split product or MSHP can be recommended as cost-effective under most scenarios. The MSHP upgrade has the potential for much higher energy savings and meets the 10% electricity savings target with average savings of 14%. While field testing has shown good performance from MSHPs, modeling can overestimate energy savings by predicting a higher percentage of operation at lower speeds resulting in lower seasonal performance under real-world conditions than what is estimated by the models (Miller, Wilcox, & Conant, 2020). MSHPs require trained installers to ensure that the systems are designed, installed, and commissioned properly, including properly sizing equipment and ductwork. Yet, MSHPs are quickly gaining market share in California and the CEC has been working with manufacturers to ensure a minimum level of performance from products while providing a reasonable level of credit under the Title 24, Part 6 energy code.

Replace gas furnace with a heat pump (14 and 16 SEER split and MSHP)

These measures replace a furnace and air conditioner with a SEER 14 or SEER 16 standard split heat pump or a ducted 20 SEER, 11.5 HSPF MSHP. The two standard split upgrades were only found to be cost-effective in 26% of cases for the 14 SEER and 9% for the 16 SEER. However, the MSHP upgrade was cost-effective in 99% of cases. It was also estimated to have the greatest impact on GHG savings across SCP territory. Fuel substitution equipment typically has a slightly higher incremental costs due to added costs for providing electrical infrastructure to the equipment location. These costs can be eliminated by using equipment without electric resistance backup heating. Utility costs were also higher in some instances even though efficiency is higher, because of the relative electricity versus gas tariffs. However, these measures provide significant GHG savings, as is the case with all three of these upgrades and are being considered by many state and local governments as a strategy to meet climate goals. These measures apply to a large portion of SCP territory because ducted gas furnaces are the most common HVAC system type. The same considerations mentioned about MSHPs in the above section apply here as well.

This work did not evaluate the costs to upgrade to a heat pump when there is no existing air conditioning and no plan to install air conditioning. Past work by the Team has found that the additional cost of the heat pump when compared to a baseline with a furnace replacement only is significant and is not justified by heating energy savings alone. Utility programs that encourage fuel substitution may want to consider how they can support this portion of the population with incentives.

Replace electric furnace with a standard split heat pump (14 and 16 SEER)

These measures replace an existing ducted electric resistance furnace and air conditioner with either a 14 or 16 SEER heat pump. Both upgrades were found to be cost-effective in all cases. Average electricity savings were 28% to 31% of total electricity. Electric furnaces are very costly to operate, particularly in the colder coastal climates, making heat pumps very cost-effective. As a result, the 2022 Title 24, Part 6 code includes a new requirement that requires heat pumps to be installed when a ducted electric resistance furnace and air conditioner are replaced in most areas throughout California, including in all of SCP territory. Electric furnaces are only estimated in 3% of existing homes in SCP territory and therefore the potential community-wide impact is less.

Other strategies

Hydronic heating and cooling with air-to-water heat pumps is as an alternative to air-to-air heat pumps that can provide comparable or better energy performance and comfort, although current product costs are typically higher. This strategy applies well in projects where electrification of both space heating and water heating is desired, but utility panel capacity is limited, or no breaker space is available. The air-to-water heat pump can serve both loads from the existing breaker used for air conditioning or an electric resistance water heater. This also saves breaker space and panel capacity for other energy retrofits, such as an induction cooktop or electric vehicle chargers.

Nighttime ventilation is a relatively low-cost retrofit that can be marketed as a niche product to homeowners with relatively small homes, central heating systems with the air handling unit in the attic, and no air conditioning. It can provide an improvement in comfort, at a lower cost than installing central AC. However, it does not provide the same level of comfort as an air conditioner. Nightime ventilation systems can also be used in homes with air conditioning reducing cooling energy use.

HVAC Ducts

Two duct related measures were evaluated. The first was a measure to seal the existing ducts to meet a maximum 10% leakage, which is the requirement for altered ducts in the 2022 Title 24, Part 6 energy code. The second was to replace the ducts with an entirely new distribution system with R-8 insulation and 5% total leakage. Duct sealing and new ducts were found to be cost-effective in 52% and 25%, respectively, of the homes for which they were evaluated. Numerous studies have shown that old ductwork can be very leaky resulting in high energy use, comfort concerns, and reduced equipment lifetime. In many homes ducts are located in a vented attic and can be reasonably accessed for sealing. Ductwork that is located within a dropped ceiling or between floors or walls generally has less of an impact on energy use, is much more challenging to access, and typically cannot be sealed unless an aerosol strategy such as Aeroseal is applied. Aeroseal wasn't evaluated in this study, but it is an alternative strategy that can provide effective sealing reaching low leakage rates. Large holes or gaps must first be manually sealed and therefore the time and effort to apply Aeroseal is dependent on the existing conditions, as is also the case with manual sealing.

Water Heating Equipment

All of the water heating equipment measures were evaluated at the end of the life of the existing equipment. Three upgrades were evaluated and are individually discussed below.

Upgrade gas water heater

This measure upgrades the replacement gas storage water heater to a condensing water heater and was found to be cost-effective in 83% of evaluated homes. This measure provides gas savings only and results in a minor increase in electricity use because of the fan and controls required in a condensing product. Savings were much higher in the coastal region where hot water loads and tank losses were higher than in the inland region due to the colder temperatures.

Replace gas water heater with HPWH

This measure replaces the gas water heater with a HPWH and was only found to be cost-effective in 2% of cases. The HPWH has a higher cost than the gas water heater due to higher equipment costs (HPWH is a more complex system), costs for providing electrical infrastructure to the equipment location, and costs for properly disposing of the produced condensate. Utility costs were also higher in some instances because of the relative electricity versus gas tariffs. However, fuel substitution results in significant GHG savings and average per home GHG savings for this measure were the seventh highest across all the evaluated measures. While this measure was not often found to be cost-effective, it may be recommended as a strategy to meet climate goals.

Replace electric water heater with HPWH

This measure replaces an existing electric resistance storage water heater with a HPWH. Across the ResStock base dataset the measure was found to be cost-effective 89% of the time. 26% of homes in the inland region (Climate Zone 2) and 30% of homes in the coastal region (Climate Zone 1) were estimated to have existing electric resistance water heaters; therefore, the potential impact from this measure is broad throughout SCP territory. Utility cost savings for the customer for this upgrade are high, as electric resistance equipment is expensive to operate. This measure should be recommended for homes with electric resistance water heaters.

Water Heating Load Reduction Measures

Insulating existing accessible hot water pipes was found to be cost-effective in 48% of evaluated homes. Average savings are low, 14 kWh for homes with electric water heaters and 0.5 therms for homes with gas water heaters, because it was assumed only about 10 ft of pipe is accessible, typically where the pipe is accessible near the water heater or under sinks. The cost is also very low as pipe insulation is cheap and installation is simple. The cost does account for professional installation, but assumes a contractor is already onsite for other work. Otherwise, the cost for a dedicated visit to install pipe insulation would likely be higher. Pipe insulation can also be easily installed by the owner or occupant.

Low flow fixtures were found to be cost-effective in every case and is a good strategy in any home where the existing showerheads and faucets do not meet CalGREEN standards.

Appliances

The five appliance measures were evaluated at the end of the life of the existing equipment. Upgrading to an ENERGY STAR refrigerator, clothes washer, or clothes dryer was found to be cost-effective in over 90% of cases with average savings of 168 kWh, 188 kWh, and 291 kWh, respectively. The ENERGY STAR dishwasher upgrade was only cost-effective 32% of the time with average electricity savings of 73 kWh per home.

The induction stove upgrade was found to be cost-effective in less than 1% of homes where it was evaluated. This measure covered upgrades to both electric and gas stoves and resulting energy savings from induction cooking are small while the incremental cost is high. There are only a few residential induction products on the market today and many of them also provide additional features that add to the additional cost. Induction cooking provides various other benefits related to safety and cooking performance that was not quantified in this analysis.

Lighting

Upgrading to LED lamps was found to be cost-effective under all scenarios where the existing lamps were a mix of incandescent and CFL technologies. Table 27 presents average electricity and NPV savings per home based on whether the 80 lm/W LEDs were replacing 15 lm/W incandescent bulbs or 55 lm/W CFLs. Many homes will have a more complicated mix of existing lamp types including a percentage already upgraded to LEDs. Whenever there are existing CFL or incandescent lamps in a home it is cost-effective to upgrade at any time to an LED.

Table 27: Average Savings per Home for LED Lamps Based on Existing Lighting Type

Existing Home Lighting Type	Average kWh	Average NPV
100% CFL	155	$964
60% CFL / 40% Incandescent	524	$3,681
100% Incandescent	1,144	$8,149

Measure Bundling and Other Considerations

This study did not directly evaluate packages of measures and focused rather on a robust analysis of individual measures. However, based on the Team's experience with modeling and monitoring of homes as well as review of individual measure results and their sensitivity to home conditions, the Team makes the following recommendations for how optimally to combine measures and stage their implementation.

There are interactive effects among many of the measures evaluated. In some cases, bundling certain measures together results in improved cost-effectiveness. In others, cost-effectiveness is reduced. For example, for a measure that impacts heating and cooling the cost-effectiveness of said measure is reduced once another measure that reduces heating and cooling energy use is implemented. However, there are various reasons for combining measures even when cost-effectiveness is reduced.

Envelope measures

When retrofitting a home, the first aspect to consider is the envelope as this reduces the equipment loads, improves the occupant experience, and can improve assembly durability. Ideally, load reducing measures should be considered before equipment upgrades. Adding insulation, especially to uninsulated or minimally insulated assemblies can greatly increase occupant comfort during both the summer and winter. Mean radiant temperature (MRT) is the "temperature of an imaginary isothermal black enclosure in which an occupant would exchange the same amount of heat by radiation as in the actual non-uniform environment" (ASHRAE, 2015). MRT is a key indicator of thermal comfort in a building and expresses the combined effect of surface temperatures and air temperature on occupant comfort. On a hot day, surfaces of uninsulated or minimally insulated building assemblies would have a higher surface temperature than a highly insulated surface, contributing to a higher MRT of the space. Even though the cooling system may be operating as expected and the indoor air temperature in the space is acceptable, the occupant may still be uncomfortable as a result of the higher MRT. When all building assemblies in a space are well insulated, the MRT is more in line with the interior air temperature resulting in greater occupant.

Insulation has a longer lifetime than equipment measures providing persistency of savings over a longer period. It also provides an opportunity to downsize to lower cost HVAC equipment. As a result, investing in envelope measures before equipment measures is preferred.

When the building shell is being improved, air sealing is an important component to be addressed. Tightening the building reduces drafts in the house and limits unfiltered air from infiltrating into the conditioned space from other locations. When air sealing is coupled with insulation it reduces air infiltration through the insulation improving the durability of the insulation. Air sealing of the boundary between the attic and living space should be addressed any time there is significant work in the attic, such as adding attic insulation and sealing or replacing ductwork. The boundary between the living space and vented attics is where a significant amount of building air leakage can occur and sealing these areas prior to covering the attic floor with insulation is both practical and effective. When ductwork is located in the attic there are synergies with addressing all three of these building aspects at the same time. In homes with crawlspaces air sealing the boundary between the crawlspace and living space is also critical for indoor air quality as it reduces infiltration of air from the crawlspace that can be moist and may contribute to mold growth.

Electrification and Load Reduction

Electrification or fuel-substitution measures increase electricity use while reducing gas consumption. In many scenarios this can increase total utility costs due to the relative rates for electricity and gas per unit of energy, even though efficiency is usually much higher for electric equipment. Existing homes with poor performing envelopes have high heating and cooling loads which can sometimes present issues aligning with an optimal heat pump operating regime. In heating mode, heat pumps supply cooler air temperatures than gas heaters requiring longer run periods to warm up the house after a setback period, often engaging inefficient electric resistance supplementary heat.

As a result, electrification is best combined with envelope measures which reduce building loads and provide a more consistent MRT throughout the home. Proper design of the delivery system and thermostat control are also critical with heat pumps. This helps to ensure that occupants receive the expected performance from heat pumps and reduces or eliminates any increase in total utility bills.

When replacing a ducted gas furnace with a heat pump, the distribution system must be considered for suitability to function properly with a heat pump. Existing duct systems designed for a gas furnace are often undersized for a heat pump. The implication is that ducts cannot support adequate airflows to deliver sufficient thermal capacity to satisfy loads and occupant comfort requirements. Ductwork often needs to be upgraded or replaced entirely. In addition to ensuring adequate performance from the heat pump an improved duct system also saves energy by reducing thermal and infiltration losses through the ducts.

It's critical to conduct heating and cooling load sizing calculations that account for any envelope improvements that will occur. Heat pumps should be sized to meet both the heating and cooling loads and the heat pump compressor should be sized to meet the entire heating load at design conditions. Even in the colder coastal region it is possible to largely avoid supplemental electric resistance heating through proper equipment selection. Cold climate heat pumps certified through NEEP's Cold Climate Air Source Heat Pump Specifications[10] are good to consider in colder regions.

Electrification also presents opportunities for load shifting and grid-interactive homes. While not necessarily leading to energy savings, grid-interactivity can make fuel substitution more cost-effective because most California utilities offer time-of-use rates or credits on utility bills for demand-responsive or load-shifting equipment.

Electrification and PV

Combining fuel substitution measures with solar photovoltaic (PV) systems provides benefits in reducing total utility costs similar to the synergies between envelope and electrification measures. PV systems were not directly evaluated within this study, but they do result in high

10 https://neep.org/heating-electrification/ccashp-specification-product-list

annual electricity savings and can significantly reduce utility costs. Other studies have found that PV system installation in existing homes is cost effective based on current utility tariffs related to net energy metering (Statewide Reach Code Team, 2021). When switching from a gas to an electric appliance, electricity loads are increased, sometimes moving customers into upper utility tariff tiers increasing the average cost per kWh. Reasonably sized PV systems can greatly reduce average electricity costs, making fuel substitution measures more cost-effective

4.2: Commercial Buildings

Measure Summary and Other Considerations

Of the 14 commercial measures evaluated, six of them were found to be cost-effective for at least one of the two prototype vintages. Table 28 summarizes NPV and percent electricity savings only for the measures that were found to be cost-effective. The grey cells reflect cases that were not found to be cost-effective. None of the individual measures meet the 20% savings target for commercial buildings. While measure bundles weren't evaluated as part of this study, some combination of measures may result in the 20% savings target.

Table 28: Results Summary for Cost-Effective Commercial Measures

Measure	1978 NPV	1998 NPV	1978 % Electricity Savings	1998 % Electricity Savings
LED lighting	$59,357	$27,098	17%	10%
Replace RTU fan motor	$18,851	$13,906	8%	8%
Occupancy controls	$7,342	$2,404	2%	1%
High-efficiency RTU	$4,754		2%	
New windows	$2,828		7%	
Tubular skylights & daylighting controls	$1,859		13%	

As with the residential findings, the cost-effectiveness of HVAC measures depends on heating and cooling thermostat setpoints. Unlike residential buildings, office and other commercial buildings are often internal gain dominated and the equipment and people inside the building drive heating and cooling loads more than envelope performance.

The lighting measures were found to be very cost-effective with a high NPV. LED lamps and occupancy sensors should always be recommended in buildings that don't already have these technologies installed. The tubular skylights and daylighting controls measure was cost-effective for the older vintage building based on savings for fluorescent lamps. When this measure is coupled with LED lamps the savings will be lower and would not be expected to remain cost-effective. In perimeter zones with daylighting from windows, adding daylighting controls alone may be the optimal solution for a significantly lower cost.

Reducing fan energy use by replacing the RTU fan motor was found to have a high NPV in both of the prototype vintages. It's typical for ventilation to be provided through the RTU in addition to heating and cooling, as was assumed in this modeling analysis, which results in significant electricity savings in office buildings where the fans are running continuously during occupied periods. In buildings where the RTU has reached the end of its useful life, the fan motor can be upgraded as part of the system upgrade.

Replacement windows was the only envelope measure found to be cost-effective, and it was only cost-effective for the 1978 vintage prototype. None of the HVAC replace on burnout or the service water heating measures were found to be cost-effective.

The largest end-use for both office vintages was interior equipment. This analysis did not consider measures that target interior equipment energy loads; however, there are strategies that may make sense for certain buildings. ENERGY STAR office equipment is more efficient than standard options. Companies can also institute power management protocols such as turning off equipment when not in use. Receptacle controls, such as smart outlets or smart power strips, are another option.

In some cases, no-cost interventions can have a significant impact. All commercial buildings can benefit from verifying that systems are properly scheduled based on occupancy. Actions such as ensuring that ventilation systems only operate when the building is scheduled to be occupied can result in significant electricity savings compared to fans that are always on. Where not prohibited due to safety or noise concerns, building operators and occupants can prioritize passive cooling and heating by opening windows, and scheduling the heating system to be off in the summer and the cooling system to be off in the winter. Equipment tune-ups and filter replacements can also have a large effect on savings without a large investment. These no-cost or low-cost measures are often referred to as retrocommissioning and should always be considered before replacing existing systems. These measures were not evaluated as part of this study due to limited data quantifying the condition of existing equipment and the impacts of resolving existing faults.

4.3: Conclusions and Recommendation

Table 29 presents measure level recommendations for residential buildings and Table 30 presents measure level recommendations for commercial buildings.

The residential measures that provided the greatest electricity savings were replacing electric furnaces with heat pumps, heat pump upgrades to MSHPs, and replacing electric resistance water heaters with heat pump water heaters. The lowest cost approach to meet 10 percent savings are LED lighting and ENERGY STAR refrigerators. The most cost-effective residential measures with an average net present value greater than $10,000 were replacing electric furnaces with heat pumps, MSHPs installations, and R-13 wall insulation. The residential measures that resulted in the greatest GHG savings were gas furnace upgrades to heat pumps and gas water heater upgrades to heat pump water heaters. Across SCP territory the top three measures for territory-wide GHG reductions were replacing gas furnaces with MSHPs or standard heat pumps and R-13 wall insulation.

Fewer commercial measures were found to be cost-effective. The LED replacement and daylighting measures resulted in the greatest electricity and GHG savings. The LED replacement measures was found to be the most cost-effective, followed by the RTU fan motor replacement. None of the individual measures meet the 20% savings target for commercial buildings. While measure bundles weren't evaluated as part of this study, some combination of measures may result in the 20% savings target.

This analysis and others have identified cost-effective retrofit measures for homes and commercial buildings based on existing building characteristics and location. These results can be useful for selecting technologies that receive incentives or promotion through the Advanced Energy Center. However, customized analyses based on actual building conditions and operations would better inform recommendations for a particular building. Even when this information is available, retrofit programs across the United States have been challenged with significant uptake unless incentives are high. Measures may be proven to be cost-effective over their lifetime; however, owners and occupants often have limited options to finance projects and may not resonate with a cost-effectiveness justification based on a longer time period than they may own the building. To achieve large-scale energy retrofits across the entire building stock creative solutions are needed, such as the on-bill financing approach developed by SCP for Lead Locally customers, which avoids out-of-pocket costs for building owners as long as the expected savings is achieved.

Table 29: Residential Recommendations

Measure	Recommendation
Wall Insulation	Recommended in homes with uninsulated walls.
Attic Insulation	Recommend either R-49 or R-60 in homes with R-19 attic insulation or less. Combine with sealing of the ceiling plane between the home and the attic whenever possible.
PCM	Not recommended, too costly.
Windows	Not recommended as an energy efficiency upgrade on its own because it is very costly. However, there are other significant benefits of upgrading single-pane windows, particularly if they are metal framed, such as reduction of noise and drafts and increased comfort. When a window upgrade is already planned a dual or triple pane product is recommended with a U-factor 0.30 or lower. A low SHGC is recommended in inland climates (≤0.23) and a high SHGC is recommended in coastal climates (≥0.35).
Air Sealing	The cost-effectiveness of this depends on the existing sealing level (>10 ACH50), but where testing is not already planned this measure can be recommended in homes built before 1980 where occupants experience drafts. Aerobarrier may be more expensive but is expected to provide more consistent results and should be considered when the service is available.
Upgrade Air Conditioner	Recommend upgrading to a SEER 16 air conditioner in the inland climate when the air conditioner is being replaced.

Upgrade Gas Furnace	Recommend upgrading to a condensing gas furnace when the gas furnace is being replaced.
Upgrade Heat Pump	Recommend upgrading to a 16 SEER, 9 HSPF heat pump or higher and consider a mini-split heat pump product to provide higher efficiencies.
Replace Furnace with Heat Pump	Recommend upgrading to a mini split heat pump when replacing an existing gas or electric furnace and air conditioner. Conduct load calculations to properly size the equipment. Evaluate the duct system to determine if the existing system is adequate for a heat pump, if not replace the ducts with a properly sized system. Where possible combine this with envelope upgrades to reduce building loads.
Nighttime Ventilation	Recommended as a low-cost alternative to installing air conditioning for small homes with central heating systems where the air handling unit is in the attic. Where possible combine this with envelope upgrades to reduce building loads improving the effectiveness of a nighttime ventilation system.
HVAC Ducts	Recommend inspecting ductwork as part of any retrofit project and sealing them whenever leaks are found. Consider Aeroseal when that service is available. Consider a new duct system if the existing system is 20 years old or if an entirely new HVAC systems is being installed, particularly if an existing gas furnace is replaced with a heat pump.
Upgrade Gas Water Heater	Recommend upgrading to a condensing water heater when the water heater is being replaced.
Replace Gas Water Heater with HPWH	Recommend upgrading to a heat pump water heater when replacing an existing gas water heater if incentives are available.
Replace Electric Water Heater with HPWH	Recommend upgrading to a heat pump water heater when replacing an existing electric storage water heater.
Pipe Insulation	Recommend insulating hot water pipes that are easily accessible and are not already insulated.
Low Flow Fixtures	Recommend CalGREEN compliant showerheads and faucets wherever they don’t already exist.
Appliances	Recommend upgrading to ENERGY STAR rated refrigerators, clothes washers, and clothes dryers when replacing the existing appliances. Consider induction cooktops as an alternative to electric resistance cooktops to provide performance benefits. While not cost-effective today, as more induction products are developed it’s expected costs will decline improving cost effectiveness improve.

Lighting	Recommend replacing existing incandescent and CFL lightbulbs with LED lightbulbs.

Table 30: Commercial Recommendations

Measure	Recommendation
LED lighting	Recommend replacing linear fluorescent tubes with LED tubes.
Replace RTU fan motor	For packaged units with PSC fan motors that have not reached the end of their life recommend replacing the fan motor with a brushless permanent magnet motor.
Occupancy controls	Recommend occupancy controls be installed in all spaces.
High-efficiency RTU	Recommend upgrading to a high-efficiency RTU furnace when the furnace is being replaced for offices for buildings 1980 or older or buildings with single pane windows and minimal insulation.
New windows	Recommend upgrading existing single-pane, metal framed windows to a dual or triple pane product with a U-factor 0.30 or lower. A low SHGC is recommended in inland climates (≤0.23) and a high SHGC is recommended in coastal climates (≥0.35).
Tubular skylights & daylighting controls	For buildings 1980 or older in spaces with limited daylighting recommend tubular skylights in conjunction with daylighting controls. For spaces with a reasonable amount of daylighting from existing windows and/or skylights, recommend daylighting controls be connected to the existing lighting system for a significantly lower cost.

GLOSSARY

ACH50—Air changes per hour measured at a pressure of 50 Pascals. A metric used for expressing the air leakage of a building envelope.[11]

ADVANCED ENERGY CENTER—Sonoma Clean Power's customer center located in downtown Santa Rosa, which makes the latest clean energy technologies accessible all under one roof, with 0% financing, deep discounts, and a network of qualified contractors.[12]

AEROSOL SEALING—The process of using an aerosol spray and pressure to seal a building and/or ventilation system, reducing air leakage.[13]

THE AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS (ASHRAE)—Founded in 1894, is a global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry.[14]

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

1. Forecasting future statewide energy needs
2. Licensing power plants sufficient to meet those needs
3. Promoting energy conservation and efficiency measures
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
5. Planning for and directing state response to energy emergencies.

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11 DOE EERE "Infiltration meets ACH50 requirements" webpage https://basc.pnnl.gov/information/infiltration-meets-ach50-requirements

12 SCP Advanced Energy Center about webpage https://scpadvancedenergycenter.org/about

13 EERE "Aerosol Envelope Sealing in New Construction" webpage https://www.energy.gov/eere/buildings/aerosol-envelope-sealing-new-construction

14 ASHRAE about webpage https://www.ashrae.org/about

CALIFORNIA GREEN BUILDING STANDARDS CODE (CALGreen)— A code that sets minimum requirements for California's residential and commercial buildings' sustainable practices.

CALIFORNIA CLIMATE ZONE (CZ)—One of sixteen climate zones defined by the California Energy Code to represent the diversity of climates across the statewide.

COMMERCIAL DISHMACHINES—Automated machines that can clean and sanitize a large quantity of kitchenware in a short amount of time by utilizing energy, hot water, soap, and rinse chemicals.[15]

DATABASE FOR ENERGY EFFICIENCY RESOURCES (DEER)—A database that contains information on selected energy-efficient technologies and measures. The DEER provides estimates of the energy-savings potential for these technologies in residential and nonresidential applications.[16]DEPARTMENT OF ENERGY (DOE)—A federal agency with the mission to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

DROP CEILING—A ceiling suspended from the floor or roof construction above.[17]

DUCTED MINI-SPLIT HEAT PUMP (DMSHP)— A term used to refer to variable capacity air-source heat pumps that are small (generally less than 1.5 tons of cooling) and paired to one or more ducted air handlers.[18]

ECONOMIZER (Air)—A ducting arrangement and automatic control system that allows a heating, ventilation and air conditioning (HVAC) system to supply up to 100 percent outside air to satisfy cooling demands, even if additional mechanical cooling is required.

ELECTRONICALLY COMMUTATED MOTORS (ECM)— A type of motor based on a brushless direct current permanent magnet design that uses electronic control to change it's speed.

ENERGY STAR—A United States Environmental Protection Agency program that promotes energy efficiency by using standardized methods to provide information on energy consumption of products and devices.

15 Energy Star "Commercial Dishwashers" webpage https://www.energystar.gov/products/commercial_dishwashers

16 DEER website http://www.deeresources.com/index.php/deer-versions/deer2021

17 Webster definition of "Suspended Ceiling" https://www.merriam-webster.com/dictionary/suspended%20ceiling

18 Green Building Advisor "Ducted Air-Source Heat Pumps from American Manufacturers" article https://www.greenbuildingadvisor.com/article/ducted-air-source-heat-pumps-from-american-manufacturers

EFFECTIVE USEFUL LIFETIME (EUL)—The estimated useful lifetime of a building component or system.

FORCED AIR UNIT (FAU)—A HVAC system component containing a fan or fans and other necessary equipment to perform one or more of the following functions: circulating, filtration, heating, cooling, and mixing of air; usually connected to an air-distribution system.[19]

GEOGRAPHICAL INFORMATION SYSTEM (GIS)—A type of database that is used to capture, store, display, and analyze geographic data.

GREENHOUSE GAS (GHG)—A gas that traps heat in the atmosphere by absorbing and emitting radiant energy within the thermal infrared range. These gases' ability to trap heat causes the greenhouse effect.

GRID INTERACTIVE—Systems that are designed to operate in response to signals from utilities or third-party aggregators to control operation.[20]

GRID INTEGRATED HEAT PUMP WATER HEATER—HPWHs that are designed to operate in response to signals from utilities or third-party aggregators to control operation while still providing consistent and reliable hot water to the occupants.[21]

HEAT PUMP WATER HEATER (HPWH)—Systems that heat and usually store water as for domestic use. They do this by using electricity to move heat from one place to another instead of generating heat directly.[22]

INDUCTION COOKING—The use of an electromagnetic coil to create heat in compatible cookware.[23]

LEAD LOCALLY—A grant program managed by Sonoma Clean Power, primarily funded through the California Energy Commission. The program aims to develop strategies to double energy

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19 ASHRAE Terminology webpage https://xp20.ashrae.org/terminology/

20 CEC&S "Single Family Grid Integration" https://title24stakeholders.com/wp-content/uploads/2020/10/SF-Grid-Integration_Final-CASE-Report_Statewide-CASE-Team-Clean.pdf

21 CEC&S "Single Family Grid Integration" https://title24stakeholders.com/wp-content/uploads/2020/10/SF-Grid-Integration_Final-CASE-Report_Statewide-CASE-Team-Clean.pdf

22 DOE "Heat Pump Water Heaters" webpage https://www.energy.gov/energysaver/heat-pump-water-heaters

23 Energy Star "2021-2022 Residential Induction Cooking Tops" webpage https://www.energystar.gov/about/2021_residential_induction_cooking_tops

efficiency in existing buildings and measure the results of the prospective technologies, prior to launching future customer programs.[24]

LIFECYCLE COST (LCC)—The cost over the analysis period for a building upgrade including first costs, replacement costs, maintenance costs, and residual cost at the end of the period.

MINISPLIT HEAT PUMP (MSHP)—An encased, factory-made assembly or assemblies designed to be used as permanently installed equipment to provide conditioned air to an enclosed space(s). It normally includes multiple evaporators, compressor(s), and condenser(s). [25]

NATIONAL RENEWAQBLE ENERGY LABORATORY (NREL)—A federally funded national lab that specializes in the research and development of renewable energy, energy efficiency, energy systems integration, and sustainable transportation.

NET PRESENT VALUE (NPV)—The difference between the present value of cash inflows (typically utility bill savings) and the present value of cash outflows (typically measure incremental costs) over a period of time.

NIGHTTIME VENTILATION (NTV)—An automated system to move fresh air throughout a building at night to reduce the temperature of its interior thermal mass, reducing daytime cooling usage.[26]PEAK LOAD REDUCTION—Changes to the operation of building end uses to minimize the consumption of electricity during utility peak periods.[27]

PERMANENT SPLIT CAPACITOR (PSC)—A type of single-phase AC motor where the capacitor is permanently connected during operation.

PHASE CHANGE MATERIALS (PCMs)—Materials that absorb thermal energy as they melt, releasing the absorbed energy when ambient temperatures fall below the material's melting point. By accumulating energy during the day and releasing energy overnight, PCMs reduce building cooling costs and improve energy efficiency.[28]

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24 SCP "Energy-Saving Upgrades Available to Eligible Homes and Businesses" https://sonomacleanpower.org/news/energy-saving-upgrades-available-to-eligible-homes-and-businesses

25 ASHRAE Terminology webpage https://xp20.ashrae.org/terminology/

26 Landsman, Jared "Performance, Prediction and Optimization of Night Ventilation across Different Climates " https://escholarship.org/uc/item/6n99w3bx

27 DOE EERE "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction" https://www.energy.gov/eere/buildings/downloads/impacts-commercial-building-controls-energy-savings-and-peak-load-reduction

28 DOE EERE "Phase Change Materials for Building Applications (SBIR)" https://www.energy.gov/eere/buildings/articles/phase-change-materials-building-applications-sbir

PHOTOVOLTAIC SYSTEM (PV)—A system capable of generating a voltage as a result of exposure to visible or other radiation. Generally referred to as a solar panel.[29]

RESIDENTIAL APPLIANCE SATURATION STUDY (RASS)—A statewide study performed in California to obtain comprehensive data on California's residential energy use.

RETROFIT MEASURES—An action that is taken to reduce the energy or electricity use of a home or commercial building.[30]

ROOF-TOP UNITS (RTUs)—Packaged air conditioner mounted on a roof, the conditioned air being discharged directly into the rooms below or through a duct system.[31]

SIMPLE PAYBACK—The number of years for energy bill savings after a retrofit to cover its initial investment.[32]

SITE ENERGY—The energy consumed at a building location or other end-use site.

SONOMA CLEAN POWER (SCP)—A community choice aggregator that serves the residents and businesses in Sonoma and Mendocino counties, providing clean energy from more renewable resources, such as geothermal, wind, and solar.[33]

THERM—One hundred thousand (100,000) British thermal units (1 therm = 100,000 Btu).

TIME OF USE (TOU)—Utility rate plans that can reduce expenses by shifting energy use to partial-peak or off-peak hours of the day. Rates during partial-peak and off-peak hours are lower than rates during peak hours.

UNIFORM ENERGY FACTOR (UEF)—A measure of water heater overall efficiency. The higher the UEF value is, the more efficient the water heater. UEF is determined by the Department of Energy's test method outlined in 10 CFR Part 430, Subpart B, Appendix E.[34]

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29 ASHRAE Terminology webpage https://xp20.ashrae.org/terminology/

30 DOE EERE "Retrofit Existing Buildings" https://www.energy.gov/eere/buildings/retrofit-existing-buildings

31 ASHRAE Terminology webpage https://xp20.ashrae.org/terminology/

32 Science Direct definition of "Simple Payback Time" https://www.sciencedirect.com/topics/engineering/simple-payback-time#:~:text=Simple%20payback%20time%20is%20defined,renovation%20will%20cover%20the%20investment.

33 SCP "Who We Are" webpage https://sonomacleanpower.org/whoweare

34 Energy Star "Water Heater Key Criteria" webpage https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

VARIABLE SPEED—An air conditioning system can use a variable speed compressor (variable capacity system) and or variable speed blower fan.[35]

35 DOE "Heat Pump Systems" webpage https://www.energy.gov/energysaver/heat-pump-systems

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APPENDIX A: Review of Software Tools

The Team reviewed the existing modeling tools with optimization capabilities to compare options for this analysis. Most software solutions have some form of graphic interface and have capabilities ranging from simple batch processing to built-in statistical optimization algorithms. Most tools are best suited for either residential or commercial building, very few handle both thoroughly. Other tools were found that offered less functionality but more specialized results. Analysis tools reviewed included the following:

- *ResStock Analysis Tool* [analysis tool for large-scale residential energy analysis to achieve granularity and accuracy in modeling the diversity of the existing housing stock, uses EnergyPlus simulation engine]
- *DesignBuildier* [graphical interface for the EnergyPlus and Radiance simulation engines, primarily for commercial buildings]
- *Simergy* [Building Energy Modeling – BEM – development front-end to the EnergyPlus simulation engine, primarily for commercial buildings]
- *OpenStudio* [open source collection of software tools developed by the National Renewable Energy Laboratory (NREL) and the Department of Energy (DOE) for whole building energy modeling, uses EnergyPlus simulation engine, primarily for commercial buildings]
- *BEopt - Building Energy Optimization Tool* [residential building design with sequential search optimization, uses EnergyPlus simulation engine]
- *IES-VE* [whole-building performance simulation suite of tools that can model new and existing buildings of any size and complexity, proprietary simulation engine, primarily for commercial buildings]
- *IDA ICE - Indoor Climate and Energy* [multi-zone analysis of thermal indoor comfort and airflow as well as entire building energy consumption]
- *CBECC-Res* [residential compliance software for California's Title 24, Part 6 energy code]
- *CBECC-Com* [commercial compliance software for California's Title 24, Part 6 energy code, uses EnergyPlus simulation engine]
- *BuildSimHub* [simulation & data visualization platform with cloud computing that works with EnergyPlus and OpenStudio input files]
- *LBNL's GenOpt - Generic Optimization Tool* [optimization program for the minimization of a cost function that is evaluated by an external simulation program, such as EnergyPlus]

The list of tools above was narrowed down to two tools based on features, applicability, feasibility, and ease of use. The recommended approach for this analysis is to use ResStock for residential buildings and OpenStudio for commercial buildings. Following is additional detail on the two software tools:

ResStock Analysis Tool: NREL's ResStock is an analysis methodology rather than a distinct simulation tool. It's a versatile tool that takes a new approach to large-scale residential energy analysis to achieve granularity and accuracy in modeling the diversity of the existing housing stock. The ResStock tool uses DOE's OpenStudio platform and EnergyPlus energy simulation engine and is provided free for the public to download and customize to represent local analysis needs. For the single family detached housing stock, NREL conducted a housing stock characterization that defines more than 100 components of a building using large public and private data from 11 sources. Statistical sampling identified a representative sample of 350,000 homes on which detailed sub-hourly building simulations were run. Validation was conducted by comparing the results against the U.S. Energy Information Administration's 2009 Residential Energy Consumption Survey. More than 50 efficiency upgrades have been defined within the ResStock tool. The tool has recently been expanded to cover multifamily buildings, although the housing stock model has not undergone the validation process that was done for single family.

OpenStudio: An open source collection of software tools developed by NREL and DOE that supports whole building energy modeling using EnergyPlus with a graphical interface and advanced daylight analysis using Radiance. Graphical applications include a SketchUp plug-in for modeling building geometry, the OpenStudio Application for developing mechanical systems and assigning building characteristics and a ResultsViewer for visualizing results. The Parametric Analysis Tool enables studying the impact of applying multiple combinations of OpenStudio Measures. While OpenStudio can be used for all building types, it is most appropriate for commercial buildings. It is actively maintained and improved upon by NREL and its development team as well as by other software developers who contribute to the open source code.

APPENDIX B: Existing Single Family Building Stock Characterization

ResStock references data tables for each of the 100+ covered building components that characterize the likelihood of any particular building characteristic value appearing in a single family home. Table 31 lists all of the housing characteristic tables that are referenced by ResStock housing, whether this analysis used the values directly from Restock or revised them to better reflect the housing stock in Sonoma and Mendocino counties. The table also shows the relevant dependencies for each characteristic. Many building characteristics are dependent on the vintage of the home, meaning for each vintage a separate probability breakdown of the building characteristic values are provided.

Table 31: Summary of ResStock Housing Characteristics

Housing Characteristic Table	Dependencies	Change Made	Reference
Bathroom Spot Vent Hour	N/A	N/A	ResStock
Bedrooms	Geometry House Size	N/A	ResStock
Ceiling Fan	N/A	N/A	ResStock
Clothes Dryer	Clothes Washer Presence, Heating Fuel, Usage Level	N/A	ResStock
Clothes Washer Presence	N/A	N/A	ResStock
Clothes Washer	Clothes Washer Presence, Usage Level	N/A	ResStock
Cooking Range Schedule	Cooking Range	N/A	ResStock
Cooking Range	Heating Fuel, Usage Level	N/A	ResStock
Cooling Setpoint Has Offset	Location	N/A	ResStock
Cooling Setpoint Offset Magnitude	Location, Cooling Setpoint Has Offset	N/A	ResStock

Housing Characteristic Table	Dependencies	Change Made	Reference
Cooling Setpoint Offset Period	Location, Cooling Setpoint Has Offset	N/A	ResStock
Cooling Setpoint	Location	N/A	ResStock
Corridor	N/A	N/A	ResStock
Days Shifted	N/A	N/A	ResStock
Dehumidifier	N/A	N/A	ResStock
Dishwasher	Usage Level	N/A	ResStock
Door Area	N/A	N/A	ResStock
Doors	N/A	N/A	ResStock
Ducts	Geometry Foundation Type, Vintage	Various updates. No good data available, used reasonable logic based on T24 requirements.	Title 24
Eaves	N/A	N/A	ResStock
Electric Vehicle	N/A	N/A	ResStock
Geometry Attic Type	Vintage	N/A	ResStock
Geometry Building Type RECS	N/A	N/A	ResStock
Geometry Foundation Type	Location	Remove basement options (12% for all CA locations per ResStock) and apportioned the 12% equally to crawl and slab.	Based on Team's experience with construction practices
Geometry Garage	Vintage, Geometry House Size	N/A	ResStock
Geometry House Size	Vintage, Location	Added dependency for weather file, updated to reflect census data for Sonoma/Mendocino county, by CZ. Deleted count/weight.	Census Data
Geometry Number Units	N/A	N/A	ResStock
Geometry Stories	Vintage, Geometry House Size	N/A	ResStock

Housing Characteristic Table	Dependencies	Change Made	Reference
Geometry Wall Type	N/A	Updated to 100% wood stud, 0% masonry to represent predominant construction type. ResStock data showed 73% masonry which was unrealistic.	Based on Team's experience with construction practices
Heating Fuel	Vintage, Location	Adjusted per census values for sonoma/mendocino counties, separated by CZ1/2.	Census Data
Heating Setpoint Has Offset	Location	N/A	ResStock
Heating Setpoint Offset Magnitu	Location, Cooling Setpoint Has Offset	N/A	ResStock
Heating Setpoint Offset Period	Location, Cooling Setpoint Has Offset	N/A	ResStock
Heating Setpoint	Location	N/A	ResStock
Holiday Lighting.tsv	N/A	N/A	ResStock
Hot Water Distribution	Vintage	N/A	ResStock
Hot Water Fixtures	Usage Level	N/A	ResStock
HVAC System Cooling Type	HVAC System Cooling, HVAC System Is Heat Pump	N/A	ResStock
HVAC System Cooling	Location, Vintage, Heating Fuel, HVAC System Is Heat Pump	Updated per RASS data.	RASS
HVAC System Heat Pump	Vintage, Heating Fuel, HVAC System Is Heat Pump	Updated per RASS data.	RASS
HVAC System Heating Electricity	Location, Vintage, Heating Fuel, HVAC	Updated per RASS data.	RASS

Housing Characteristic Table	Dependencies	Change Made	Reference
	System Is Heat Pump		
HVAC System Heating Fuel Oil	Vintage, Heating Fuel, HVAC System Is Heat Pump	N/A	ResStock
HVAC System Heating Natural Gas	Location, Vintage, Heating Fuel, HVAC System Is Heat Pump	Updated per RASS data.	RASS
HVAC System Heating None	Vintage, Heating Fuel, HVAC System Is Heat Pump	N/A	ResStock
HVAC System Heating Other Fuel	Vintage, Heating Fuel, HVAC System Is Heat Pump	N/A	ResStock
HVAC System Heating Propane	Vintage, Heating Fuel, HVAC System Is Heat Pump	N/A	ResStock
HVAC System Is Heat Pump	Vintage, Heating Fuel	N/A	ResStock
Infiltration	Vintage, Geometry House Size, Geometry Stories	N/A	ResStock
Insulation Crawlspace	Vintage, Geometry Foundation Type	Typical CA construction has insulation applied at the floor and not the foundation wall. ResStock assumed a certain saturation of homes with foundation wall insulation, this option was removed and the associated saturation of homes was applied to an equivalent floor insulation option.	Based on Team's experience with construction practices
Insulation Finished Basement	Vintage, Geometry Foundation Type	N/A	ResStock
Insulation Finished Roof	N/A	N/A	ResStock

Housing Characteristic Table	Dependencies	Change Made	Reference
Insulation Interzonal Floor	Vintage	N/A	ResStock
Insulation Pier Beam	Vintage, Geometry Foundation Type	N/A	ResStock
Insulation Slab	Vintage, Geometry Foundation Type	Revised to reflect 100% of slabs as uninsulated to reflect typical construction in this region.	Based on Team's experience with construction practices
Insulation Unfinished Attic	Vintage	N/A	ResStock
Insulation Unfinished Basement	Vintage, Geometry Foundation Type	N/A	ResStock
Insulation Wall	Vintage, Geometry Wall Type	Applied ResStock % for R-7 to R-11 and R-11 % to a newly created R-13 option to better reflect CA construction and T24 standards.	Title 24 Standards
Interior Shading	N/A	N/A	ResStock
Lighting Interior Use	N/A	N/A	ResStock
Lighting Other Use	N/A	N/A	ResStock
Lighting	N/A	N/A	ResStock
Location Region	N/A	Set all regions to 0 except CR11.	Based on SCP territory
Location Weather Filename	Location, Location Weather Year	Added Santa Rosa weather file option.	Based on SCP territory
Location Weather Year	N/A	N/A	ResStock
Location	N/A	Added Santa Rosa weather file option, set SR to 92% (CZ2 % of Sonoma/Mendocino counties) and Arcata to 8% (CZ1 %). Set other weather files to 0.	Census Data
Mechanical Ventilation	N/A	N/A	ResStock
Misc Extra Refrigerator	N/A	N/A	ResStock

Housing Characteristic Table	Dependencies	Change Made	Reference
Misc Freezer	N/A	N/A	ResStock
Misc Gas Fireplace	N/A	N/A	ResStock
Misc Gas Grill	N/A	N/A	ResStock
Misc Gas Lighting	N/A	N/A	ResStock
Misc Hot Tub Spa	N/A	N/A	ResStock
Misc Pool Heater	Misc Pool	N/A	ResStock
Misc Pool Pump	Misc Pool	N/A	ResStock
Misc Pool Schedule	N/A	N/A	ResStock
Misc Pool	N/A	N/A	ResStock
Misc Well Pump	N/A	N/A	ResStock
Natural Ventilation	N/A	N/A	ResStock
Neighbors	N/A	N/A	ResStock
Occupants	Bedrooms	N/A	ResStock
Orientation	N/A	N/A	ResStock
Overhangs	N/A	N/A	ResStock
Plug Loads Schedule	N/A	N/A	ResStock
Plug Loads	Usage Level	N/A	ResStock
PV	N/A	N/A	ResStock
Radiant Barrier Unfinished Attic	N/A	N/A	ResStock
Range Spot Vent Hour	N/A	N/A	ResStock
Refrigeration Schedule	N/A	N/A	ResStock
Refrigerator	Usage Level	N/A	ResStock
Roof Material	N/A	N/A	ResStock
Solar Hot Water	N/A	N/A	ResStock
Usage Level	N/A	N/A	ResStock
Vintage	Location	Updated to reflect census data for Sonoma/Mendocino county by CZ.	Census Data
Water Heater	Heating Fuel, Location	Updated per RASS data.	RASS
Window Areas	N/A	N/A	ResStock

Housing Characteristic Table	Dependencies	Change Made	Reference
Windows	Vintage, Location	Updated per RASS data, separately for CZ1/2, used ResStock data to differentiate between low-E and non.	RASS