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City of Carlsbad Energy Conservation Ordinance Cost Effectiveness Analysis

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Executive Summary

The City of Carlsbad requires a cost effectiveness study be completed to implement an energy conservation ordinance. TRC investigated measures originating from Carlsbad's Climate Action Plan and further developed by Center for Sustainable Energy (CSE).[1]. The energy ordinance would require that residential and nonresidential new construction and alterations implement efficiency and renewable energy measures that exceed the requirements of 2016 and 2019 Title 24 Building Energy Efficiency Standards (T24). Cost effectiveness analysis is required by the California Energy Commission (CEC) before adopting local energy ordinances, and may support or justify local ordinances by demonstrating that the building industry and building occupants are not unduly burdened because of the ordinance.

TRC determined cost-effectiveness in two ways: 1) using time dependent valuation (TDV) of energy as per the CEC Life Cycle Cost Methodology and 2) using San Diego Gas & Electric (SDG&E) utility rates to determine bill impacts. TRC uses a benefit to cost (B/C) ratio as the cost effectiveness metric. If the benefits of a measure are positive and greater than the costs of the measure, then the B/C ratio will be greater than 1.0 and the measure or package is considered cost effective. Cost-effective measures are highlighted in green in the following tables.

TRC analyzed the following measures for residential and nonresidential new construction individually and as a package, as shown in Figure 1 and Figure 2:

- solar photovoltaic (PV),
- heat pump water heating with
  - a federally-required minimum energy factor (EF) of 2.0, and
  - a uniform energy factor (UEF) of 3.1 representing a Northwest Energy Efficiency Alliance (NEEA) Rated Tier 3 product

Because nonresidential buildings typically have very low hot water demands, and water heaters with storage tanks may waste energy while on standby, TRC also investigated the cost effectiveness of small tank electric resistance water heaters in the nonresidential prototypes.

Figure 1 shows that both single family and low-rise multifamily residential new construction are cost effective using the Bill B/C ratio when installing HPWHs paired with PV as compared to the 2019 Title 24 baseline. However, these measures are not cost effective using the TDV B/C ratio.

New Construction	Single-family		Low-rise Multifamily	
Measure (2019 Title 24 Baseline)	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)
Federal Min HPWH + 0.3 kW Solar PV	0.0	1.1	0.0	3.0
Tier 3 HPWH + 0.3 kW Solar PV	0.5	2.1	0.5	3.2

Figure 1: New Construction Residential Summary

TRC analyzed solar PV and water heating measures individually and packaged for nonresidential new construction compared to the 2016 Title 24 baseline. As per Carlsbad measure descriptions, PV was sized at:

[1] City of Carlsbad Climate Action Plan (Sept 2015). Dyett & Bhatia Urban and Regional Planners. Available at: http://www.carlsbadca.gov/civicax/filebank/blobdload.aspx?BlobID=29361

- 15 kW per 10,000 ft^2 of gross floor area on buildings of 10,000 ft^2 or more, and
- 5 kW for buildings under 10,000 ft^2.

Figure 2 shows that electric water heating alone is not cost effective using either TDV or Bill B/C ratios. Solar PV alone, and solar PV in conjunction with electric water heating, are cost effective using both the TDV and Bill B/C ratio for each nonresidential new construction prototype with the exception of the retail strip mall, which has a very low hot water demand.

New Construction	Small Office		Medium Office		Warehouse		Retail Strip Mall	
Measure (2016 Title 24 Baseline)	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)
Solar PV	1.7	2.6	1.6	2.0	1.4	1.7	1.7	2.1
Federal Min Efficiency HPWH	-1.0	-3.3	-10.6	-22.7	-2.1	-5.6	-4.0	-4.7
Federal Min Efficiency HPWH + PV	1.3	1.9	1.5	1.8	1.4	1.7	0.9	1.2
Tier 3 HPWH	0.6	-1.1	-5.3	-12.7	-0.6	-2.8	-1.2	-0.3
Tier 3 HPWH + PV	1.6	2.2	1.5	1.9	1.4	1.7	1.3	1.7
Electric Resistance WH	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Electric Resistance WH + PV	1.6	2.2	1.4	1.7	1.4	1.7	0.7	0.7

Figure 2: New Construction Nonresidential Summary, Tier 3 HPWH.

TRC analyzed solar PV measures for nonresidential alterations compared to the 2016 Title 24 baseline. The solar PV sizing requirement for alterations is identical to that of new construction and is triggered by roof additions ≥ 2,000 ft^2 or permit valuations ≥ $1,000,000 that affect ≥ 75 percent the building. Figure 3 shows Bill Net Savings and TDV Net Savings for solar on nonresidential alterations.

Major Alterations	Small Office		Medium Office		Warehouse		Retail Strip Mall	
Measure	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)	B/C ratio (TDV)	B/C ratio (Bill)
Solar PV	1.5	2.5	1.5	2.4	1.4	1.7	1.5	3.0

Figure 3: Nonresidential Alterations Summary

Based on our analysis described in this report, TRC provides the following recommendations for reach code requirements relative to the 2016 and 2019 Title 24 requirements for the City of Carlsbad consideration:

2016 Title 24

- An ordinance to implement CAP Actions B-1 and B-2 that requires solar PV on nonresidential new construction and certain alterations. Carlsbad may allow smaller PV sizes or other exceptions for buildings that demonstrate that they will over generate with a 5 kW PV size.
- An ordinance to implement CAP Action J-2 that requires heat pump water heating in nonresidential new construction when paired with PV installation. Carlsbad may require other efficiency measures (e.g., solar thermal, compact hot water distribution, and/or drain water heat recovery) whenever a natural gas water heater is installed and require the performance path when electric resistance water heater is installed.

2019 Title 24

- An ordinance to implement CAP Action J-2 that requires heat pump water heating in all low-rise residential new construction when paired with additional 0.3 kW of solar PV. These measures were shown to be cost effective using the Bill B/C ratio, but not the TDV B/C ratio.
- Carlsbad may require other efficiency measures (e.g., solar thermal, compact hot water distribution, and/or drain water heat recovery) whenever a natural gas water heater is installed and require the performance path when electric resistance water heater is installed.

1 Introduction

The City of Carlsbad engaged TRC to research and analyze the cost effectiveness of proposed energy ordinances exceeding 2016 and 2019 Title 24 Part 6 Building Energy Efficiency Standards (T24). The T24 Standards are the minimum energy efficiency requirements for building construction in California.

The proposed ordinances are shaped by investigating measures that allow a building to perform better than minimum T24 requirements while being cost effective over the lifetime of the measures, as per the requirements in Section 10-106 of the California Code of Regulations. Cost effectiveness analysis may support or justify local ordinances by demonstrating that the building industry and building occupants are not unduly burdened because of the ordinance.

1.1 Scope

TRC has assessed the cost effectiveness of several measures, relevant to both new construction and alterations scenarios, in both residential and nonresidential buildings. TRC determined cost effectiveness by investigating and comparing the costs and energy savings benefits associated with several building energy efficiency measures, described in more detail in *Section 2: Methodology*.

The measures researched in this cost-effectiveness study are solar PV and heat pump water heating. Water heating is among the higher energy-consuming building functions that typically use natural gas for fuel.

1.2 Limitations

This study has the following limitations:

- **Location.** All analysis performed is intended to be relevant to Carlsbad climate, San Diego Gas and Electric (SDG&E) utility rates, and labor/material costs.
- **Prototypes.** The prototypes studied are low-rise residential, offices, warehouse, and retail strip mall. Findings may not pertain to accessory dwelling units, high-rise residential, or other commercial spaces, such as restaurants and fitness centers, which have much higher water heating loads.
- **Existing Conditions.** A wide range of existing conditions are possible in alterations scenarios, such as existing heating, ventilation and air conditioning (HVAC) system, domestic hot water (DHW) system, and electrical infrastructure capacity, and each has a potential to impact measure cost effectiveness. Based on industry engagement and previous research, TRC performed the analysis using one set of assumptions for existing conditions. In some cases, software capabilities dictated existing conditions.
- **Federal Preemption.** The U.S. Department of Energy (DOE) regulates the minimum efficiencies required for all appliances, such as space conditioning or water heating equipment. State or city codes that mandate appliance efficiencies higher than the DOE's may risk litigation by industry organizations. Consequently, TRC analyzed a federal minimum efficiency heat pump water heater with a Uniform Energy Factor equal to 2.0. 2019 Title 24 allows a HPWH with federal minimum efficiency to prescriptively comply when including a 0.3 kW PV system. In this study, TRC also examined a high efficiency HPWH to reflect the performance of market standard equipment, not to suggest that Carlsbad should mandate high efficiency heat pumps in a local ordinance.
- **Sensitivity.** The study assumes one set of market conditions at one specific point in time, including utility rates and equipment costs. This study does not analyze potential cost-effectiveness outcomes under a variety of market conditions. For example, TRC assumed that a solar photovoltaic (PV) array would be

purchased by a building owner because it conservatively assumes a large upfront cost, and it simplifies having to develop a long-term leasing mechanism which can vary depending on the lessor or economic conditions.

2 Methodology

TRC analyzed the cost effectiveness of potential ordinance measures by applying them to building prototypes using the CEC's life cycle cost (LCC) methodology, which used to establish the state's cost effective building energy standards (Title 24, Part 6).[2]

2.1 Cost Effectiveness

TRC determined cost effectiveness by assessing the incremental costs of each measure and comparing them to the energy cost savings over the measure life. Incremental costs represent the equipment, installation, replacements, and maintenance costs of the proposed measure relative to the 2016 or 2019 Title 24 Standards minimum requirements. We estimated savings using both time dependent valuation (TDV) of energy and utility bill rates:

- **TDV** is a normalized monetary format developed and used by the CEC for comparing electricity and natural gas savings, and it considers the cost of electricity and natural gas consumed during different times of the day and year. The 2016 or 2019 TDV values are based on long term discounted costs—30 years for all residential measures and 15 years for all nonresidential measures except envelope measures.
- **Utility bill impacts** are estimated for each calendar month for electricity and natural gas consumption for each prototype using Title 24 compliance simulation software outputs and spreadsheets. TRC used the below SDG&E rates to estimate bill impacts, which include net energy metering:[3]
    - Residential: DR-SES for electricity and GR for gas.
    - Commercial: TOU-A or AL-TOU for electricity and GN-3 for gas

The EECC commodity rate plan is implemented in conjunction with the TOU-A and AL-TOU rate schedules for buildings with less than 20 kW and greater than 20 kW of monthly peak demands, respectively.

TRC obtained measure costs through interviews with California contractors and distributors and reviewed online sources, such as Home Depot and RS Means. We added taxes and contractor markups as appropriate. Please find detailed costs in *Appendix B: Cost Data*. Measure costs are the same when comparing to either TDV or utility bill savings.

TRC performed a net present value (NPV) calculation over 30 years for residential and 15 years for nonresidential prototypes, assuming a 3% discount rate and a 2% energy escalation rate. These values are selected to be consistent with the CEC LCC methodology and studies commissioned by the CEC. TRC uses a benefit to cost (B/C) ratio as the cost effectiveness metric. If the benefits of a measure are positive and greater than the costs of the measure, then the B/C ratio will be greater than 1.0 and the measure or package is considered cost effective.

2.2 Prototypes

TRC estimated the energy impacts of most measures using CEC-approved modeling software. TRC used CBECC-Res 2019.0.9 to simulate the residential prototypes and CBECC-Com 2016.3.0 for the nonresidential prototypes

[2] Architectural Energy Corporation (January 2011) Life-Cycle Cost Methodology. California Energy Commission. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/2011-01-14_LCC_Methodology_2013.pdf

[3] Available at: https://www.sdge.com/rates-and-regulations/current-and-effective-tariffs.

in California climate zone 7 (CZ7).[4] TRC used seven prototypes as the basis for determining cost effectiveness, coordinated with the City of Carlsbad:

- 2,100 ft^2 single-family single-story home
- 2,700 ft^2 single-family two-story home
- 6,960 ft^2 low-rise multifamily residential building, with two stories and eight dwelling units
- 5,502 ft^2 one-story small office building
- 53,628 ft^2 three-story medium office building
- 49,495 ft^2 one-story warehouse building
- 9,375 ft^2 retail strip mall

Prototypes are based on CEC prototypes in the Residential and Nonresidential Alternate Calculation Method Manuals, with equal geometry oriented facing north, east, south, and west.[5] The prototype geometries were developed with both new construction and alterations characteristics. The residential new construction prototypes meet 2019 Title 24 prescriptive requirements. The commercial new construction prototypes meet 2016 T24 prescriptive requirements and the alterations prototypes use estimated characteristics for buildings constructed prior to an energy code. See *Section 3 Measure Descriptions* for further detail on why the T24 code baselines differed for residential and nonresidential buildings, and for the City of Carlsbad's list of measure action items. A summary of baseline prototype characteristics is available in *Appendix A: Prototype Details*.

Solar PV

The residential baseline prototypes include PV arrays that are automatically sized by the compliance software based on the electrical consumption of a prescriptive mixed-fuel home. Electrifying one or more appliances does not automatically increase the PV size in the model in the baseline model. TRC includes the costs and energy savings associated with increasing the PV array size from the baseline model's automatically sized PV array.

CBECC-Com is not currently capable of simulating solar PV. For this study, TRC instead determined the PV output of a solar array in CZ7 using CBECC-Res and then applied the outputs to CBECC-Com hourly results. During periods of over-generation (i.e., when electricity from the PV system is being fed into the grid), the TDV of the PV output needs to be reduced to fairly portray the value of solar export relative to TDV associated with reducing energy consumption. TRC reduced the TDV associated with solar output by removing the retail rate adder component of the calculation.

[4] More information on CBECC-Res available at: http://www.bwilcox.com/BEES/BEES.html. More information on CBECC-Com available at: http://bees.archenergy.com/software.html

[5] Available at: https://www.energy.ca.gov/title24/2016standards/

3 Measure Descriptions

TRC investigated HPWH and solar PV measures intended to reduce greenhouse gas emissions associated with fossil fuels that were provided by the Center for Sustainable Energy and the City of Carlsbad. TRC recommended that Carlsbad investigate HPWH and PV measures in different code cycles (2016 and 2019 T24) for residential and nonresidential measures because:

- 2019 T24 includes prescriptive compliance pathways for HPWH and includes solar PV requirements for residential buildings only (see Section 3.1 for more detail). Measures based on 2019 T24 requirements will simplify compliance for the local building industry when the new T24 code is implemented on January 1, 2020.
- 2016 T24 does not include prescriptive compliance pathways for HPWH or solar PV for nonresidential buildings. Measures that require HPWH and solar PV would require building industry outreach and education efforts under either 2016 or 2019 T24. Thus, a nonresidential ordinance could be enacted earlier to begin reducing emissions earlier.

TRC investigated the following measures:

1. **Individual Water Heating Measures –** Per Carlsbad's CAP Thermal Ordinance Measure J-2, TRC investigated requiring HPWH or electric resistance water heating in nonresidential new construction under 2016 T24.
2. **Individual Solar PV Measures –** TRC investigated the following nonresidential measures under 2016 T24.
    a. New Construction – PV Ordinance Measure B-1
        i. Require a minimum of 5 kW PV for all nonresidential new construction under 10,000 ft^2
        ii. Require 15 kW PV per 10,000 ft^2 for nonresidential new construction ≥ 10,000 ft^2
    b. Alterations – PV Ordinance Measure B-2. For existing nonresidential buildings that have roof additions ≥ 2,000 ft^2 and/or with a permit valuation of ≥ $1,000,000 that affect ≥ 75 percent of the building
        i. Require a minimum of 5 kW PV on buildings < 10,000 ft^2
        ii. Require 15 kW PV per 10,000 ft^2 on buildings ≥ 10,000 ft^2
3. **Packaged Measures** – TRC packaged electric water heating and solar PV measures together.
    a. Nonresidential New Construction (2016 Title 24) – PV Ordinance Measure B-1 & Thermal Ordinance Measure J-2
        i. Require the installation of a HPWH or electric resistance water heating.
        ii. Require a minimum of 5 kW PV for all nonresidential new construction < 10,000 ft^2.
        iii. Require 15 kW PV per 10,000 ft^2 for all nonresidential new construction ≥ 10,000 ft^2.
    b. Residential New Construction (2019 Title 24) – Thermal Ordinance Measure J2
        i. Require the installation of a HPWH for domestic hot water needs.
        ii. Require 0.3 kW PV in addition to 2019 Title 24 PV requirements per HPWH.

TRC investigated electric resistance water heating in nonresidential buildings because nonresidential buildings typically have very low service hot water demand, and consequently have small tank (~15 gallons) or tankless hot water systems installed. Tankless heat pump water heaters are not yet readily available on the market, thus TRC investigated electric resistance water heaters as an alternative.

TRC developed specific measure characteristics, such as appropriate manufacturers and efficiency levels, by requiring that the measure must be readily available in the Carlsbad region and that the measure may not

trigger federal preemption. Please see *Appendix B: Cost Data* for disaggregated costs. TRC estimated the cost effectiveness of individual measures and as part of packages for relevant building types, described in *Section 4 Cost Effectiveness Results*.

3.1 Electric Water Heating

In general, heat pumps use a refrigeration cycle to absorb heat from one medium and reject heat to another medium. HPWHs have tanks and require an air supply for heat rejection, which can be either ambient or ducted. They can be installed in conditioned or unconditioned spaces, though locating a HPWH in conditioned space will impact space conditioning loads.[6] The size and shape of the HPWH is comparable to a natural gas storage water heater, and condensate draining is required. HPWHs can produce similar temperatures to natural gas water heaters under typical weather conditions but may occasionally need to switch to an electric resistance mode in cold weather.

2019 T24 offers several prescriptive paths for residential DHW compliance, including pathways for HPWHs. The prescriptive pathways in 2019 Title 24 Section 150.1(c)8, and which would yield zero TDV savings benefits by definition, are summarized below for CZ7:

1. Gas instantaneous water heater
2. Gas storage water heater < 55 gallons + low U-factor fenestration + one of:
    a. compact HW distribution or
    b. drain water heat recovery
3. Gas storage water heater > 55 gallons
4. HPWH + one of:
    a. compact HW distribution and drain water heat recovery, or
    b. 0.3 kW PV system
5. HPWH meeting Northeast Energy Efficiency Alliance (NEEA) Advanced Water Heater Specification Tier 3

Federal preemption prevents the City of Carlsbad from mandating a higher than minimum efficiency level.[7] Nonetheless, TRC simulated both federal minimum heat pump water heating and NEEA Tier 3 heat pump water heating efficiency levels to explore a variety of cost effectiveness scenarios. Tier 3 HPWH are more prevalent on the market than HPWH meeting federal minimum efficiency, and there does not appear to be a correlation between HPWH efficiency and cost. Since the federal minimum efficiency for a smaller 50-gallon water heater is electric resistance rather than heat pump equipment, both Tier 3 and federal minimum water heaters were simulated with a 66-gallon tank size to fully avoid any potential preemption concerns.

- **Relevance:** Residential and nonresidential new construction**.**
- **Baseline assumptions:** TRC assumed one water heater in the single story single-family prototype, nonresidential prototype, and each multifamily dwelling unit.[8]

[66] TRC modeled HPWHs located in conditioned space.
[7] Federal minimum efficiencies for water heaters are available at: https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8
[8] When a HPWH is selected, the CBECC-Res standard model assumes that a HPWH is in conditioned space. This impacts space conditioning loads, which are also reflected in the standard model.

- Residential: Gas tankless water heater, EF=0.82, 20-year EUL based on DEER. 125V, 20A circuit as per prescriptive T24 requirements. Floor drain required. Flushing required every five years by a service professional.
- Nonresidential:
  - Gas water heater, 15 gallons, EF=0.68, 15-year EUL based on DEER. 120V, 20A circuit. Floor drain required.

- **Proposed measure:**
  - Residential: HPWH, UEF=3.1 (NEEA Tier 3) or federal minimum efficiency (EF=2.0). 66 gallons. 15-year EUL based on DEER. 240V, 30A circuit. Located in conditioned space, non-ducted, including condensate drained to a floor drain. No additional maintenance that requires a service professional.
  - Nonresidential:
    - HPWH, UEF=3.1 (Tier 3) or federal minimum efficiency (EF=2.0), 66 gallons. Same specifications as residential HPWH above.
    - Electric storage water heater, 15 gallons, EF=0.95, 15-year EUL based on DEER. 240V, 30A circuit. Floor drain required.

Cost sources: Home Depot, Lowes, EComfort, DEER, contractor interviews.

3.2 Solar Photovoltaics

2019 Title 24 prescriptively requires installation of solar PV on residential new construction, but neither 2016 nor 2019 does so for nonresidential new construction. TRC assumed that all renewable energy would be generated on-site through a solar PV installation. This represents the highest potential upfront cost and assumes that off-site procurement would be more economical.

TRC applies savings from the federal income tax credit (ITC). Because it is schedule to be phased out between 2020 and 2022, an average ITC of 16% is used for residential systems and 19% for commercial systems. While the long-term availability of the ITC is unknown, TRC assumes that the ITC will be available during the majority of Carlsbad's local ordinance implementation.

- **Relevance:** Nonresidential new construction and alterations, residential new construction
- **Baseline assumptions:** No solar PV installed for nonresidential, prescriptive PV for residential
- **Proposed measure:**
  - Residential new construction: 0.3 kW solar PV per HPWH
  - Nonresidential new construction, and for existing nonresidential buildings that have roof additions ≥ 2,000 ft^2 and/or with a permit valuation of ≥ $1,000,000 that affect 75 percent or more of the building:
    - 15 kW solar PV per 10,000 ft^2 on buildings with gross floor area of ≥ 10,000 ft^2
    - 5 kW solar PV on buildings with < 10,000 ft^2

- **Cost sources:** NREL, LBNL[9,10]

Note that TDV savings for solar PV during time of export are calculated by assuming all TDV components except the retail adjustment.[11] The solar PV sizing definitions result the in the following PV sizes for each prototype, as show in Figure 4 below.

	Small Office	Medium Office	Warehouse	Retail Strip Mall
Gross Floor Area (ft^2)	5,502	53,628	49,495	9,375
Solar PV Rule	5 kW	15 kW/ 10,000 ft^2	15 kW/ 10,000 ft^2	5 kW
Solar PV Size	5 kW	80 kW	74 kW	5 kW

Figure 4: Nonresidential PV Sizing

[9] F. Ran et al. (September 2016) U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016. National Renewable Energy Laboratory. Available at: https://www.nrel.gov/docs/fy16osti/66532.pdf

[10] Barbose, G. and Darghouth, N. (September 2017) Tracking the Sun 10. Lawrence Berkeley National Laboratory. Available at: http://eta-publications.lbl.gov/sites/default/files/tracking_the_sun_10_report.pdf

[11] Correspondence with Environment, Energy and Economics (E3). August 5th, 2018.

4 Cost Effectiveness Results

Cost effectiveness results are presented in this section for residential and nonresidential measures, separately for new construction and alteration measures. Each measure or package cost effectiveness is provided within an individual row. Because of the impact of PV generation, net metering credits, and monthly minimum charges, an individual measure's energy impacts (both TDV and Bill) may not sum to the package. Similarly, the kWh and therms savings, multiplied by the utility rates, will not equate to the NPV bill impacts.

Cost effectiveness is determined over a 15-year or 30-year lifespan (as described in *Methodology*), including first costs, equipment replacements, maintenance, and energy savings. TRC uses a benefit to cost (B/C) ratio as the cost effectiveness metric. If the benefits of a measure are positive and greater than the costs of the measure, then the B/C ratio will be greater than 1.0 and the measure or package is considered cost effective. Within each prototype results, therms savings vary by type of water heater because water heaters are located in conditioned space and affect space heating loads slightly differently.

Results are sensitive to the assumptions outlined in *Section 3 Measure Descriptions*. Measures that are not cost effective by a few hundred dollars over a 30-year timespan may be easily switched to being cost effective (and vice versa) through minor changes in assumptions and/or changes in the policies underlying those assumptions. Cells highlighted in green emphasize that measures or packages are cost effective.

4.1 Residential New Construction

Single-family and low-rise multifamily new construction results are presented below in Figure 5 and Figure 6. Single family results represent averages of the 2,100 ft^2 and 2,700 ft^2 prototypes.

TRC analyzed new construction residential buildings for heat pump water heating with 0.3 kW PV per water heater in addition to 2019 Title 24 prescriptive PV requirements. A federal minimum efficiency HPWH paired with 0.3 kW PV is a 2019 T24 prescriptive pathway (see *Section 3.1 Electric Water Heating* item 4.b), so this package produces $0 of TDV savings. Similarly, a Tier 3 HPWH is also a 2019 T24 prescriptive compliance pathway and produces $0 of TDV savings by itself, so the TDV Savings of the Tier 3 HPWH + 0.3 kW PV are due solely to the PV system. Results in Figure 5 and Figure 6 show that the HPWH with PV measure is cost effective by using Bill B/C ratio though not by TDV B/C ratio.

Average Single Family New Construction	kWh savings	therms savings	Life cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
Federal Min. Efficiency HPWH + 0.3 kW PV	-919	104	$1,533	$0	$1,704	0.0	1.1
Tier 3 HPWH + 0.3 kW PV	-297	103	$1,533	$841	$3,146	0.5	2.1

Figure 5: Average Single-family New Construction Cost Effectiveness Summary

In the multifamily building, HPWHs with PV are cost effective using the Bill B/ C Ratio (Figure 6). Multifamily TDV Savings are approximately eight times that of single family since there are eight units in the multifamily residential prototype. Multifamily Bill Savings, however, are more than eight times greater than that of single family because the energy usage of the eight HPWHs in the multifamily building is only about five times as great as one HPWH, thus having eight times as much solar PV system has a greater net effect. The lack of a one-to-one relationship between HPWHs and energy usage can be explained in part by the smaller dwelling unit size in the multifamily prototype.

Multifamily New Construction	kWh savings	therms savings	Life cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
Federal Min. Efficiency HPWH + 0.3 kW PV	-3,244	582	$12,262	$0	$36,233	0.0	3.0
Tier 3 HPWH + 0.3 kW PV	-135	547	$12,262	$6,674	$39,385	0.5	3.2

Figure 6: Multifamily New Construction Cost Effectiveness Summary

4.2 Nonresidential

Small office, medium office, warehouse, and retail strip mall new construction and alterations results are presented below in Figure 7 through Figure 11.

4.2.1 New Construction

TRC analyzed new construction buildings for heat pump water heating and solar PV. As shown in Figure 7 through Figure 10, electric water heating alone is not cost effective by TDV or Bill B/C ratio in any nonresidential new construction case. Solar PV and solar PV + HPWH show both TDV and Bill B/C ratios greater than 1 in every case, except that of the retail strip mall with a federal minimum efficiency HPWH or electric resistance water heating.

Small Office New construction	kWh savings	therms savings	Life-cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
5 kW PV	8,190	0	$10,494	$17,595	$27,682	1.7	2.6
Federal Min Efficiency HPWH	-2,272	252	$1,619	-$1,624	-$5,281	-1.0	-3.3
Federal Min Efficiency HPWH + 5 kW PV	5,919	252	$11,857	$15,971	$22,402	1.3	1.9
Tier 3 HPWH	-1,241	249	$1,619	$900	-$1,761	0.6	-1.1
Tier 3 HPWH + 5 kW PV	6,949	249	$11,857	$18,495	$25,922	1.6	2.2
Electric Resistance WH	-2,629	248	-$939	-$2,564	-$6,550	< 1	< 1
Electric Resistance WH + 5 kW PV	5,561	248	$9,556	$15,032	$21,133	1.6	2.2

Figure 7: Small Office New Construction Cost Effectiveness Summary

Medium Office New Construction	kWh savings	therms savings	Life-cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
80 kW PV	131,764	0	$168,835	$268,099	$346,008	1.6	2.0
Federal Minimum Efficiency HPWH	-9,802	449	$1,619	-$17,121	-$36,717	-10.6	-22.7
Federal Minimum Efficiency HPWH + 80 kW PV	121,962	449	$170,198	$251,536	$309,808	1.5	1.8
Tier 3 HPWH	-6,311	433	$1,619	-$8,614	-$20,535	-5.3	-12.7
Tier 3 HPWH + 80 kW PV	125,454	433	$170,198	$259,864	$326,188	1.5	1.9
Electric Resistance WH	-14,087	495	-$939	-$27,269	-$60,700	< 1	< 1
Electric Resistance WH + 80 kW PV	117,677	495	$167,896	$241,478	$284,372	1.4	1.7

Figure 8: Medium Office New Construction Cost Effectiveness Summary

Warehouse New Construction	kWh savings	therms savings	Life-cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
74 kW PV	121,609	0	$155,823	$223,221	$272,625	1.4	1.7
Federal Minimum Efficiency HPWH	-2,673	182	$1,619	-$3,425	-$8,990	-2.1	-5.6
Federal Minimum Efficiency HPWH + 74 kW PV	118,936	182	$157,186	$220,765	$264,219	1.4	1.7
Tier 3 HPWH	-1,553	172	$1,619	-$927	-$4,493	-0.6	-2.8
Tier 3 HPWH + 74 kW PV	120,056	172	$157,186	$222,872	$268,272	1.4	1.7
Electric Resistance	-2,757	171	-$939	-$3,797	-$11,340	< 1	< 1
Electric Resistance + 74 kW PV	118,852	171	$154,885	$220,609	$262,224	1.4	1.7

Figure 9: Warehouse New Construction Cost Effectiveness Summary

Retail Strip Mall New Construction	kWh savings	therms savings	Life-cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
5 kW PV	8,190	0	$10,494	$17,583	$22,026	1.7	2.1
Federal Minimum Efficiency HPWH	-3,205	141	$1,619	-$6,445	-$7,630	-4.0	-4.7
Federal Minimum Efficiency HPWH + 5 kW PV	4,985	141	$11,857	$11,145	$14,035	0.9	1.2
Tier 3 HPWH	-1,352	127	$1,619	-$1,871	-$435	-1.2	-0.3
Tier 3 HPWH + 5 kW PV	6,838	127	$11,857	$15,716	$20,740	1.3	1.7
Electric Resistance	-4,857	138	-$939	-$11,012	-$15,791	< 1	< 1
Electric Resistance + 5 kW PV	3,333	138	$9,556	$6,577	$6,462	0.7	0.7

Figure 10: Retail Strip Mall New Construction Cost Effectiveness Summary

4.2.2 Alterations

TRC analyzed alterations buildings for solar PV. The cost of installing PV in a retrofit is approximately $0.25/W higher than new construction costs. As shown in Figure 11, solar PV remains cost effective using both TDV and Bill B/C ratios.

Alterations Prototype	kWh savings	therms savings	Life-cycle Costs	$TDV savings	$Bill savings	B/C ratio (TDV)	B/C ratio (Bill)
Small Office, 5 kW PV	8,190	0	$11,503	$17,596	$28,563	1.5	2.5
Medium Office, 80 kW PV	131,764	0	$185,057	$272,452	$453,105	1.5	2.4
Warehouse, 74 kW PV	121,609	0	$166,083	$234,348	$278,098	1.4	1.7
Retail Strip mall, 5 kW PV	8,190	0	$11,503	$17,593	$34,962	1.5	3.0

Figure 11: Nonresidential Alterations Cost Effectiveness Summary

5 Conclusions and Recommendations

TRC provides these conclusions and recommendations based on the cost-effectiveness findings.

5.1 2019 Residential New Construction

5.1.1 Heat Pump Water Heating and Solar PV – Thermal Ordinance Measure J-2

Both federal minimum efficiency and Tier 3 heat pump water heating systems, when paired with 0.3 kW of additional PV per water heater, are cost effective using a Bill B/C ratio, but not a TDV B/C ratio. This suggests that TDV rate assumptions do not align with current SDG&E utility rates.

While Tier 3 HPWH analysis was performed to provide a market-ready alternative to a federally minimum compliant HPWH, Carlsbad cannot mandate an equipment efficiency higher than the federal minimum without triggering federal preemption.[12] As described in in *Section 3 Measure Descriptions*, HPWHs are prescriptively allowed in the 2019 Title 24 through the following pathways:

- Heat pump water heater + 0.3 kW PV system
- Heat pump water heater + compact HW distribution and drain water heat recovery
- Tier 3 heat pump water heater

These cost effectiveness findings support reach code requirements for only the first implementation pathway (HPWH + PV), but the alternate pathways may also comply with the reach code:

- Some property developers may wish to install natural gas water heaters. To accommodate these developers, Carlsbad may allow natural gas water heaters to be installed when accompanied by higher efficiency measures, such as solar thermal collectors, compact hot water distribution, and/or drain water heat recovery.
- 2019 Title 24 does not describe a prescriptive path for electric resistance water heaters. Property developers can choose to install an electric resistance water heater but would have to compensate in other areas of the home through the performance path. Carlsbad may require the performance path when installing an electric resistance water heater.

TRC recommends that Carlsbad coordinate with the CEC on how to appropriately require HPWH + PV systems as a reach measure, while providing adequate options for the building community.

5.2 2016 Nonresidential New Construction

5.2.1 Solar PV – PV Ordinance Measure B-1

Solar PV on nonresidential new construction is cost effective using both the TDV and Bill B/C ratios. TRC recommends a prescriptive compliance pathway based on gross floor area which would require:

- Nonresidential new construction buildings of 10,000 ft^2 or more to install a minimum of 15 kW of solar PV per 10,000 ft^2 of gross floor area.
- Nonresidential new construction buildings less than 10,000 ft^2 to install 5 kW of solar PV.

[12] Federal minimum efficiencies for water heaters are available here: https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8

These PV sizing requirements generally fall well short of the utility limits on PV array sizes that are intended to mitigate widespread overgeneration. The only exception may be that a 5 kW PV array may generate more electricity than consumed over the course of a year in a small building (e.g., < 3,000 ft^2). Carlsbad may wish to allow smaller PV sizes or other exceptions for buildings that demonstrate that they will over generate with a 5 kW PV size.

5.2.2 Electric Water Heating – Thermal Ordinance Measure J-2

Electric water heating alone was not cost effective using either TDV or Bill B/C ratios in any nonresidential prototype. TRC does not recommend requiring electric water heating individually.

5.2.3 Solar PV and Electric Water Heating – PV Ordinance Measure B-1 & Thermal Ordinance J-2

Solar PV paired with electric water heating is cost effective using both TDV and Bill B/C ratios in every nonresidential prototype, except in the retail strip mall. The retail strip mall is cost effective with a HPWH and solar PV using the Bill B/C ratio, but not the TDV B/C ratio, because it has a very small hot water heating load.

TRC recommends that Carlsbad provide property developers with options of different types of water heating technologies while making heat pump water heaters the default choice. Carlsbad may choose to require other efficiency measures (e.g., solar thermal) whenever a natural gas water heater is installed and require the performance path when electric resistance water heater is installed.

There City of Carlsbad may seek to develop policy for two building types that that were not investigated directly in this study:

1. **High rise multifamily buildings**: Because CBECC-Res and CBECC-Com hot water simulation algorithms are identical for low-rise or high-rise multifamily dwelling units, TRC suggests that low-rise multifamily family building results may also be applicable to high-rise multifamily buildings that have individual water heaters at each dwelling unit. TRC found that in low-rise multifamily buildings with individual heat pump water heaters at each dwelling unit, plus PV, was cost effective.
2. **Service water heating in restaurants**: While a restaurant prototype was not studied in-depth, cost effectiveness trends in Figure 5 through Figure 10 indicate that heat pump water heaters plus PV are cost effective with higher hot water demands (i.e., therms savings). For example, the Retail Strip Mall had the lowest hot water consumption and was less cost effective than the other scenarios. The 2,500 ft^2 small restaurant prototype service hot water system has a hot water demand (~600 therms/year) slightly higher than the prototypes analyzed in this study (e.g., medium office with ~450 therms/year). Thus, it is probable that service water heating in restaurants would also be cost effective with HPWH + PV.

5.3 2016 Nonresidential Alterations

5.3.1 Solar PV – PV Ordinance Measure B-2

Solar PV on nonresidential alterations is cost effective using both a TDV and Bill B/C ratio. TRC recommends a prescriptive compliance pathway based on gross floor area which would require nonresidential buildings that have roof additions ≥ 2,000 ft^2 and/or with a permit valuation of ≥ $1,000,000 that affect ≥ 75 percent of the building to install a minimum of:

- 5 KW PV on buildings < 10,000 ft^2
- 15 kW of solar PV per 10,000 ft^2 of gross floor area on buildings on buildings ≥ 10,000 ft^2

Appendix A: Prototype Details

New construction prototypes baseline characteristics are summarized in Figure 12 and Figure 13, and they are based on prescriptive 2019 T24 requirements.

Building Type	One-Story	Two-Story	Low-Rise Multifamily
Dwelling Units	1	2	8
Area (ft^2)	2,100	2,700	6,960
Roof Area (ft^2)	2,540	1,690	3480
# of floors	1	2	2
Window-to-Floor Area Ratio	20%	20%	15%
HVAC System	Central Ducted Split Air Conditioner with Gas Furnace		
HVAC Distribution System	Ducts in Attic	Ducts in Attic	Ducts in Conditioned Space
Thermal Zones	1	1	2
Domestic Water Heating	Natural Gas Tankless Water Heater, 0 Gallon Tank, EF=0.82		8x Natural Gas Tankless Water Heater, 0 Gallon Tank, EF=0.82

Figure 12: Residential Baseline Prototypes Summary

Building Type	Medium Office	Small Office	Warehouse	Retail Strip Mall
Floor Area (ft2)	53,628	5,502	49,495	9,375
# of Floors	3	1	1	1
Window-to-Floor Area Ratio	13%	11%	0.4%	6%
HVAC Distribution System	3x Packaged Variable Air Volume with VAV Hot Water Reheat	5x Packaged Single Zone Air Conditioners	3x Packaged Single Zones	4x Packaged Single Zone Air Conditioners
Cooling System	Direct Expansion, 9.8 EER, Economizer	Direct Expansion, 13 SEER, No Economizer	Direct Expansion, 11.0 EER, Economizer	Direct Expansion, 11.0 EER, Economizer
Heating System	Boiler, 80% Thermal Efficiency	Furnace, 78% AFUE	Furnace, 78% AFUE	Furnace, 78% AFUE
Conditioned Thermal Zones	18	5	3	4
Domestic Water Heating	Natural Gas Small Storage, EF = 0.64	Natural Gas Small Storage, EF = 0.71	Natural Gas Small Storage, EF = 0.67	Natural Gas Small Storage, EF = 0.65

Figure 13: Nonresidential Baseline Prototypes Summary

Figure 14 and Figure 15 compare the building characteristics for new construction and alteration scenarios. TRC simulated alteration prototypes with "pre-code" conditions according to the Residential Compliance Manual Appendix B to estimate the energy impact of measures in alteration scenarios.[13] Generally, we assumed building characteristic that pre-date code without substantial upgrades. While lighting or fenestration upgrades are likely over time, we used pre-code characteristics to represent the highest potential energy usage in the building stock, while the new construction code represent the lowest potential energy usage.

The differences between pre-code and new construction nonresidential prototypes applies to envelope characteristics and lighting power density (see Figure 15); while for residential prototypes, the differences apply to HVAC characteristics as well.

[13] Available at: http://www.energy.ca.gov/2015publications/CEC-400-2015-024/CEC-400-2015-024-CMF-REV3.pdf

	Component	Pre-Code	New Construction (2019 T24)
Envelope	Attic Insulation (R-value)	13	38
	Radiant Barrier	No	Yes
	Below Roof Deck Insulation (R-value)	0	19
	Window U-Factor	1.28	0.30
	Window SHGC	0.80	0.23
	Infiltration ACH50	10	5
Lighting	Power Adjustment Multiplier	0.63	0.63
	Fraction Portable	0.22	0.22
HVAC	Duct Location	Attic	Attic
	Duct Leakage	10%	5%
	HERS Verified Duct Sealing	No	No
	Duct Insulation (R-value)	2.1	8.0
	IAQ Fan W/cfm	None	0.25
	Whole House Fan	No	No

Figure 14: Residential Pre-code and New Construction Assumptions

Component	Pre-Code	New Construction (2016 T24)
Roof Insulation (R-Value)	8	19.63
Roof Solar Reflectance	0.10	0.63
Wall Insulation (R-Value)	0	14
Window U-Factor	1.23	0.36
Window SHGC	0.71	0.25
Window VT	0.60	0.42
Lighting Power Density (W/ft^2)	1.2	0.75

Figure 15: Nonresidential Pre-code and New Construction Assumptions

Appendix B: Cost Data

Heat Pump Water Heating

Residential: New Construction				
HP Water Heater	***Single-Family***		***Multifamily***	
Cost Type	**Baseline**	**Proposed**	**Baseline**	**Proposed**
First Cost	$2,494	$3,158	$19,951	$25,264
Water Heater	*$789*	*$1,713*	*$6,312*	*$13,704*
Installation	*$1,017*	*$945*	*$8,136*	*$7,560*
Flue	*$313*	*$0*	*$2,504*	*$0*
Electrical	*$375*	*$500*	*$3,000*	*$4,000*
Replacement	$1,806	$2,658	$14,451	$21,264
Maintenance (per year)	$59	$0	$474	$0
EUL (years)	20	15	20	15

Figure 16. Residential New Construction Heat Pump Water Heating Costs

Nonresidential: New Construction		
HP Water Heater	***All Prototypes***	
Cost Type	**Baseline**	**Proposed**
First Cost	$1,919	$2,658
Water Heater	*$941*	*$1,713*
Installation	*$666*	*$945*
Flue	*$313*	*$0*
Replacement	$1,606	$2,658
Maintenance	$0	$0
EUL (years)	15	15

Figure 17. Nonresidential New Construction HPWH Costs

Electric Resistance Water Heating

Nonresidential: New Construction		
Electric Resistance Water Heater	***All Prototypes***	
Cost Type	**Baseline**	**Proposed**
First Cost	$1,794	$1,100
Water Heater	*$600*	*$600*
Natural Gas Piping	*$550*	*$0*
Flue	*$313*	*$0*
Electrical	*$331*	*$500*
Replacement	$600	$600
EUL (years)	15	15

Figure 18. Nonresidential New Construction Electric Resistance Water Heater Costs

Solar PV Measures

Residential: New Construction				
PV	***Single-Family***		***Multifamily***	
Cost Type	**Baseline**	**Proposed**	**Baseline**	**Proposed**
PV Size	0 kW	0.3 kW	0 kW	2.4 kW
First Cost	$0	$738	$0	$5,907
Cost	$0	$879	$0	$7,032
ITC	$0	$(141)	$0	$(1,125)
1st Inverter Replacement	$0	$45	$0	$360
2nd Inverter Replacement	$0	$36	$0	$288
Maintenance (per year)	$0	$6	$0	$48
Inverter EUL (years)	n/a	11	n/a	11

Figure 19. Residential Now Construction Solar PV Costs

Nonresidential: New Construction						
PV	*Small Office/ Retail Strip Mall*		*Medium Office*		*Warehouse*	
Cost Type	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
PV Size	0 kW	5 kW	0 kW	80 kW	0 kW	74 kW
First Cost	$0	$8,591	$0	$138,215	$0	$127,653
Cost	$0	$10,650	$0	$171,341	$0	$158,137
ITC	$0	$(2,059)	$0	$(33,126)	$0	$(30,573)
1st Inverter Replacement	$0	$750	$0	$12,066	$0	$11,136
2nd Inverter Replacement	$0	$600	$0	$9,653	$0	$8,909
Maintenance	$0	$100	$0	$1,609	$0	$1,485
Inverter EUL (years)	n/a	11	n/a	11	n/a	11

Figure 20. Nonresidential New Construction Solar PV Costs

Nonresidential: Alterations								
PV	*Small Office*		*Medium Office*		*Warehouse*		*Retail Strip Mall*	
Cost Type	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
PV Size	0 kW	5 kW	0 kW	80 kW	0 kW	74 kW	0 kW	5 kW
First Cost	$0	$9,599	$0	$154,438	$0	$137,824	$0	$9,599
Cost	*$0*	*$11,900*	*$0*	*$191,452*	*$0*	*$176,697*	*$0*	*$(2,301)*
ITC	*$0*	*$(2,301)*	*$0*	*$(37,014)*	*$0*	*$(38,873)*	*$0*	*$(2,301)*
1st Inverter Replacement	$0	$750	$0	$12,066	$0	$11,136	$0	$750
2nd Inverter Replacement	$0	$600	$0	$9,653	$0	$8,909	$0	$600
Maintenance	$0	$100	$0	$1,609	$0	$1,458	$0	$100
Inverter EUL (years)	n/a	11	n/a	11	n/a	11	n/a	11

Figure 21. Nonresidential Alterations Solar PV Costs