DOCKETED

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Project Title:	2022 Energy Code Pre-Rulemaking
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Document Title:	Presentation - 2022 Pre-Rulemaking for Building Energy Efficiency Standards
Description:	by Payam Bozorgchami, P.E. - Staff and Contractor Presentations at the October 6, 2020 Energy Code Workshop. - October 6, 2020 Staff Workshop Presentations on PV and Electrification
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Docketed Date:	10/7/2020

2022 Pre-Rulemaking for Building Energy Efficiency Standards

Payam Bozorgchami, P.E.

October 6, 2020

Start Time: 9:00 AM

What We Will Covering Today

- Opening Comments from Commissioner McAllister
- Key Information on the Development of Title 24, Part 6
- **Mazi Shirakh, P.E.**
  - General Overview of Heatpump Baselines and PV/Battery Storage Requirements for HRMF and Selected Nonresidential Buildings
- **NORESCO**
  - Highrise Multifamily (HRMF) Heatpump Baseline
  - Nonresidential Heatpump Baselines
- **NORESCO & E3**
  - HRMF and Nonresidential PV and Battery Storage
- **Mazi Shirakh, P.E.**
  - Cleanup Language
    - Section 150.1(c)14 Exceptions
    - New Exception to Section 150.1(c)14
    - JA11 and JA12
    - Section 10-115, Community Solar Language
    - Section 10-109, PV System Requirements

2022 Standards Process

2022 STANDARDS UPDATE SCHEDULE	
DATE	**MILESTONES**
November 2018 - November 2019	Updated Weather Files
November 2018-December 2019	Metric Development
November 2018-July 2019	Measures Identified and approval
August 2019 to October 2020	Stakeholder meeting/workshop & final staff workshop
August 2020-October 2020	CASE Reports submitted to the CEC
February 2021	45-day Language Hearings
July 2021	Adoption of 2022 Standards at a Business Meeting
July 2021 to November 2021	Staff work on Software, Compliance Manuals, Electronic Documents Available to Industry
December of 2021	Approval of the Manuals
January 2022	Software, Compliance Manuals, Electronic Documents Available to Industry
January 1, 2023	Effective Date

Tentative Pre-Rulemaking Schedule

- **September 1**
  - Energy Savings and Process Improvements for Alterations and Additions
    - Roof deck insulation for low-slope roofs
    - Prescriptive attic insulation for alterations
    - Prescriptive duct sealing
    - Electric resistance water heating
    - Electric resistance space heating
    - 40-ft trigger for prescriptive duct requirements
    - Cool roof for steep-slope roofs
    - Cool roof for low-slope roof
- **September 9**
  - Nonresidential Grid Integration
  - Controlled Receptacle, CEA Proposal
- **September 10**
  - Verification Testing
- **September 22**
  - Outdoor lighting
  - Daylighting
- **September 23**
  - Computer Room Efficiencies
  - Pipe Sizing and Leak Testing for Compressed Air Systems
  - Refrigeration System Operation

Tentative Pre-Rulemaking Schedule (Cont.)

- **September 30**
  - Indoor Air Quality Roundtable discussion with the outside world
- **October 6 and November 19**
  - Solar Photo Voltaic and Electrification
  - Multifamily All Electric
- **October 7**
  - Nonresidential Indoor Lighting
  - Air Distribution
  - Nonresidential HVAC Controls
- **October 13**
  - Multifamily Domestic Hot Water
  - Multifamily Restructuring
- **October 20**
  - Nonresidential High Performance Envelope
- **October 27**
  - Control Environmental Horticulture
  - New Construction Steam Trap
- **October 29 Place holder (Commissioner roundtable discussion on September 30 on IAQ)**
  - Indoor Air Quality

Key Web-Links

2022 Title 24 Utility-Sponsored Stakeholder
http://title24stakeholders.com/

Building Energy Efficiency Program
http://www.energy.ca.gov/title24/

Comments to be submitted to:
https://efiling.energy.ca.gov/EComment/EComment.aspx?docketnumber=19-BSTD-03

NOTE: For this workshop comments To Be Submitted By October 20, 2020

Building Standards Staff Contact Information – Energy Commission

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Comments For Todays Workshop

Due Date: October 20, 2020 By 5:00 PM

Comments to be submitted to:
https://efiling.energy.ca.gov/EComment/EComment.aspx?docketnumber=19-BSTD-03

Questions ?

Thank You!

2022 Building Energy Efficiency Standards Overview

October 6, 2020 Staff Workshop

Heatpump Baselines and PV Requirements

Mazi Shirakh, PE: Building Decarbonization Lead

2022 T24 Standards Building Decarbonization Team

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Building Decarbonization Lead

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Senior Technical and Program Advisor

Larry Froess, PE
Senior Engineer

Danny Tam
Mechanical Engineer

Payam Bozorgchami, PE
Project Manager, Building Energy Efficiency Standards

Will Vicent
Office Manager, Building Standards Office

Consulting Team:

Energy + Environmental Economics (E3)
NORESCO
TRC

Heatpump Baseline and PV/Storage Workshops

Two workshops, twice the fun:

There are two workshops scheduled for heatpump baselines and nonresidential PV and battery storage requirements:

October 6, 2020

- High level overview of the proposed requirements for heatpump baseline scenarios and PV and storage requirements; will only include “TDV” and not “source energy” baseline options
- Draft language will not be presented today
- Seek public input for concepts presented
- Comments due to Commission by COB October 20

November 19, 2020

- Draft language and detailed analysis will be presented
- Will include both “source energy” and “TDV” baselines
- After seeking further public comments, will become the basis for 45-day language

2022 T24 Standards Goals

Heatpump Baselines For:

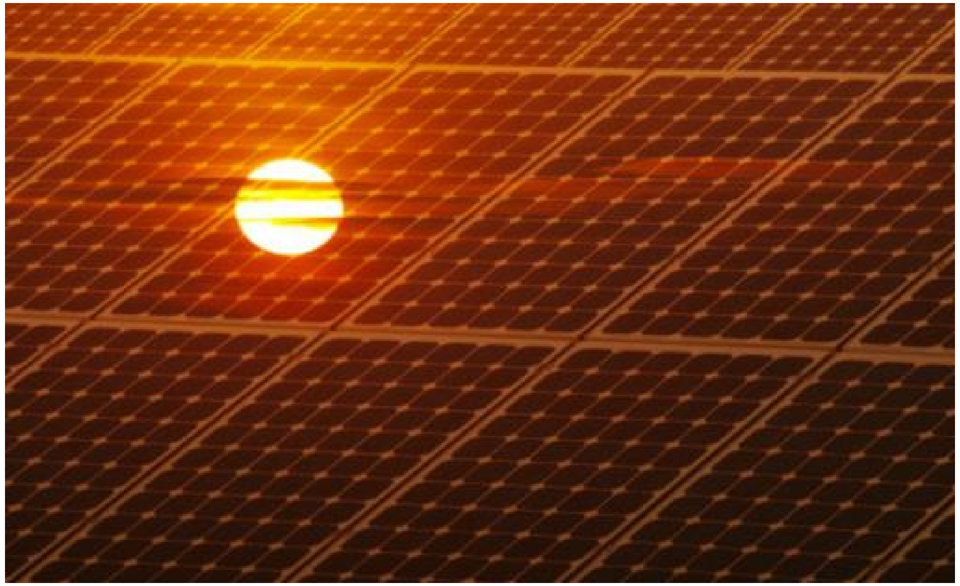
1. Lowrise Residential Buildings
2. Highrise Multifamily
3. Selected Nonresidential Occupancies

PV and Battery Storage Requirements For:

1. HRMF
2. Selected Nonresidential Occupancies

2022 T24 Standards Occupancies

New Electrified Baselines and PV Requirements for:



1. LRMF and HRMF
2. Office
3. Retail and Wholesale
4. Educational facilities
5. Warehouses
6. Mixed occupancy building where one or more of these types-of-uses makeup at least 80 percent of the floor areas of the building

Heatpump Baselines

Heatpump for space and water heating in the baseline for:

- HRMF and selected nonresidential occupancies
- Establish appropriate source energy and TDV baselines
- Must be feasible and cost effective

Creating feasible and cost-effective heatpump baselines may be a significant challenge for some occupancies

PV & Battery Storage Requirements

PV and Possibly Battery Storage Requirements for HRMF and Selected Nonresidential Occupancies:

1. Considering NEM2 and alternative NEM tariffs with hourly exports compensated at avoided cost
2. Emphasize maximizing self-utilization of PV generation and minimizing exports thru:
   i. "Right sizing" the PV system to avoid large exports
   ii. Coupling with battery storage, EV charging, and other load-shifting strategies to maximize self-utilization
3. Possible credit for standalone battery storage systems

Availability of suitable rooftop areas for PV installation may be a limiting factor

Heatpump Baseline For Lowrise Residential Buildings

For Part 6:

- Create a ~2 EDR credit (plus credit for T4 HPWH and DR) for builders who voluntarily switch to both HPWH and HPSH
  - ✓ Make R13 roofdeck insulation mandatory requirement
  - ✓ Make 0.064 U-factor walls mandatory requirement
- The mixed-fuel baseline will not be affected

For Part 11 (Calgreen):

- Include HPWH and more efficient windows in the standard design
  - ✓ HPWH and HPSH can also comply
  - ✓ Make R13 roofdeck insulation mandatory requirement
  - ✓ Make 0.064 U-factor walls mandatory requirement

Battery Storage Ready

New residential mandatory battery storage ready requirements

1. Panel requirements to accommodate electric end-uses, PV, EVs, and future battery storage installation

2. Identification and isolation of emergency circuits

3. Compatibility with both battery storage systems and backup generators to help with PSPS events

Will reduce the future battery storage installations by $2,000 or more

Cleanup Language

2022 Building Standards Cleanup

1. Make sure PV sizing equation 150.1(c) is consistent with 2022 TDVs
2. New exception for PVs systems that are less than 2.0 kWDC per building
   - ✓ May also address the ADU issue
3. Exception 1 - PV systems are not required to be larger than what can be installed in the Available Effective Annual Solar Access Area (EASAA); clarify the what happens when EASAA is greater than 80 square feet, but smaller than the area required for full NEM compliance
4. Exceptions 2 (CZ15), 3 (2-story buildings), 4, (3-story buildings) – Do we still need these Exceptions given items 2 and 3 above?
5. New Exception for occupied roofs (flat patio areas) - Consider referring to Part 2 provisions for occupiable roofs
6. New Exception for areas for high snow loads

Cleanup Continued

7. 10-109(k) PV Determinations - Review to determine whether this language needs to be clarified or amended
8. 10-115 Community Solar - Review to determine whether this language needs to be clarified or amended; consider lessons learned from SMUD CS application and interactions with the IOUs
9. Other changes proposed by stakeholders?

Cleanup Continued

11. **JA 11:**

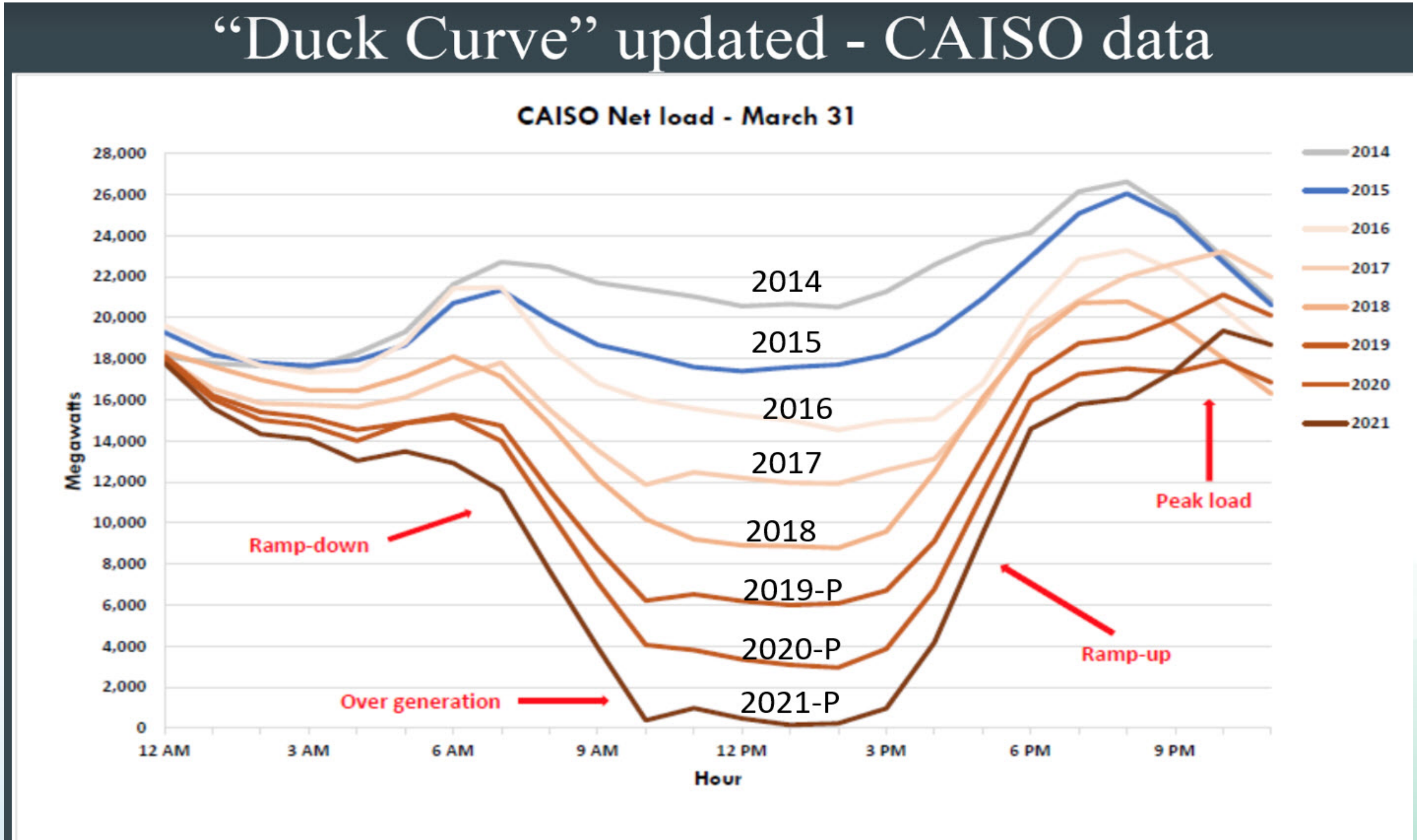
    i. Clean up language on system orientation, there is some confusion on the prescriptive and performance requirements
    ii. Solar assessment tool - Amend language based on lessons learned from prior approval of solar assessment tools: create clear list of functions needed for approval
    iii. Clearly define in Part 6 “Annual Solar Access”, “Effective Annual Solar Access”, and “Effective Annual Solar Access Areas”; how about EASAA facing north?
    iv. Others?

Cleanup Continued

12. **JA 12:**
    i. Allow credit for standalone battery storage systems
    ii. Revisit roundtrip efficiency
    iii. Revisit control strategies requirements: Basic, TOU, and Advanced DR
    iv. Others?

Why Batteries? Bad Duck

2018 Oversupply and Ramping: A challenge as more renewables are integrated into the grid



Solutions
Target energy efficiency
Increase storage and demand response
Enable economic dispatch of renewables
Decarbonize transportation fuels
Retrofit existing power plants
Align time-of-use rates with system conditions
Diversify resource portfolio
Deepen regional coordination

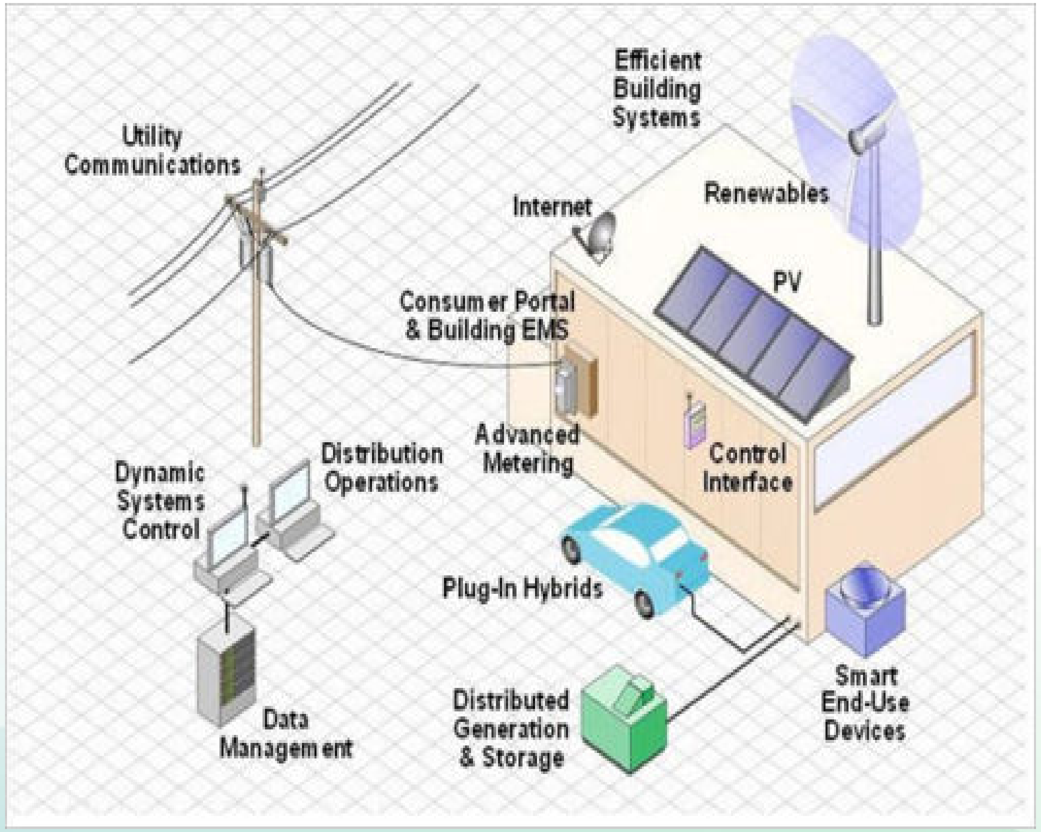
Grid Harmonization

Grid harmonization strategies (GHS) when coupled with customer owned PV systems bring maximum benefits to the grid, environment, and occupants

Grid Harmonization Strategies Defined:

Grid Harmonization are strategies and measures that allow the home occupants to use their energy assets to maximize self-utilization of PV array output, and limit grid exports to periods beneficial to the grid and the ratepayer;

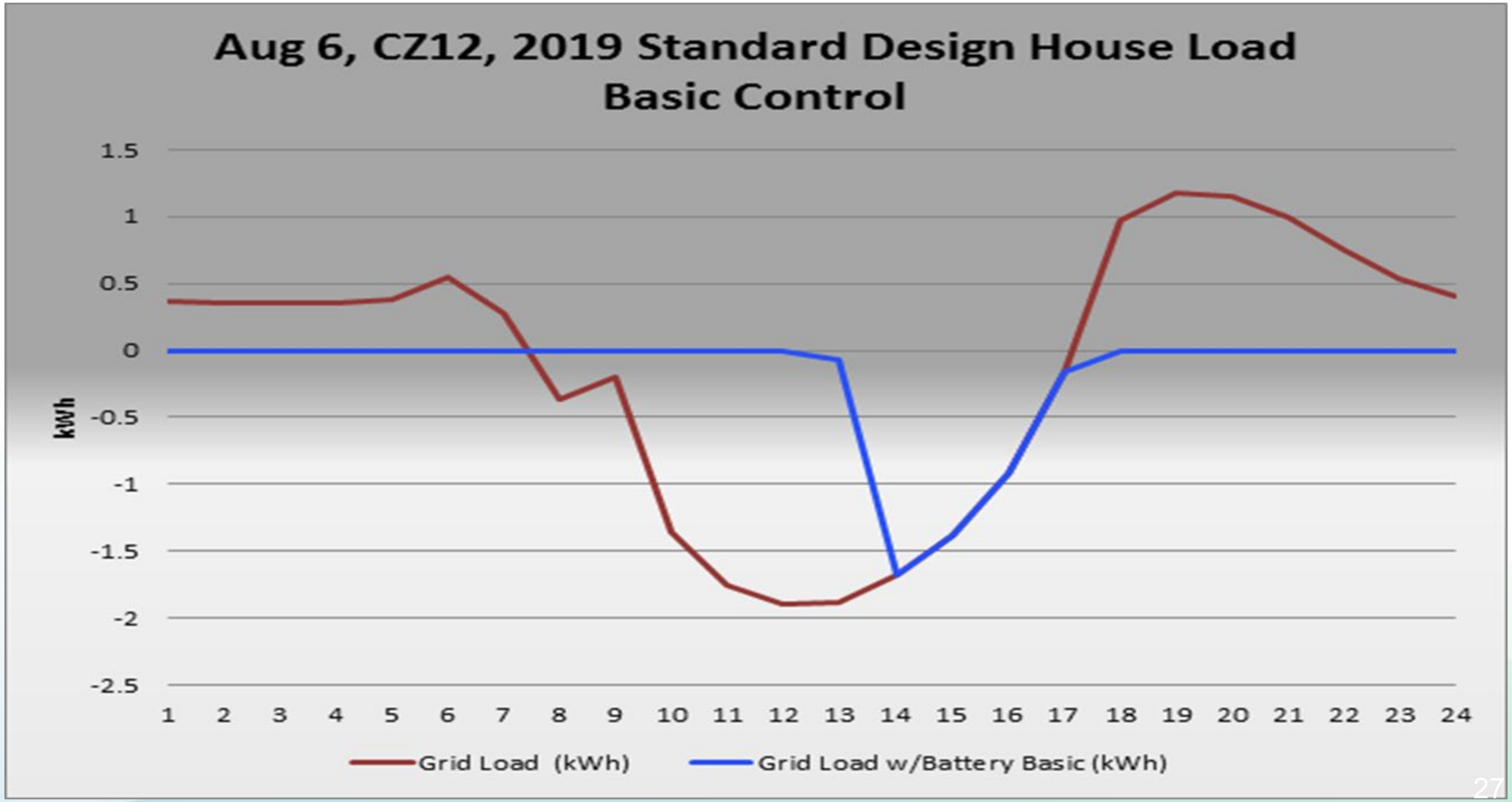
Examples of GHS include but are not limited to PVs in combination with battery storage, demand response, thermal storage, and in the future Electric Vehicle (EV) harmonization.



Good Duck

The Invisible House - PV Plus Basic Battery – A "Mild" Summer Day

"Annual" netting assumes all hours of the day/year have the same emission and energy cost values, not a correct assumption - Blue line smooths out the belly of the duck and achieves zero carbon and zero energy without resorting to netting



Questions?

Title 24 2022 ACM: Electric Baseline Analysis
High-Rise Residential Buildings

October 6, 2020

Nikhil Kapur

NORESCO

OBJECTIVES

- Identify all-electric HVAC systems for consideration as 2022 ACM Baselines
- Evaluate performance relative to current ACM Baselines
  - All current baselines use gas heat
  - TDV expected to increase when switching to electric heat
- Improved glazing options also considered for inclusion

APPROACH

- Use CEC prototype
  - 10 Story High-rise Residential
- Service and Domestic Hot Water Systems – Electric Only

ELECTRIC BASELINE SYSTEM OPTIONS

	Current Baseline	Systems Analyzed
Highrise Residential Dwelling Units*	Single Zone Air Conditioner with Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump w/ Gas Supplemental Heat ▪ Variable Refrigerant Flow ▪ Water Source Heat Pump w/ Elec. Boiler
Ventilation	Balanced Ventilation	Balanced Ventilation
*HVAC systems for nonresidential spaces were modeled to match the baseline for all options		

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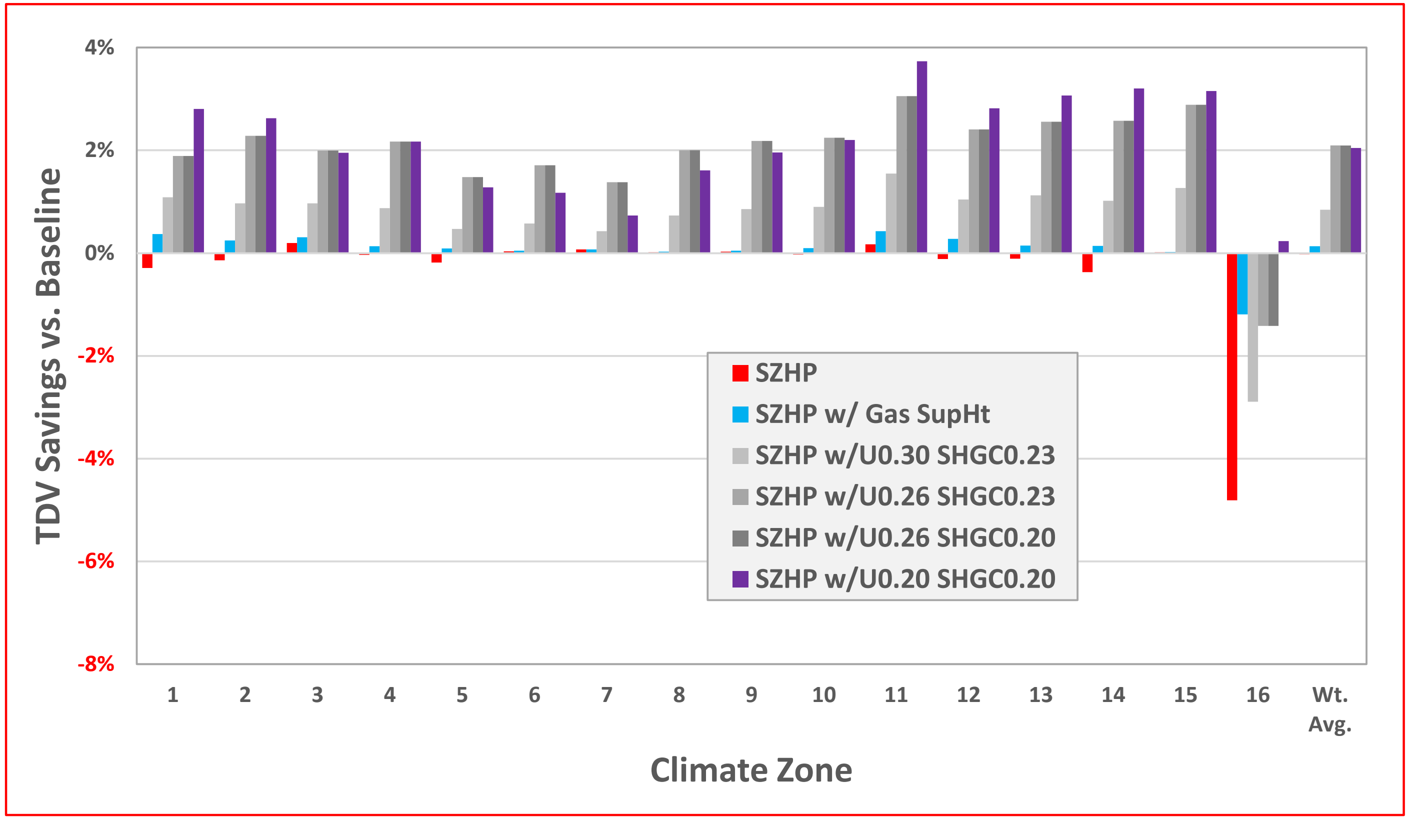
RESULTS

High-Rise Residential

- Baseline is Single Zone Air Conditioner (SZAC) with gas furnace
- Heat pump gives TDV results close to baseline, but negative savings in many climate zones
- Switch to gas supplemental heat provides TDV savings in all zones except CZ16
- SZHP with improved glazing, particularly lower U-factor, can achieve savings in all climate zones



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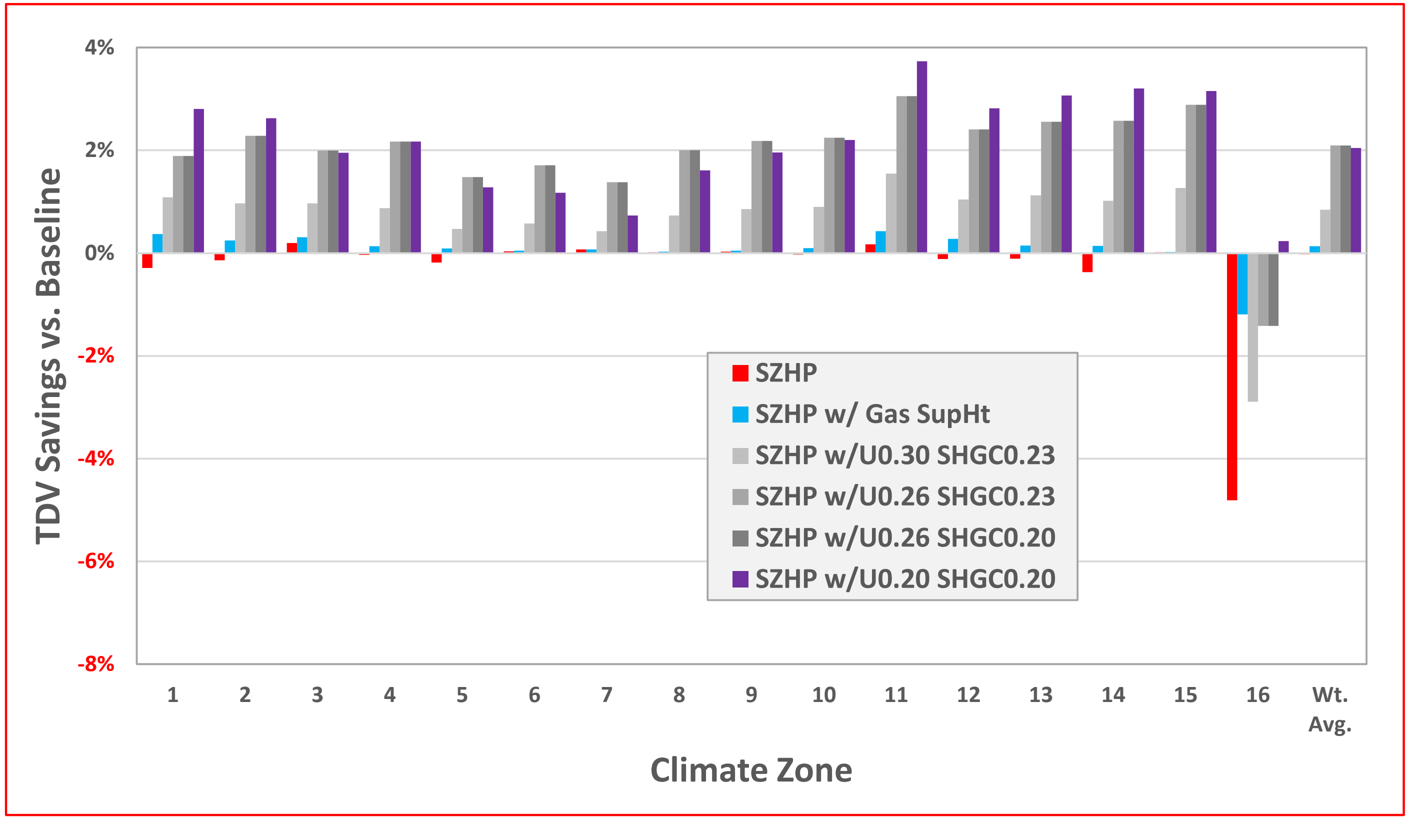
High-Rise Residential

- Heat pump with electric supplemental heat in all climate zones
  - U-Factor 0.36 glazing (current baseline) in CZ3, 6, 7, 8, 9, 11 and 15
  - U-factor 0.30 glazing in CZ1, 2, 4, 5, 10, 12, 13, and 14
  - U-factor 0.20 glazing in CZ 16
- Alternatively for CZ16, gas supplemental heat and U-factor 0.30 glazing



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Title 24 2022 ACM: Heat Pump Baseline Analysis – Nonresidential Buildings

October 6, 2020

Roger Hedrick, Eric Shadd,
Rahul Athalye

NORESCO

OBJECTIVES

- Identify heat pump based HVAC systems for consideration as 2022 ACM Baselines
- Evaluate performance relative to current ACM Baselines
  - All current baselines use gas heat
  - TDV expected to increase when switching to electric heat
- Identify systems that have lower TDV consumption, but result in a minimal increase in stringency
  - A new baseline with higher TDV consumption would decrease stringency for projects with electric heat
  - Systems with large differences from the baseline in TDV consumption are excluded from the results that will follow

NORESCO

APPROACH

- Use CEC prototypes
  - Office – Small, Medium and Large
  - Retail – Small, Medium and Large
  - Small Restaurant
  - Small School
  - Warehouse
- Service and Domestic Hot Water Systems – Electric Only
- Cooling parameters match baseline
  - Federal standards may impact this if baselines change in CBECC-Com
- Fan parameters also match baseline
- For similar system types, impacts are due to heating type only.

ALTERNATIVE SYSTEM OPTIONS

	Current Baseline	Systems Analyzed
Small Office	Single Zone Rooftop – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Supplemental Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat ▪ Variable Refrigerant Flow + DOAS
Medium Office	Packaged Variable Air Volume – Hot Water Heat with Gas Boiler	▪ Packaged VAV – Electric Resistance Reheat ▪ Packaged VAV – Electric Reheat & Parallel Fan Boxes ▪ Packaged VAV w/ Heat Pump Boiler ▪ Variable Refrigerant Flow + DOAS ▪ Water Source Heat Pump w/ Elec. Boiler + DOAS
Large Office	Built-Up Variable Air Volume – Hot Water Heat with Gas Boiler	▪ Variable Air Volume (VAV) w/ Elec. Reheat ▪ VAV w/ Electric Reheat & Parallel Fan Boxes ▪ VAV w/ Heat Pump Boiler ▪ Water Source Heat Pump w/ Elec. Boiler + DOAS

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ALTERNATIVE SYSTEM OPTIONS

	Current Baseline	Systems Analyzed
Small Retail	Single Zone and Single Zone Variable Air Volume (VAV) – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Sup. Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat
Medium Retail	Single Zone and Single Zone VAV – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Sup. Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat
Large Retail	Single Zone VAV – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Sup. Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat

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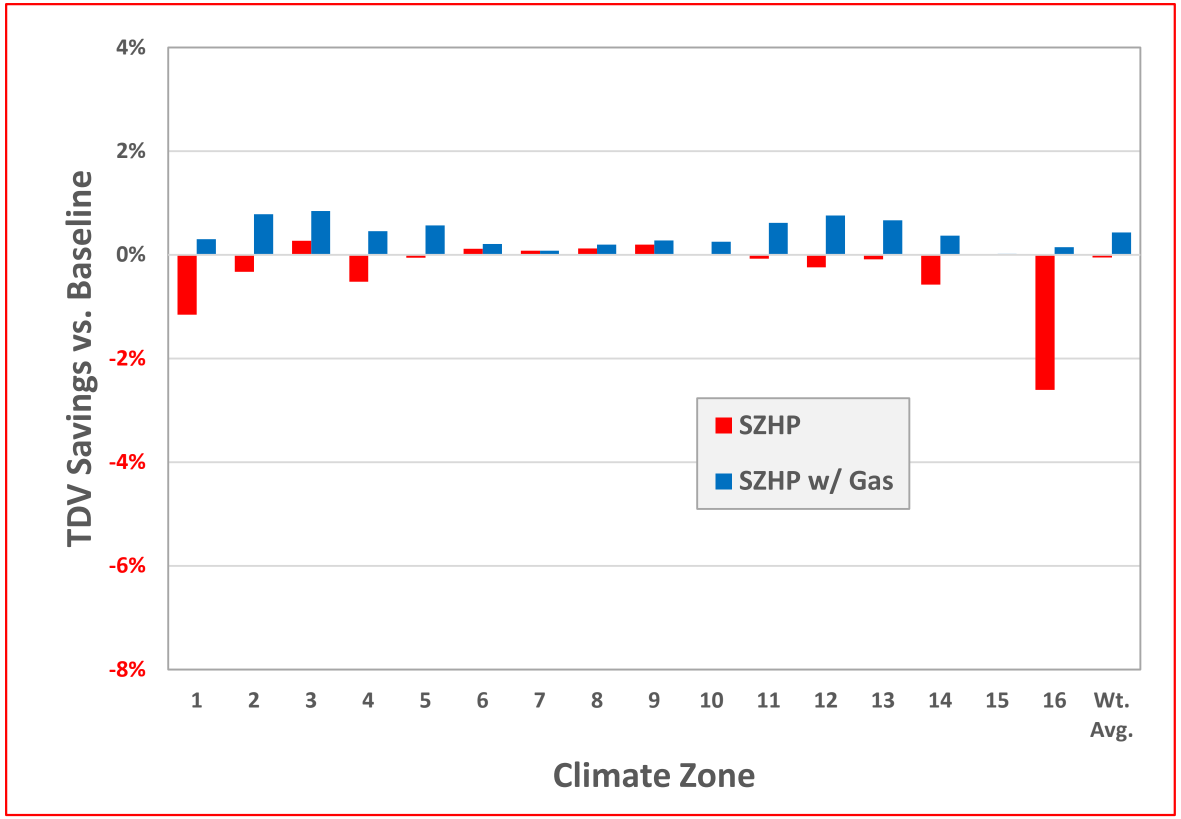
ALTERNATIVE SYSTEM OPTIONS

	Current Baseline	Systems Analyzed
Restaurant (Small)	Single Zone and Single Zone VAV – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Sup. Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat
School (Small)	Single Zone and Single Zone VAV – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Sup. Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat ▪ Packaged VAV – Electric Resistance Reheat ▪ Packaged VAV – Electric Reheat & Parallel Fan Boxes ▪ Variable Refrigerant Flow ▪ Water Source Heat Pump w/ Elec. Boiler + DOAS
Warehouse	Single Zone VAZ (Office), Heating Ventilating System (Storage) – Gas Furnace Heat	▪ Single Zone Heat Pump ▪ Single Zone Heat Pump with Gas Sup. Heat ▪ Single Zone VAV Heat Pump ▪ Single Zone VAV Heat Pump with Gas Sup. Heat

RESULTS

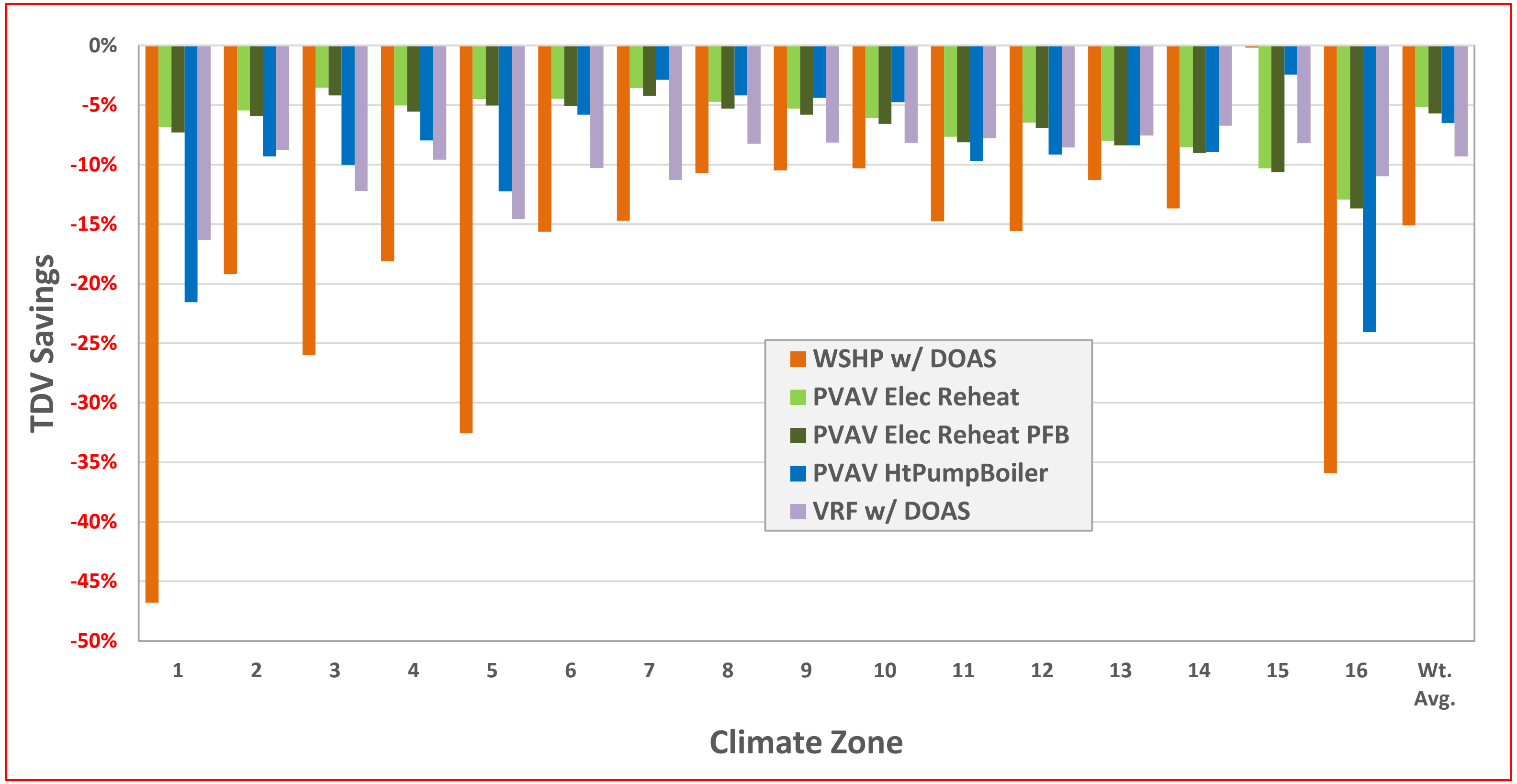
Small Office

- Baseline is single zone air conditioners (SZAC) with gas furnace heat
- Changing furnace to heat pump heat - small reduction in TDV in some climate zones, small increase in others
- Changing supplemental heat to gas gives TDV savings in all CZ



Medium Office

- Baseline is Packaged VAV with hot water reheat from a gas boiler
- Electric reheat options increase TDV
- Heat Pump Boiler and VRF models do not provide TDV savings



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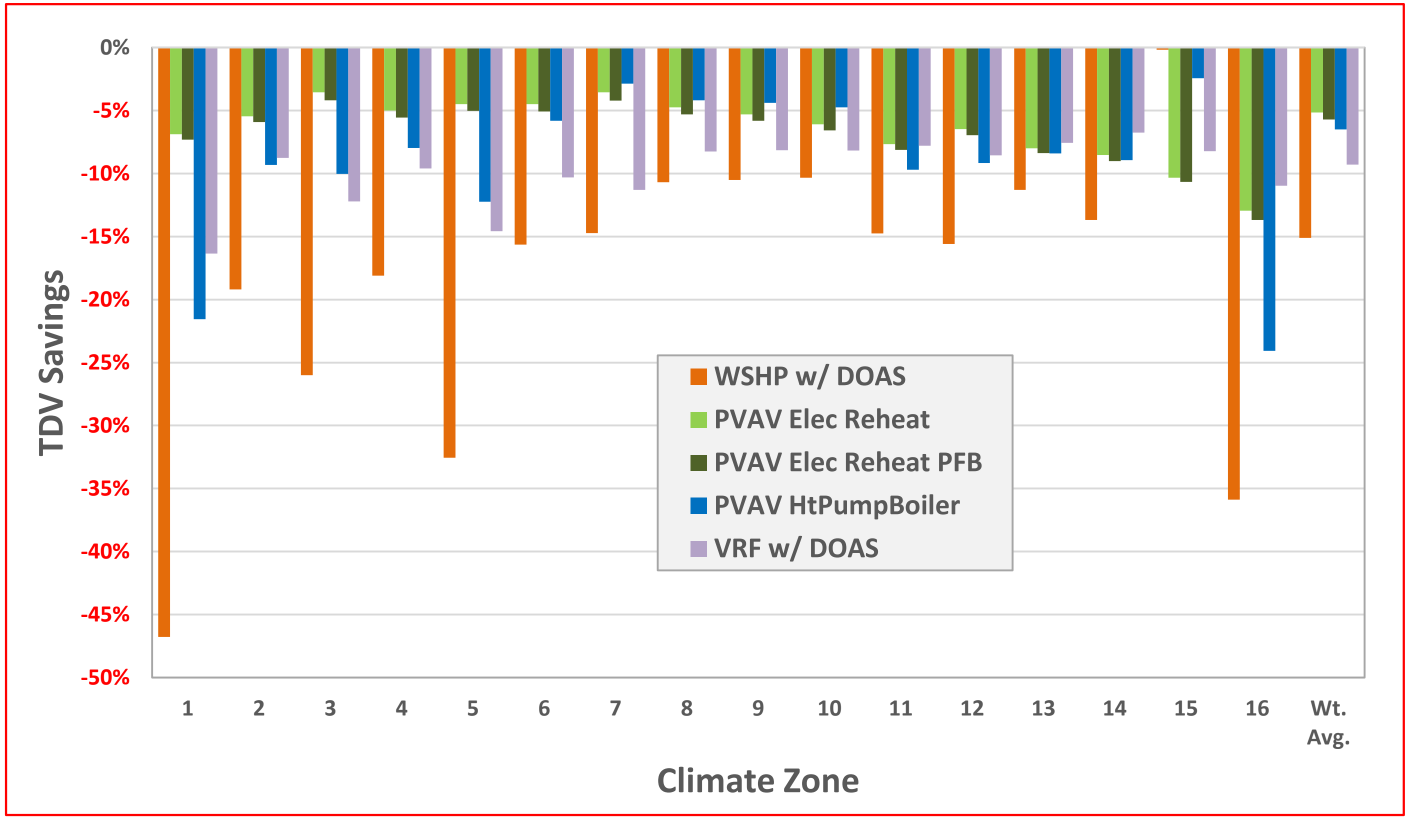
RESULTS

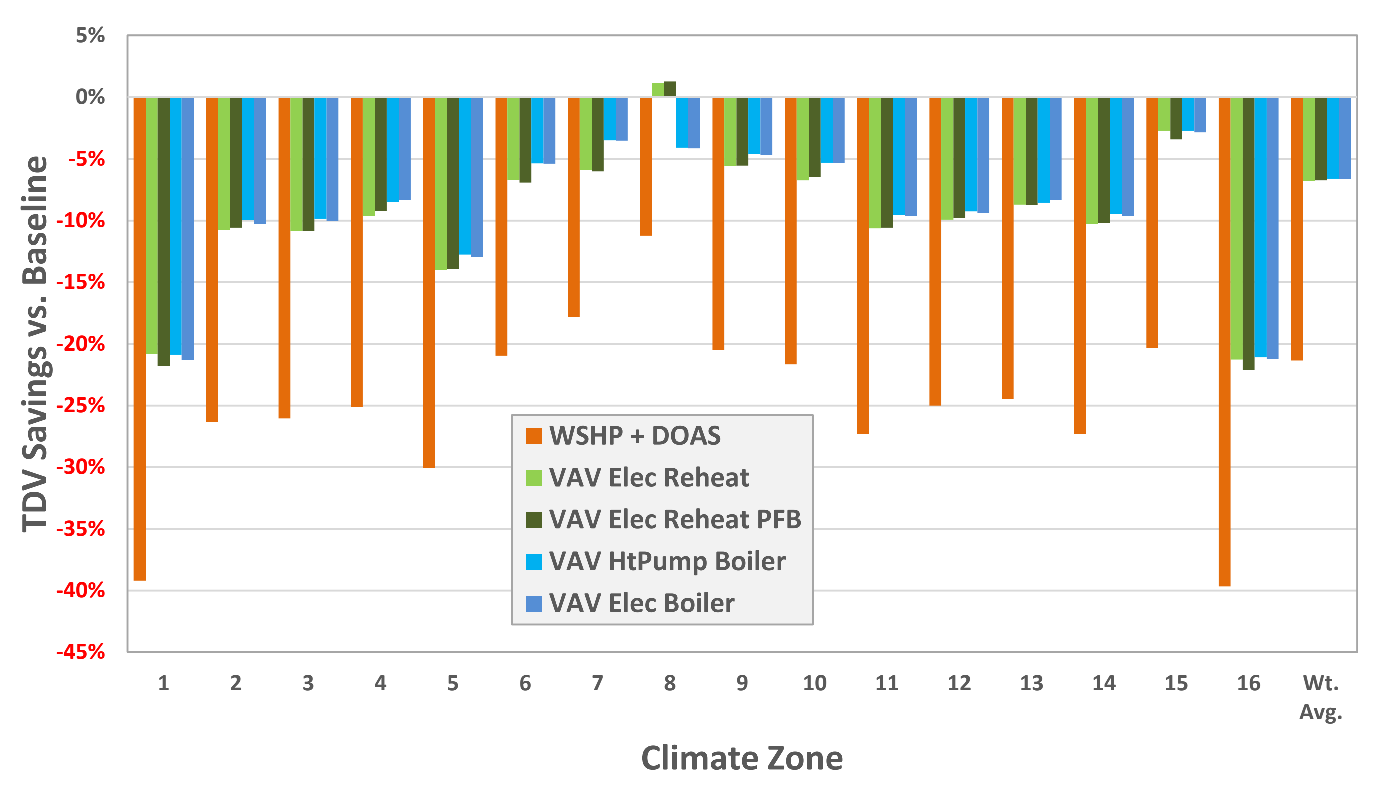
Medium Office

- Baseline is Packaged VAV with hot water reheat from a gas boiler
- WSHP shows much higher TDV consumption
- Electric reheat, heat pump boiler and VRF models do not provide TDV savings



Large Office

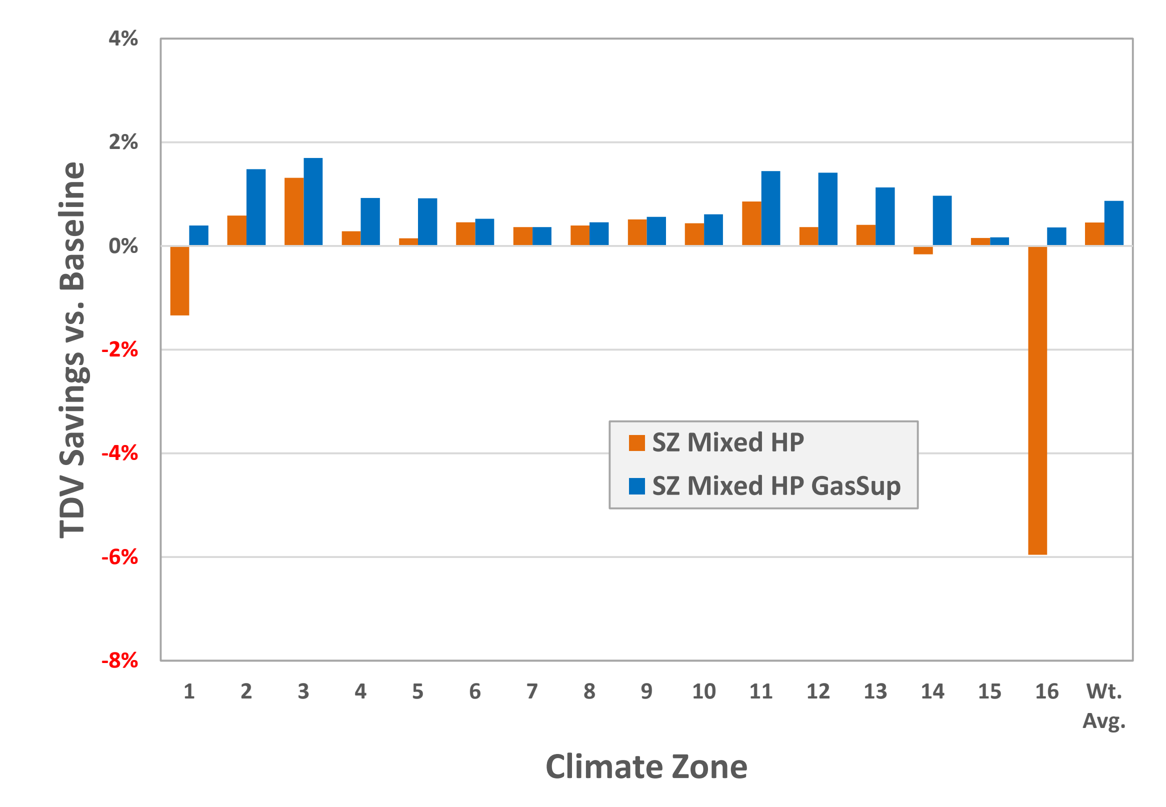
- Baseline is a Built-up VAV with chillers and hot water reheat from a gas boiler
- WSHP shows much higher TDV consumption
- Electric reheat options increase TDV except in CZ8
- Electric boiler options do not perform much better



RESULTS

Small Retail

- Baseline is a mix of SZAC and single zone VAV air conditioners (SZVAVAC), all with gas furnace heat.
- Changing furnace to heat pump heat - small reduction in TDV except in CZ1 and CZ16
- Changing supplemental heat to gas gives TDV savings in all CZ



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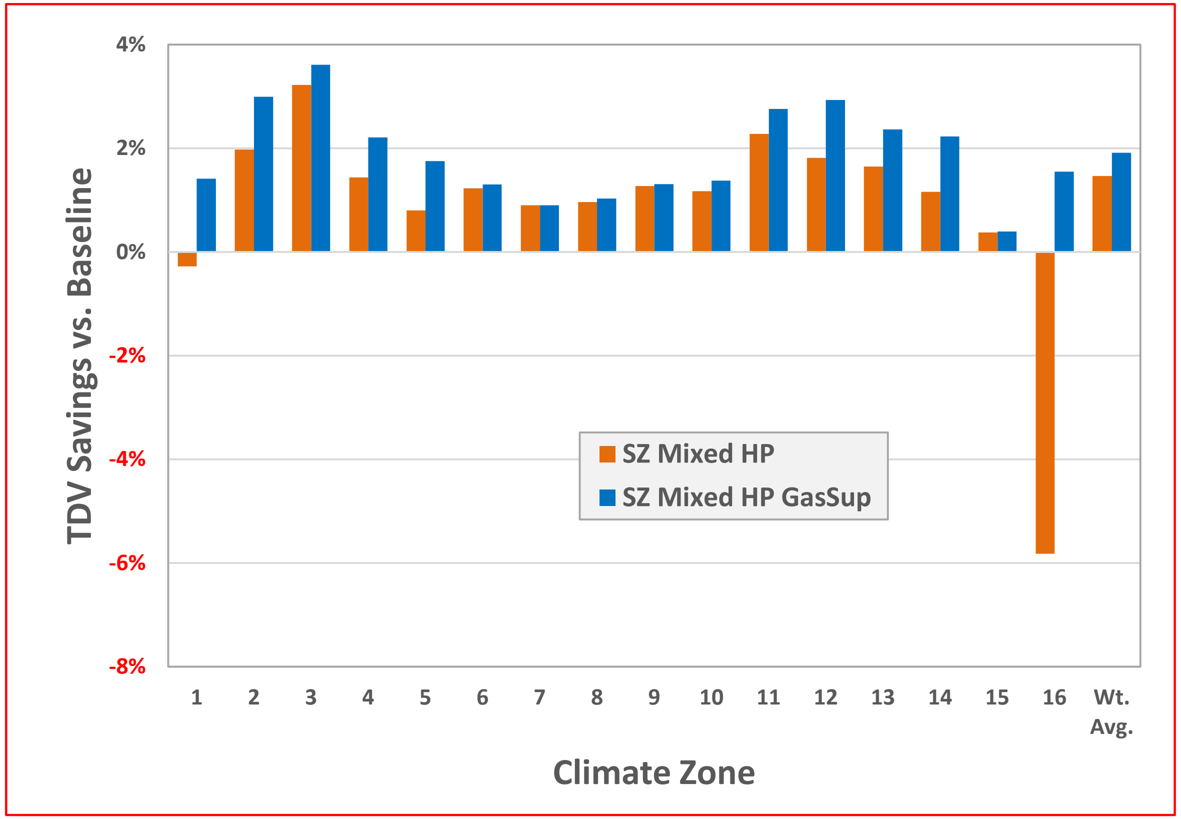
Medium Retail

- Baseline is a mix of SZAC and SZVAVAC, with gas furnace heat.
- Changing furnace to heat pump heat - small reduction in TDV except in CZ1 and CZ16
- Changing supplemental heat to gas gives TDV savings in all CZ



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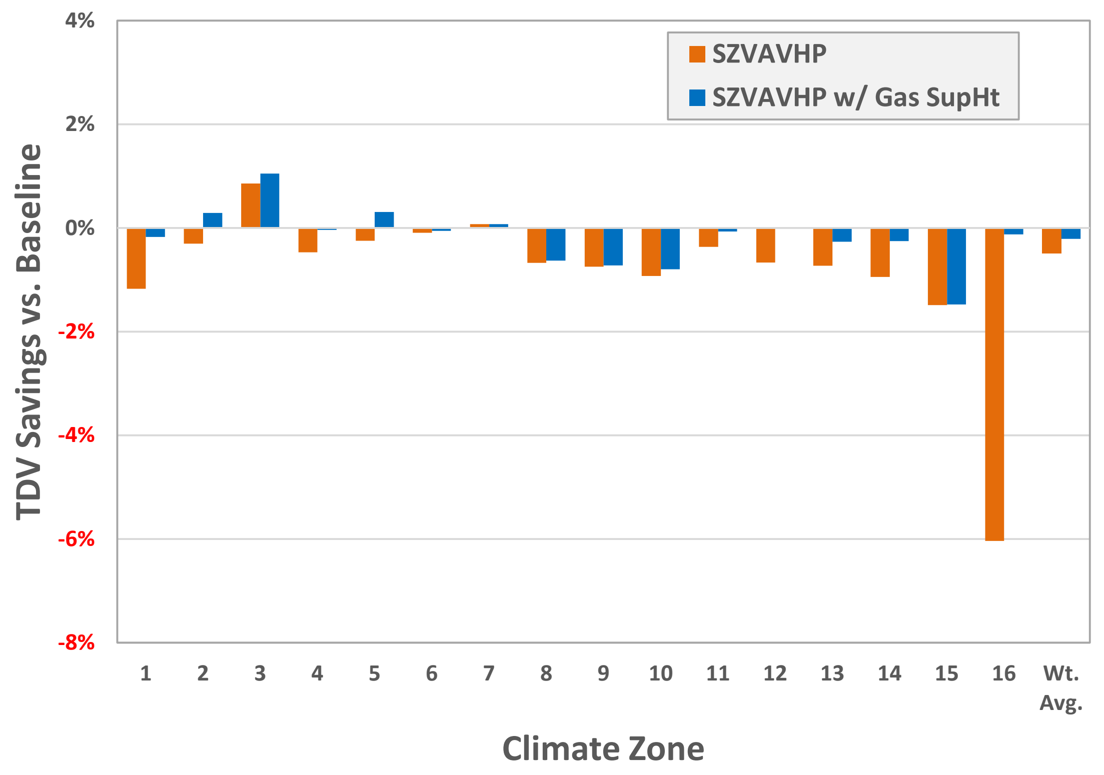
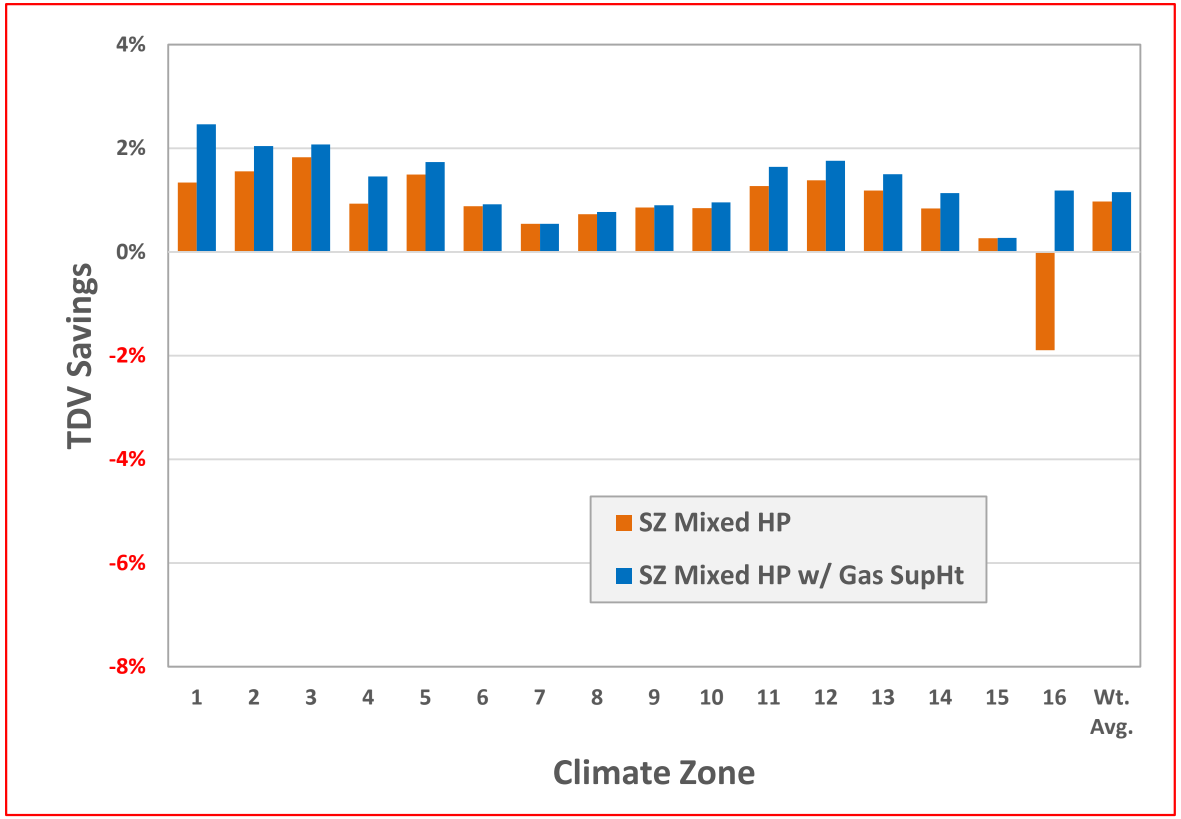
Large Retail

- Baseline is SZVAVAC with gas furnace heat.
- Changing furnace to heat pump heat - small reduction in TDV except in CZ1 and CZ16
- Changing supplemental heat to gas gives TDV savings in all CZ



Small Restaurant

- Baseline is a mix of SZAC and SZVAVAC, both with gas furnace heat
- Switch to heat pump provides TDV savings in every climate zone except CZ16
- Gas supplemental heat gives TDV savings in CZ16 too



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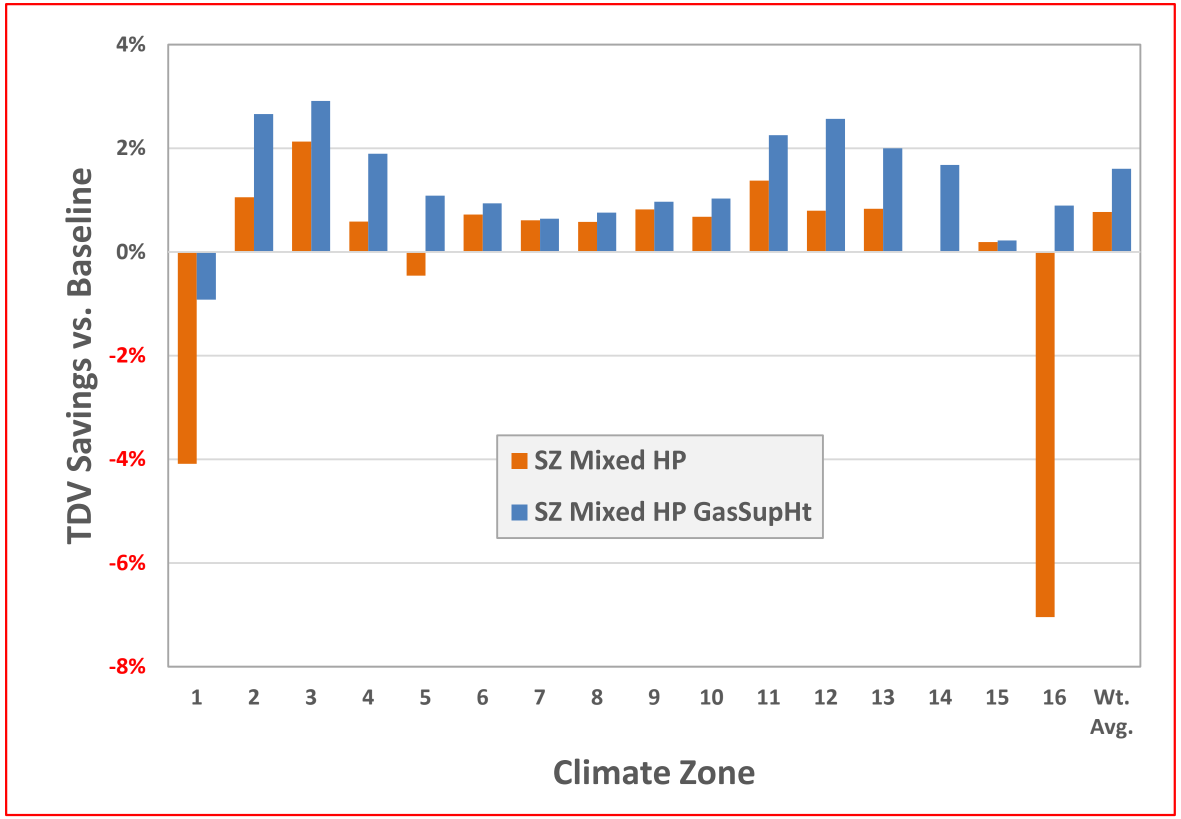
RESULTS

Small School

- Baseline is a mix of SZAC and SZVAVAC, all with gas furnace heat.
- Changing furnace to heat pump heat - small reduction in TDV except in CZ1, CZ5 and CZ16
- Changing supplemental heat to gas provides TDV savings except in CZ1



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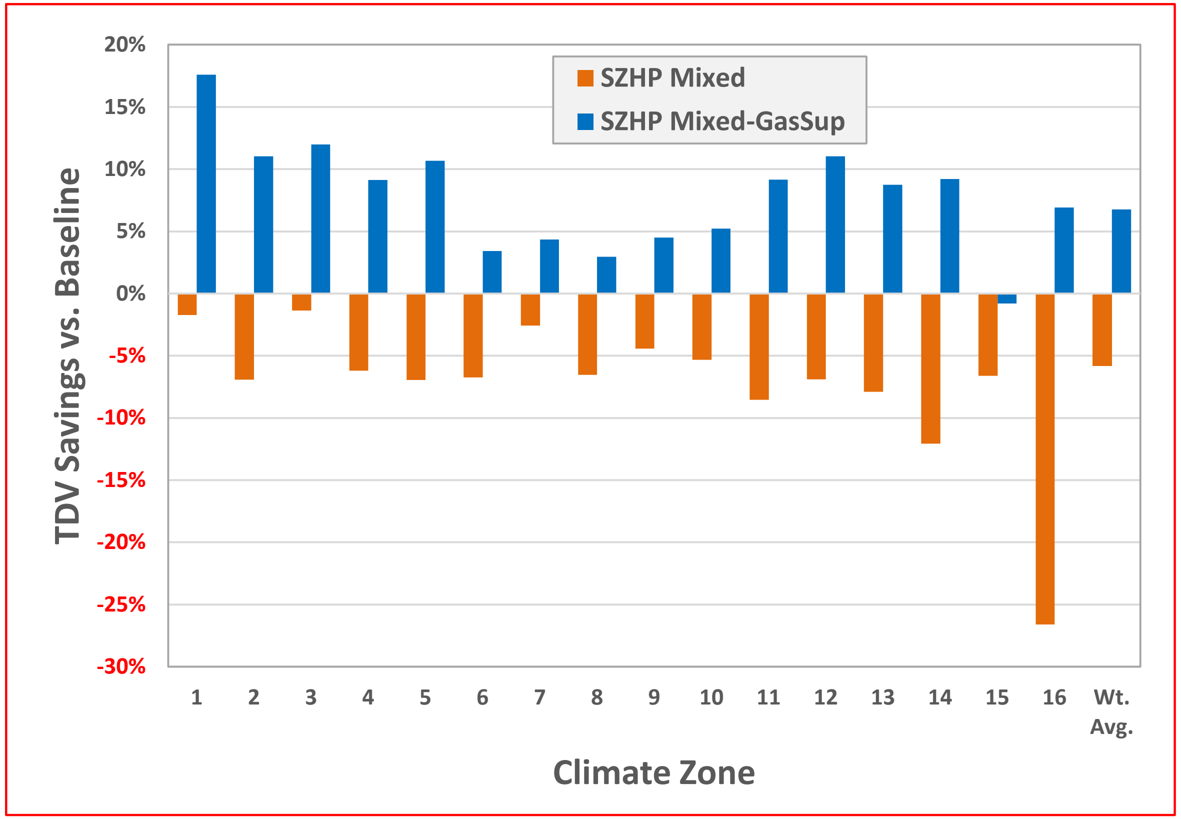
RESULTS

Warehouse

- Baseline is a SZVAVAC serving the office and heating/ventilating units serving storage areas, all with gas furnace heat.
- No direct electric heat alternative to the H/V units
- Constant volume heat pumps show increased TDC
- Change to gas supplemental heat reduces TDV in all climate zones



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CONCLUSIONS

- Switch of baseline from gas furnace to heat pump appears viable
  - Need to evaluate impact of Federal minimum cooling efficiencies
  - Need to investigate additional options to avoid baseline with higher TDV consumption
    - Envelope changes?
    - Climate zone specific additional measures?
- Electric alternatives to gas boilers problematic
- Need to evaluate Federal cooling efficiency minimums
- Will be looking at inclusion of DOAS options

NORESCO

2022 Title 24 PV Measure

PV and Storage Cost Summary

October 6, 2020

Presented by: John Arent

NORESCO

OBJECTIVES

- Determine costs for inclusion in economic analyses
- PV systems
  - Installation relative to array size
- Battery systems
  - Installation versus capacity and duration
  - Replacement costs for 10-year expected life

NORESCO

METHODOLOGY

- Project and representative costs
  - Contacted top 50 installing contractors with commercial projects in CA
  - Contacted MEP and sustainability firms
  - Contacted facility managers of large corporations
  - Distributed cost survey to respondents for PV and storage prices
- Literature review for PV and storage prices
  - Current prices
  - Price trends
- Storage:
  - Contacted battery storage manufacturers and providers
  - Reviewed other sources of cost data

SOURCES

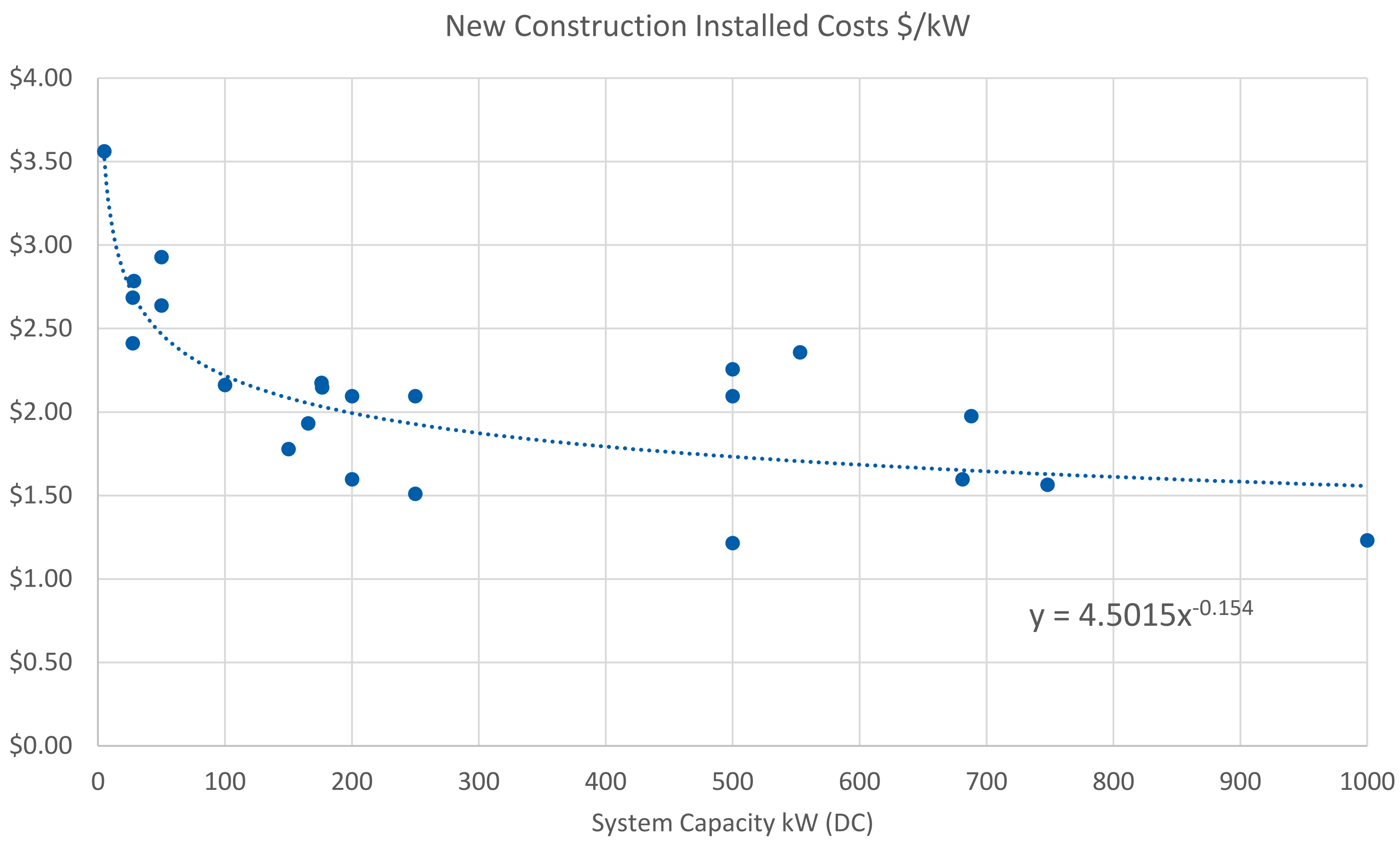
- PV System Cost
  - EnergySage, 2020 Commercial PV estimates
  - LBNL – Barbose, Darghouth 2019. Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States. October 2019
  - NREL - https://www.nrel.gov/analysis/solar-installed-system-cost.html
  - Sourced Survey Estimates (Solar Contracting Firms-2, MEP-1, Facility Manager-1)
  - Elshurfa, Amro et. al. 2018. Estimating the learning curve of solar PV balance-of-system for over 20 countries: Implications and policy recommendations. Journal of Cleaner Production 196: pp. 122-134
  - NEM Interconnected Data Set, https://www.californiadgstats.ca.gov/downloads/, accessed Sept. 24, 2020
  - Friedman, Brent 2014. Comparing Photovoltaic (PV) Costs and Deployment Drivers in the Japanese and U.S. Residential and Commercial Markets . Technical Report NREL/TP-6A20-60360 Revised June 2014

- Battery System Cost
  - NREL – Cole, Frazier 2019. Cost Projections for Utility-Scale Battery Storage. June 2019.
  - Solar Contracting Firm – survey estimate
  - Leading Manufacturer / Turnkey Provider – survey and interview
  - Lazard 2019. https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf

NORESCO

PV COST RESULTS – NEW CONSTRUCTION

- Combined Data Sources: Survey (contractors, Facility Mgr, MEP), LBNL data, NEM median binned data
- Adjusted data to NC with $0.18/W reduction for customer acquisition costs (Friedman 2014)
- Data gathered for 2018 through 2020 and includes commercial PV costs for 5 kW through 1000 kW
- Cost adjusted to 2023 based on projected PV cost. Inflation not applied

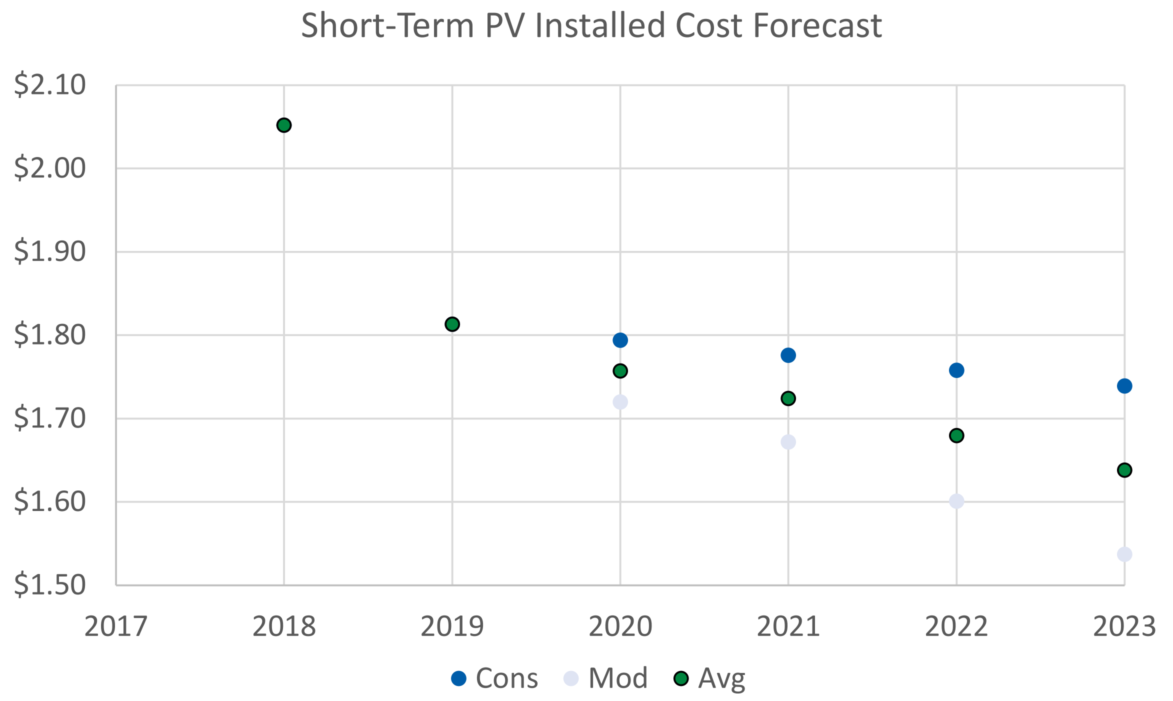


NEW CONSTRUCTION COST REDUCTION - ACQUISITION COSTS

- Customer acquisition costs average $0.18/W for commercial projects (Friedman 2014)
- Companies with growth plan may incur higher acquisition costs
- Other soft costs include:
  - PII – permitting, inspection and interconnection
  - EPC – engineering, procurement and construction
- Possibility of additional reduction in operating costs
  - Reduction in other soft costs
  - Reduction in costs of balance-of-system (BOS) costs with infrastructure in place

PV PROJECTION FOR 2023

- Between 2019 and 2023, the NREL Forecast Scenarios estimate a drop in installed costs of 3%, 15% or 20% for conservative, moderate, and aggressive scenarios, respectively
- This analysis assumes a reduction midway between the conservative and moderate scenarios, for a 9% reduction in cost between 2019 and 2023
- Applied adjustment factors to cost data based on year system was installed



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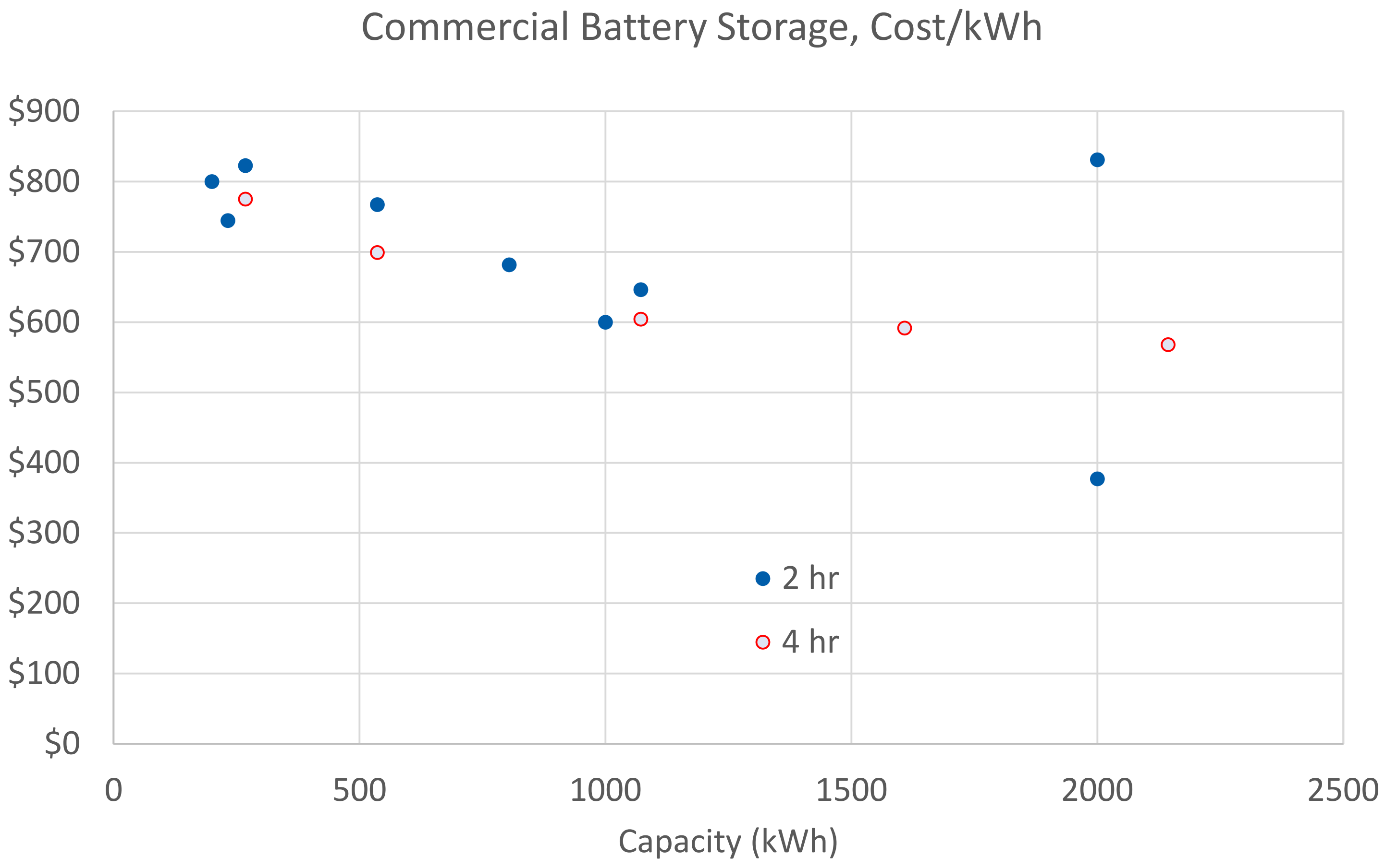
FURTHER STUDY

- Small commercial PV systems (< 25 kW) have a much higher cost ($/W) than larger systems
  - Requires further study to understand cost drivers

- Current data sources do not sufficiently differentiate between new construction and retrofit costs
  - In the process of collecting further information
  - Acquisition costs have been adjusted for, but there may be other costs that may not be incurred in new construction projects

BATTERY STORAGE ESTIMATES

- Commercial Battery: installed costs of $600 to $800 per kWh
  - $600/kWh for large systems
  - $800/kWh for systems below 100 kW
- Battery cost of 4-hour storage is 10-15% lower than 2-hour storage
- Expected life of 10 years
  - Replacement costs will be at least 30% lower (2/3 are hard costs)
  - Future battery costs projected to drop by 30% at year 10
  - Overall replacement cost is 50% lower than first cost



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BATTERY STORAGE – DESIGN CONSIDERATIONS

- Some major battery installers do not offer systems below 100 kW
  - Tesla Powerwall may be offered by other providers
- Footprint: a 100 kW system takes up a full parking space
- Duration: systems available in 1- to 4-hour duration
  - 2 hour most common (aligned with SGIP program)
  - 4 hour more useful for alignment with ISO / grid
  - Costs are higher for higher current output (shorter duration): approximately 10-15% lower cost/kWh for 4-hr batteries, per contractor estimate and NREL study

BATTERY PROJECTION FOR 2023

- NREL Study shows battery storage costs dropping by 11%, 45%, to 67% for three projection scenarios. Future cost trends are important for storage, given 10-year expected life
- Recommend average of high (conservative) and Mid (moderate) scenarios, for an estimated 30% drop by 2030

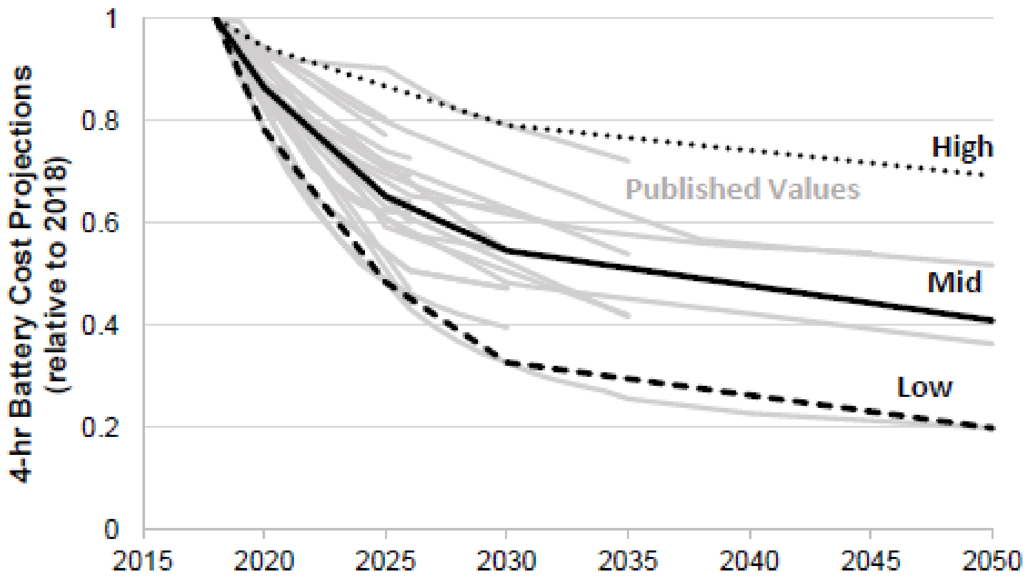

Figure 1. Battery cost projections for 4-hour lithium-ion systems, with values relative to 2018. The high, mid, and low cost projections developed in this work are shown as the bolded lines. Figure values are included in the Appendix.

TESLA POWERWALL COSTS

- Slight cost reduction for multiple battery systems
- Potential additional cost reduction for new construction

Qty	kWh	Usable kWh	Battery Cost	Total System Cost	Cost/kWh	Source
1	14	13.5	$6,500	$11,000	$815	https://www.solarreviews.com/blog/is-the-tesla-powerwall-the-best-solar-battery-available
2	28	27	$13,000	$21,500	$796	https://www.solarreviews.com/blog/is-the-tesla-powerwall-the-best-solar-battery-available
5	70	67.5	$32,500	$53,000	$785	Projected based on reduced installation cost of second unit
1	14	13.5	$9,250	$13,400	$993	https://www.buildwithrise.com/stories/tesla-powerwall2-basics
3	42	40.5	$19,500	$24,691	$610	2020 Estimate for Davis Residence, from Tesla Palo Alto, CA

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PRELIMINARY RECOMMENDATIONS

- PV installed cost (regression from cost data) :

  Cost ($/W) = 4.5015 x kW^$^{-0.154}$

PV kW DC	PV Cost ($/W)
10	$3.16
20	$2.84
50	$2.46
100	$2.21
200	$1.99
500	$1.73
1000	$1.55

- Battery installed cost
  - Replacement Cost at 10 years:
    $600/kWh x 30% price drop – 30% soft costs
    = $284/kWh replacement
  - Replacement Cost at 20 years:
    $600/kWh x 38.5% price drop – 30% soft costs

Battery Size	Battery First Cost ($/kWh)	Battery Replacement Cost ($/kWh)
< 100 kW	$800	$392 (year 10) $344 (year 20)
> 100 kW	$600	$284 (year 10) $258 (year 20)

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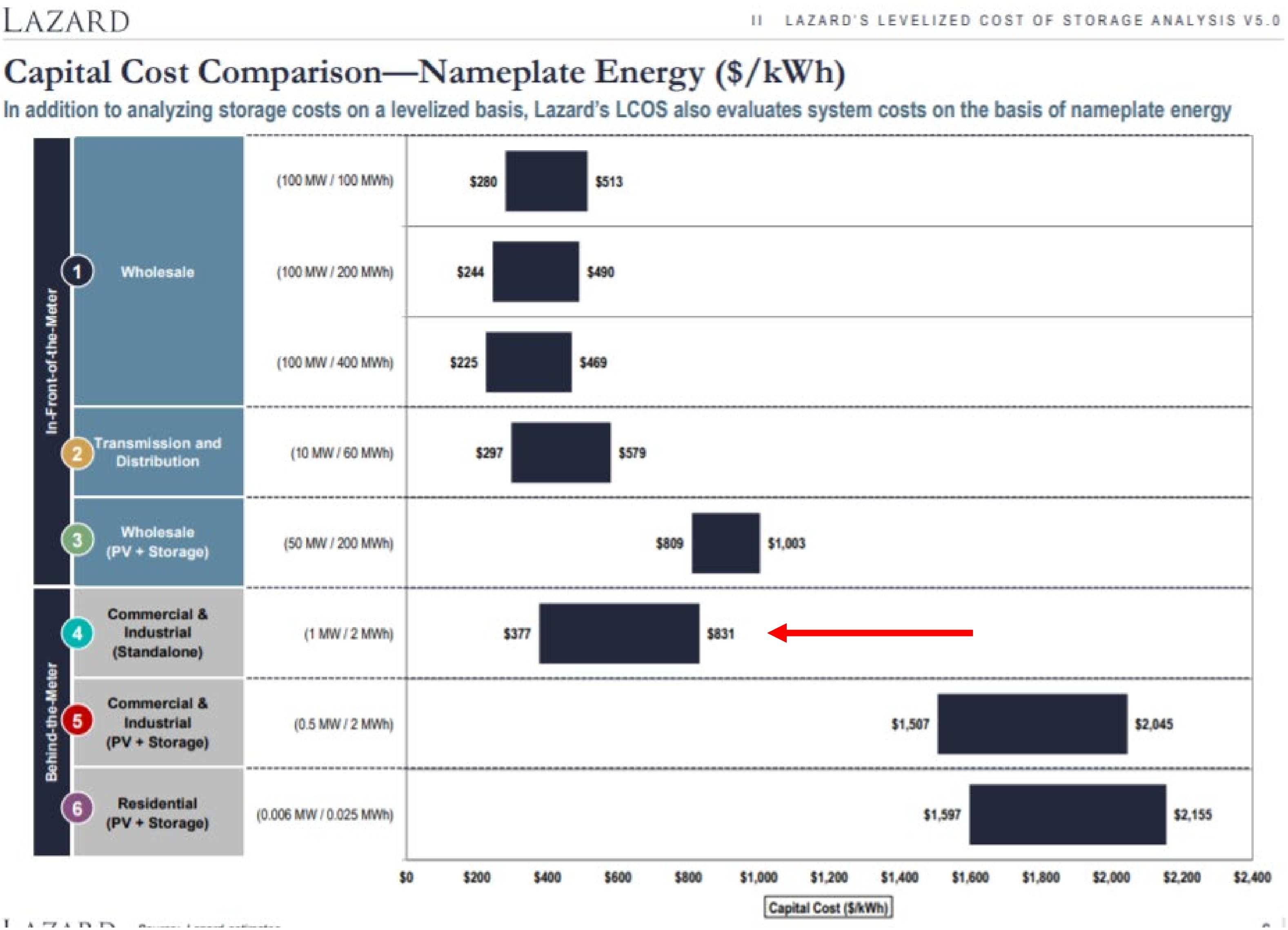
NEXT STEPS

- Collect feedback from workshop attendees and incorporate into cost data
- Refine costs for small systems (< 25 kW)
- Investigate cost differential between new construction and retrofit projects

ACKNOWLEDGEMENTS

NORESCO Team: Roger Hedrick, Silas Taylor, Rahul Athalye

BACKUP SLIDE: BATTERY COST DATA FROM LAZARD



Energy+Environmental Economics

Nonresidential PV and Battery Cost-Effectiveness Draft Results

October 7, 2020

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Mike Sontag
Jun Zhang
Emily Peterson
Brian Conlon
Sierra Spencer
Sumin Wang

Agenda

+ Background and Context
+ Scope of Analysis and Dimensions Considered
+ Medium Office Deep Dive
  - PV-only Cost Effectiveness
  - Storage-only Cost Effectiveness
  - PV + Storage Cost Effectiveness
+ Storage Duration Sensitivity
+ Reliability and Resiliency Sensitivity
+ EV Charging Compliance Option Framework
+ Appendix

Goals of this Analysis

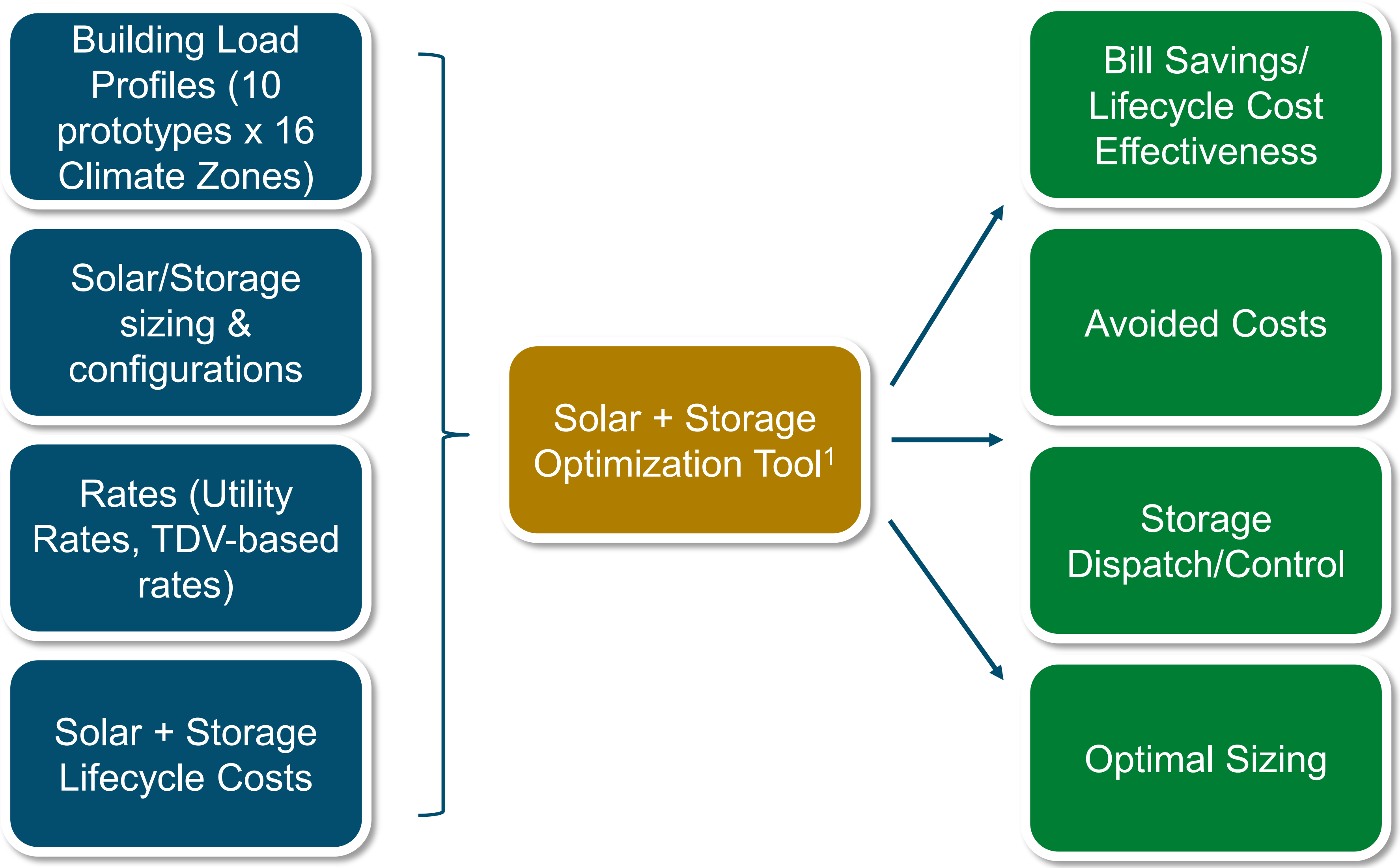
- **Evaluate participant benefits and cost effectiveness of behind the meter PV and storage in HRMF and Nonresidential new construction**
- **Study multiple configurations and sizes of PV and storage, with focus on limited grid exports**
- **Cost-effectiveness measured under both TDV-based rates and current retail rates**
  - TDV cost-effectiveness evaluated with multiple configurations to bound potential future rate design
- **Evaluation covers HRMF and nonresidential prototype buildings in each of the 16 climate zones**
- **Present data inputs and methodology in a transparent manner**
  - Open to improved data on capital costs, technology characteristics, storage control operations, future price signals, etc

Key Findings

- **PV + Storage as a package (smaller configuration) is cost-effective for most building categories due to co-benefits of combined systems**
  - PV + Storage provides additional participant benefits, including reliability and resiliency
- **PV is cost effective across all scenarios from participant perspective, except under most significant rate reform**
  - Minimizing exports allows for significant PV benefits, while having robust cost-effectiveness in all rate sensitivities
  - Note: most significant rate reform is analogous to “buy all - sell all” on avoided cost treatment of rooftop PV
- **Storage-only presents large grid benefits, but is generally not cost-effective in this analysis**
- **Next Steps:**
  - Collect additional relevant data from stakeholders,
  - Perform additional analysis to refine optimal size and configuration in context of building codes and standards

Modeling Inputs and Dimensions

Cost-Effectiveness Modeling Framework



[1]See CEC Docket Log 19-MISC-04 for additional information and documentation: https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=19-MISC-04

Scope of the Analysis

+ **9 major sensitivities – many combinations!**

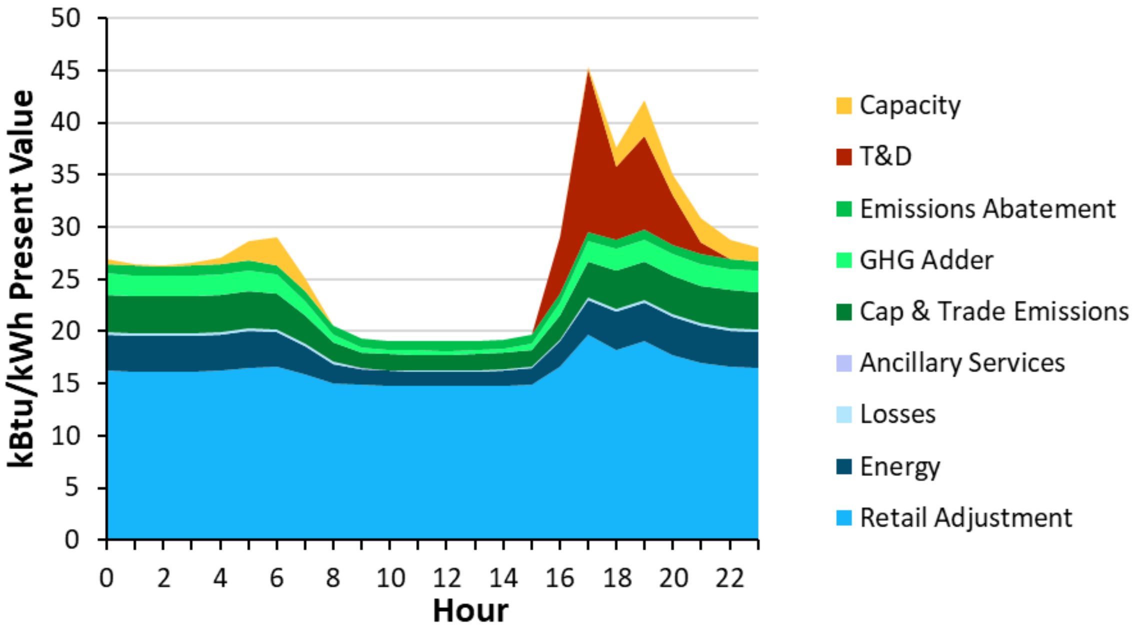
Rates	PV Size	Storage Size	Storage Dispatch	Configurations	Building Types	Building Fuels	Climate Zones	Reliability/ Resiliency
Full TDV	Full NEM	PV Capacity	Optimal	PV only	Small Office	Mixed Fuel	All CZs	Not included
Export on Avoided	Self-Util	Minimize Solar Exports	Basic	Storage Only	Medium Office	All-Electric		Included
Export on wholesale	15% Exports			PV+ storage	Large Office			
Avoided Cost for all	Roof Space				Small Retail			
Utility Rates					Medium Retail			
					Large Retail			
					Small School			
					Warehouse			
					Large School			
					High-Rise Res			

What are TDVs?

+ **The TDVs (Time Dependent Value) are a long-term forecast of hourly electricity, natural gas and propane costs to building owners and are used for cost-effectiveness activities in Title 24 Building Code**
+ **The TDVs answer the question of what is cost-effective in the long term, as required by the Warren-Alquist Act**

- Time-differentiation reflects the underlying marginal cost of producing and delivering energy
- Area-correlation reflects underlying marginal cost shapes correlated with each climate zones weather file

Sample Annual Average Electric TDV, 2022, CZ12



Rates Sensitivities Considered

Rate Name	Compensation for Self-Utilized Electricity (Imports)	Compensation for Exports
Existing Utility Retail Rates	Retail Rate + Non-bypassable charge	Retail Rate
Full TDV (NEM2.0)	Full TDV	Full TDV – Non-bypassable charges
Export on Avoided Costs	Full TDV	Avoided Costs
Export on Wholesale Costs	Full TDV	Wholesale Costs
Self-utilized/export on Avoided Costs	Avoided Costs	Avoided Costs

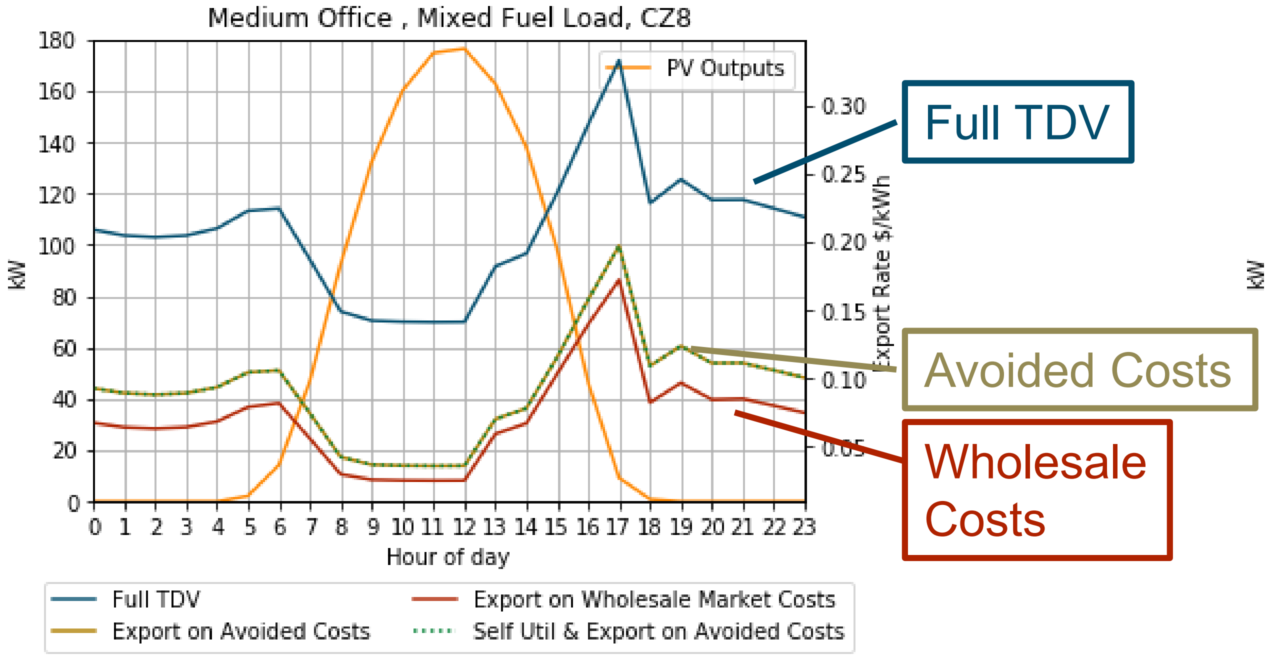
Increasing NEM rate reform

+ **Self-utilized electricity is generated and consumed behind the meter**
+ **Imported electricity is taken from the grid to power end-use loads**
+ **Exported electricity is generated behind the meter and sent to the grid**

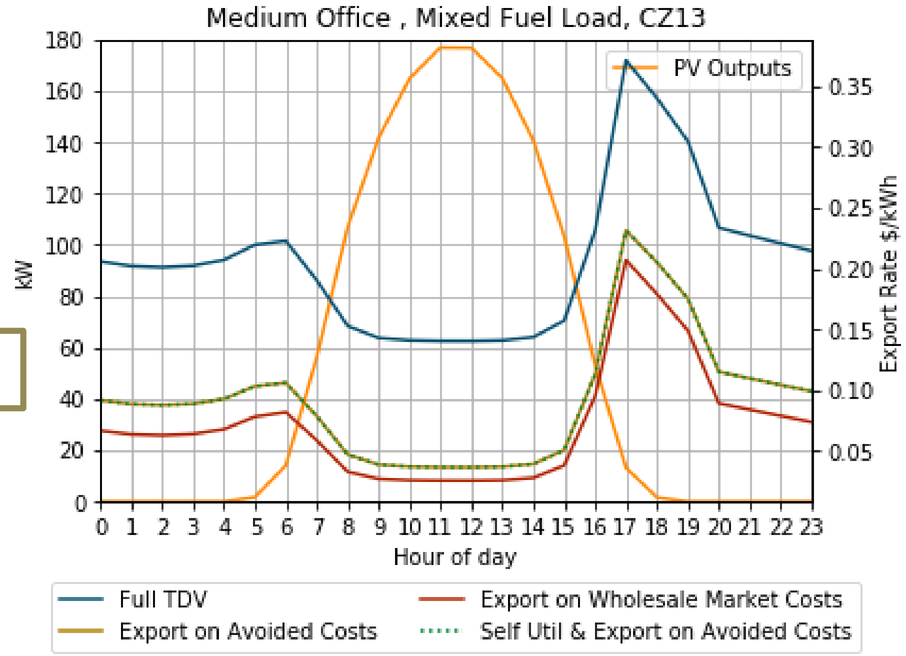
TDV Rate Sensitivities

- **Full TDV is highest, avoided costs and wholesale costs are similar in magnitude**
- **Different Climate zones have different hourly profiles due to local T&D peaks**
  - Climate zones in inland LA Basin have slightly higher midday rates

Medium Office, Mixed Fuel Load, CZ8



Medium Office, Mixed Fuel Load, CZ13



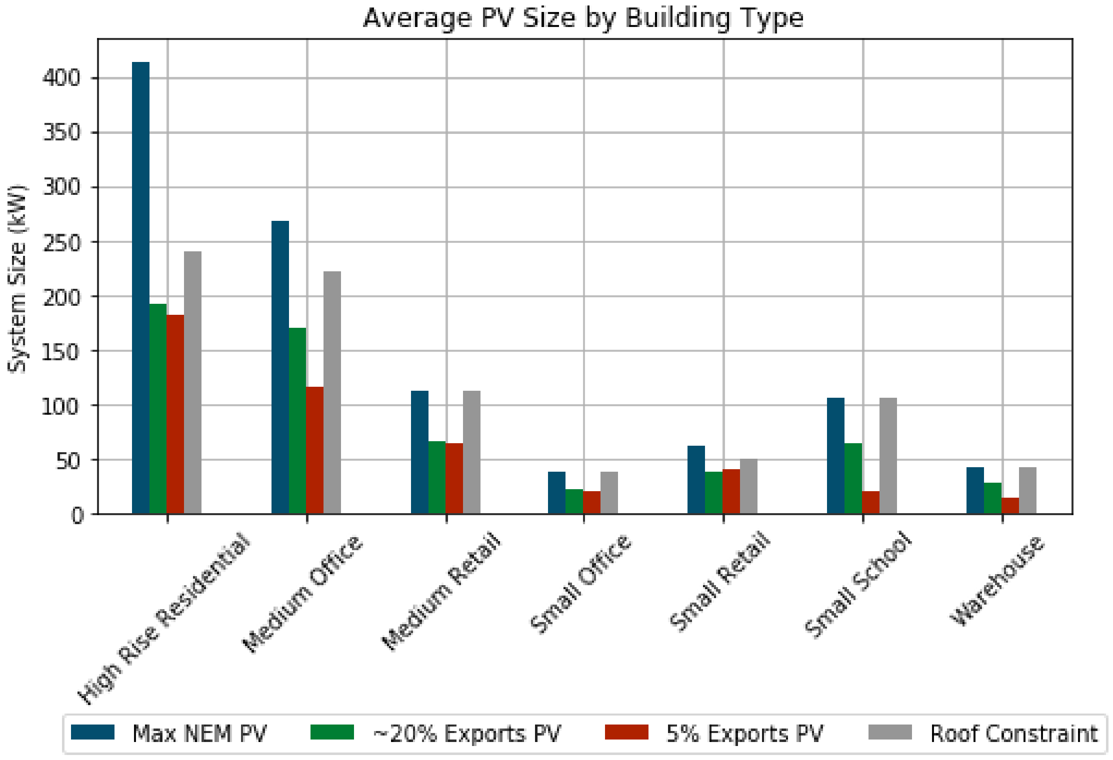
Note: TDV rate on y-axis is levelized lifetime present value

PV Sizing

+ **Three sizing options for each building type and climate zone**
  - Max NEM Complaint
    - Annual solar gen = annual total building consumption
    - ~40% of annual PV generation is exported to grid
  - Self-utilization (~20% Exports PV)
    - Sized to generate the amount of PV that is self-utilized in *Max NEM Compliant* case
    - ~20% of annual PV generation is exported to grid
  - 5% Exports
    - 5% of annual PV generation is exported to grid

+ **PV sizes compared to roof area constraints to ensure viable system size**

Average PV Size by Building Type



(See appendix for Large Office sizing)

Key PV Inputs

+ **PV Costs**
  - Considers full lifetime capital & replacement costs, fixed O&M costs, investment tax credit
  - 2% Inflation rate
  - 3% Real discount rate
+ **Fixed O&M: $11/kW$_{DC}$-yr (2018$)[1]**
+ **ITC: 10%**
+ **Lifetime: 30 years**
+ **PV Tilt: assumed zero tilt, to maximize roof utilization**
+ **PV Azimuth: South-facing**
+ **Inverter Load Ratio: 1.0**

PV (kWdc)	CAPEX (2020$/W$_{DC}$)	Lifetime NPV Costs used in this analysis ($2023/kW$_{DC}$)
10	$3.16	$3,263
20	$2.84	$2,957
50	$2.46	$2,594
100	$2.21	$2,355
200	$1.99	$2,145
500	$1.73	$1,897
1000	$1.55	$1,725

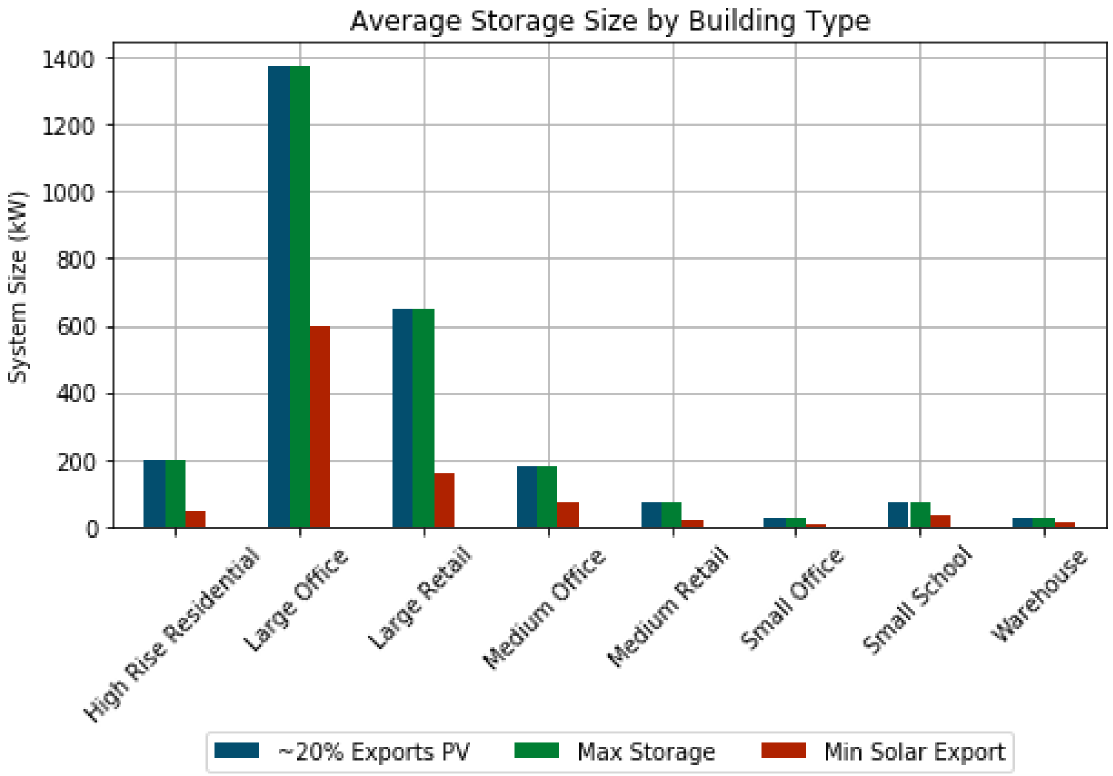
[1] NREL 2020 Annual Technology Baseline https://atb.nrel.gov/electricity/2020/index.php?t=sd

*Fixed OM costs in 2020 NREL ATB include annualized large component replacement costs over technical life (e.g., inverters at 15 years)

Storage Sizing

+ **Two sizing options for each building type, climate zone**
  - **Max Storage:** Sized to *Self-utilization* (~20% Exports) PV capacity
  - **Min Solar Export:** Sized to minimize net solar exports
    - Reduces PV gen exports form 20% to ~10%
+ **Typical assumption is 4-hr duration**
+ **Additional sensitivity with 2-hr duration**

Average Storage Size by Building Type



Key Storage Inputs

- **Storage Costs**
  - Considers full lifetime capital & replacement costs, fixed O&M costs, investment tax credit
- **Fixed O&M: $29.61/kW$_{DC}$-yr (2018$)[2]**
- **10% ITC**
- **Storage RTE: 85%**
- **Storage duration: 4 hours**
- **Storage lifetime: 10 years (cell replacement)**
- **AC-coupled**
- **Inverter Load Ratio : 1.0 - No PV generation "clipping"**
- **Exclude SGIP incentive in cost-effectiveness evaluation for code requirement**
- **Assumed only charge from solar to maximize ITC**

Battery Size (kW)	Battery CAPEX (2020 $/kWh)	Battery Replacement Cost (2020$/kWh)
< 100	$800	$392 (year 10) $344 (year 20)
> 100	$600	$284 (year 10) $258 (year 20)

[2] NREL 2020 Annual Technology https://atb.nrel.gov/electricity/2020/index.php?t=st

Levels of Battery Control

+ Two major factors impact energy storage economic benefit

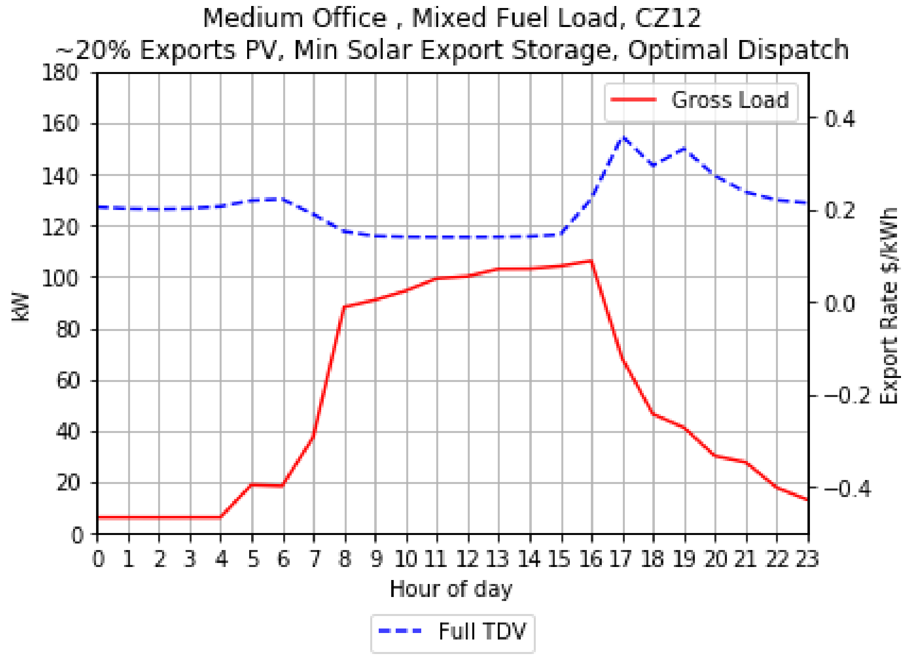
- **Controls scheme**: Commercially available energy storage does have sophisticated controls, but cannot match perfect foresight
- **Price signal**: Current retail rates have limited alignment between participant benefits and grid benefits

	Near-term Proxy	Aspirational
Controls Scheme	Basic	Optimal Dispatch (Perfect Foresight)
Rate Signal/ Participant Benefits	Retail Rates	Full TDV-based rate signal

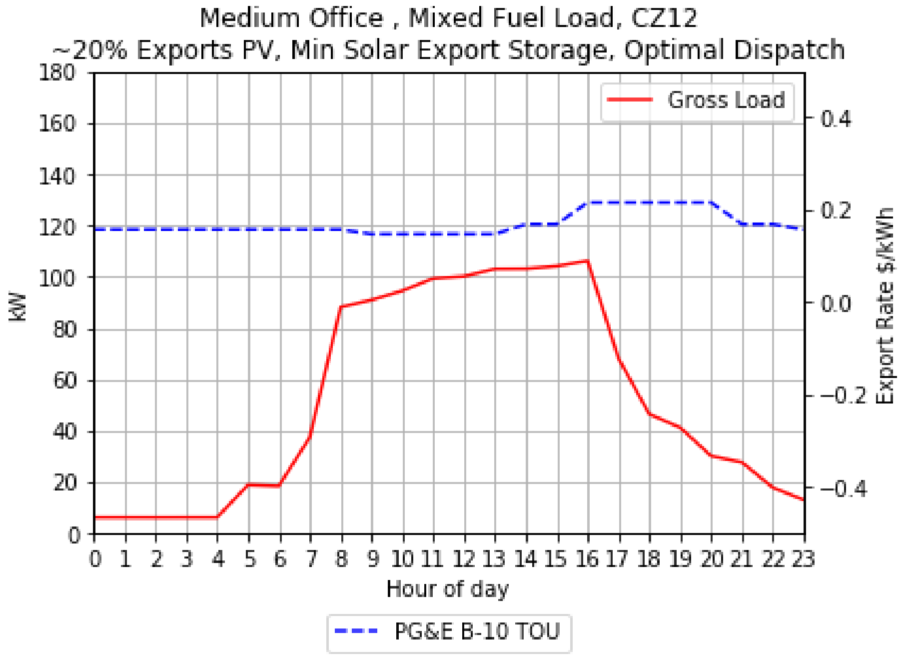
Optimal Dispatch Option

- Optimal dispatch responds based on customer load, PV generation, different rate signals to maximize customer benefit
- These plots show annual average of rate signals
- TOU rate also includes demand charges (not shown)

Full TDV



PG&E B-10 TOU

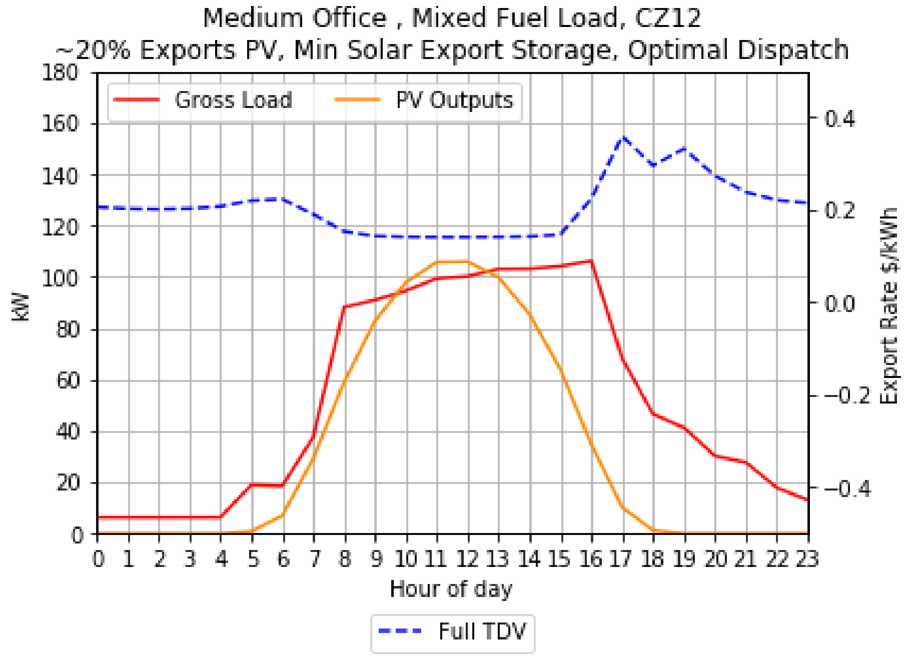


TDV and retail rates are both in levelized lifetime present value

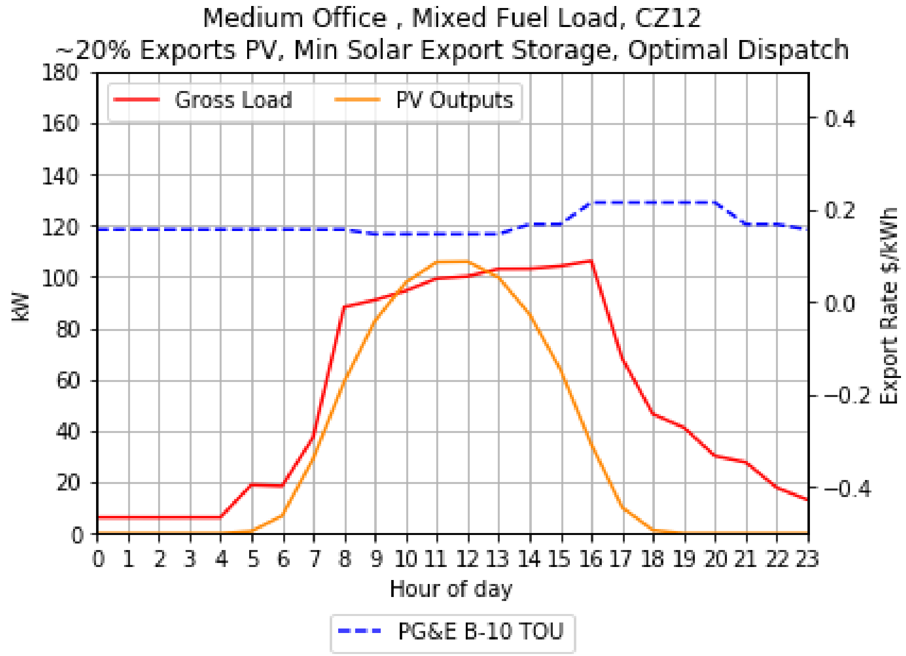
Optimal Dispatch Option

+ **Behind the meter PV largely coincides with Medium office load profile**
  - Some continued load after PV gen decreases, contributing to duck curve

Full TDV



PG&E B-10 TOU

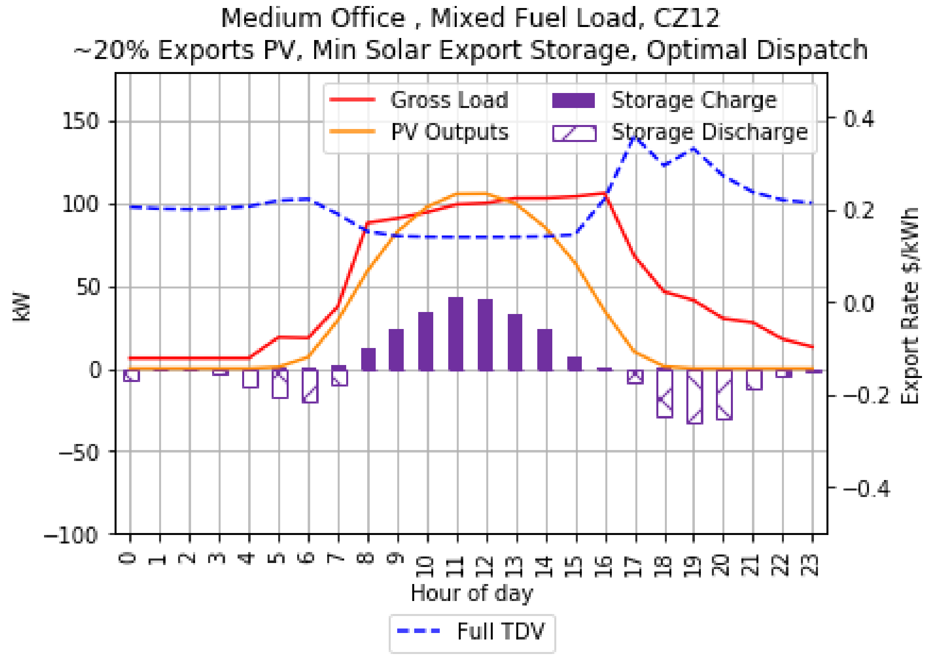


TDV and retail rates are both in levelized lifetime present value

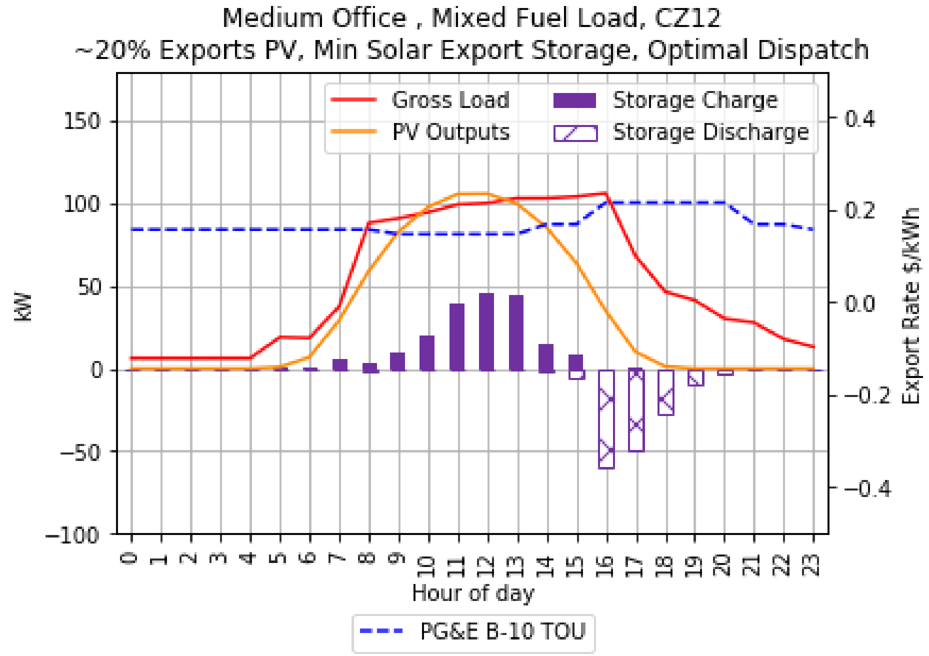
Optimal Dispatch Option – Rate Signals

- Under TDV based rate, optimal storage charging is mid-day, and discharges in evening (spring, summer, fall) and morning (winter), matching grid marginal costs
- Commercial retail rates are dominated by demand charges, and optimal dispatch focuses on more lucrative demand charge clipping

Full TDV



PG&E B-10 TOU

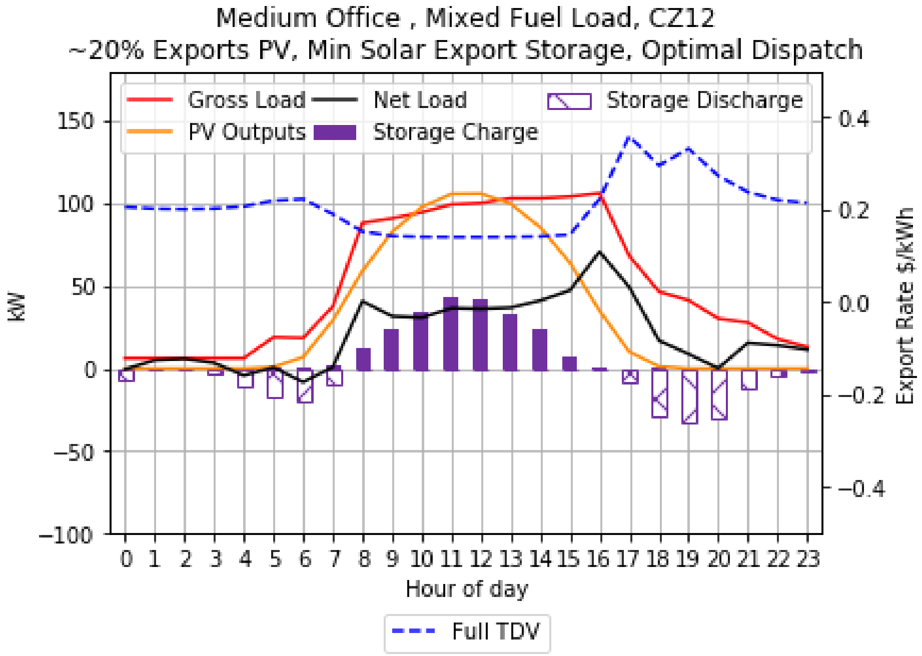


TDV and retail rates are both in levelized lifetime present value

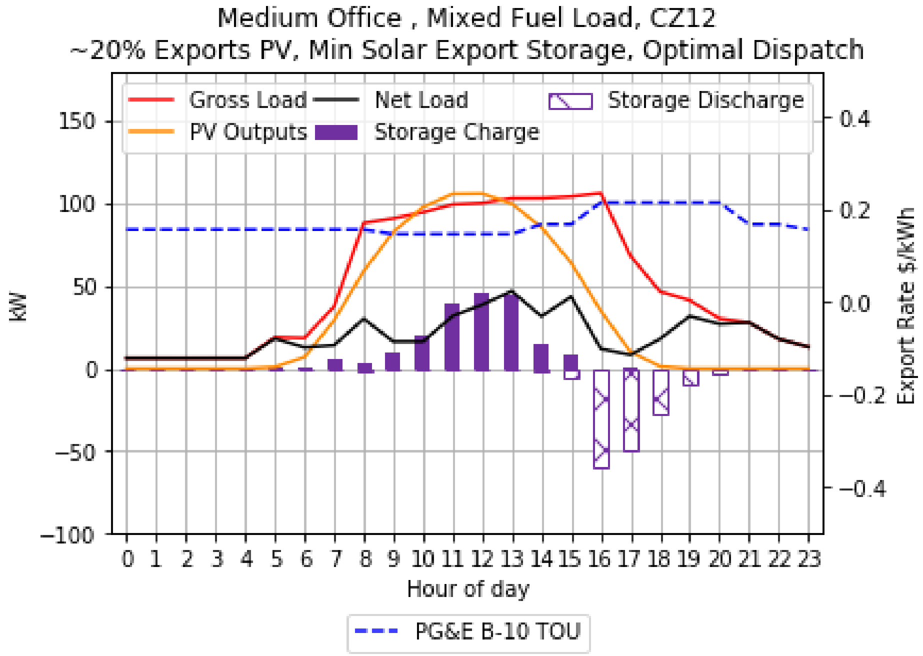
Optimal Dispatch Option – Rate Signals

- Under TDV based rate, net load is increased mid-day to take advantage of cheap electricity, decreased in late evening to avoid expensive grid power
- Under retail rate signal, net demand is minimized, even though it does not necessarily align with grid peak

Full TDV



PG&E B-10 TOU

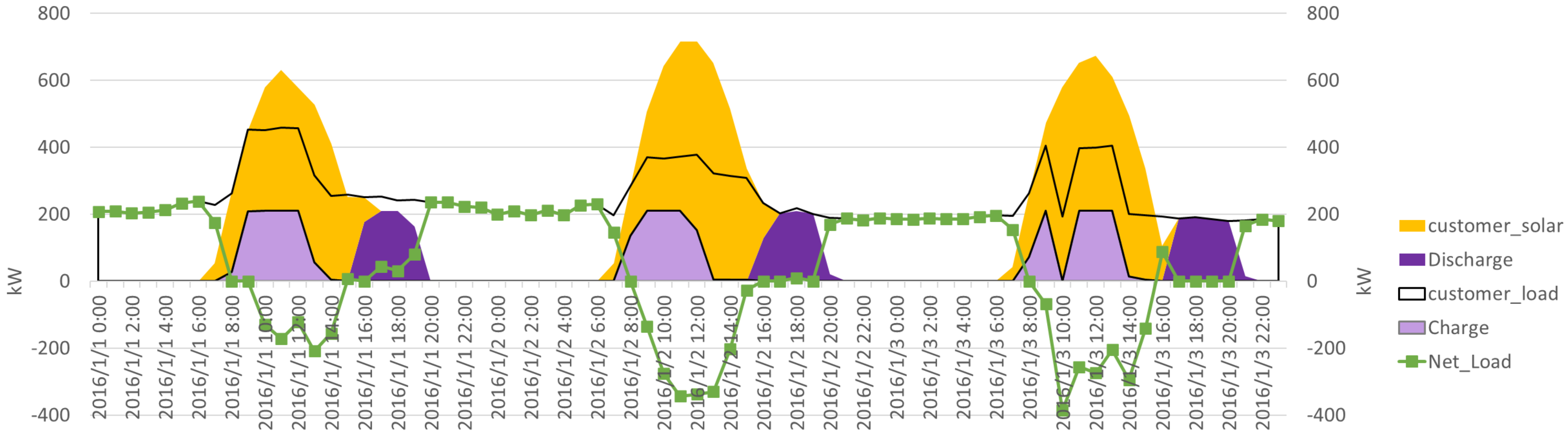


TDV and retail rates are both in levelized lifetime present value

Basic Dispatch Option

- Battery charges on PV net exports and discharges when load again exceeds PV production
- Demonstrates simple "maximize solar consumption" control scheme

Example PV & Storage Dispatch under "Basic Dispatch"



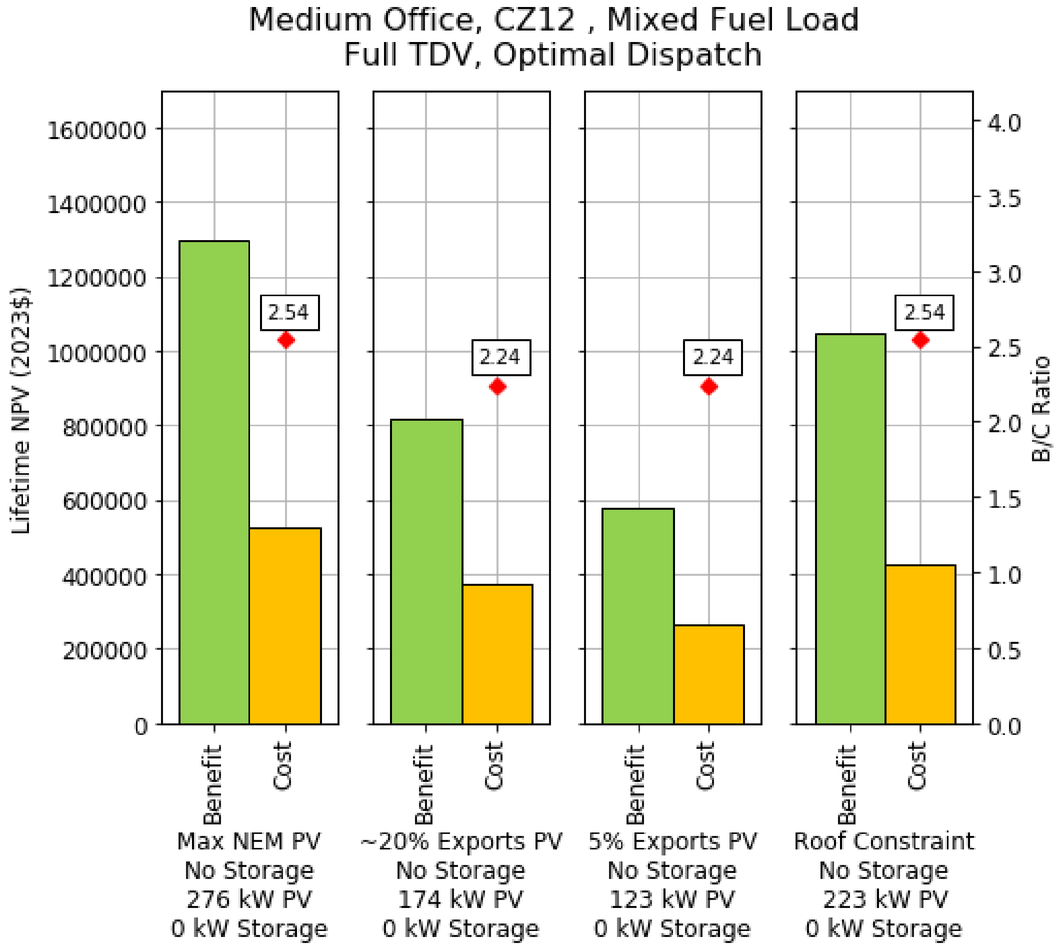
Energy+Environmental Economics

PV-Only Cost-Effectiveness

PV Cost-Effectiveness with Full TDV Rate

- Under Full TDV rate, self-utilized electricity generation is compensated nearly the same the same as exported electricity
- Benefit/Cost ratio stays largely the same, regardless of PV size (except in case of PV cost reductions due to economies of scale)
- No added incentive for limited exports
- PV is cost-effective for all sizes

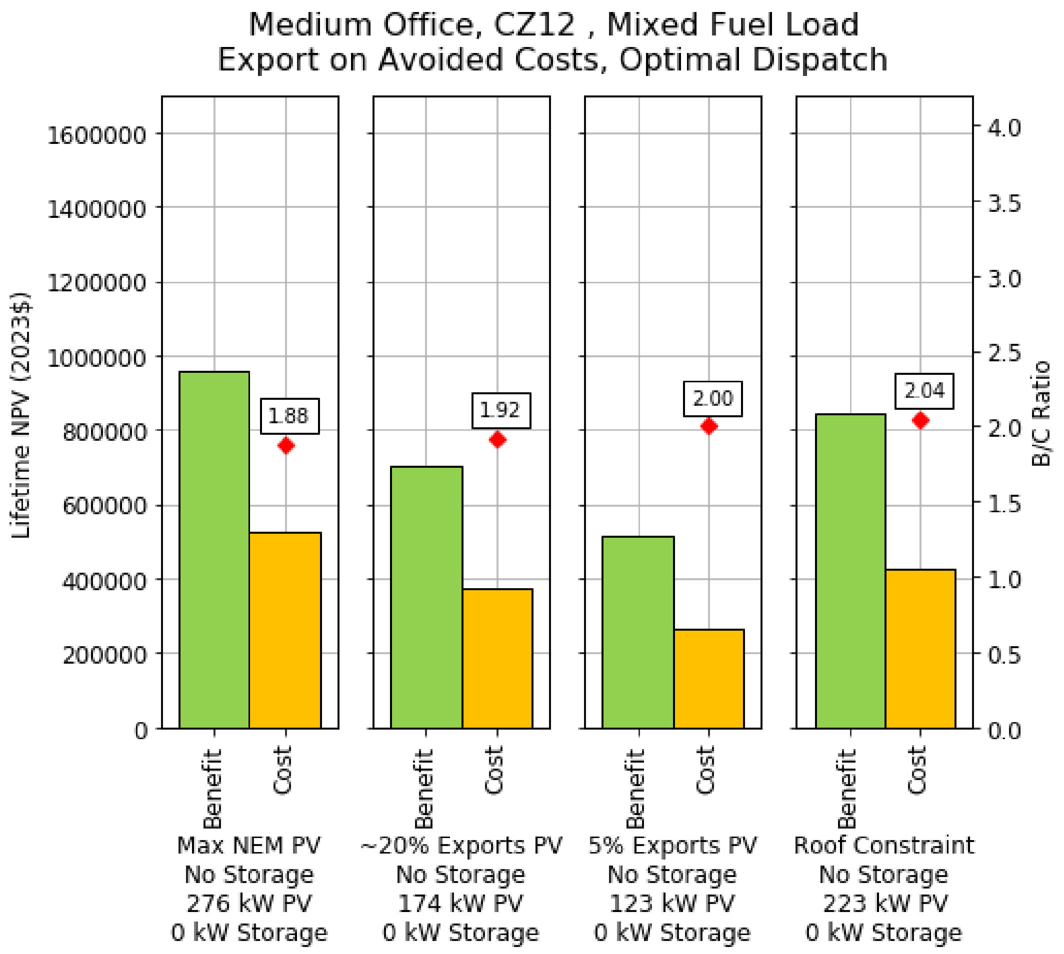
Cost Effectiveness



PV Cost-Effectiveness with Export on Avoided Costs

- "Export on Avoided Costs" and "Export on Wholesale Costs" rates have higher compensation for self-utilized PV generation than exports
- Benefit/Cost ratio increases with smaller PV size
- Increased incentive to self-utilize PV generation
- PV cost effective for all sizes

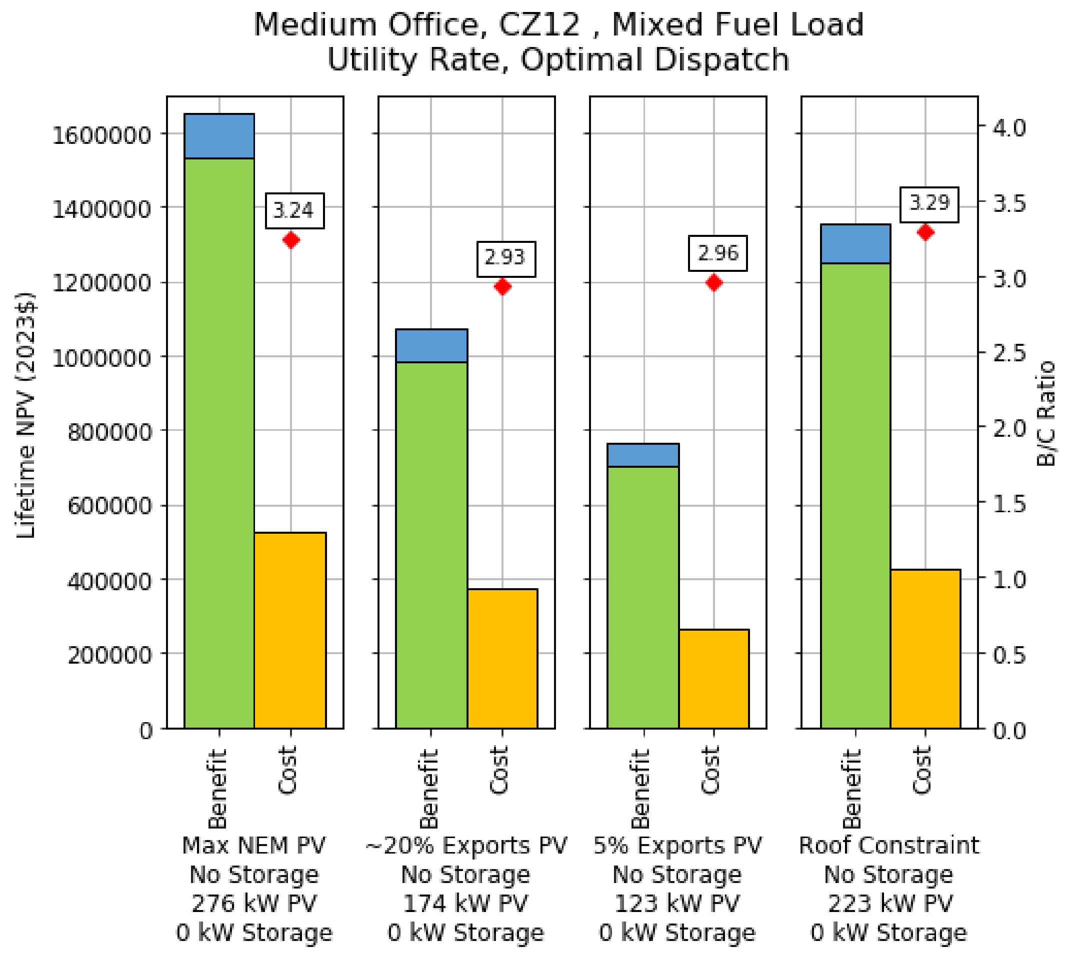
Cost Effectiveness



Utility Rates Increase PV cost-Effectiveness

- PV more cost-effective under existing retail rates than all TDV-based rates
- Current utility retail rates compensate exports at nearly the same rate as self-utilized generation (with the exception of “Non-Bypassable Charges”)
- Higher mid-day prices during behind the meter PV generation drive higher cost-effectiveness
- Little incentive to limit exports

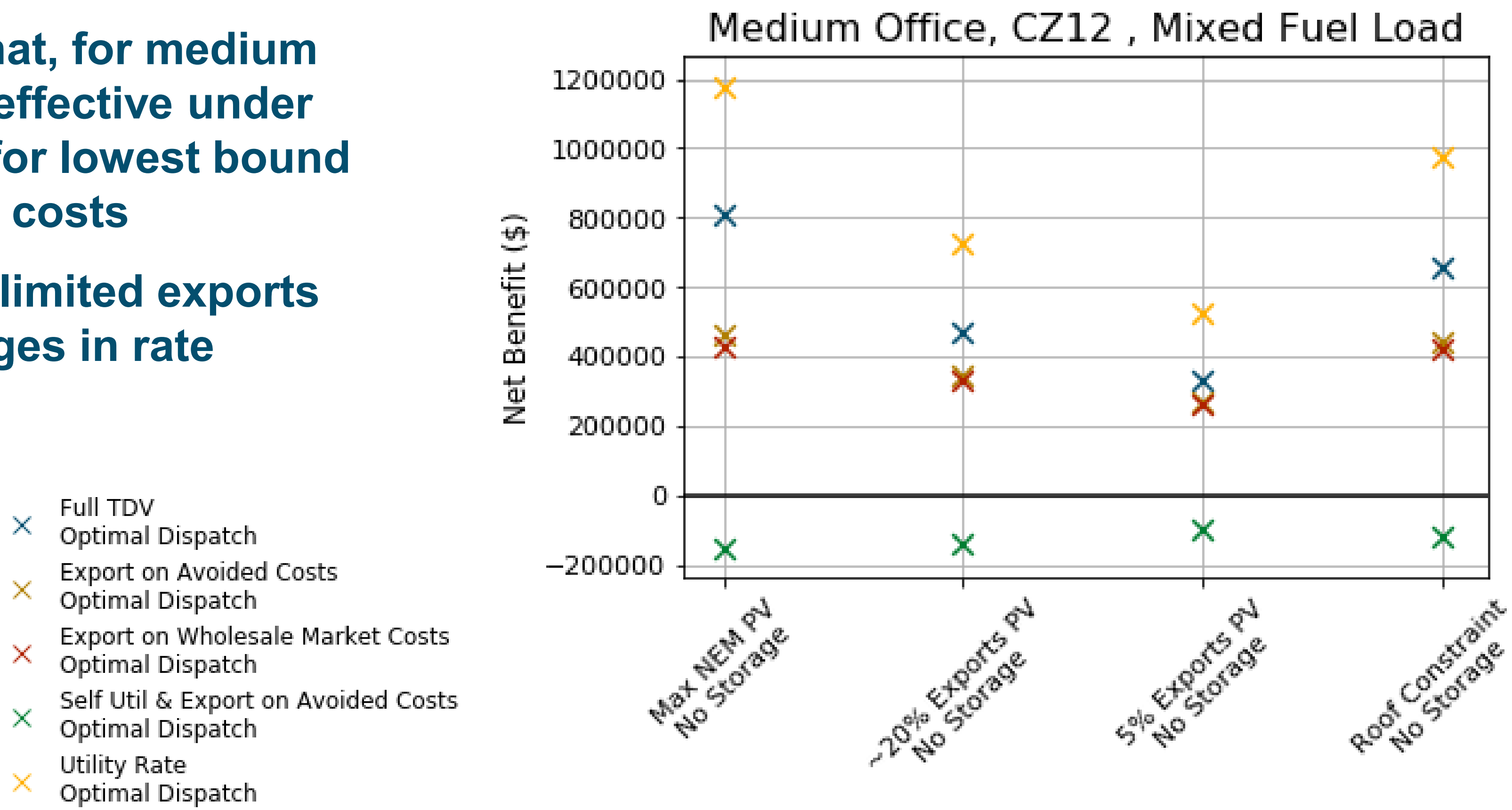
Cost Effectiveness – B10-TOU Rate



PV System Net Benefits

+ Below chart summarizes preceding benefit/cost charts
+ Map of Net Benefit shows that, for medium office, all PV sizes are cost effective under all rate sensitivities except for lowest bound of import/export on avoided costs
+ Smaller sized systems with limited exports are insulated to major changes in rate design

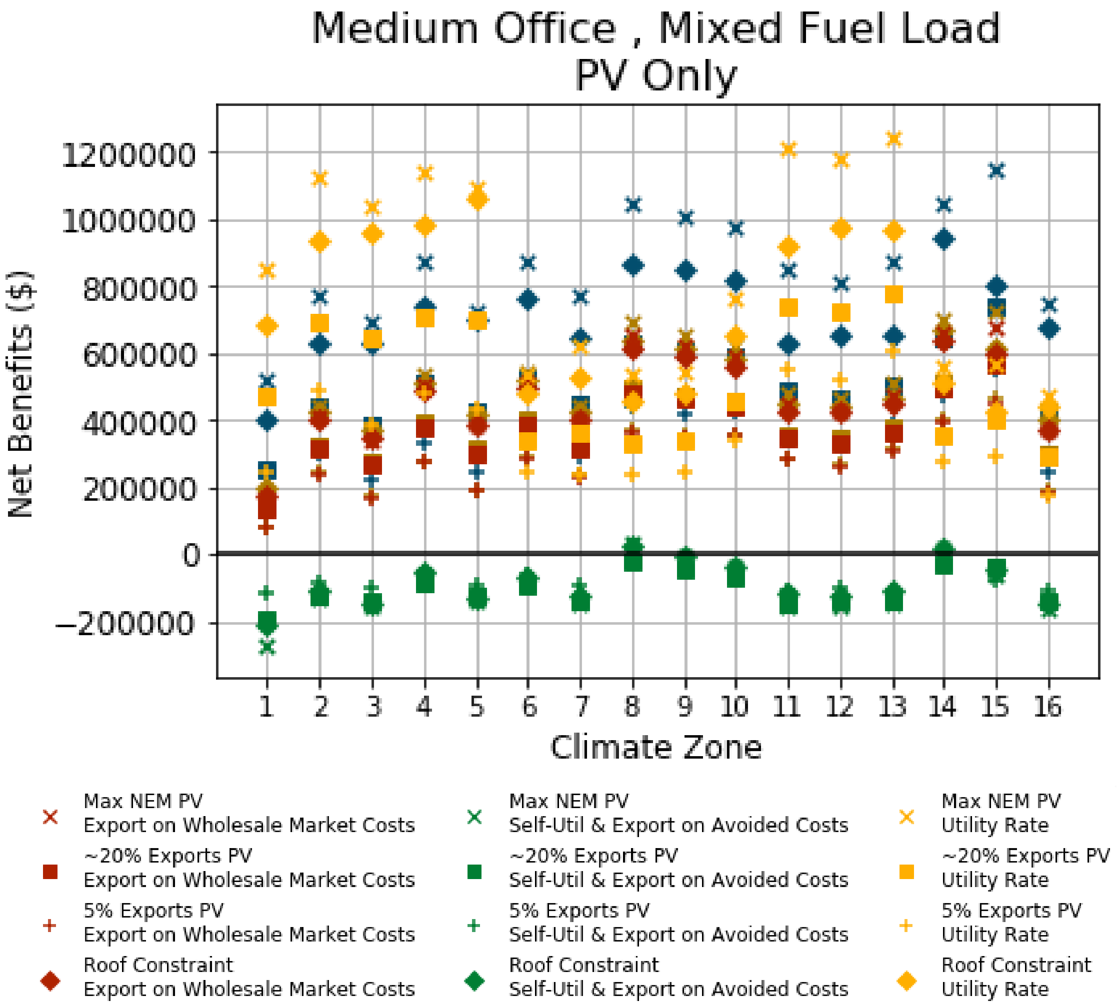
Cost Effectiveness, All Sizes, All Rates



PV System Net Benefits

- Expanding to Medium office, all climate zones, general trend stays consistent
- Climate zone 1, 16 are less cost-effective than other climate zones due to limited PV output
- Rate sensitivity of import/export under avoided costs are on the brink of cost-effectiveness

Cost Effectiveness, All Sizes, Rates, Climate Zones



PV Only Net Benefit on TDV/Exported on Avoided Costs Building Types

~20% Exports PV, No Storage, Export on Avoided Costs
Mixed Fuel Load, Optimal Dispatch

Building Type \ Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
High Rise Residential	0.95	2	1.9	2.5	2.2	2.6	2.1	3.3	3	3.1	2.3	2.1	2.4	3.2	3	2.1
Large Office	1.3	2.4	2.3	2.8	2.5	2.9	2.3	3.3	3.2	3.1	2.3	2.4	2.5	3.6	3.1	2.4
Medium Office	0.93	1.9	1.8	2.4	2.1	2.4	1.9	2.9	2.8	2.7	1.9	2	2	3.1	2.9	2
Small Office	0.57	1.6	1.5	2.1	1.8	2.1	1.6	2.5	2.5	2.3	1.6	1.6	1.7	2.8	2.3	1.7
Large Retail	1.5	2.5	2.5	3	2.8	3.1	2.5	3.5	3.4	3.2	2.5	2.5	2.6	3.7	3.1	2.6
Medium Retail	0.88	1.9	1.8	2.4	2.1	2.5	1.9	2.9	2.8	2.6	1.9	1.9	2	3.1	2.5	2
Small Retail	0.68	1.7	1.7	2.2	2	2.3	1.7	2.7	2.7	2.5	1.7	1.8	1.8	3	2.4	1.9
Small School	0.67	1.6	1.5	2	1.8	2.1	1.6	2.5	2.5	2.3	1.6	1.6	1.7	2.8	2.3	1.7
Warehouse	0.47	1.4	1.4	1.9	1.6	1.9	1.4	2.4	2.3	2.2	1.4	1.5	1.6	2.7	2.2	1.5

Net Benefits per Watt PV ($)

PV Only Net Benefit on Utility Rates Across Building Types

~20% Exports PV, No Storage, Utility Rate
Mixed Fuel Load, Optimal Dispatch

Net Benefits per Watt PV ($)

Building Type \ Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
High Rise Residential	7.3	9	9.3	9.6	10	8.3	9.7	8.2	8.4	11	9.4	9.4	9.7	9.2	8.7	7.9
Large Office	2	3.6	3.2	3.4	3.7	2.3	2.5	2.2	2.3	3	3.2	3.3	3.3	2.4	2	2.1
Medium Office	3	4.1	4.3	4.3	4.7	2.1	2.1	1.9	2	2.7	4	4.2	4.2	2.2	2	1.9
Small Office	4.2	5.4	5.7	5.8	6.1	1.6	1.5	1.5	1.7	2.2	5.5	5.6	5.7	1.8	1.3	1.5
Large Retail	1.9	3	2.9	3	3.1	1.5	2	1.4	1.5	2.5	2.8	2.9	2.7	1.7	1.3	1.4
Medium Retail	2.6	3.6	3.7	3.8	4	1.1	1.4	0.94	1.1	1.8	3.6	3.7	3.6	1.3	0.98	1.1
Small Retail	4.2	5.4	5.7	5.8	6.2	0.89	1.2	0.77	0.88	1.6	5.5	5.7	5.7	1.1	0.75	0.91
Small School	2.9	4.1	4.2	4.4	4.9	1.8	1.4	1.7	1.8	2	3.8	4	4	1.8	1.5	1.3
Warehouse	4.2	5.4	5.6	5.8	6.1	1.6	1.5	1.4	1.5	2.1	5.4	5.6	5.6	1.9	1.3	1.5

CZ	Utility
1	PG&E
2	PG&E
3	PG&E
4	PG&E
5	PG&E
6	SCE
7	SDG&E
8	SCE
9	SCE
10	SCE
11	PG&E
12	PG&E
13	PG&E
14	SCE
15	SCE
16	SCE

PV Cost Effectiveness Across Building Types

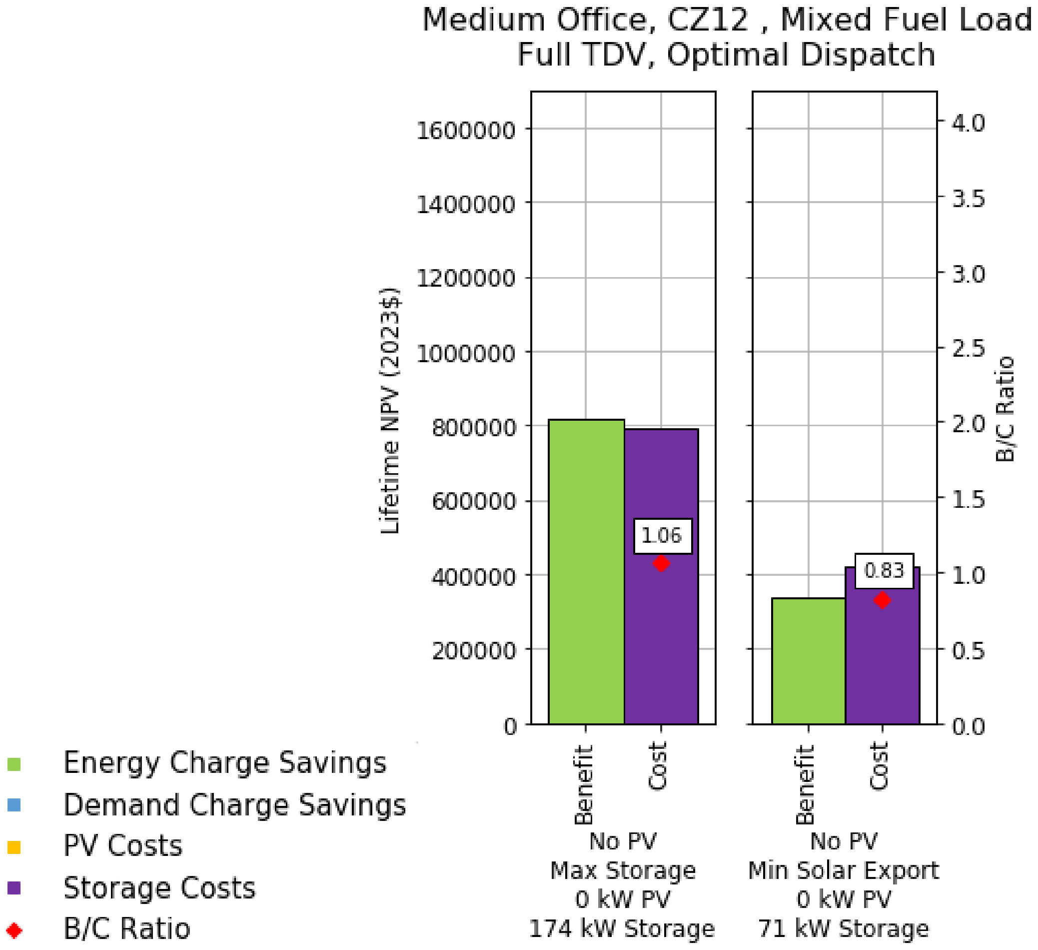
- **With exception of some edge cases, PV is cost effective across building types and climate zones, even under conservative compensation assumptions (TDV rate with exports on avoided costs)**
- **Larger buildings have improved cost effectiveness due to lower PV costs**
- **Under TDV rates, some further variation in cost effectiveness between building types, likely driven by coincidence of building loads and PV generation**
- **Utility rates impact cost-effectiveness of PV, depending on utility, selected rate tariff**
  - Note: Some utilities have options for alternative rate tariffs for customers within a given customer class (Ex. one tariff option with high demand charges and low volumetric charges, and one tariff option with low demand charges and high volumetric charges). This analysis did not attempt to optimize rate design for PV customers

Storage-Only Cost-Effectiveness

Storage Cost-Effectiveness with Full TDV Rate

- Storage-only is borderline cost-effective under Full TDV Rate
- With Full TDV rate, storage imports energy from the grid, to reduce load in high cost hours, arbitraging high and low price signals
- Larger battery has higher BC ratio due to proportionally lower battery cost ($/kWh)
- Note: basic dispatch defined by charging on solar, so only optimal dispatch tested for storage-only

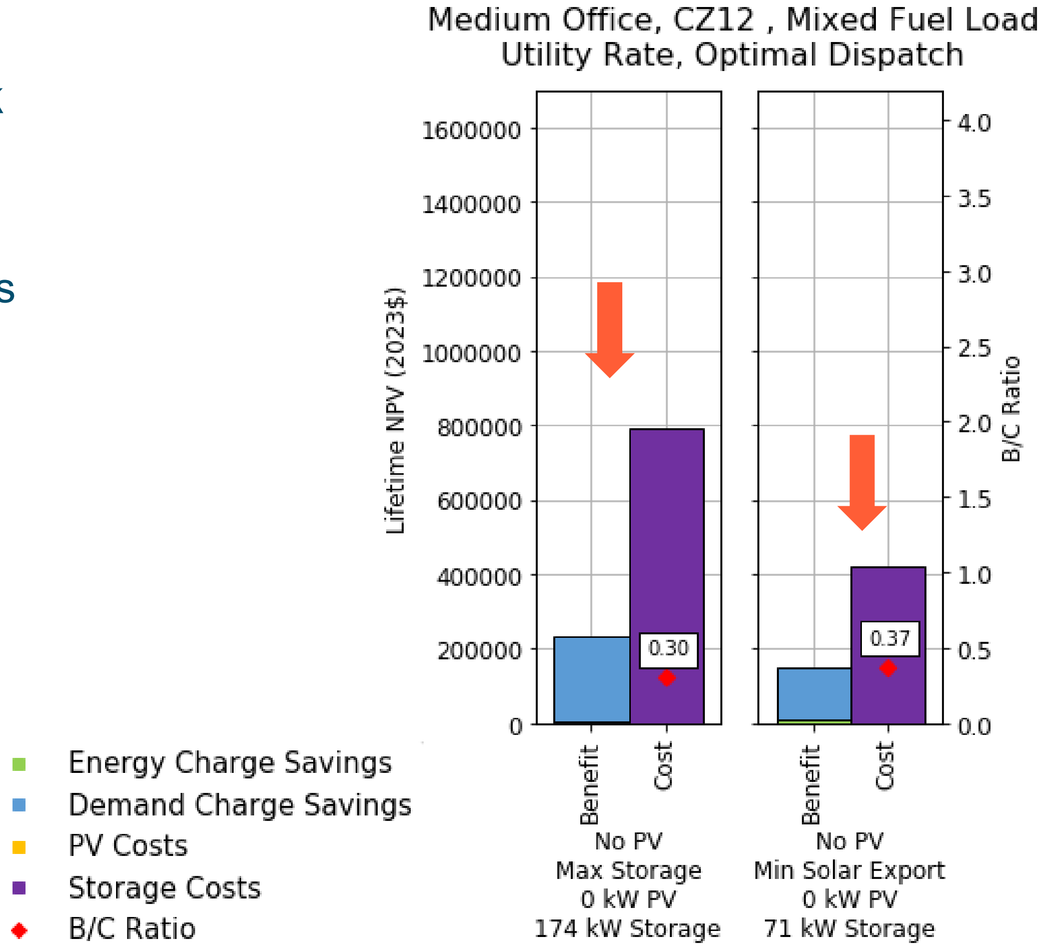
Cost Effectiveness



Utility rates Affect Cost-effectiveness

- **Storage generally less cost-effective under existing utility rates**
- **Storage benefit is largely comprised of peak demand clipping of monthly demand charges**
  - This specific utility rate has lower demand charges than other examined rates
  - Energy arbitrage opportunity is limited
- **Note that prototype buildings may have flatter load profiles than actual buildings, limiting opportunity for demand charge reduction**
  - Many real-world scenarios where BTM energy storage is cost-effective for participants

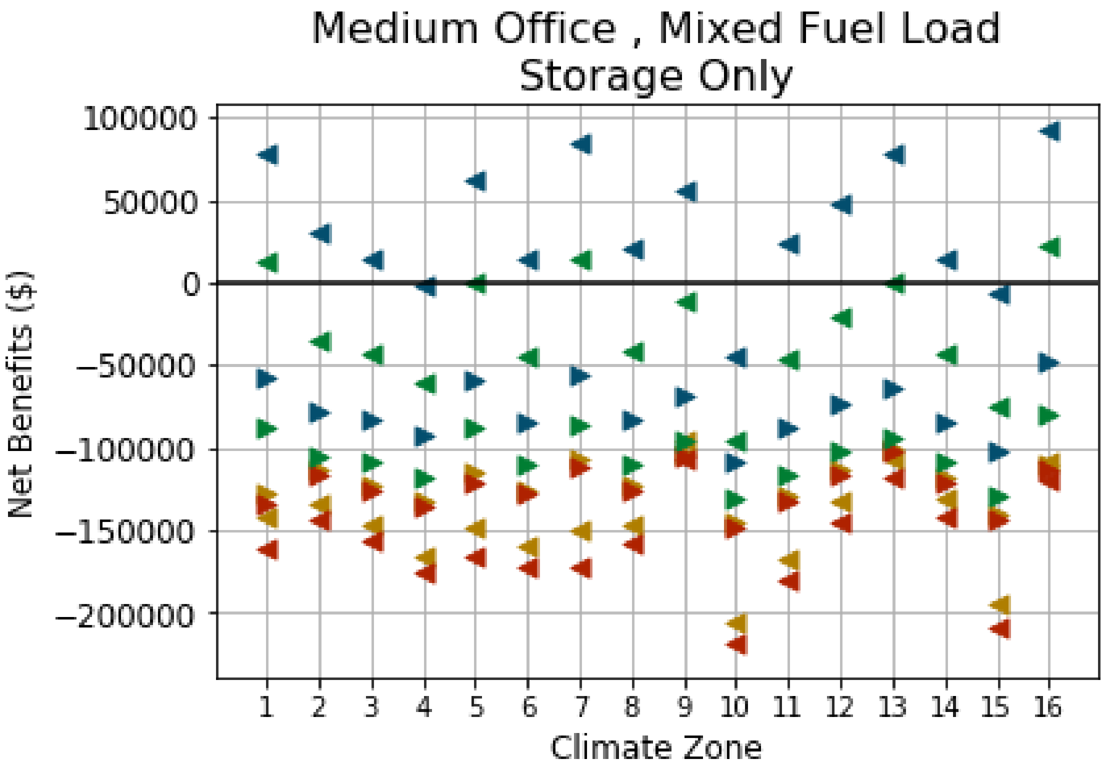
Cost Effectiveness – B10-TOU Rate



Storage System Net Benefits

- Expanding to medium office, all climate zones, cost-effectiveness does not change dramatically based on climate zone for storage-only systems
- Largely not cost-effective, but could change based on storage cost projections, and potential cost declines

Cost Effectiveness, All Sizes, Rates, Climate Zones



- Max Storage, Optimal Dispatch Full TDV
- Min Solar Export Storage, Optimal Dispatch Full TDV
- Max Storage, Optimal Dispatch Export on Wholesale Market Costs
- Min Solar Export Storage, Optimal Dispatch Export on Wholesale Market Costs
- Max Storage, Optimal Dispatch Export on Avoided Costs
- Min Solar Export Storage, Optimal Dispatch Export on Avoided Costs
- Max Storage, Optimal Dispatch Self-Util & Export on Avoided Costs
- Min Solar Export Storage, Optimal Dispatch Self-Util & Export on Avoided Costs

(without utility retail rate sensitivity)

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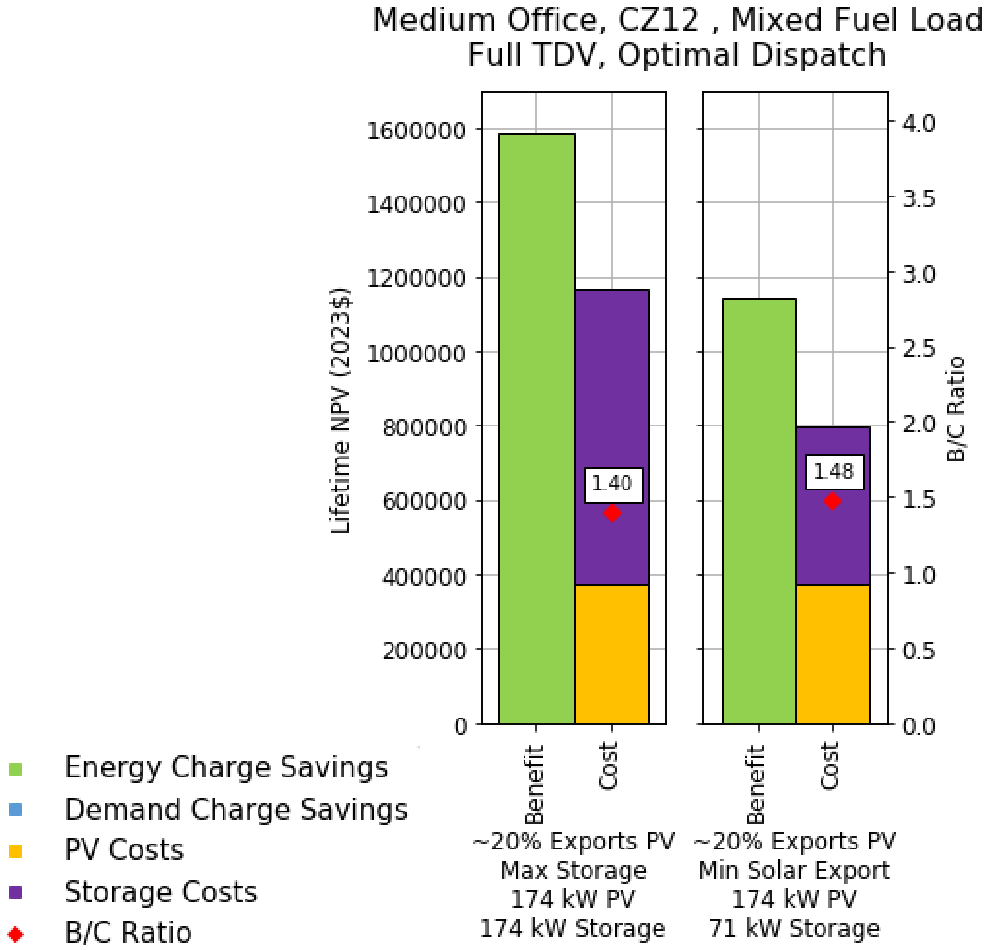
PV+Storage Cost-Effectiveness

PV+Storage Cost-Effectiveness with Full TDV Rate

- Focused on Self-utilization (~20% Exports) PV size with larger and smaller storage sizes
- PV+Storage combined as a package has a lifetime net benefit under Full TDV rate
- Smaller storage system has higher Benefit-cost ratio due to diminishing returns in benefits of storage sizing

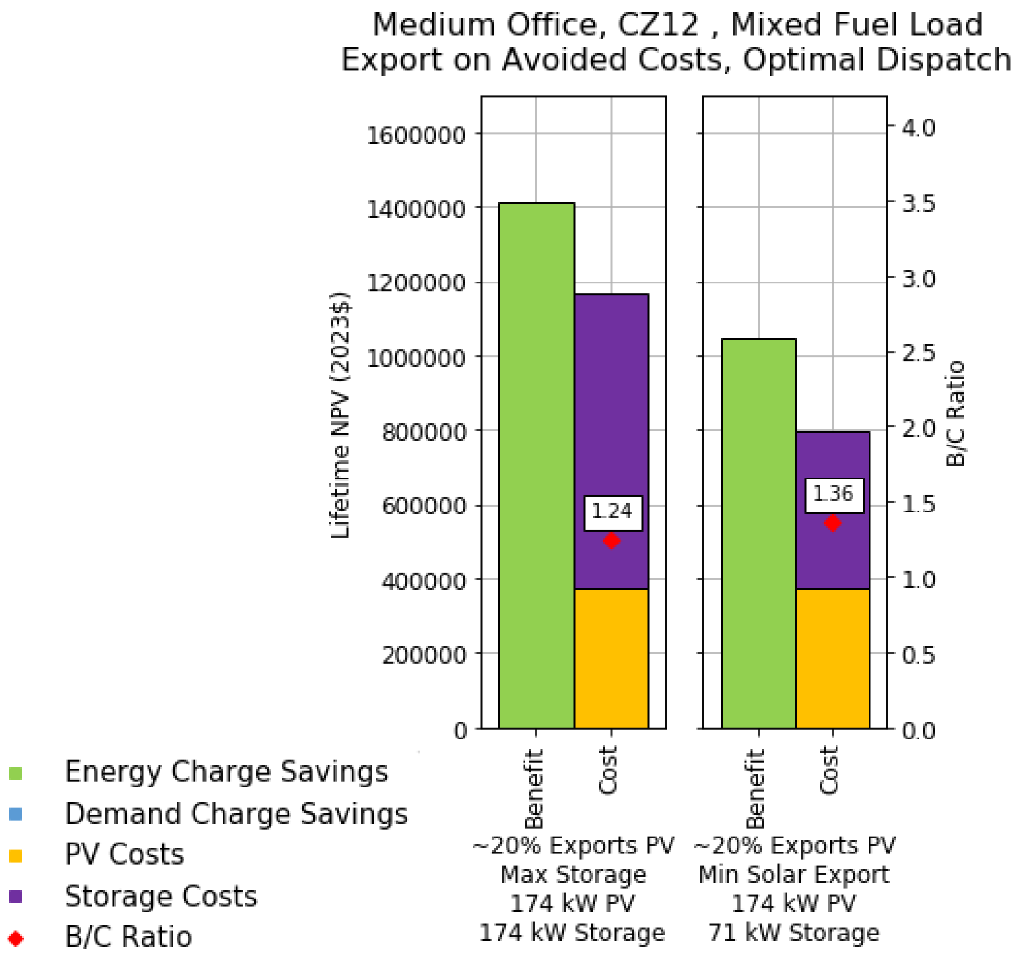
Cost Effectiveness



PV+Storage Cost-Effectiveness with Exports on Avoided Costs

- On Export on Avoided Costs rate, smaller system has higher net benefit than larger storage system
- Smaller system size is more insulated to potential NEM rate reforms

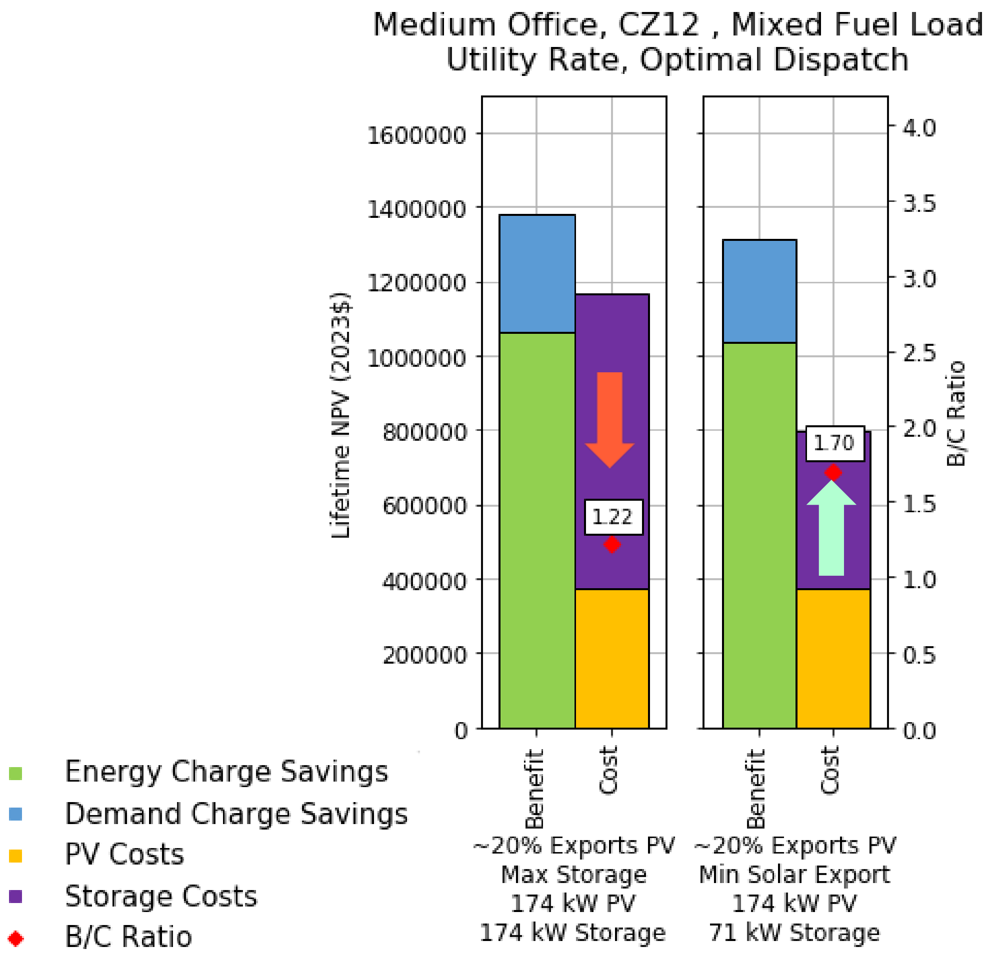
Cost Effectiveness



Utility rates affect cost-effectiveness

- Utility retail rate increases on cost-effectiveness for PV+Storage for smaller battery size, due to strong cost-effectiveness of PV, potential for large demand charge reduction opportunities
- Net benefit with smaller storage size notably higher than larger storage configuration

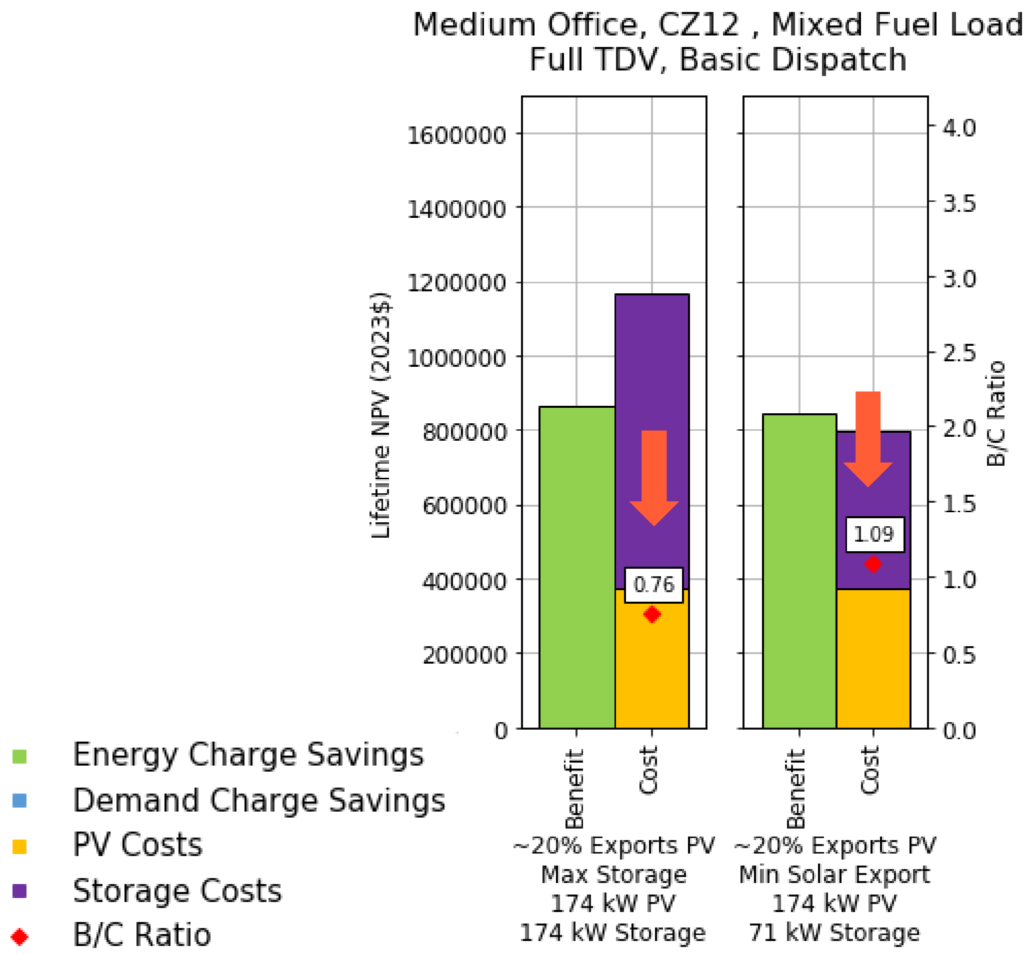
Cost Effectiveness – B10-TOU Rate



Basic dispatch limits cost-effectiveness

- **Smaller PV+Storage configuration still cost-effective with Basic dispatch under Full TDV rate scenario**
  - Battery only charges on PV net exports and discharges when load again exceeds PV production
- **Due to diminishing returns, smaller storage size is cost-effective while large storage size is not**
- **This case represents a low-booked value for PV+storage cost-effectiveness**

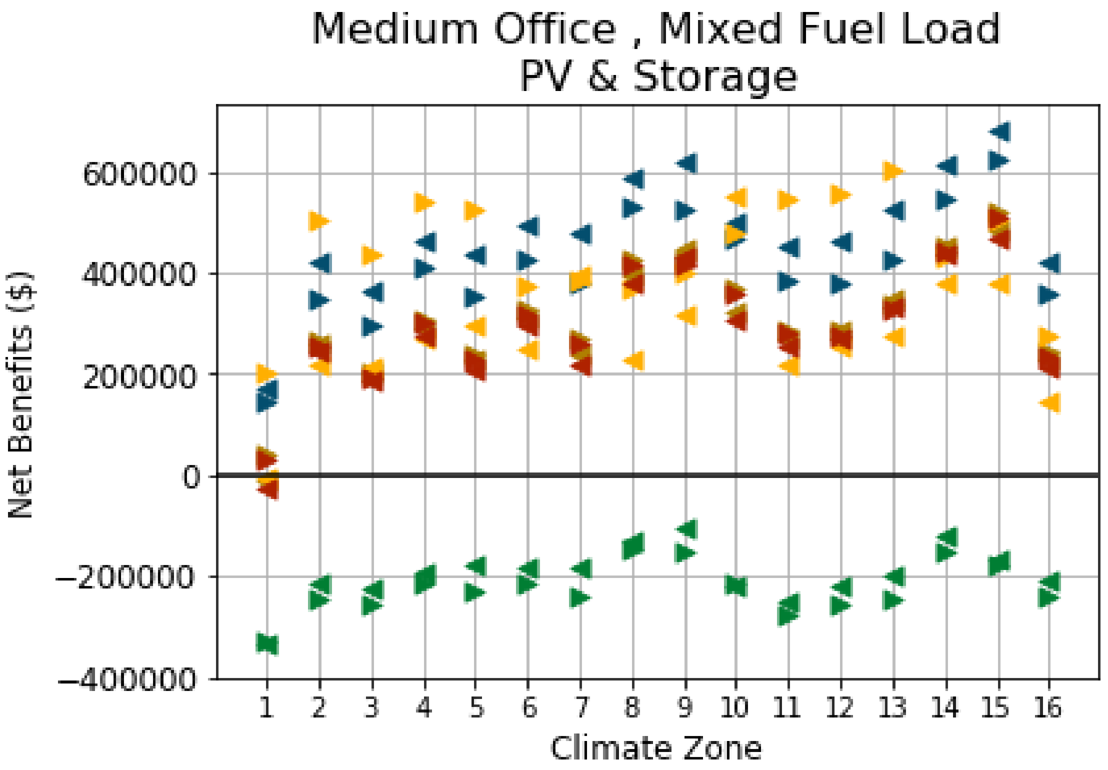
Cost Effectiveness – Basic Dispatch



PV+Storage System Net Benefits, Optimal Dispatch

- Expanding to medium office, all climate zones, general trend stays consistent
- Climate zone 1, 16 are less cost-effective than other climate zones due to limited PV output
- Rate sensitivity of import/export under avoided costs is not cost-effective
- Utility rate has mixed impacts on cost-effectiveness

Cost Effectiveness, All Rates & Climate Zones



~20% Exports PV
Max Storage, Optimal Dispatch
Full TDV

~20% Exports PV
Min Solar Export Storage, Optimal Dispatch
Full TDV

~20% Exports PV
Max Storage, Optimal Dispatch
Utility Rate

~20% Exports PV
Min Solar Export Storage, Optimal Dispatch
Utility Rate

~20% Exports PV
Max Storage, Optimal Dispatch
Export on Avoided Costs

~20% Exports PV
Min Solar Export Storage, Optimal Dispatch
Export on Avoided Costs

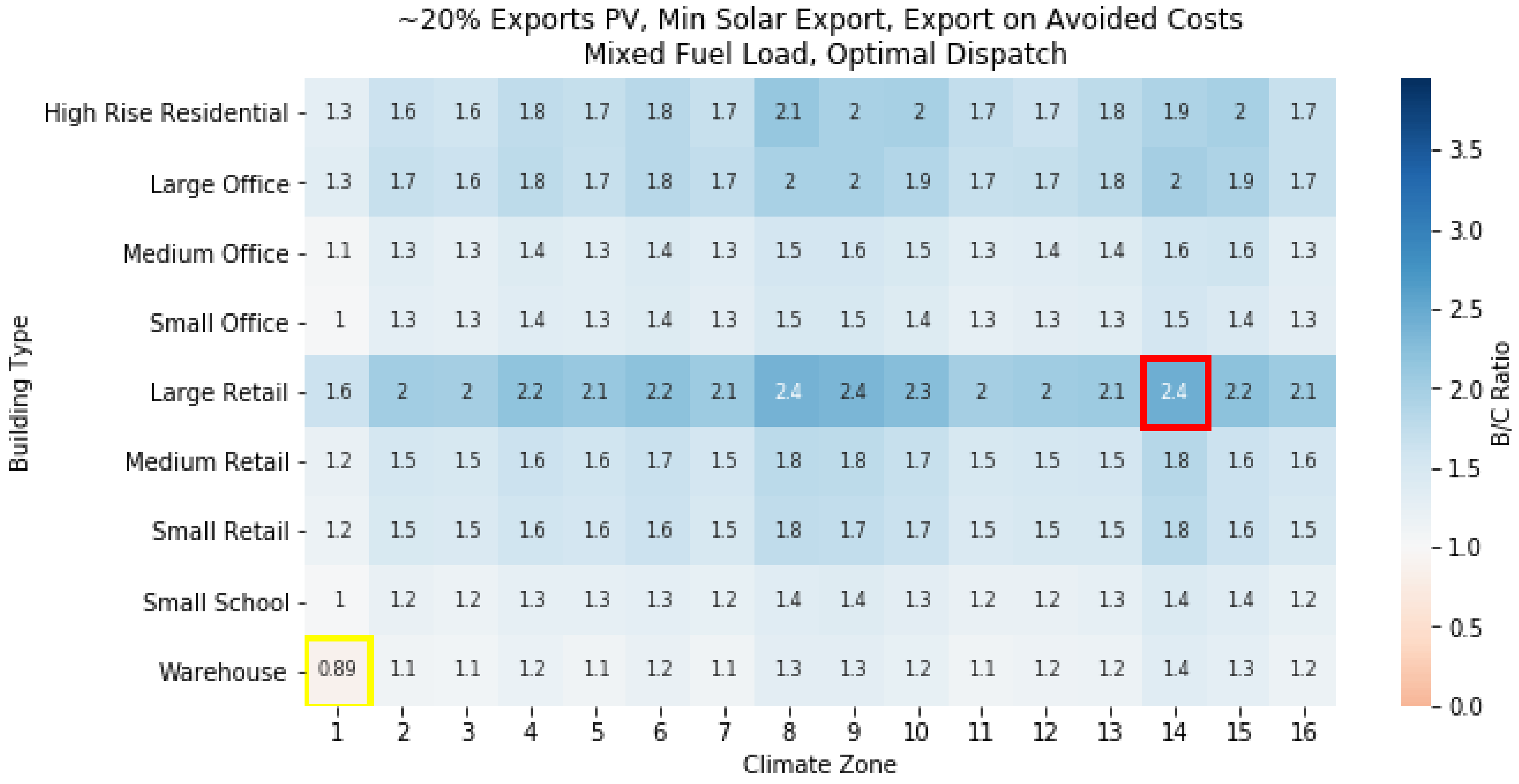
~20% Exports PV
Max Storage, Optimal Dispatch
Export on Wholesale Market Costs

~20% Exports PV
Min Solar Export Storage, Optimal Dispatch
Export on Wholesale Market Costs

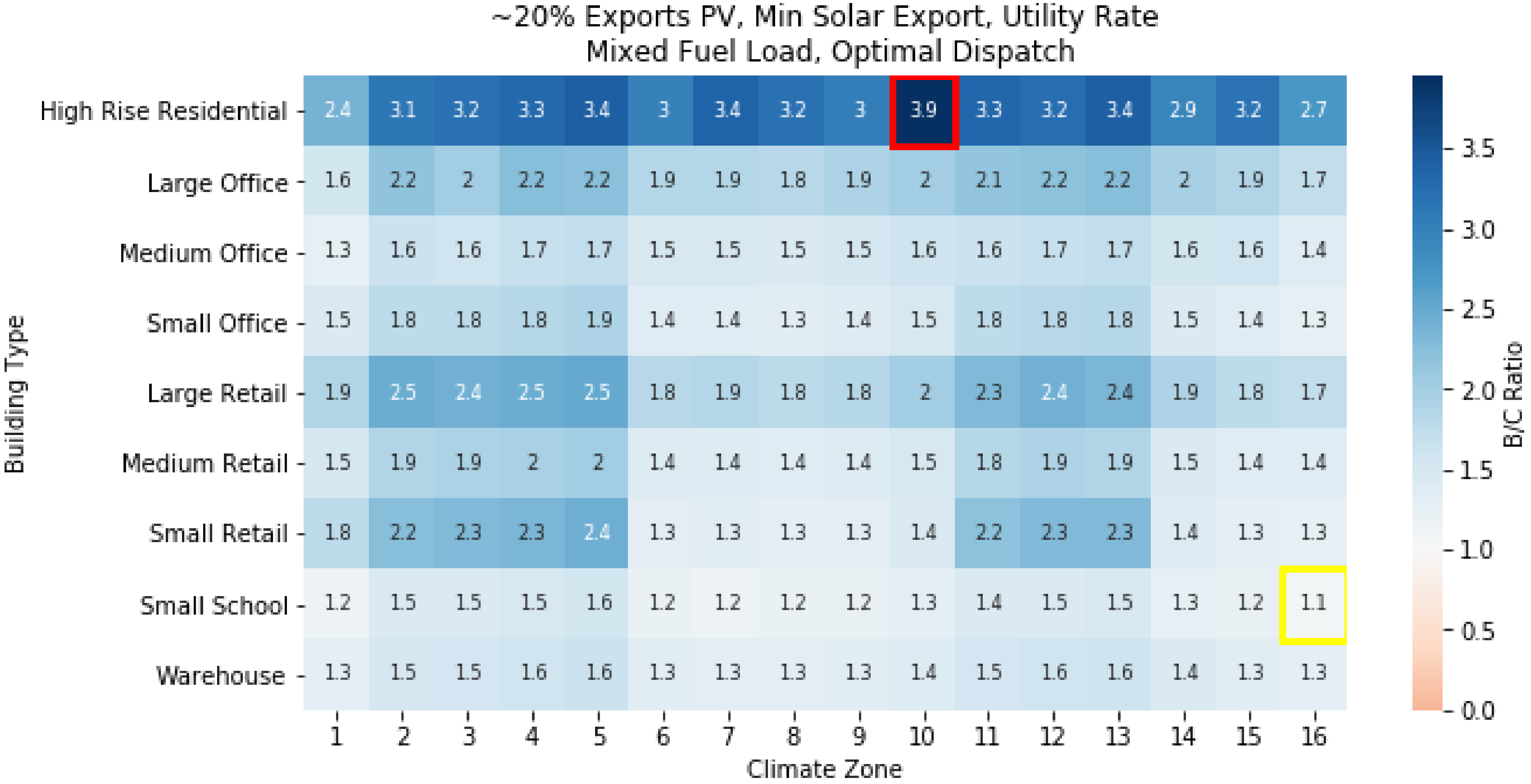
~20% Exports PV
Max Storage, Optimal Dispatch
Self-Util & Export on Avoided Costs

~20% Exports PV
Min Solar Export Storage, Optimal Dispatch
Self-Util & Export on Avoided Costs

PV + Storage Optimal Dispatch on TDV/Exported on Avoided Costs Across Building Types



PV + Storage Optimal Dispatch on Utility Rates Across Building Types



CZ	Utility
1	PG&E
2	PG&E
3	PG&E
4	PG&E
5	PG&E
6	SCE
7	SDG&E
8	SCE
9	SCE
10	SCE
11	PG&E
12	PG&E
13	PG&E
14	SCE
15	SCE
16	SCE

PV+Storage Cost Effectiveness Across Building Types

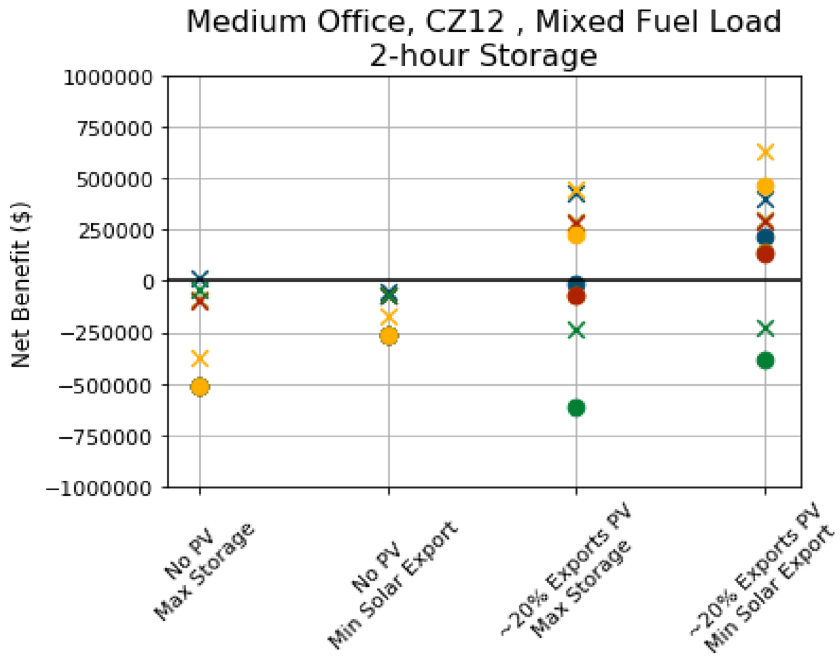
- With exception of some edge cases, PV+storage with the smaller sizing configuration is cost effective across building types and climate zones, even under conservative compensation assumptions (TDV rate with exports on avoided costs)
- Basic dispatch diminishes cost effectiveness across building types, yielding some non-cost-effective combinations
- Cost-effectiveness by building type largely driven by cost declines for larger systems
- Under TDV rates, some further variation in cost effectiveness between building types, likely driven by building load profile and ability for PV+storage to impact net load
- Using selected utility rates, co-benefits of PV and storage yields a generally cost-effective solution for prototype buildings

Storage Duration & Size Sensitivity

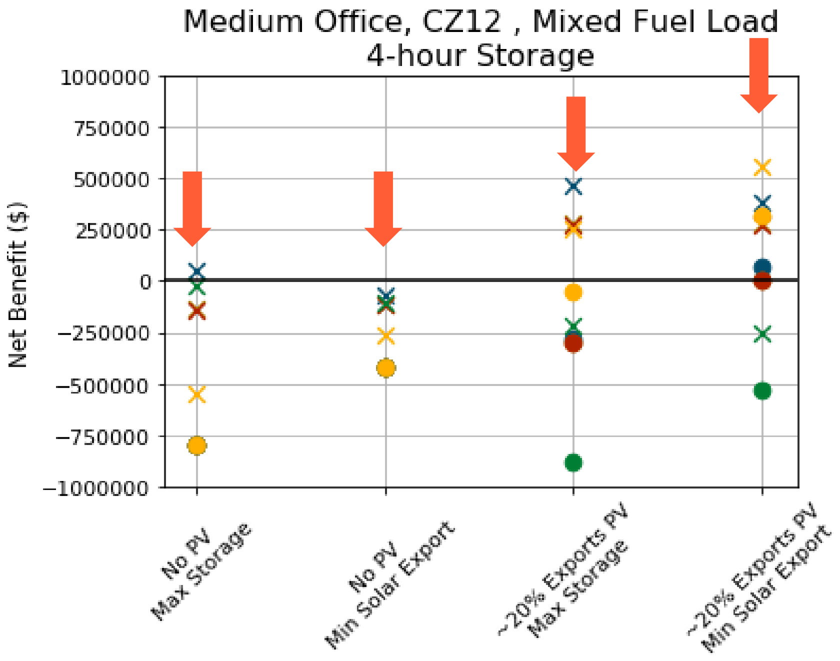
Storage Duration Sensitivity

+ **2-hour duration improves cost-effectiveness**

2-hour Storage



4-hour Storage



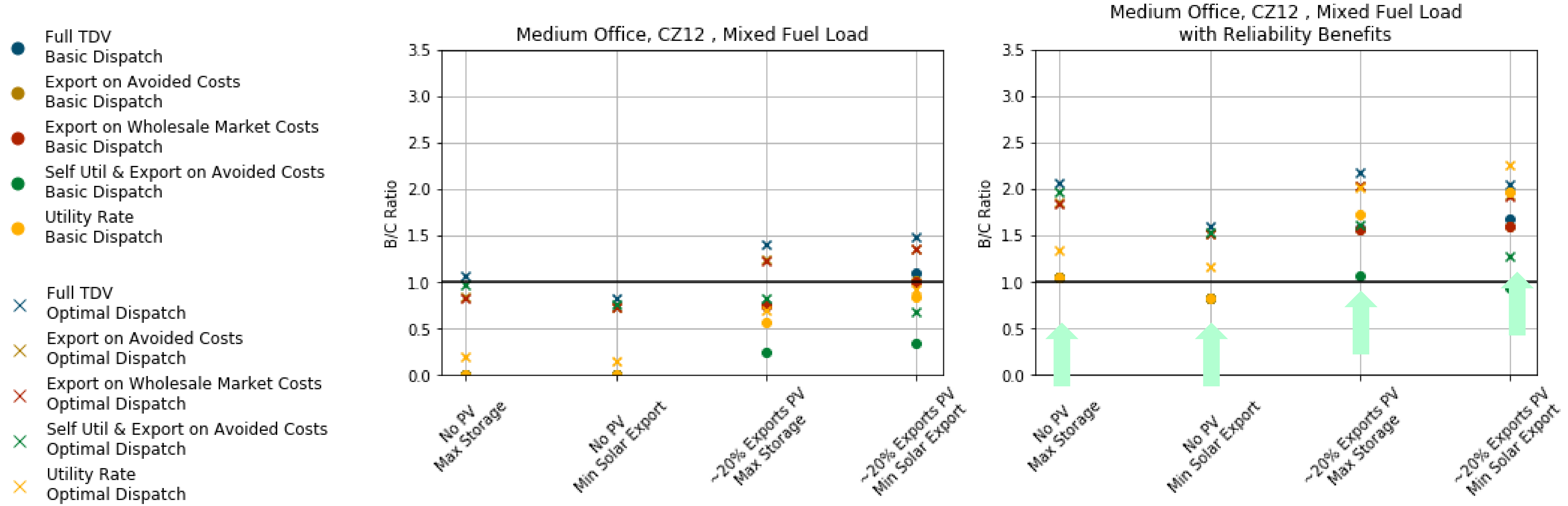
Reliability & Resiliency Value Sensitivity

Reliability Benefit Improves Cost-Effectiveness

+ If considered, reliability value can largely improve cost-effectiveness

- Reliability benefit comes from having PV generation or reserving storage energy for unplanned short T&D power interruptions

Without Reliability, Resiliency Value	With Reliability Value Only

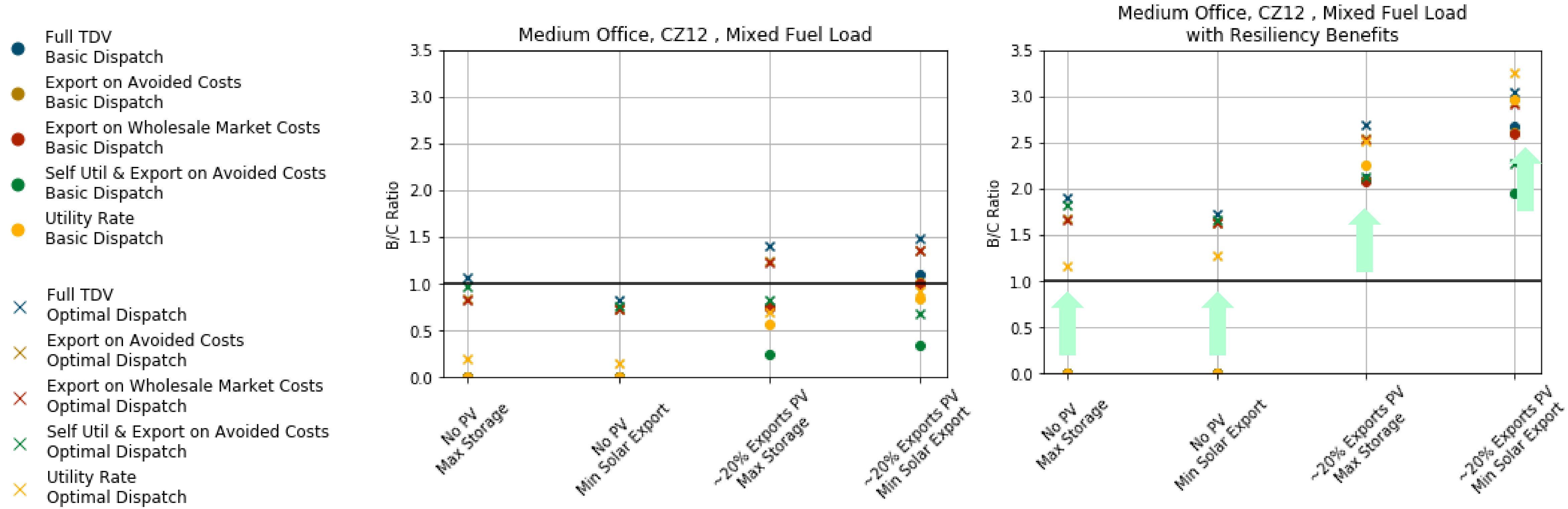


Resiliency Benefit Improves Cost-Effectiveness

+ If considered, resiliency value can largely improve cost-effectiveness

- Resiliency benefit comes from covering critical load during planned outage days (ex. Public Safety Power Shutoff)

Without Reliability, Resiliency Value | **With Resiliency Value Only**



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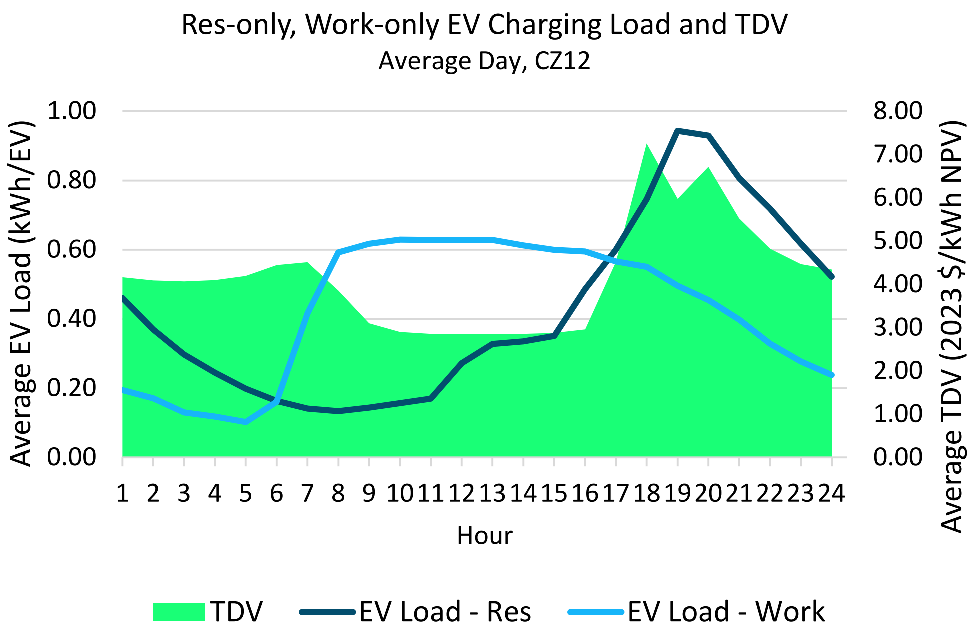
EV Charging Compliance Option Framework

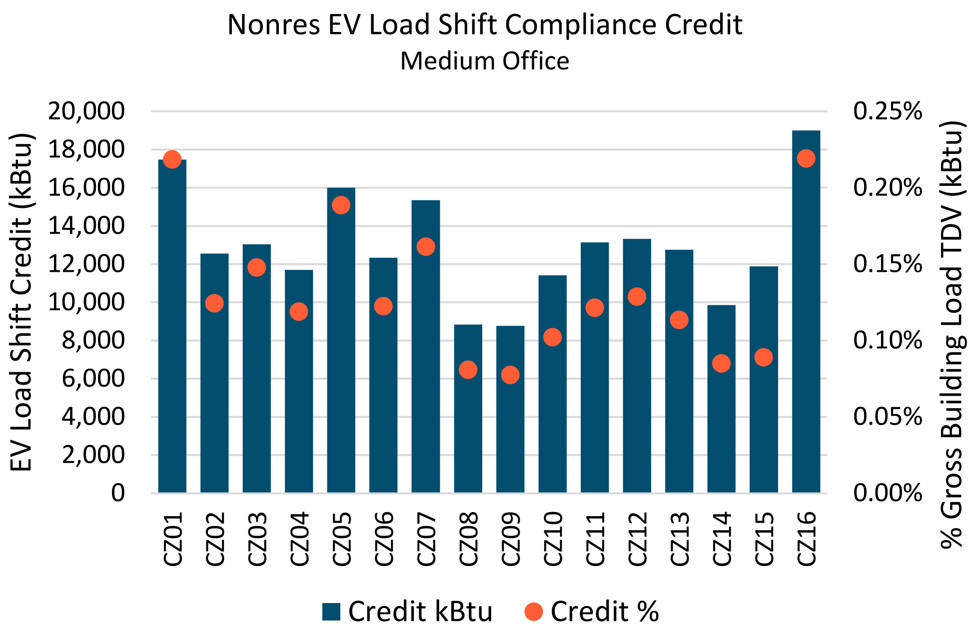
Proposed framework for nonresidential EV compliance credit and initial example

- In order to meet California's 2025 ZEV goals, CARB estimates an additional need of 8,000-76,000 public/workplace level 2 (L2, ~7 kW) EV chargers, beyond those forecast under current building codes and incentives
- Title 24, Part 11 (CALGreen) requires ~6% of a building's parking spaces be "EV Capable" – cable raceway and sufficient panel capacity to support Electric Vehicle Supply Equipment (EVSE) – but does not require installation of the charger equipment itself
- Granting Title 24, Part 6 compliance credit for EVSE installation in non-residential buildings could help fill this gap
- Designing proposal so that it does not double count with LCFS
- This compliance credit is based on chargers in daytime charging locations that provide grid benefits:
    - TDV value of shifting EV charging load from a typical residential charging shape (during peak or evening hours) to a more solar-aligned workplace charging shape

How significant would the credit be?

- **Compliance Credit per Charger**
  - TDV 8,777 to 19,000 kBtu per charger lifecycle
  - Levelized Source Energy 3,172 to 3,194 kBtu per charger per year
  - Savings of at least 0.2 Tonnes CO2-e per charger per year
- **Figures assume EV charges on grid energy – greater savings from PV charging**





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Conclusions and Next Steps

Key Findings

- **PV + Storage as a package (smaller configuration) is cost-effective for most building categories due to co-benefits of combined systems**
  - PV + Storage provides additional participant benefits, including reliability and resiliency
- **PV is cost effective across all scenarios from participant perspective, except under most significant rate reform**
  - Minimizing exports allows for significant PV benefits, while having robust cost-effectiveness in all rate sensitivities
  - Note: most significant rate reform is analogous to “buy all - sell all” on avoided cost treatment of rooftop PV
- **Storage-only presents large grid benefits, but is generally not cost-effective in this analysis**

Next Steps

+ **Refine sizing and configuration**
+ **Calculate source energy, emissions impacts of selected configurations**
+ **Refine battery controls**
  - Optimal dispatch is an upper bound
  - Basic dispatch is likely too conservative
  - Explore more realistic controls, or heuristic for benefit captured in real world vs optimal dispatch
+ **Collect real-world data from interested stakeholders**
  - Capital and operating costs
  - Technology characteristics
  - Battery control schemes
  - Typical storage duration
  - Future rate design

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Thank you!

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Appendix

Appendix Contents

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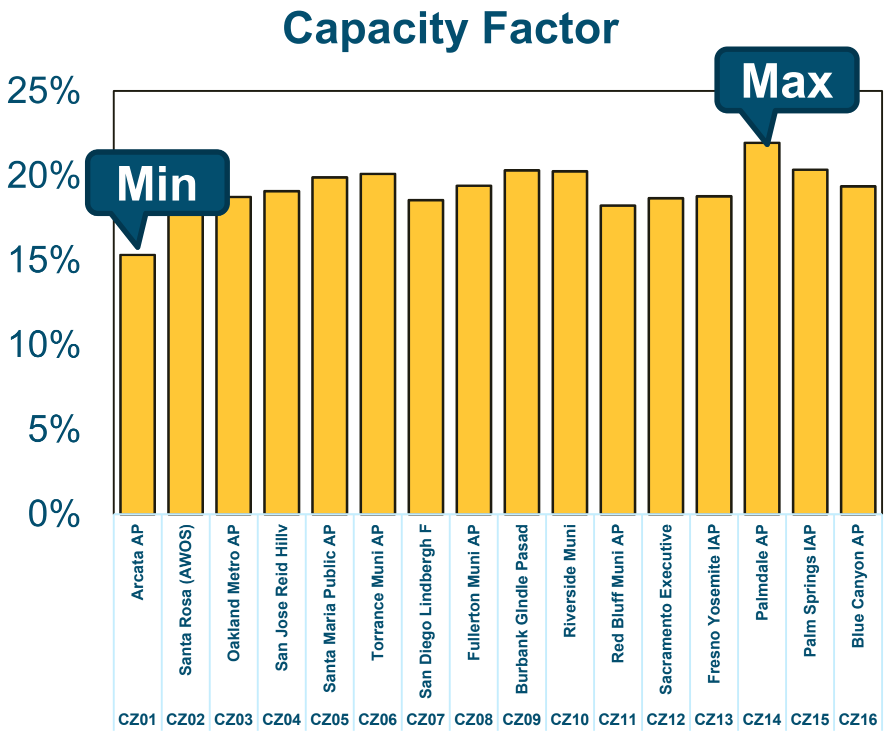
Appendix – Additional PV-Only and Storage-Only Results

PV Capacity Factor

+ **CZ01 has much lower PV output (les cost-effective), CZ14 has much higher PV output (more cost-effective)**

Climate Zone	Weather Station Name	Capacity Factor
CZ01	Arcata AP	15.3%
CZ02	Santa Rosa (AWOS)	18.1%
CZ03	Oakland Metro AP	18.7%
CZ04	San Jose Reid Hillv	19.1%
CZ05	Santa Maria Public AP	19.9%
CZ06	Torrance Muni AP	20.1%
CZ07	San Diego Lindbergh F	18.6%
CZ08	Fullerton Muni AP	19.4%
CZ09	Burbank Glndle Pasad	20.3%
CZ10	Riverside Muni	20.3%
CZ11	Red Bluff Muni AP	18.2%
CZ12	Sacramento Executive	18.7%
CZ13	Fresno Yosemite IAP	18.8%
CZ14	Palmdale AP	21.9%
CZ15	Palm Springs IAP	20.3%
CZ16	Blue Canyon AP	19.4%

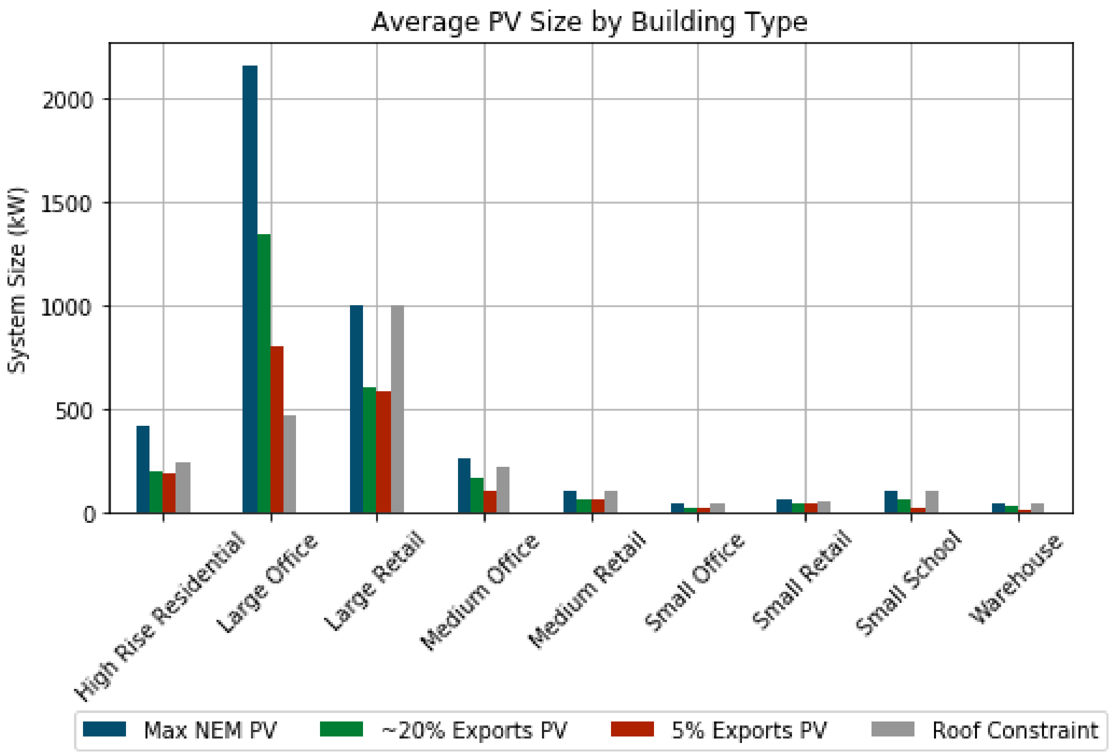


PV Sizing

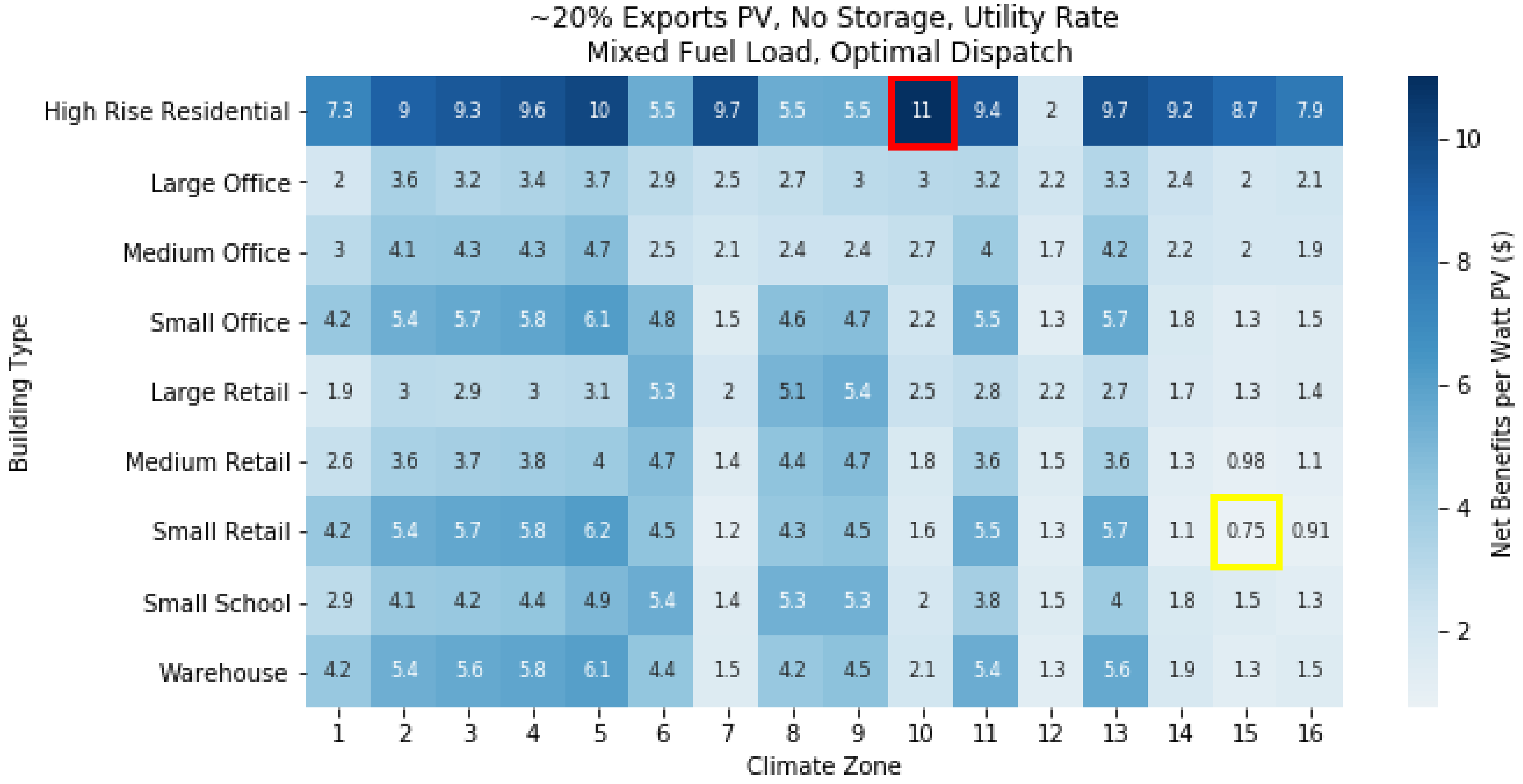
+ **Three sizing options for each building type and climate zone**
  - Max NEM Complaint
    - Annual solar gen = annual total building consumption
    - ~40% of annual PV generation is exported to grid
  - Self-utilization (~20% Exports PV)
    - Sized to generate the amount of PV that is self-utilized in *Max NEM Compliant* case
    - ~20% of annual PV generation is exported to grid
  - 5% Exports
    - 5% of annual PV generation is exported to grid

+ **PV sizes compared to roof area constraints to ensure viable system size**

Average PV Size by Building Type



PV Only Net Benefit on Utility Rates Across Building Types w/ LADWP & SMUD

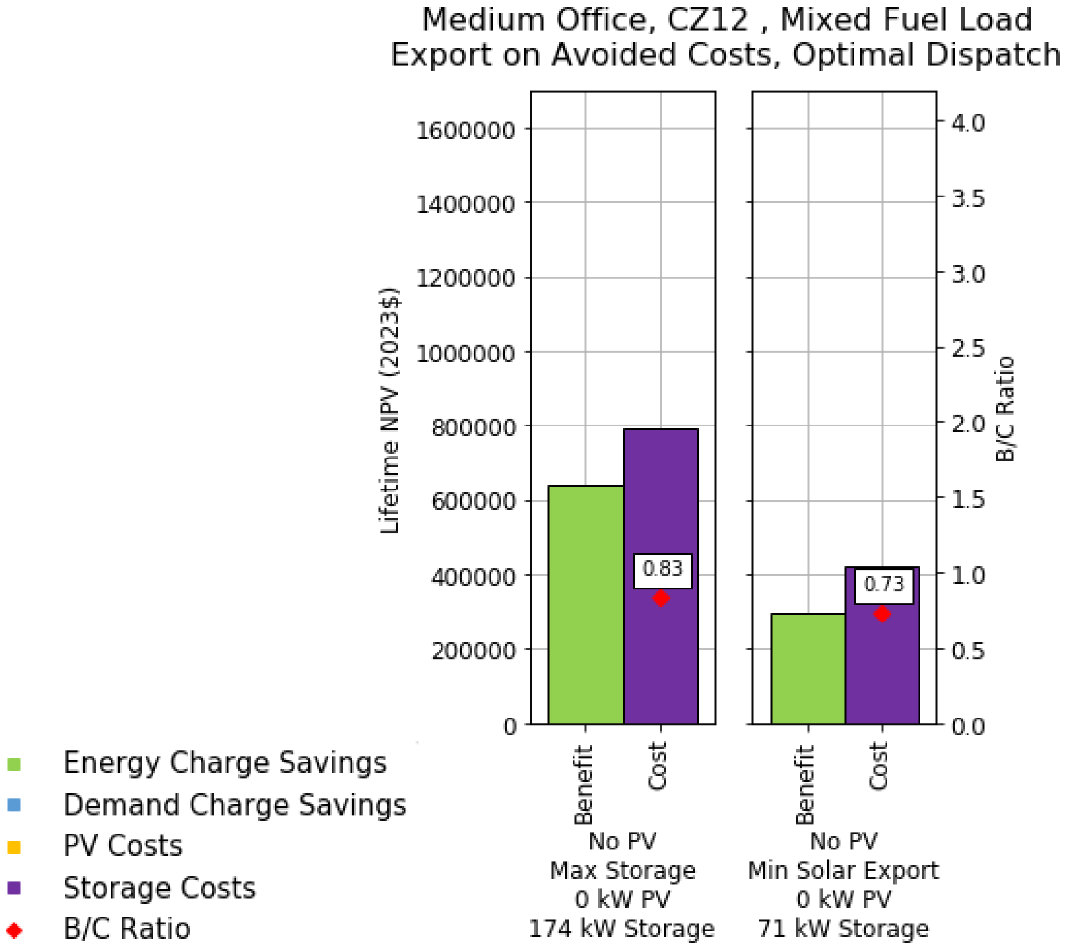


CZ	Utility
1	PG&E
2	PG&E
3	PG&E
4	PG&E
5	PG&E
6	**LADWP**
7	SDG&E
8	**LADWP**
9	**LADWP**
10	SCE
11	PG&E
12	**SMUD**
13	PG&E
14	SCE
15	SCE
16	SCE

Storage Cost-Effectiveness with Export on Avoided Costs

- Storage-only is slightly less cost-effective under Export on Avoided Costs
- Larger battery has higher BC ratio due to proportionally lower battery cost ($/kWh)
- Significant benefits, but benefits do not out-weigh costs

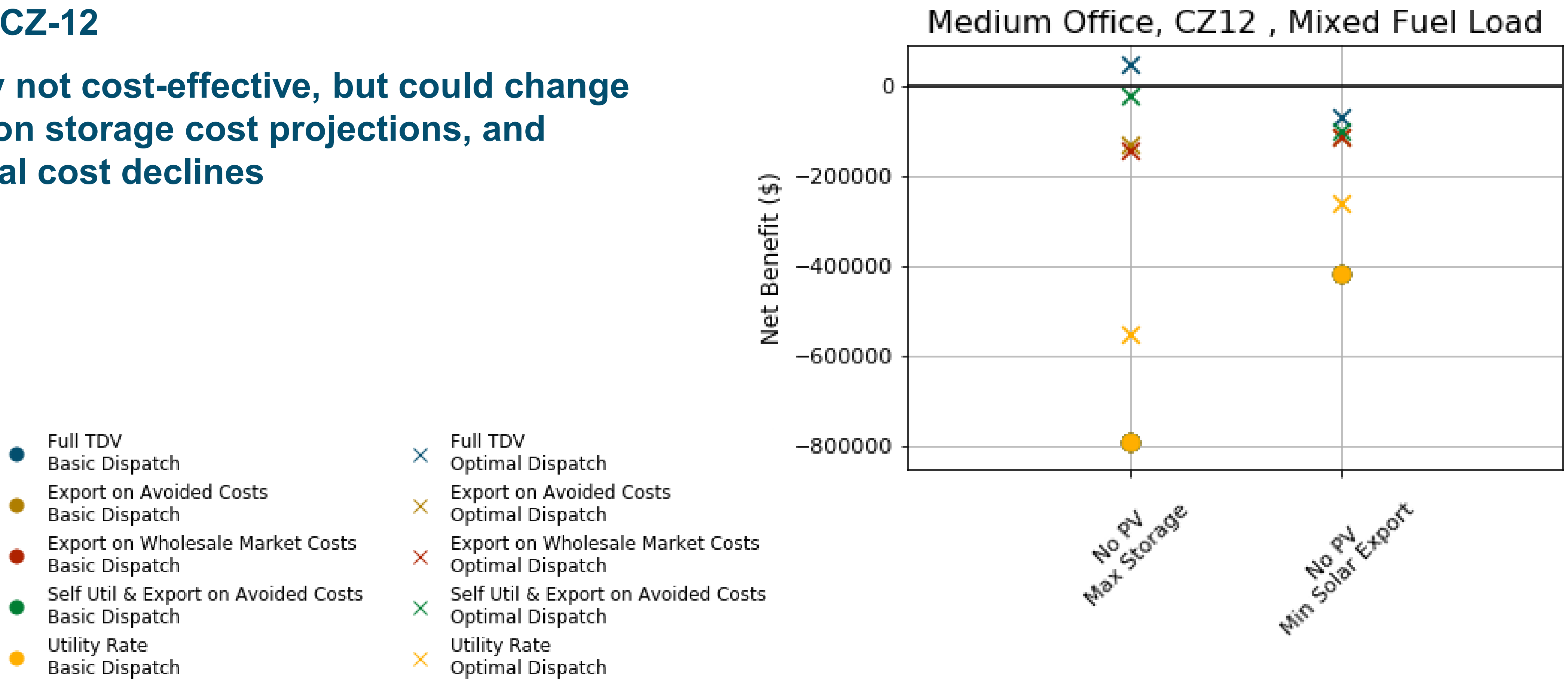
Cost Effectiveness



Storage System Net Benefits

- The chart aggregates previous storage only charts, with all rate sensitivities for Medium Office, CZ-12
- Largely not cost-effective, but could change based on storage cost projections, and potential cost declines

Cost Effectiveness, All Sizes, All Rates



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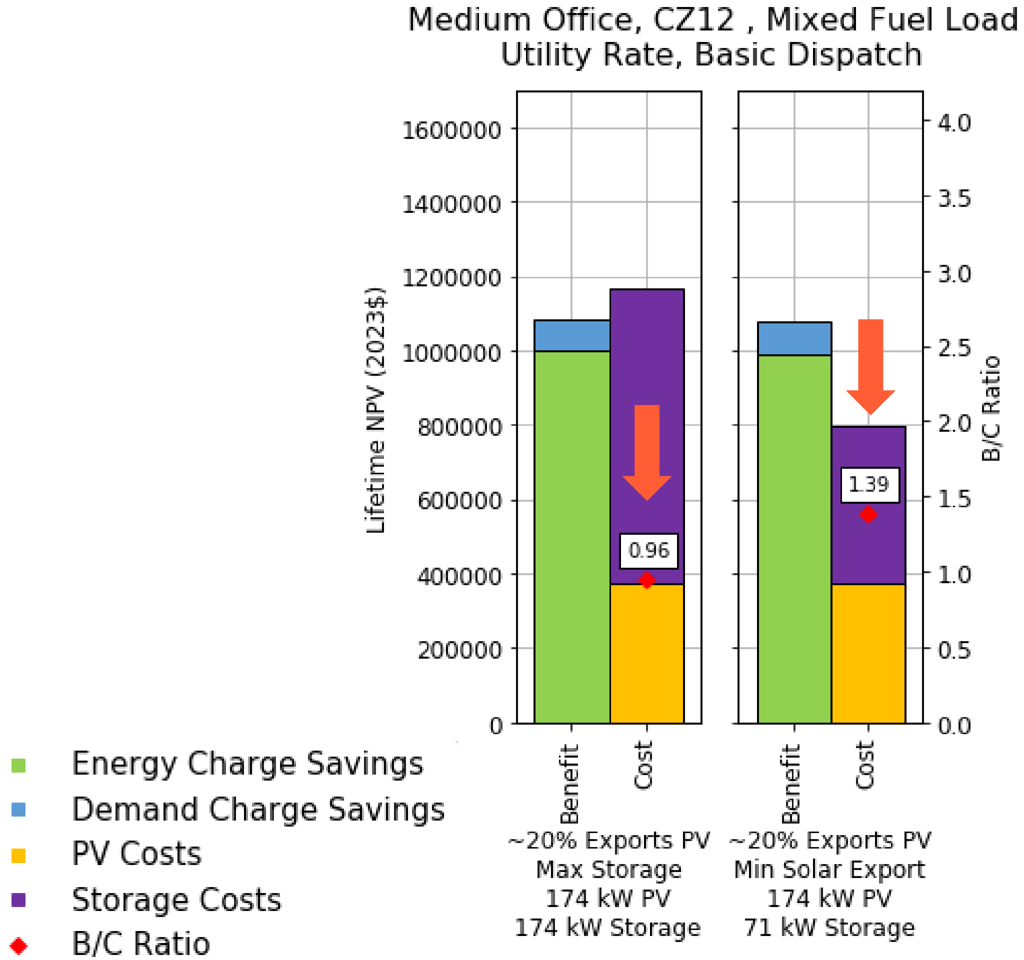
Appendix – PV+Storage Additional Results

Basic dispatch limits cost-effectiveness

+ **PV+Storage still cost-effective with Basic dispatch under utility rates**
  - Battery charges on PV net exports and discharges when load again exceeds PV production
+ **Basic dispatch matches TOU-periods, and building load profile reasonably well, to reduce energy costs and demand charges**

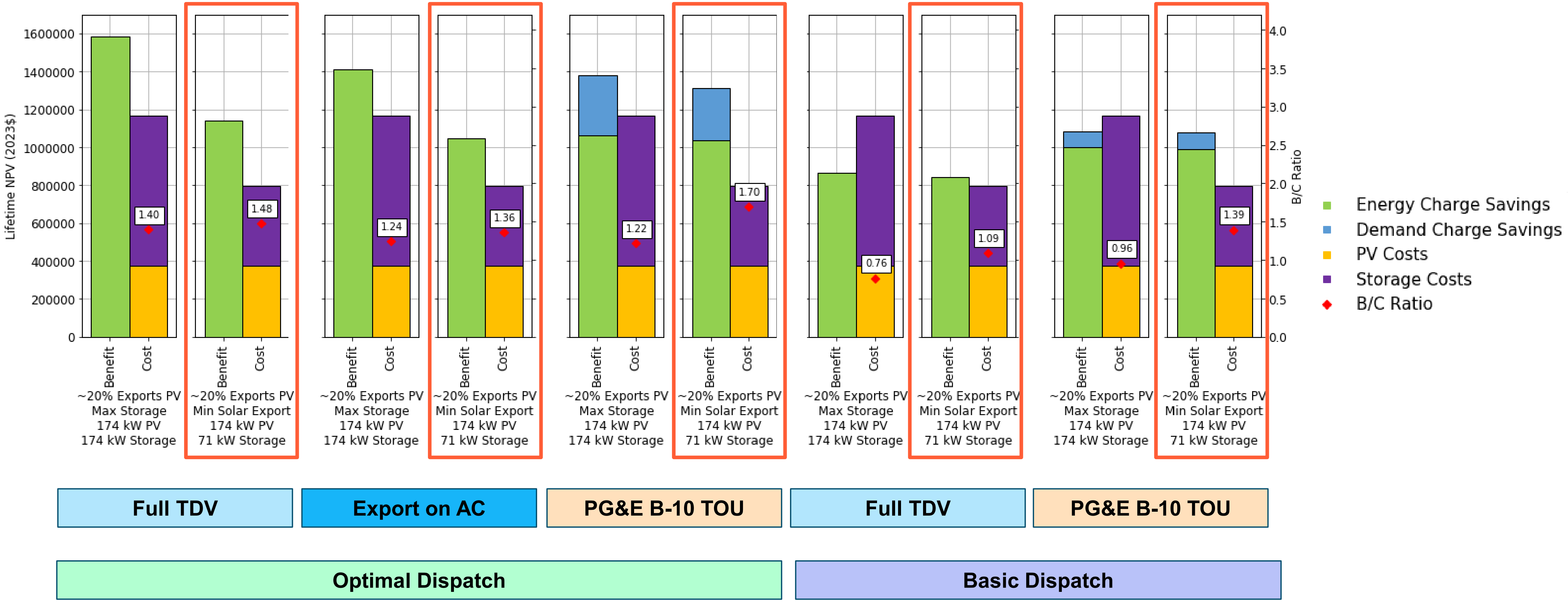
Cost Effectiveness – B10-TOU Rate, Basic Dispatch



PV+Storage Cost Effectiveness Summary

+ For smaller storage size, cost effective across all configurations

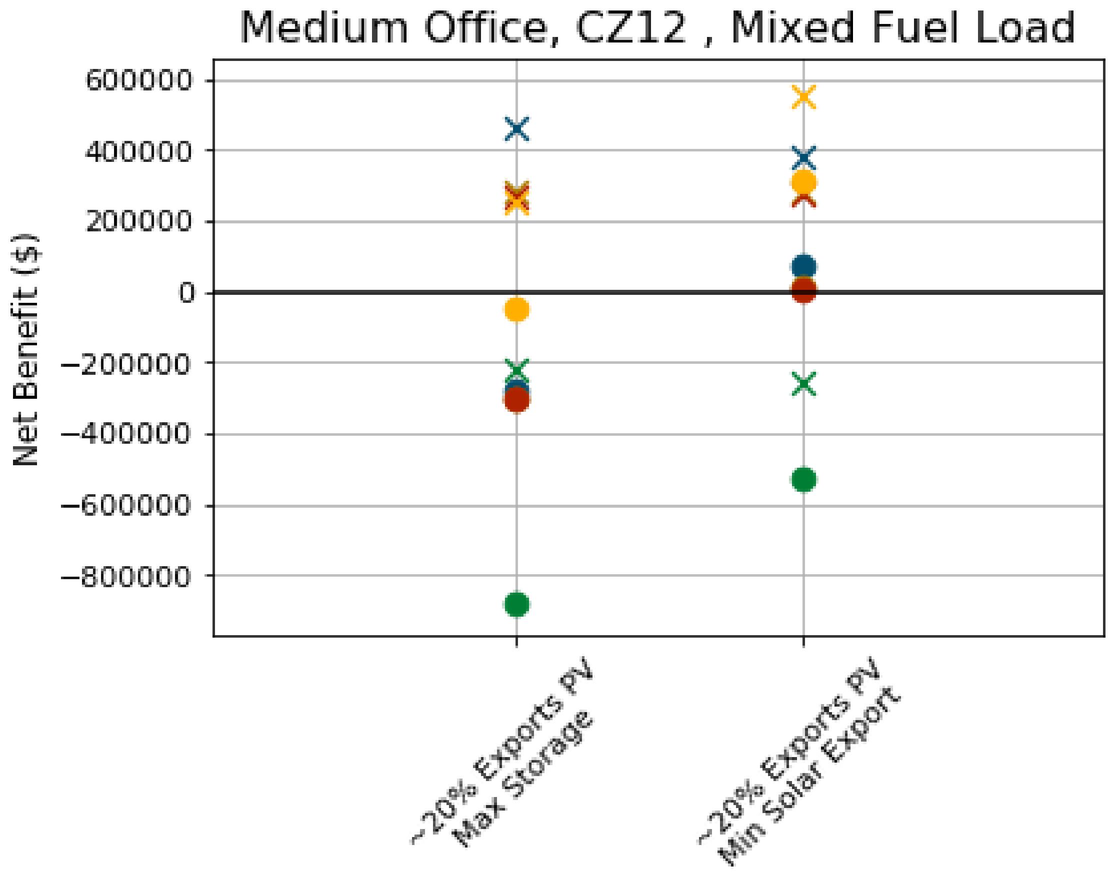
Medium Office, CZ 12, Mixed Fuel

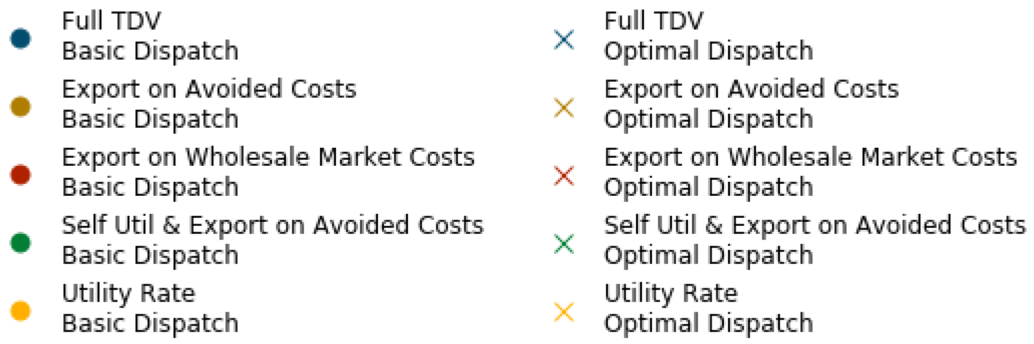


PV+Storage System Net Benefits

+ **Basic dispatch limits cost-effectiveness, but PV+Storage is still cost-effective**

Cost Effectiveness, All Sizes, All Rates

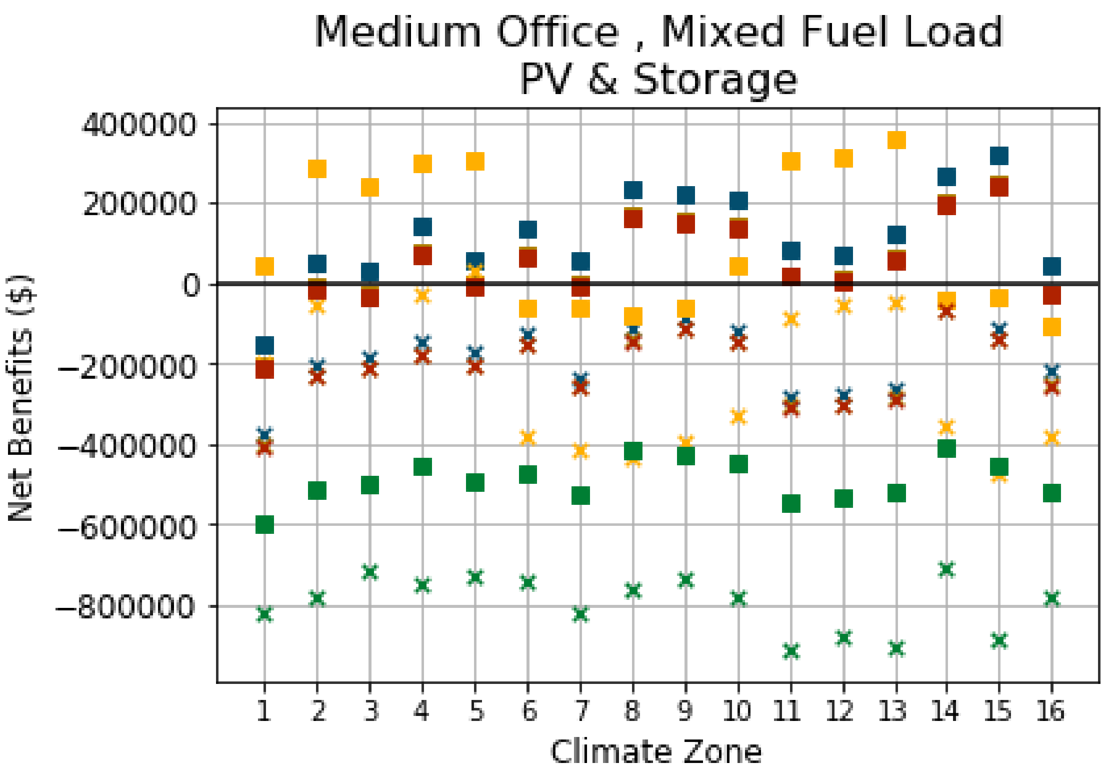




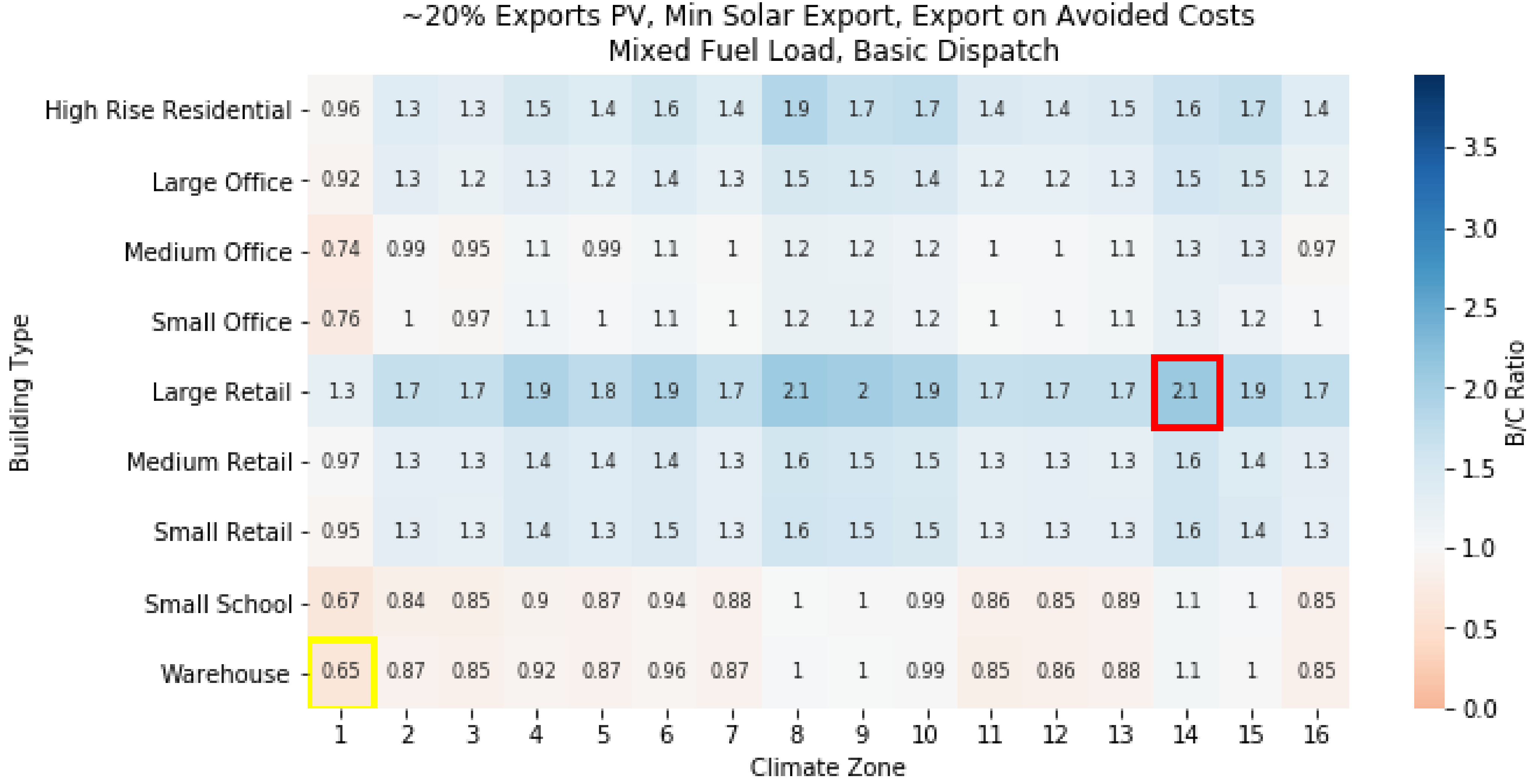
PV+Storage System Net Benefits, Basic Dispatch

- Expanding to medium office, all climate zones, general trend stays consistent
- Basic dispatch limits cost-effectiveness, but smaller PV+Storage is still cost-effective in most climate zones
- Rate sensitivity of import/export under avoided costs is not cost-effective
- Utility rate has mixed impacts on cost-effectiveness

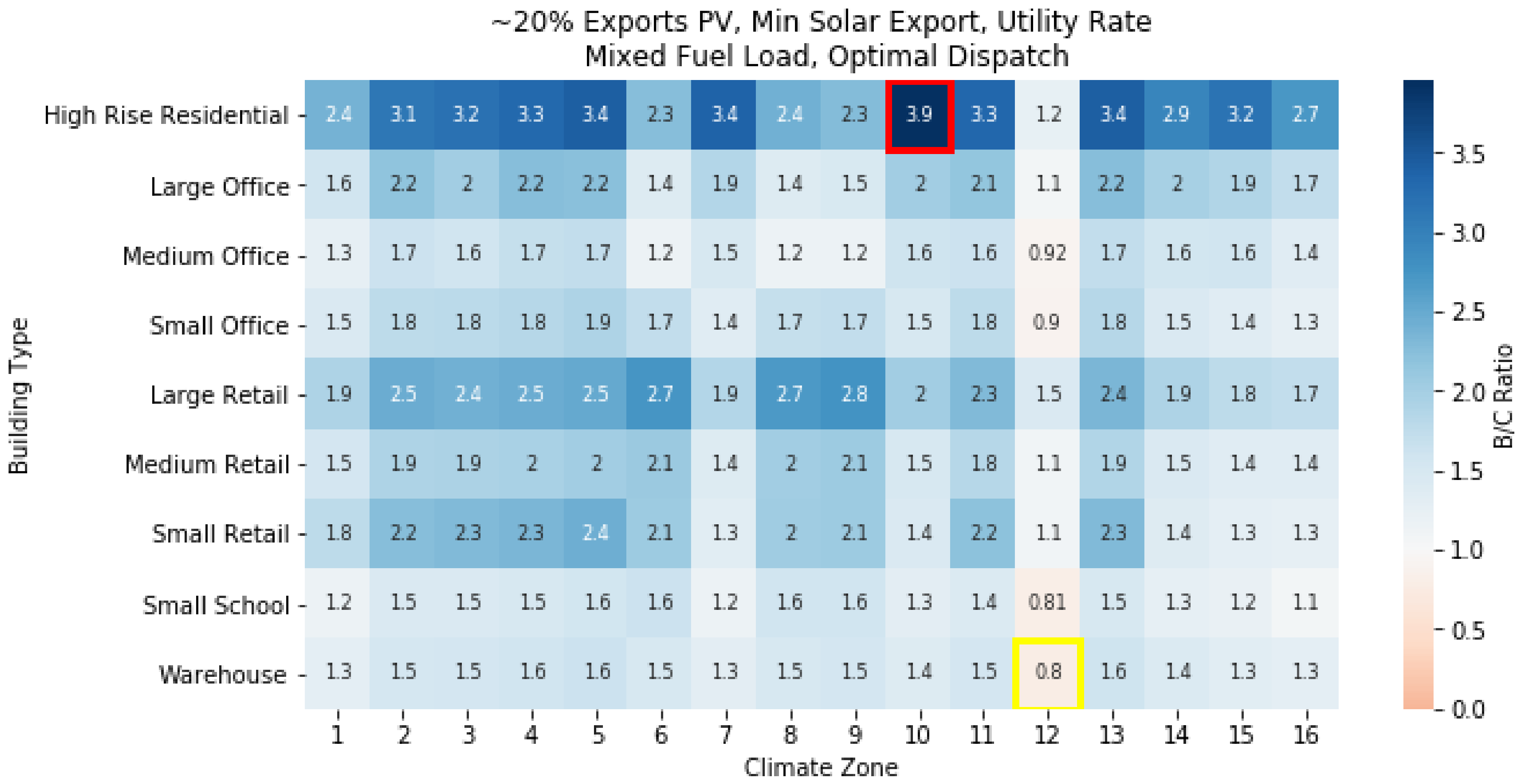
Cost Effectiveness, All Rates & Climate Zones



PV + Storage Basic Dispatch on TDV/Exported on Avoided Costs Across Building Types



PV + Storage Optimal Dispatch on Utility Rates Across Building Types w/ LADWP & SMUD



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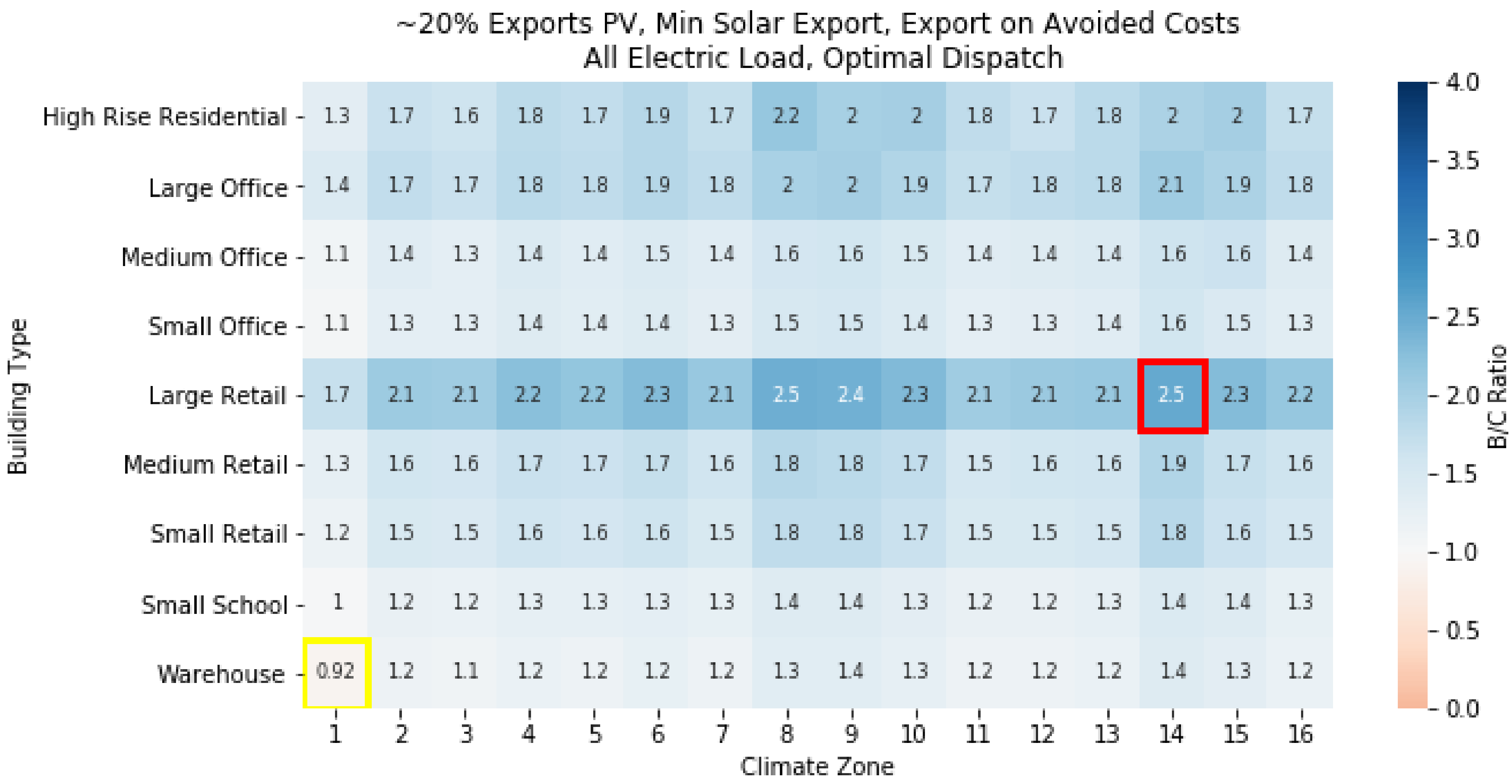
12	SMUD
13	PG&E
14	SCE
15	SCE
16	SCE

PV + Storage Optimal Dispatch on TDV/Exported on Avoided Costs Across Building Types – All-Electric



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Appendix - Reliability & Resiliency Inputs

Key Reliability & Resiliency Assumptions

Benefit calculation methodology

- Reliability (ability to cover short-duration unplanned T&D power interruptions)
  - average T&D interruption probability * energy availability in PV and storage * interruption costs (VoLL)
- Resiliency (ability to cover long-duration multi-day planned outage events)
  - covered critical load by PV and storage during outage days * interruption costs (VoLL) + covered non-critical load * VoLL * 50%

Reliability metrics

- From PGE 2019 Reliability Report
- SAIDI – 117.7
- SAIFI – 1.010
- CAIDI – 116.5

Interruption costs (VoLL)

- From LBNL Interruption Cost Estimate (ICE)
- By building type
  - Medium Office: 85.39 2016$/kWh

Outage events

- A 3-day outage event within the first week of November

Critical load

- Assume 10% of building load

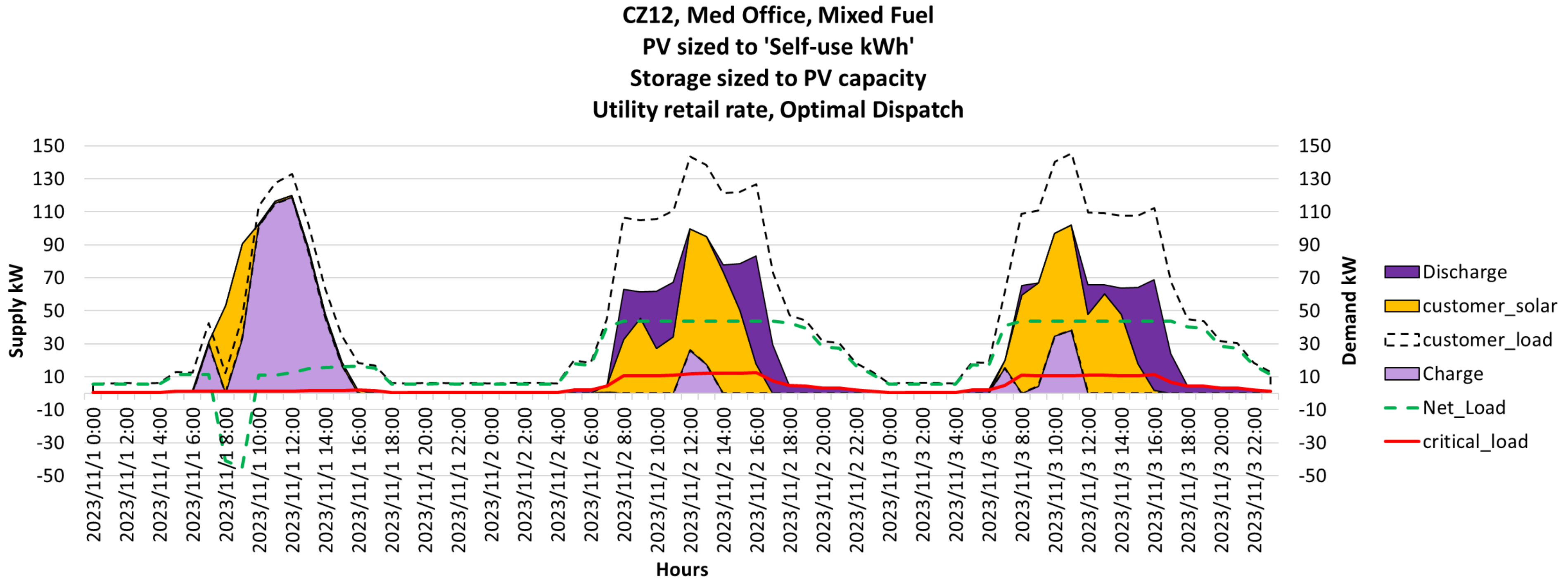
Storage will be encouraged to cover critical load during planned outage days to obtain resiliency benefits

VoLL Assumptions by Building Type

Building Type	Load Type	MWh	Sector	VoLL 2016 $/kWh
High-rise Res	Mixed-fuel	691	Medium and Large C&I	69.86
Large Office	Mixed-fuel	3609	Medium and Large C&I	31.63
Medium Office	**Mixed-fuel**	**453**	**Medium and Large C&I**	**85.39**
Small Office	Mixed-fuel	62	Small C&I	223.41
Large Office	Mixed-fuel	1754	Medium and Large C&I	44.75
Medium Retail	Mixed-fuel	188	Medium and Large C&I	129.44
Medium Retail	Mixed-fuel	103	Small C&I	145.65
Small School	Mixed-fuel	179	Small C&I	91.17
Warehouse	Mixed-fuel	73	Small C&I	194.73

Detailed Operation – Outage Days

- Optimal storage dispatch under utility retail rate
- Storage discharges conservatively during non-solar hours to make sure it covers critical loads during these outage days as much as possible
- Storage still discharges to reduce customer peak demand to minimize demand charges



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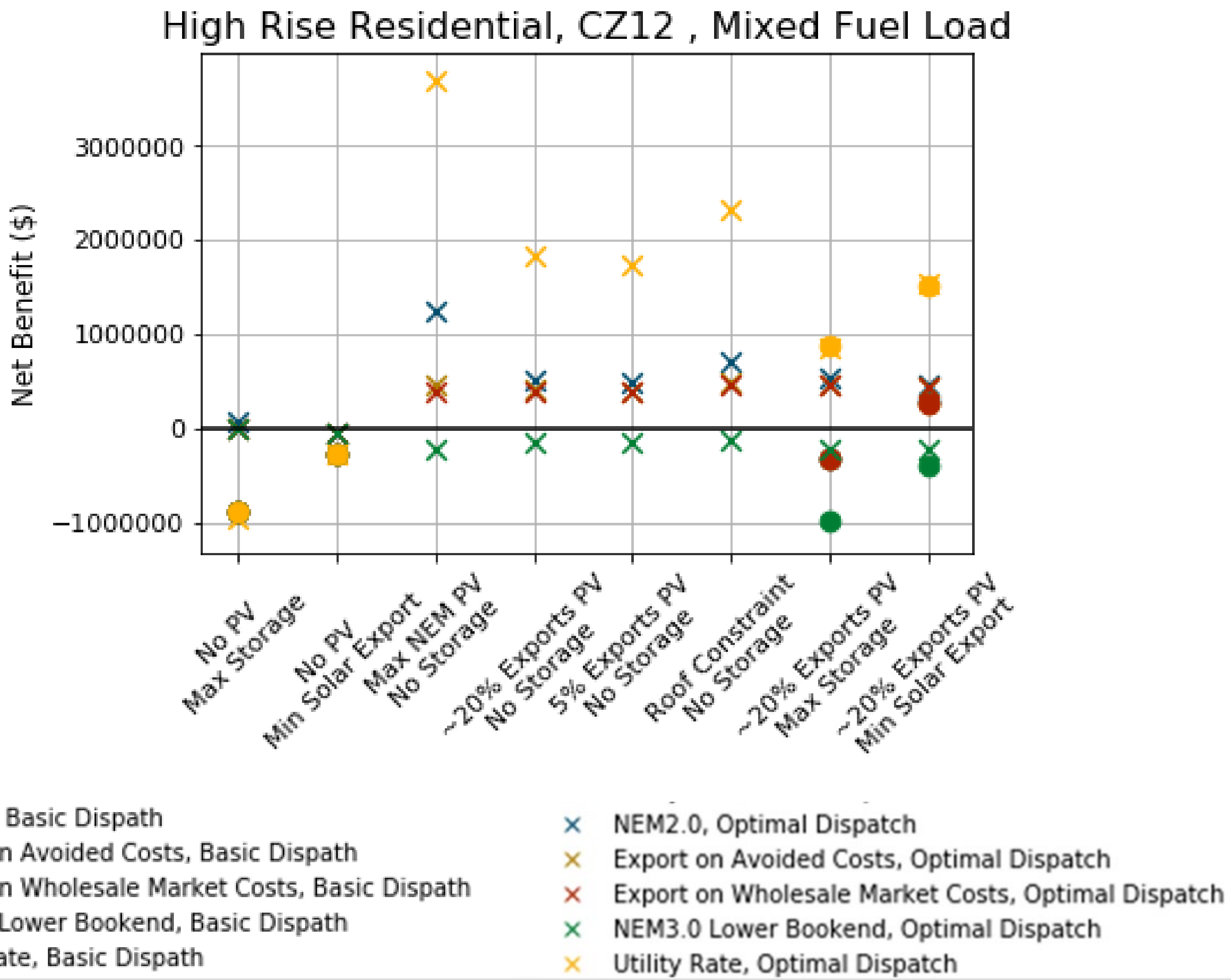
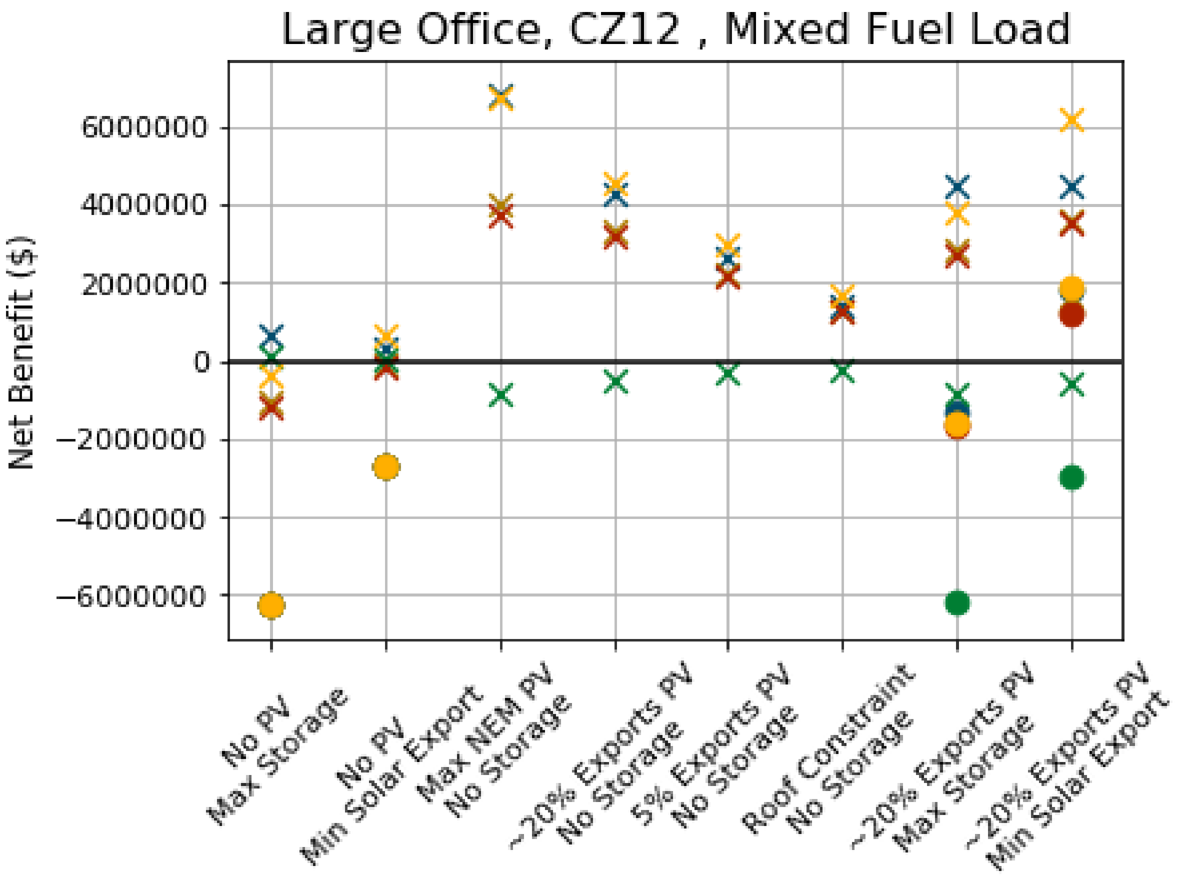
Appendix - Net Benefit Results By Building Type (CZ 12)

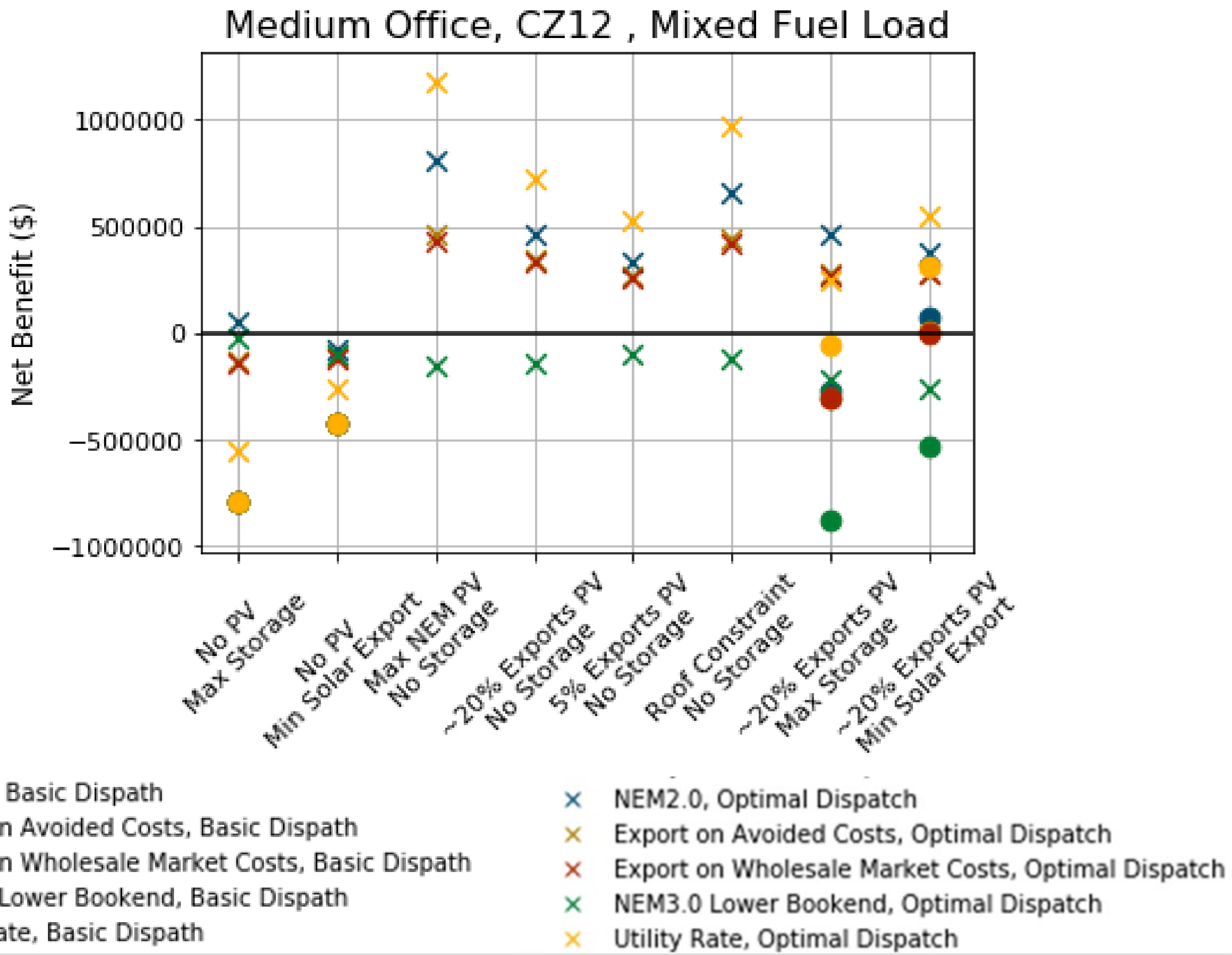
High Rise Residential



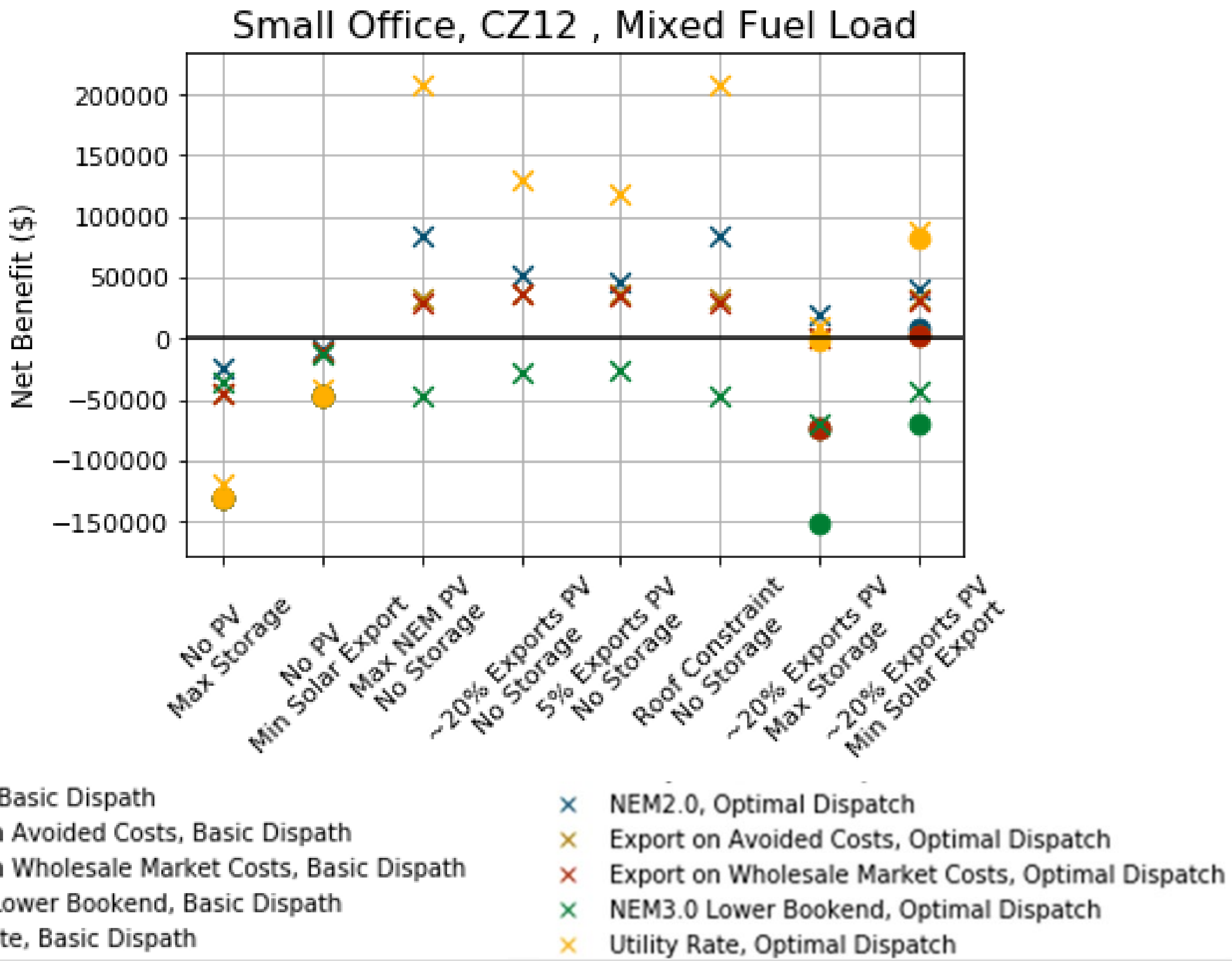
Large Office



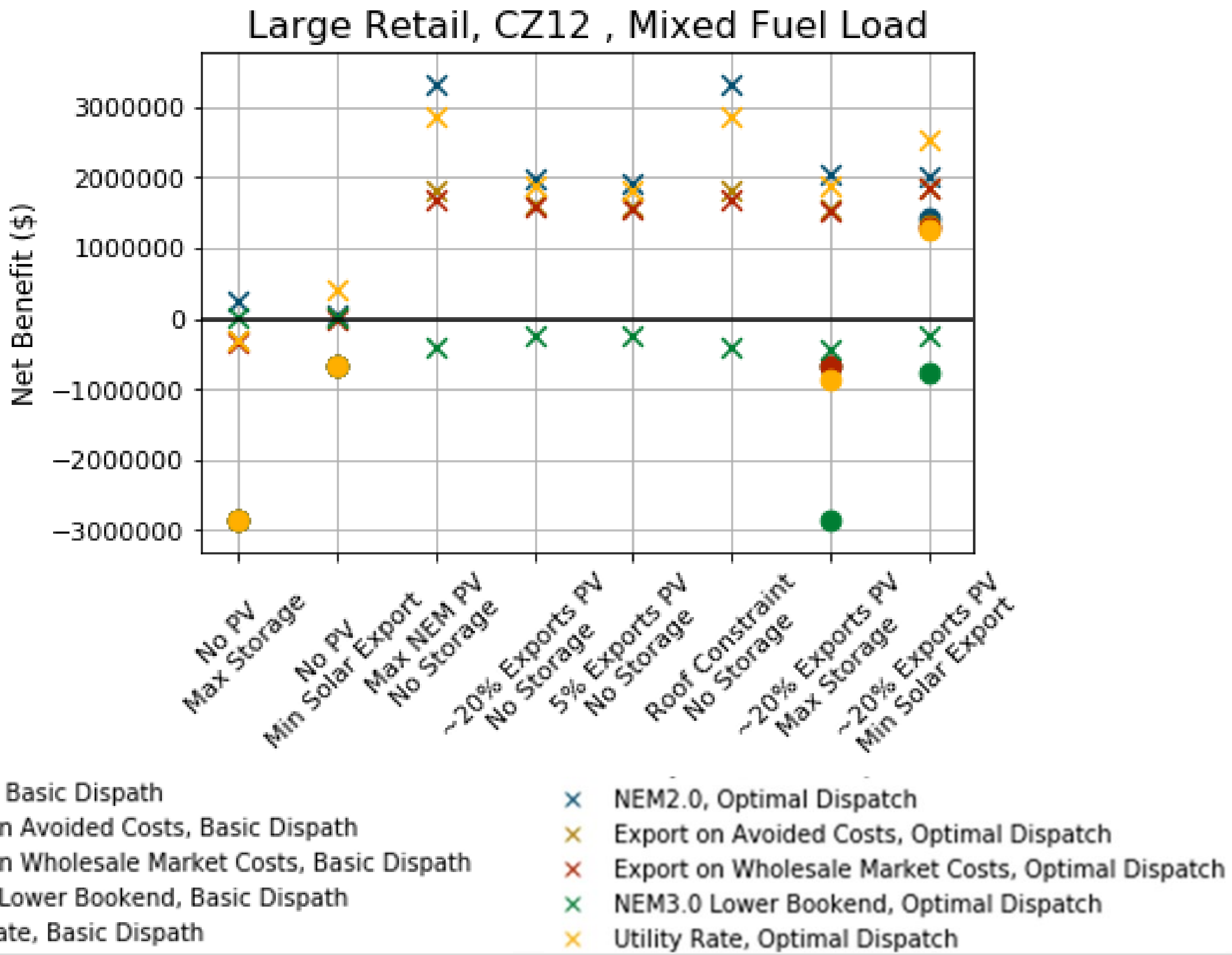
Medium Office



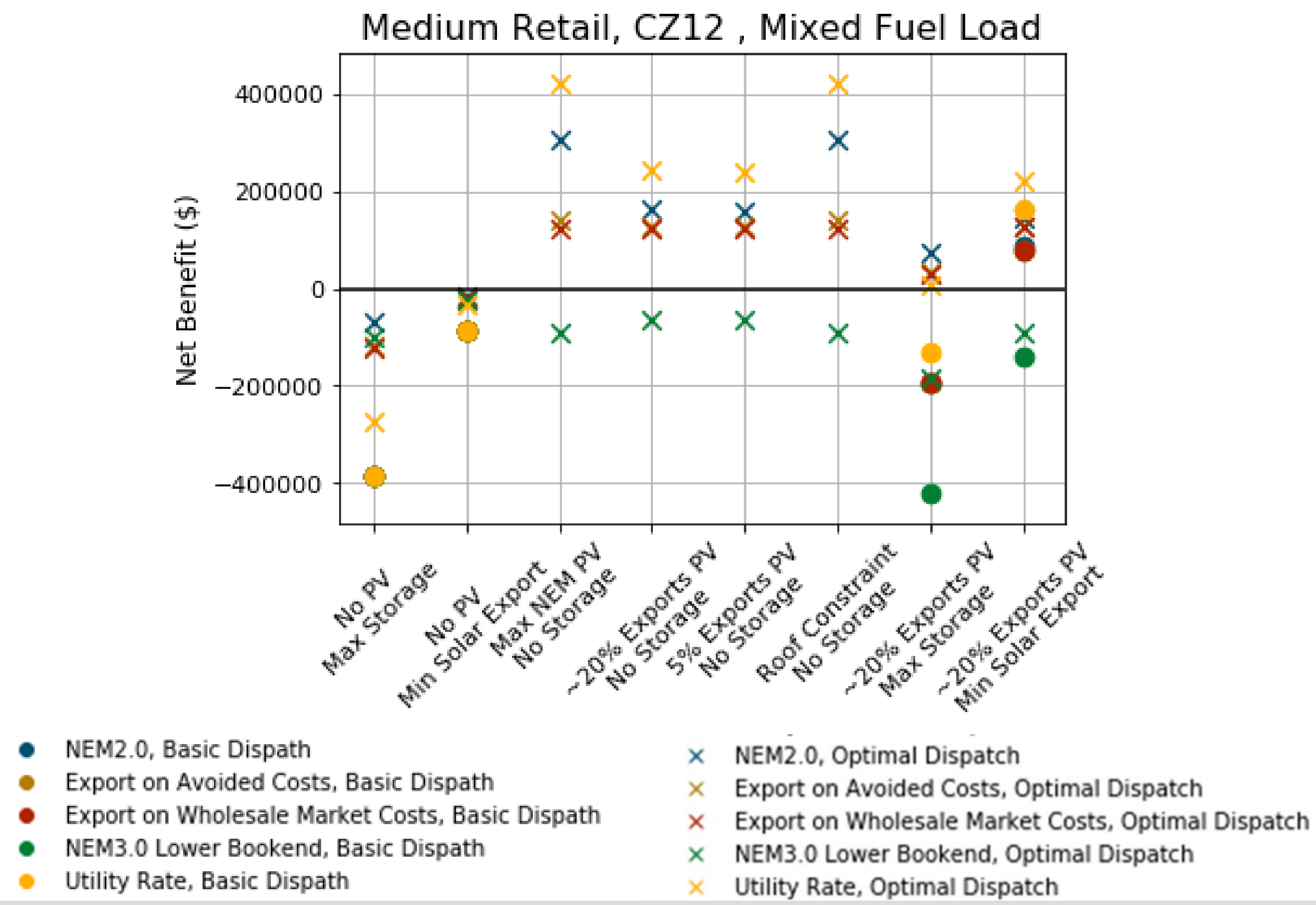
Small Office



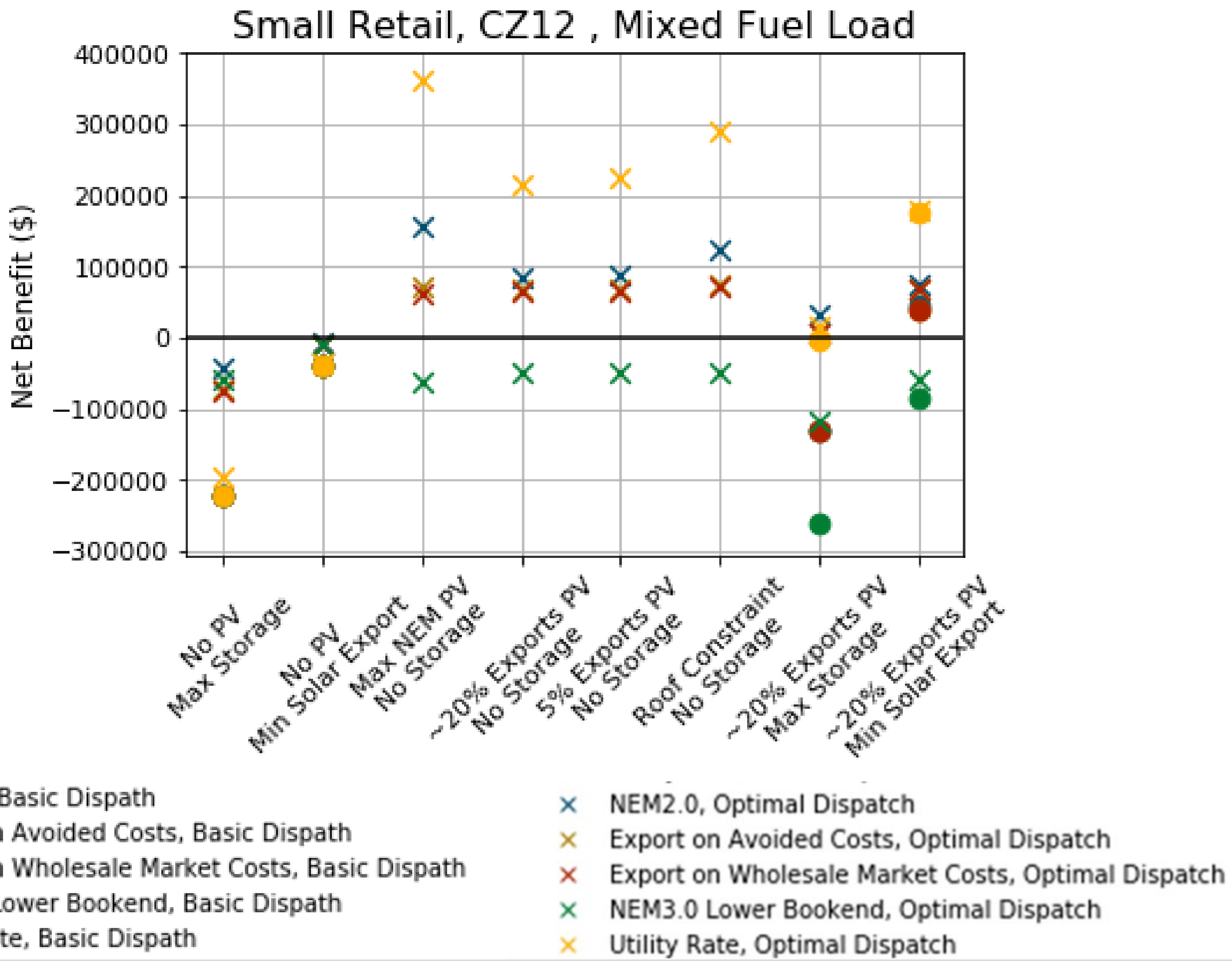
Large Retail



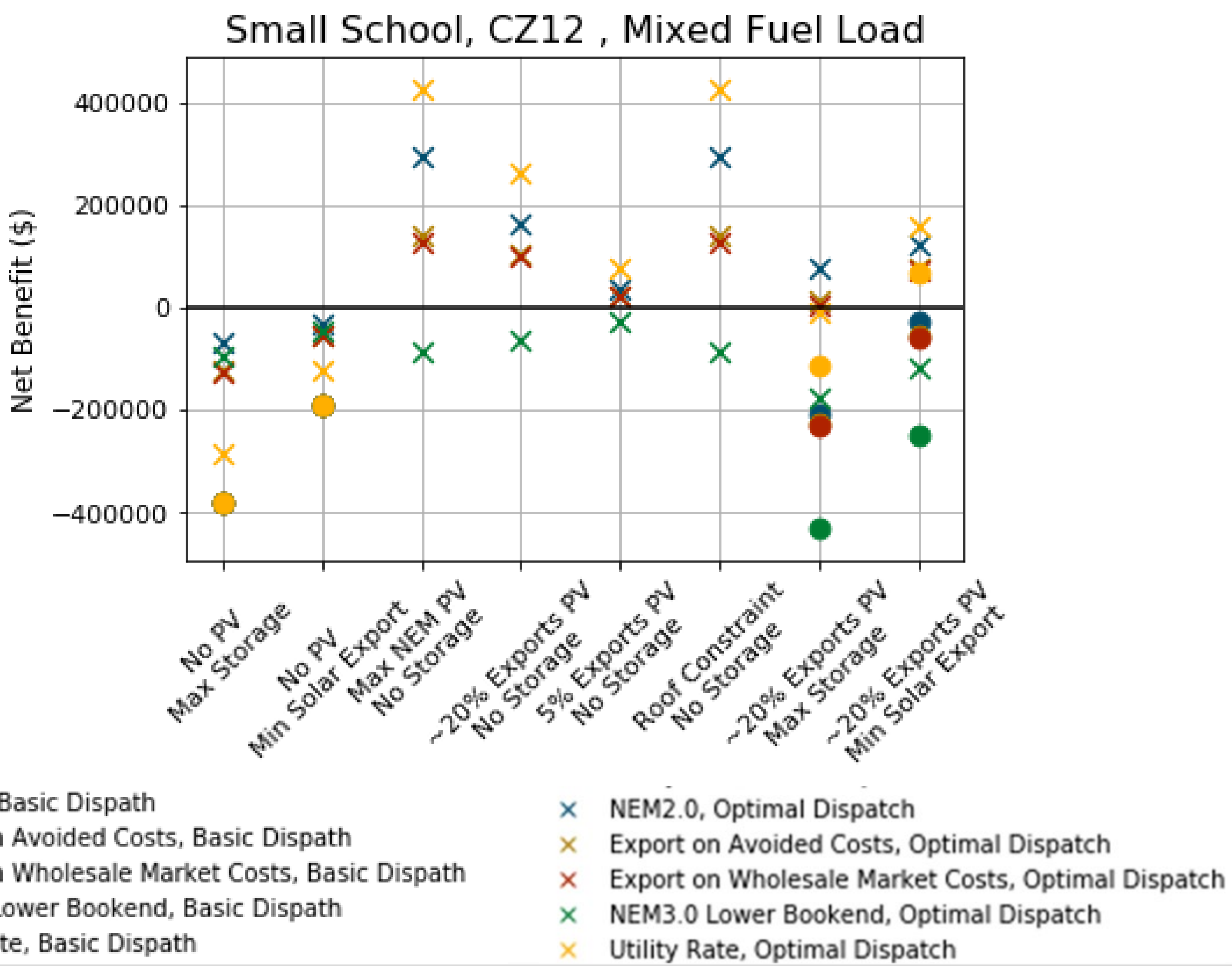
Medium Retail



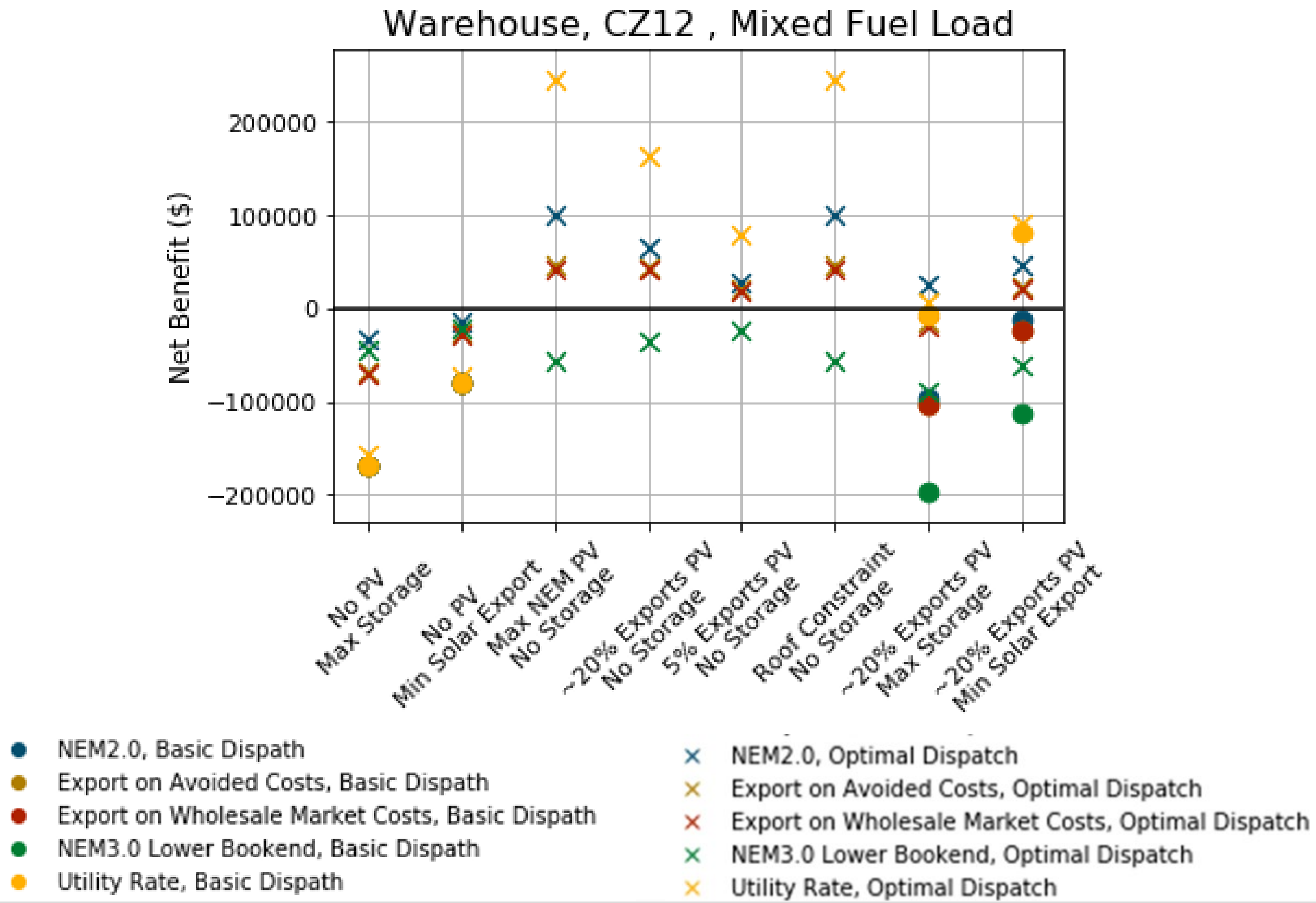
Small Retail



Small School



Warehouse

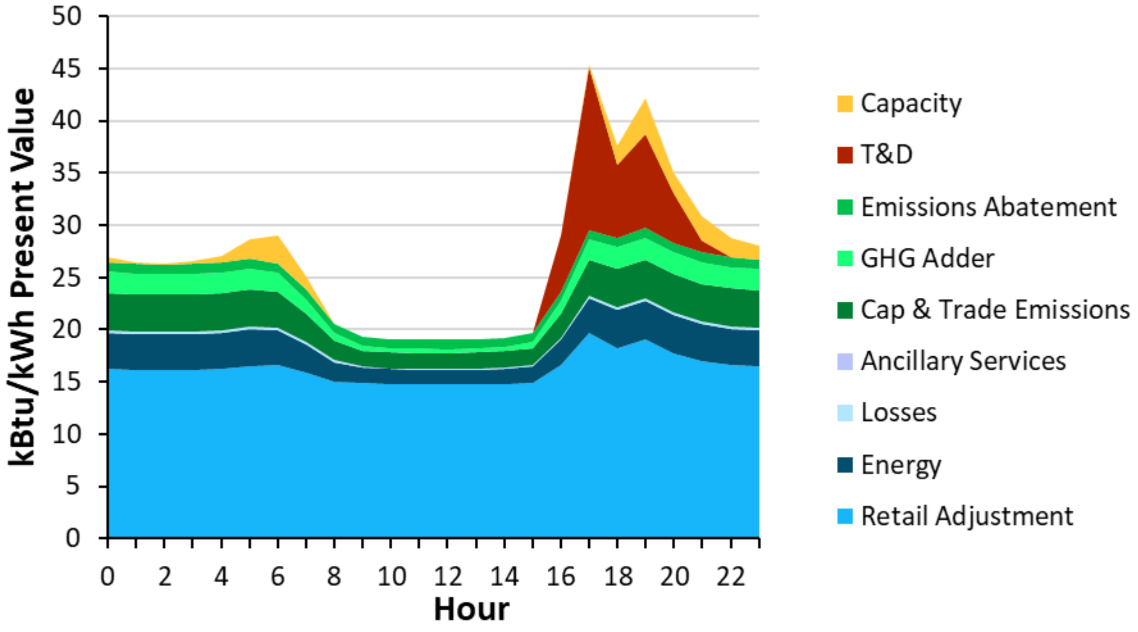

Warehouse, CZ12 , Mixed Fuel Load
Net Benefit ($)
200000
100000
0
−100000
−200000
No PV
Max Storage
No PV
Min Solar Export
Max NEM PV
No Storage
~20% Exports PV
No Storage
5% Exports PV
No Storage
Roof Constraint
No Storage
~20% Exports PV
Max Storage
~20% Exports PV
Min Solar Export
NEM2.0, Basic Dispath
Export on Avoided Costs, Basic Dispath
Export on Wholesale Market Costs, Basic Dispath
NEM3.0 Lower Bookend, Basic Dispath
Utility Rate, Basic Dispath
NEM2.0, Optimal Dispatch
Export on Avoided Costs, Optimal Dispatch
Export on Wholesale Market Costs, Optimal Dispatch
NEM3.0 Lower Bookend, Optimal Dispatch
Utility Rate, Optimal Dispatch

Appendix - Rate Assumptions

TDV-Based Rate Sensitivity Definitions

- **Full TDV:** All TDV cost components
- **Non-Bypassable Charges (NBC's):** Calculated based on existing NEM2.0 NBC's
- **Avoided Costs:** All cost components except Retail Adjustment
- **Wholesale Costs** All cost components except Retail Adjustment, Emissions Abatement, and GHG Adder

Rate Name	Compensation for Self-Utilized Electricity	Compensation for Exports
NEM 2.0	Full TDV	TDV – NBC's
Export on Avoided Costs	Full TDV	Avoided Costs
Export on Wholesale Costs	Full TDV	Wholesale Costs
Import/export on Avoided Costs	Avoided Costs	Avoided Costs



TDV Frequently Asked Questions

+ **Why do we measure cost-effectiveness with TDV instead of actual retail rate structures that are in place?**
  - We want the building code to be relatively stable over time and from cycle to cycle, the TDVs reflect a ‘perfect’ marginal cost of service which is a long-term signal for retail rates
  - By using the underlying system marginal costs we are reflecting building measures that provide the greatest underlying value to the energy system, even if retail rates are flat or have a different time of use period

Climate Zone/Utility Rate Mapping

Climate Zone	PG&E	SCE	SDG&E	LADWP	SMUD
CZ01	X				
CZ02	X				
CZ03	X				
CZ04	X				
CZ05	X	X			
CZ06		X		X	
CZ07			X		
CZ08		X		X	
CZ09		X		X	
CZ10		X			
CZ11	X				
CZ12	X				X
CZ13	X				
CZ14		X	X		
CZ15		X	X		
CZ16		X			

Utility Rates Assumptions - PG&E

- Retail rates are assigned based on prototype building peak load and CZ
- Climate Zones in PG&E territory, for example use these rates (see Appendix for other utilities)

Building Type	Mix-fuel Peak Load (kW) / All-electric Peak Load (kW)	PG&E Retail Rate
OffLrg	1582/1611	B-20 Extra Large General - Time of Use (1000 +)
OffMed	210/230	B-10 Medium General - Time of Use
OffSml	23/27	B-6 Small General Time of use (0-75 kW)
RetlLrg	808/1012	B-19 Large General Time of use (or Extra large general TOU) (500-1000)
RetlMed	99/118	B-10 Medium/Large General Time of use
RetlSml	40/54	B-6 Small General Time of use (0-75 kW)
Whse	29/210	B-6 Small/Medium General TOU
SchSml	87/164	B-10 Medium General TOU
HRR10Story	5	E-TOU-C-NEM2 Residential - Time of Use - Rate C (NEM 2.0)

Utility Rates Assumptions - SCE

- Retail rates are assigned based on prototype building peak load and CZ
- Climate Zones in SCE territory use these rates

Building Type	Mix-fuel Peak Load (kW) / All-electric Peak Load (kW)	SCE Retail Rate
OffLrg	1610/1838	TOU-8 Large General- TOU Option D (Below 2kV) (NEM 2.0)(500+)
OffMed	236/262	TOU-GS-3 General-TOU Demand Metered, Rate D (NEM 2.0) (200-500kW)
OffSml	25/30	TOU-GS-2 General-TOU Demand Metered, Option D (NEM 2.0) (20-200kW)
RetlLrg	960/1117	TOU-8 Large General- TOU Option D (Below 2kV) (NEM 2.0)(500+)
RetlMed	106/134	TOU-GS-2 General-TOU Demand Metered, Option D (NEM 2.0) (20-200kW)
RetlSml	46.59	TOU-GS-2 General-TOU Demand Metered, Option D (NEM 2.0) (20-200kW)
Whse	33/207	TOU-GS-2 General-TOU Demand Metered, Option D (NEM 2.0) (20-200kW)
SchSml	104/179	TOU-GS-2 General-TOU Demand Metered, Option D (NEM 2.0) (20-200kW)

Utility Rates Assumptions - SDG&E

- Retail rates are assigned based on prototype building peak load and CZ
- Climate Zones in SDG&E territory use these rates

Building Type	Mix-fuel Peak Load (kW) / All-electric Peak Load (kW)	SDG&E Retail Rate
OffLrg	1610/1665	AL-TOU General-Time Metered (20+)
OffMed	236/262	AL-TOU General-Time Metered (20+)
OffSml	25/27	AL-TOU General-Time Metered (20+)
RetlLrg	960/1117	AL-TOU General-Time Metered (20+)
RetlMed	106/114	AL-TOU General-Time Metered (20+)
RetlSml	46/51	AL-TOU General-Time Metered (20+)
Whse	33/207	AL-TOU General-Time Metered (20+)
SchSml	104/148	AL-TOU General-Time Metered (20+)

Utility Rates Assumptions – SMUD

- Retail rates are assigned based on prototype building peak load and CZ
- Climate Zones in SMUD territory use these rates

Building Type	Mix-fuel Peak Load (kW) / All-electric Peak Load (kW)	SMUD Retail Rate
OffLrg	1423/1523	GS-TOU1 Large General -TOU (1000+)
OffMed	204/229	GSS_T General-Demand (20+)
OffSml	22/24	GSS_T General-Demand (20+)
RetlLrg	764/957	GSS_T General-Demand (20+)
RetlMed	81/111	GSS_T General-Demand (20+)
RetlSml	40/46	GSS_T General-Demand (20+)
Whse	29/205	GSS_T General-Demand (20+)
SchSml	82/164	GSS_T General-Demand (20+)

Utility Rates Assumptions – LADWP

+ **Retail rates are assigned based on prototype building peak load and CZ**
+ **Climate Zones in LADWP territory use these rates**

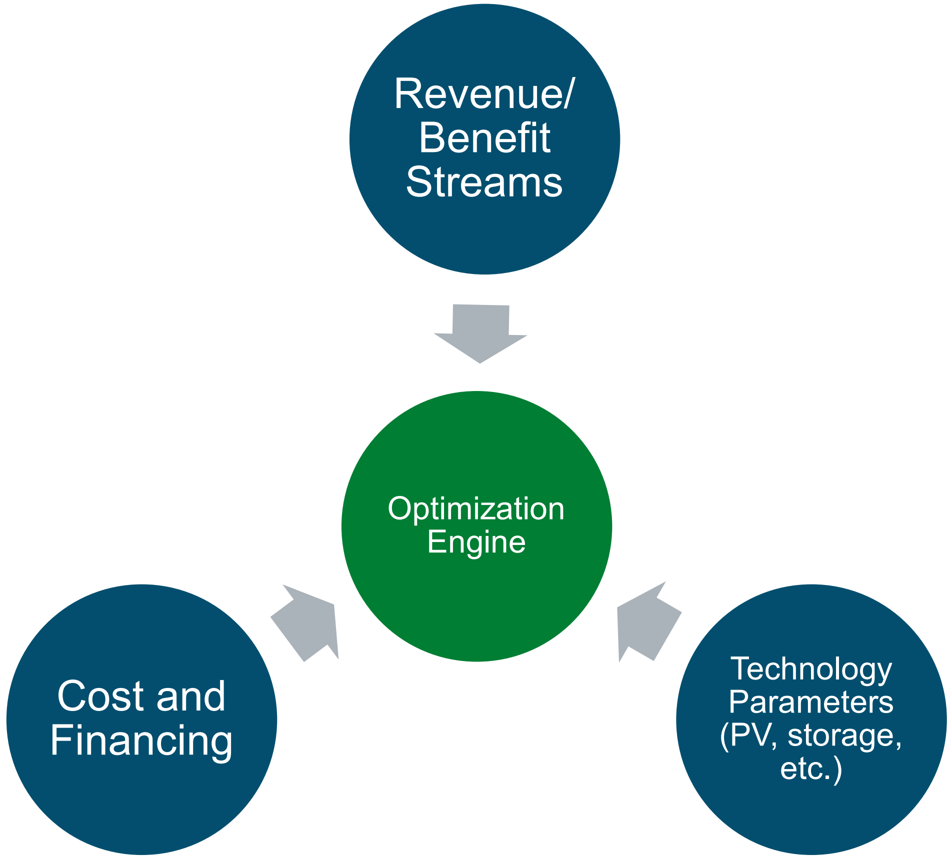
Building Type	Mix-fuel Peak Load (kW) / All-electric Peak Load (kW)	LADWP Retail Rate
OffLrg	1582/1485	CG-2 Customer Generation-Primary, Rate A
OffMed	202/225	CG-2 Customer Generation-Primary, Rate A
OffSml	22/23	A-1 Small General TOU, Rate B
RetlLrg	780/964	CG-2 Customer Generation-Primary, Rate A
RetlMed	87/108	CG-2 Customer Generation-Primary, Rate A
RetlSml	40/42	CG-2 Customer Generation-Primary, Rate A
Whse	32/178	CG-2 Customer Generation-Primary, Rate A
SchSml	85/143	CG-2 Customer Generation-Primary, Rate A

Energy+Environmental Economics

Appendix – Solar + Storage Tool Details

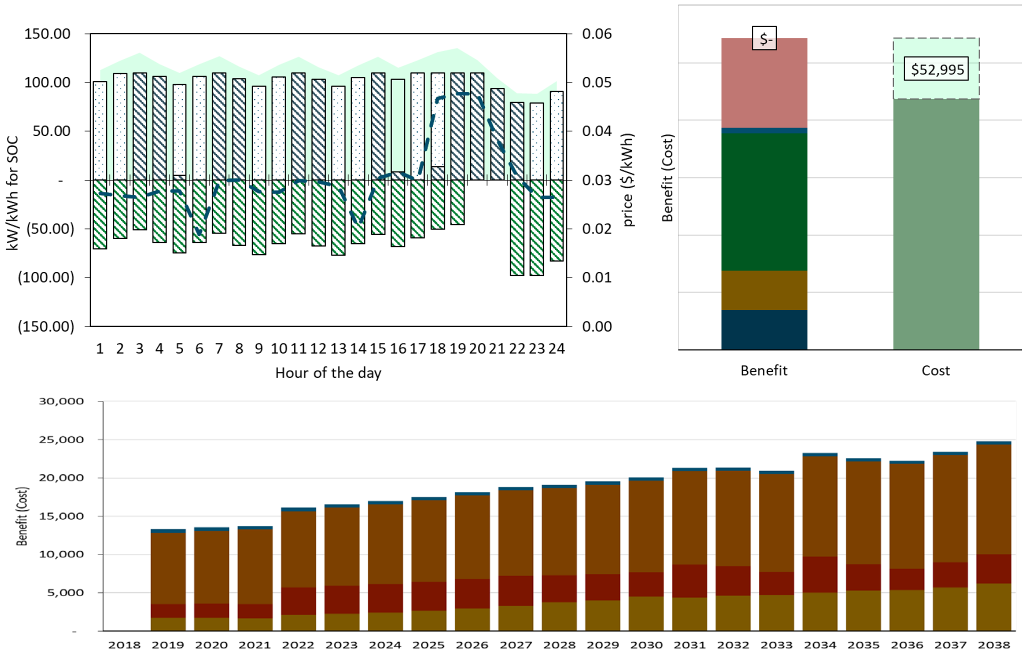
Solar + Storage Tool Overview

+ A DER valuation tool with an optimization engine for dispatch



<u>Results</u>:

- NPV and annual benefits and costs
- Cost tests
- DER optimal dispatch



[1]See CEC Docket Log 19-MISC-04 for additional information and documentation: https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=19-MISC-04

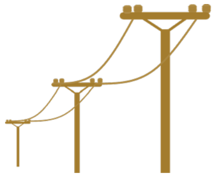
Solar + Storage Tool Optimal Dispatch Algorithm

- **Maximizing net benefits, subject to**
  - Technology operating constraints
  - Program and market rules
- **Value-stacking and customizable benefits selection**
- **Co-optimization among DER technologies**
  - PV, storage, and other generators can "work" together to maximize net benefits
- **Flexible optimization window (Daily, Monthly, Annual) and Intervals (Hourly, 15mins, 5mins)**

Customers Control
• Bill savings • Utility program revenues (e.g. DR) • Back-up power

Utility Control
• System avoided costs *or* wholesale energy and capacity market • Transmission and distribution deferral value • Ancillary service revenue • Avoided GHG costs

Joint Control
• Joint optimization • Bill savings + Avoided system costs • Bill savings + Avoided GHG costs



[1]See CEC Docket Log 19-MISC-04 for additional information and documentation: https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=19-MISC-04

Solar + Storage Tool Capabilities

+ Dispatchable

- Objective function: minimizing net costs
- Subject to technology, market, and incentive (e.g. ITC) constraints
- Co-optimization across multiple technologies with perfect foresight
- Price taker

+ Partial Dispatchable

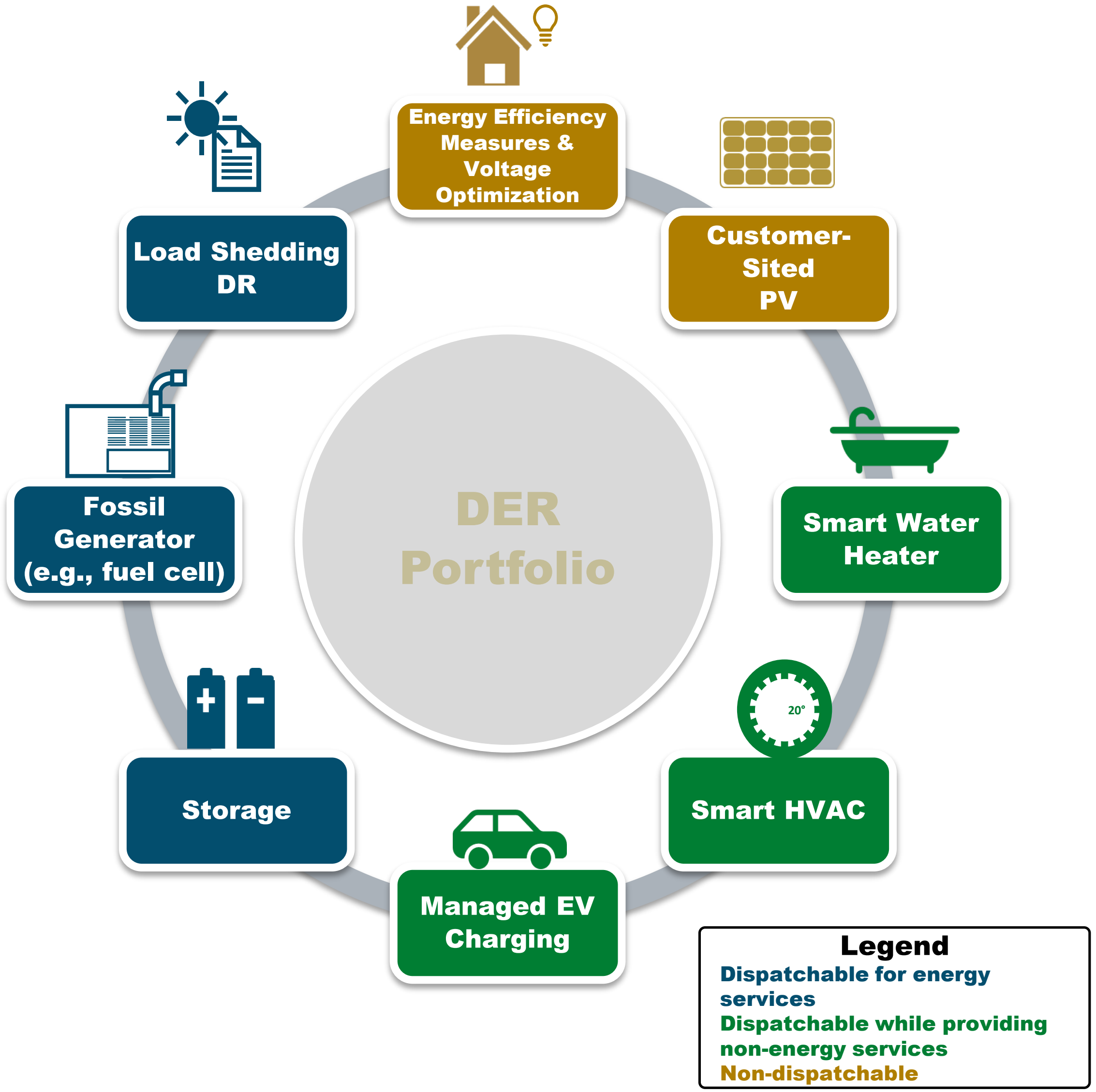
- Dispatch with the consideration of customer comfort level
- Co-optimize with both dispatchable and partial dispatchable technologies

+ Fixed shapes

- User input based on the specific project or customer
- Default PV shapes pre-loaded for each climate zone

Other highlights

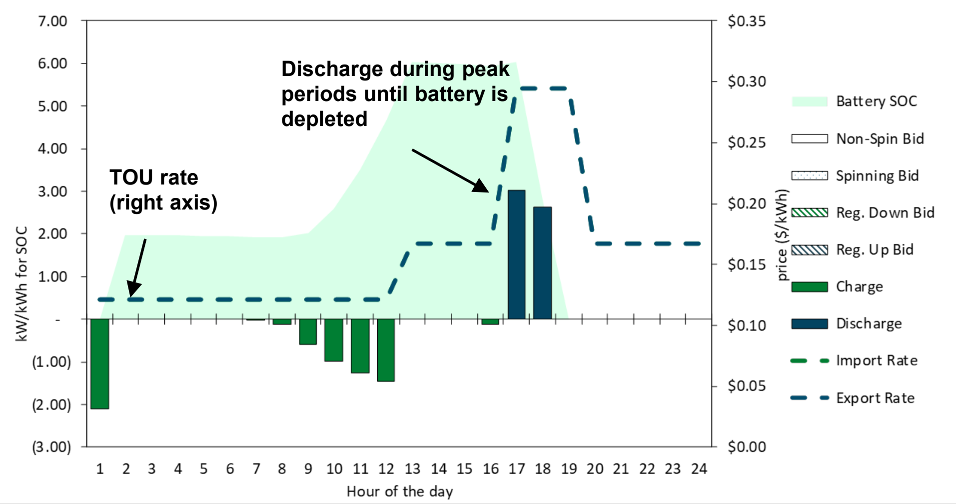
- Temperature-based day mapping
- Flexible Optimization Window (Daily, Monthly, Annual) and Intervals (Hourly, 15mins, 5mins)



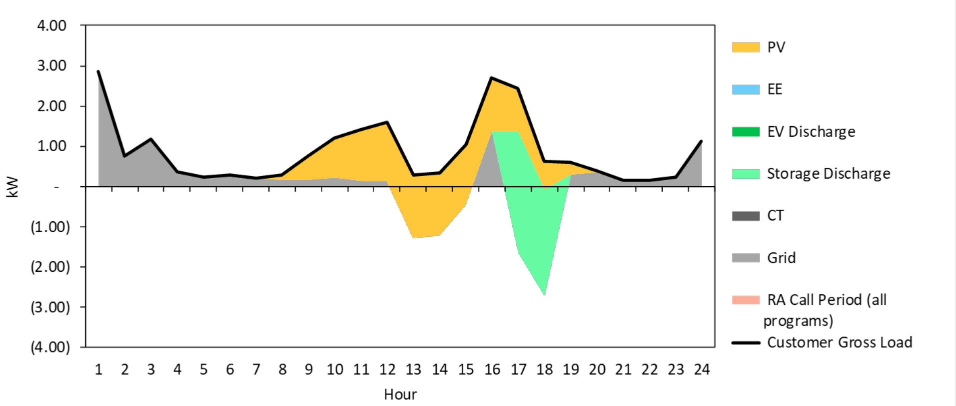
Example Dispatch – PV + Storage

Storage dispatch under a TOU rate

Storage Dispatch for July 28, 2020

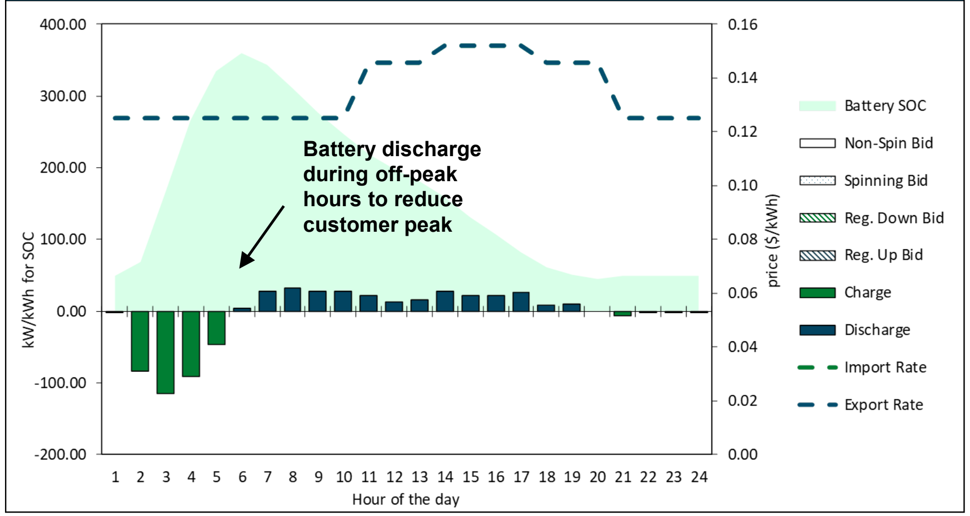


Energy Supply for July 28, 2020



Storage dispatched to reduce demand charges

Storage Dispatch for September 5, 2020



Energy Supply for September 5, 2020