STAFF REPORT

DATE: April 9, 2019

TO: City Council

FROM: Ashley Feeney, Assistant City Manager
Gregory Mahoney, Assistant Director, Community Development and Sustainability

SUBJECT: Ordinance to adopt a Nonresidential and High-rise Residential Energy and Green Reach Code (Nonresidential Reach Code).

Recommendation

Introduce an Ordinance Amending Sections 8.01.060 Related to Electrical Requirements and 8.01.090 Related to Green Building and Adding Section 8.01.094 Related to Energy Efficiency Standards for Nonresidential and High-Rise Multifamily Buildings Under the Green Building Code, which accomplishes the following:

Enacts an energy efficiency and green "reach code" for nonresidential and high-rise residential projects that would require a 10% compliance margin per cost effectiveness study prepared by TRC, dated July 2017.

Codifies the Davis Electric Vehicle (EV) Charging Plan previously adopted by Council resolution.

Requires installation of photovoltaics (PV) to achieve the lessor of approximately 80% offset of the building's modelled annual electric load or 15 DC watts per sq. ft. of solar zone[1], as supported by cost effectiveness study prepared by TRC.

Adopts the latest draft or publication of the International Code Council (ICC) Commissioning (Cx) Guideline to clarify and define the required commissioning process.

Requires a 120 volt receptacle at the most remote sink, measured from the water heater, for a new single family dwellings, additions and remodels to accommodate the future installation of an on-demand hot water recirculation pump.

Executive Summary

Davis has a history of leadership in energy efficiency and sustainability. In the 1970s, Davis adopted an energy code before the State of California had developed a statewide energy code. The City was also the first jurisdiction to adopt a green building ordinance in the region. The State has a goal of Zero Net Energy by 2030 for all new nonresidential buildings. On March 5, 2019, City Council approved a Resolution declaring a climate emergency and proposed mobilization efforts to restore a safe climate that included an acceleration of the carbon neutrality goal for the Davis community from 2050 to 2040. Approval of the proposed Ordinance would further these efforts.

In recent years, there has been uncertainty around green building requirements for projects seeking discretionary entitlements. This has resulted in project specific requirements being negotiated through the City commission process and ultimately at the dais. Approval of the proposed Ordinance would provide clarity and certainty of green building expectations for architects, developers, builders, staff, and the community. An understanding of these expectations at the beginning of a project planning process will have greater benefit for all rather than learning what the requirements are at the end of project processing. Adoption of the proposed Ordinance would also save time for the applicant, staff, and the Natural Resources Commission as project specific energy efficiency requirements will no longer need to be reviewed on an individual project basis.

In the absence of an approved "reach code" for nonresidential and high-rise residential, several project approvals have been conditioned to achieve Leadership in Energy and Environmental Design (LEED) Silver or more commonly, Gold equivalency. The LEED rating system is a proprietary system for rating buildings where LEED certification requires some pre-requisites, but the majority of the measures are selected from a self-chosen menu of sustainability choices. LEED Gold equivalency is not necessarily an efficient path for developers and applicants as compliance with two separate sustainability approaches (LEED and Code) can be challenging, confusing, and costly. The equivalency standard requires third party verification and because of the menu approach, there is a lack of certainty regarding what will ultimately be required to comply. The LEED menu approach results in some projects benefiting on the point scale by way of the project location and other means that do not have anything to do with energy efficiency. The City also has limited ability to verify compliance because the LEED process is not consistent with the State and local sustainability nor the energy code compliance process.

The proposed Ordinance is based on a comparison of the LEED rating system with CALGreen, the Energy Code and the Davis Municipal Code. In comparing the existing City requirements, including CALGreen Tier 1 and the Davis Municipal Code, a compliant design would result in approximately a LEED Silver level of sustainability. Rather than allow an arbitrary path from effectively a LEED Sliver level equivalency to LEED Gold equivalency, in the proposed Ordinance, staff have included requirements for photovoltaics (PV) and enhanced energy efficiency (approximately 10% more efficient than code) beyond what is required by the Energy Code. The proposed Ordinance also codifies the EV charging requirements already approved by Council resolution. Finally, the proposed Ordinance recognizes the importance of energy systems to perform "as designed" by utilizing a defined commissioning process which is essential to optimize the efficiency of energy systems. CALGreen and the California Energy Code require commissioning but the process is not clearly defined. The International Code Council (ICC) has developed a Commissioning Guideline to be used by code officials and designers to clarify and provide consistency in the commissioning process. The proposed Ordinance requires projects to be consistent with the ICC G4 Guideline to Commissioning.

In an effort to get community feedback on the proposed reach code, the proposed Ordinance in both conceptual and final form was presented to the Natural Resources Commission three time over the last 16 months. The NRC unanimously supports the proposed Ordinance. Cool Davis is also a supportive of the proposed Ordinance. The proposed Ordinance has been presented to the Chamber of Commerce on two occasions to solicit feedback and address concerns. The Chamber has voiced appreciation for the engagement on the matter and has taken a neutral position on the proposed Ordinance (Attachment 7).

The proposed Ordinance provides a meaningful and clear path to LEED Gold equivalency through using code requirements that City staff can review and verify without the costs of a third party. Approval of the proposed Ordinance would also relieve architects, builders, developers, and the community of drawn-out negotiations and related to uncertain green building requirements.

Fiscal Impact

The minor increase in staff time associated with reviewing plans, issuing building permits and conducting inspections will be recovered through plan check and permit fees.

City Council Goals

The proposed Ordinance is consistent with adopted City Council goal:

- Pursue environmental sustainability

Background and Analysis

There have been several projects in Davis approved with a condition to achieve Leadership in Energy and Environmental Design (LEED) Silver or Gold equivalency. The LEED rating system is a proprietary system for rating green buildings. LEED enjoys wide market recognition but there are several important considerations with this strategy for incorporating sustainable measures into new projects. First, Davis City plan review and inspection staff are not trained in the LEED rating system. Consequently, LEED equivalency requires third party verification which comes at an additional cost to the applicant and project. However, City staff are well trained in the California Green Building Standards Code (CALGreen) and California Energy Code compliance. Second, LEED is a rating system that does not have specific requirements other than the prerequisites included in the program. The design team is allowed to choose which measures are most easily achievable rather than which measures are most meaningful for the City. There is the potential for projects to earn significant credit based solely on the location rather than sustainable measures included in the project design. In many cases, it may be more beneficial to the City to require measures such as PV systems and EV charging systems rather than allow the project design team to select other less beneficial measures. Finally, since the LEED rating system and the other sustainable codes enforced in Davis (CALGreen and the California Energy Code) are not necessarily consistent with one another there are questions concerning how reasonable and fiscally appropriate it is to require compliance with two separate "green" approaches. Staff recommends adoption of sustainable measures selected by staff, in concurrence with the NRC that would be most beneficial to the City and would be essentially equivalent to LEED Gold.

The 2016 California Green Building Standards Code (CALGreen) contains checklists for residential and nonresidential projects. The checklists specify mandatory measures for all new construction. CALGreen also provides a list of additional "Tier 1" and "Tier 2" voluntary measures for designers and property owners who seek to design a more sustainable building and environment. CALGreen includes requirements for residential and commercial alterations, remodels, or additions. While most cities do not require it, the City of Davis has required Tier 1 compliance as mandatory, not optional. Adoption of Tier 1 energy efficiency measures requires California Energy Commission approval prior to implementation.

LEED certification equivalency would require a design that would achieve a minimum number of points to meet the Gold threshold. There are 110 possible points with a score of 60 to 79 points required for LEED Gold certification. There are seven (7) different categories from which an applicant could earn points. There is no defined energy efficiency required other than the prerequisite which is to conduct a building simulation demonstrating an improvement of 5% for new construction compared to the baseline performance rating; or Prescriptive compliance (ASHRAE 50% Advanced Energy Design Guide); or Prescriptive compliance (Advance Buildings™ Core Performance ™ Guide). These standards fall well short of the California Energy Code requirements. There are only three (3) possible points for incorporating renewables into a project. PV is not a prerequisite for LEED Gold. Nor are EV Charging stations. Although LEED certification enjoys market recognition it does not necessarily achieve the level of sustainability desired. LEED and CALGreen are similar in some ways and inconsistent in others. It is staff's opinion that it is unnecessary to require both CALGreen Tier 1 and LEED Gold compliance. CALGreen compliance is not optional; it is required by the State of California. The City has chosen to increase the level of compliance to Tier 1 for all measures and to require additional measures that are meaningful to the City.

The concept of developing LEED Gold equivalent building standards by utilizing existing Davis Municipal Code, California Energy Code in addition to the required and voluntary measures found in the CALGreen was first proposed to the NRC in November of 2017. Staff requested feedback from the NRC regarding sustainability measures that should be incorporated into projects under review. In a subsequent meeting, staff provided a comparison of LEED and the codes currently being enforced as well as other voluntary measures that could be incorporated into projects under review. The purpose of the comparison was to identify sustainable measures that are important to the City's plan to be zero carbon by 2050. A LEED comparison (Attachment 2) lists all of the possible LEED measures that can be incorporated in to a project. A comparison is made between LEED and the measures included in CALGreen, California Energy Code and the Davis Municipal Code. The current codes in effect including the CALGreen Tier 1 compliance get projects very close to the LEED Silver threshold of 50 points. Some specific measures such as PV, EV Charging, Enhanced Commissioning and increased energy compliance allow projects to be equivalent to LEED Gold without consideration of location.

The cost effectiveness study prepared by TRC (Attachment 3) shows that nonresidential buildings in all California climate zones have a market-ready and cost effective set of measures to achieve at least 10% energy performance higher than the California Energy Code requirements. Thus, the City has the required justification for adopting a 10% nonresidential reach code meeting the requirements of section 10-106 of the California Code of Regulations Title 24, Part 1.

The Zero Net Energy option was not shown to be cost effective in Davis (Climate Zone 12) at this time. Staff will continue to monitor the cost effectiveness of ZNE and additional energy efficiency measures as the market and technology allow. Table 1 below shows the cost effective compliance margins for all climate zones in California. The City of Davis is in Climate Zone 12.

TABLE 1 – Recommended Compliance Margins

Climate Zone	Cost Effective Compliance Margin	B/C Ratio		Recommended Reach Code Compliance Margin
		TDV Methodology	On-Bill Methodology	
1	15.7%	3.0	5.3	15%
2	12.8%	1.4	2.3	10%
3	15.5%	1.2	2.0	15%
4	13.1%	1.4	2.3	10%
5	15.9%	1.2	2.0	15%
6	14.7%	1.4	1.5	10%
7	15.6%	1.4	2.3	15%
8	13.7%	1.4	1.5	10%
9	12.6%	1.4	1.5	10%
10	11.6%	1.5	2.5	10%
11	11.0%	1.6	2.5	10%
12	11.8%	1.4	2.2	10%
13	10.8%	1.6	2.5	10%
14	11.0%	1.6	1.8	10%
15	10.4%	1.9	2.1	10%
16	12.8%	1.5	2.3	10%

Staff recommends continued compliance with the previously adopted California Green Buildings Standards Code. The previously adopted provisions include the following:

- All new construction, both residential and non-residential, would be required to comply with both the mandatory measures and the measures contained in Tier 1.
- All residential and non-residential remodels and additions would also be required to comply with both the mandatory measures and the measures contained in Tier 1, as applicable.

Photovoltaic Requirements

The proposed Ordinance would require PV sizing consistent with the methodology included in the cost effectiveness study also prepared by TRC (Attachment 4). The PV sizing calculations were developed such that the PV size would be the lessor of approximately 80% offset of the electricity used on site or 15 DC watts per sq. ft. of solar zone.

Codification of EV Ready

The proposed Ordinance would reinforce compliance with the EV Ready plan adopted by council resolution (Attachment 5). The tables below specify the number and type of charging

stations required for new nonresidential and multifamily buildings. The proposed Ordinance will also augment the current CALGreen requirement regarding single family dwelling EV readiness by requiring #8 gauge conductors to be installed in the required conduit for a future EV charging station.

TABLE 2 - Non-Residential EV Charging Station Standards

Non-Residential Land Use Category	**Required Parking Spaces**	**EV Chargers**	**Land use (From City Parking Code; City Code Section** 40.25.090**)**
Retail	0-10	0	1. Automobile or machinery sales and service garages 2. Banks, post offices, business and professional offices 3. Furniture and appliance stores, household equipment or furniture repair shop 4. Launderettes 5. Restaurants, beer parlors, nightclubs, and cardrooms 6. Retail stores, shops, etc. 7. Rooming and lodging houses 8. Shopping center, neighborhood 9. Shopping center, community 10. Land uses where up to 50% of spaces serving employees.
	11-51	1	
	52-102	2	
	Every additional 50	+1	
Non-Retail	0-10	0	1. Group care homes 2. Hospitals 3. Hotels and motor hotels, motels 4. Manufacturing plants, research or testing laboratories and bottling plants 5. Medical or dental clinics 6. Rest home, sanatorium, convalescent home or hospital 7. Wholesale establishments, warehouses 8. Land uses where more than 50% of spaces serving employees.
	11-26	1	
	27-42	2	
	Every additional 15	+1	
Destination	0-10	0	1. Bowling alleys 2. Churches, schools, day care centers and nursery schools 3. Dance halls and assembly halls without fixed seats, exhibition halls except assembly rooms in conjunction with auditorium 4. Funeral home, mortuaries 5. Sports arenas auditoriums, theaters, assembly halls
	11-36	1	
	37-62	2	
	Every additional 25	+1	

Notes:

1. All other non-modified Tier 1 standards for non-residential EV charging apply.
2. All required charging is Level 2 with the exception of non-retail (Workplace) charging, which can be satisfied by 50% level 1 chargers with 50% payment-ready level 2 chargers due to longer dwell times. Note: calculations for total number of chargers shall be rounded up and rounding shall favor Level 2 chargers.
3. The first two chargers placed at non-retail (Workplace) locations must be payment ready Level 2 with subsequent chargers optionally Level 1.
4. 50% of required non-retail (Workplace) chargers to be installed prior to issuance of Certificate of Occupancy if approved prior to January 1, 2020. Remaining required chargers do not have to be installed at time of construction but must be pre-wired and have adequate electrical panel capacity for each future charger. After January 1, 2020, all required chargers must be fully installed.
5. Chargers should be placed to serve multiple parking spaces – see design recommendations in Section 5 of Davis EV Charging Plan.
6. EV charging parking spaces shall be included in the required number of parking spaces per Article 40.25 of the City of Davis Zoning Ordinance. If space is available in a parking lot, additional EV charging spaces may be installed beyond the minimum number required subject to review and approval by the Department of Community Development and Sustainability.
7. Conversion of existing parking spaces for EV charging purposes shall be reviewed and approved by the Director of Community Development & Sustainability to assure a balance between full-size parking spaces, compact parking spaces and parking spaces for persons with disabilities.

TABLE - 3 Residential Standards

Development Type	Tier 1 Modifications	Notes
Single Family (1-3 units)	1. Single Family Residential development required to pre-install 8 Gauge wiring plus reserve room in electrical panel necessary to support Level 2 electric vehicle charging.	1. Addresses key barrier for adding Level 2 Home EV charger.
Multi-family (4 or more units)	1. Multi-family Residential development projects are required to provide: (1) Level 1 charging at 5% of all required parking spaces with a minimum of 2 parking spaces served, (2) Level 2 charging at 1% of all required parking spaces where more than 20 parking spaces are required with a minimum of 1 parking space served, (3) conduit adequate for Level 2 charging to serve or reasonably be extended in the future to 25% of all parking spaces, and (3) room in panel(s) and capacity to serve 20%	1. Addresses key barrier for EV use in residential rental settings.

	of all parking spaces with Level 1 charging and 5% of all parking spaces with Level 2 charging. Notes: (1) properly located, a single charger can serve multiple parking spaces; (2) Reasonable future extension of conduit would not include the removal or trenching of hardscaped surfaces or areas where mature trees would be expected to establish (e.g. pavement, tree wells, etc.)	

Notes:

1. All other non-modified Tier 1 standards for residential EV charging apply.
2. Chargers in Multi-family residential settings should be placed to serve multiple parking spaces – see design recommendations in Section 5 of the Davis EV Charging Plan.
3. Level 1 in the context above is defined as a 20A 120V circuit and Level 2 is defined a 40A 208V/240V circuit
4. Level 1 is defined as a 120V hardwired EVSE not a household outlet.
5. Monitoring equipment to properly charge tenants is encouraged at multi-family locations

The two referenced studies provided by TRC show that the proposed energy reach code (10% compliance margin) and the proposed PV portion of the proposed Ordinance are cost effective in compliance with the Warren/ Alquist Act of 1974.

Commissioning Guideline

CALGreen includes basic commissioning[2] for nonresidential and high-rise residential projects over 10,000 sq. ft. The proposed Ordinance will include a requirement to adopt the International Code Council (ICC) G4 Commissioning Process Application. The ICC G4 is a set of commissioning guidelines to define and clarify the commissioning process (Attachment 6). Exceptions to the application of the commissioning requirement will be consistent with CALGreen. Exceptions include unconditioned warehouses and open parking garages.

120 Volt Receptacle Requirement

The most significant obstacle to the installation of a code compliant on-demand hot water recirculation pump is the installation of a 120-volt receptacle under the most remote sink. This is a simple and cost effective installation during construction but significantly more costly and time consuming as a retrofit. Installation of a 120-volt receptacle during construction or remodel will allow the occupant to install an on-demand pump without any plumbing or electrical modifications other than to install the necessary hoses to connect the pump. The purpose of the recirculation pump is to significantly reduce the amount of water wasted while waiting for hot water at a sink or shower. The recirculation pump fills the hot water system with hot water so that when the faucet is opened hot water is at the fixture with little or no water loss. The current energy code only allows on-demand pumps.

[1]2016 Nonresidential Compliance Manual section 9.3.1 solar zone must have a total area of no less than 15% of the total roof area.

[2]Basic commissioning is the process of verifying and documenting that the building and its systems and assemblies are planned, designed, installed, tested, operated and maintained to meet the owner's project requirements.

Commissions

On November 27, 2017 at a Natural Resources Commission meeting staff introduced the concept of utilizing existing codes and a reach code to replace LEED Gold equivalency as a standard for new construction. Staff presented a proposed reach code ordinance and sought feedback during two subsequent Natural Resources Commission meetings on June 26, 2018 and September 24, 2018. A final draft was presented to the Natural Resources Commission on November 26, 2018 for approval. The Commission recommended approval of the final version of the proposed reach code Ordinance with a 5-0 vote.

Outreach

Staff presented the proposed reach code Ordinance to the Davis Chamber of Commerce on two separate occasions. Local developers attended these meetings. The Chamber has submitted a letter expressing gratitude for staff outreach and stating a neutral position on the proposed Ordinance (Attachment 7). Cool Davis is supportive of the proposed Ordinance.

Attachment

1. Ordinance
2. LEED comparison
3. Nonresidential Cost Effectiveness Study (10% compliance margin)
4. PV System Cost Effectiveness Study
5. EV Readiness Plan adopted by council resolution
6. ICC Cx Guidelines (Draft)
7. Davis Chamber of Commerce Letter on Building Standards

ORDINANCE NO.

ORDINANCE OF THE CITY COUNCIL OF THE CITY OF DAVIS AMENDING SECTIONS 8.01.060 RELATED TO ELECTRICAL REQUIREMENTS AND 8.01.090 RELATED TO GREEN BUILDING AND ADDING SECTION 8.01.094 RELATED TO ENERGY EFFICIENCY STANDARDS FOR NONRESIDENTIAL AND HIGH-RISE MULTIFAMILY BUILDINGS UNDER THE GREEN BUILDING CODE

NOW, THEREFORE, THE CITY COUNCIL OF THE CITY OF DAVIS DOES HEREBY ORDAIN AS FOLLOWS:

SECTION 1. Subsection (c) of Section 8.01.060 of the Davis Municipal Code is hereby amended to read in full as follows:

1. In new single family residential construction a 120 volt receptacle shall be installed under the sink of the most remote sink, measured from the water heater, to accommodate the future installation of an on-demand hot water recirculation pump.

   Exception: Where compact hot water design credit is achieved, the receptacle for a future recirculation pump is not required.

2. In bathroom or kitchen remodels and additions that include the most remote sink, measured from the water heater, a 120 volt receptacle shall be installed under the sink to accommodate the future installation of an on-demand hot water recirculation pump.

   Exception: If it is determined that the installation of the 120 volt receptacle is not practical because the existing wiring is not easily accessible the receptacle is not required.

SECTION 2. Subsection (e) of Section 8.01.090 of the Davis Municipal Code is hereby amended to read in full as follows:

1. Chapter 4 Section 4.106.4.1 of the California Green Building Standards Code is hereby amended to add a sentence to the end of the paragraph to read as follows :

Single Family Residential developments are required to pre-install 8 Gauge wiring to support Level 2 electric vehicle charging.

SECTION 3. Section 8.01.090 of the Davis Municipal Code is hereby added to read in full as follows:

8.01.094 Energy Efficiency "Reach" Green Building Code Requirements for Nonresidential and High-Rise Residential Buildings

In addition to all requirements of the Green Building Code applicable to new nonresidential and high-rise multifamily dwellings, the following shall apply:

1. New Nonresidential Buildings. New nonresidential buildings shall comply with the Tier 1 (10% compliance margin) requirement for energy efficiency by employing energy efficiency measures. In addition, a PV system sized to offset a portion of the total building energy use based on TDV energy is required. The PV sizing shall be consistent with the methodology included in the cost effectiveness study provided by TRC. The PV sizing calculations were developed such that PV size would be the lessor of approximately 80% offset of the building's modelled annual electric load or 15 DC watts per sq. ft. of solar zone[1].

2. New High-rise Multifamily Dwellings. New high-rise multifamily dwellings shall comply with the Tier 1 (10% compliance margin) requirement for energy efficiency by employing energy efficiency measures. In addition, a PV system sized to offset a portion of the total building energy use based on TDV energy is required. The PV sizing calculations were developed such that PV size would be the lessor of approximately 80% offset of the building's modelled annual electric load or 15 DC watts per sq. ft. of solar zone[1].

3. New nonresidential and high-rise multifamily buildings shall incorporate EV charging stations as determined by tables 1 and 2. Each EV charging station installed shall be credited toward the California Green Building Standards Code requirement for charging spaces.

TABLE 1 - Non-Residential EV Charging Station Standards

Non-Residential Land Use Category	**Required Parking Spaces**	**EV Chargers**	**Land use (From City Parking Code; City Code Section** 40.25.090**)**
Retail	0-10	0	1. Automobile or machinery sales and service garages 2. Banks, post offices, business and professional offices 3. Furniture and appliance stores, household equipment or furniture repair shop 4. Launderettes 5. Restaurants, beer parlors, nightclubs, and cardrooms 6. Retail stores, shops, etc. 7. Rooming and lodging houses 8. Shopping center, neighborhood 9. Shopping center, community 10. Land uses where up to 50% of spaces serving employees.
	11-51	1	
	52-102	2	
	Every additional 50	+1	
Non-Retail	0-10	0	1. Group care homes

[1]2016 Nonresidential Compliance Manual section 9.3.1: solar zone must have a total area of no less than 15% of the total roof area.

	11-26	1	2. Hospitals 3. Hotels and motor hotels, motels 4. Manufacturing plants, research or testing laboratories and bottling plants 5. Medical or dental clinics 6. Rest home, sanatorium, convalescent home or hospital 7. Wholesale establishments, warehouses 8. Land uses where more than 50% of spaces serving employees.
	27-42	2	
	Every additional 15	+1	
Destination	0-10	0	1. Bowling alleys 2. Churches, schools, day care centers and nursery schools 3. Dance halls and assembly halls without fixed seats, exhibition halls except assembly rooms in conjunction with auditorium 4. Funeral home, mortuaries 5. Sports arenas auditoriums, theaters, assembly halls
	11-36	1	
	37-62	2	
	Every additional 25	+1	

Notes:

1. All other non-modified Tier 1 standards for non-residential EV charging apply.
2. All required charging is Level 2 with the exception of non-retail (Workplace) charging which can be satisfied by 50% level 1 chargers with 50% payment-ready level 2 chargers due to longer dwell times. Note: calculations for total number of chargers shall be rounded up and rounding shall favor Level 2 chargers.
3. The first two chargers placed at non-retail (Workplace) locations must be payment ready Level 2 with subsequent chargers optionally Level 1.
4. 50% of required non-retail (Workplace) chargers to be installed prior to issuance of Certificate of Occupancy if approved prior to January 1, 2020. Remaining required chargers do not have to be installed at time of construction but must be pre-wired and have adequate electrical panel capacity for each future charger. After January 1, 2020, all required chargers must be fully installed.
5. Chargers should be placed to serve multiple parking spaces – see design recommendations in Section 5 of the City of Davis EV Charging Plan.
6. EV charging parking spaces shall be included in the required number of parking spaces per Article 40.25 of the City of Davis Zoning Ordinance. If space is available in a parking lot, additional EV charging spaces may be installed beyond the minimum number required subject to review and approval by the Department of Community Development and Sustainability.
7. Conversion of existing parking spaces for EV charging purposes shall be reviewed and approved by the Director of Community Development & Sustainability to assure a balance between full-size parking spaces, compact parking spaces and parking spaces for persons with disabilities.

TABLE - 2 Residential Standards

Development Type	Tier 1 Modifications	Notes
Single Family	1. Single Family Residential development	1. Addresses key barrier

[1]2016 Nonresidential Compliance Manual section 9.3.1: solar zone must have a total area of no less than 15% of the total roof area.

(1-3 units)	required to pre-install 8 Gauge wiring plus reserve room in electrical panel necessary to support Level 2 electric vehicle charging.	for adding Level 2 Home EV charger.
Multi-family (4 or more units)	1. Multi-family Residential development projects are required to provide: (1) Level 1 charging at 5% of all required parking spaces with a minimum of 2 parking spaces served, (2) Level 2 charging at 1% of all required parking spaces where more than 20 parking spaces are required with a minimum of 1 parking space served, (3) conduit adequate for Level 2 charging to serve or reasonably be extended in the future to 25% of all parking spaces, and (3) room in panel(s) and capacity to serve 20% of all parking spaces with Level 1 charging and 5% of all parking spaces with Level 2 charging. Notes: (1) properly located, a single charger can serve multiple parking spaces; (2) Reasonable future extension of conduit would not include the removal or trenching of hardscaped surfaces or areas where mature trees would be expected to establish (e.g. pavement, tree wells, etc.)	1. Addresses key barrier for EV use in residential rental settings.

Notes:

1. All other non-modified Tier 1 standards for residential EV charging apply.
2. Chargers in Multi-family residential settings should be placed to serve multiple parking spaces – see design recommendations in Section 5 of the City of Davis EV Charging Plan.
3. Level 1 in the context above is defined as a 20A 120V circuit and Level 2 is defined a 40A 208V/240V circuit
4. Level 1 is defined as a 120V hardwired EVSE not a household outlet.
5. Monitoring equipment to properly charge tenants is encouraged at multi-family locations

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4. The most current version of the International Code Council (ICC) G4 Commissioning Process Application (Cx Guidelines) shall be adopted by reference. Compliance with the guidelines shall be required for nonresidential and high-rise residential projects. The application shall be consistent with the application specified in the current version of the California Green Building Standards Code and the California Energy Code.

SECTION 3. Express Findings

As required by Health and Safety Code sections 17958.7, 18941.5(c) and 18942, the City Council of the City of Davis hereby expressly finds that the above amendment to the California Building Standards Code is necessary for the protection of the public health, safety and welfare, due to the

[1]2016 Nonresidential Compliance Manual section 9.3.1: solar zone must have a total area of no less than 15% of the total roof area.

local climatic, geological or topographical conditions. The amendment is justified by all of the following conditions.

Express Finding #1: Climatic

The effects of climate change are increasingly self-evident, and costly. Hurricanes wildfires and other natural disasters take many lives and cost billions of dollars. Across the globe, higher temperatures are contributing to record heat waves and droughts, rising sea levels, more intense storms, wildfires, and floods. Even if humanity was to immediately stop releasing CO_2, the climate would continue to change because the greenhouse gases that we have already released into the atmosphere could take years to dissipate. Climate change is the fundamental design problem of our time. The threat climate change poses is existential, and buildings are large contributors.
In Davis climate is one of the greatest impacts to fire behavior and other major emergency events because it cannot be controlled. The drying out of wood shakes and wild land fuels in the summer months allows for easy ignition. The combustible weeds on vacant urban lots coupled with windy conditions are a recipe for disaster. The Sacramento region has extreme variations in weather patterns. Summers are arid and warm; winters are cool to freezing, but void of significant snowfall. Fall and spring can bring any combination of weather pattern together. The doubling of average rainfall called an "El Nino" event has occurred from time to time and does cause the grass to mature and grow in excess of six feet high before it dries out. Ten (10) square feet of this type of fuel is equivalent to the explosive force of one gallon of gasoline. Average yearly rainfall for the City is approximately 17.87 inches. This rainfall normally occurs from October to April. Low-level fog (tulle-fog) is present throughout the winter months, which brings visibility to almost zero feet. The fog delays emergency responders. The fog can also cause freezing and slick roadways. During the summer months there is generally no measurable precipitation. Temperatures for this dry period range from 70 to 112 degrees F and are frequently accompanied by light to gusty Delta winds. The relative humidity during the summer month's range from 2 to 30 mm HG, which is classified as arid. The severe hot climate for several summer months makes it essential to provide for future solar power, paddle fans, electric vehicles and drip irrigation.

Express Finding #2: Geological

The City of Davis is subject to ground tremors from seismic events as the City is located in Design Category C, which relates to a high risk of earthquakes. Gas appliance located in attics or garages must be adequately braced and protected from damage from moving objects. Large portions of the City of Davis have very poor soil conditions. The soil is often expansive in nature and very acidic which leads to pre-mature deterioration of plumbing piping installed in the ground. Potable water is predominately pumped from City wells and has a higher than usual content of minerals contributing to extremely hard water. Additionally, the very low elevations are subject to a very high water table. Prior experience with lightly-loaded footing and foundations and concrete slabs on grade revealed structural cracks resulting in differential settlement in addition to moisture migrating from the soil to occupied, habitable areas of buildings.

Express Finding #3: Topographical

[1]2016 Nonresidential Compliance Manual section 9.3.1: solar zone must have a total area of no less than 15% of the total roof area.

The City features include open space, drainage canals, freeways and railroad tracks. Traffic has to be channeled around several of these topographical features and limitations which creates traffic congestion and delays in emergency response. These features are located between the Fire Stations located within the City of Davis. Heavy traffic congestion on the City streets already acts as a barrier to timely response for fire and emergency vehicles. In the event of an accident or other emergency at one of the key points of intersection between a road and freeway, sections of the City could be isolated or response times could be sufficiently slowed so as to increase the risk of injury or damage. The topography of the downtown area together with traffic congestion makes it necessary reduce or eliminate overhead power lines to allow large fire trucks easy access to this area.

SECTION 4. The City Clerk is hereby directed to file a copy of this ordinance with the California Building Standards Commission of the State of California.

SECTION 5. This ordinance shall take effect and be in full force thirty (30) days from and after the date of its final passage and adoption.

SECTION 6. The City Clerk shall certify to the adoption of this ordinance and shall cause a summary thereof to be published at least five (5) days prior to the meeting at which the proposed ordinance is to be adopted and shall post a certified copy of the proposed ordinance, and within fifteen (15) days of its adoption, shall cause a summary of it to be published, including the vote for and against the same, and shall post a certified copy of the adopted ordinance, in accordance with California Government Code Section 36933.

INTRODUCED on the ____th day of _____, 2019, and PASSED AND ADOPTED by the City Council of the City of Davis on this ____th day of _____, 2018, by the following vote:

AYES:

NOES:

ABSENT:

Brett Lee
Mayor

ATTEST:

[1]2016 Nonresidential Compliance Manual section 9.3.1: solar zone must have a total area of no less than 15% of the total roof area.

Zoe S. Mirabile, CMC
City Clerk

[1]2016 Nonresidential Compliance Manual section 9.3.1: solar zone must have a total area of no less than 15% of the total roof area.

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LEED V4 comparison to Davis Municipal Code, CALGreen and the California Energy Code

LEED V4	INTENT	LEED	CALGreen, California Energy Code, Davis Municipal Code	LEED Possible Points	Proposed Ordinance LEED Eq Points
Integrative Process	Maximize opportunities for integrated, cost effective adoption of green design and construction strategies, emphasizing human health as a fundamental evaluative criterion for building design, construction and operational strategies. Utilize innovative approaches and techniques for green design and construction.	Assemble integrated project team, minimum 4 members (disciplines). Prepare OPR addressing economic, environmental and social goals for the project.	**CEC and CALGreen Commissioning.** Establish and review OPR and BOD. Document design review team meeting with CEC forms. CEC-120.8, CALGreen-5.408, NRCC-CXR-01-E, NRCC-CXR-05-E,NRCC-CXR-04-E.	**1**	1
					N/A
Location and Transportation				**16**	
LEED for Neighborhood Development Location	To avoid development in inappropriate sites, reduce vehicle traffic and to enhance livability and health.	Locate project in a LEED for Neighborhood Development	The project location is typically not a part of the regulatory design other than to determine the appropriateness of the selected site and zoning compliance. The approval process does address appropriateness of site for the development.	16	
Sensitive Land Protection	To avoid the development of environmentally sensitive lands a reduce the environmental impact.	Locate the footprint on a previously developed site, or do not locate the site on prime farmland, floodplain, sensitive habitat, within 100 feet of a body of water or within 50 feet of wetlands.	**CEQA/**DMC 13A. This credit area is addressed by CEQA. The environmental documentation will assess whether the land has been previously developed, is on prime farmland, or is in a floodplain. However, the City could conclude that that significant impacts of a project are overridden by public benefits. A planner on a project would be able to confirm consistency with this credit.	1	1
High Priority Site	To encourage project location in areas with development constraints and promote health of surrounding area.	Locate project on historical infill site; or brownfield site ; or other challenged site such as Federal Empowerment Zone, Federal Enterprise Community, Low-Income Community, Difficult Development Area etc.	CALGreen Tier 1 elective; 'The project location is typically not a part of the regulatory design other than to determine the appropriateness of the selected site and zoning compliance.	2	
Surrounding Density and Diverse Uses	To conserve farmland and wildlife habitat by encouraging development in areas with existing infrastructure. Promote walkability and transportation efficiency. Improve health by encouraging physical activity.	Locate site where the existing combined density of res and non-res within 1/4 mile meets values specified (Table 1-A); or locate project within 1/2 mile of 4 out of 7 listed publicly available diverse uses such as retail, bank, restaurants post office etc.	CALGreen Tier 1 Elective; 'The project location is typically not a part of the regulatory design other than to determine the appropriateness of the selected site and zoning compliance.	5	
Access to Quality Transit	To encourage development in locations with transportation options, thereby reducing GHGs and pollution.	Locate project within 1/4 mile of bus, streetcar or other transit stops or within 1/2 mile of rapid transit, light rail or rail stops.	CALGreen Tier 1 Elective; 'The project location is typically not a part of the regulatory design other than to determine the appropriateness of the selected site and zoning compliance.	5	
Bicycle Facilities	To promote bicycling and improve health through recreational physical activity.	Locate project within 200 yards of a bicycle network that connects at least one of the following: 10 diverse uses, a school or employment center, rapid transit stop (light or heavy rail, commuter rail)	All building sites are presumably within 200 yards of a bicycle network as required by LEED.	1	1
Bicycle Parking	Not Included in LEED		CALGreen 106.4 and DMC 40.25A CALGreen- provide short term bicycle racks within 200 feet of the entrance for 5% of the parking spaces. For buildings with 10 or more tenant occupants provide long term bicycle parking for 5% of the parking spaces. 40.25A.040 Bicycle parking standards Table specifies number of bicycle racks required based on sq. ft. and divided between short and long term. Helps to comply with LEED reduced parking footprint		1
Reduced Parking Footprint	To minimize the environmental harm associated with parking including auto dependence, land consumption and rainwater runoff.	Projects without "surrounding density" credit must achieve 20% reduction from base ratios; or Projects earing "surrounding density" credit achieve a 40% reduction in base ratios.	CALGreen Tier 1 Elective, employ strategies to reduce on-site parking.	1	

Green Vehicles	To reduce pollution by promoting alternatives to conventionally fueled vehicles.	Install EV Charging stations in 2% of all parking spaces in addition to 5% preferred parking for green vehicles; or install liquid or gas alternative fueling facilities equal to at least 2% of parking spaces.	CALGreen 106.5.3 requires infrastructure for approx. 6% of parking for future EV stations. ***Additional requirement for 2% of parking to be EV stations would satisfy LEED credit.*** Parking requirements exceed LEED, Future infrastructure requirements exceed LEED; A5.106.1 Tier 1 requires 10% of parking spaces be designated clean air vehicles. Require compliance with Council resolution on EV charging stations.	1	1
Sustainable Sites				**10**	
Construction Activity Pollution Prevention	To reduce pollution from construction activities through erosion and sediment control and limiting air borne dust.	Create and implement an erosion and sediment control plan. Conform to the EPA Construction General Permit or local equivalent whichever is more stringent.	Projects over an acre are required to comply with NPDES and the City's Construction General Permit (CGP). Projects that disturb under and acre are required to comply with CALGreen BMPs. CALGreen-5.106 and A5106.3 , DMC Chapter 30.	Required	
Site Assessment	To protect the health of vulnerable populations through site assessment for environmental contamination and to assess site conditions before design to evaluate sustainable options.	Conduct a phase I environmental site assessment per ASTM E1527-05 or local equivalent to determine whether environmental contamination exists at the site. If contaminated, remediate to meet standards. Complete and document a site survey that includes topography, hydrology, climate, vegetation, soils, human use, and human health effects.	**CEQA/**DMC 13A. Many of these factors are considered during CEQA and planning review of a proposed project. This includes topography, hydrology, soils, and human health. The City does not receive documentation that the assessment is conducted "before design."	1	1
Site Development - Protect or Restore Habitat	To conserve existing natural areas and restore damaged areas to provide habitat and bio diversity.	Preserve 40% of the greenfield area on the site and restore 30% of previously disturbed portions (including building footprint) using native vegetation; or provide financial support equivalent to .40¢ per sq. ft.	**CEQA/**DMC 13A. CEQA will assess obligations to protect habitat or require mitigation through the Yolo Habitat Conservancy. For greenfield projects, 40% on-site preservation may render development infeasible. For infill projects, on-site restoration of habitat, or financial support for conservation organization would not ordinarily be required.	2	1
Open Space	To create exterior open space that encourages interaction with the environment, social interaction, passive recreation and physical activities.	Provide outdoor space greater than or equal to 30% of the total site with a minimum of 25% vegetated (not turf) or have a vegetated canopy	CEQA/DMC 13A. Usable open space requirements are evaluated during planning design review of a project. The requirement for 30% of the site to be open space may preclude developer interest in obtaining this credit.	1	0.5
Rainwater Management	To reduce runoff volume and improve water quality by replicating hydrology and water balance of the site, based on undeveloped ecosystems in the e region.	In a manner replicating natural hydrology processes manage on site runoff from the site for the 95th percentile of the regional or local rainfall event using LID; or 98th percentile using LID; or for zero lot lines in a manner replicating natural hydrology processes manage on site runoff from the site for the 85th percentile of the regional or local rainfall event using LID; or manage the annual increase in volume from the natural land cove condition to the post developed condition.	**Construction General Permit, DMC, CALGreen.** The compliance thresholds are: 2,500, 5,000 and 1 acre of created or replaced impervious surfacing. The General Permit provides development standards for these different thresholds. For either of the later two project types we also require maintenance mechanisms in place and require access for annual inspections. The City require the 85th percentile for 5,000 sf projects. In the event a project site creates more runoff than the original pre-project condition, then the project will have to bio-retain the 85th percentile. The City requires redevelopment projects to implement Site Design Measures for projects that exceed 2,500 sf but do not reach the 5,000 sf threshold. The City requires large sites with an acre or more or created or replaced impervious surface to detain the 2 year 24 hour storm event on site prior to permitting it to discharge to the City's storm drain system.	3	2
Heat Island Reduction	To minimize effects on microclimates and human and wildlife habitats by reducing heat islands.	(0.5) area of non roof Heat Island Effect (HIE) plus (o.75) are of high reflectance roof plus (0.75) area of vegetated roof $\geq$ total site area plus total roof area; or 75% of parking under cover with an aged SRI of 32 or vegetated roof or PV.	**DMC, California Energy Code, CALGreen.** DMC 37.04- 50% of the paved parking lot surface shall be shaded with tree canopies within fifteen years. CEC 140.3 Aged solar reflectance of 0.63 and minimum thermal emittance of 0.75. CALGreen A5.106.11. (Shade structures that support PV?)	2	2
Light Pollution Reduction	To increase night sky access, improve nighttime visibility, and reduce the consequences of development for wildlife and people.	Meet up light and trespass requirements using either BUG ratings or calculations in compliance with Tables 1 - 4.	**DMC, CALGreen.** CALGreen 5.106.8, DMC- 8.17 Very similar requirements not exact match.	1	1

Tenant Design and Construction Guidelines	To educate tenants in implementing sustainable design and construction features in Tenant Improvements.	Publish a guidance document for tenants that includes the following credit information: Indoor water use reduction, minimum energy performance, fundamental refrigeration management, optimize energy performance, advanced energy metering, renewable energy production, enhanced refrigeration management, storage and collection of recyclables, minimum indoor air quality performance, tobacco smoke control, enhanced indoor air quality management, strategies, low-emitting materials, construction indoor air quality management, indoor air quality assessment, thermal comfort, interior lighting, daylight, quality views, acoustic performance.	**CALGreen 5.410.2.4, 5.410.2.5, 5.410.4.5.** A systems manual is required to document the operational aspects of the building, A training program for staff is required, An operation and maintenance manual is required to be provided to the owner of the building with detailed operation and maintenance information.	1	0.5
Grading and Paving	Not included in LEED		CALGreen 5.106.10. Construction plans shall indicate how site grading and drainage system will manage all surface water flows and keep water from entering the building .		1
Water Efficiency				**11**	
Outdoor Water Use Reduction	To reduce outdoor water consumption.	No irrigation required; or Reduce landscape water requirement by 30% for peak watering month.	DWR-MWELO, DMC 40.42	Required	
Indoor Water Use Reduction	To reduce indoor water consumption	Reduce aggregate water consumption by 20% from baseline.	CALGreen 5.303.3 20% reduction of indoor water use.	Required	
Building-Level Water Metering	To support water management and identify opportunities for additional water savings by tracking water consumption.	Install water meters that measure the total water use for the buildings and associated grounds.	DMC Water meters required for water service.	Required	
Outdoor Water Use Reduction	To reduce outdoor water consumption.	No irrigation required; or reduce landscape water requirement by 50% for peak watering month.	DWR-MWELO, DMC 40.42	2	2
Indoor Water Use Reduction	To reduce indoor water consumption	Further reduce water use, points are based on percentage of reduction. 25%-1, 30%-2, 35%-3, 40%-4, 45%-5, 50%-6.	CALGreen A5.303.2.3.1 Tier 1 = 32% required, ***Tier 2 A5.303.2.3.2 would be equivalent to 5=45%***	6	2
Cooling Tower Water Use	To conserve water being used for cooling tower make-up water while controlling microbes, corrosion, and scale.	Conduct a water analysis measuring five control parameters. Limit cooling tower cycles to avoid exceeding maximum values for any of these parameters.	Not Addressed in DMC, CALGreen or CEC	2	
Water Metering	To support water management and identify opportunities for additional water savings by tracking consumption.	Install water meters for two or more of the flowing subsystems: Irrigation, Indoor plumbing fixtures, Domestic hot water, Boiler water use, Reclaimed water, other process water.	**CALGreen 5.303.1.** Separate meters required for new buildings over 50,000 sq. ft. for each tenant projected to consume over 100 gpm, for make-up water for cooling towers with flow greater than 500 gpm, Make-up water for evaporative coolers greater than 6gpm, steam and hot water boiler over 500,000 btus/h. 5.303.1.2 Submeter required when tenant is projected to use more than 1000 gpm.	1	1
Commercial Kitchen equipment	Not Included in LEED		C**ALGreen 5.303.4** Food waste disposers shall either modulate the use of water to no more than 1gpm or shall automatically shut off after no more than 10 minutes of inactivity. Disposers shall not use more than 8gpm.		
Energy and Atmosphere				**33**	
Fundamental Commissioning and Verification	To support design, construction, and eventual operation of a project that meets the owner's project requirements for energy, water, indoor environmental quality and durability.	Complete the following commissioning process activities: Develop OPR, Develop BOD, Review OPR, BOD and project design, Develop and implement Cx plan, Confirm incorporation of Cx requirements in construction documents, Develop construction checklists, Develop system test procedures, Verify system test execution, Maintain issues log, Cx report, Document all findings and recommendation to the owner.	CEC and CALGreen Commissioning. Establish and review OPR and BOD. Document design review team meeting with CEC forms. CEC-120.8, CALGreen-5.408, NRCC-CXR-01-E, NRCC-CXR-05-E,NRCC-CXR-04-E. CALGreen 5.410.2 Commissioning required for new buildings exceeding 10,000 sq. ft.	Required	
Minimum Energy Performance	To reduce the environmental and economic harms of excessive energy use by achieving a minimum level of energy efficiency for the building and its systems.	Whole building simulation demonstrating an improvement of 5% for new construction compared to the baseline performance rating; or Prescriptive compliance (ASHRAE 50% Advanced Energy Design Guide); or Prescriptive compliance (Advance Buildings™ Core Performance ™ Guide)	California Energy Code	Required	
Building-Level Energy Metering	To identify energy management and identify opportunities for additional energy savings by tracking building level energy use.	Install building level energy meters, or submeters that can be aggregated to provide building-level data representing total building energy consumption.	Utility Meters required	Required	

Fundamental Refrigerant Management	To reduce stratospheric ozone depletion	Do not use chlorofluorocarbon-based refrigerants in new HVAC refrigeration systems.	CALGreen 5.508.1	Required	
Enhanced Commissioning	To further support design, construction, and eventual operation of a project that meets the owner's project requirements for energy, water, indoor environmental quality and durability.	Path 1-Complete the following commissioning activities: Review contractor submittals, verify systems manual in construction documents, verify training requirements in the construction documents, Verify systems manuals, Verify operator and occupant training, verify seasonal testing, review building operations 10 months after completion, Develop an ongoing commissioning plan; or Path 2-Enhanced Monitoring-Based Commissioning which include Path 1 and inclusion of the following in the Cx plan: Roles and responsibilities, measurement requirements, points to be tracked including frequency and duration, limits of acceptable values for tracked points, elements used to evaluate performance, action plan for identifying and correction operational errors, training to prevent terrors, planning of repairs, frequency of analysis in the first year; and/or Envelope commissioning including: Review contractor submittals, verify systems manual in construction documents, verify training requirements in the construction documents, Verify systems manuals, Verify operator and occupant training, verify seasonal testing, review building operations 10 months after completion, Develop an ongoing commissioning plan.	CEC-120.8 Commissioning required , CALGreen 5.410.2 Commissioning required for new buildings exceeding 10,000 sq. ft. Adopt and require compliance with the ICC Cx Guidline to be consistent with Enhanced commissioning.	6	6
Optimize Energy Performance	To achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic harms associated with excessive energy use.	Whole Building Energy Simulation. Complete a basic energy analysis prior to the simulation. 1-16 points awarded based on % improvement above basic energy analysis. 6%=1 point up to 50%=16 points; or Prescriptive Compliance (ASHRAE Advanced Energy Design Guide) 1-6 points.	CEC compliance = 22% (9 points) increase in efficiency. Proposed ordinance (based on cost effectiveness study) would require and additional 10% increase in efficiency which would equate to an additional 5 points. CALGreen Tier 1-requirement 10% reduction in outdoor lighting power; CALGreen Tier 1 requirement- Solar thermal water heater for restaurants > 8000 sq. ft.; CALGreen Tier 1 requirement- 10% increase in efficiency overall.	18	14
Advanced Energy Metering	To support energy management and identify opportunities for additional energy savings by tracking building-level and system-level energy use.	Install advance level energy metering for the following: all whole building energy sources used by the building, any individual energy uses that represent 10% or more of the total annual consumption of the building	CEC 130.5 Disaggregation of circuits to enable metering of different load types.	1	0.5
Demand Response	To increase participation in demand response technologies and programs that make energy generation and distribution systems more efficient, increase grid reliability and reduce green house gas emissions.	Participate in an existing demand response program and complete the following activities: Design a system with capability for fully automated demand response, enroll in a one-year demand response program, develop a plan for meeting the contractual obligations of the program, Include demand response in the scope of work for Cx Provider.	CEC requires demand response capability, not dependent upon contractual agreement.	2	2
Renewable Energy Production	To reduce the environmental and economic harms associated with fossil fuel energy by increasing self-supply of renewable energy.	Utilize renewable energy systems to offset energy use. 1% = 1, 5%=2 and 10% = 3 points	CALGreen Tier I Elective; DMC ordinance being considered to offset ≥10% of energy used with PV (waiting for cost effectiveness study) Adopt PV requirement to offset 10% of energy use.	3	3
Enhanced Refrigerant Management	To reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to climate change.	No refrigerants or low impact refrigerants; or Select refrigerants to minimize or eliminate the emission of compounds that contribute to ozone depletion of climate change.	CALGreen 5.508.1 requires no CFCs for HVAC and Fire suppression systems. 5.508.2 Includes requirements for new supermarket refrigeration systems to employ leak reduction strategies.	1	1
Green Power and Carbon Offsets	To encourage the reduction of green house gas emissions through the use of grid-source, renewable energy technologies and carbon mitigation projects.	Engage in a contract for a minimum of five years that provides at least 50% or 100% of the projects energy from green sources.	CALGreen Tier 1 Elective Require renewable energy portfolio	2	1
Materials and Resources				**13**	
Storage and Collection of Recyclables	To reduce the waste that is generate by building occupants and hauled to and disposed of in landfills.	Provide dedicated areas for the collection and storage of recyclable materials for the entire building.	CALGreen	Required	
Construction and Demolition Waste Management Planning	To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing and recycling materials.	Develop and implement a construction and demolition waste diversion plan. Establish waste diversion goals for the project identifying at least five materials targeted for diversion.	CALGreen	Required	

Building Life-Cycle Impact Reduction	To encourage adaptive reuse and optimize the environmental performance of products and materials.	Demonstrate reduced environmental effects during initial project design by reusing existing building resources. Option 1- Historic Building reuse; or Option 2 - Renovation of existing or blighted building; or Option 3 - Building and Material reuse; or Option 4 - Whole Building Life-Cycle Assessment identifying reduction in three of the following categories: global warming potential, ozone depletion, acidification, eutrophication, formation of tropospheric ozone, depletion of renewable resources.	CALGreen Tier 1 Elective	5	
Building Product Disclosure and Optimization - Environmental Product Declarations	To encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. To reward project teams for selecting products form manufacturers who have verified improve environmental life-cycle impacts.	Option 1- Use at least 20 products sourced from at least five manufacturers that meet the following criteria: Life cycle assessment conforming with ISO 14044 that have at least a cradle to gate scope valued at 1/4 of a product for the purpose of credit. Environmental Product Declarations conforming to ISO requirements and have at least cradle to gate scope; or Option 2 - Use products that comply with the following criteria of 50% , by cost of the total value of products installed in the project: global warming potential, ozone depletion, acidification, eutrophication, formation of tropospheric ozone, depletion of renewable resources.	CALGreen Tier 1 Elective	2	
Building Product Disclosure and Optimization - Sourcing of Raw Materials	To encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. To reward project teams for selecting products form manufacturers who have verified improved environmental life cycle impacts.	Option 1- Raw material source and extraction reporting. Use at least 20 products sourced from at least five manufacturers that released a report confirming extraction locations, ecological responsible land use a commitment to reducing environmental harm; or Option 2- Leadership Extraction Practices. Use products that meet at least one of the responsible extraction criteria for at least 25% by cost of the total value of the installed building products of the project.	Not Addressed in DMC, CALGreen or CEC	2	
Building Product Disclosure and Optimization - Material Ingredients	To encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. To reward project teams for selecting products for which the chemical ingredients in the product are inventoried using an accepted methodology and for selecting products verified to minimize the use and generation of harmful substances. To reward raw material manufacturers who produce products verified to have improved life-cycle impacts.	Option 1 - Material Ingredient Reporting. Use at least 20 products sourced from at least five manufacturers that use approved programs to demonstrate the chemical inventory of the product to at least 0.1% (1000 ppm); and/or Option 2 - material Ingredient Optimization. Use products that document their material ingredient optimization using approved paths for at least 25%, by cost, of the total value of permanently installed products in the project; and/or Option 3 - Product Manufacturer Supply Chain Optimization. Use products for at least 25%, by cost, of the total value of the installed products in the project that are sourced from manufacturers who engage in validated, robust safety and health, hazard, and risk programs. Are sourced from product manufacturers with independent third party verification of supply chain.	Not Addressed in DMC, CALGreen or CEC	2	
Recycled Content	Not Included in LEED		CALGreen Tier 1 requirement A5.405.4- Recycled content for 10% of the total material cost.		
Construction and Demolition Waste Management	To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing and recycling materials.	Option 1 - Divert 50% (1 point), Divert 75% (2 points); or Option 2- Do not generate more than 2.5 pounds of waste per sq. ft.	CALGreen Tier 1 requires 65% Waste Diversion	2	1.5
Indoor Environmental Quality				**16**	
Minimum Indoor Air Quality Performance	To contribute to the comfort and well being of building occupants by establishing minimum standards for indoor air quality	Comply with ASHRAE 62.1	CALGreen	Required	
Environmental Tobacco Smoke Control	To prevent or minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to environmental tobacco smoke.	Prohibit smoking in the building. Prohibit smoking outside the building except in designated area located at least 25 feet form entries or air intakes or operable windows.	CALGreen	Required	
Enhanced Indoor Air Quality Strategies	To promote occupants comfort, well-being and productivity by improving air quality.	Option1 - Enhanced IAQ Strategies (1 point) Mechanically ventilated spaces, naturally ventilated spaces, mixed mode spaces; and Option 2 - Additional Enhanced IAQ Strategies (1 point)	CEC requires mechanical or natural ventilation	2	2

Low-Emitting Materials	To reduce concentrations of chemical contaminants that can damage air quality, human health, productivity, and the environment.	Achieve the threshold level of compliance with emissions and content standards for the number of product categories listed: Interior paints and coatings applied on site, Interior Adhesives and sealants applied on site, Flooring, Composite wood, Insulation, Furniture.	CALGreen requires low-emitting materials in all of the same products	3	3
Construction Indoor Air Quality Management Plan	To promote the well-being of construction workers and building occupants by minimizing indoor air quality problems associated with construction and renovation.	Develop an IAQ management plan for the construction and pre-occupancy phases of the building. Incorporate the SMACNA IAQ Guidelines: Air handlers and ducts are to be pre-wrapped when delivered to the site, If used during construction the air-handling equipment must be designed to accommodate MERV 8 filtration.	CALGreen	1	1
Indoor Air Quality Assessment	To establish better quality indoor air in the building after construction and during occupancy.	Option 1 - Flush-out (1 point) Before Occupancy. Install filtration media and perform flush-out by supplying a total air volume of 14,000 cubic feet of outdoor air per square foot; or During Occupancy. If occupancy is desire prior to flush-out is completed the space may be occupied after delivery of 3500 cubic feet of outdoor air per square foot. Option 2 - (2 points) After construction but before occupancy, perform indoor IAQ testing.	CALGreen 5.504.5.3 Requires minimum MERV 8 filtration of ventilated buildings	2	1
Thermal Comfort	To promote occupants productivity, comfort, and well-being by providing quality thermal comfort.	Option 1 - Comply with ASHRAE 55-2010 Standards for Thermal Comfort; or Option 2 - Comply with ISO and CEN Standards for Thermal Comfort.	CALGreen Tier 1 Elective	1	
Interior Lighting	To promote occupants productivity, comfort, and well-being by providing high quality lighting.	Option 1 - Lighting Control (1 point). For at least 90% of occupant spaces provide individual lighting controls, with at least three lighting levels, midlevel is 30% to 70% of the max illumination; or Option 2 - (1 point) Lighting Quality. Comply with 4 out of 8 specified lighting strategies	CEC requires robust interior lighting controls that exceed the LEED requirement.	2	2
Daylight	To connect building occupants with the outdoors, reinforce circadian rhythms, and reduce the use of electrical lighting by introducing daylight into the space.	Option 1 - Simulation: Spatial Daylight Autonomy and Annual Sunlight Exposure (2-3 points); or Option 2- Simulation: Illuminance Calculations (1-2 points).	CEC include prescriptive requirements for daylighting and daylighting controls.	3	3
Quality Views	To give building occupants a connection to the natural outdoor environment by providing quality views.	Achieve a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area.	CALGreen Tier 1 Elective	1	
Acoustic Performance	To provided workspaces and classrooms that promote occupants well-being, productivity, and communications through effective acoustic design.	Meet requirements for HVAC background noise, sound isolation, and sound reinforcement and masking. Comply with ASHRAE Handbook, Chapter 48, Table 1or local equivalent, Comply with STC rating in Table 1or local building code which ever is more stringent. For large conference rooms (more than 50 occupants) evaluate whether sound reinforcement is needed. The design levels for masking systems must not exceed 48 decibels.	CALGreen 5.507.4 Required STC ratings for building assemblies for both interior and exterior sound transmission.	1	0.5
Innovation				**6**	
Innovation	To encourage projects to achieve exceptional or innovative performance.	Achieve significant, measurable environmental performance using a strategy not addressed in LEED		5	
LEED Accredited Professional	To encourage the team integration required by a LEED project and to streamline the application and certification process.	At least one principal project member must be a LEED AP.		1	
Regional Priority				**4**	
Regional Priority: Specific Credit	To provide an incentive for the achievement of credits that address geographically specific environmental, social equity, and public health priorities.		CALGreen Tier 1 Elective	1	
Regional Priority: Specific Credit				1	
Regional Priority: Specific Credit				1	
Regional Priority: Specific Credit				1	
					60.5
TOTALS		Gold Range: 60 to 79 Points	Possible LEED Points:	**110**	**60.5**
		Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110			

Exceeds LEED requirements

Equivalent to LEED requirements

In addition to LEED requirement

Not equivalent to LEED requirement (partial credit)

Measure differs from LEED requirement

Preapproved by USGBC/LEED for California code compliance

LEED v4 for BD+C: Core and Shell

Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1

Y	?	N		Location and Transportation	20
			Credit	LEED for Neighborhood Development Location	20
			Credit	Sensitive Land Protection	2
			Credit	High Priority Site	3
			Credit	Surrounding Density and Diverse Uses	6
			Credit	Access to Quality Transit	6
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

Y	?	N		Sustainable Sites	11
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
			Credit	Tenant Design and Construction Guidelines	1

Y	?	N		Water Efficiency	11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

Y	?	N		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Y	?	N		Materials and Resources	14
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	6
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

Y	?	N		Indoor Environmental Quality	10
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Daylight	3
			Credit	Quality Views	1

Y	?	N		Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

Y	?	N		Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

Y	?	N			
0	0	0	TOTALS	Possible Points:	110

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED v4 for BD+C: Schools
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1

0	0	0	Location and Transportation		15
			Credit	LEED for Neighborhood Development Location	15
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	4
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

0	0	0	Sustainable Sites		12
Y			Prereq	Construction Activity Pollution Prevention	Required
Y			Prereq	Environmental Site Assessment	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
			Credit	Site Master Plan	1
			Credit	Joint Use of Facilities	1

0	0	0	Water Efficiency		12
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	7
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

0	0	0	Energy and Atmosphere		31
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	16
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

0	0	0	Materials and Resources		13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

0	0	0	Indoor Environmental Quality		16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
Y			Prereq	Minimum Acoustic Performance	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

0	0	0	Innovation		6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

0	0	0	Regional Priority		4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

0	0	0	TOTALS	Possible Points:	110

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED v4 for BD+C: Retail

Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1

Y	?	N		Location and Transportation	16
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

Y	?	N		Sustainable Sites	10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

Y	?	N		Water Efficiency	12
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	7
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

Y	?	N		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Y	?	N		Materials and Resources	13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

Y	?	N		Indoor Environmental Quality	15
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1

Y	?	N		Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

Y	?	N		Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

Y	?	N		Possible Points:	110
0	0	0	TOTALS		

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED v4 for BD+C: Data Centers

Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1

Y	?	N		Location and Transportation	16
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

Y	?	N		Sustainable Sites	10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

Y	?	N		Water Efficiency	11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

Y	?	N		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Y	?	N		Materials and Resources	13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Decla	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

Y	?	N		Indoor Environmental Quality	16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

Y	?	N		Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

Y	?	N		Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

Y	?	N	TOTALS	Possible Points:	110
0	0	0			

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED v4 for BD+C: Warehouses and Distribution Centers

Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1

Y	?	N		Location and Transportation	16
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

Y	?	N		Sustainable Sites	10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

Y	?	N		Water Efficiency	11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

Y	?	N		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Y	?	N		Materials and Resources	13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

Y	?	N		Indoor Environmental Quality	16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

Y	?	N		Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

Y	?	N		Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

Y	?	N	TOTALS	Possible Points:	110
0	0	0			

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED v4 for BD+C: Hospitality

Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1

Y	?	N		Location and Transportation	16
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

Y	?	N		Sustainable Sites	10
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1

Y	?	N		Water Efficiency	11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

Y	?	N		Energy and Atmosphere	33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

Y	?	N		Materials and Resources	13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2

Y	?	N		Indoor Environmental Quality	16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1

Y	?	N		Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

Y	?	N		Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

Y	?	N		TOTALS	Possible Points:	110
0	0	0				

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED v4 for BD+C: Healthcare

Project Checklist

Project Name:
Date:

Y	?	N			
Y			Prereq	Integrative Project Planning and Design	Required
			Credit	Integrative Process	1

0	0	0	Location and Transportation	9
			Credit	LEED for Neighborhood Development Location	9
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	1
			Credit	Access to Quality Transit	2
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1

0	0	0	Sustainable Sites	9
Y			Prereq	Construction Activity Pollution Prevention	Required
Y			Prereq	Environmental Site Assessment	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	1
			Credit	Open Space	1
			Credit	Rainwater Management	2
			Credit	Heat Island Reduction	1
			Credit	Light Pollution Reduction	1
			Credit	Places of Respite	1
			Credit	Direct Exterior Access	1

0	0	0	Water Efficiency	11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	1
			Credit	Indoor Water Use Reduction	7
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1

0	0	0	Energy and Atmosphere	35
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	20
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2

0	0	0	Materials and Resources	19
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
Y			Prereq	PBT Source Reduction- Mercury	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	PBT Source Reduction- Mercury	1
			Credit	PBT Source Reduction- Lead, Cadmium, and Copper	2
			Credit	Furniture and Medical Furnishings	2
			Credit	Design for Flexibility	1
			Credit	Construction and Demolition Waste Management	2

0	0	0	Indoor Environmental Quality	16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	1
			Credit	Daylight	2
			Credit	Quality Views	2
			Credit	Acoustic Performance	2

0	0	0	Innovation	6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

0	0	0	Regional Priority	4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

0	0	0	TOTALS	Possible Points:	110

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

436 14th St, Oakland, CA 92618
Phone: (916) 844-1033
Email: FFarahmand@trcsolutions.com

Statewide Nonresidential Reach Code Cost Effectiveness Analysis

July 2017

Submitted To:

Southern California Edison
Mr. Chris Kuch
1515 Walnut Grove
Rosemead, CA 91770

TABLE OF CONTENTS

TABLE OF FIGURES

TRC would like to acknowledge and thank the following entities for their support during this study: sixteen5hundred, EFCO Corporation, Viracon, and SSG MEP, Inc.

EXECUTIVE SUMMARY

Southern California Edison (SCE) engaged TRC to provide a cost effectiveness study to support nonresidential new construction reach code requirements above 2016 Title 24, Part 6, Building Energy Efficiency Standards (T24) in all California climate zones (CZs). The T24 Standards are the minimum energy efficiency requirements for building construction in California, and a reach code would require energy performance beyond the minimum in jurisdictions that adopt it.

Based on the results of TRC's analysis, the cities in all California CZs may move forward with a reach code requiring that nonresidential buildings improve energy performance by at least 10% better than the state minimum requirements, and 15% better in CZs 1, 3, 5, and 7.

TRC conducted cost data collection and energy simulations of four lighting and two envelope energy efficiency measures to show that nonresidential new construction can comply with a 10% reach code cost effectively:

- Reduced lighting power density
- Open office occupancy sensors
- Daylight dimming-plus-off
- Institutional tuning
- Reduced window solar heat gain coefficient
- Cool roofs

Note that the measures are not intended to serve as prescriptive measures, but one possible package achieving 10%. The 10% compliance margin improvement is measured in terms of Time Dependent Valuation (TDV). Measures were simulated in 2016 CBECC-Com compliance software to inform energy impacts using a medium office prototype. TRC quantified the incremental costs for the construction, maintenance, and replacement of the proposed measures relative to T24 through industry expert interviews and online research.

TRC's analysis consisted of two methods to estimate and quantify the value of the energy savings over the 15-year life of the measures:

- **TDV:** The California Energy Commission Life Cycle Cost (LCC) methodology using 2016 Time Dependent Valuation (TDV) of energy, and
- **On-Bill:** Customer cost effectiveness using utility rate schedules to value On-Bill energy impacts.

Each cost effectiveness methodology (TDV and On-Bill) determines cost effectiveness by comparing the incremental cost of a measure to the energy cost savings, in a combined Benefit to Cost (B/C) Ratio metric. The B/C Ratio is the incremental energy costs savings divided by the total incremental costs. When the B/C ratio is greater than 1.0, the added cost of the measure is offset by the discounted energy cost savings, and the measure is cost effective.

TRC's analysis shows that nonresidential buildings in all California CZs have a market-ready and cost effective set of measures to achieve at least 10% energy performance higher than the T24, through both the TDV and On-Bill cost effectiveness methodologies. Thus, all California jurisdictions have justification for adopting a 10% nonresidential reach code meeting the requirements of Section 10-106 of the California Code of Regulations Title 24, Part 1. Furthermore, TRC found 15% compliance margins cost effective in CZs 1, 3, 5 and 7, and recommends the a 15% nonresidential reach code in these climate zones (Figure 1). Final measure packages represent one possible way to achieve higher compliance margins, and are not intended to represent a mandatory or prescriptive set of measures.

Figure 1. Compliance Margin and Cost Effectiveness Summary Results

Climate Zone	Cost Effective Compliance Margin	B/C Ratio		Recommended Reach Code Compliance Margin
		TDV Methodology	On-Bill Methodology	
1	15.7%	3.0	5.3	15%
2	12.8%	1.4	2.3	10%
3	15.5%	1.2	2.0	15%
4	13.1%	1.4	2.3	10%
5	15.9%	1.2	2.0	15%
6	14.7%	1.4	1.5	10%
7	15.6%	1.4	2.3	15%
8	13.7%	1.4	1.5	10%
9	12.6%	1.4	1.5	10%
10	11.6%	1.5	2.5	10%
11	11.0%	1.6	2.5	10%
12	11.8%	1.4	2.2	10%
13	10.8%	1.6	2.5	10%
14	11.0%	1.6	1.8	10%
15	10.4%	1.9	2.1	10%
16	12.8%	1.5	2.3	10%

1. INTRODUCTION

Southern California Edison (SCE) engaged TRC to provide a cost effectiveness study to support nonresidential new construction reach code requirements above 2016 Title 24 Building Energy Efficiency Standards (T24), in all California climate zones (CZs). The T24 Standards are the minimum energy efficiency requirements for building construction in California, and a reach code would require energy performance beyond the minimum. The 2016 T24 Standards became effective on January 1, 2017.

Based on the results of TRC's analysis, the cities in all California CZs may move forward with a reach code requiring that nonresidential buildings improve energy performance by at least 10% better than the state minimum requirements, and 15% better in CZs 1, 3, 5, and 7.

1.1 Scope and Limitations

TRC attempted to show that nonresidential new construction can comply with a 10% reach code cost effectively by using CEC-approved compliance software and without triggering federal preemption.[1] The 10% compliance margin improvement is measured in terms of Time Dependent Valuation (TDV), described further in Section 2.1.1. TRC researched measures drawn from multiple sources in efforts to develop cost effective packages. Measures were simulated in compliance software to inform energy impacts, and costs were attained through expert interviews and online research. Final measure packages represent one possible way to achieve higher compliance margins, and are not intended to represent a mandatory or prescriptive set of measures.

This study has the following scope limitations:

- **Prototype.** The only building studied is a medium office prototype, further described in Section 2.2.3, because the California Energy Commission (CEC) nonresidential new construction forecast lists offices as being the most widely built building type for 2017 through 2019. Findings may not pertain to high-rise residential or other commercial spaces, such as restaurants and fitness centers, which have very different space conditioning loads and occupancy schedules. However, findings may be more pertinent to other nonresidential spaces, such as retail and school buildings, which have similar occupancy schedules, internal conditioning loads, and domestic water heating loads as office spaces. Using one representative prototype to estimate impacts on a broad range of building types aligns with analyses methods used in previous Title 24 Code and Standards Enhancement (CASE) studies and local reach code studies. Nonetheless, local jurisdictions can choose to analyze other prototypes during the Reach Code adoption process.
- **Federal Preemption.** The 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 risk litigation by manufacturer industry organizations. Thus, TRC did not use increased equipment efficiencies as reach code measures, although these measures are often the simplest and most affordable measures to increase energy performance. While this study is limited by federal pre-emption, developers can use any package of measures to achieve reach code goals, including the use of high efficiency appliances that are federally regulated.
- **Modeling Capability.** TRC used CEC-approved compliance software, CBECC-Com, to ensure that a free and readily available software could be used by permit applicants to show compliance with the reach code. CEC-approved compliance software does not have the capability to model the energy

[1] List of CEC-approved simulation software available at: http://www.energy.ca.gov/title24/2016standards/2016_computer_prog_list.html

performance of some measures typically associated with energy savings, such as radiant systems, variable refrigerant flow, or chilled beams. TRC limited the packages to include measures that could be modeled in CEC-approved compliance software.

- **Non-Regulated Loads.** Energy consuming end-uses that are not regulated by the CEC, such as receptacle and process loads (e.g., computers and elevators), have been explicitly excluded from the scope of this study. CEC-approved simulation software does not allow compliance credit for energy efficiency improvements in these end-uses.
- **Renewable Generation, including Solar PV.** TRC did not consider on-site or off-site renewable solar generation as a means of complying with the reach code. The reach code measures solely improve the efficiency of building systems. Furthermore, the CEC does not currently allow compliance credit for solar generation.

2. METHODOLOGY

TRC assessed the cost effectiveness of 2016 reach code packages by analyzing several energy efficiency measures applied to prototype buildings. TRC's analysis consisted of two methods to capture benefits and costs:

1. **TDV:** The CEC Life Cycle Cost (LCC) methodology using 2016 Time Dependent Valuation (TDV) of energy, and
2. **On-Bill:** Customer cost effectiveness using utility rate schedules to value On-Bill energy impacts.

Both methodologies require estimating and quantifying the value of the energy impact associated with energy efficiency measures over the life of the measures (15 years) as compared to the baseline T24 medium office prototype. The main difference between the methodologies is how they value energy and the associated cost savings of reduced energy consumption, described in Section 2.1.

Both methodologies also require quantifying the incremental costs for the construction, maintenance, and replacement of the proposed measure relative to the 2016 Title 24 Standards prescriptive requirements. Incremental costs for each measure are described in Section 3.

2.1 Cost Effectiveness Methodologies

With each of the cost effectiveness methodologies (TDV and On-Bill), TRC determined cost effectiveness by comparing the incremental costs of a measure to the energy cost savings, in a combined Benefit to Cost (B/C) Ratio metric. The B/C Ratio is the incremental energy costs savings divided by the total incremental costs. When the B/C ratio is greater than 1.0, the added cost of the measure is offset by the discounted energy cost savings, and the measure is cost effective.

2.1.1 Life Cycle Cost Methodology Using Time Dependent Valuation

The CEC LCC Methodology is approved and used by the CEC to establish cost effective statewide building energy standards.[2] The methodology uses 2016 TDV of energy savings as the primary metric for energy savings, which reflects not only the retail costs to the end-user, but also the value of reduced energy demand, such as reduced greenhouse gas emissions and reduced strain to the electric grid.[3] The TDV methodology assigns dollar values to electricity and natural gas delivered for each hour in the year. TDV accounts for retail rates, greenhouse gas emissions, and several other factors to value electricity generation. The TDV of gas generally hovers around one value in the spring and summer, and higher value in the fall and winter, without much fluctuation.

TDV values are based on long term discounted costs over 15 years. The period of analysis is associated with the associated measure life – lighting, air conditioning, or water heating measures may only be in place for 15 years. Envelope measures, such as windows and roofs are typically operational for 30 years, but TRC assumed a 15 year period of analysis for simplification.

The CEC developed the 2016 TDV values for all climate zones used in this study. TDV energy estimates are presented in terms of "TDV kBtus," which combine electricity and natural gas energy units.[4] Compliance

[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] E3 (July 2014) Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2016 Time Dependent Valuation (TDV) Data Sources and Inputs. California Energy Commission. Available at: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/

[4] kBtus = thousands of British Thermal Units.

software calculates TDV energy savings in terms of per-square-foot of the building. The present value of the energy savings is calculated by multiplying the TDV savings/ft^2 by the building conditioned floor area, and then by the Net Present Value (NPV) factor. The NPV factor is $0.089/TDV kBtu for all nonresidential measures with a 15-year useful life.

2.1.2 Customer Cost Effectiveness Using On-Bill Impacts

The customer cost effectiveness methodology captures the energy cost savings from energy efficiency measures resulting from lower energy bills. TRC determined the NPV of the On-Bill savings over a 15-year lifetime, including a 3% discount rate and a 3% energy cost inflation rate.

On-Bill savings were estimated by calculating monthly electricity (kWh) and natural gas (therms) savings resulting energy efficiency measures using current commercial utility (IOU) rate schedules as shown in Figure 2. The commercial IOUs represent a large majority of California residents, and were the primary supporters of this study. Please see *Appendix B – Utility Rate Schedules* for further detail.

Figure 2. Investor-Owned Utility (IOU) Rate Schedules

Climate Zones	Utility	Commodity	Schedule
1, 2, 3, 4, 5, 11, 12, 13, 16	Pacific Gas and Electric Company	Electric	A-10 (TOU)
		Gas	G-NR1
6, 8, 9, 14, 15	Southern California Edison	Electric	TOU-GS-2-A
	Southern California Gas Company	Gas	G-10
7, 10	San Diego Gas and Electric Company	Electric	AL-TOU
		Gas	GN-3

2.2 Measure Analysis

TRC used CBECC-Com 2016.2.1 (build 868) for simulating energy efficiency measures in the medium office prototype.[5] CBECC is a free public-domain software developed by the CEC for use in complying with the Title 24 Standards. Software algorithms are updated continuously, and new versions of the software are released periodically. CBECC-Com 2.1 uses EnergyPlus v8.5 as the simulation engine to perform the analysis.

2.2.1 Energy Savings

CEC approved compliance software simulations output TDV, kWh, and therms energy totals for a proposed building, and compare them to a prescriptive standard building. The 10% compliance margin goal is determined by comparing the proposed building TDV energy usage to the standard building TDV energy usage – the proposed building should use 10% less than the standard building's TDV energy usage. The TDV energy budget

[5] More information on CBECC-Com available at: http://bees.archenergy.com/software.html

and compliance margin is a standard output for building permit applicants completing a performance calculation. The TDV energy budget requirements are described in 2016 T24 Sections 100.2 and 140.1.

Because TDV combines electric and gas energy impacts, different energy efficiency measures can have different kWh and therms impacts while having the same TDV impact. The measure packages in Section 4 represent one possible way to achieve a higher compliance margin – these packages are not intended to represent a mandatory set of reach code measures. Other packages of measures can also achieve higher compliance margins, but will have different kWh and therms impacts.

TRC investigated potential energy efficiency measures to apply to the medium office prototype in each climate zone. TRC utilized previous reach code studies and program experience to investigate reach code measures that would have the greatest impact on reducing the largest energy consuming end uses (see Figure 6). TRC conducted market research to assess measure feasibility, costs, and potential energy impact.

2.2.2 Costs

TRC gathered costs for four regions within California to best represent localized costs (Figure 3). TRC reviewed previous studies for relevant cost data, such as Codes and Standards Enhancement (CASE) studies, if available. TRC conducted cost research by accessing online retailers and interviews with contractors and distributors serving each region. Costs include upfront costs, maintenance, and replacement if the end of useful life is prior to the end of the measure life for a product. For replacements, a three percent (3%) inflation rate was assumed. Detailed costs are provided in *Appendix A – Cost Data*.

The main cause of variation in costs among the regions is due to labor rates, based on RS Means research. There are also slight changes in material costs from region to region, based on local quotes received. Taxes and contractor markups were added as appropriate.

Figure 3. Climate Zones Grouped by Geographic Region

Region	Climate Zone
North Coastal	1-5
South Coastal	6-10
Central	11-13
Inland	14-16

Specifically, when gathering cost data on windows and lighting improvements, TRC found that stakeholders were supportive of the potential measures and in general agreement on TRC's assumptions for potential costs, but would not provide specific cost data themselves. Further detail is provided in Section 3.

2.2.3 Prototype

TRC used a 53,628 ft^2 medium office prototype to run simulations in all California CZs. This prototype is a DOE building model used for analysis of ASHRAE Standard 90.1, but is often used to justify nonresidential T24 standard enhancements and is summarized in the 2016 T24 Nonresidential Alternative Calculation Method

(ACM) Reference Manual.[6] TRC chose an office prototype because, according to the CEC new construction forecast, offices are projected to be the most widely built building type during the 2016 T24 code cycle (Figure 4). TRC chose the medium office (as opposed to a small or large office) to represent an average sized office, and a building type that is likely to get built in both small and large California cities.

Figure 4. CEC Nonresidential New Construction Forecast

Building Type	2017 – 2019 Forecasted Construction (% of total)
Small, Medium, and Large Office	22%
Retail	16%
Warehouse	14%
Restaurant/Food	7%
School	5%
Hotel	5%
College	4%
Hospital	4%
Miscellaneous	23%

TRC initialized the medium office prototype to be exactly compliant with the prescriptive minimum 2016 T24 requirements (0% compliance margin) in each climate zone, summarized in Figure 5. The prototype has a 33% window-to-wall ratio area (WWR) with the glazing area evenly distributed in the four geometry facings – north, east, south, and west – to ensure that results are applicable regardless of the orientation of a building. The TDV of energy savings for energy efficiency measures were derived by applying packages to the minimally code compliant prototype.

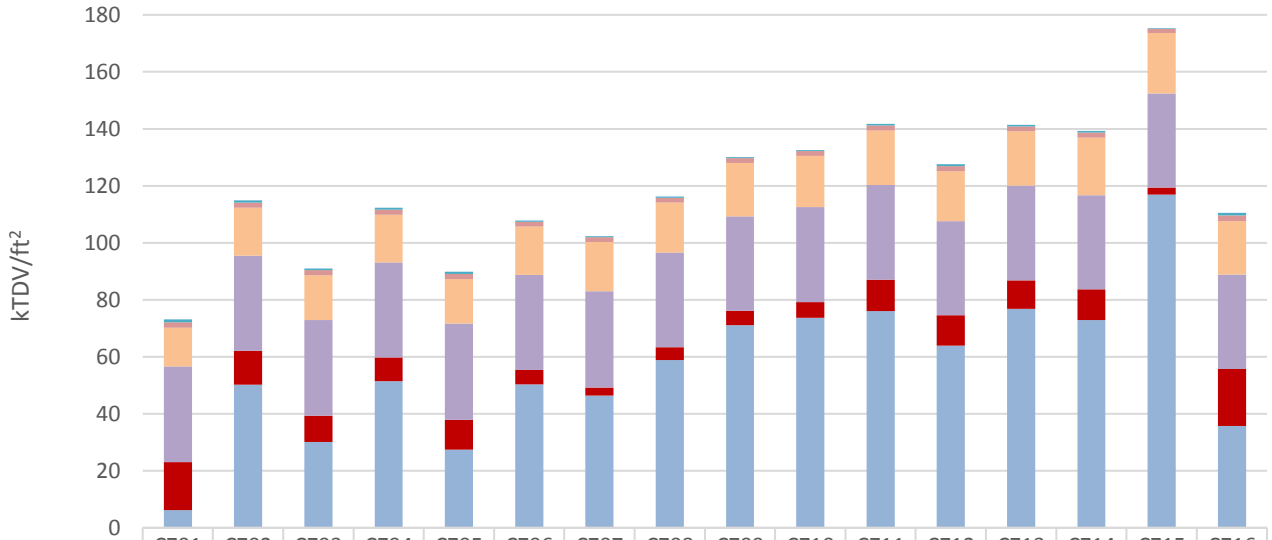
[6] Available at: http://www.energy.ca.gov/title24/2016standards/nonresidential_manual.html

Figure 5. Medium Office Prototype Summary

Building Type		Medium Office
Floor Area (ft2)		53,628
# of floors		3
Window-to-Wall Area Ratio		33%
HVAC Distribution System		3x Packaged Variable Air Volume with VAV Hot Water Reheat
Cooling System		Direct Expansion, 9.8 EER, Economizer
Heating System		Boiler, 80% Thermal Efficiency
Conditioned Thermal Zones		15
Domestic Water Heating		Natural Gas Small Storage, EF = 0.64
Roof Insulation (U-Value)		0.034 / 0.049 depending on CZ
Low-sloped Roof Solar Reflectance		0.63
Metal-framed Wall Insulation (U-Value)		0.062 / 0.069 / 0.082 depending on CZ
Window (fixed)	U-factor	0.36
	Solar Heat Gain Coefficient (SHGC)	0.25
	Visible Transmittance (VT)	0.42
Lighting Power Density (W/ft^2)		0.75

The minimally compliant energy consumption of the medium office prototype in each climate zone is summarized by end-use in Figure 6. Note that outdoor lighting, receptacle and process loads (such as computers or elevators) are not regulated end uses in T24, and thus cannot count be modeled as efficiency measures. Except for CZ 1, the largest energy consumers in the medium office prototype are space cooling and indoor lighting. The total energy values in Figure 6 represent only the regulated energy end uses.

Figure 6. Medium Office Prototype Compliance kTDV/ft² by End-use



	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Pumps & Misc	1	1	1	1	1	0	0	0	0	0	1	1	1	1	0	1
DHW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Indoor Fans	14	17	16	17	16	17	17	18	19	18	19	18	19	20	21	19
Indoor Lighting	34	33	33	33	34	33	34	33	33	33	33	33	33	33	33	33
Heating	17	12	9	8	10	5	3	4	5	5	11	11	10	11	2	20
Cooling	6	50	30	51	27	50	46	59	71	74	76	64	77	73	117	36

3. Measure Descriptions and Costs

This section provides a description, general modeling parameters, market overview, and summarized costs for energy efficiency measures. After initial investigation and analysis of several energy efficiency measures, TRC selected the measures described below and the subsequent packages described in Section 4 based on cost effectiveness and technical feasibility in the California nonresidential new construction market:

- Lighting measures
  - Reduced lighting power density (LPD)
  - Open office occupancy sensors
  - Daylighting dimming-plus-off
  - Institutional tuning
- Envelope measures
  - Cool roof
  - Reduced window solar heat gain coefficient (SHGC)

Detailed measure costs are available in *Appendix A – Cost Data*.

TRC investigated the possible inclusion of several heating, ventilation, and air-conditioning (HVAC) measures, but was unable to find a market-ready measure that would not trigger federal pre-emption (such as improving IEER or AFUE values) and was able to be modeled in CBECC-Com. Furthermore, HVAC systems are highly integrated – meaning it is difficult to isolate a singular component to improve in efficiency without effecting other parts of the system, and subsequently requiring a whole system redesign. All of these issues proved challenging to isolating costs and energy impacts, and thus cost effectiveness, within the scope of this study.

3.1 Lighting Measures

TRC proposed lighting measures are all Power Adjustment Factors (PAFs) in 2016 Title 24, except the Reduced LPD measure. For Title 24 compliance, PAFs allow a building to install wattages that are higher than prescriptively allowed, due to improvements in controls. For the analysis, TRC did not assume that the PAF was being used to install higher wattages elsewhere in the building, as this would negate any energy impact from the measures.

3.1.1 Reduce Lighting Power Density

This measure reduces the lighting power density (LPD) from the 2016 Title 24 prescriptive requirement of 0.75 W/ft^2 for open office areas to 0.65 W/ft^2. TRC's analysis assumes LED as the primary light source type to achieve this lower LPD. Lighting design varies depending on lighting goals, interior layout, and technology types. TRC reached out to several lighting manufacturer representatives, but because of the large variety of lighting designs possible, representatives were reticent to provide general cost data points. Where necessary, TRC calculated the lighting layouts using Visual Interior Tool v2.0.3.1, and products recommended by manufacturer representatives. In addition to cost data provided by manufacturer representatives, TRC used product costs available on retail websites such as 1000bulbs.com, lightingdirect.com, grainger.com, globalindustrial.com, cesco.com, and homedepot.com.

Lighting costs are dependent on a variety of factors, including lighting output, number of luminaires in the space, and product quality. TRC's Cost research shows that, depending on the lighting design goals and product quality, some T8 fluorescent luminaires may be more costly than LED luminaires. This is because fluorescent fixtures require dimming ballasts to comply with Title 24 multilevel lighting requirements, while most LED fixtures include a dimming driver automatically. In many cases, the cost may be equivalent or very similar once

the dimming ballast cost is considered. Lighting manufacturer representatives and online retail sources show cost equivalency for linear fluorescent troffers with dimming ballasts and LED troffers. Although several manufacturer representatives would not provide cost data, their general feedback is that LEDs are now considered the market standard design and that it is feasible to design a project with LEDs at a lower LPD than prescriptive requirements with no incremental cost.

TRC's found that it is technologically feasible to achieve 0.65 W/ft^2 design at no incremental cost. The products in Figure 7 represent basic quality luminaires that provide 50 footcandles of illuminance to the space (calculated with no internal furniture or cubicle walls). Although the cost analysis is based on LEDs, research identified that it is feasible to reach an LPD of 0.65 with some fluorescent luminaires at no additional cost. For example, Cooper Lighting 2AC 232 UNV EB81 U linear fluorescent troffer can achieve this LPD, depending on layout, and is less expensive than some fluorescent luminaires meeting the prescriptive LPD.

Figure 7. Reduced LPD Incremental Cost Summary

Base Case	Proposed Measure	Base Case Cost ($/ft^2)	Proposed Case ($/ft^2)	Incremental Cost ($/ft^2)	Total Incremental Cost ($/bldg)
Linear Fluorescent Troffer at 0.75 W/ft^2 + Dimming Ballast	LED Troffer at 0.65 W/ft^2	$2.33	$2.06	($0.27)	None

3.1.2 Open Office Occupancy Sensors

This measure draws from the findings of the 2013 Indoor Lighting Controls CASE Report.[7] This CASE report investigates the use of occupancy controls in open office spaces at various control group sizes and proposes one occupancy sensor for every four workstations (approximately 500 ft^2). The energy savings associated with occupancy sensors are based on the 0.20 PAF credit in Table 140.6-A of the 2016 T24 Standards. In other words, TRC assumes that installing open office occupancy sensors is equivalent to a 20% reduction in installed LPD in open office areas. TRC assumes that 53% of the building is open office, equating to a net reduction of 11% in LPD.

Occupancy controls have been commercially available for several decades, and the technology is readily available from a wide variety of manufacturers. Both passive infrared and ultrasonic occupancy sensors are widely accepted in office buildings, have been acknowledged to save energy successfully, and are frequently required by codes. The incremental costs for this measure include the costs of the sensors and installation labor, according to the CASE report. The cost for the sensor from online retailers and a manufacturer rep is $126.47 per sensor. The cost for installation and commissioning varies by region. Costs summarized in Figure 8 assume 59 sensors for the medium office and that recommissioning would occur in year 10 after initial commissioning. Costs can be reduced in areas where daylighting sensors will be installed if the selected controls include both passive infrared and daylighting sensing abilities.

[7] California Utilities Statewide Codes and Standards Team (October 2011) Nonresidential Indoor Lighting Controls Codes and Standards Enhancement Initiative. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Lighting_Controls_Bldg_Power/2013_CASE_NR_Indoor_Lighting_Controls_Oct_2011.pdf

Figure 8. Open Office Occupancy Sensors Incremental Costs Summary

CA Region	Base Case	Proposed Measure	PIR Sensor Cost ($/sensor)	Commissioning Cost ($/sensor)	Total Cost + Maintenance
North Coast	No occupancy sensors	Occupancy sensors in open office	$126.47	$75.35	$14,894
South Coast			$126.47	$55.81	$12,967
North Central			$126.47	$54.49	$12,837
Inland			$126.47	$51.86	$12,577

3.1.3 Daylight Dimming-Plus-Off

This measure revises the control settings for mandatory daylight sensors to be able to shut-off completely when adequate daylight levels are provided to the space. Current requirements are for sensors to dim lighting to 20% full power. TRC used a report by the Pacific Northwest National Laboratory for guidance on the feasibility of this measure.[8] To model this measure in CBECC-Com, TRC revised the daylight control type from Continuous (with a minimum dimming light and power fractions of 0.20), to Continuous Plus Off (which effectively reduces the dimming light and power fractions to 0).

There is no associated cost with this measure, as the 2013 T24 Standards already require multilevel lighting and daylight sensors in primary and secondary daylit spaces. This measure is simply a revised control strategy, and does not increase the number of sensors required or labor to install and program a sensor.

3.1.4 Institutional Tuning

Institutional tuning is currently a PAF in the 2016 T24 Standards. To show compliance with this measure, a designer should meet the requirements of 2016 Title 24 Section 140.6(d). This measure works in conjunction with dimmable ballasts, which were adopted as a requirement in the 2013 T24 Standards. Tuning addresses the frequent practice of designing light levels in a space to exceed that needed for the tasks of the space. Based on space factors and normal lighting design practices, a lighting designer typically overdesigns the light levels specified for a space to ensure adequate lighting is provided. The higher light levels are often a result of designing a space to meet the required light levels while satisfying the luminaire spacing or ceiling layout. The resulting design provides more light (e.g. 65 footcandles) than is necessary or recommended in the space (e.g. 50 footcandles).[9]

Institutional tuning sets the maximum light levels in a space at a lower level than the fully installed light levels, but still at an acceptable level for occupants. The maximum power use is thus lower and energy is continuously saved. Tuning requires that lighting designers commission the lighting system after installation and tune down the lighting to meet the design criteria. In the previous example, the lighting designer may tune down the

[8] Pacifica Northwest National Laboratory (August 2013) Analysis of Daylighting Requirements within ASHRAE 90.1. Available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22698.pdf

[9] A footcandle is the illuminance on a one square foot surface from a uniform source of light. It is a commonly used metric for lighting design.

lighting from 65 footcandles to 55. The designer wants to maintain initial light levels above the minimum requirement to account for depreciation in lamp efficacy over time.

TRC conservatively assumes a 10% reduction in LPD for an office (assuming this measure is in conjunction with the LPD reduction measure above), in line with the PAF factor of 0.10 in Table 140.6-A. Note in this table that institutional tuning has a lower PAF of 0.05 for daylit spaces. TRC did not use this lower PAF in daylit spaces because CBECC-Com already models the impact of daylighting, thus the interactive effects of tuning and daylighting controls do not need to be manually accounted for in the reduced LPD.

The additional cost for this measure is the labor required to tune the lighting in each space, as shown in Figure 9. This cost is dependent on the particular design of an office and the number of unique areas that a lighting designer must address. Based on a field study report by Seventhwave[10] the labor cost required to implement institutional tuning is $0.06 per square foot of space where tuning occurs. The study is representative of lighting installations in Minnesota. TRC used RSMeans Online to compare Minnesota labor rates with California labor rates for interior commercial LED installations. On average, considering several California city labor rates, the Minnesota labor rate and California labor rates are close in value; therefore, the cost estimate applies in California.

Figure 9. Institutional Tuning Incremental Costs Summary

Base Case	Proposed Measure	Commissioning Cost	Total Cost
0.75 W/ft^2 (no tuning)	0.68 W/ft^2 (with tuning)	$0.06/ft^2	$3,218

3.1.5 Modeling All Lighting Measures

Figure 10 summarizes the LPD impact from the lighting measures described above. The final LPD modeled in CBECC-Com is 0.52 W/ft^2. The impact of daylighting dimming-plus-off is not captured through a reduced LPD, but rather through a separate simulation control, and so is not included in Figure 10.

Figure 10. LPD Impact from All Lighting Measures

Base Case	+ LED Fixtures	+ Open Office Occupancy Sensors (11% LPD Reduction)	+ Institutional Tuning (10% LPD Reduction)
0.75 W/ft^2	0.65 W/ft^2	0.58 W/ft^2	0.52 W/ft^2

[10] Schuetter, S., Li, J., and M. Lord. 2015. Adjusting lighting levels in commercial buildings: energy savings from institutional tuning. August 2015.

3.2 Envelope Measures

3.2.1 Reduced Window Solar Heat Gain Coefficient

2016 Title 24 prescriptive requirements vary by fenestration type, including fixed windows, curtainwalls, and storefront windows. TRC used fixed windows for the analysis, which have prescriptive requirements for a maximum U-factor of 0.36, a maximum relative solar heat gain coefficient (RSHGC) of 0.25, and a minimum visual transmittance (VT) of 0.42. The U-factor depicts the rate of heat transfer of a product, and includes the entire window assembly (glass and frame). The RSHGC is reflective of the heat gain through a window from direct sun exposure, and can be impacted by coatings and tints. The VT is a metric that describes the appearance of a window and ability of light to enter in through the window. A higher VT allows for more light to enter the space and promotes daylighting. In currently available products, RSHGC and VT are linked because factors that may lower RSHGC – such as tinting – can also reduce VT. TRC considered several window values to balance the benefits from reducing RSHGC and increasing daylighting with higher VT. Additionally, higher VTs are more market acceptable for appearance and occupant comfort.

TRC analyzed windows ranging from RSHGC 0.20 to 0.23 with VTs greater than or equal to 0.42, which is the prescriptive minimum value. To be conservative, TRC modeled all windows with the prescriptive minimum VT of 0.42 even though windows were identified with higher VT (which will provide more daylighting energy savings benefits). Based on feedback from glass manufacturers and window fabricators about market acceptance of low RSHGC windows, which tend to be heavily tinted, TRC selected RSHGC 0.22, which has a wider range of product availability without significant tinting.

However, in Climate Zone 15, which has a substantial cooling load, TRC used an RSHGC of 0.20. TRC initially considered 0.20 RSHGC for all climate zones, but feedback indicated that the commercial market is generally unaccepting of most products that can achieve this lower RSHGC because of heavy tint that may give a blue or green appearance.

To gather costs associated with reduced RSHGC, TRC contact several window fabricators and glass manufacturers. Window components are often manufactured at separate facilities under independent organizations, and then a fabricator will design and combine the final product; therefore, the individuals TRC contacted often did not feel confident providing pricing if they only deal with one component, such as the glass. Additionally, contacts noted that the price of windows can fluctuate substantially by the size of the project and the windows, further adding to the hesitation to provide cost information. TRC overcame this barrier by identifying or asking about similar products from each manufacturer that only varied in solar heat gain coefficient (SHGC) value. SHGC is only a feature of the glass, so isolating this value eliminated variation in price from components that do not impact SHGC, such as framing, and allowed the analysis to use costs provided for only the glass.

The cost for reducing the SHGC of a fixed window from 0.25 to 0.22 and 0.20 is summarized in Figure 11. The prototype building has 7,027 ft^2 of fenestration. Based on discussions with window manufacturers and fabricators, cost increases are not directly correlated with SHGC reductions because of the variety of coating and tinting available. There is not a significant cost escalation for going to an SHGC of 0.20 versus 0.22 for the particular products that TRC researched.

Note that Title 24 also allows for modelers to reach an RSHGC of 0.20 by using permanent exterior shading through overhangs or fins, as well as interior automated blinds. For the purposes of the cost effectiveness analysis, TRC modeled and assumed costs for a window with SHGC of 0.20 in Climate Zone 15 instead of exterior shading elements, but notes that shading is an alternative option for builders who want low RSHGCs but want to avoid blue or green appearances on their windows.

Figure 11. Reduced Window RSHGC Incremental Cost Summary

Source	RSHGC	Incremental Cost ($/square foot of window)	Incremental Cost per Building ($)
Manufacturer 1	0.25 (baseline)	n/a	n/a
	0.22 (proposed)	$3.59	$25,227
	0.20 (proposed)	($3.88)	($27,265)
Manufacturer 2	0.25 (baseline)	n/a	n/a
	0.22 (proposed)	$5.00	$35,135
	0.20 (proposed)	$10.00	$70,270
Average 0.22 RSHGC		**$4.44**	**$31,172**
Average 0.20 RSHGC		**$4.45**	**$31,256**

3.2.2 Cool Roofs

The 2016 T24 Standards prescriptively require a Cool Roof Rating Council certified minimum 3-year aged solar reflectance (ASR) based on roof pitch, where steep slope is defined as a slope of > 2:12, and low slope is ≤ 2:12. Low slope cool roofs are typically constructed of field applied coatings, modified bitumen, or single ply thermoplastic roofing. Steep slope roofs are typically constructed of asphalt or tile shingles. Low-sloped roofs are much more common for offices and other commercial buildings, and the medium office prototype has a low-sloped roof. This measure proposes an aged solar reflectance ASR = 0.70 for low slopes, compared to ASR = 0.63 prescriptive requirements. TRC maintained the modeling default of Thermal Efficiency (TE) = 0.85 because most products can achieve this value.

TRC conducted interviews regarding low slope roof products with roofers and roof supply distributors throughout California, and supplemented the interviews with costs available through online retailers. Multiple roofers and product distributors made the statement that there is little or no additional labor to install cool roof products, and in some instances, there is even material cost savings associated with choosing a low sloped cool roof. The cost of cool roof products meeting the Reach Code ASR can be cheaper than their darker, non-cool roof counterparts, depending on the product type. Additionally, according to Cool Roof Rating Council[11] certified product directory, there are about three times as many cool roof products available at the proposed ASR = 0.70 value than at the current required ASR = 0.63.

Costs for cool roof materials varied by climate zone region and tend to be highest in the North and South Coast regions where cool roofs may not be as prominent. Lowest costs tend to be in the North Central and Inland regions with significant cooling loads. To be conservative, TRC estimated an incremental cost in all climate zones by climate region for products that meet the proposed nonresidential low sloped cool roof requirements (ASR = 0.63 to ASR = 0.70), summarized in Figure 12. This incremental cost represents product types that may have

[11] Available at: http://coolroofs.org/products/results

higher costs to meet the proposed values, and varies by region. To estimate this cost, TRC averaged the incremental costs for all cool roof types to meet the proposed ASR value. The incremental cost for a cool roof ASR = 0.70 ranges from $0.05 to $0.20 per square foot of roof, depending on the California region. Individual product types range from $(0.10) to $(0.51) per square foot of roof depending on climate region and product type; membranes (e.g. cool caps) are the most expensive cool roof option. Based on product specification sheets, TRC assumed that a cool roof would need maintenance or an entirely new roof after 10 years. The cost for a new roof after 10 years with a 3% inflation rate is included in the total cost estimate in Figure 12.

Figure 12. Cool Roof Incremental Cost Summary

CA Region	Base Case	Proposed Case	Incremental Cost[12] ($/square foot of roof)	Incremental Cost ($/building)
North Coast	ASR = 0.63 TPO/PVC, Membrane, or Field Applied Coating	ASR = 0.70 TPO/PVC, Membrane, or Field Applied Coating	$0.15	$6,106
South Coast			$0.20	$8,279
North Central			$0.11	$4,762
Inland			$0.05	$2,040

An important consideration in cool roof design is the potential for condensation and ice to build up under the roof membrane in cold climates. In traditional roof construction (non-cool roofs), the roof heats up in between periods of precipitation, allowing any wet areas on the roof or under points of roof failures to dry out. Cool roofs may prevent roofs from getting hot enough to completely dry out in between periods of precipitation, and moisture continues to accumulate. The cool roof is not the sole cause of moisture issues; there must be a failure that allows water to enter from the exterior or significant interior humidity levels, both which allow moisture to enter the assembly. Important practices to ensure that cool roofs do not exacerbate moisture-related roof failures are to:

- Ensure proper roof construction and drainage[13]
- Maintain appropriate interior relative humidity[14]
- Add insulation above the roof deck[14] (as per Joint Appendix JA4)

TRC assumed that these practices are part of standard design practice for new construction in a high precipitation climate, and did not assume any additional costs to prevent condensation solely resulting from the construction of a cool roof. The majority of cited condensation and moisture issues with cool roofs are for re-roofs where an existing failure had been maintained by periods of drying, and this wet/dry balance being upset by the addition of a cool roof.

[12] Incremental cost assumes that reroof will occur in year 10 after construction.

[13] Department of Energy. Available at: https://energy.gov/energysaver/cool-roofs

[14] Dregger, P. 2012. "Cool" Roofs Cause Condensation – Fact or Fiction? *Western Roofing*, January/February 2012, 48-62 or March 2013, 19-26. Available at: http://www.epdmroofs.org/attachments/2012-jan_coolroofscausecondensation_dregger_wr01123.pdf

4. Cost Effectiveness Results and Recommendations

The results for the medium office energy efficiency packages are presented in this section for each climate zone. TRC determined cost effectiveness by comparing the incremental cost of each package to the NPV of energy cost savings over the 15-year period. Incremental costs represent the construction, maintenance, and replacement costs of the proposed measure relative to the 2016 Title 24 Standards prescriptive requirements.

Results include measure compliance margin, present value of energy savings, costs, and benefit to cost (B/C) ratio. The B/C ratio is the incremental energy costs savings divided by the total incremental costs. When the B/C ratio is greater than 1.0, the added cost of the measure is offset by the discounted energy cost savings and the measure is cost effective. See Section 2.1 for further detail.

Nonresidential buildings in all California CZs have a market-ready and cost effective set of measures to achieve at least 10% higher than the Title 24 Standards, both through the TDV and On-Bill cost effectiveness methodologies. Thus, all California jurisdictions have proper justification for adopting a 10% nonresidential reach code meeting the requirements of Section 10-106 of the California Code of Regulations Title 24, Part 1. Furthermore, TRC found 15% compliance margins cost effective in CZs 1, 3, 5 and 7.

Note that the only prototype that required use of an RSHGC-0.20 window to achieve the 10% compliance margin cost effectively was in Climate Zone 15 – all other climate zones could achieve a 10% compliance margin using a 0.22 RSHGC window.

4.1 Life Cycle Cost Methodology Using TDV

The CEC LCC Methodology uses a Time Dependent Valuation (TDV) of energy savings, intended to capture the concept that energy efficiency measure savings should be valued differently depending on which hours of the year the savings occur to the utility system, to better reflect the actual costs of energy to consumers. The net present value is calculated using a 15-year lifetime.

As shown in Figure 14, all climate zones achieve a 10% or greater compliance margin cost effectively, indicated by the B/C ratio being equal to or greater 1.0. Climate zones 1, 3, 5, and 7 can achieve a 15% compliance margin cost effectively.

Figure 13. TDV Cost Effectiveness Results

CZ	Cool Roof ASR	Reduced RSHGC	Reduced LPD	Institutional Tuning	Lighting Controls (Daylight Dimming Plus Off, Open Office Occupancy Sensors)	Compliance %	NPV of Savings (kTDV)	Incremental Cost	B/C Ratio
1	n/a	n/a	0.65	x	x	15.7%	$55,509	$18,112	3.0
2	0.70	0.22	0.65	x	x	12.8%	$70,400	$48,902	1.4
3	0.70	0.22	0.65	x	x	15.5%	$67,202	$55,390	1.2
4	n/a	0.22	0.65	x	x	13.1%	$70,448	$49,284	1.4
5	0.70	0.22	0.65	x	x	15.9%	$68,300	$55,390	1.2
6	0.70	0.22	0.65	x	x	14.7%	$75,603	$55,636	1.4
7	0.70	0.22	0.65	x	x	15.6%	$76,319	$55,636	1.4
8	0.70	0.22	0.65	x	x	13.7%	$75,984	$55,636	1.4
9	0.70	0.22	0.65	x	x	12.6%	$78,466	$55,636	1.4
10	0.70	0.22	0.65	x	x	11.6%	$73,646	$48,676	1.5
11	0.70	0.22	0.65	x	x	11.0%	$74,075	$47,098	1.6
12	0.70	0.22	0.65	x	x	11.8%	$71,546	$51,988	1.4
13	0.70	0.22	0.65	x	x	10.8%	$73,216	$47,098	1.6
14	0.70	0.22	0.65	x	x	11.0%	$73,264	$45,781	1.6
15	0.70	0.20	0.65	x	x	10.4%	$87,058	$45,865	1.9
16	0.70	0.22	0.65	x	x	12.8%	$67,298	$45,781	1.5

4.2 Customer Cost Effectiveness Using On-Bill Impacts

The customer cost effectiveness methodology uses utility rate schedules to estimate the retail On-Bill cost savings of energy efficiency to the customer. The net present value is calculated using a 15-year lifetime, including a 3% rate of energy inflation and a 3% discount rate. TRC used Time of Use (TOU) rate schedules, which results in more value applied to energy savings that occur during peak periods.

Using customer cost effectiveness results, B/C ratios improve over the TDV cost effectiveness results. As shown in Figure 14, all climate zones achieve a 10% or greater compliance margin cost effectively, and CZs 1, 3, 5, and 7 can achieve a 15% compliance margin cost effectively.

Figure 14. On-Bill Cost Effectiveness Results

CZ	Cool Roof ASR	Reduced RSHGC	Reduced LPD	Institutional Tuning	Lighting Controls (Daylight Dimming Plus Off, Open Office Occupancy Sensors)	Compliance %	Annual kWh Savings	Annual Therm Savings	On-Bill Savings	Incremental Cost	B/C Ratio
1	n/a	n/a	0.65	x	x	15.7%	26,084	(366)	$95,361	$18,112	5.3
2	0.70	0.22	0.65	x	x	12.8%	31,026	(433)	$114,859	$41,164	2.8
3	0.70	0.22	0.65	x	x	15.5%	29,508	(405)	$109,322	$45,243	2.4
4	n/a	0.22	0.65	x	x	13.1%	31,028	(322)	$114,311	$43,339	2.6
5	0.70	0.22	0.65	x	x	15.9%	30,179	(414)	$111,303	$45,243	2.5
6	0.70	0.22	0.65	x	x	14.7%	32,792	(185)	$82,359	$55,636	1.5
7	0.70	0.22	0.65	x	x	15.6%	32,678	(222)	$129,100	$44,389	2.9
8	0.70	0.22	0.65	x	x	13.7%	33,398	(240)	$83,662	$44,389	1.9
9	0.70	0.22	0.65	x	x	12.6%	33,510	(242)	$85,235	$44,389	1.9
10	0.70	0.22	0.65	x	x	11.6%	32,649	(244)	$121,226	$40,469	3.0
11	0.70	0.22	0.65	x	x	11.0%	32,640	(351)	$118,022	$40,373	2.9
12	0.70	0.22	0.65	x	x	11.8%	31,968	(371)	$116,533	$44,214	2.6
13	0.70	0.22	0.65	x	x	10.8%	32,744	(325)	$119,413	$40,373	3.0
14	0.70	0.22	0.65	x	x	11.0%	33,216	(353)	$80,520	$39,290	2.0
15	0.70	0.20	0.65	x	x	10.4%	38,959	(181)	$96,324	$45,320	2.1
16	0.70	0.22	0.65	x	x	12.8%	30,153	(603)	$106,614	$39,290	2.7

4.3 Greenhouse Gas Savings

New construction commercial buildings complying with the reach code will reduce energy consumption and thereby reduce greenhouse gas (GHG) emissions. TRC multiplied saved energy by a factor of 0.65 lbs of CO_2 equivalent (CO_2e) per kWh, and 11.7 lbs of CO_2e per therm, as per Environmental Protection Agency research, to attain estimates of GHG savings.[15] Jurisdictions adopting a reach code can use Figure 15 below to approximate the typical reductions of GHG emissions in a typical nonresidential building, expressed in pounds of carbon dioxide equivalent (lbs CO_2e)

Figure 15. Estimated GHG Savings per Building

Climate Zone	kWh Savings / Bldg	Therms Savings / Bldg	Lbs CO2e Avoided/Prototype	Lbs CO2e Avoided/ft^2	% GHG Savings per Bldg
1	26,084	(366)	12,686	0.24	4%
2	31,026	(433)	15,111	0.28	4%
3	29,508	(405)	14,454	0.27	5%
4	31,028	(322)	16,413	0.31	5%
5	30,179	(414)	14,789	0.28	5%
6	29,806	(219)	16,819	0.31	5%
7	32,678	(222)	18,655	0.35	6%
8	33,398	(240)	18,912	0.35	6%
9	33,510	(242)	18,962	0.35	6%
10	32,649	(244)	18,378	0.34	5%
11	32,640	(351)	17,120	0.32	5%
12	31,968	(371)	16,455	0.31	5%
13	32,744	(325)	17,494	0.33	5%
14	33,216	(353)	17,472	0.33	5%
15	38,959	(181)	23,216	0.43	6%
16	30,153	(603)	12,556	0.23	3%

These GHG reduction estimates are based on complying with the 10% packages using the measures analyzed in this study. Compliance with the 10% Reach Code may be achieved through a variety of measures, each of which will have varying electric and natural gas usages, and therefore varying GHG savings. Note also that these are percentage savings of the total greenhouse gas emissions from the buildings, including unregulated loads, which currently are not regulated within the constraints of Title 24, Part 6.

Each jurisdiction can estimate annual city-wide GHG savings by multiplying the CO_2e savings per square foot by the new construction commercial square footage constructed within city limits during an average year.

4.4 Reach Code Recommendations

TRC recommends that California jurisdictions adopt reach codes meeting the compliance margin requirements in Figure 16. Recommended reach code values are more lenient than the levels found to be cost effective –

[15] United States Environmental Protection Agency. 2015. "Emission Factors for Greenhouse Gas Inventories." Available at: https://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf.

compliance margins are rounded down. Final measure packages represent one possible way to achieve higher compliance margins, and are not intended to represent a mandatory or prescriptive set of measures.

Figure 16. Compliance Margin and Cost Effectiveness Summary Results

Climate Zone	Cost Effective Compliance Margin	B/C Ratio		Recommended Reach Code Compliance Margin
		TDV Methodology	On-Bill Methodology	
1	15.7%	3.0	5.3	15%
2	12.8%	1.4	2.3	10%
3	15.5%	1.2	2.0	15%
4	13.1%	1.4	2.3	10%
5	15.9%	1.2	2.0	15%
6	14.7%	1.4	1.5	10%
7	15.6%	1.4	2.3	15%
8	13.7%	1.4	1.5	10%
9	12.6%	1.4	1.5	10%
10	11.6%	1.5	2.5	10%
11	11.0%	1.6	2.5	10%
12	11.8%	1.4	2.2	10%
13	10.8%	1.6	2.5	10%
14	11.0%	1.6	1.8	10%
15	10.4%	1.9	2.1	10%
16	12.8%	1.5	2.3	10%

5. APPENDIX A – COST DATA

Figure 17. Reduced LPD Detailed Costs

Product	Lamp Technology	LPD[1]	Product Cost ($/luminaire)	Dimming Ballast Cost ($/ballast)	Total Cost per square foot[2] ($/ft²)
Lithonia 2RT8S 232 MVOLT GEB10IS + dimming ballast	Fluorescent	0.73	$138.74	$52.00	$2.29
2VT8 232 ADP GEB10IS + dimming ballast	Fluorescent	0.73	$145.60	$52.00	$2.37
Lithonia 2BLT4 40L ADSM EZ1 LP840	LED	0.60	$138.39	n/a	$2.06
Cooper Lighting 2AC 232 UNV EB81 U	Fluorescent	0.63	$123.50	$52.00	$1.83

[1] Normalized to provide 50 footcandles of illuminance
[2] Square footage covered to provide 50 footcandles of illuminance

Figure 18. Occupancy Sensor Detailed Costs

Product	Coverage (ft²)	Installation	Viewing Angle	Proposed Cost ($/unit)
Acuity Sensor Switch Occupancy Sensor	452	Ceiling	360 Degrees	$133.15
Acuity Sensor Switch Occupancy Sensor	500	Ceiling	360 Degrees	$115.20
Acuity Lithonia Occupancy Sensor	452	Ceiling	360 Degrees	$158.25
Acuity Lithonia Occupancy Sensor	452	Ceiling	360 Degrees	$146.40
Hubbel Wiring Device-Kellems Occupancy Sensors	450	Ceiling	360 Degrees	$150.75
Hubbel Wiring Device-Kellems Occupancy Sensors	450	Ceiling	360 Degrees	$110.95
Hubbel Wiring Device-Kellems Occupancy Sensors	450	Ceiling	360 Degrees	$159.25
Hubbel Wiring Device-Kellems Occupancy Sensors	450	Ceiling	360 Degrees	$154.25
Leviton Self-Contained	530	Ceiling	360 Degrees	$64.45
Leviton Occupancy Sensor	450	Ceiling	360 Degrees	$100.90
Leviton Occupancy Sensor	530	Ceiling	360 Degrees	$128.50
Leviton Occupancy Sensor	600	Ceiling	284 Degrees	$54.40

Leviton Ceiling Mount Dual tech	500	Ceiling	360 Degrees	$85.86
Sensor Switch CM9 D	500	Ceiling	360 Degrees	$107.90
Watt Stopper Occupancy Sensor	500	Ceiling	360 Degrees	$127.45
Watt Stopper Occupancy Sensor	500	Ceiling	360 Degrees	$123.50
Watt Stopper Occupancy Sensor	500	Ceiling	360 Degrees	$156.75

Figure 19. Reduced Window SHGC Detailed Costs

Source	Product	SHGC	VT	Incremental Cost from SHGC 0.25 ($/ft^2)
Manufacturer 1	VNE1-63 with silkscreen	0.25	53%	n/a
	VUE24-50	0.25	52%	n/a
	VNE1-53	0.23	49%	($4.61) to ($4.21)
	VNE8-63	0.22	44%	$3.39 to $3.79
	VNE6-53	0.20	42%	($4.08) to ($3.68)
Manufacturer 2	EFCO 325X F with SolarBan70XL	0.25	>42%	n/a
	EFCO PX32 F	0.23	>42%	$0 - $10
	EFCO 325X F with SunGuard SNX 51/23	0.20	>42%	$5 - $15

Figure 20. Low-Slope Cool Roof Detailed Costs

Product Type	ASR	Average Cost ($/ft²)			
		North Coast	South Coast	North Central	Inland
TPO	0.63	$0.75	$0.94	$0.75	$0.75
	0.70	$0.85	$0.85	$0.85	$0.85
Incremental Cost		$0.09	-$0.10	$0.09	$0.09
Membrane	0.63	$0.63	$1.13	$1.07	$1.07
	0.70	$1.07	$1.64	$1.19	$1.19
Incremental Cost		$0.44	$0.51	$0.12	$0.12
Field Applied Coating	0.63	$0.55	$0.60	$0.48	$0.57
	0.70	$0.46	$0.79	$0.61	$0.50
Incremental Cost		-$0.09	$0.19	$0.13	-$0.07
Average Incremental Cost		**$0.15**	**$0.20**	**$0.11**	**$0.05**

6. APPENDIX B – UTILITY RATE SCHEDULES

Below are hyperlinks to the rates used for each utility. Detailed rate schedules are provided in subsequent sections.

- Southern California Edison
  - Electric: Schedule TOU-GS-2-A. Available at: https://www.sce.com/NR/sc3/tm2/pdf/ce329.pdf
- Southern California Gas
  - Electric: Schedule No. G-10. Available at: https://www.socalgas.com/regulatory/tariffs/tm2/pdf/G-10.pdf
- Pacific Gas and Electric
  - Electric: Schedule A-10, Table B (TOU). Available at: https://www.pge.com/tariffs/tm2/pdf/ELEC_SCHEDS_A-10.pdf
  - Gas: Schedule G-NR1. Available at: https://www.pge.com/tariffs/tm2/pdf/GAS_SCHEDS_G-NR1.pdf
- San Diego Gas and Electric
  - Electric: Schedule AL-TOU. Available at: http://regarchive.sdge.com/tm2/pdf/ELEC_ELEC-SCHEDS_AL-TOU.pdf
  - Gas: Schedule GN-3. Available at: http://regarchive.sdge.com/tm2/pdf/GAS_GAS-SCHEDS_GN-3.pdf

6.1 Electric Rates

Figure 21. Southern California Edison Commercial Electric Rates (TOU-GS-2-A)

Southern California Edison (SCE) Commercial Electric Rates	
Rate TOU-GS-2-A	Effective 1/1/2017
Winter ($/kWh) (Oct 1 through May 31)	
Mid-Peak (8AM - 9PM weekdays except holidays)	$0.07589
Off-Peak	$0.06573
Summer ($/kWh) (Jun 1 through Sept 31)	
On-Peak (12-6PM weekdays except holidays)	$0.34167
Mid-Peak (8AM - 12PM and 6PM - 11PM weekdays, except holidays)	$0.11601
Off-Peak	$0.05918
Additional Charges	
Facilities Related Demand Charge ($/kW/meter/month)	$15.48
Customer Charge ($/meter/month)	$220.30
Single Phase Service ($/month)	($11.71)
Voltage Discount, Demand ($/kW)	
2kV to 50kV	($0.20)
50kV to <220kV	($6.79)
220kV	($11.27)
Voltage Discount, Energy ($/kWh)	
2kV to 50kV	($0.00165)

50kV to <220kV	($0.00391)
220kV	($0.00395)
CA Alternate Rates for Energy Discount (%)	100%
TOU Option ($/meter/month RTEM)	$71.01
CA Climate Credit ($/kWh)	($0.00416)

Figure 22. Pacific Gas and Electric Commercial Electric Rate (Schedule A-10, Table B)

Pacific Gas and Electric (PG&E) Commercial Electric Rates	
Rate Schedule A-10, Table B	Effective 3/1/2017
Winter ($/kWh) (Nov 1 through Apr 30)	
Mid-Peak (8:30AM-9:30PM, weekdays except holidays)	$0.13641
Off-Peak	$0.11935
Summer ($/kWh) (May 1 through Oct 31)	
On-Peak (12-6PM, weekdays except holidays)	$0.21972
Mid-Peak (8:30AM-12PM and 6-9:30PM, weekdays except holidays)	$0.16459
Off-Peak	$0.13652
Demand Charge ($/kW/meter/month)	
Summer	$16.78
Winter	$9.45
Additional Charges	
Customer Charge ($/meter/day)	$4.59959
CA Climate Credit ($/kWh)	($0.0038)

Figure 23. San Diego Gas and Electric Commercial Electric Rate (AL-TOU)

San Diego Gas and Electric (SDG&E) Commercial Electric Rates	
Rate AL-TOU	Effective 3/1/2017
Winter ($/kWh) (Nov 1 through Apr 30)	
On-Peak (5-8PM, weekdays except holidays)	$0.11085
Mid-Peak (6AM-5PM and 8-10PM, weekdays except holidays)	$0.09574
Off-Peak	$0.07492
Summer ($/kWh) (May 1 through Oct 31)	
On-Peak (11AM-6PM, weekdays except holidays)	$0.12252
Mid-Peak (6-11AM and 6-10PM, weekdays except holidays)	$0.11305
Off-Peak	$0.08294
Demand Charge ($/kW/meter/month)	
Non-Coincident	$24.51
Summer - On-Peak	$20.84
Winter - On-Peak	$7.57
Additional Charges	
Basic Service Fee ($/meter/month)	$116.44

6.2 Gas Rates

Figure 24. Southern California Gas Commercial Natural Gas Rate (G-10)

Southern California Gas (SCG) Commercial Gas Rates	
Rate G-10	Effective 3/10/2107
Base Charges ($/therm)	
TIER 1 (up to 250 therms)	$0.89387
TIER 2 (251 to 4,167 therms)	$0.65334
TIER 3 (>4,167 therms)	$0.49206
Additional Charges	
Customer charge ($/meter/day)	$0.49315

Figure 25. Pacific Gas and Electric Commercial Natural Gas Rates (G-NR1)

Pacific Gas and Electric (PG&E) Commercial Gas Rates	
Rate G-NR1	Effective 3/1/2017
Winter ($/therm) May 1 - Nov 30	
TIER 1 (up to 4,000 therms)	$1.13678
TIER 2 (>4,000 therms)	$0.83428
Summer ($/therm) Dec 1 - Apr 30	
TIER 1 (up to 4,000 therms)	$1.02592
TIER 2 (>4,000 therms)	$0.77060
Additional Charges	
Customer charge ($/meter/day) 0 - 5.0 ADU[1]	$0.27048
Customer charge ($/meter/day) 5.1 - 16.0 ADU[1]	$0.52106
Customer charge ($/meter/day) 16.1 - 41.0 ADU[1]	$0.95482

[1]ADU is Average Daily Usage. It is the usage for the entire billing period divided by the number of days within the billing period.

Figure 26. San Diego Gas and Electric Commercial Natural Gas Rates (GN-3)

San Diego Gas and Electric (SDG&E) Commercial Gas Rates	
Rate GN-3	Effective 3/10/2017
Base Charges ($/therm)	
TIER 1 (up to 1,000 therms)	$0.80449
TIER 2 (1,001 to 21,000 therms)	$0.68176
TIER 3 (>21,000 therms)	$0.64710
Additional Charges	
Customer charge ($/meter/month)	$10.000

CALIFORNIA ENERGY CODES & STANDARDS

A STATEWIDE UTILITY PROGRAM

2016 Title 24, Part 6
Local Energy Efficiency Ordinances

Cost Effectiveness Study:
Statewide Nonresidential PV Cost Effectiveness Analysis
(New Construction and Retrofits)

Prepared for:
Christopher Kuch
Codes and Standards Program
Southern California Edison

Prepared by:
TRC

December 22, 2018

SDGE A Sempra Energy utility®

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Table of Contents

List of Figures

1 Introduction

The California Building Energy Efficiency Standards Title 24, Part 6 (Title 24) (CEC, 2016b) is maintained and updated every three years by two state agencies, the California Energy Commission (CEC) and the Building Standards Commission (BSC). In addition to enforcing the code, local jurisdictions have the authority to adopt local energy efficiency ordinances, or reach codes, that exceed the minimum standards defined by Title 24 (as established by Public Resources Code Section 25402.1(h)2 and Section 10-106 of the Building Energy Efficiency Standards). Local jurisdictions must demonstrate that the requirements of the proposed ordinance are cost-effective and do not result in buildings consuming more energy than is permitted by Title 24. In addition, the jurisdiction must obtain approval from the CEC and file the ordinance with the BSC for the ordinance to be legally enforceable.

The goal of this study is to evaluate on-bill cost effectiveness of installing photovoltaic (PV) panels on nonresidential buildings for all sixteen climate zones in California. This investigation is in response to jurisdictions' interest in incorporating PV in the nonresidential Title 24 code:

1) Applicability
   a) All nonresidential new construction
   b) All high-rise multifamily residential new construction
   c) All nonresidential redevelopment at least 10,000 ft^2
2) Requirements
   a) Expand solar zone requirement for new nonresidential to include buildings with four to ten habitable stories
   b) Require PV systems with a capacity of either
      i) 80% of the building's modelled annual electric load
      ii) 15 DC watts per square foot of solar zone[1]

At the time of this memo, utility rate modeling and related energy cost calculations are finalized for PG&E and SCE territories. The utility rate modeling for SDG&E territory is being reviewed by the utility for all prototypes. **The analysis for SDG&E territory, including climate zones 7, 10 and 14, is excluded from this memo until full clarification is received from the utility.**

2 Methodology and Assumptions

2.1 Building Prototypes

TRC selected nonresidential new construction building types intended to represent boundary conditions for utility bill cost effectiveness analysis when accounting under net energy metering 2.0 (NEM 2.0). In other words, a large building and small building are likely to have different utility rate structures because they will have high and low energy usage, respectively. Thus they represent the boundaries that other building types would fall in between. If

[1] 2016 Title 24, Part 6, Section 110.10(b)1B: For high-rise multifamily (ten habitable stories or fewer) and nonresidential (three habitable stories or fewer), The solar zone shall be located on the roof or overhang of the building or on the roof or overhang of another structure located within 250 feet of the building or on covered parking installed with the building project and have a total area no less than 15 percent of the total roof area of the building excluding any skylight area.

both buildings are proven to be cost effective, then all buildings in between can be assumed to be cost effective. For the large building, TRC used High-Rise Multifamily prototype to represent multistory mixed-use new construction.

TRC modeled a retail strip mall of 9,375 ft^2 for the nonresidential redevelopment scenario to support cost effectiveness for alterations greater than 10,000 ft^2. TRC chose the retail strip mall prototype because it was the DOE prototype with a floor area closest to 10,000 ft^2. TRC assumed that the >10,000 ft^2 threshold in the proposed ordinance was chosen to ensure that 'large-enough' alterations projects would be subject to the ordinance – projects that have a high nominal cost. Because savings potential increases with building size, TRC assumed that demonstrating cost-effectiveness for an approximately 10,000 ft^2 prototype shows that the PV installations are economical for projects >10,000 ft^2.

TRC developed a total of 64 prototypes -- four building types in 16 climate zones. The four building types, based on the prototype selection include the following, described in more detail in Figure 1:

- New construction, large nonresidential building – three-story Medium Office - 53,628 ft^2
- New construction, small nonresidential building – single-story Small Office - 5,502 ft^2
- New construction high-rise residential building – twelve-story High-Rise Multifamily - 94,088 ft^2
- Existing (pre-1978 code), nonresidential – single-story Retail Strip Mall - 9,375 ft^2

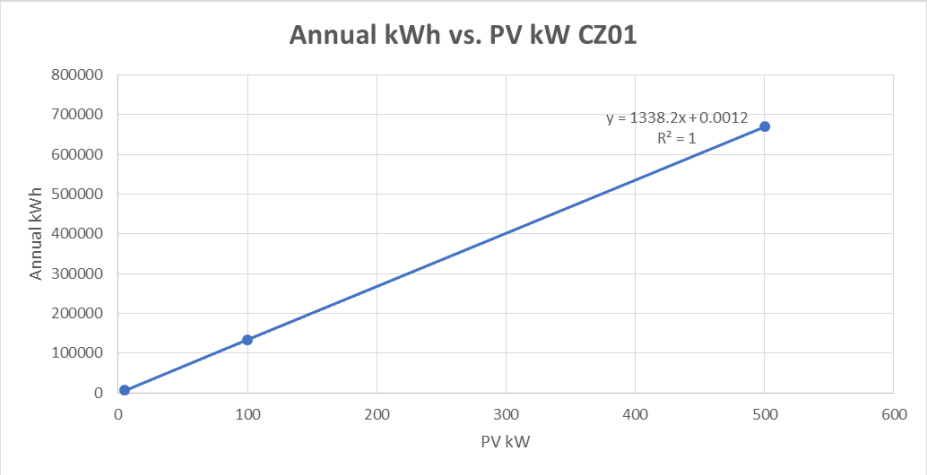
Figure 1. Prototype Characteristics Summary

Building Type	Medium Office	Small Office	High-Rise Multifamily	Retail Strip Mall
Area (ft^2)	53,628	5,502	94,088	9,375
Roof Area (ft^2)	17,876	5,502	8,512	9,375
# of floors	3	1	12 (9-residential floors, 75-dwelling units)	1
Window-to-Floor Area Ratio	13%	11%	27.35%	8.21%
HVAC Distribution System	3x Packaged Variable Air Volume with VAV Hot Water Reheat	5x Packaged Single Zone Air Conditioners	*Common Areas:* PVAV *Dwelling Units:* Four-pipe fan coil	Single Zone Air Conditioner
Cooling System	Direct Expansion, 9.8 EER	Direct Expansion, 13 SEER	*Common areas:* Direct expansion *Dwelling Units:* Chilled Water	Direct Expansion, 13 SEER
Heating System	Boiler, 80% Thermal Efficiency	Furnace, 78% AFUE	Boiler, 80% Thermal Efficiency	Furnace, 78% AFUE
Conditioned Thermal Zones	18	5	40	4
Domestic Water Heating	Natural Gas Storage, 24 Gallon Tank, EF = 0.64	8x Natural Gas Storage, 2 Gallon Tank, EF = 0.71	Natural Gas Storage, 100 Gallon Tank, EF = 0.8	Natural Gas Small Storage, 14 Gallon Tank, EF = 0.65
Lighting Power Density (LPD)	0.75 W/ft^2	0.75 W/ft^2	Dwelling units – 0.5 W/ft^2; Corridor – 0.6 W/ft^2; Nonresidential areas – 0.7-1.2 W/ft^2	2.2 W/ft^2

2.2 Energy Simulations

TRC used CBECC-Com software version 2016.3.0 SP1 to simulate all the building prototypes and obtain the hourly consumption data without PV. CBECC-Com software does not have the capability to model PV in buildings. Hence, TRC simulated a residential building prototype in CBECC-Res software version 2016.3.0 (934 SP1) to obtain hourly PV generation output for each of the sixteen climate zones. TRC simulated three different PV system sizes covering a wide range of output (e.g., 5 to 500 kW) to obtain a relationship between PV system size and kWh generation for each building type. The analysis results in a linear relationship used to scale the PV generation for the desired PV sizes, an example shown in Figure 2 below.

Figure 2. Linear curve between annual PV generation (kWh) and installed PV size (kW) in Climate Zone 1



In summary, TRC performed the following simulations:

- CBECC-Com: All four prototypes under 16 climate zones, total 64 simulations
- CBECC-Res: One prototype, three PV system sizes and 16 climate zones, total 48 simulations

The final results overlay the scaled PV generation output to the hourly consumption output from CBECC-Com simulations to determine the net hourly consumption for the two desired PV definitions and four building types.

In other words,

Net hourly kWh consumption = Hourly kWh consumed (CBECC_Com) - Hourly kWh generated (CBECC_Res)

2.3 Cost Effectiveness

This section discusses how on-bill cost effectiveness is determined for the solar PV and solar ready measures.

2.3.1 Solar PV

TRC evaluated cost effectiveness of PV using the net present value (NPV) metric over 30 years, assuming a 3% discount rate and a 2% energy escalation rate. The analysis included benefit-to-cost (B/C) ratio and discounted payback metrics, defined as follows:

- **Net present value (NPV):** Present value of total benefits from utility bill savings minus present value of all costs including maintenance and replacement over 30 years. The criteria for cost effectiveness is NPV greater than 0.

- **Benefit-to-cost ratio (B/C): Ratio of present value of all benefits over present value of all costs over 30 years. The criteria for cost effectiveness is B/C greater than 1.0.**
- **Discounted payback:** Number of years it takes to break even from undertaking the initial expenditure, by discounting future cash flows and accounting for the time value of money.

Solar PV on-bill energy benefits and installation costs are estimated as discussed below.

2.3.1.1 Energy Cost Benefits

The on-bill cost-effectiveness methodology evaluates savings based on the customer's utility bills using rate structures of California's three major Investor Owned Utility (IOU) including Net Energy Metering (NEM) 2.0, shown in Figure 3 below.[2,3] Because climate zones 10 and 14 overlap with both SCE and SDG&E territory, TRC evaluated cost effectiveness under both utility rate structures in these climate zones.

Figure 3. IOU distribution by climate zone

IOU	Climate zones
Pacific Gas & Electric (PG&E)	1-5, 11-13, 16
Southern California Edison (SCE)	6, 8-10, 14, 15
San Diego Gas & Electric (SDG&E)	7, 10, 14

The specific electricity rate schedules within IOU territory are applied to each of the 64 prototypes based on the climate zone, estimated monthly peak load and annual kWh consumption (Figure 4). Utility territories and climate zones boundaries do not perfectly align; one utility territory contains multiple climate zones, and one climate zone can contain multiple utility territories. A prototype simulated in different climate zones will have different monthly peak loads, and may consequently fall under a different utility rate structure. For example, SCE rate TOU-GS-2-A may apply to the medium office prototype in one climate zone, while TOU-GS-3-A may apply in another climate zone.

Figure 4. Applicable rate schedules by building type

Building type	PG&E	SCE	SDG&E[4]
Small office	A-1 TOU	TOU-GS-1-A; TOU-GS-2-A	-
Medium office	A-10	TOU-GS-2-A; TOU-GS-3-A	-
HRMF	E-TOU A	TOU-D-T	-
Retail strip mall	A-10	TOU-GS-2-A	-

[2] More information on NEM available at: http://www.cpuc.ca.gov/General.aspx?id=3800

[3] The distribution of IOUs across sixteen climate zones is aligned with: Residential Retrofit High Impact Measure (HIM) Evaluation Report, *Prepared for California Public Utilities Commission (CPUC) Energy Division, February 8, 2010*

[4] The applicable rate schedules for SDG&E are still being reviewed and are subject to change.

For high-rise multifamily building utility bill calculations, two simplifying assumptions were necessary:

1. TRC approximated that each dwelling unit had the same energy consumption profile, because energy simulation software aggregates residential energy usage for all individual dwelling units. [5]
2. TRC performed energy calculations at an hourly level, even though utilities may determine bill amounts based on sub-hourly billing intervals for simplification.

TRC does not expect these assumptions to significantly affect the overall results.

2.3.1.2 PV Installation Costs

TRC sourced the PV cost information from nationwide studies done by NREL and LBNL[6,7]. As shown in Figure 5 below, the cost includes the system cost, installation and inverter costs accounting for inflation rate and federal tax credits for nonresidential buildings. TRC applied savings from the federal income tax credit (ITC), although because it is scheduled to be phased out between 2020 and 2022, an average ITC of 16% is used for residential systems and 19% for commercial systems. TRC assumed inverter replacements at years 11 and 21. The cost for a PV retrofit is an additional $0.25/W, resulting in a total $1.97/W only for the retail strip mall prototype existing construction scenario. The federal incentive is applied to the combined system and retrofit cost.

Figure 5. Nonresidential New construction PV costs summary

Cost type	$/W
First Cost	1.72
System Cost	*2.13*
Federal Income Tax Credit	*19.2%*
Inverter Replacement at year 11	0.15
Inverter Replacement at year 21	0.12
Annual Maintenance	0.02

2.3.2 Solar Ready

Because the 'solar ready' measure is an enabling measure, rather than a requirement to install a solar system, there are no associated direct energy savings. Solar-ready measures include:

- Roof area be reserved for solar equipment

[5] Aggregated energy data impacts how utility bills are calculated. As an example in PG&E territory, the baseline allocation and minimum customer charge per unit is multiplied for 75 units of the building. So, the aggregated energy consumption of the building is compared to 75 times the baseline allocation for individual unit to calculate energy costs. Aggregation does not account for real-world variations in energy usage across the dwelling units.

[6] 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

[7] 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

- A pathway for piping and/or conduit be indicated on plans
- Roof structural design loads be shown on plans
- Adequate electrical capacity be provided
- Spare electric breaker space be provided

Costs for reserving roof area, reserving a pathway for piping/conduit, and structural design load calculations are design costs, which are excluded in the CEC's LCC methodology, though realizing these measures will require additional attention from architects and designers. In summary, because a conventional cost-effectiveness analysis would compare zero energy savings to zero costs, no cost effectiveness analysis was performed.

3 Results

Results are provided in Figure 6 through Figure 13 in the following pages. To account for the multiple utilities within climate zones 10 and 14, there is an additional row added in each of the figures below to show cost effectiveness under both rate structures. 10-1 and 14-1 are for SCE utility rate results, and 10-2 and 14-2 are for SDG&E utility rate results (which are still under review by SDG&E, and are thus not presented).

Cost effectiveness results are evaluated for both the proposed PV system size definitions:

- **PV Measure Definition 1**: Generation equating to 80% of the total annual electric consumption
- **PV Measure Definition 2**: 15 Watts DC per square foot of solar zone

Both PV measure definitions are cost-effective for all four building types. Medium office and high-rise multifamily buildings have less roof space available than the single story buildings, resulting in smaller PV system sizes per Definition 2. Smaller PV systems result in lower costs as well as lower bill savings than Definition 1 for these prototypes, as seen when comparing Figure 8 vs. Figure 9 or Figure 10 vs. Figure 11.

The 'kWh savings' are similar across all climate zones for a particular prototype and PV definition because they are only attributable to the PV system generation. However, the 'life cycle bill savings' are influenced by both kWh savings and utility rate schedules. 'Life cycle bill savings' are similar across climate zones when under the same rate schedule, but differ when there are different rate schedules and/or utility territories.

As an example, in Figure 7, both CZ3 (under PG&E territory) and CZ6 (under SCE territory) show similar kWh savings but have significantly different bill savings of $117,445 and $78,957, respectively. TRC compared the PG&E rate to the SCE rate, and found that the SCE rates have lower volumetric charges but higher monthly fixed charges – thus the volumetric savings resulting from PV have a smaller impact on the bill when compared to minimum fixed charges

Even for the same building type within the same IOU territory, differences may occur across different climate zones because of climatic impacts on building energy consumption. Climate-dependent energy consumption, primarily space heating and space cooling, informs the on-peak and off-peak energy consumption along with the peak kW demand. These variabilities dictate both utility rate schedule selection and corresponding energy costs. For example, climate zones within SCE territory can follow under TOU-GS-1, TOU-GS-2 or TOU-GS-3 depending on their monthly loads, and each of these rate schedules have different structures.

High rise multifamily follows a residential rate schedule as opposed to commercial rates applied to the other three prototypes. Residential and commercial rate schedules are structured differently, the major difference being the peak load demand charges included in commercial rates only. PG&E's residential rate plan also includes a credit awarded for usage up to their baseline allocation. As a result, life cycle bill savings of high-rise multifamily building cannot be easily compared against the other prototypes of similar size or energy consumption.

TRC has attempted to model utility rates as accurately as possible and in coordination with the utilities, but has not identified an exhaustive set of causalities for any trends across the buildings, utilities, and climate zones.

Key takeaways include:

- Solar PV is cost effective with both sizing methods, across all building types, utility territories, and climate zones analyzed in this study. Benefit to cost ratios across all results range from 1.5 to 7.4. While TRC could not analyze all possible permutations of building sizes and rates, this suggests that these sizing methods are appropriate in the majority of possible cases.
- The Small Office has similar B/C Ratios using both PV Definitions for sizing PV systems.
- The Medium Office and HRMF prototypes have generally higher B/C Ratios with smaller PV systems (PV Definition 2) as compared to PV Definition 1. However, larger PV systems have higher NPV savings over 30 years.
- The Retail Strip Mall has higher B/C ratios with a larger PV system (PV Definition 1) as compared to PV Definition 2.

Figure 6. Cost effectiveness results – Small office – PV definition 1

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-1	29.3	39,217	$70,289	$230,936	$160,647	3.3	7
2	PG&E	A-1	28.4	44,422	$68,087	$262,268	$194,181	3.9	6
3	PG&E	A-1	26.6	42,035	$63,875	$247,967	$184,092	3.9	6
4	PG&E	A-1	28.0	45,152	$67,254	$266,207	$198,954	4.0	6
5	PG&E	A-1	25.0	42,133	$60,080	$247,451	$187,372	4.1	6
6	SCE	TOU-GS-1	28.9	45,664	$69,371	$180,640	$111,269	2.6	10
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	30.1	47,559	$72,098	$220,008	$147,910	3.1	8
9	SCE	TOU-GS-2	29.6	48,277	$70,892	$223,082	$152,190	3.1	8
10-1	SCE	TOU-GS-2	30.8	50,202	$73,866	$226,056	$152,190	3.1	8
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-1	31.5	50,149	$75,540	$295,240	$219,699	3.9	6
12	PG&E	A-1	30.0	47,102	$71,989	$277,602	$205,613	3.9	6
13	PG&E	A-1	32.5	50,256	$77,997	$295,612	$217,615	3.8	6
14-1	SCE	TOU-GS-2	28.5	51,180	$68,326	$224,963	$156,637	3.3	7
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-2	35.6	59,568	$85,408	$243,624	$158,216	2.9	9
16	PG&E	A-1	27.7	47,016	$66,388	$276,326	$209,938	4.2	6

Figure 7. Cost effectiveness results – Small office – PV definition 2

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-1	12.4	16,567	$29,693	$99,717	$70,024	3.4	7
2	PG&E	A-1	12.4	19,372	$29,693	$116,592	$86,899	3.9	6
3	PG&E	A-1	12.4	19,540	$29,693	$117,445	$87,752	4.0	6
4	PG&E	A-1	12.4	19,935	$29,693	$119,760	$90,067	4.0	6
5	PG&E	A-1	12.4	20,823	$29,693	$124,345	$94,652	4.2	6
6	SCE	TOU-GS-1	12.4	19,546	$29,693	$78,957	$49,265	2.7	9
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	12.4	19,587	$29,693	$59,942	$30,249	2.0	15
9	SCE	TOU-GS-2	12.4	20,221	$29,693	$60,906	$31,213	2.1	15
10-1	SCE	TOU-GS-2	12.4	20,180	$29,693	$60,206	$30,513	2.0	15
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-1	12.4	19,712	$29,693	$118,521	$88,828	4.0	6
12	PG&E	A-1	12.4	19,428	$29,693	$116,843	$87,150	3.9	6
13	PG&E	A-1	12.4	19,132	$29,693	$115,046	$85,353	3.9	6
14-1	SCE	TOU-GS-2	12.4	22,241	$29,693	$63,850	$34,157	2.2	14
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-2	12.4	20,710	$29,693	$57,101	$27,408	1.9	17
16	PG&E	A-1	12.4	21,029	$29,693	$126,070	$96,377	4.2	6

Figure 8. Cost effectiveness results – Medium office - PV definition 1

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-10	226.4	303,042	$543,148	$1,368,713	$825,566	2.5	10
2	PG&E	A-10	222.4	348,075	$533,510	$1,615,140	$1,081,630	3.0	8
3	PG&E	A-10	206.3	325,611	$494,786	$1,504,648	$1,009,862	3.0	8
4	PG&E	A-10	220.5	355,050	$528,839	$1,623,929	$1,095,090	3.1	8
5	PG&E	A-10	194.8	327,649	$467,219	$1,493,119	$1,025,900	3.2	8
6	SCE	TOU-GS-2	230.2	363,468	$552,169	$1,110,412	$558,243	2.0	16
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	237.4	375,540	$569,306	$1,159,835	$590,529	2.0	15
9	SCE	TOU-GS-3	233.4	381,176	$559,732	$1,320,521	$760,789	2.4	13
10-1	SCE	TOU-GS-3	237.9	387,771	$570,554	$1,314,698	$744,144	2.3	13
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-10	244.2	388,810	$585,670	$1,760,419	$1,174,749	3.0	8
12	PG&E	A-10	235.8	370,084	$565,629	$1,683,325	$1,117,696	3.0	8
13	PG&E	A-10	254.7	393,559	$610,802	$1,772,341	$1,161,539	2.9	8
14-1	SCE	TOU-GS-3	217.4	390,525	$521,362	$1,297,029	$775,667	2.5	10
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-3	280.1	468,546	$671,793	$1,495,913	$824,121	2.2	14
16	PG&E	A-10	199.8	339,442	$479,299	$1,516,862	$1,037,563	3.2	8

Figure 8. Cost effectiveness results – Medium office - PV definition 1

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-10	226.4	303,042	$543,148	$1,368,713	$825,566	2.5	10
2	PG&E	A-10	222.4	348,075	$533,510	$1,615,140	$1,081,630	3.0	8
3	PG&E	A-10	206.3	325,611	$494,786	$1,504,648	$1,009,862	3.0	8
4	PG&E	A-10	220.5	355,050	$528,839	$1,623,929	$1,095,090	3.1	8
5	PG&E	A-10	194.8	327,649	$467,219	$1,493,119	$1,025,900	3.2	8
6	SCE	TOU-GS-2	230.2	363,468	$552,169	$1,110,412	$558,243	2.0	16
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	237.4	375,540	$569,306	$1,159,835	$590,529	2.0	15
9	SCE	TOU-GS-3	233.4	381,176	$559,732	$1,320,521	$760,789	2.4	13
10-1	SCE	TOU-GS-3	237.9	387,771	$570,554	$1,314,698	$744,144	2.3	13
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-10	244.2	388,810	$585,670	$1,760,419	$1,174,749	3.0	8
12	PG&E	A-10	235.8	370,084	$565,629	$1,683,325	$1,117,696	3.0	8
13	PG&E	A-10	254.7	393,559	$610,802	$1,772,341	$1,161,539	2.9	8
14-1	SCE	TOU-GS-3	217.4	390,525	$521,362	$1,297,029	$775,667	2.5	10
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-3	280.1	468,546	$671,793	$1,495,913	$824,121	2.2	14
16	PG&E	A-10	199.8	339,442	$479,299	$1,516,862	$1,037,563	3.2	8

Figure 9. Cost effectiveness results – Medium office - PV definition 2

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-10	40.2	53,825	$96,472	$353,359	$256,887	3.7	6
2	PG&E	A-10	40.2	62,941	$96,472	$408,113	$311,641	4.2	6
3	PG&E	A-10	40.2	63,487	$96,472	$397,970	$301,498	4.1	6
4	PG&E	A-10	40.2	64,769	$96,472	$410,637	$314,165	4.3	6
5	PG&E	A-10	40.2	67,654	$96,472	$430,527	$334,055	4.5	5
6	SCE	TOU-GS-2	40.2	63,503	$96,472	$346,995	$250,523	3.6	7
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	40.2	63,637	$96,472	$355,618	$259,146	3.7	6
9	SCE	TOU-GS-3	40.2	65,697	$96,472	$391,040	$294,568	4.1	6
10-1	SCE	TOU-GS-3	40.2	65,566	$96,472	$393,515	$297,043	4.1	6
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-10	40.2	64,045	$96,472	$417,553	$321,081	4.3	5
12	PG&E	A-10	40.2	63,121	$96,472	$406,773	$310,300	4.2	6
13	PG&E	A-10	40.2	62,160	$96,472	$408,211	$311,738	4.2	6
14-1	SCE	TOU-GS-3	40.2	72,262	$96,472	$411,201	$314,729	4.3	5
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-3	40.2	67,285	$96,472	$426,125	$329,653	4.4	5
16	PG&E	A-10	40.2	68,322	$96,472	$412,717	$316,245	4.3	5

Figure 10. Cost effectiveness results – High-rise multifamily - PV definition 1

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	E-TOU	238.4	322,852	$571,845	$2,025,220	$1,453,375	3.5	7
2	PG&E	E-TOU	225.6	371,193	$541,137	$2,187,767	$1,646,630	4.0	6
3	PG&E	E-TOU	210.5	344,653	$504,938	$2,040,935	$1,535,997	4.0	6
4	PG&E	E-TOU	221.9	376,983	$532,167	$2,226,673	$1,694,506	4.2	6
5	PG&E	E-TOU	197.6	348,463	$473,866	$2,011,233	$1,537,367	4.2	6
6	SCE	TOU-D-T	226.5	300,595	$543,263	$2,060,969	$1,517,706	3.8	6
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-D-T	233.3	312,666	$559,574	$2,143,444	$1,583,870	3.8	6
9	SCE	TOU-D-T	231.4	323,601	$555,088	$2,199,218	$1,644,131	4.0	6
10-1	SCE	TOU-D-T	235.7	330,150	$565,263	$2,235,530	$1,670,267	4.0	6
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	E-TOU	249.0	421,808	$597,311	$2,400,718	$1,803,407	4.0	6
12	PG&E	E-TOU	237.4	397,092	$569,400	$2,230,664	$1,661,264	3.9	6
13	PG&E	E-TOU	256.3	425,413	$614,846	$2,354,303	$1,739,457	3.8	6
14-1	SCE	TOU-D-T	220.5	339,752	$528,831	$2,305,881	$1,777,050	4.4	5
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-D-T	275.4	403,210	$660,453	$2,719,247	$2,058,794	4.1	6
16	PG&E	E-TOU	211.1	377,068	$506,410	$2,290,624	$1,784,213	4.5	5

Figure 11. Cost effectiveness results – High-rise multifamily - PV definition 2

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	E-TOU	19.2	25,630	$45,937	$273,401	$227,464	6.0	4
2	PG&E	E-TOU	19.2	29,970	$45,937	$320,775	$274,838	7.0	3
3	PG&E	E-TOU	19.2	30,231	$45,937	$313,753	$267,816	6.8	3
4	PG&E	E-TOU	19.2	30,841	$45,937	$329,443	$283,506	7.2	3
5	PG&E	E-TOU	19.2	32,215	$45,937	$328,745	$282,808	7.2	3
6	SCE	TOU-D-T	19.2	30,238	$45,937	$286,837	$240,900	6.2	4
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-D-T	19.2	30,302	$45,937	$290,631	$244,694	6.3	4
9	SCE	TOU-D-T	19.2	31,283	$45,937	$299,840	$253,903	6.5	4
10-1	SCE	TOU-D-T	19.2	31,221	$45,937	$300,028	$254,091	6.5	4
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	E-TOU	19.2	30,496	$45,937	$340,273	$294,336	7.4	3
12	PG&E	E-TOU	19.2	30,056	$45,937	$328,635	$282,698	7.2	3
13	PG&E	E-TOU	19.2	29,599	$45,937	$319,894	$273,957	7.0	3
14-1	SCE	TOU-D-T	19.2	34,409	$45,937	$322,608	$276,671	7.0	3
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-D-T	19.2	32,039	$45,937	$329,110	$283,173	7.2	3
15	PG&E	E-TOU	19.2	32,039	$45,937	$340,897	$294,960	7.4	3

Figure 12. Cost effectiveness results – Existing Retail strip mall – PV definition 1

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-10	84.0	112,424	$218,442	$510,358	$291,916	2.3	13
2	PG&E	A-10	84.6	132,460	$220,099	$611,335	$391,237	2.8	9
3	PG&E	A-10	77.0	121,554	$200,239	$561,986	$361,746	2.8	9
4	PG&E	A-10	83.0	133,623	$215,763	$609,041	$393,279	2.8	9
5	PG&E	A-10	71.9	120,997	$187,046	$551,377	$364,331	2.9	8
6	SCE	TOU-GS-2	86.7	136,919	$225,491	$418,301	$192,811	1.9	17
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	90.0	142,367	$233,969	$439,701	$205,731	1.9	17
9	SCE	TOU-GS-2	88.3	144,288	$229,691	$444,818	$215,127	1.9	16
10-1	SCE	TOU-GS-2	92.6	150,878	$240,662	$461,482	$220,820	1.9	17
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-10	91.9	146,301	$238,904	$658,800	$419,896	2.8	9
12	PG&E	A-10	88.8	139,284	$230,777	$626,075	$395,299	2.7	9
13	PG&E	A-10	96.4	149,044	$250,763	$664,580	$413,816	2.7	10
14-1	SCE	TOU-GS-2	82.6	148,433	$214,824	$446,955	$232,131	2.1	15
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-2	107.0	178,916	$278,095	$528,901	$250,806	1.9	17
16	PG&E	A-10	78.5	133,261	$203,988	$593,882	$389,894	2.9	9

Figure 13. Cost effectiveness results – Existing Retail strip mall - PV definition 2

Climate zone	Utility	Rate schedule	PV size	kWh savings	Life cycle Costs	Life cycle bill savings	Net savings (NPV)	B/C ratio	Discounted payback (yrs.)
1	PG&E	A-10	21.1	28,229	$54,848	$141,450	$86,602	2.6	10
2	PG&E	A-10	21.1	33,009	$54,848	$169,518	$114,670	3.1	8
3	PG&E	A-10	21.1	33,295	$54,848	$171,209	$116,361	3.1	8
4	PG&E	A-10	21.1	33,968	$54,848	$172,320	$117,472	3.1	8
5	PG&E	A-10	21.1	35,481	$54,848	$183,129	$128,281	3.3	7
6	SCE	TOU-GS-2	21.1	33,304	$54,848	$84,760	$29,912	1.5	26
7	SDG&E	-	-	-	-	-	-	-	-
8	SCE	TOU-GS-2	21.1	33,374	$54,848	$86,054	$31,205	1.6	25
9	SCE	TOU-GS-2	21.1	34,455	$54,848	$88,645	$33,796	1.6	24
10-1	SCE	TOU-GS-2	21.1	34,386	$54,848	$87,635	$32,787	1.6	24
10-2	SDG&E	-	-	-	-	-	-	-	-
11	PG&E	A-10	21.1	33,588	$54,848	$163,366	$108,518	3.0	8
12	PG&E	A-10	21.1	33,103	$54,848	$161,184	$106,336	2.9	8
13	PG&E	A-10	21.1	32,600	$54,848	$157,723	$102,875	2.9	9
14-1	SCE	TOU-GS-2	21.1	37,898	$54,848	$94,785	$39,936	1.7	19
14-2	SDG&E	-	-	-	-	-	-	-	-
15	SCE	TOU-GS-2	21.1	35,287	$54,848	$86,315	$31,467	1.6	25
16	PG&E	A-10	21.1	35,831	$54,848	$173,246	$118,398	3.2	8

2017

Davis Electric Vehicle Charging Plan

City of Davis

Adopted

February 2017

City of Davis Electric Vehicle Charging Plan

How To Use This Document

The Davis EV Charging Plan (Plan) forecasts local PEV demand and establishes standards and guidelines for the installation of charging infrastructure to meet that demand. The demand for charging is driven by two primary factors: (1) the demand created by plug-in electric vehicle (PEV) drivers, and (2) the role of PEVs in helping balance the electricity grid (i.e. taking power when it's abundant and releasing it when it's not). The Plan enhances local PEV planning efforts by informing local decisions on the number, type, and location of chargers associated with different land use types.

This document was designed for City planners and code officials as well as developers and property owners seeking guidance on how to meet customer, tenant, and employee demand for charging. The primary focus of this Plan is on the installation of PEV charging infrastructure, also called electric vehicle supply equipment (EVSE). Section one of this document provides an overview of the policy basis for the Plan. Section two contains a review of PEV and EVSE technology as well as the deployment of PEVs and EVSE in Davis. Section three describes the PEV demand model that informs the standards, design guidelines, and best practices found in Sections four and five. Section six provides practical information related to signage while Section seven looks past the current demand to suggest where the City and its partners could look for future opportunities to enhance and further integrate the Davis EV charging system into the community.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The 2010 Davis Climate Action and Adaptation Plan (CAAP) sets community Greenhouse Gas (GHG) reduction goals to reach zero net carbon by 2050. The CAAP includes specific short-term objectives to increase efficiency of passenger vehicles and achieve measurable fuel switching to continue Davis' transition to a low carbon mobility system. Plug-in electric vehicles are a key component in achieving this goal.

The Davis EV Charging Plan (Plan) is an implementation document for the CAAP. It provides guidance for choosing and siting charging infrastructure and guide its installation and pricing. Overall community demand modeling for PEV charging over the next ten years and potential future interactions between the electricity grid and electric vehicles are the foundation for the Plan. These drive both its policy level recommendations as well as the prescriptive measures for new development. The specific objectives of the Plan are:

- Increase the availability of public chargers to maximize plug-in vehicle miles traveled.
- Increase the number of plug-in vehicles sold and used in the city for private and public applications.
- Prepare for the integration of EV's and the grid to improve grid balancing and stability.
- Reduce local GHG emissions from the transportation sector.
- Reduce local air pollution from the transportation sector.

Sections 1 and 2 of the Plan provide background while Section 3 outlines the demand modeling that informs the policy and development standards found in Section 4. Section 5 recommends best practices related to specific site design and pricing that are anticipated to be useful to City planners, developers, property owners, business owners, and employers wishing to install chargers. Section 6 addresses sign requirements and basic EV charging etiquette guidelines. Section 7 outlines future considerations and opportunities related to PEVs. The central organizing principle of the Plan is to establish a well-designed data driven local charging system that meets the current and future needs of Davis and visitors to the community.

Key Findings:

- Demand forecast should include both direct PEV demand as well as the role of PEVs in balancing the electricity grid (Vehicle to Grid – V2G).
- Direct PEV demand and pricing strategy is driven by three primary factors: (1) parking dwell time, (2) distance traveled, and (3) vehicle battery size.
- In the near term most charging will take place at home; V2G is likely to shift charging patterns toward non-home charging as variable renewable energy generation increases (e.g. solar), and value is established for the role PEVs play in grid balancing and stability.
- Half of Workplace charging can be satisfied with Level 1 charging due to parking dwell time.

Key Recommendations:

- Modify CalGreen standards for Davis to incorporate differentiation for PEV charging installation requirements based on land use.

- In recognition that V2G based demand will increase in the future, prior to 2020, require minimum number of network-ready Level 2 chargers with 50% of the total Workplace chargers installed as part of original construction and 50% prewired for future installation. Post 2020, require all chargers to be installed as part of original construction.
- Unless creating incentives for employees, tenants, customers, or V2G interconnections, chargers should generally be priced equal to the cost to charge at home to encourage need-based charging and discourage convenience-based charging.

Section 1: Vision, Goals, and Objectives

More than 50% of local carbon emissions in Davis are directly linked to the transportation sector (Davis Greenhouse Gas (GHG) inventory 2008, updated 2013). The Davis Electric Vehicle Charging Plan (Plan) sets standards and provides guidance that implement local transportation sector carbon reduction objectives. Local action, in turn, contributes to the State's carbon emissions reduction goals.

Section 1 outlines the local and State policy foundation that supports the implementation actions included in the Plan.

1.1 Local Vision

The 2010 Davis Climate Action and Adaptation Plan (CAAP) sets community Greenhouse Gas reduction goals to reach zero net carbon by 2050. The CAAP includes specific short-term objectives to increase efficiency of passenger vehicles and achieve measurable fuel switching to continue Davis' transition to a low carbon mobility system. Plug-in electric vehicles are a key component in achieving this goal.

> Davis 2050: "Alternative transportation becomes the "normal" way for Davis residents to travel and fossil fueled vehicles become collectors' items that are only seen in the annual "Sustainability Days" parade through the downtown."
>
> - Davis Climate Action and Adaptation Plan – 2010

The Davis EV Charging Plan incorporates State and local goals and implementing actions to transition from a fossil fueled based transportation system to one dominated by low/no carbon fuel sources. With this Plan, the City is addressing the practical day-to-day issues related to current vehicle charging needs while also looking over the horizon to anticipate and plan for future advancements related to decarbonizing the transportation system (e.g. vehicle to grid connection, matching EV with rooftop solar, electrified autonomous vehicles, etc).

1.2 City Goals

Climate Action and Adaptation Plan

The GHG inventories conducted by the City in establishing its climate goals show that the transportation sector accounts for more than half of local GHG emissions. Therefore, actions that address transportation-related GHG emissions are vital to the CAAP's success. The CAAP includes the following specific local goals and actions related to lowering GHG emissions from the transportation sector:

> CAAP Transportation Goal: Increase the overall efficiency of passenger vehicles operated by Davis residents by 5% (over new Federal fuel economy standards).
>
> - Develop a plan to de- carbonize personal transportation in Davis
> - Develop medium speed Neighborhood Electric Vehicle (NEV) program (35 mph)
> - Create local incentives and financing opportunities for the purchase of high efficiency vehicles and the retirement of inefficient vehicles.
> - Provide increased parking for fuel efficient vehicles (e.g. permit system)

- Work with local vehicle dealerships to promote local participation in any State and/or Federal programs established to encourage the purchase of high efficiency vehicles and the retirement of inefficient vehicles.

General Plan Transportation Element

In 2013, the City of Davis updated its General Plan Transportation Element to improve local mobility while reducing reliance on fossil fuels. A primary goal of the updated Element is to evolve the local transportation system to meet future mobility needs while improving air quality, reducing carbon emissions, and boosting public health. The City will implement these goals by planning for, encouraging, and developing infrastructure to increase the use of clean, energy-efficient, active (i.e. human powered), and economically sustainable means of travel.

Transportation Element Goal: Reduce carbon emissions from the transportation sector by 61% by 2035.

- Promote the use of electric vehicles and other low-polluting vehicles, including NEVs.
- New development shall include infrastructure for electric vehicles consistent with the future growth in the number of electric vehicles.
- Establish charging stations, preferably employing sustainable energy generation, for electric vehicles in public parking lots in accordance with the future growth in the number of electric vehicles.
- Require residential development to pre-install wiring necessary to support electric vehicle charging.
- Develop medium-speed NEV program (35 mph).

The City has integrated various clean fuel technologies in its vehicle fleet and has invested in electric vehicle infrastructure, with several public charging stations located within the City. The City has purchased electric vehicles, hybrid vehicles, and fuel-flexible sedans that can run on any combination of methanol, ethanol and gasoline.

Based on the General Plan and CAAP policies, pre-wiring and charging stations for electric and plug-in electric vehicles (PEVs) are being installed with new development. The City of Davis adopted CalGreen Tier 1 building standards in 2015 which dictate the number of EV Capable parking spaces required in new or altered parking lots.

A key recommendation of the Davis EV ChargingPlan is to modify the City's code requirements for EV Capable and EV Ready parking spaces based on the findings of the model developed for the Plan. The Plan also recommends modification of these existing CalGreen standards as they apply to Electric Vehicle Supply Equipment (EVSE) installation in Davis while also suggesting best practices to ensure that infrastructure supports both adoption and utilization of EVs.

1.3 State Goals

In response to threats posed by climate change, the State of California has adopted ambitious goals to reduce greenhouse gas emissions pursuant to AB 32. The current goals of the California Climate Strategy include a 50% reduction in petroleum use in vehicles (Figure 1).With transportation being such an integral part of the State's economy as well as a major source of emissions, Governor Brown

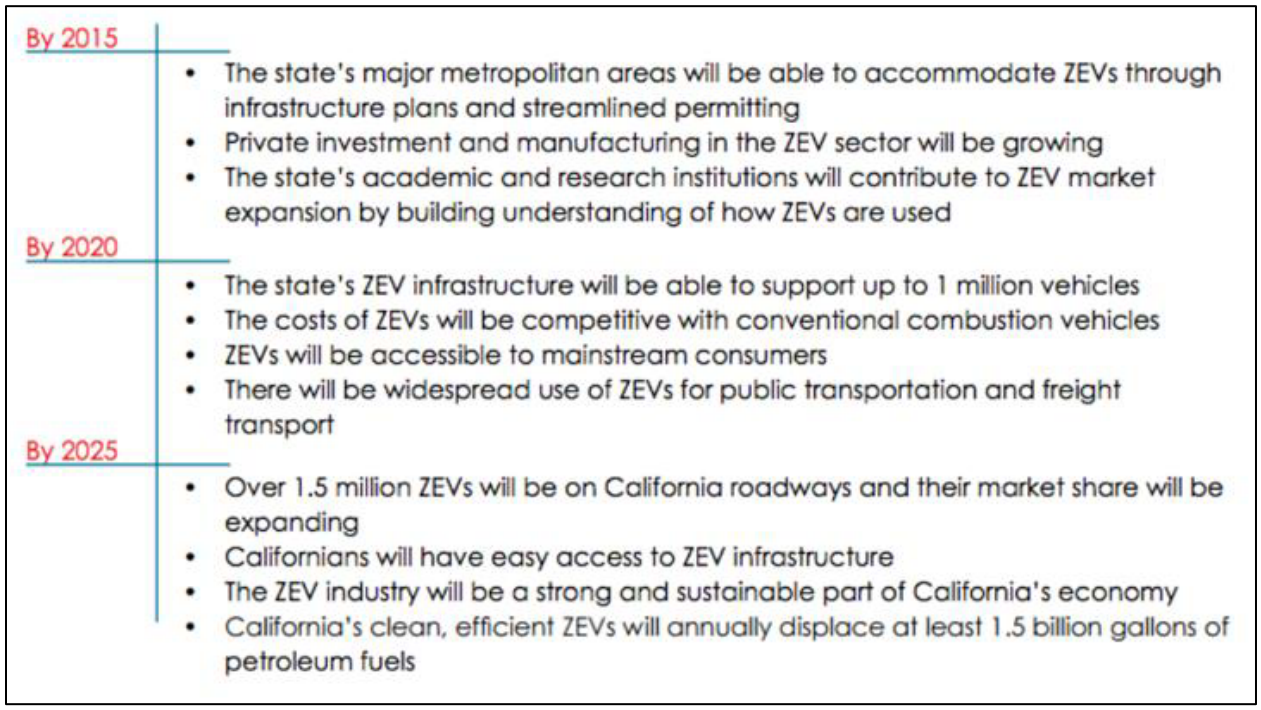
has put an emphasis on establishing cleaner vehicle technologies, reducing vehicle miles traveled, and the development of low carbon fuels.

Figure 1: California Climate Strategy Vision & Goals

(http://www.arb.ca.gov/cc/pillars/pillars.htm)

In 2012, Governor Brown issued an Executive Order that included benchmarks and goals on the path to reducing emissions from the transportation sector. Figure 2 summarizes the key objectives of the Executive Order and lays out the path for action by the State. The Zero Emission Vehicle (ZEV) Action Plan was created in 2013 to implement the Executive Order and accelerate the electric vehicle market in order to reduce emissions and pollution. The Davis EV Charging Plan is a local response to the Governor's direction that all "Californians will have easy access to ZEV infrastructure" by 2025.

Figure 2: ZEV Action Plan Benchmarks (citation?)



In addition, the Executive Order directs that:

- All state agencies support and facilitate the rapid commercialization of ZEVs in California.
- Greenhouse gas emissions from the transportation sector be 80% less than 1990 levels by 2050.
- The state fleet increase the number of ZEVs in the fleet through gradual vehicle replacement.
- By 2015, ZEVs make up at least 10% of fleet light-duty vehicle (LDV) purchases.
- By 2020 at least 25% of fleet light-duty vehicles (LDV) purchases be ZEVs.

(Reference Executive Order B-16, 2012)

As noted, the City of Davis EV Charging Plan is consistent with and helps implement Executive Order B-16, 2012 and the ZEV Action Plan.

1.4 Davis EV Charging Plan Objectives

The key objectives of the Plan are to:

- Increase the availability of public chargers to maximize plug-in vehicle miles traveled.
- Increase the number of plug-in vehicles sold and used in the city for private and public applications by providing a local charging infrastructure system.
- Prepare for the integration of EV's and the grid to improve grid balancing and stability.
- Reduce local GHG emissions from the transportation sector.
- Reduce local air pollution from the transportation sector.

In addition, the City and its partners recognize that there are emerging technologies and trends that are rapidly changing how people and goods will move in the future. Cleaner fuels (e.g. electricity), distributed electrical generation (e.g. rooftop solar), energy storage, smart grids (e.g. vehicle to grid power sharing), autonomous vehicles, lower personal vehicle ownership rates, etc. all have the potential to reduce transportation related emissions while expanding mobility options. Given this rapidly changing mobility landscape, this plan is focused on providing an EV charging infrastructure that is compatible with a variety of future needs.

Section 2: Background

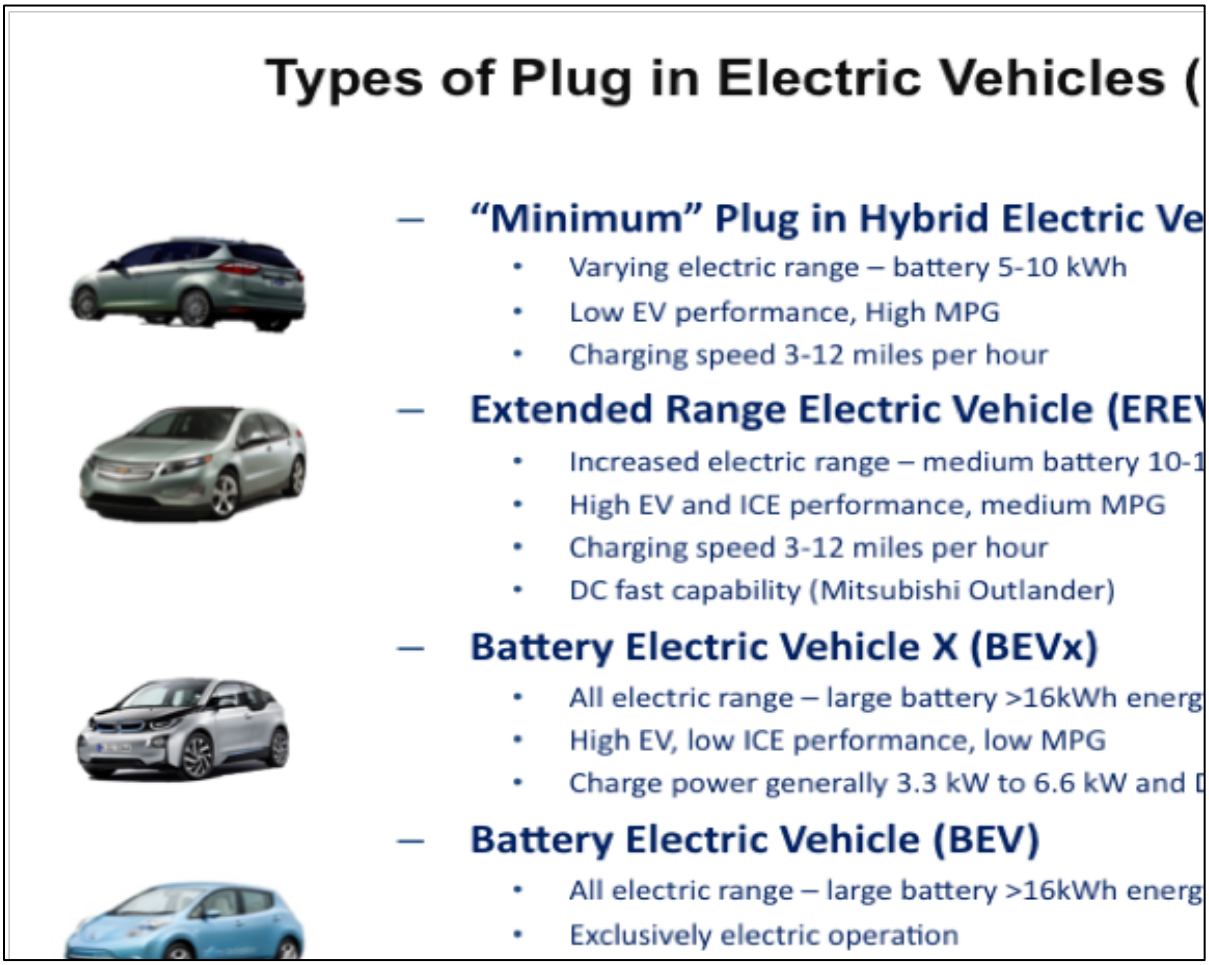
The UC Davis Institute for Transportation Studies (ITS), developed a model to forecast local demand for EV charging. Using socioeconomic data and direct community engagement, the City and its partners were able to estimate the number and type of PEVs in Davis over the next ten years. In addition, current research indicates that EV charging is positioned to play a key role in allowing greater amounts of intermittent renewable power (e.g. solar and wind), to be accommodated by the electricity grid. As a battery on wheels, an EV can take electricity from the grid when renewables produce more than the normal demand and put it to use or store it. This can help "balance the grid" by better aligning electricity demand with renewable power generation.

Overall, the analysis found that demand for EV charging in Davis is expected to increase by nearly 10 times by 2025. The model incorporates state, regional, and local inputs to develop the demand forecasts. The Plan sets the community on a path to meet this demand, making it more practical for Davis residents, visitors, and travelers to use low/no carbon vehicles while reinforcing a balanced electricity grid. Specifically the Plan is designed to inform local decisions related to the installation of electric vehicle charging infrastructure. These decisions are driven by several key factors: (1) the type of vehicle and capacity of the battery, (2) the ability to provide cost effective charging infrastructure, (3) the current and projected demand in different sections of the City, and(4) the future need for connection of EV's to the grid (Vehicle to Grid or V2G). This section of the plan provides basic background information on the types of vehicles and their current charging needs. Note: Detail on the model and associated standards are provided in Section 3 (Davis EV Charging Demand Model), and Section 4 (Davis EV Charging Needs by Land Use Type).

2.1 PEV 101

Plug-in electric vehicles (PEVs) operate on battery power and are recharged with electricity from the grid. While there are multiple types of PEVs, they are typically divided into two categories, battery electric vehicles (BEVs) and plug in hybrid electric vehicles (PHEVs). Figure 3 shows the general types of PEVs and are listed from smallest battery capacity to largest.

Figure 3: Types of Plug-in Electric Vehicles



*Note: "ICE" – Internal Combustion Engine

Types of Chargers

There are three basic types of Electric Vehicle Supply Equipment (EVSE), also referred to as a "charger" in this document, currently available on the market. While acknowledging the development of new charging systems (e.g. wireless), the Plan focuses on the charging systems that are likely to be the most common over the next ten years.

- Level 1 charging provides AC electricity to the vehicle from 120V either from an outlet or a hardwired EVSE. It takes longer to charge, but does not require the installation of a dedicated charging station and can be used by all types of PEVs.
- Level 2 charging provides AC electricity to the vehicle at 208V/240V. It does require a charging station (EVSE), but takes less time to charge than level 1.
- DC Fast charging provides DC electricity at typically higher power than AC outlets for faster charging. It requires significant investment in infrastructure and installation and can only be used by some PEVs.

Figure 4 shows the standardized J1772 system and the two most common DC Fast standards (excluding Tesla). Table 1 provides additional detail on average charging times and range associated with each level of charging. All of these factors are important considerations in designing a community charging system that meets current and future demand.

Figure 4: Charger Types

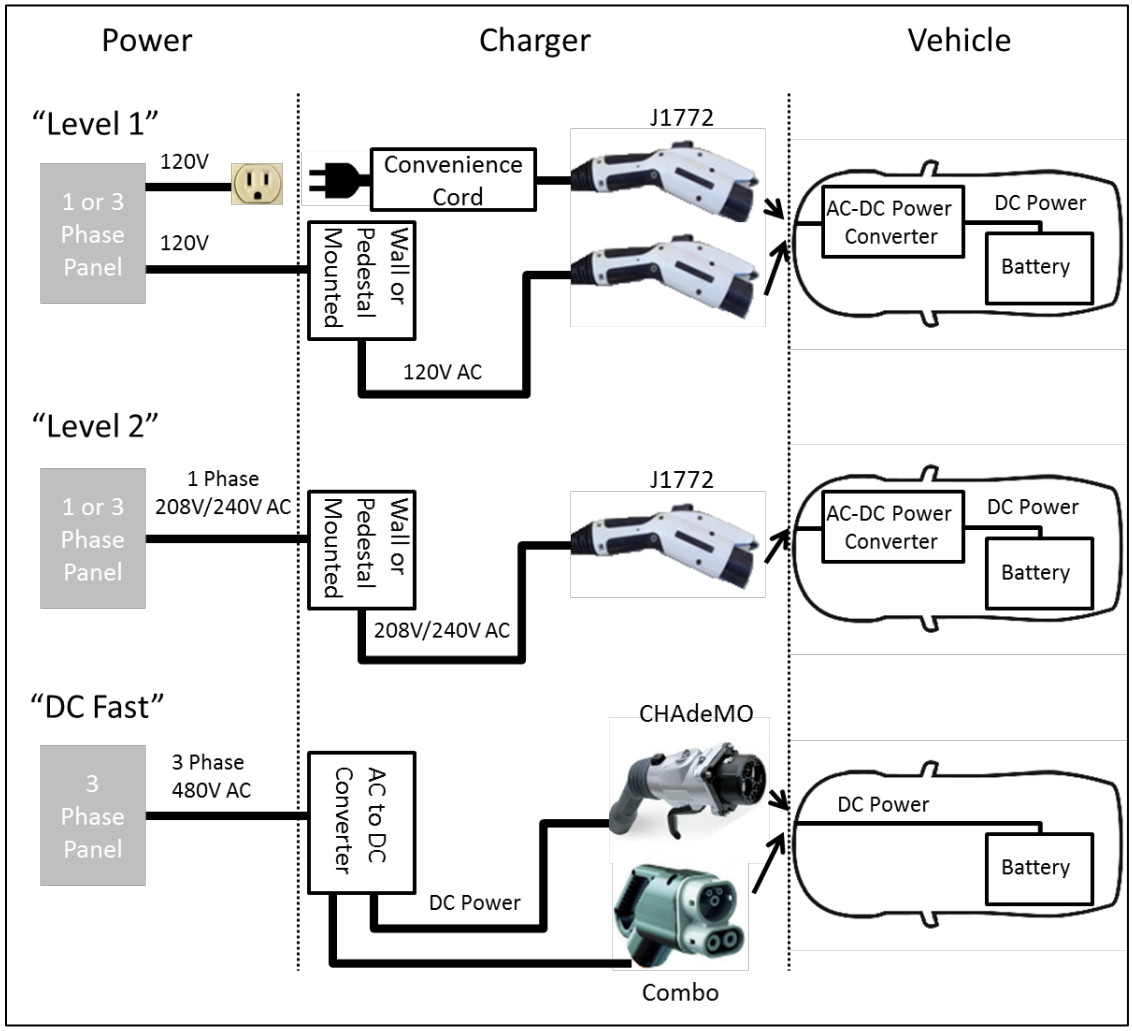


Table 1: Types of Plug-in Electric Vehicle Chargers

Charging Level	Power Supply	Charger Power	Miles of Range/Hour of Charge	Charging Times	
				BEV	PHEV
Level 1	120 VAC Single Phase	1.4kW @ 12 amp (on-board charger)	~3-4	~17 Hours	~7 Hours

Level 2	240 VAC Single Phase up to 19.2kW (up to 80 amps)	3.3 kW (on-board)	~8-10	~7 Hours	~3 Hours
		6.6+ kW (on-board)	~17-20	~3.5 Hours	~1.4 Hours
DC Fast	200-450 VDC up to 90 kW (~200 amp)	45kW (off-board)	~50-60	~30-45 Minutes (to ~80%)	~10 Minutes (to ~80%)

As noted, different vehicle types have different charging needs. The charging times for typical BEVs and PHEVs are shown in Table 1. BEVs typically charge at 6.6kW or higher depending on the capability of the charger. PHEVs are able to operate solely on gasoline when the battery runs out, so are unlikely to use fast charging often due to typically higher cost versus gasoline and the fact that few PHEVs currently have the capability to fast charge. The speed of charging may also be less critical for PHEVs than BEVs as the batteries are smaller and a gasoline engine is available when the battery depletes. Conversely, due to the relatively small size of its battery, a PHEV needs to charge more frequently. Finally, current PHEVs typically charge at 3.3kW (half the rate of BEVs) meaning that every charger that is designed to provide 6.6kW is underutilizing capacity if it is being used primarily to charge PHEVs. This is expected to become less of an issue over time as PHEVs with extended range enter the market in the next several years (i.e. PHEV 40+). These different needs and capabilities among vehicles in the context of parking dwell times shows a need for a mix of charging types.

2.2 Profile of Davis PEV Ownership

Currently there are approximately 500 PEVs in Davis, with over 200,000 operating in the State. Based on modeling and ownership demographics compiled by Institute for Transportation Studies, Davis is projected to have 4,500 PEVs by 2025 (See Appendix A). This means that between 15% to 20% of Davis households will have a least one plug-in electric vehicle in operation by 2025. The Plan is designed to accommodate this increase in PEV ownership and improve the availability of local charging. Figures 5 and 6 summarize model projections for the total number of PEV's and sub-types in Davis and California based on their battery range (e.g. BEV 200 = a battery electric vehicle with a range of 200 miles). This differentiation of range is an important factor in determining the demand for different levels of charging.

Figure 5: Davis PEV Ownership

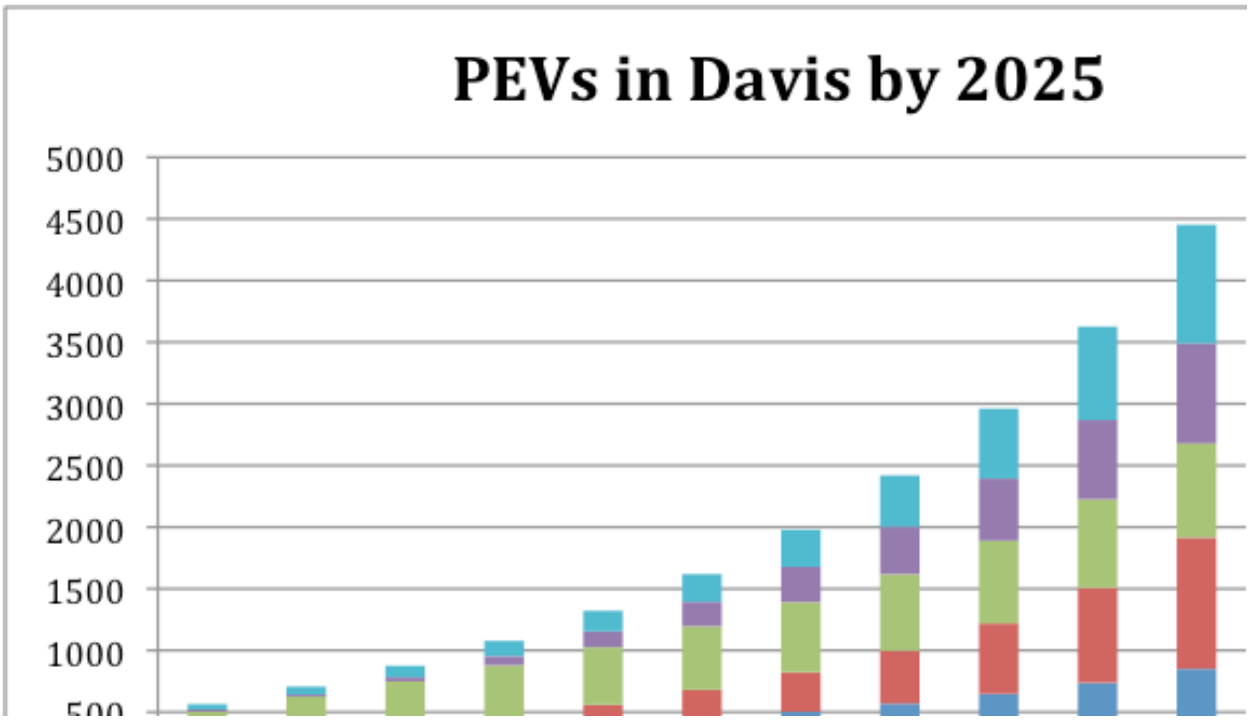
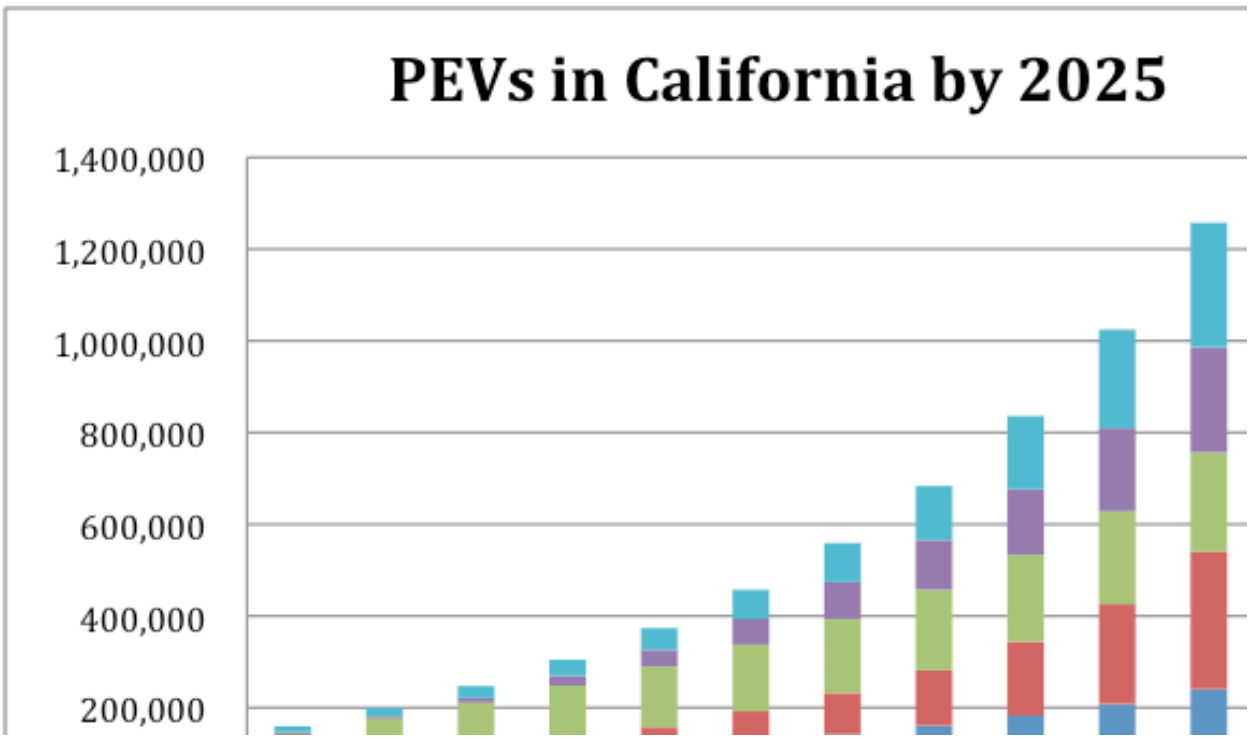


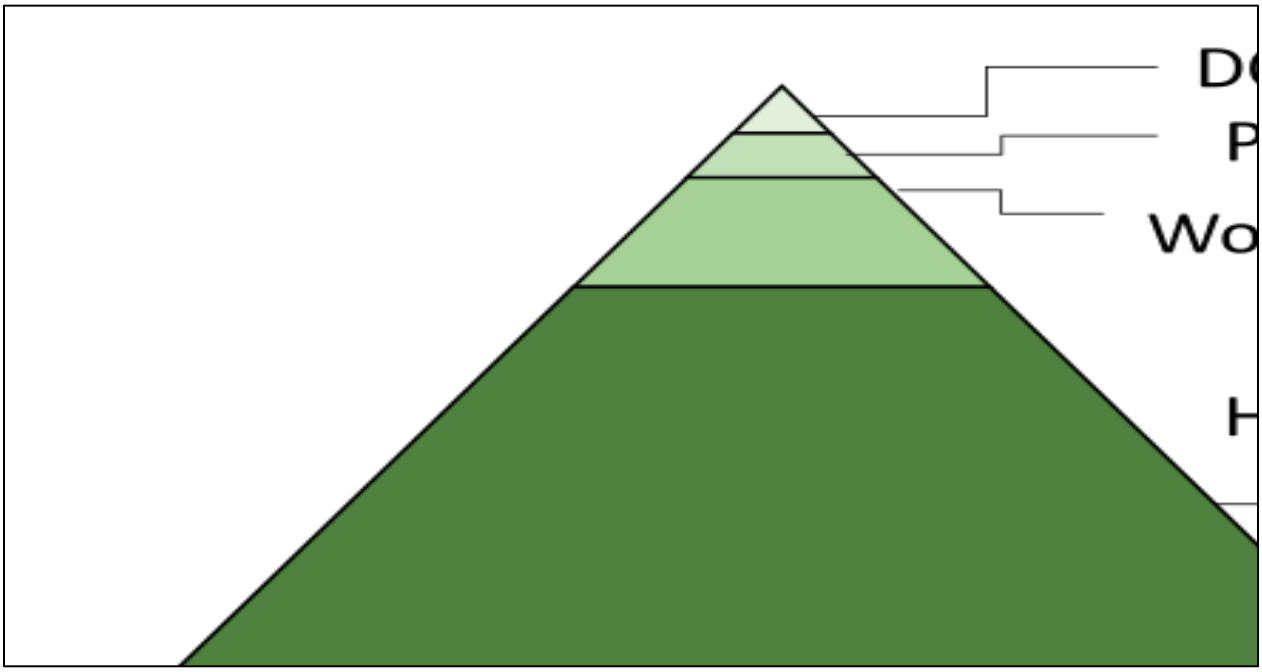
Figure 6: California PEV Ownership



2.3 Charging Demand - Basics

Charging can generally be split into four main categories: (1) Home, (2) Work, (3) Public, and (4) DC fast charging. The first three categories of charging are location based while DC fast charging is typically related to the need of long-distance travelers needing quick charging to continue or complete their trip. The categories are listed generally in terms of the frequency of need, but usage depends greatly on availability and how charging is priced. The pyramid figure below (Figure 6), shows the general proportion of the frequency of where charging is forecast to take place. The Davis EV Charging Plan is organized on this rank-ordered charging system approach with most local charging assumed to be occurring at home in the near term.

Figure 6 Charging systems ranked by Frequency of Use



While the current forecast is that the majority of charging takes place at home during non-work hours (evenings/weekends), a long-term goal is to transition charging times to mid-day when electricity generation is cleanest and EV's could assist with grid balancing. Therefore, daytime Workplace charging may become more common than Home charging in a solar-heavy generation mix. However, until this generation transition to greater renewable energy mix takes place and pricing incentives are established by utilities and Community Choice Energy programs, publicly accessible charging is assumed to serve a supplementary role for those with home charging.

With the exception of DC Fast, the charging categories are related to the location where an activity takes place. In place-0based chargers, the amount of time a vehicle is parked is the primary factor in determining the level of charging provided. At Home and Workplace, with the greatest parking times, both level 1 and level 2 chargers can be effective depending on the vehicle battery size. Public chargers include any non-work purpose where parking times are typically an hour or less, such as customer parking in retail settings. An example of Public charging in Davis is the Level 2 charger in the E Street Parking Lot that primarily serves customers of downtown businesses.

It should be noted that the categories are not mutually exclusive. For example, workplace chargers in a downtown setting may be utilized by nearby residents after business hours, effectively converting a Workplace charger to a Home charger after employees no longer need the parking space. Additionally, a Workplace charger that is publicly accessible may also be used by retail shoppers if the activities are co-located. And, although DC Fast is generally thought of as a charger to connect nearby metropolitan regions together along a highway corridor, they can also be useful near home, work and retail centers to supplement local charging needs. With thoughtful design and pricing, these charging relationships can be mutually beneficial and optimize the use of chargers.

Home Charging

Currently, home charging is a mix of Level 1 and Level 2 chargers. Based on a 2015 UC Davis survey, Level 1 Home charging is generally more popular for PHEVs with Level 2 being more popular for BEV drivers. Level 1 charging at home is relatively inexpensive and can be an important transition strategy even for those who plan to install Level 2 home charging at a later date (e.g. with other home upgrades). Additionally, when BEV owners reside in rental housing they may not have the option to install Level 2 charging, creating greater demand for DC Fast charging and Level 2 charging elsewhere in the community.

Workplace Charging

As shown in Figure 6 above, the need/demand for Workplace charging ranks highly due to longer travel and parking dwell times generally associated with this category. Because of the long parking dwell times, Level 1 charging can generally be expected to satisfy 50%-80% of workplace charging needs. In Workplace settings, a high proportion of Level 2 chargers can provide flexibility to meet both employee demand and needs associated with shorter parking dwell times such as customers or clients. In addition, Level 2 charging at workplaces addresses the electricity grid issues noted above. Note: Section 5 of the Plan provides greater detail on Workplace charging, including best practices associated with pricing, mix of charger types, and parking lot placement.

Public Charging

Public charging is a broad category encompassing all charging occurring outside of the Home and Workplace charging categories. Similar to Workplace charging, the primary determining factors for Public charging demand are vehicle range/technology, parking dwell time and travel distance from home. In addition, the research and demand model that supports the Plan's recommendations indicate that there are a wide variety of use cases that help determine the type, location, and number of chargers needed in this category. These use cases range from long distance travelers along the I-80 corridor to sporting events with long parking dwell times to a local convenience store with short parking dwell times and local customers. For example, a retail center primarily serving local customers may choose to offer charging as a service to entice customers to spend a longer time in its stores rather than targeting longer-distance travelers who may need charging to complete their trip. This range of scenarios were assessed in the demand model and helped guide the implementation strategies included in the Plan. Note: Section 5 of the Plan provides greater detail on Public charging, including best practices associated with pricing, mix of charger types, and parking lot placement.

DC Fast Charging

The need for DC Fast charging is assumed to arise from travelers along the highway corridors (I-80/SR 113). Though there may be local demand for convenience, the need identified in the model is associated with travelers with a driving distance that exceeds the battery range of their vehicle. In general there are three types of charging demand that might appear at DC Fast charging locations:

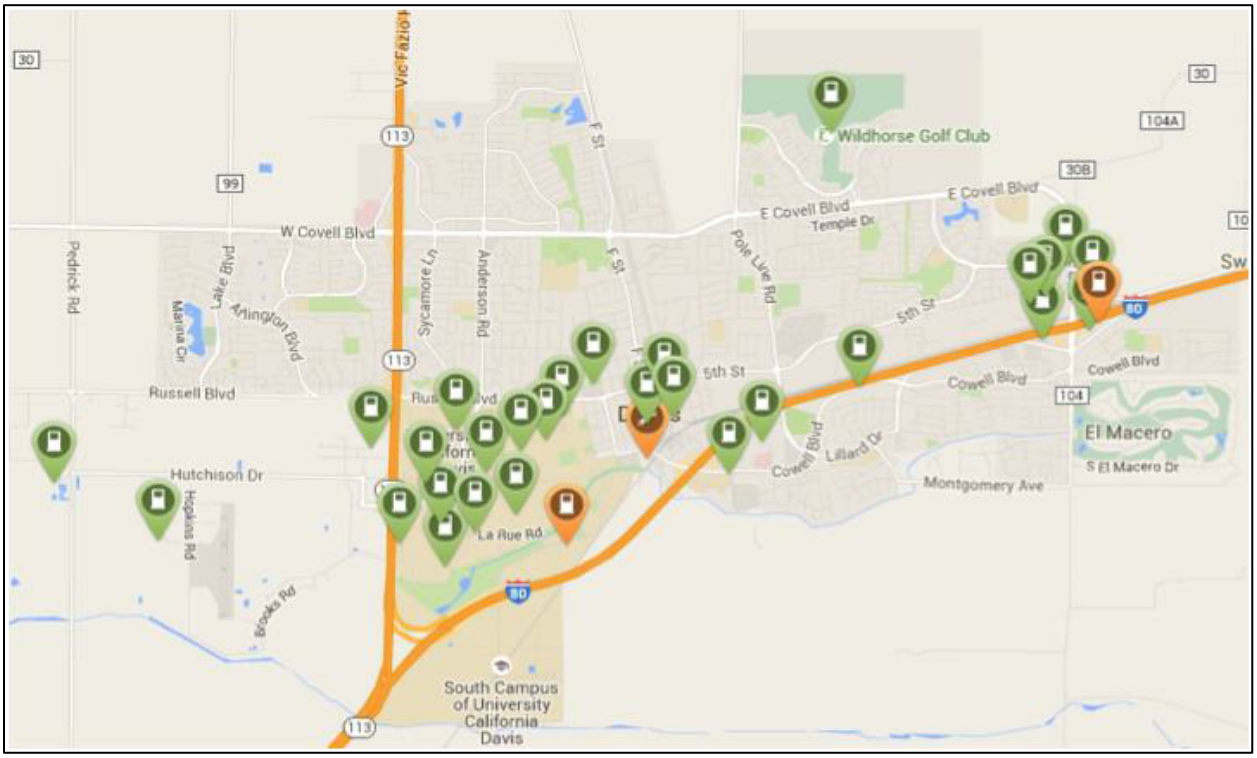
1. Corridor Demand: primarily from travelers with a driving distance that exceeds the battery range;
2. Workplace Demand: primarily from commuters who use fast charging stations near their workplace as an alternative to Level 1 or 2 workplace chargers when they are all occupied;
3. Home Demand: primarily from BEV drivers who use fast charging stations near their home as an occasional supplement to home chargers or when they need to charge their BEVs in a short period of time.

The Plan is designed to optimize charging infrastructure planning and implementation in Davis by balancing multiple factors that determine the demand for charging in particular locations. Based on the modeled demand, the Plan provides guidance on locating DC Fast chargers to achieve the highest benefit with the lowest investment. Note: Section 4 of the Plan provides additional detail on the recommended number and locations for DC Fast Chargers.

2.4 Current Locations

Currently there are over 25 Level 2 charging spaces and 3 DC Fast chargers in Davis, including the UC Davis campus. Selection of the locations of these existing chargers was generally based on the opportunity to install a charger and the availability of funds. The Plan will allow for a more deliberate, data-driven pro-active approach to selecting and installing the correct chargers where they can provide the greatest benefit. Figure 7 shows the current location of Level 2 and DC Fast chargers in Davis which are generally located in retail settings except those located on the UC Davis campus that generally serve as Workplace chargers. This information was a factor in determining the recommended locations for new chargers in the Plan.

Figure 7 Current Charging Locations in Davis



http://www.plugshare.com/

Section 3: Model and Results for Davis

The Davis EV Charging Plan forecasts the demand for charging infrastructure within the next 10 years, allowing the City, businesses, and private property owners to plan for and install the optimal number and type of chargers in the most useful locations. The Plan's key findings and recommendations are based on a set of GIS modeling tools developed by the UC Davis Institute for Transportation Studies (ITS) to forecast the future PEV market and usage in California and Davis.

Model design and inputs

The model is based on publicly available market and census data and on surveys of PEV owners in Davis and across the state. The approach utilized a four step modeling tool to estimate the demand for charging events in the city of Davis. The tool included: (1) a market demand model for state and local PEV adoption, (2) a destination charging model to estimate workplace charging demand, (3) a DC fast charging model based on inter-city travel, and (4) a model that matched activity based results with city land-use designations to predict the number of chargers needed by land use type and location. A detailed description of the modeling tool and results are included in Appendix A.

To provide additional local data and model calibration, the City, ITS, and Cool Davis conducted stakeholder meetings and public outreach events. Details on outreach efforts and outcomes are included in Appendix B.

With these inputs, the model was used to estimate the overall demand for local infrastructure needed to meet the City's portion of the Governor's goal of 1.5 million PEVs by 2025. The model estimated that about 4,500 households in the City overall will drive a plug-in vehicle as State sales

reach 1.5 million in 2025. These results indicate that Davis is expected to have a larger percapita share of PEVs than average across the State, which is reflected by current sales. These forecast results are generally based on Davis' above-average household incomes, its share of detached houses, and the general environmental attitudes adopted by residents.

With an understanding of the total number of forecasted PEVs in 2025, the question turned to where the demand was most likely to occur. To derive more specific location-based demand, ITS applied a PEV Market Demand tool to simulate the geographic dispersion of various new car buying and PEV buying scenarios in the City, including new and used BEVs and PHEVs (see Appendix A). The tool estimates the number of vehicles per census block group, given the 1.5 million PEV vehicles expected in California and Davis-specific demographic data. The forecasted distribution of Davis households with PEV's in 2025 is shown in Figure 8.

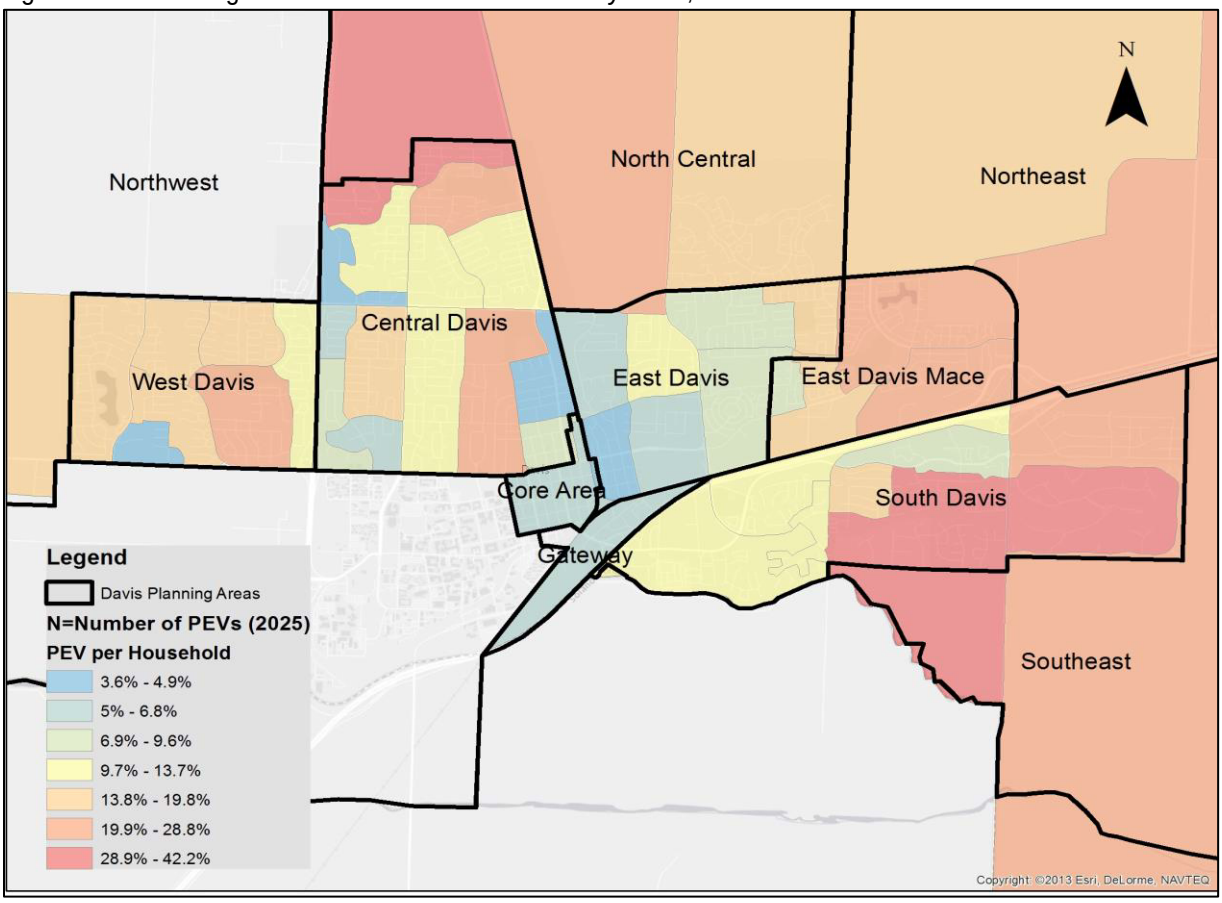
In addition to Household forecasts, analysis of employee, customer, and visitor demand based on land-use type and patterns allowed the City and its partners to forecast the number, type and locations of chargers needed across the community. Specific attention was given to the demand generated in the downtown core area due to its importance as a cultural, entertainment, and commercial center for the City. Each of the four main categories of charging are examined below – (1) Home, (2) Workplace, (3) Public, and (4) DC fast. Note, the forecast numbers and locations included in the maps below (Figures 8-11) provide planning level guidance and should not be considered prescriptive.

3.1 Home Charging

As noted, home charging is anticipated to be the primary charging location for most PEVs. The Plan provides a forecast of PEV households in 2025 by location. As detailed in Appendix A, the modeling for Home Charging indicates PEV penetration rates are highly correlated with income and single family housing but also effected by density and other local factors such as college student use of used PEVs. The model combines these factors with commute trips and average travel patterns to estimate the demand for home charging. The model projects that most PHEVs will use a 120V outlet and that Level 2 charger installation at private homes will be associated with BEVs since the benefit of Level 2 home charging is higher with the larger batteries typically found in full battery electric vehicles. Overall the model estimates approximately 1,400 home Level 2 chargers will be installed in Davis in the next 10 years The projection can be altered if the anticipated market composition changes particularly as more affordable longer range vehicles enter the market.

The model forecast provides important information about likely demand for home charging. Specifically, this modeling information: (1) informs the City and utility as they make electricity load forecasts and infrastructure planning decisions, (2) provides the City and its partners the opportunity to develop targeted messaging and outreach where PEV households are most likely to occur, and (3) provides the City and researchers the ability to track location-based PEV adoption over time and compare to this forecast.

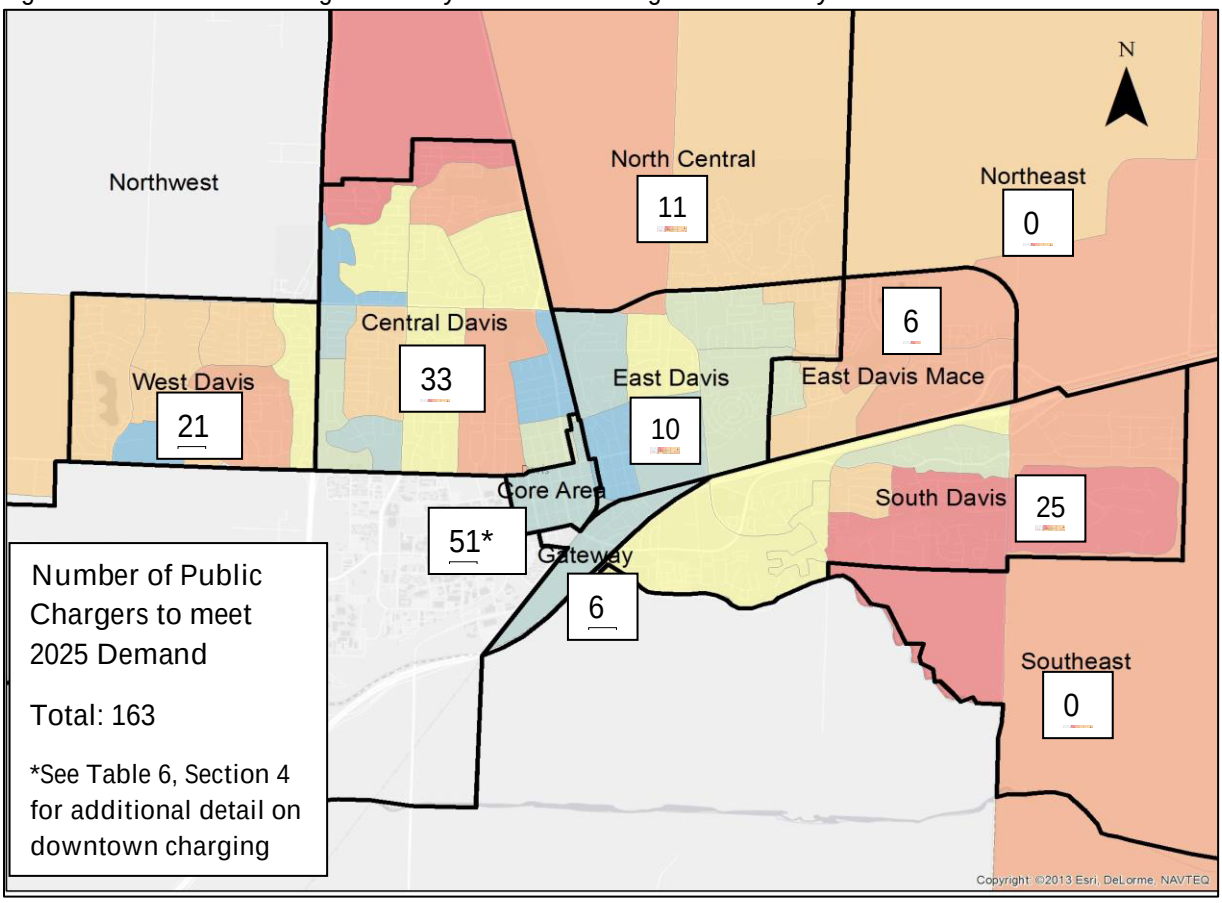
Figure 8 - Percentage of PEV households forecast by 2025, based on census track.



3.2 Publicly Accessible Charging

The model assumes that not every owner will be able to install a charger or even have access to a regular plug at home (e.g. apartments). Figure 9 shows the number and general location of Publically accessible chargers that would be needed by 2025 to serve PEV owners with limited or no access to Home charging. For the purposes of the Plan, Publically accessible charging includes both chargers located in public parking areas and Workplace charging that is available to non-employees (generally for a fee after business hours). Dual purpose charging locations create efficiencies and reduce the need for EV charging infrastructure.

Figure 9 Number of Overnight Publicly Accessible Chargers needed by 2025



The model estimates Publically accessible charging demand based on PEV owners charging needs that cannot be met at home. In addition, as shown in Figure 9, the model distributes the demand for Publically accessible chargers across the City with higher concentrations in areas with renters, apartment complexes and areas with high ratios of student households. This is due primarily to the limited ability of PEV owners ability to either install or access charging in rental housing.

While the Plan does not mandate the installation of Public chargers in certain areas of the City, it does indicate the geographical distribution of charging needs and allows the City to assess if adequate charging infrastructure is being provided. Further, if the private sector does not provide an adequate number or opportunities for Public charging, the Plan provides the basis for the City to pursue resources (e.g. grants), and/or modify development standards to meet the forecasted demand.

In addition, since Publically accessible charging supplements Home charging, the Plan assumes that Public charging will be priced equal to Home charging or adjusted down in the future if oversupply of renewables are cheaply available at certain times of day. As detailed in the Workplace charging description below, pricing has a significant effect on the demand for chargers. In general, pricing charging equal to Home charging reduces the demand for Public charging by 50% since PEVs drivers are more likely to charge only when necessary and not out of simple convenience.

3.3 Workplace Charging

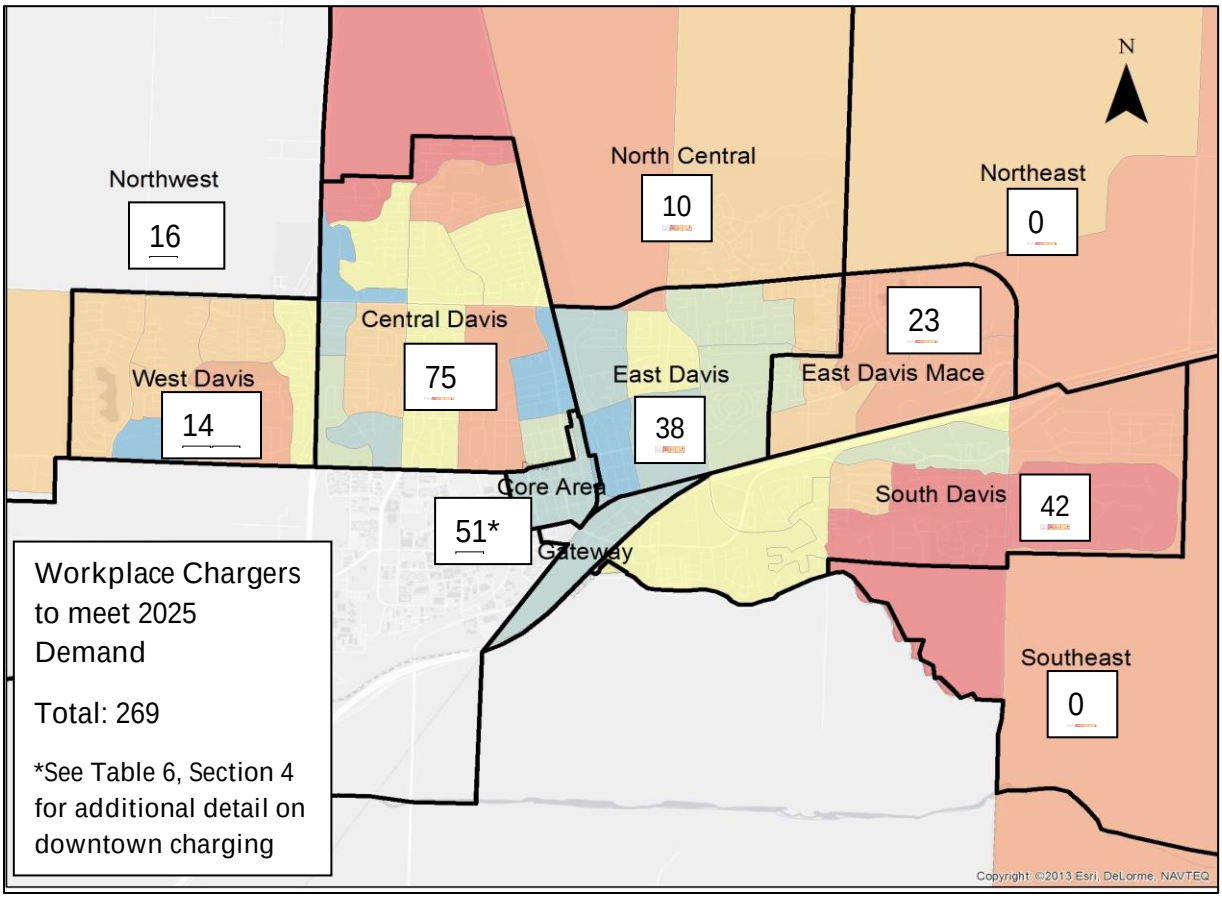
Workplace charging is the next highest demand after home charging. As detailed in Appendix A, Workplace charging primarily serves drivers who commute to Davis since commuter vehicles are less likely to be able to make the return trip home on electricity without additional charging. Demand for Workplace charging was estimated using statewide survey data to determine distances employees travel to their workplace. In addition, as noted, energy policy objectives and the availability of lower priced renewable energy during mid-day, are anticipated to result in future price adjustments designed to encourage PEV drivers to charge during the day. This will have the effect of increasing future demand for Workplace charging. However, if an employee driving a BEV can make the round-trip from home to work on a single charge with some safety margin and Workplace charging is priced more than Home charging, commuters will not utilize Workplace charging on a regular basis.

Given these considerations, overall demand for Workplace charging, including future projection for interconnection of PEVs with the electricity grid, is shown in Figure 10. Note: This assumes all chargers are level 2.

Though not recommended, free charging can generate notable benefits. For example free Workplace charging can:

- Stimulate market demand for PEVs by 2-8 percent (reference).
- Simplify administration of charging infrastructure since there are no fees paid to charging network operators to administer the fee mechanism.
- Provide an employee benefit to attract/retain employees.

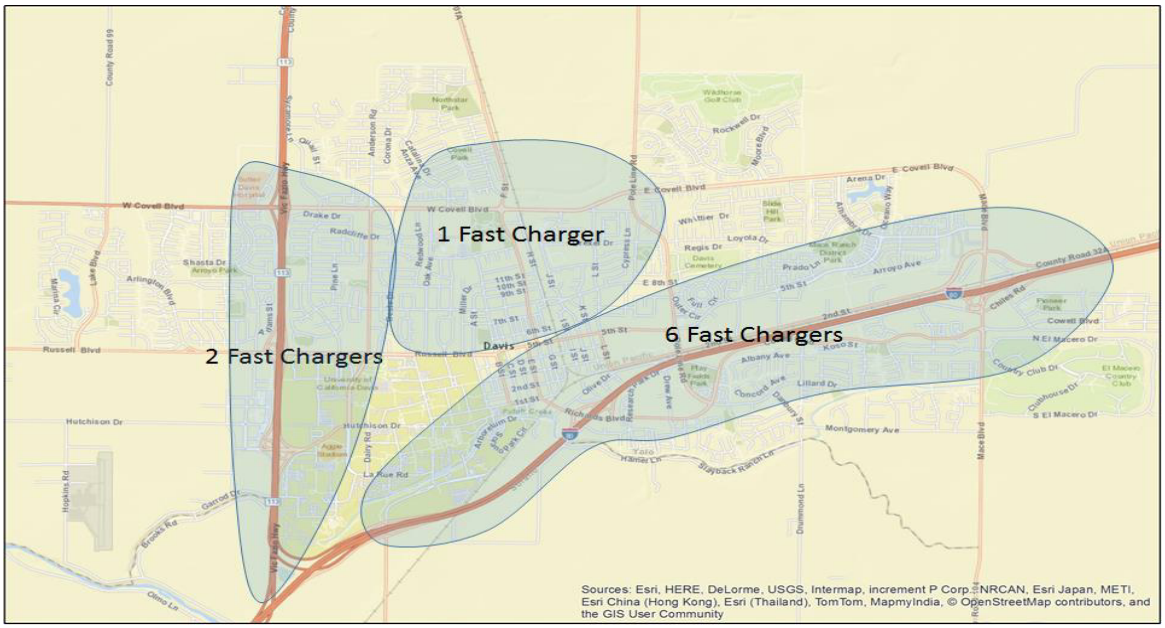
Figure 10 Workplace Chargers 2025



3.4 Fast Charger Locations

Fast chargers are designed to primarily serve vehicles traveling to or through Davis. The fast charger estimate is calculated by examining the 2012 California Household Travel and Charging Survey to determine the likely origin/destination distances a plug-in vehicle is traveling when it passes through or arrives in Davis. This determines how many drivers will be low on range adjusted for vehicle range. Additionally some demand is added based on overflow Home and Workplace charging demand. The total number and general location of recommended Fast chargers are shown in Figure 11.

Figure 11 Fast charger approximate locations and numbers.



The zone boundaries are approximate and are meant to reflect the demand along Highway 113 and Interstate 80. In general, Fast chargers should be located near the freeway, but 1 or 2 could be sited along major arterials such as Pole Line Road that are slightly farther from the freeway. Priority site location is determined by a combination of electrical capacity and appropriate land use. For example, shopping centers near the freeway are an ideal Fast charger location since they support a variety of activities (restaurants, shopping, etc.), that travelers can utilize while they charge. This approach also can stimulate local economic activity.

3.5 Customer Demand - Link to Land Use Type

As noted above, the Plan provides guidance on the type, number, and general location of chargers for Home, Workplace, Public, and Fast chargers. An additional factor is the demand for Workplace and Public charging generated by customers and visitors to commercial and industrial locations. The model estimated the additional charging demand generated by customers by activity type and linked the results to the City's land use designations. This is an often neglected consideration since this category of charging is variable in dwell time and duration. The model and analysis provided the opportunity to integrate activity purpose from the 2012 California Household Travel Survey (CHTS), to distance traveled and dwell time to develop a California- wide estimate of public charging need by land use type. The details of this analysis are included in Appendix A.

By combining these factors and linking these activities with land use categories, the City was able to incorporate customer and visitor demand into the recommended development standards detailed in Section 4 of the Plan. In addition, Table 3 below can serve to inform analysis by the City and property owners in estimating the demand for charging for existing non-residential properties. For example, if a property owner simply wishes to upgrade an existing shopping center with multiple businesses, Table 3 can help estimate the demand for PEV charging. In general, land uses with longer dwell times where customers travel from greater distances generate greater demand for charging. For example, a convention center that regularly hosts day-long events generates a higher

demand than a bank or retail store that primarily serves local customers. In recognition that commercial and industrial buildings often transition to new uses over time and that the best opportunity to make a site "EV ready" is at the time of construction, the Plan recommends that low cost PEV readiness measures be incorporated into new non-residential and multi-family projects.

Table 3 Charging events by Davis land use code

Land use	Public Charging Events per 100 EV customers
Automobile or machinery sales and service garages	1.24
Banks, post offices, business and professional offices	0.97
Bowling alleys	6.16
Churches, schools, day care centers and nursery schools	3.32
Dance halls and assembly halls without fixed seats, exhibition halls except assembly rooms in conjunction with auditorium	16.54
Funeral home, mortuaries	5.14
Furniture and appliance stores, household equipment or furniture repair shop	4.44
Group care homes	5.71
Hospitals	5.71
Hotels and motor hotels, motels,	10.91
Launderettes	0.97
Manufacturing plants, research or testing laboratories and bottling plants	0.00
Medical or dental clinics	5.71
Rest home, sanatorium, convalescent home or hospital	3.32
Restaurants, beer parlors, nightclubs, and cardrooms	7.33
Retail stores, shops, etc.,	2.16
Rooming and lodging houses	0.00
Shopping center, neighborhood	2.16
Shopping center, community	2.16
Sports arenas auditoriums, theaters, assembly halls	16.54
Wholesale establishments, warehouses,	4.44

Section 4: Development Standards

Section 4 presents development standards to implement the City's EV Charging infrastructure goals based on the planning level demand findings outlined in Section 3. These standards modify the City-adopted California Energy Code Tier 1 requirements for EV charging. This section also provides guidance for implementation of EV charging infrastructure for the mixed-use downtown Davis area. Note: Section 5 of the plan provides guidance and a planning tool for property owners who wish to add charging to existing locations. See Section 5 for specific recommendations regarding parking lot design and pricing considerations.

4.1 Standards – Non-Residential

Consistent with the demand model, the number of EV chargers required in the development standards are based on two primary factors:

1. Dwell time – how long a PEV driver will be staying at a location.
2. Distance – how far the PEV traveled to the potential charging location.

An additional consideration for workplace charging is the mix of employees and customers/visitors. A higher percentage of employees generally indicates the need for more chargers since they will typically be at the location for extended periods of time whereas customers/visitors will typically be at a location for more limited periods of time and are less likely to come from far away. For consistency, EV charging standards for non-residential land uses are based on land uses included in the City's parking standards. These non-residential land uses are grouped into three categories with similar characteristics for dwell time, distance, and employee/customer mix. Generally, locations with higher employee numbers equate to a higher ratio of chargers per required parking spaces.

As noted in Section 3.5, the model and analysis provided the opportunity to integrate activity purpose from the 2012 California Household Travel Survey (CHTS), to distance traveled and dwell time to develop a California- wide estimate of public charging need by land use type. Table 3 summarizes the application of these estimates to Davis land use types found in the City's parking standards. This provides the basis for establishing the standards shown in Table 4 below. As these standards are applied to new development projects, the City and its partners will have the ability to assess if the numbers and distribution are generally consistent with the information presented in Figures 9 and 10. If they do not, the City will have the basis to adjust its standards.

Table 4 Non-Residential Standards

Non-Residential Land Use Category	Required Parking Spaces	EV Chargers	Land use (From City Parking Code; City Code Section 40.25.090)
Retail	0-10	0	1. Automobile or machinery sales and service garages 2. Banks, post offices, business and professional offices
	11-51	1	
	52-102	2	
	Every additional	+1	

	50		3. Furniture and appliance stores, household equipment or furniture repair shop 4. Launderettes 5. Restaurants, beer parlors, nightclubs, and cardrooms 6. Retail stores, shops, etc. 7. Rooming and lodging houses 8. Shopping center, neighborhood 9. Shopping center, community 10. Land uses where up to 50% of spaces serving employees.
Non-Retail	0-10	0	1. Group care homes 2. Hospitals 3. Hotels and motor hotels, motels 4. Manufacturing plants, research or testi ng laboratories and bottling plants 5. Medical or dental clinics 6. Rest home, sanatorium, convalescent home or hospital 7. Wholesale establishments, warehouses 8. Land uses where more than 50% of spaces serving employees.
	11-26	1	
	27-42	2	
	Every additional 15	+1	
Destination	0-10	0	1. Bowling alleys 2. Churches, schools, day care centers and nursery schools 3. Dance halls and assembly halls without fixed seats, exhibition halls except assembly rooms in conjunction with auditorium 4. Funeral home, mortuaries 5. Sports arenas auditoriums, theaters, assembly halls
	11-36	1	
	37-62	2	
	Every additional 25	+1	

Notes:

1. All other non-modified Tier 1 standards for non-residential EV charging apply.
2. All required charging is Level 2 with the exception of non-retail (Workplace) charging which can be satisfied by 50% level 1 chargers with 50% payment-ready level 2 chargers due to longer dwell times. Note: calculations for total number of chargers shall be rounded up and rounding shall favor Level 2 chargers.
3. The first two chargers placed at non-retail (Workplace) locations must be payment ready Level 2 with subsequent chargers optionally Level 1.
4. 50% of required non-retail (Workplace) chargers to be installed prior to issuance of Certificate of Occupancy if approved prior to January 1, 2020. Remaining required chargers do not have to be installed at time of construction but must be pre-wired and have adequate electrical panel capacity for each future charger. After January 1, 2020, all required chargers must be fully installed.
5. Chargers should be placed to serve multiple parking spaces – see design recommendations in Section 5.

6. EV charging parking spaces shall be included in the required number of parking spaces per Article 40.25 of the City of Davis Zoning Ordinance. If space is available in a parking lot, additional EV charging spaces may be installed beyond the minimum number required subject to review and approval by the Department of Community Development and Sustainability.
7. Conversion of existing parking spaces for EV charging purposes shall be reviewed and approved by the Director of Community Development & Sustainability to assure a balance between full-size parking spaces, compact parking spaces and parking spaces for persons with disabilities.

Table 5 below provides guidance on applying the standards for non-residential workplace (non-retail) development projects.

Table 5 – Non-residential Charger Requirements

Charger Requirement												
1	Option 1	Wiring	L2									
		Charger	L2									
2	Option 1	Wiring	L2	L2								
		Charger	L2									
3	Option 1	Wiring	L2	L2	L2							
		Charger	L2	L2								
	Option 2	Wiring	L2	L2	L1							
		Charger	L2	L2								
4	Option 1	Wiring	L2	L2	L2	L2						
		Charger	L2	L2								
	Option 2	Wiring	L2	L2	L1	L1						
		Charger	L2	L2								
5	Option 1	Wiring	L2	L2	L2	L2	L2					
		Charger	L2	L2	L2							
	Option 2	Wiring	L2	L2	L1	L2	L1					
		Charger	L2	L2	L1							
6	Option 1	Wiring	L2	L2	L2	L2	L2	L2				
		Charger	L2	L2	L2							
	Option 2	Wiring	L2	L2	L1	L2	L1	L1				
		Charger	L2	L2	L1							
10	Option 1	Wiring	L2	L2	L2	L2	L2	L2	L2	L2	L2	L2
		Charger	L2	L2	L2	L2	L2					
	Option 2	Wiring	L2	L2	L2	L1	L1	L2	L2	L1	L1	L1
		Charger	L2	L2	L2	L1	L1					

Note: L2: Level 2 Charger; L1: Level 1 Charger

4.2 Standards - Residential

As noted, Home charging is the most common type of charging that will occur in Davis. The following standards modify Tier 1 of the California Energy Code for the installation of EV chargers in

new residential development projects. The following modifications to the Tier 1 standards for new development are recommended:

Table 5 Residential Standards

Development Type	Tier 1 Modifications	Notes
Single Family (1-3 units)	1. Single Family Residential development required to pre-install 8 Gauge wiring plus reserve room in electrical panel necessary to support Level 2 electric vehicle charging.	1. Addresses key barrier for adding Level 2 Home EV charger.
Multi-family (4 or more units)	1. Multi-family Residential development projects are required to provide: (1) Level 1 charging at 5% of all required parking spaces with a minimum of 2 parking spaces served, (2) Level 2 charging at 1% of all required parking spaces where more than 20 parking spaces are required with a minimum of 1 parking space served, (3) conduit adequate for Level 2 charging to serve or reasonably be extended in the future to 25% of all parking spaces, and (3) room in panel(s) and capacity to serve 20% of all parking spaces with Level 1 charging and 5% of all parking spaces with Level 2 charging. Notes: (1) properly located, a single charger can serve multiple parking spaces; (2) Reasonable future extension of conduit would not include the removal or trenching of hardscaped surfaces or areas where mature trees would be expected to establish (e.g. pavement, tree wells, etc.)	1. Addresses key barrier for EV use in residential rental settings.

Notes:

1. All other non-modified Tier 1 standards for residential EV charging apply.
2. Chargers in Multi-family residential settings should be placed to serve multiple parking spaces – see design recommendations in Section 5.
3. Level 1 in the context above is defined as a 20A 120V circuit and Level 2 is defined a 40A 208V/240V circuit
4. Level 1 is defined as a 120V hardwired EVSE not a household outlet.
5. Monitoring equipment to properly charge tenants is encouraged at multi-family locations

4.3 Davis Downtown Chargers

Downtown Davis has a mix of activities and mixed parking uses. Utilizing the Downtown Parking Study (2013) and the existing land use mix, the need for chargers in the downtown area was modeled based on the different land uses served and parking times allowed. Overall, if chargers in

the downtown are priced equal to home charging and chargers are provided to accommodate Vehicle to Grid integration as recommended, 51 Level 2 chargers will be needed to meet the demand of customers, employees, and visitors including users who substitute for Home charging. Table 6 details the need of chargers by location and parking time. Most chargers are anticipated to be used by employees, while only a small number of the short parking time customers/visitors will need chargers.

Table 6: Downtown Charging

Space Type	Parking supply	Chargers needed	Where
90-min only	35	1	H Street (between Second & Third)
2-hr only	1,012	5 + additional to promote customer attraction	Most of downtown (street & lots)
3-hr / Daily	199	2	Parking structures
Employee and/or shared (e.g. 90-min / X-permit)	670	30	Downtown periphery, First & F garage
Paid	56	1+ additional to promote customer attraction	E Street Plaza lot
Amtrak only	134	12+ additional to promote customer attraction	Amtrak lot

The Plan recognizes the role and benefits of chargers bringing business to downtown. In recognition of this benefit, the Plan recommends additional chargers at the short term and paid lots. The City may choose to make chargers in these locations free if customers/visitors pay for parking based on the assumption that their need for charging is likely low and the primary benefit would be the parking location and availability. This approach can increase the standing of the Downtown as a destination for EV drivers. In addition, the City may consider the benefits of a full parking lot(s) that provide access to Level 1 charging at all parking stalls with no dedicated charging spaces (e.g. 120V EVSE on all parking lot light posts). This would allow customers and visitors to receive low level charging at minimal operation and maintenance effort by the City or downtown merchants.

Section 5 Site Specific Recommendations

When planning a new parking area or retrofitting an existing parking area, providing key EV charging design features can make the difference between a missed opportunity and a high performing lot that can adapt to future needs. This Section considers factors such as charger placement, charging level, and pricing and provides developers and planners with best practices to achieve desired outcomes.

5.1 Parking Lot Charger Placement

The placement of chargers in a parking lot has four main considerations: visibility, reducing conflict with gasoline vehicles, reducing conflict with PEVs that do not need to charge, and maximizing the number of spaces that can be reached with a charging cord. These considerations apply equally to retail and workplace charging.

Some businesses choose to place stations in prominent locations convenient to a business entrance. This strategy is employed oftentimes to demonstrate environmental values and provide a perk to those with similar values. The location of existing electrical service, which is often next to a building's entrance, also has a strong influence on charger placement.

Placing chargers convenient to entrances, however can create conflict with non-PEVs and even with PEV drivers who do not need charging but desire a better parking place. Placing chargers near the entrance should be done with the knowledge that it is mostly a parking perk and not the most effective charging strategy. If it is done, a higher charging price or shorter parking time limit relative to other charging spaces is an effective strategy to discourage unnecessary use of these prized parking spaces.

Best Practice #1 EV Charger Location. Adopt a "charging-first strategy" and ensure that a majority of chargers are not near business entrances unless they are for those with disabilities. Combining the perk of charging with the perk of preferential parking increases the likelihood of a charging space being occupied by PEV users that may not need to charge. Locating chargers in spaces less likely to be used by other vehicles is a more effective strategy to provide reliable charging to those who actually need it and discourage those who do not.

In Figure 12, Location 1 may have the best access to electrical power, but is a popular parking place creating conflict. Location 3 creates the least conflict with other vehicles and is the best location to ensure that charging is dependably available for those that need it. A mixed strategy such as Location 2 can also be employed where some EV charging spaces are convenient to provide a perk with more dependably available charging located elsewhere.

Figure 12 Charger Parking Lot Location Options

Best Practice #2 Charger spacing. If possible, a charger should be placed to reach as many spaces as possible. While Location 3 in Figure 12 provides the least conflict, Location 2 provides the greatest reach for a single charger because it is in the middle of an island surrounded by parking. In this example, one charger can reach up to eight spaces. This allows for employees to stay in one space all day and the next charger user simply moves the cord instead of moving the car. Moving vehicles mid-day to allow for other people to charge is often impractical at the workplace. Figure 13 shows that by placing a charger in Location 2 between parking stalls b, c, g and h allows the charger to be accessed by those four spaces. In many cases, depending on the type of charger that is installed, spaces a, d, f and i can also be reached. If a charger is able to be reached from multiple spaces the need for time restrictions and reserved parking diminishes. Note: at a minimum it is prudent to sign at least two spaces per charger as reserved for EVs.

Figure 13 Spaces reached per charger

Best Practice #3 Number of spaces per charger. Initially Location 2 may have only one charger, but as demand grows, two chargers reaching spaces b, c, g, and h provides parking flexibility. Although 4 or even 8 chargers could be mounted at location 2, the best practice is to limit spaces per charger to 2. If a, d, f and i are reachable, then increasing chargers at location 2 is possible, but this requires stretching cords or perhaps backing into spaces, so should be avoided if other options are available. Finally, chargers should be placed between spaces and recessed to reduce the chance that vehicles will hit them. If they are placed directly in front of a space, bollards can be used to protect the chargers.

5.2 Selecting Appropriate Charging Levels

As outlined in Section 2, there are many different speeds of charging available and the speed needed is a function of the vehicle capabilities, travel distance, and parking dwell time.

Best Practice #4 Charger Level. If a vehicle travels a significant distance relative to its battery range and only has a short amount of time to spend at a location (e.g. 30 min), Fast charging will be needed. Conversely, if a vehicle travels from a medium to far distance away, but has many hours to charge, Level 1 or Level 2 is appropriate. Many times a mix of charging speeds with different prices maximizes the use of a given panel capacity and minimizes cost.

For retail applications, parking dwell time is relatively short so Level 2 is appropriate in most cases. For very long dwell times level 1 can be used. For workplace applications up to 50% can be Level 1, with the rest being Level 2. Additional variables to consider:
For practical purposes, Level 2 requires that drivers move their vehicle after 4 hours or move cords to allow the next driver to charge. Often this extra effort to move cars or cords makes Level 1 an attractive option for many users if accompanied with no parking time limits.
Level 1 maximizes panel capacity. On a 200 amp 3-phase electrical panel, 8-9 Level 2 chargers can be installed, while 40 Level 1's can be installed with the same service.
All other factors being equal, research indicates that PEV drivers prefer Level 2 charging. To encourage self-selection, Level 2's should be priced higher than Level 1 service or have shorter parking time limits. In some cases, Level 1 has been given away for free as the slow speed limits overuse.

Best Practice #5 Consider charger options. Power splitting chargers and chargers responsive to signals from the grid may be important options to consider for certain needs/objectives of property owners. Power splitting chargers take a Level 2 and divides the power among all the vehicles plugged into the unit. When one vehicle is plugged in, full power goes to one vehicle. When two vehicles are plugged in, half of the power goes to one vehicle and half to another. If vehicle to grid services are desired or there is a differential electricity rate at a certain time of day, some chargers can "listen" for a signal to take advantage of these time windows. If timing is important, Level 2 chargers can deliver more energy in a short amount of time and are better than Level 1 for this application.

5.3 General Guide - Cost of Installation, Hardware, and Administration

Table 4 EVSE installation and hardware costs

EVSE Type	Installation Cost Range	Hardware
Level 1	$0-$3,000	$300-$1,5
Level 2	$600-$12,700	$400-$6,5

Simple chargers tend to be on the low end of the range and "smart"/networked chargers tend to be on the upper end of the price range. For workplace scenario purposes we assume the cost of installation and hardware is distributed over 10 years and the costs are as follows.

Table 5 Upfront charger costs for charger scenario

EVSE Type	Installation	Hardwa
Level 1 Free	$500	$400
Level 2 Free	$3,000	$1,200

Administration for the networked charger is assumed to be $250/year. Electricity is $0.12/kWh and Paid charging is assumed to be $0.165/kWh. Level 1 chargers are assumed to be actual EVSE not simply wall outlets. Level 2 serves 2 vehicles per day. As shown in Table 6 below, to serve 10 people, the number of chargers decreases if drivers are charged since only those who need charging will plug in. In many cases those who do not need charging never plug in. Using these assumptions, the general cost of installing and operating a charging station can be estimated.

Table 6 Charger Installation and Operation Cost Estimates

EVSE Type	Chargers needed per 10 people	Electricity 10 people 10 yr	Admin 10 yr	Total +Hardware for 10 Cars	Tota car
Level 1 Free	8	$26,611		$33,811.20	
Level 2 Free	4	$26,611		$43,411	

Using these assumptions, the total cost to serve 1 car with free level 1 chargers is $338/car/year, free level 2 is $434/car/year and with paid charging, $157/car/year. If there were 1000 workers commuting to Davis in PEVs, it will cost employers $338,000/year to serve those cars with free electricity on level 1 with 800 chargers (amortizing the cost of those chargers over 10 years). Under a paid scenario, an extra $0.045/kWh on top of electricity cost of $0.12/kWh will create a payback equal to the cost of administration making the chargers cost neutral if the cost of the charger is negated. However $0.165/kWh will not be an attractive price to many with low gasoline prices, so demand must be continually adjusted as gas prices rise and fall. A price higher than home charging and lower than gasoline per mile is a reasonable target range. This means that a charger price closer to $0.12-$0.13 cents/kWh might be targeted to encourage beneficial use. At this price, however, the cost of charging will not cover the yearly administration costs in many cases.

Downtown Davis has metered paid parking at the E Street lot between Second & Third Streets. If chargers are free for those who pay the parking, about $3.00 in electricity cost must be recovered per day plus $0.32 for the amortized cost of the charger hardware. Other solutions exist for retail such as making the first 2 hours free and then charging money after two hours have elapsed. This creates a situation where drivers will want to stay in the Downtown for up to 2 hours to shop/dine/etc., but also move so others can charge when they have completed charging.

5.4 Price to Charge

The decision whether to charge money for the charging service has many considerations. Free charging can attract business to a retailer with the value of the electricity dispensed less than the amount of profit made on the customer. Further free charging may spur vehicle sales 2%-8%. Free charging is easier to administer as the chargers are cheaper and there is no network fee to monitor and no money to collect.

Best Practice #6 Consider the advantages and disadvantages of free charging
Advantages:
Attract business to a retailer with the value of the electricity dispensed less than the amount of profit made on the customer.
Spur vehicle sales 2%-8%.

Minimize administrative costs since the chargers are cheaper and there is no network fee to monitor and no money to collect.

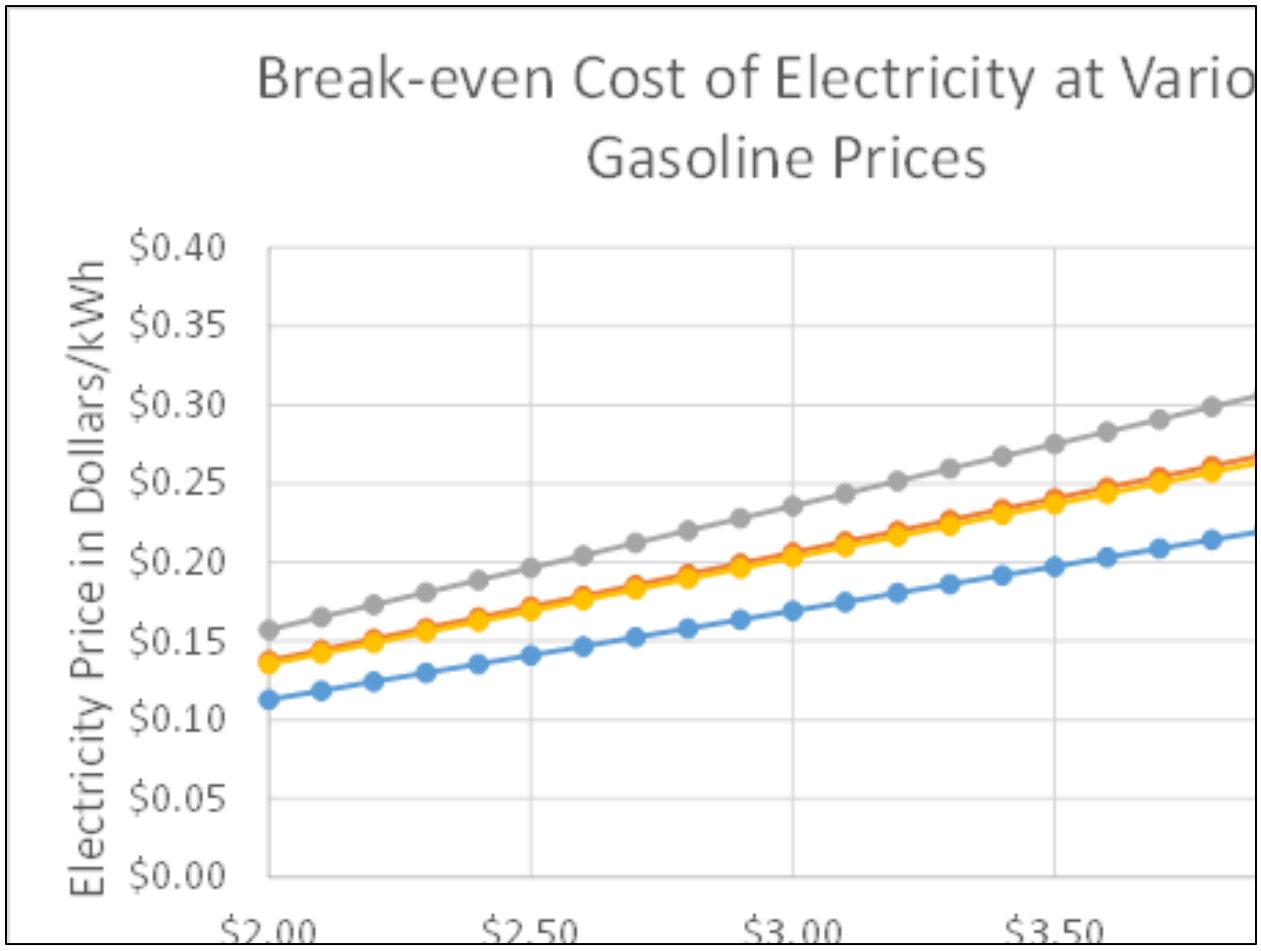
Disadvantages:
Requires a host site to install 3-4 times as much infrastructure to serve the same number of vehicles since people will use the free charging even when they do not need it.

- Increases congestion. Chargers are always occupied to the point that a vehicle that actually needs to charge will cease to depend on it at that location.

- Decreases the incentive for a site host to install more charging, as the electricity and hardware are simply costs with no return.

The business model for charging does not provide high margins if gasoline prices are low. Charging for charging however can be used to limit the cost downside while still providing people a lower cost per mile than a gasoline vehicle. Figure 15 shows the break-even costs of electricity at various gasoline prices for four vehicles. The Leaf is compared to a standard Prius at 50 MPG.

Figure 15 Break even costs of electricity versus gasoline for 3 PHEVs and 1 BEV



At $2.00 per gallon the break-even costs range from 11 cents for the Plug-in Prius to 16 cents for the Chevrolet Volt. If charging costs more than these amounts, gasoline will be cheaper on a cents per mile basis. If the cost of gasoline is higher, then the break-even price of charging can go up.

Pricing Considerations

There are three basic methods to set rates for charging:

1. Charge by energy (kWh). This is similar in concept to charging by the gallon of gasoline.
2. Charge by the hour. This is a way to charge for both parking and charging but favors BEVs over PHEVs with slower charging.
3. Flat connection fee per charging event. This has the effect of discouraging short charging sessions.

For the purposes of comparing different pricing strategies, an average PG&E residential electricity rate of 16 cents/kilowatt hour is assumed. Current PG&E residential rates can be found at: http://www.pge.com/tariffs/electric.shtml. User costs are illustrated in Table 6.

Table 6 User Cost/Pricing Methods

1 hour charging session				
		Charge by		
	Total kWh transferred	kWh (@16¢)	Hour (@$1/hr)	Co
Plug in Prius (2kW)	2	$0.32	$1	
Chevrolet Volt (3.3kW)	3.3	$0.53	$1	

Each vehicle has a maximum charging speed. As Table 6 shows different vehicle models have a maximum number of kWh that can be transferred per hour. The speed of charging and what type of plug-in vehicle type the City, business owner, or employer wants to encourage is a key consideration in determining a pricing structure for charging. To illustrate, the pricing characteristics of the Plug-in Prius (PHEV) and Leaf (BEV) are outlined below.

- Prius. Maximum charge speed is 2kW even if the charger can provide power at more than 2kW; in this example the Plug-in Prius receives 2kWh of energy every hour.
- Leaf. Maximum charge speed is 6.6kWh. At this speed, it would be utilizing the full capacity of a typical charger

If a flat rate is set at $1 per hour, the Prius will pay $0.50/kWh. As shown in Figure 15 above, this is approximately 300% higher than the current price of gasoline at $3/gal, which would incentivize a Prius Plug-in driver to charge at home. By contrast, the Leaf charges at 6.6kWh, translating to a $0.15/kWh price for a flat $1/hr fee. This rate is often lower than average home charging so a BEV driver would be incentivized to charge away from home. Charging by kWh is the most economical for PHEVs with a slower charging rate, but the capacity of a Level 2 charger would be underutilized. An additional consideration is that charging a flat fee by hour can be easier to administer as it can be easily integrated into existing City parking enforcement or into an employer's parking policy. However, if the goal is to displace gasoline, the effective $/kWh should be in the $0.13-$0.16 range.

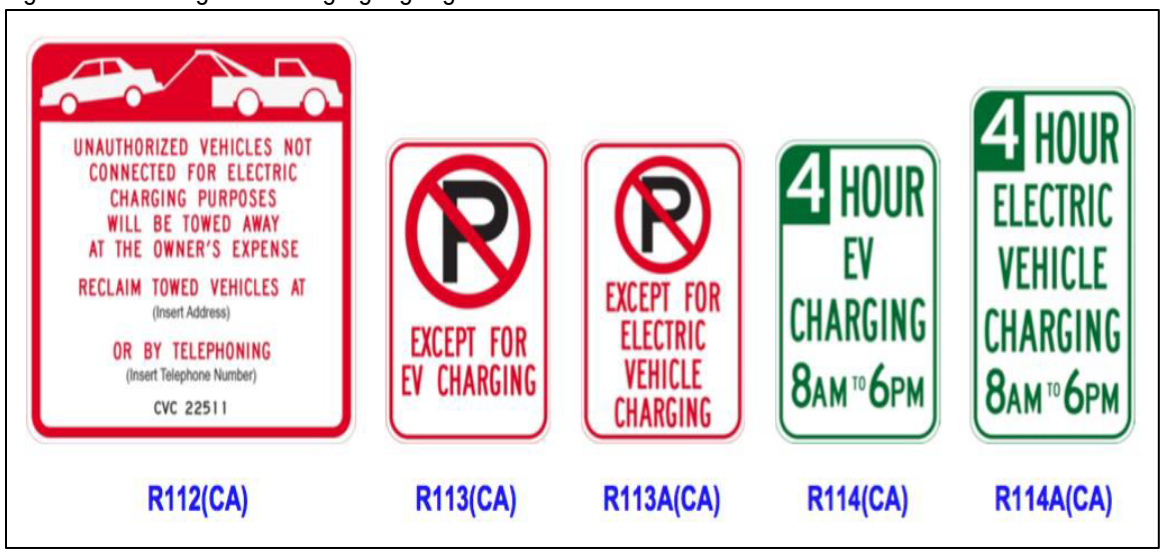
Best Practice #7 Pricing. Consider the objectives that the organization/business/property owner is trying to achieve and price charging accordingly. Charging by kWh is most fair to PHEVs, but to promote BEV and PHEVs with larger batteries/electric range and to simplify administration, the Plan recommends that the City establish a price per hour fee for charging at Public chargers.

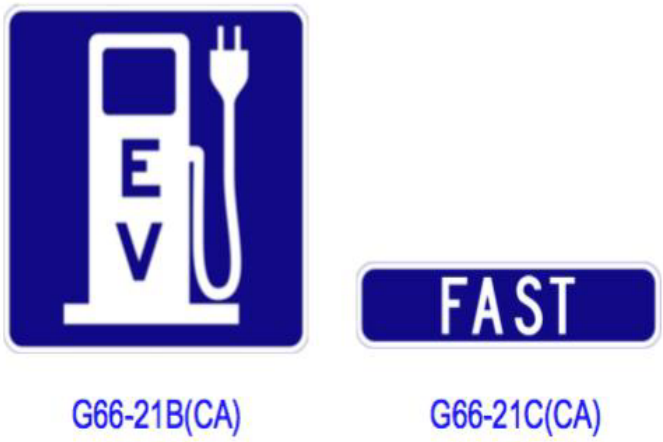
Section 6: Policies and Signage

6.1 Signage

The California Department of Transportation (Caltrans), has adopted the following regulatory and general information signs and pavement markings to guide and regulate PEV drivers. To ensure consistency for PEV drivers, the Plan recommends that the City adopt the same sign standards and designs for PEV charging and parking.

Figure 14 Parking and Charging Signage





Additionally, signage should indicate whether the space is primarily for parking or charging and who is allowed to charge during which hours (eg. Some spaces many be reserved for employees or customers during business hours, but available to the public overnight).

6.2 Parking

Enforcement

The Plan recommends that the City of Davis update the City Code (Section 22.16 Electrical Vehicles and Car Share Vehicles), to set standards consistent with this Plan and allow for parking officials to enforce time limits and fees for EV charging spaces. Parking in spaces dedicated for EV charging by non-electric or non-hybrid vehicles shall be subject to parking enforcement action, i.e. towing at the owner's expense.

Accessible Parking/Charging

In-lieu of established State standards regarding accessible charging, the Plan recommends that the City utilize the guidelines established by the California Plug-in Electric Vehicle Collaborative (PEV Collaborative). The Collaborative's Accessibility and Signage for Plug-in Electric Vehicle Charging Infrastructure report can serve as a policy for installing charging equipment serving accessible EVSE. The City will adopt State standards for accessible EV charging as new standards are approved.

6.3 Fleet

The State has set the following goals to increase the number of zero emission vehicles (ZEVs), in its fleet through gradual vehicle replacement.

- By 2015, ZEVs should make up at least 10% of fleet light-duty vehicle (LDV) purchases.
- By 2020 at least 25% of fleet LDV purchases should be ZEVs.

The Plan recommends that the City adopt the same minimum goals for its fleet and investigate the feasibility of increasing the percentages. Charging level and location decisions to serve the increasing number of City PEVs will be based on the findings in the Plan. Consistent with the overall objectives, the City will investigate the feasibility of making its chargers available for Public charging after business hours and weekends and holidays.

Current Fleet Ecosystem

Many fleets in Davis have adopted alternative fuel vehicles in order to lower emissions, cut costs, and reduce environmental impact. Both Yolobus and Unitrans have converted the majority of their fleets to CNG buses. UPS deploys trucks fueled by natural gas to Davis. Davis Waste Removal has taken advantage of Clean Air Program grants to add CNG trucks to its fleet. Whole Foods is currently converting their delivery fleet to biodiesel as well as adding aerodynamic aprons and a system which allows for engines to be turned off during loading and deliveries. Even small businesses have switched to cleaner vehicles; a real estate office has been utilizing electric vehicles since 2002. The City of Davis currently utilizes electric utility vehicles and nearly one third of the City fleet is made up of hybrid vehicles. The City's vehicle replacement review includes plans to switch out many of the City's current vehicles with electric or hybrid vehicles in the future.

Fleet Recommendations

The Plan recommends that the City update fleet purchasing policies to match State fleet goals. Utilize Ready, Set, Charge, Fleets as a guide/resource, and consider joining Energy Secure Cities Coalition (ESCC) that provides guidance on transition to PEVs. Examples of where ESCC is active include:

- Conversion of public fleets to PEV.
- Training on PEVs and charging.
- Making charging infrastructure easy and convenient for employees to plug-in
- Matching vehicles to use

Section 7 Key Findings, Recommendations, and Future Considerations

In developing the Plan, the City and its partners identified several key findings, recommendations and future considerations related to EV charging. The purpose of this Section is to summarize these findings and recommendations and note the emerging policy and issue areas and provide decision makers with initial guidance on how they might be addressed.

7.1 Key Findings and Recommendations

Key Findings:

- Demand forecast should include both direct PEV demand as well as the role of PEVs in balancing the electricity grid (Vehicle to Grid – V2G).
- Direct PEV demand and pricing strategy is driven by three primary factors: (1) parking dwell time, (2) distance traveled, and (3) vehicle battery size.
- In the near term most charging will take place at home; V2G is likely to shift charging patterns toward non-home charging as variable renewable energy generation increases (e.g. solar), and value is established for the role PEVs play in grid balancing and stability.
- Half of Workplace charging can be satisfied with Level 1 charging due to parking dwell time.

Key Recommendations:

- Modify CalGreen standards for Davis to incorporate differentiation for PEV charging installation requirements based on land use.
- In recognition that V2G based demand will increase in the future, prior to 2020, require minimum number of network ready Level 2 chargers with 50% of the total Workplace chargers installed as part of original construction and 50% prewired for future installation. Post 2020, require all chargers to be installed as part of original construction.
- Unless creating incentives for employees, tenants, customers, or V2G interconnections, chargers should generally be priced equal to the cost to charge at home to encourage need based charging and discourage convenience based charging.

7.2 EV/PV Home Charging

Adding an electric vehicle will increase electricity energy use at home and with it the awareness of energy cost and clean energy opportunities. Given the Plan's recommendations to emphasize Home charging, the City and its partners should consider how to develop and disseminate basic photo voltaic (PV) system sizing information for homeowners who are considering adding a PEV. The Plan provides a starting point for development of this information in Section 5 (pricing), and the public outreach conducted for the plan provides a local communications network for PEV drivers to share information. In addition, the City and Cool Davis have initiated a community campaign to double the number and capacity of residential roof-top solar systems in Davis between 2015 and 2020. Connecting the EV/PV message to that campaign could be an effective approach.

Another future opportunity is the pending formation of a local Community Choice Energy (CCE) program to serve the electricity needs of Davis and unincorporated Yolo County electricity customers. The CCE program may be in position to support EV/PV Home charging through its rate

setting authority. In its position as one of the forming members of the local CCE, the City can bring this concept to the CCE for analysis and consideration in future years. Sonoma Clean Power, a CCE serving Sonoma County is pursuing a policy to advance PEV adoption by installing publicly accessible chargers.

7.3 Vehicle to Grid (V2G)

As noted throughout the Plan, the connection between PEVs and the electricity system is an important consideration. Vehicle to Grid, or V2G, describes an interaction between the vehicle's battery and the electricity grid where power can flow in both directions. One of the most important concepts is how V2G can help the electricity grid stay balanced. For example, in the middle of day when solar is providing significant amounts of clean renewable energy to the grid, a PEV plugged into a Managed charger can take excess electricity that might otherwise go unused or be curtailed (the value of unneeded electricity drops). Conversely, a PEV that was fully charged and plugged in could be "asked" by grid operators to release electricity to the grid when and where it is needed to avoid brownouts during hot days. Additionally, a PEV parked at home with more power than it needs for the next day's travel could supplement home energy use at night with the clean renewable electricity it stored during the day while sitting in a parking lot at a workplace.

The City and its CCE partners should consider examples such as Sonoma Clean Power that are exploring how to implement V2G and the smart and micro-grid technology that will enable PEVs to play an important and integrated role in Davis' energy future. The Plan recommends the installation of chargers with communication capability that can be used for managed charging and V2G when applicable.

7.4 Autonomous Plug-in Electric Vehicles (APEV)

Autonomous self-driving vehicles are expected to emerge and become mainstream within the timeframe of this plan (2025). Electric autonomous vehicles will provide additional benefits of low carbon/clean air vehicles that can work in conjunction with regional public transportation to provide efficient response based mobility. The City and its partners at the UC Davis Institute for Transportation Studies should consider how PEV charging infrastructure can be designed to efficiently serve self-charging autonomous vehicles. For example, a clustered remote self-charging station that allows the APEV with the least charge to park and charge near the center of the cluster while other APEVs with sufficient charge are "dispatched" to serve customers of ride sharing services. Advances in charging system technology will be necessary to optimize this emerging mobility system but the City and its partners should be prepared to be a test bed.

7.5 Shared Charger Use

As noted in Section 4, shared charger use can optimize the use of EV charging infrastructure. Typically this opportunity would occur where an employment center/workplace and retail establishment are co-located (e.g. professional offices and restaurant). Another important opportunity identified by the Plan development team are neighborhood shopping centers located near high-density multi-family housing. In this circumstance, EV chargers could serve as both Workplace chargers during business hours and as overnight chargers close to residences. Priced appropriately this could present mutually beneficial opportunities for the shopping center and nearby residents. This is already occurring on a limited scale with the two Level 2 chargers located at City Hall – employee/visitor charging during business hours and nearby PEV owners charging

overnight. The City and its partners could engage neighborhood shopping owners who want to provide an amenity to their customers/employees and nearby apartment owners who can market to prospective renters that they are "EV Friendly". With the foundation created by the Plan, many other examples of this market based approach could be identified and initiated by the City and its partners.

7.6 Short-term Action Plan

The following actions are based on the research and analysis conducted for the Plan and are anticipated to be implemented by 2020. The short-term actions are identified to provide the City and its partners with guidance for charging infrastructure as resources become available. The short-term actions do not preclude activities or investments consistent with the overall Plan and updates to the short-term actions listed below are anticipated to adapt to changing technological and/or marketplace conditions. A total of 85 Level 2 and 3 DC Fast chargers spread across the City in key locations that serve multiple user types (e.g. workplace + supplemental home charging). This represents approximately 32% of the estimated 2025 demand for workplace charging.

City Region	Location	Charger Type	Number	Description/Primary Purpose
Central	City Hall	Level 2 networked	4	Workplace/supplemental home charging for nearby rental housing. Upgrade 2 existing Level 2 chargers; add 2 additional Level 2 chargers.
Central	City Hall	DC Fast	1	DC Fast Charge local network. Located at existing water well to minimize infrastructure costs.
Central	University Mall – Central Davis	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
Central	Davis High School/Veterans Memorial Center/Yolo County Public Library/Community – Central Davis	Level 2 networked	8	Visitors/workplace/ supplemental home charging for nearby rental housing.
Central	Market Place Shopping Center	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing/Highway 113 Corridor travelers.
Downtown	Downtown Davis – E Street Parking Lot	Level 2 networked	2	Upgrade existing Level 2 charger. Customer attraction/workplace.

Downtown	Downtown Davis – Core Area USDA/F Street Parking Garage	Level 2 networked	6	Workplace/customer attraction/supplemental home charging for nearby rental housing.
Downtown	Downtown Davis – Core Area Cinema/G Street Parking Garage	Level 2 networked	4	Workplace/customer attraction/ I-80 Corridor travelers.
Downtown	Downtown Davis – E Street Parking Lot	Level 2 networked	2	Upgrade existing Level 2 charger. Customer attraction/workplace.
Downtown	Downtown Davis – Train Station Parking Lot	Level 2 networked	4	Upgrade 2 existing Level 2 chargers; add Level 2 chargers. Workplace/ Customer attraction/ Capitol Corridor travelers/I-80 Corridor travelers.
West	Arroyo Park Swimming Pool Parking – West Davis	Level 2 networked	1	Visitors/supplemental home charging for nearby rental housing.
West	Westlake Shopping Center – West Davis	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
West	West Manor Park – West Davis	Level 2 networked	1	Visitors/Supplemental home charging for nearby rental housing.
NW	Sutter Davis Hospital/Medical Offices – Northwest Davis	Level 2 networked	2	Workplace/ visitors/Highway 113 Corridor travelers.
NW	Sutter Davis Hospital/Medical Offices – Northwest Davis	DC Fast	1	Highway 113 Corridor travelers/workplace/ visitors.
North Central	Cannery Commercial Center – North Central	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
North Central	Wildhorse Golf Course – North Central	Level 2 networked	1	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
East	Davis Police Department	Level 2 networked	3	Police Department Fleet.

East	Davis Public Works Department – 1717 5th St	Level 2 networked	2	Public Works Department Fleet.
East	Davis Parks Department – 1818 5th St	Level 2 networked	2	Parks Department Fleet/Fleet Service Shop.
East	Slide Hill Park	Level 2 networked	1	Visitors/supplemental home charging for nearby rental housing.
East	Davis Joint Unified School District Corporation Yard – East Davis	Level 2 networked	2	School Fleet.
East	Cantrill Business Center – East Davis	Level 2 networked	2	Workplace/ visitors/I-80 Corridor travelers.
East	Manor Shopping Center – East Davis	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
East	Nugget Shopping Center – East Davis	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
South	Playfields Park – Sports Complex	Level 2 networked	1	Visitors/supplemental home charging for nearby rental housing.
South	Safeway Shopping Center – South Davis	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing.
South	Kaiser Permanente Medical Offices – South Davis	Level 2 networked	2	Workplace/ visitors/I-80 Corridor travelers/ supplemental home charging for nearby rental housing.
South	Drew Avenue Business Center – South Davis	Level 2 networked	4	Workplace/ visitors/I-80 Corridor travelers.
South	Nugget Shopping Center – South Davis	Level 2 networked	2	Customer attraction/workplace/ supplemental home charging for nearby rental housing/I-80 Corridor travelers.
South	Nugget Shopping Center – South Davis	DC Fast	1	I-80 Corridor travelers.
	Totals		86 Level 2; 3 DC Fast	

City of Davis EV Charging Plan

Appendix A Modeling

We used a four step modeling tool to estimate the demand for charging events in the city of Davis. 1. Market model. 2. Destination charging model (workplace charging) 3. DC fast charging model. For these three models we added a fourth model that matched the activity base results with the city land-use designations to predict the number of chargers needed by land use type and location.

Part 1: Market Modeling:

Plug-in electric vehicles (PEVs), including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), have been increasing their sales levels globally and in California over the past few years, but remain at a relatively low overall market share (2.3% of California. light-duty vehicle sales in 2015). In order to have a significant impact on CO2 emissions and oil use they must reach much larger sales volumes and market shares. The State of California, whose goals are summarized in the Zero Emission Vehicle (ZEV) Action Plan, wants to accelerate the penetration of PEVs and fuel cell vehicles to 1,500,000 vehicles by 2025 (Governor's Interagency Working Group, 2013). California's ZEV mandate aims to reach about 10%-15% of new vehicles sold in California by 2025 (California Air Resources Board, 2014). This paper takes the approach of a deeper examination of how PEVs are selling in specific markets to understand what are the factors correlated with current sales and what may be needed to increase sales. We use two models: a logit model and a Bass diffusion model. In the logit model, we focus on spatial modeling of sales in California in order to study the impact of sociodemographic, travel patterns including high occupancy lane usage and exposure to PEVs in the region on sales. We than try to estimate market growth based on a second Bass Diffusion model, using diffusion of innovation theory to predict the number of households by location who are likely to adopt a plug-in vehicle. Finally we consider the policy landscape and how this might be changed to better encourage sales of PEVs and faster market growth in the future.

Literature review

A wide variety of models are being used to predict the PEV market growth. Consumer choice models are commonly used to examine different explanatory variables, such as consumers' socio-demographic characteristics, vehicle performance, incentive policies, etc. usually by using stated preference surveys on future vehicle choice. Lin and Greene [1] build a nested multinomial logit (NMNL) model to describe consumer choice of PHEVs and to predict PHEV market segmentation. Their study examined factors including vehicle purchase, operation and maintenance costs, vehicle performance, technology risk, model availability, vehicle usage intensity, and refueling and charging availability. The model was used to answer how these factors will influence consumer choice among light-duty vehicles. Some research [2] focuses more on socioeconomic and policy variables, and employ cross-sectional analysis to built a logit model to examine how the market share of hybrid vehicles is influenced by consumer income, vehicle-miles traveled (VMT), high occupancy vehicle (HOV) lane accessibility, gas price,

policy incentives, and etc. Agent-based models (ABMs) are also very popular in examining the interaction between consumer demand, vehicle supply, policy maker, and fuel suppliers [3,4,5]. There are also some studies [6,7] that focus on consumers and use only consumer agents to simulate how the interpersonal interaction impact the adoption process. Consumer socioeconomic characteristics are also considered in the model by integrating the ABM with a consumer choice model [6]. But the complexity of the ABM makes it hard to validate. Interpersonal influence in consumer behavior is well-recognized [8,9] and both diffusion models and ABMs have the inherent capacity to capture such an influence. To explain some of the impact of exposure to the new technology we added the result of a gravity model as an explanatory variable. Gravity models are among the most widely used types of interaction models [8], and the mass-related attraction is considered as a type of network externality in the economics literature [10,11]. Brynjolfsson and Kemerer [12] built a regression model, which includes the network externality effect, to explain software price changes. Different from the diffusion models which concerns the rate of diffusion, the interpersonal influence is measured in a static approach as the extent to which individuals are sensitive to social cues relevant to their product adoption [13]. Models that combine aggregate data on a local buyer's characteristics with market performance can improve our understanding of the impact of policies and regulation on the market lack of explanation power of changes in preference and attitudes over time.

Data and Modeling

Almost 200,000 Plug-in vehicles were sold in California between 2010 and 2016. More than 150,000 applied for state rebate and have their data included in our study. We use a subsample of 134,426 privately owned vehicles categorized by vehicle type and census tract level location. Overall we have 7,164 tracts with PEVs out of total 8,057 in the state or 89 percent of the track with population of nearly 33.7 million. PEV sales data by 2016 based on clean vehicle rebate program (CVRP) records was aggregated to census tract level and used to build the models. Four models were built for the penetration rate of all PEVs, PHEVs, Tesla, and Other BEVs respectively. The spatial distribution of PEV penetration is shown in Figure 1: PEV owners are concentrated in the Bay Area and SCAG region, and urban areas with higher income generally have higher PEV penetration.

Socioeconomic data including median income and employment ratio of each census tract were derived from California household travel survey (CHTS) data [14]. The weighted average commute distance of residents from each census tract and the ratio of the length of available HOV lane on the shortest commute route over the total commute distance (HOV share) were calculated based on LODES data [15]. Since home is the primary charging location for most PEV owners, home charging availability can be an important factor to influence a household's eligibility of PEV purchase [16], and the ratio of households who own a single house (own single ratio) was used as an indicator of the home charging availability in the model.

Table 1 Vehicle Ownership Overview

		2010	2011	2012	2013	2014	2015
Num. of vehicles	PEV	67	4491	15608	44612	88159	134032
	PHEV	0	0	7376	20991	39929	54837
	MBEV	2	4351	7647	17178	36111	58145
	Tesla	65	140	585	6443	12119	21050
Num. of tracts with such type of vehicles / total tracts with pop.	PEV	0.81%	25.94%	52.17%	73.18%	84.55%	89.61%
	PHEV	0.00%	0.00%	39.06%	60.96%	74.50%	79.98%
	MBEV	0.03%	25.47%	36.72%	56.20%	71.24%	78.67%
	Tesla	0.79%	1.67%	5.33%	25.64%	36.27%	46.78%
Num. vehicles / households (excluding tracts with no such type)	PEV	0.05%	0.12%	0.21%	0.45%	0.79%	1.15%
	PHEV	0.00%	0.00%	0.13%	0.25%	0.40%	0.52%
	MBEV	0.07%	0.12%	0.14%	0.22%	0.37%	0.55%
	Tesla	0.05%	0.05%	0.07%	0.17%	0.23%	0.32%

Total census tract in CA: 8057

Tracts with population: 7987

Tracts with at least 10 households: 7981

We estimate exposure to other PEVs using a gravity model defined as:

$$F = \beta \frac{m_1 m_2}{r^2} \qquad (2)$$

where F is the gravity force between the two objects, m_1 and m_2 are their respective masses, and r is the Euclidean distance between the centers of the two objects.

In order to indicate the interpersonal interaction's impact on PEV purchase behavior, the gravity force attracted in census tract i, or in another word the exposure to PEV propaganda at census

tract i, is proportional to PEV penetration of census tract i and all surrounding tracts. Therefore, the interpersonal intersection indicator F_i is calculated as:

$$F_i = \frac{\sum_{t \in T, j \in N_i} s_{i,t} \frac{m_{i,t} * m_{j,t}}{r_{ij}^2}}{\sum_t s_{i,t}} \quad (3)$$

Where

t is a time period which is set to be a quarter for calculation efficiency and accuracy purposes,

T is the set of all quarters between the 1st quarter of 2011 and the 4th quarter of 2015,

$s_{i,t}$ is the marginal increase of vehicle ownership in census tract i during time period t,

$m_{i,t}$ is the total vehicle ownership in in census tract i before time period t,

N_i is the set of all neighbor tracts of the census tract i within a radius of 100 miles, and

r_{ij} is the Euclidean distance between the center of census tract i and j.

Detailed model specifications are given in Table 2. All chosen explanatory variables have significant impact on vehicle penetration except that commute distance is insignificant for Tesla. Considering that Tesla has a range of over 200 miles, Tesla drivers are less likely to have range anxiety than mid-range BEV (MBEV) drivers, especially if they drive a Tesla for commute purposes. Therefore, the insignificance of commute distance to Tesla penetration is understandable.

Median income and employment ratio are positively related to the penetration of all four types of EVs. Areas with higher median income and higher employment ratio are more likely to have higher PEV penetration, which is also shown in Figure 1.

For commute distance, it is not surprising to see that commute distance is negatively related to the penetration of MBEVs. Since MBEVs have a relatively short battery range (~100 mi), drivers are more likely to have range anxiety, especially when they are not familiar with this technology. Therefore, people with a longer commute distance are less likely to buy MBEVs. However, it is unexpected to see that commute distance is negatively related to the PHEV penetration. One possible explanation is that the average commute distance reflects the geographical location of an area, where urban areas have relatively shorter commute distance and rural areas have relatively longer commute distances. Currently, most available models of PHEV and BEV are compacts and sedans while people living in rural area may prefer models with more power such as SUV and pickup.

The ratio of the length of available HOV lane on the shortest commute route over the total commute distance (HOV share) is positively related to PEV penetration except Tesla. This indicates that HOV accessibility is a strong incentive for people to buy PEVs, especially PHEVs

[17]. For Tesla penetration, the HOV share is negatively related, which might be because Tesla buyers are more likely to live in areas with relatively shorter commute distance, and HOV accessibility is not a primary consideration when purchasing a Tesla [18].

The ratio of households who own a single-family home (own single ratio), as an indicator of the home charging availability, shows significantly positive impact to PEV penetration. It has the biggest impact for MBEV penetration, which indicates that home charging availability is an important factor which influences the penetration of BEVs with limited range, and it also reflects BEV driver range anxiety. For Tesla and PHEVs, since they have much longer range, the impact of home charging availability is smaller.

Finally, the interpersonal interaction shows positive relation with PEV penetration. It indicates that the neighbors of existing PEV drivers are more likely to buy PEVs. This factor shows even higher impact on MBEVs penetration. It could be because neighbors of existing BEV drivers know the technology better and they are less likely to have range anxiety, eventually leading to higher penetration. This is also consistent with the theory of diffusion that at the early adoption phase, more innovators will result in a higher diffusion rate [19].

TABLE 2 Model Coefficients Specification

	PEV Estimate	Sig.	PHEV Estimate	Sig.	MBEV Estimate	Sig.	Tesla Estimate	Sig.
(Intercept)	-7.15E+00	***	-7.68E+00	***	-7.46E+00	***	-8.06E+00	***
Median Income	2.30E-05	***	1.70E-05	***	1.42E-05	***	1.70E-05	***
Employment Ratio	6.72E-01	***	1.37E+00	***	1.94E+00	***	4.16E-01	***
Commute Distance	-4.96E-03	***	-4.97E-03	***	-6.09E-03	***	-1.05E-04	
HOV share	7.99E-01	***	1.41E+00	***	2.97E-01	***	-3.86E-01	***
Own Single House Ratio	1.04E+00	***	1.03E+00	***	1.92E+00	***	1.39E+00	***
Exposure to PEVs	1.14E-08	***	8.07E-09	***	1.24E-08	***	7.60E-09	***
Adjusted R-squared	0.64		0.55		0.56		0.49	
Mean Sq. Error	1.89E-03		9.13E-05		2.20E-04		2.28E-04	

The model result in the number of sales per year and after adding the expected iteration based on half-life of 12 years we estimate 1.3 million PEVs on California roads by 2025 as described in figure 1.

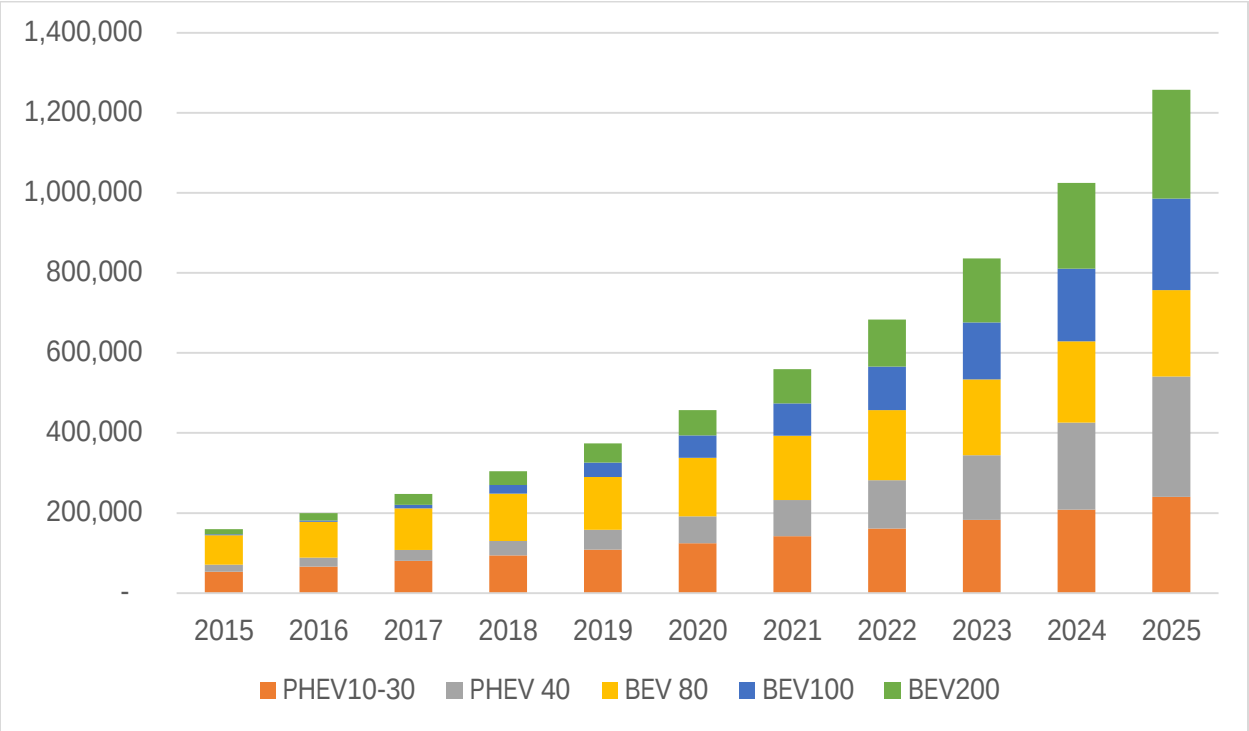


FIGURE 1 Simulated PEV Penetration in t

Table 3, shows the Davis market for each year based on the new sales prediction and an equal share of the used PEV in the state.

TABLE 3: Davis PEVs by year

fleet	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
PHEV10-30	189	235	285	332	384	441	503	569	647	737	851
PHEV 40	61	77	95	128	175	239	319	428	572	771	1,065
BEV 80	262	317	369	419	467	516	570	622	671	718	763
BEV100	8	13	33	75	128	198	285	384	504	642	811
BEV200	45	65	94	124	168	225	302	417	568	759	963
Total	572	714	883	1,086	1,330	1,626	1,987	2,427	2,968	3,635	**4,460**

We adjusted the results to include 15% households with 2 BEVs based on the PH&EV center 2015 PEV buyers' results and included higher rates of used PEVs within the student complexes to accommodate for the higher purchasing power of low income students who drive family owned vehicles. Figure 2 represent Davis final PEV fleet shows penetration rates are highly correlated with income and single family housing but also effected by density and other factors.

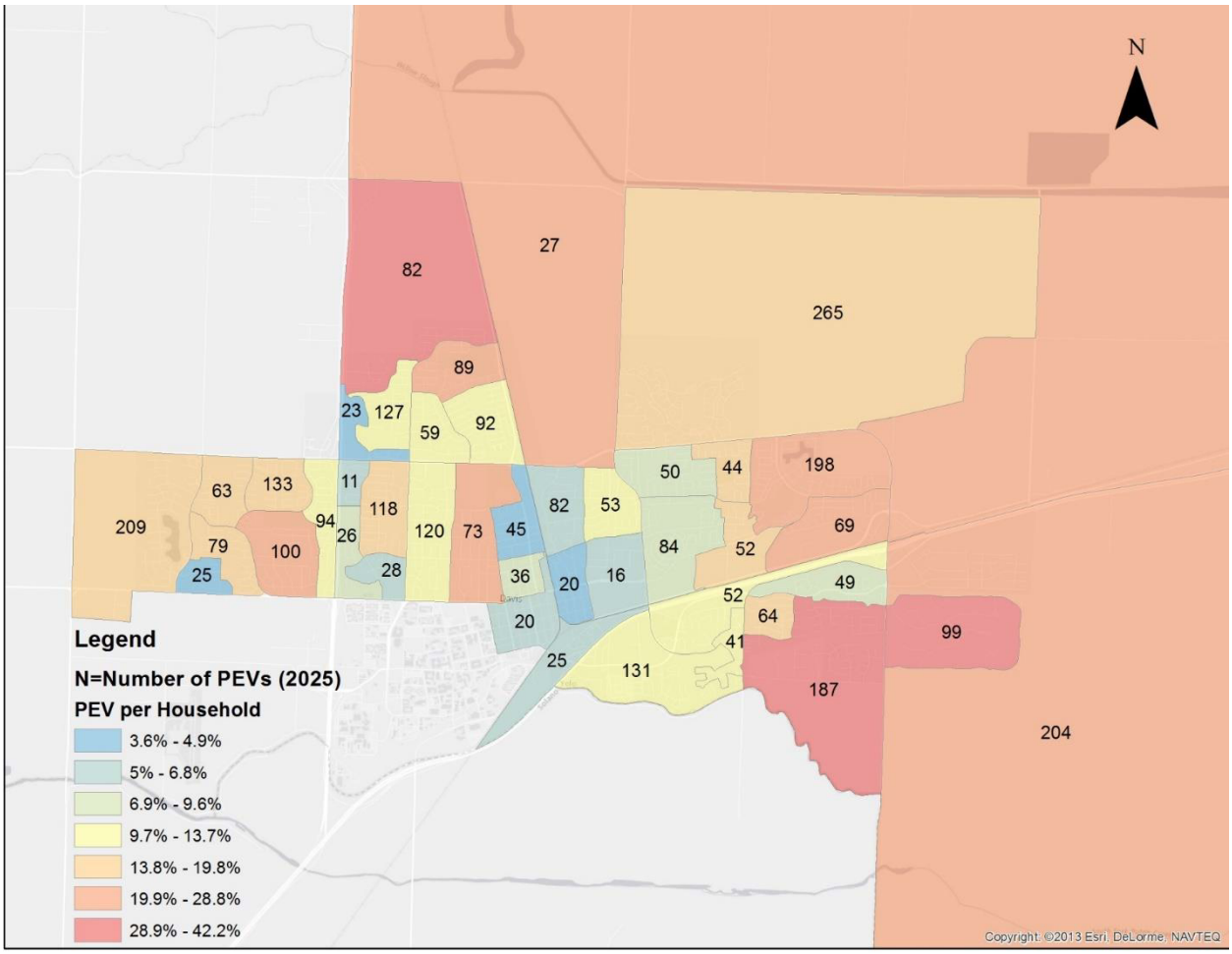


FIGURE 2: PEV ownership 2025

WORKPLACE CHARGING

The tool used to model workplace charging in the City of Davis is built based on ArcGIS, and the motivation to develop this tool is to help predict work charging demand. Four forms of data are essential: commute distance, PEV ownership, split ratio of different PEV models, and vehicle efficiency. The tool can be found at (http://phev.ucdavis.edu/project/uc-davis-gis-ev-planning-toolbox-for-mpos/). The commute data is estimated from the publicly available Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) Data. It provides detailed information about employment including home and work block group, travel distance, and the total number of jobs. Using this national dataset we can determine the number of commuters and the distance they travel to get to Davis.

Charging events and electricity consumption are calculated based on travel distance and battery range. This tool also allows two additional charging strategies. If work charging is free, PEV drivers will avoid charging at home to the extent possible. Conversely, if there is a cost to charge at work which is more expensive than home electricity but still cheaper than

conventional fuel, PEV drivers will try to avoid charging at work to the extent possible. If prices at home and work are equal, drivers will split charging between home and work to the extent possible.

Figure.1 shows a sample result for people who live in block group A or B and work and block group C.

- Taking PHEV30s from block group A as an example, the travel distance from A to C is 20 miles which is within its range. But since its range cannot complete a round trip between A and C, it will always charge for 20-miles regardless of whether it's free or not to charge at work, and the electricity consumption at work (assuming the vehicle efficiency is 3 miles/kWh) is

  $$20 \text{ miles} / 3 \text{ mile/kWh} = 6.7 \text{kWh}$$

- For PHEV15 from block group A, since its range is shorter than the travel distance, the electricity consumption at work will be equivalent to its range which is

  $$15 \text{ miles} / 3 \text{ mile/kWh} = 5 \text{kWh}$$

- BEVs behave similarly to PHEVs, with some safety buffers, but if its range is shorter than the one-way travel distance, the model will consider this vehicle not eligible to be used for commute purpose.
- For PEVs whose range is longer than the round-trip travel distance, its charging strategy will be determined based on whether charging at work is free or paid. Taking a BEV80 from block group A as an example, the round-trip travel distance between A and C is 40 miles which is shorter than BEV80's range. Therefore, if charging at work is free, the BEV80 will charge at work and the electricity consumption at work will be equivalent to the round-trip travel distance which is

  $$40 \text{ miles} / 3 \text{ mile/kWh} = 13.3 \text{ kWh}$$

  But if commuters have to pay a higher price to charge at work than at home, drivers of a BEV80 won't charge at work unless the round trip distance exceeds useful range (the useful range is the range minus a user defined mileage buffer). If the useful range were 72 miles, if the workplace were more than 72 miles round trip, the driver would charge at work in all cases.
- If the trip to work is very short, then the BEV will not charge every day. If the modeler decides this a maximum period of 3 days before charging at work, then a BEV that has less than 24 miles round trip to work (72miles/3days) would charge on every third day if charging were free.
- If the price of charging is the same as home, the BEV will always plug in at home and only plug in at work sometimes similar to a price higher than home. The difference is that the "sometimes" is further controlled by the convenience buffer. The convenience buffer reduces the useful range of the vehicle. If the minimum range buffer is 8 miles on a BEV 80, the battery only has a useful range of 72 miles. A convenience buffer of 12 miles will reduce the range to 60 miles. If the price at home and work is the same, this

convenience buffer is the "nice-to-have range" representing the value that overcomes the inconvenience of plugging in.

- The total charging events and electricity consumption will be all commuters who work at a block group. For the sample of Figure.3, total charging at block group C will be the sum of commuters from block group A and B.

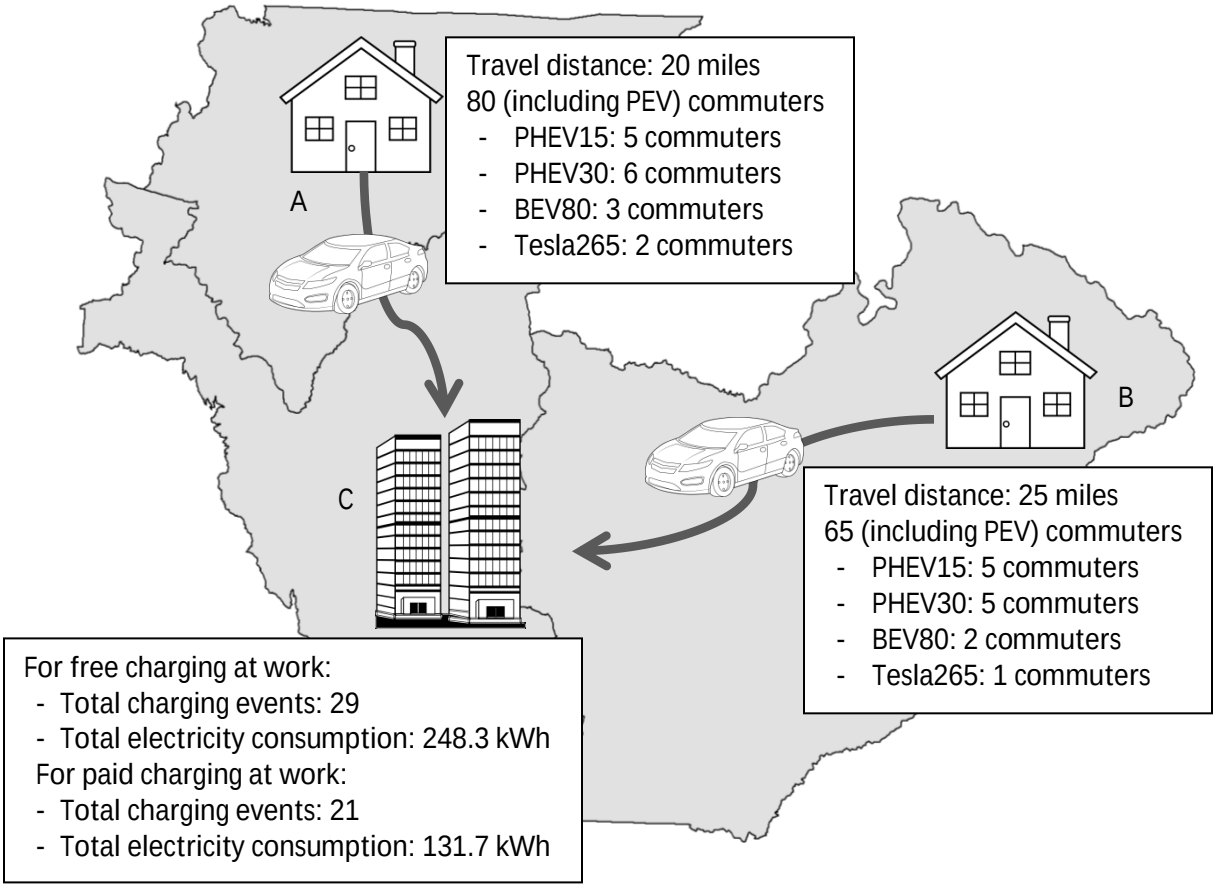


Figure.3 Demonstration of Work Charging Demand Analysis

DATA REQUIREMENTS

The spatial resolution of results depends on user's input data. If the input data is at block group level, the prediction will be at block group level. If the input data is at county level, the prediction will be at county level. Following descriptions are at block group level.

Detailed number of travelers who commute between block groups is calculated based on user-defined information about commute trips (Table.4), PEV ownership (Table.5), and PEV scenarios . Assume there are a total of 447 people who live in block group A and work in block group B, C, or E, as Table.4 shows. Among these commuters, 53 of them own PHEV, 28 of them own a Tesla, and 19 of them own other BEVs, as Table.5 shows, and the information of each specific

PEV modes are given in Table.3. Based on these data, the number of each PEV model that commute between each pair of block groups can be calculated. Detailed calculation processes are given later.

Commute Trips

Commute trips are determined by LODES data that contain commute number of commuters between homes and job block groups and distance between block group pairs. The total jobs demonstrate the split ratio of households from block group A to different block groups for work and it will be used to calculate commute trip numbers of corresponding block group pairs.

Table.4 Sample of Commute Trips

Home_BlkGrp	Work_BlkGrp	Distance	total_Jobs
060150002023	060150002024	31.4	128
060150002023	060150002025	53.2	254
060150002023	060150002026	25.6	65

PEV Ownership

PEV ownership is provided and represents the total number of PEVs at each block group. There are two categories of PEVs Long PEVs and short PEVs based on the range a vehicle can go without refueling and is explained later. To show how a population of PEVs is split among different commute routes, assume there are 28 LongPEV households in block group A. They will be assigned proportionally to the three routes based on number of jobs at each destination (whether they drive a PEV or not) which is defined in Table.4. Thus, the number of LongPEV households who commute from block group A to block group B will be:

$$28 * \frac{128}{128 + 254 + 65} \approx 9.4$$

Table.5 Sample of PEV Ownership

GEOID	NewCarHHs	PEVHHs	LongPEVHHs	ShortBEVHHs
060150002023	237	48	28	20
060150002024	144	17	10	7

PEV Scenario

PEV scenario is a table that contains the split ratio of different PEV modes. Users can define vehicle populations two ways: generally (assume the split ratio is consistent everywhere in California in each block group) or specifically where each block group (or tract or county) vehicle population is defined. For Davis we used the split defined in Table 3 in the market

section where in 2025 the ratio is 19% PHEV 10-30, 24% PHEV40, 17% BEV80, 18% BEV100, and 22% BEV 200+.

Range Buffer (Miles)

This value is the minimum value drivers will arrive home with after a round-trip commute. In a BEV80 with a range buffer of 10 miles, the driver will never use more than 70 miles of the available 80 miles. A BEV80's "useful range" is 80 minus its range buffer.

Convenience Buffer (Miles)

A further range reduction is possible for BEVs with the "convenience range" or the amount of extra travel required to overcome the inconvenience of plugging in. If this is again 10 miles, the "preferred range" of the vehicle would be 60 miles. 60 miles is used as the threshold for determining whether a user will plug in when they don't technically need it, but if it is the same price as home, they will plug in at work anyway. If it is free, it will help determine how many days a user skips plugging in if the commute is short.

Work Charging Price

Price, range, and the inconvenience of plugging in have an interaction that affects charging demand. For the workplace scenarios, we assume a straightforward interaction where users will minimize cost to the extent possible within the range limits of their vehicle. Driving using home electricity is assumed to be cheaper than driving on gasoline. There are three pricing scenarios at work: free, equal to home and more than home but less than gasoline on a cents per mile basis. Inconvenience is reflected in a reduction of battery range of the vehicle.

The range in a PHEV is simply the nameplate range of the car so that a PHEV20 will have 20 miles of useful range. There are 3 ranges for a BEV80. Nameplate = 80 miles, Useful = (Nameplate minus Range Buffer), and Preferred = (Useful minus Convenience Buffer). Here are some of the interactions these ranges have with price.

1. By default, the charging price at work is assumed to be the same as charging at home. In this case, if the vehicle cannot complete a round-trip between home and work on electricity, the PEV will charge at work and the electricity consumption is determined by commute distance and battery size. If the vehicle can complete a round-trip on electricity, PEV drivers will not charge at the workplace. For BEVs when the price of electricity is the same at home and work, and additional factor is considered, a "convenience buffer". If the round trip is longer than the preferred range, but still possible a BEV will plug in at home and work.
2. By choosing free work charging, it is assumed that commuters will charge at work as many times as possible while avoiding charging at home. If the vehicle can complete at least one round-trip on electricity, there are two more parameters that define charging strategy: the PEV won't be charged if it can make more than one round trip within the preferred range, the but PEV will be charged at least every maximum charging interval days.
3. By choosing paid work charging, it is assumed that the charging price at work is higher than at home, so people will only charge at work when it is necessary to stay on electric drive within the useful range of the car.

Below are some scenarios to explain the interactions

Scenario 1: Interval threshold is once per 2 days. Range buffer set to 10 miles. Convenience range at 11 miles. Preferred range is 59 miles. Useful range is 70 miles. 7 mile one-way commute.

- Free work charging.
    - BEV80 with 7 mile commute will charge 28 mi/day every 2 days
    - PHEV20 with a 7 mile commute will charge 14 mi/day
- Same price as home (neither checked)
    - BEV80 with 7 mile commute will charge 0 miles per day
    - PHEV20 with a 7 mile commute will charge 0 mi/day
- Paid work charging
    - BEV80 with 7 mile commute will charge 0 mi/day
    - PHEV20 with a 7 mile commute will charge 0 mi/day

Scenario 2: Interval threshold is once per 2 days. Range buffer set to 10 miles. Convenience range at 11 miles. Preferred range is 59 miles. Useful range is 70 miles. 15 mile one-way commute.

- Free work charging.
    - BEV80 with 15 mile commute will charge 30 mi/day every day
    - PHEV20 with a 15 mile commute will charge 15 mi/day
- Same price as home (neither checked)
    - BEV80 with 15 mile commute will charge 0 miles per day
    - PHEV20 with a 15 mile commute will charge 15 mi/day
- Paid work charging
    - BEV80 with 15 mile commute will charge 0 mi/day
    - PHEV20 with a 15 mile commute will charge 15 mi/day

Scenario 3: Interval threshold is once per 2 days. Range buffer set to 10 miles. Convenience range at 11 miles. Preferred range is 59 miles. Useful range is 70 miles. 30 mile one-way commute.

- Free work charging.
    - BEV80 with 30 mile commute will charge 60 mi/day every day
    - PHEV20 with a 30 mile commute will charge 20 mi/day
- Same price as home (neither checked)
    - BEV80 with 30 mile commute will charge 30 miles per day
    - PHEV20 with a 30 mile commute will charge 20 mi/day
- Paid work charging
    - BEV80 with 30 mile commute will charge 0 mi/day
    - PHEV20 with a 30 mile commute will charge 20 mi/day

Davis Scenarios

Directly out of the model we created three price scenarios as a basis for further analysis. The final numbers were adjusted from these scenarios based on updated data and local knowledge. The first scenario is for the free scenario (Figure 4).

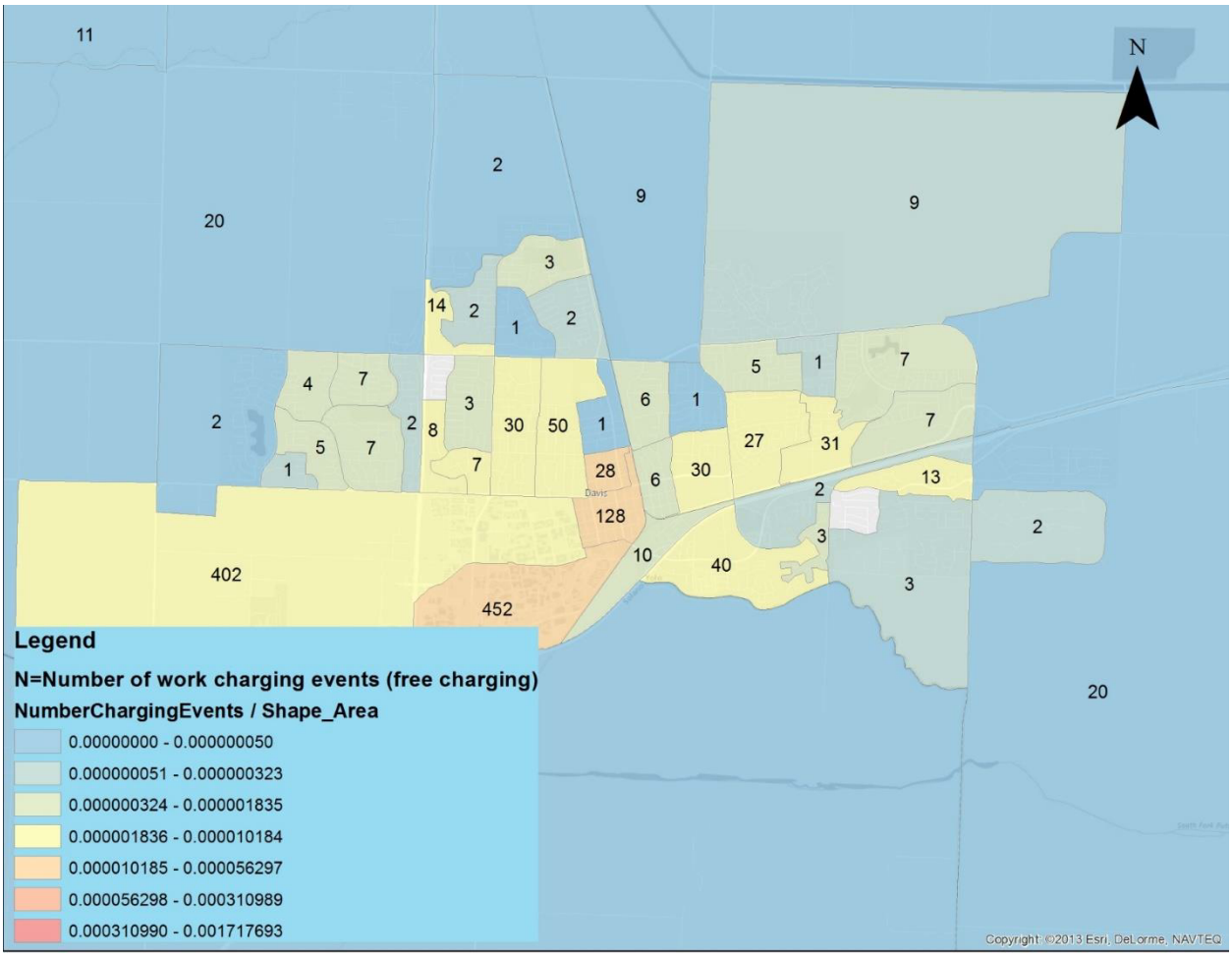


Figure 4 Free scenario events per day. Number of chargers will be less than these numbers based on more than one use per charger per day

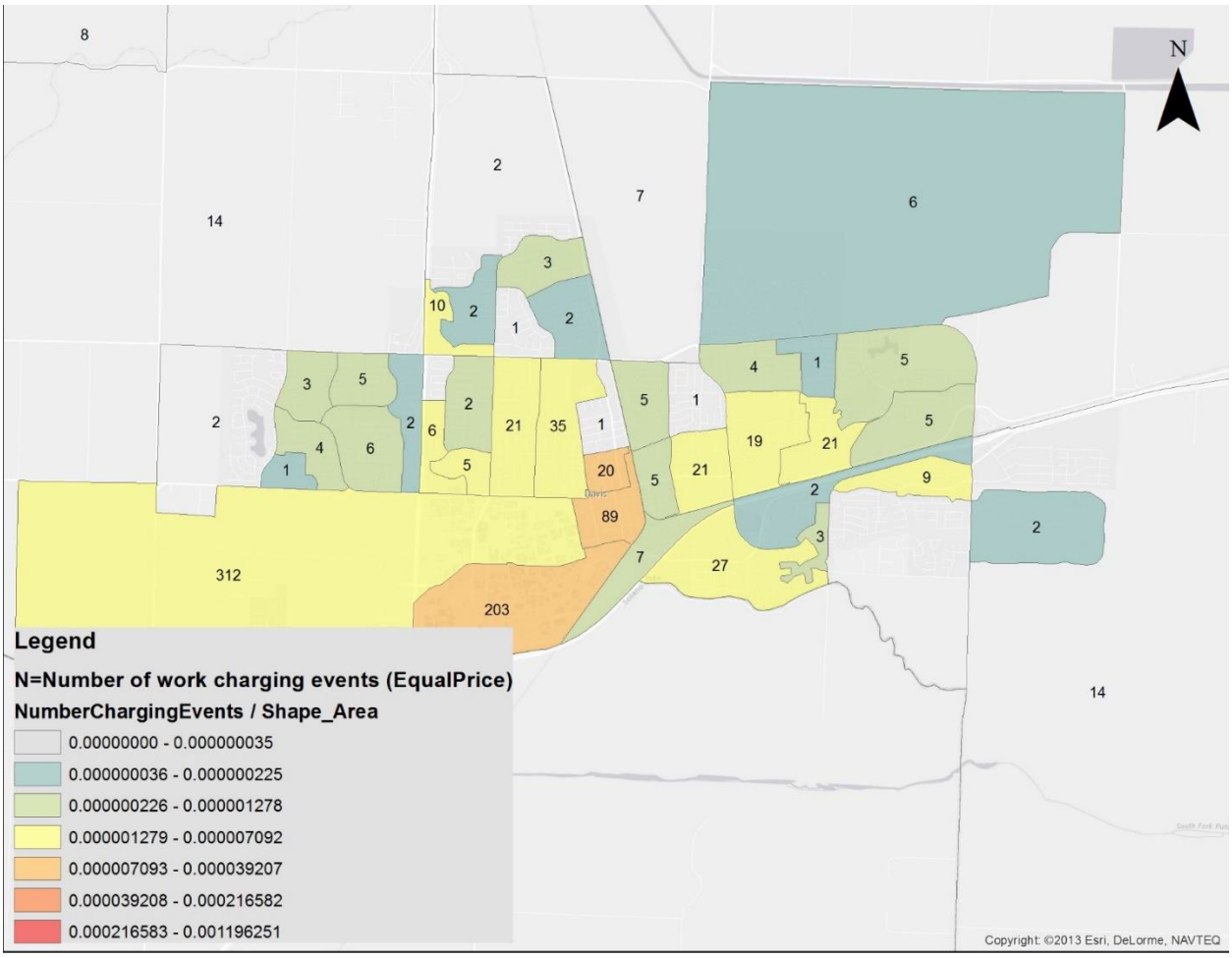


Figure 5 Price equal to home scenario. Number of chargers will be less than these numbers based on more than one use per charger per day.

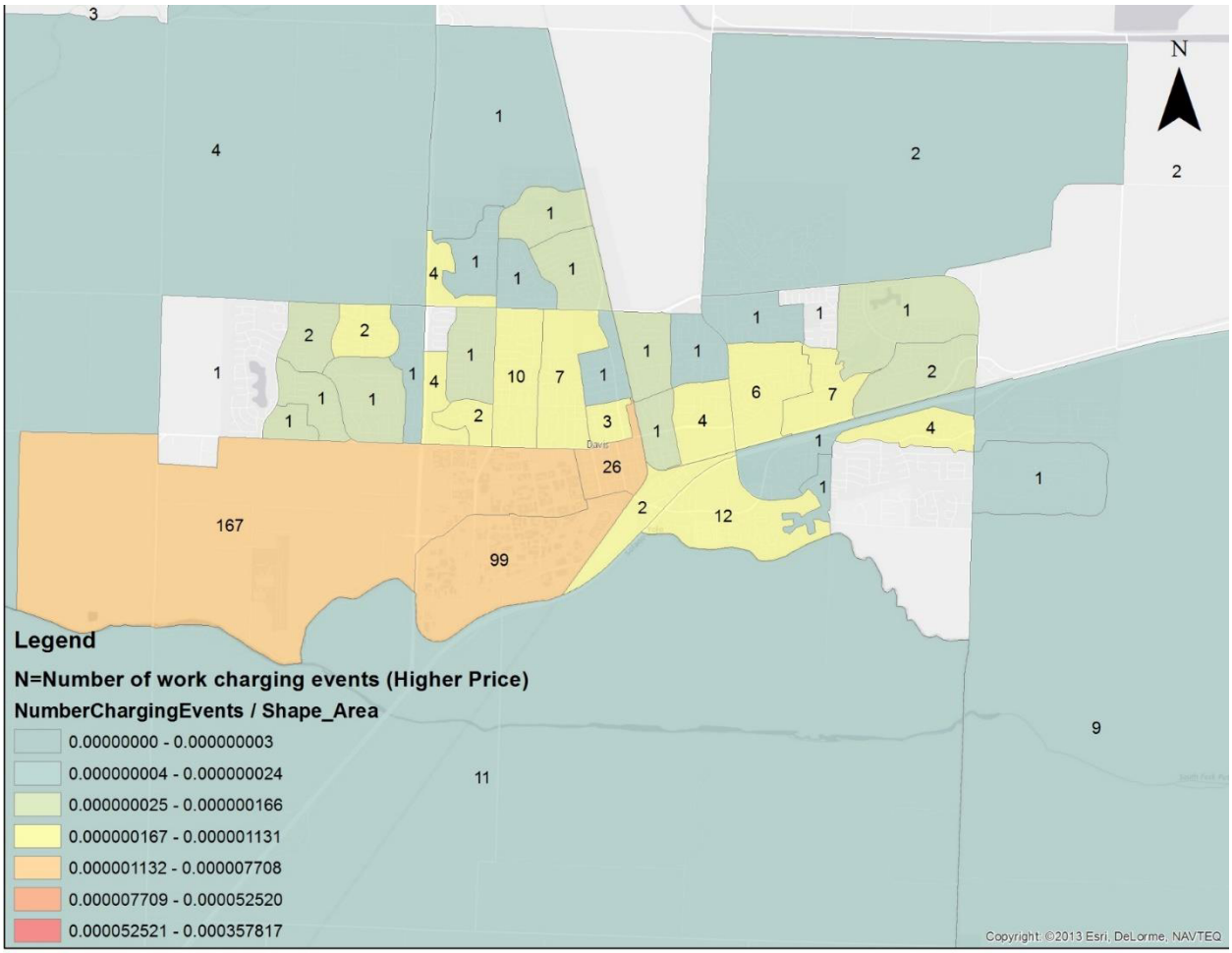


Figure 6 Price higher than home less than gasoline. Number of chargers will be less than these numbers based on more than one use per charger per day.

Included in these figures is UC Davis which shows a very large workplace demand for charging, much higher than for the city of Davis. This is a result of a combination of a large workforce and long commute distances. Also notably different from the final scenarios is downtown Davis showing more demand for free workplace charging in the downtown than the final estimation. This is a reflection of the limited parking spaces available downtown where one parking space is not occupied by the same worker throughout the day reducing the overall number of chargers. The relatively low charging demand in the high price scenario is a reflection of the short distances that many people travel to work in Davis showing that they don't need charging.

There are several ways to turn the number of events into number of chargers. If all chargers are Level 1 then the number of chargers will equal the number of events. If all chargers are Level 2, then the number of chargers will equal half the events. Different breakdowns are shown in Table 6.

Table 6 Breakdown of scenarios by tract for workplace charging.

GEOID	Charging event free	Charging event equal	Charging events higher	Free work 100% L1	Equal price work 100% L1	Higher price work 100% L1	50% L1 free	50% L1 equal	50% L1 higher	80% level 1 free	80% L1 equal	80% L1 higher
61130105012	450.6	202.0	98.2	452	203	99	339	152	74	407	182	89
61130105011	401.0	311.0	165.5	402	312	167	302	233	125	362	280	150
61130107014	127.2	88.2	24.9	128	89	26	96	66	20	115	79	23
61130107011	49.4	34.2	6.5	50	35	7	38	26	5	45	31	6
61130106082	38.7	25.8	10.6	40	27	12	30	19	9	36	23	11
61130106065	29.6	20.0	6.1	31	21	7	23	15	5	28	18	6
60952533002	29.6	20.1	9.5	31	21	11	23	15	8	28	18	10
61130107041	29.1	20.3	9.1	30	21	10	23	15	8	27	18	9
61130106023	29.4	20.0	3.4	30	21	4	23	15	3	27	18	4
61130107013	26.9	18.8	2.0	28	20	3	21	14	2	25	17	3
61130106064	26.3	17.6	5.0	27	19	6	20	13	5	24	16	5
61130104012	19.5	12.6	8.0	20	14	9	15	9	7	18	11	8
61130105051	18.9	12.7	3.3	20	14	4	15	10	3	18	11	4
61130105103	12.6	9.2	3.3	14	10	4	11	7	3	13	8	4
61130106071	12.0	7.8	2.6	13	9	4	10	6	3	12	7	4
61130112062	9.6	7.1	2.2	11	8	3	8	5	2	10	6	3
61130106024	8.9	6.1	1.4	10	7	2	8	5	2	9	5	2
61130105052	8.5	5.6	1.3	9	7	2	7	4	2	8	5	2
61130105053	7.6	5.2	1.4	9	6	2	7	4	2	8	5	2
61130107033	6.6	4.8	3.3	8	6	4	6	4	3	7	4	4
61130106051	6.2	4.3	0.4	7	5	1	5	3	1	6	4	1
61130107034	5.8	4.1	1.4	7	5	2	5	3	2	6	4	2
61130105122	6.4	4.5	0.2	7	6	1	5	3	1	6	4	1

61130106052	6.4	4.3	0.7	7	5	2	5	3	2	6	4	2
61130105112	6.3	4.3	1.0	7	5	2	5	3	2	6	4	2
61130106021	5.2	3.6	0.3	6	5	1	5	3	1	5	3	1
61130106022	5.2	3.6	0.4	6	5	1	5	3	1	5	3	1
61130106062	3.7	2.6	0.1	5	4	1	4	2	1	5	2	1
61130105131	3.9	2.7	0.2	5	4	1	4	2	1	5	2	1
61130105111	3.2	2.2	0.7	4	3	2	3	2	2	4	2	2
61130106083	2.3	1.6	0.0	3	3	1	2	1	1	3	1	1
61130107032	2.1	1.4	0.2	3	2	1	2	1	1	3	1	1
61130106073	2.0	0.0	0.0	3	1	1	2	1	1	3	1	1
61130105104	2.5	1.8	0.3	3	3	1	2	1	1	3	2	1
61130105092	0.9	0.6	0.2	2	2	1	2	1	1	2	1	1
61130105101	1.4	0.9	0.3	2	2	1	2	1	1	2	1	1
61130105121	1.1	0.8	0.1	2	2	1	2	1	1	2	1	1
61130104011	1.5	0.9	0.2	2	2	1	2	1	1	2	1	1
61130106081	1.0	0.7	0.1	2	2	1	2	1	1	2	1	1
61130105081	0.7	0.5	0.1	2	2	1	2	1	1	2	1	1
61130105102	1.5	1.1	0.1	2	2	1	2	1	1	2	1	1
61130107031	0.0	0.0	0.0	1	1	1	1	1	1	1	1	1
61130106061	0.2	0.1	0.0	1	1	1	1	1	1	1	1	1
61130106063	0.3	0.2	0.0	1	1	1	1	1	1	1	1	1
61130106072	0.0	0.0	0.0	1	1	1	1	1	1	1	1	1
61130105132	0.3	0.2	0.1	1	1	1	1	1	1	1	1	1
61130107012	0.0	0.0	0.0	1	1	1	1	1	1	1	1	1
61130105091	0.2	0.1	0.0	1	1	1	1	1	1	1	1	1

Fast Charger Modeling

There are three types of charging demand important for estimating fast charging demand:

1. Corridor Demand: From travelers whose driving distance is longer than the battery range;

2. Workplace Demand: this could be from commuters who need work charging, but may not reliably be able to charge prompting occasional fast charging

3. Home Demand: from BEV drivers who occasionally need faster charging (perhaps level 1) or forget to charge at home

Modeling corridor demand for fast chargers is based on methods described in a paper by Ji, Nicholas and Tal[20]. Long distance trips needing fast charging are based on the California Household Travel Survey (CHTS) where gasoline vehicle drivers are asked about their origins and destinations. Based on the location and number of these trips, an estimate of the need for fast charging is created. The model is best shown by the example shown in Figure 7. Assuming a BEV driver wants to travel from Elk Grove to Livermore, the distance is 85 miles, as shown in Route D. One fast charge is needed to reach the destination as the BEV has a range of 80 miles. With a safety buffer of 20% the vehicle can only go 64 miles before needing to charge, creating an upper limit to the charge window. The maximum number of miles that can be traveled from a fast charger is 48 miles (from 80% to 20% SOC) so the lower limit of the charge window is 85-48 or at mile 37. Therefore the charge window for this trip is from mile 37 to mile 64.

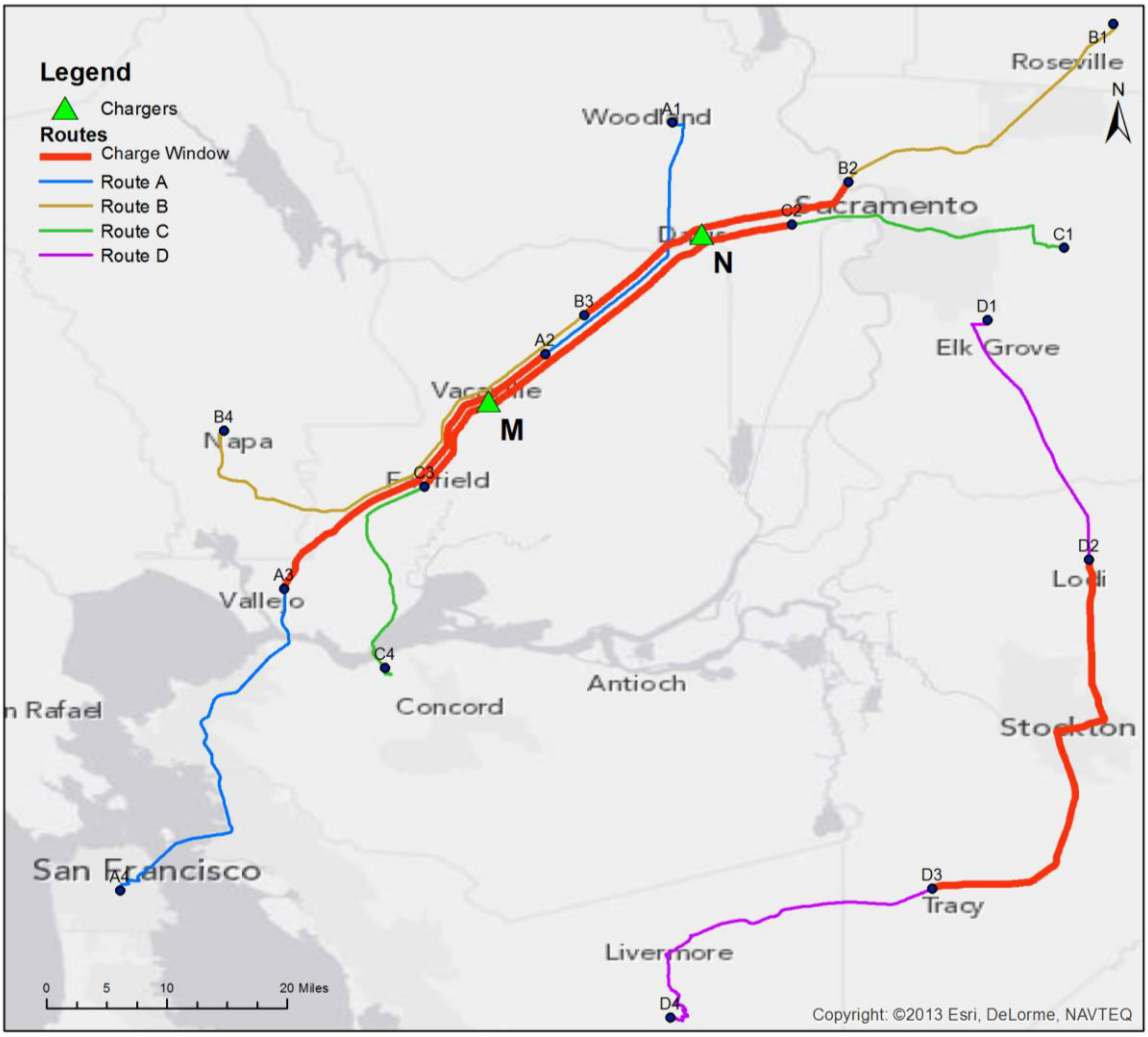


Figure 7 Fast charger model [20]

The number of vehicles at the origin of these points is determined by the market model, such that the model can be scaled to weight origins with many PEV sales. A statewide demand map such as that in Figure 8 can be created.

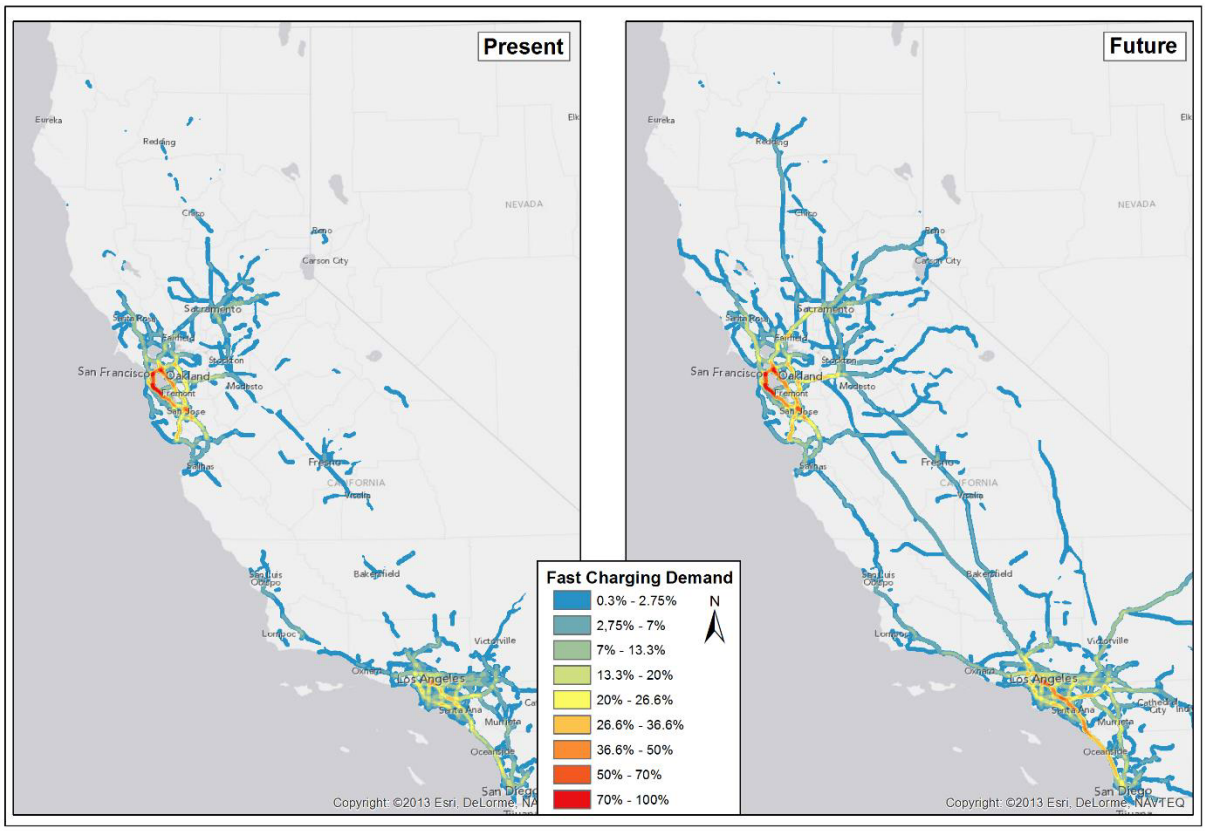


Figure 8 Present and future scenarios for California fast charging demand[20]

The future scenario in Figure 8 is used to estimate demand in Davis whose inset is shown in Figure 9.

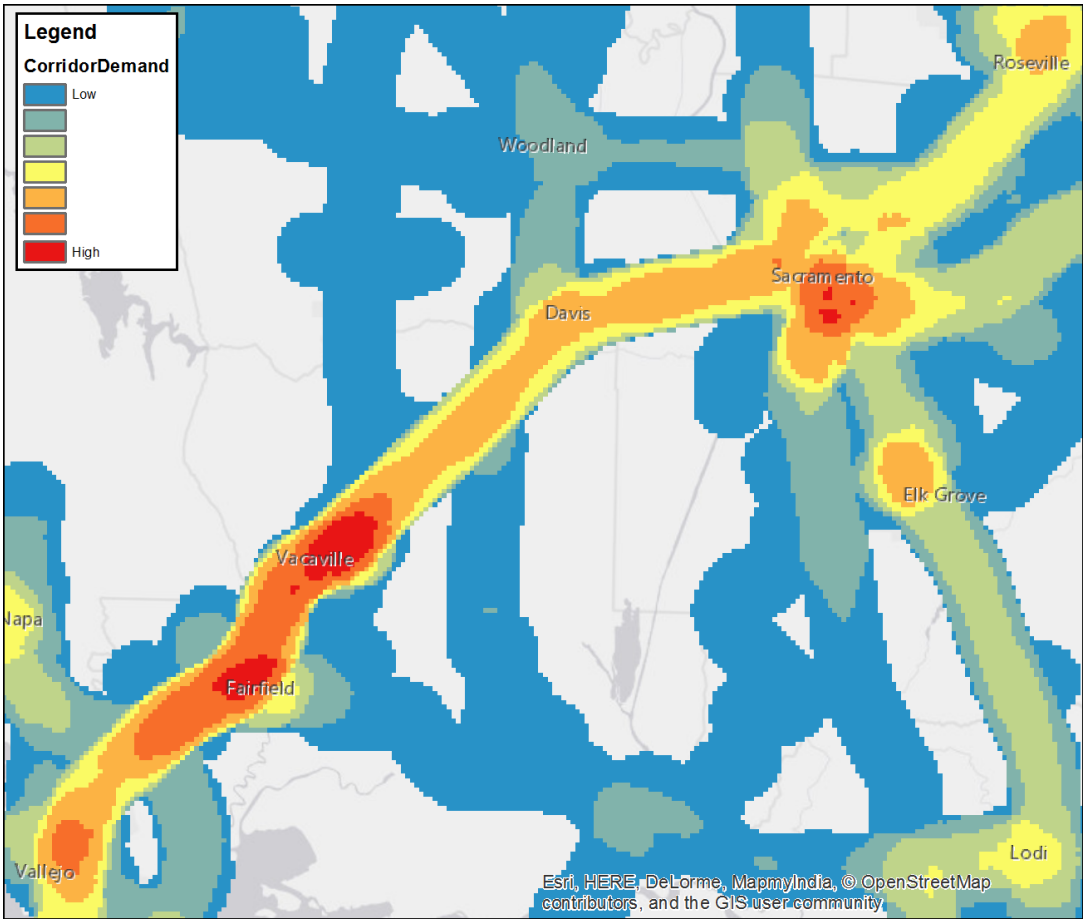


Figure 9 Fast charger demand in Davis

Davis is passed by many long distance travelers who are expected to stop and charge. Most are along Interstate 80, but some are along highway 113 as well.

Workplace Fast Charging

Workplace fast charging is estimated to be a portion of Level 2 or Level 1 workplace charging demand. Because of workplace congestion some users who need to charge to return home may be unable to do so. Those with longer commutes are more likely to need fast charging. 5% of demand from BEVs beyond round trip range from home are expected to use fast charging. Since there are not a large number of commuters beyond the range of a BEV, this number is relatively small. The map of this demand is similar to the paid charging map in the workplace charging section.

Home fast charging

Home based fast charging is for occasional use by BEVs when drivers have longer travel days with many trips near home. Sometimes level 1 or level 2 does not meet their needs and fast charging is needed. We estimate that 0.6 percent of home charging events will be fast charge events

Aggregation of Events

All these trip purposed result in the following estimations also shown graphically in Figure 10:

- I-80 corridor demand 43 events per day (3-5 chargers)
- HW 113 – 12 events per day (1-2 chargers)
- Home substitute 8 events per day (one charger in north Davis more than 5 minute drive from the corridor chargers)
- Workplace DC fast substitute 8 events form UC Davis and 4 from other locations (1 extra charger on I-80 corridor or downtown)

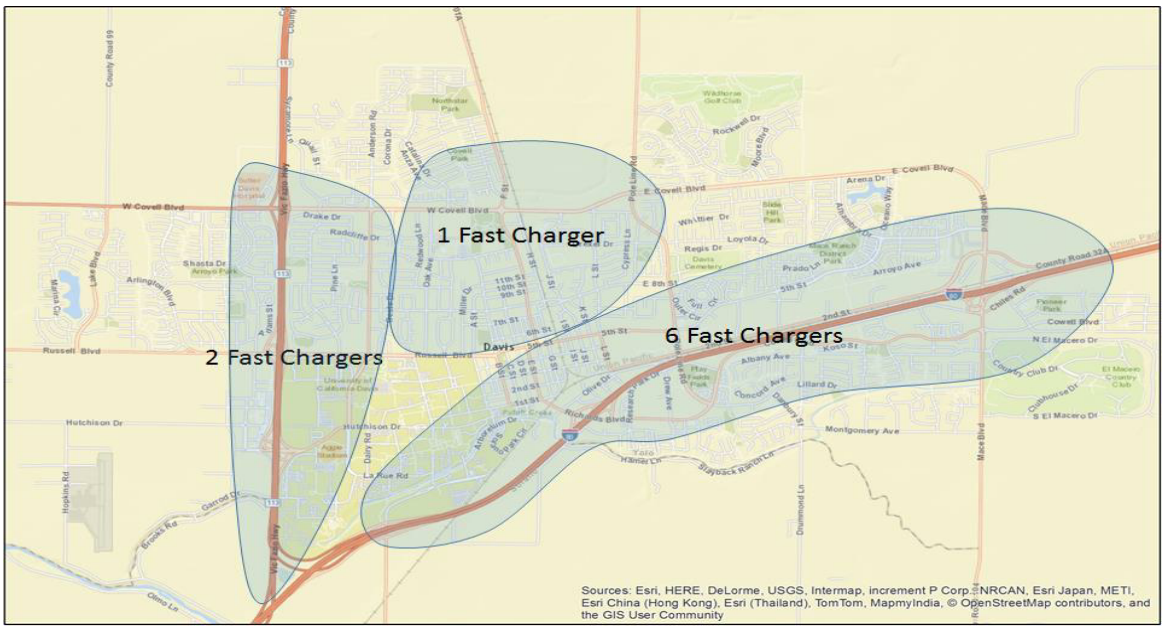


Figure 10: Final DC Fast demand estimation

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International Code Council

Guideline 4

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ICC G4 - 2019 COMMISSIONING PROCESS APPLICATION

DRAFT

By: ICC Guideline Revision Committee

August 29, 2018

ICC Commissioning Guideline 4

1.0 Introduction

1.1 Guideline Purpose and Scope: The purpose and scope of this document is to provide guidance for a code official or regulator to use in order to understand and effectively enforce the commissioning process application on new construction projects, either with in-house staff or the use of a third party agency. It is not intended to specify what the various aspects of the commissioning process are; rather it deals with the issues related to the above goals and criteria (to accept, implement, enforce and document the commissioning provisions established in codes to accepted national commissioning standards). This guideline can also be used by entities utilizing the commissioning process for complying with code requirements or developing owners project requirements and project documentation. This guideline is not a code and, therefore, is not written in enforceable language. However, this document could be adopted in whole or in part by the authority having jurisdiction (AHJ) and utilized by other entities. In writing this document, an effort was made to make this document as comprehensive as possible, so that it can be used in conjunction with codes and standards that require or include commissioning.

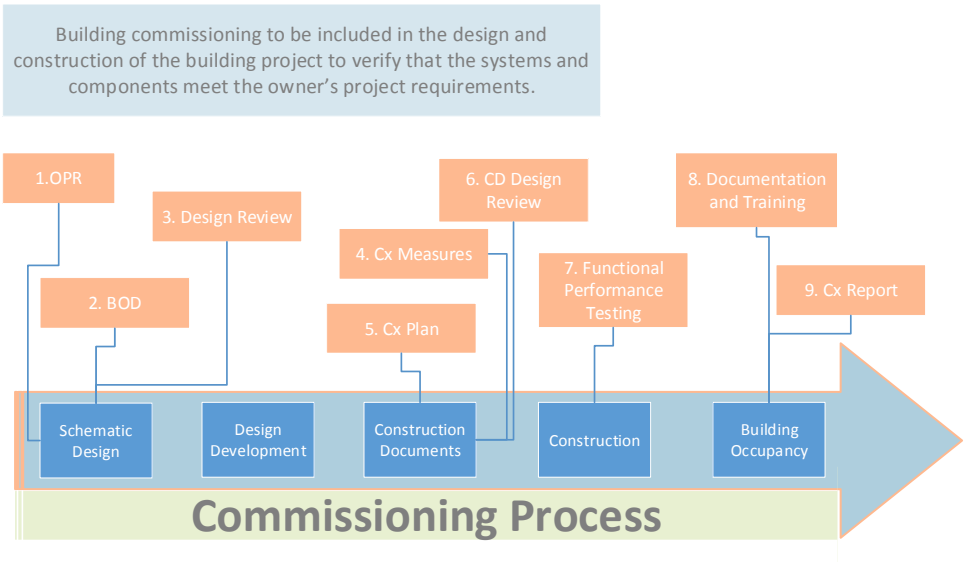
In most codes and building standards, the document does not address how building commissioning should be verified by the building official or AHJ, nor does it address the process of commissioning, it simply specifies which systems need to be commissioned. The enforcement and verification is usually determined by the local AHJ.

In order to facilitate the building official or enforcement agency's verification that building commissioning is performed appropriately and by qualified personnel, this guideline provides process recommendations to specify the components that must be examined within each system being commissioned, the forms that should be completed, and the information that must be provided in the commissioning plans and reports, as well as other documents. This guideline also provides recommendations on the minimum qualifications, knowledge, equipment, and skills that commissioning providers should have.

1.2 Commissioning Background: Building commissioning has been practiced for many years, but only recently has it become a code requirement in some jurisdictions. As a result, commissioning has not been regulated widely. Commissioning varies in how it is applied with HVAC and energy using systems usually being the focal point. Additionally, industry practices and codes are moving into new areas of commissioning other than HVAC, such as plumbing systems, electrical systems, building envelope, and renewable energy systems. Based on the expansion of building commissioning into other areas, its growing popularity, and the desire to make this document suitable for most codes and standards, the guideline addresses more areas than required by most of the current building codes, such as elevators, building enclosures, and fire suppression systems.

Moreover, the guideline addresses what are deemed essential commissioning activities such as; the owner's project requirements, basis of design, commissioning plans, specifications, design plan and submittal reviews, inspection and verification, functional and performance testing, systems manual, training and reporting. Given their significance to the commissioning process, these activities are appropriate and important to address in this document, and in commissioning enforcement.

Current building commissioning practice does not have a standard for the minimum number of systems or components and equipment within a system that need to be tested. The decision on inclusion of minimum systems to be commissioned is determined by the applicable code. The addition of other systems to be commissioned is left up to the owner and commissioning provider. As part of the commissioning process, a project commissioning plan is to be provided that will list and include all the components, equipment and systems to be commissioned along with process descriptions, requirements, and responsibilities.



This guideline is intended primarily for new building and major renovation commissioning application. There can be major variations in the commissioning process for existing buildings operations and those variations are not detailed in this guideline.

1.3 **Referenced Standards:**

The standards referenced in this guideline shall be considered part of the process and recommendations of this guideline to the prescribed extent of each such reference

1.3.1 ASHRAE/ANSI Standard 202-2013, the Commissioning Process for Buildings and Systems.

1.3.2 International Energy Conservation Code-2015

1.3.3 International Green Construction Code - 2015

2 Definitions

2.1 a. General. For the purpose of this guideline, the terms listed have the indicated meaning.

b. Undefined terms. The meaning of terms not specifically defined in this document or in referenced codes and standards shall have ordinarily accepted meanings such as the context implies.

c. Interchangeability. Words, terms and phrases used in the singular include the plural and

the plural the singular.

2.2 Acronyms

The following acronyms are used throughout the guideline.

BAS Building Automation Systems
BOD Basis of Design
CF Compliance Form
Cx Commissioning Process
CxA Commissioning Authority
CxP Commissioning Provider
EPA Environmental Protection Agency
FT Functional Test
PT Performance Test
FPT Functional and Performance Test
HVAC Heating, Ventilating and Air Conditioning
LEED Leadership in Energy and Environmental Design
OCx On-Going Commissioning Process
O&M Operations and Maintenance
OPR Owner's project requirements

2. Commissioning Definitions (reference ASHRAE Standard 202)

The following definitions are industry accepted definitions utilized in Commissioning Standards and are presented here to improve the understanding of the commissioning process.

***Acceptance Test*:** A formal action, taken by a person with appropriate authority (which may or may not be contractually defined) to declare that some aspect of the project meets defined requirements, thus permitting subsequent activities to proceed.

***Basis of Design (BOD)*:** A document that records the concepts, calculations, decisions, and product selections used to meet the Owner's Project Requirements and to satisfy applicable regulatory requirements, standards, and guidelines. The document includes both narrative descriptions and lists of individual items that support the design process.

***Checklists*:** Project and element-specific checklists that are developed and used during all phases of the commissioning process to verify that the Owner's Project Requirements are being achieved. Checklists are used for general evaluation, testing, training, and other design and construction requirements.

***Commissioning (Cx)*:** See Commissioning Process.

***Commissioning Provider*:** An entity identified by the Owner who leads, plans, schedules, and coordinates the commissioning team to implement the Commissioning Process.

***Commissioning Plan (Cx Plan)*:** A document that outlines the organization, schedule, allocation of resources, and documentation requirements of the Commissioning Process.

***Commissioning Process*:** A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements and project design.

***Commissioning Process Activities*:** Components of the Commissioning Process.

***Commissioning Progress Report*:** A written document that details activities completed as part of the Commissioning Process and significant findings from those activities, and is continuously updated during the course of a project.

***Commissioning Team*:** The individuals and agencies, who through coordinated actions, are responsible for implementing the Commissioning Process.

Functional Testing: The evaluation and documentation of the equipment and assemblies: delivery and condition; installation; proper function according to the manufacturer's specifications, and project documentation to meet the criteria in the Owner's Project Requirements.

Construction Checklist*:** A form used by the commissioning team to verify that appropriate materials and components are on-site, ready for installation, correctly installed, functional, and in compliance with the Owner's Project Requirements. Also see ***Checklists.

***Construction Documents*:** This includes a wide range of documents, which will vary from project to project, and with the Owner's needs and regulations, laws, and jurisdictional requirements. Construction documents usually include the project manual (specifications), plans (drawings), and General Terms and Conditions of the contract.

Construction Team: the construction team consists of the professionals responsible for providing materials and labor to construct the systems and assemblies in the project. Where a construction project follows a design/build approach, the construction team includes licensed design professionals who are part of the design team

***Contract Documents*:** This includes a wide range of documents, which will vary from project to project and with the Owner's needs, regulations, laws, and jurisdictional requirements. Contract Documents frequently include price agreements, construction management process, sub-contractor agreements or requirements, requirements and procedures for submittals, changes, and other construction requirements, timeline for completion, and the Construction Documents.

***Coordination Drawings*:** Drawings showing the work of all trades to illustrate that equipment can be installed in the space allocated without compromising equipment function or access for maintenance and replacement. These drawings graphically illustrate and dimension manufacturers' recommended maintenance clearances.

Current Facility Requirements (CFR): A written document that details the current functional requirements of an existing facility and the expectations of how it should be used and operated. This includes goals, measurable performance criteria, cost considerations, benchmarks, success criteria, and supporting information to meet the requirements of occupants, users, and owners of the facility.

Cx Provider Team (CxP Team): The CxP Team is the team of specialists and related support staff who are responsible for the management of actions and the generation of deliverables by the CxP as outlined in the contract between the Owner and the CxP, and the Cx Plan. The CxP Team may consist of several

companies, including subcontractors to the CxP who acts as the contact to the owner.

Design Checklist: A form developed by the commissioning team to verify that elements of the design are in compliance with the Owner's Project Requirements. Also see ***Checklists***.

***Design Review – PEER*:** An independent and objective technical review of the Project design or a part there of conducted at specified stages of design completion by one or more qualified professionals, for the purpose of enhancing the quality of the design.

***Design Review – Constructability*:** The review of effective and timely integration of construction knowledge into the conceptual planning, design, construction and field operation of a project to achieve project objectives efficiently and accurately at the most cost effective levels to reduce or prevent errors, delays and cost overruns.

***Design Review – Code or Regulatory*:** A review of a document conducted by staff or designated entity of an Authority Having Jurisdiction to determine whether the content of the document complies with regulations, codes, or other standards administered by the Jurisdiction.

***Design Review – Commissioning*:** A review of the design documents to determine compliance with the Owner's Project Requirements, including coordination between systems and assemblies being commissioned, features and access for testing, commissioning and maintenance, and other reviews required by the OPR and commissioning plan.

***Evaluation*:** The process by which specific documents, components, equipment, assemblies, systems, and interfaces among systems and their performance are confirmed with respect to the criteria required in the Owner's Project Requirements.

***Existing Building Commissioning Process*:** A quality-focused process for developing the Current Facility Requirements of an existing facility and its systems and assemblies being commissioned. The process focuses on planning, investigating, implementing, verifying, and documenting that the facility and/or its systems and assemblies are operated and maintained to meet the Current Facility Requirements, with a program to maintain the enhancements for the remaining life of the facility.

***Facility Guide*:** A basic building systems description and operating plan with general procedures and confirmed facility operating conditions, set points, schedules, and operating procedures for use by facility operations to properly operate the facility.

***Final Commissioning Report*:** A document that records the activities and results of the Commissioning Process and is developed from the final Commissioning Plan with all of its attached appendices.

***Issues and Resolution Log*:** A formal and on-going record of problems or concerns and their resolutions that have been raised by members of the Commissioning Team during the course of the Commissioning Process.

***On-Going Commissioning Process (OCx)*:** A continuation of the Commissioning Process that extends well into Occupancy and Operations in order to continually improve the operation and performance of a facility to meet current and evolving Current Facility Requirements or Owner's Project Requirements. On-Going Commissioning Process activities occur throughout the life of the facility.

***Owner's Project Requirements (OPR)*:** A document that details the requirements of a project and the expectations of how it will be used and operated including project goals, measurable performance criteria, cost

considerations, benchmarks, success criteria, training requirements, documentation requirements and supporting information. (The term Project Intent or Design Intent is used by some owners for their Commissioning Process Owner's Project Requirements.)

Performance Test (PT): Performance Testing is the process of verifying that a material, product, assembly, or system meets defined performance criteria. The methods and conditions under which performance is verified are described in one or more test protocols.

Project Team: the project team consists of select members of all the teams defined in the project documents. The project team provides a venue for coordinating actions and information flows between all staff who are involved in the project and Cx activities.

***Re-Commissioning*:** (See Existing Building Commissioning.) An application of the Commissioning Process requirements to a project that has been delivered using the Commissioning Process.

Retro-Commissioning: (See Existing Building Commissioning.) The Commissioning Process applied to an existing facility that was not previously commissioned.

Sequence of operation. A written description of the intended function and response of each control element and feature of the equipment and associated systems based on a given set of anticipated operating conditions

***Systems Manual*:** A system-focused composite document that includes the design and construction documentation, facility guide and operation manual, maintenance information, training information, commissioning process records, and additional information of use to the Owner during occupancy and operations.

***Test Procedure*:** A written protocol that defines methods, personnel, and expectations for tests conducted on components, equipment, assemblies, systems, and interfaces among systems to verify compliance with the Owner's Project Requirements.

***Training Plan*:** A document that details the expectations, schedule, duration and deliverables of Commissioning Process activities related to training of project operating and maintenance personnel, users, and occupants.

3 Commissioning Process Fundamentals

3.1 Standard Process for New Building Commissioning– ASHRAE Standard 202

In ASHRAE Standard 202-2013, *The Commissioning Process for Buildings and Systems,* **i**s defined as "A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements."

As a process, commissioning has a series of actions for proper completion with each action having specific deliverables. These deliverables define the building requirements, the commissioning requirements, and the documentation of the process and performance results for the building, systems and assemblies commissioned.

The actions in the commissioning process are as follows:

1. INITIATION: The owner initiates the Commissioning Process at the beginning of the project, and determines the roles and responsibilities of the project and commissioning teams. Procedures and contracts should be prepared and executed. The Commissioning Provider should be retained at this

time.

2. OWNER'S PROJECT REQUIREMENTS: Next the project requirements should be determined and documented. This includes not only the building scope and use but also the system performance, training, testing, commissioning and documentation requirements. The deliverable for this action is the Owner's Project Requirements (OPR) document which is the guiding instruction for the project. The OPR is updated throughout the design and construction of the project.

3. COMMISSIONING PLAN: The initial Commissioning Process Plan should be developed that shows the commissioning scope, roles and responsibilities, communication procedures, and design and construction requirements for providing and integrating commissioning into the project. The deliverable is the Commissioning Process Plan that is updated throughout the project with checklists, schedules and documentation details.

4. BASIS OF DESIGN: The design team then determines and documents the design approach to meet the Owner's Project Requirements. The deliverable for this action is the Basis of Design (BoD) document which is the guiding technical process for the project on the approach the design team will take to accomplish the OPR. The Commissioning Provider reviews the Basis of Design (BOD) for conformance to the OPR.

5. SPECIFICATIONS: During the design phase the contractor commissioning requirements should be determined for each system and included in the commissioning specifications for the construction documents package. The Commissioning Provider assists the design team in the development of the commissioning specifications.

6. DESIGN REVIEW: In the design phase and at the completion of design the Commissioning Provider reviews the design and documents for conformance to the OPR. These reviews should be assembled in the design review report. The design review by the commissioning provider is not considered a PEER review, or a code review, and does not replace these functions.

7. SUBMITTAL REVIEW: Early in the project construction, the commissioning team reviews the materials and equipment submittals for conformance to the OPR and construction documents This provides familiarity with the building systems for development of testing and commissioning procedures, requirements, and checklists. These reviews should be summarized in the submittal review report.

8. SYSTEM VERIFICATION: As the project is constructed, the commissioning team observes and verifies the installation and performs or witnesses the equipment start up and testing. The air conditioning system test and balance process and report should be reviewed and verified by the Commissioning Provider to assure system operation and compliance with the project documents.

9. FUNCTIONAL AND PERFORMANCE TESTING: At system completion, functional and performance testing is conducted to verify performance compliance with the OPR and design documents. The results of these verification processes should be recorded in the construction checklists and reports. These reports should be included in the project commissioning report.

10. ISSUES and RESOLUTION LOG: One of the main functions and benefits of the commissioning process is the identification and resolution of project issues, both design and construction. These actions should be presented in the issues and resolution log facilitating communications, and project team collaboration, and the ultimate resolution of the issue. The final issues log should be included in the final commissioning report.

11. SYSTEMS MANUAL: During the design and construction of the project, the design and construction

documents should be assembled into the systems manual. This assembly of documents provides the details and history of the design and construction of the building and information needed to properly operate the building. The systems manual includes the project final OPR, BOD, construction record documents, submittals, completed startup, verification checklists, functional and performance checklists, verified sequence of operation, facility guide, training records, and commissioning report. The systems manual should be used in the initial and subsequent training of the building operations staff and occupants. The systems manual should be updated throughout the life of the building.

12. TRAINING: To operate the building in accordance with the OPR and design capabilities, the building staff must be trained on the installed equipment and systems. The suppliers and contractors will normally conduct the training with the training being observed by the commissioning team. The training plans and records should be retained and updated for use in later training.

13. OPERATION PHASE: Commissioning that was not performed due to climatic conditions or equipment availability before initial certificate of occupancy should be conducted during post occupancy. The end of warranty commissioning report documents these activities. The final testing results should be included in the final commissioning report and systems manual.

14. COMMISSIONING REPORT: Commissioning plans and interim reports should be collected and distributed throughout the project as required by the commissioning plan. A preliminary commissioning report should be prepared that shows the commissioning progress and equipment performance to date at the time the Certificate of Occupancy is issued. At the completion of the project the final commissioning report should be assembled and provided to the owner and others as required by the OPR and local jurisdiction requirements. This report includes the final commissioning plan, copy of design and submittal review reports, all startup, inspection, verification, functional and performance test forms and reports, the verified sequence of operation, the final issue and resolution log, and summary of the performance of commissioned systems.

3.2 New Building Commissioning Process Activity, Deliverables, and Responsibilities

The application of the commissioning process can be for the delivery of either all or selected systems and assemblies in a project. The commissioning scope will depend upon how the project will be designed, built, and operated. The scope is defined in the Owner's Project Requirements and the Commissioning Plan, and performed based on the extent of commissioning effort defined and procured. The process described in the following sections and appendices is written for a generic project and must be adapted to each project. The Commissioning Process can be supplemented by companion technical documents and guidelines to describe the specific details and to properly implement the Commissioning Process relative to a specific facility, system, or assembly. This process can be applied to both new and renovation projects. Commissioning of existing buildings, unless covered in a renovation, is not included in this guideline for two reasons. First, the focus of this guideline is on code required commissioning on new projects, and second the commissioning process on an ongoing building operation is much more variable and dependent upon specific building operation and project requirements, and may not be code required.

The requirements of the commissioning process are to:

a) Provide the activities for the application of the Commissioning Process in the design, development, construction, operation, and modification of physical buildings, systems and assemblies.

b) Establish the commissioning process activities and sequence of activities.

c) Establish commissioning deliverables and documentation for the process application.

d) Establish an acceptance procedure for commissioned systems and project completion

Acceptance. The process for each activity and deliverable shall include an acceptance step as defined in the OPR and Commissioning Plan. This step shall formalize the acceptance of the commissioning deliverable by the owner or client, and/or the Authority Having Jurisdiction if required. Under common practice, the Commissioning Provider is not required to "accept" designers or contractors work on behalf of the owner or jurisdiction.

THE COMMISSIONING PROCESS

This chart provides an outline of normal activities, documentation, and responsibility included in the Commissioning Process

THE COMMISSIONING PROCESS ACTIVITIES, DELIVERABLES AND RESPONSIBILITIES (Reference ASHRAE Standard 202 and ASHRAE Guideline 0)

Item	Activity	Deliverable	Normally Provided By	Normally Approved By	For Use By
1.	Project Commissioning Initiation	Contract and work orders: Roles and Responsibilities	Owner	Owner	Owner
2	Owner's Project Requirements	OPR document	Owner with assistance from design and Cx teams	Owner	Owner, Design Team, Cx Team
3	Basis of Design	BoD document	Design team	Owner with review by CxP	Owner, Design Team, Cx Team
4	Commissioning Plan	Cx Plan	Cx provider with input from owner, design team, and contractor	Owner with reviews by design team and contractor team	Cx Team, Construction Team, AHJ
5	Contractor Cx Requirements	Project specifications	Design team and Cx provider	CxP with Owner review	Contractors and Suppliers
6	Design Review	Design review report	Cx provider	CxP with Design Team Response	Owner, Design Team
7	Submittal Review	Submittal review report	Cx provider	CxP with Owner review and contractor response	Design Team, Contractors, Suppliers
8	Cx designated systems inspections, functional and performance testing	Installation, inspection, functional test reports, performance test reports	Contractors, manufacturers, Cx provider and team	CxP with owner review	Contractors and Suppliers
9	Issue and Resolution Log	Issue and resolution logs	Cx provider with input from design and construction team	CxP with Owner, Design Team and Contractor response.	Owner, Design and Cx Teams, Contractors
10	Develop Systems Manual	Systems Manual	Contractors with review by Cx provider	CxP with review by Owner, Operators and Design Team	Owner, Building Operators

11	Training	Training plan and reports	Contactors and manufacturers with review by Cx provider	Owner with CxP review	Building Operators
12	Preliminary Cx Report	Preliminary Cx report	Cx provider	CxP, Owner and if required, AHJ	Owner, Contractors, AHJ
13	Post Occupancy Operation	Additional information, testing, and updates to reports	Cx provider and building operations	Owner	Owner, Building Operators
14	Commissioning Reports	Preliminary and Final Cx reports	Cx provider	CxP, Owner and if required, AHJ	Owner, Operators, AHJ

4 Code Compliance with Building Commissioning Process

4.0 INTRODUCTION: The application of the Commissioning Process starts at the beginning of the project inception and goes through building occupancy. Each project phase has required activities that need to be completed during that phase. During the planning and design process, the Commissioning Provider is retained, the systems to be commissioned are selected, the Owner's Project Requirements are developed, the Basis of Design documents are developed and reviewed, the preliminary commissioning plan is written, and commissioning specifications are included in the construction documents. While the code required building systems must be on the list of selected systems to be commissioned, the owner or designer may also select additional systems.
The AHJ needs assurance that these activities are completed before a permit is issued. The AHJ can request a copy of all the documents for review or rely on the approval by the Commissioning Provider and Owner or owner's representative.

4.1 Commissioning Process Management: A qualified Commissioning Provider is designated at the beginning of the project to coordinate the commissioning process and the work of any Commissioning Specialists, and to submit the documentation required by code. Qualified Commissioning Specialists are designated to commission systems for which specialized technical certification or licenses are required.

Where more than one system and more than one person or entity is involved in the commissioning process the principal Commissioning Provider is selected and coordinates the process and the documentation.

4.2 Documentation of Applicable Commissioning Code Requirements

The following documentation is provided for each instance of an applicable commissioning requirement in an applicable code or standard

a. Applicable code requirements, with code section reference numbers and including any performance, environmental, sustainability, or efficiency requirements of those codes;
b. Description of technical approach to compliance;
c. Equipment and systems to be commissioned; and
d. Specific process requirements for the commissioning of each element, including: plans, reviews, logs, evaluation, testing, training, reports, and documentation.

4.3 Commissioning documentation required at permit application. At the time of permit application, the designated commissioning provider verifies that the following documentation is provided for each system requiring commissioning according to the national commissioning standard, applicable codes and jurisdictional requirements:

a. The Commissioning Plan has been developed.

b. Design documents include a requirement to perform commissioning in accordance with this standard and applicable codes, system and equipment performance criteria has been included, and the design documents have been reviewed by the Commissioning Provider.

c. Where an Owner's Project Requirements document is available or required by an applicable code or the code official, or the owner, it is provided.

d. Where a Basis of Design document is available or required by an applicable code or code official, or owner, it is provided.

4.4 Commissioning documentation required before final inspection or issuance of the certificate of occupancy. Prior to final inspection and issuance of the certificate of occupancy, documentation is provided demonstrating that the Commissioning Plan was completed as applicable up to the time of final inspection. The following commissioning work must have been completed according to national commissioning standard for each system for which applicable standards and codes require commissioning, and according to the commissioning plan, project documentation, and standards:

a. Materials and equipment submittals have been reviewed by the commissioning team for conformance to project documentation.

b. Commissioning Issue and Resolution Logs have been maintained and code items completed.

c. Equipment testing has been performed, witnessed, and documented by the commissioning team.

d. Project documents have been assembled and the Systems Manual prepared and provided to the owner.

e. The building operations, maintenance, and facility staff has been trained on the installed and commissioned equipment and systems. The training plans and records have been retained and updated for use in later training.

f. The preliminary commissioning report has been completed and provided to the owner.

4.5 Post Occupancy Commissioning The building commissioning shall be completed with the results and documentation provided to the owner in accordance with the commissioning plan at the end of construction. The authority having jurisdiction may request reports and documentation at their discretion. Subsequent to the commissioning process during construction, an on-going commissioning process can be utilized to verify and maintain continuing building performance. The procedures for the on-going process may vary with the owner's requirements and the type of facility.

4.6 Documentation and Compliance Checklists

4.6.1 DESIGN DOCUMENTS-COMMISSIONED SYSTEMS: Energy and Green Codes usually require at a minimum that mechanical systems, service water heating systems and lighting control systems be completed and commissioned. The construction documents including notes and specifications shall clearly indicate provisions for commissioning, and system performance and completion requirements.

These construction document requirements convey the owner's requirements (OPR) and the designer's criteria (BOD) for the performance and commissioning process for the designated systems.

4.6.2 COMMISSIONING PLAN: The following is an outline of the contents of a typical commissioning plan. The Commissioning Plan is developed by an approved commissioning provider for all systems to be commissioned and/or tested and shall include the following items:

a. A narrative of the commissioning process developed specifically for the project.
b. The roles and responsibilities for the commissioning providers and the commissioning team through final commissioning activities.
c. Documentation of communication channels and processes including the distribution of the commissioning plan, logs, testing documents and reports during the design and construction process.
d. A detailed description of conditions and schedules of the commissioning process activities, and the list of operations, functions, systems, and assemblies that will be commissioned. Measurable performance criteria shall be included where not shown on the construction documents.
e. The project design documentation and submittal review procedures and reports.
f. Inspection checklists and testing forms, issues and resolution log, and commissioning progress reports to be used during the project to communicate and track commissioning and inspection process information, including format, approvals and distribution.
g. The procedures to follow for resolution where the system performance does not meet the Owner's Project Requirements or design documents.

4.6.3 Construction Phase Commissioning Reports Some of the commissioning testing can be done after the certificate of occupancy inspections. Environmental and seasonal condition may not provide adequate testing condition, particularly for mechanical equipment. Construction schedules may not allow testing of incomplete systems. Thus, it is necessary to verify the required commissioning performance up to the point of final AHJ inspection. This can be done by having the revised commissioning and project documents collected along with the testing results up to that time. The preliminary commissioning report and issue logs need to include the project open items including future testing and equipment and systems currently not meeting requirements.

Depending upon the jurisdictional requirements, this preliminary commissioning report or a form approved by the Commissioning Provider and/or Owner or owner's representative is submitted and reviewed by the AHJ.

4.6.4 FUNCTIONAL and PERFORMANCE TESTING REPORTS: Equipment functional and performance testing shall demonstrate the installation and operation of components, systems, and system-to-system interfacing relationships in accordance with approved plans and specifications such that operation, function and maintenance serviceability for each commissioned system is confirmed in all modes of operation.

4.6.5 TESTING and BALANCING REPORT: HVAC systems shall be balanced in accordance with industry accepted engineering standards, and the project documents. A written report shall be submitted and reviewed by the Commissioning Provider describing the activities and measurements completed.

4.6.6 SYSTEMS MANUAL: A Systems Manual **i**ncluding an operations and maintenance manual is provided and includes:

a. Submittal data and intended operation

b. Manufacturer's operations manuals and maintenance manuals
c. Listing of at least one service agency
d. Controls maintenance and calibration information
e. Verified sequence of operation with set points
f. Schedule for inspecting and recalibrating

4.6.7 COMMISSIONING REPORTS: The following are outlines of typical contents for the preliminary and final commissioning reports. Due to project scheduling, it may be necessary to provide a preliminary commissioning report on project commissioning status and equipment operation to obtain a certificate of occupancy. Some codes require that the design professional or approved agency provide the preliminary report to the owner. The code could also require that the owner then provides a letter of receipt for the preliminary report to the AHJ to proceed with final inspection.

4.6.7.1 Preliminary Commissioning Report: The commissioning provider submits a Preliminary Commissioning Report to the owner that includes the following information:

a. Performance of commissioned equipment, systems, and assemblies, including a review of the HVAC test and balance report.
b. Issue and resolution logs including itemization of deficiencies found during testing and commissioning that have not been corrected at the time of report preparation.
c. Deferred tests that cannot be performed at the time of preliminary report.
d. A plan for the completion of commissioning including climatic and other conditions required for performance of the deferred tests.

4.6.7.2 Final Commissioning Report: The Commissioning Provider submits a final Commissioning Report to the owner prior to project completion that includes the following information:

a. A copy of the final commissioning plan including functional and performance test procedures used during the commissioning process including measurable criteria for test acceptance.
b. A copy of the design and submittal reviews as required by the commissioning plan
c. Results of all evaluations, startup data, functional and performance tests, reports and checklists by suppliers, contractors, observers, and commissioning providers.
d. Issue logs and disposition of all deficiencies found during testing, including details of corrective measures used or proposed.
e. Equipment, systems, and assemblies repaired and adjustments to calibrations.
f. Equipment and systems sequences and settings shall be documented and submitted in the final sequence of operation with set points and in the O&M or systems manual.
g A resolution plan identifying all the issues unresolved and incomplete at the end of the project.

4.6.8 **COMMISSIONING CHECKLIST FOR PERMIT:** The following checklist is a guide for collecting the information associated with the Commissioning Process activities prior to the issuance of a construction permit. The information should be developed by the project team in collaboration with the owner. All documents are retained and included in the Systems Manual and/or final commissioning report. The recommended contents for the commissioning documents listed are shown in other sections of this guide. The form can be completed by the owner, CxP or design team. The CxP reviews the subject information and approves the form for submission with the permit request. This assures that the CxP has been engaged before the start of construction.

COMMISSIONING PLAN DOCUMENTATION FOR PERMIT		
Project Name:_____		
Project Address:_____ Permit Number:_____		
Commissioning Provider:_____		
Company/Entity address: _____		
CxP Phone Number: _____ CxP email address:_____		
CxP Certification (if required)_____		
ITEM #	**COMMISSIONING DOCUMENTATION COMPLETED**	**APPROVAL**
	1. Commissioning Project Design Requirements	
	Project commissioning requirements, listing of equipment to be commissioned, system performance requirements, commissioning specification shown on project contract documents.	
	2. Commissioning Plan	
	Initial commissioning plan (for Permit) completed with required contents and provided for Owner and AHJ review.	
	3. Design Review	
	Commissioning design documents review, report completed with response.	
Commissioning Provider Acknowledgement		
I have reviewed the documents and verified that they meet the owner's project requirements:		
Name: _____		
Company Name _____		
CxP Signature: _____ Date: _____		

4.6.9 COMMISSIONING CHECKLIST FOR CERTIFICATE OF OCCUPANCY: The checklist below is a guide for collecting the information associated with the Commissioning Process activities up to the time of final or CO inspection. The information should be developed by the project team in collaboration with the Commissioning Provider and owner. All documents are retained and included in the Systems Manual and/or final commissioning report. The recommended contents for the commissioning documents listed are shown in other sections of this guide. The review and approval by the CxP and Owner assures the AHJ that the Commissioning Process has been implemented and completed to the extent necessary for the issuance of the CO.

Commissioning activities and documentation developed after certificate of occupancy inspection shall also be included in the Systems Manual and final commissioning report. These records are provided to the Owner or owner's representative and, if requested, to the AHJ.

COMMISSIONING DOCUMENTATION for FINAL INSPECTION and CO		
Project Name:_____		
Project Address:_____ Permit Number:_____		
Commissioning Provider (CxP):_____		
Company/CxP address : _____		
CxP Phone Number: _____ CxP email address:_____		
CxP Certification (if required)_____		
ITEM #	**COMMISSIONING DOCUMENTATION**	**APPROVAL CxP INITIAL**
	1. Project Commissioning Requirements	
	Project commissioning requirements included in project contract documents.	
	2. Commissioning Plan	
	Commissioning Plan with checklists (before start of functional testing) completed.	
	3. Contractor and Construction Instructions	
	Plans and commissioning specifications utilized.	
	4. Design and Construction Submittal Review	
	Design documents review and construction submittal review and reports completed	
	5. Commissioning Issue and Resolution Log	
	Issues and Resolution Logs completed up to time of final inspection with open items shown.	
	6. Commissioning Testing	
	Commissioning checklists completed up to time of final inspection	
	7. Equipment Commissioned and to be commissioned	
	Listing of equipment with commissioning complete. Listing of equipment that remain to be commissioned and deferred tests. Plan for completion.	
	8. Test and Balance Report	
	Test and balance of HVAC completed and report reviewed.	
	9. Systems Manual	
	Project documentation and Systems and O&M Manual completed with available information for use in training program before occupancy	
	10. Commissioning Report	

	Preliminary Commissioning Report available (at time of final inspection for CO) and submitted to Owner and to AHJ (if required).	

Commissioning Provider Acknowledgement

I have reviewed the documents and verified that they meet the owner's project requirements:

CxP Name: _____

Company Name _____

CxP Signature: _____ Date: _____

Owner/Owner's Representative Acknowledgement

The project documents include the items listed in this form and have been received by the owner or owner's representative:

Name: _____

Owner ☐ Owner's Representative ☐

Company Name _____

Signature: _____ Date: _____

5 Commissioning Provider Qualifications and Selection

5.1 Selecting trained personnel for commissioning. This guideline emphasizes that commissioning process is managed and performed by qualified and certified personnel with experience on projects of comparable size and complexity. The approved personnel manage and facilitate the commissioning process. The approved personnel develop and implement the commissioning tasks and documentation relating to systems in the applicable code and project requirements. The commissioning team may include; a commissioning provider, appropriate members of owner's staff, contractor and design team, as well as, other independent commissioning professionals.

It is essential that a single person be designated to lead and manage the commissioning process activities. In practice, this individual has been referenced by various identifiers, such as a commissioning provider, authority, agent, coordinator, lead, manager etc. In this guideline, the term Commissioning Provider "CxP", is used. The designated CxP should be an independent third-party commissioning professional.

Methods of evaluating the designated CxP and trained personnel include review of the following:

- Independent of Design and Construction team
- Technical knowledge.
- Relevant experience.
- Professional certifications and training.

- Communication and organizational skills.
- Reference and sample work products.
- Availability of appropriate testing equipment

Additional information about the commissioning provider skills, knowledge and abilities for specific systems is provided in the appendixes in this guideline.

5.2 Recommended Commissioning Provider Independence & Qualifications

A Commissioning Provider typically has the following qualities to ensure appropriate independence and minimum qualifications on a building project:

1. Independence . The approved commissioning provider is independent from the manufacturers and installers of the systems being commissioned, and the project designers of the systems. The provider is typically asked to disclose possible conflicts of interest so that independence can be confirmed.

2. Equipment. The approved provider possesses, has access to or is requiring others to provide equipment required to perform the functional and performance tests. The equipment is periodically calibrated in accordance with manufacturer's specifications.

3. Personnel Experience. The approved provider employs personnel experienced in conducting or supervising and evaluating functional and performance tests, and when applicable, performing commissioning activities prior to and subsequent to the tests. Where possible, the approved commissioning provider has completed the commissioning process on two or more projects of equal or larger scope and complexity, or can demonstrate adequate experience and training in the fundamentals and application of the commissioning process.

4. Registration, Licensure or Certification. Where available and required, the approved commissioning provider is certified, registered or licensed in a relevant discipline or certified according to the provisions of ISO 17024 or another approved certification process.

APPENDIXES

The following appendixes provide information for the application of the commissioning process.

A.0 Building Commissioning Documentation

A.0.1 Documentation of Commissioning Requirements in Applicable Codes: Code requirements for commissioning should be documented and completed as required by the applicable code or standard.

A.0.2 The following documentation should be provided for each instance of an applicable commissioning requirement in an applicable code or standard:

a. Applicable code requirements, with code section reference numbers and including any environmental, sustainability, or efficiency requirements of those codes;

b. Description of technical approach to compliance;

c. Equipment and systems to be commissioned;

d. Specific process requirements for the commissioning of each element, including: logs, reviews, reports, evaluation, testing and documentation requirements; and

e. Training requirements where required

f. Documentation requirements

1. **A.0.3** The following checklist in IECC-2018 can be used to verify project commissioning completion for specific systems. This checklist is similar to the commissioning documentation checklist in section 4.6.9 in this guideline. Either or both checklists may be used as appropriate to the AHJ's compliance requirements.

COMMISSIONING COMPLIANCE CHECKLIST for FINAL INSPECTION and CO		
Project Name: _____		
Project Address: _____ Permit Number: _____		
Commissioning Provider (CxP): _____		
Company/CxP address: _____		
ITEM #	**COMMISSIONING DOCUMENTATION**	**APPROVAL**
1.	**Project Commissioning Requirements**	
	Project commissioning requirements included in project contract documents.	
2.	**Commissioning Plan**	
	Commissioning Plan with checklists (before start of functional testing) completed. (Section C408.2.1)	
3.	**Commissioning Plan Utilized**	
	Commissioning Plan was used during construction and includes items required in Section 408.2.1	
4.	**Systems Adjusting and Balancing**	

	Systems Adjusting and Balancing has been completed	
5	**HVAC Equipment**	
	HVAC Equipment Functional Testing has been executed. If applicable, deferred and follow up testing is scheduled to be completed on _____	
6.	**HVAC Controls**	
	HVAC Controls Functional Testing has been executed. If applicable, deferred and follow up testing is scheduled to be completed on _____	
7.	**Economizers**	
	Economizer Functional Testing has been executed. If applicable, deferred and follow up testing is scheduled to be completed on _____	
8.	**Service Water Heating**	
	Service Water Heating Functional Testing has been executed. If applicable, deferred and follow up testing is scheduled to be completed on _____	
9.	**Systems Manual**	
	Project documentation, and Systems and O&M Manual, and training completed or scheduled.	
10.	**Commissioning Report**	
	Preliminary Commissioning Report submitted to Owner and includes all items required in C408.2.4	

Owner/Owner's Representative Acknowledgement

I hereby certify that the commissioning provider has provided me with evidence of mechanical, service water heating and lighting systems commissioning in accordance with the 2018 IECC

Name/Company: _____

Owner☐ Owner's Representative ☐

Signature: _____Date: _____

A.1.1 Owner's Project Requirements

Contents. The contents of the Owner's Project Requirements (OPR) should include the following information applicable to the code requirements:

1. Facility size, location, user requirements, including space usage, occupancy, operation and project schedules, codes, standards, and indoor environmental requirements, including temperature, humidity, and ventilation.
2. Commissioning process requirements, including logs, reviews and reports and listing of equipment, systems and assemblies requiring commissioning with installation evaluation and testing requirements.
3. Commissioned equipment, systems and assemblies requirements, including maintainability, access, and operational performance requirements.
4. Environmental, sustainability, and efficiency goals and benchmarks for code requirements.
5. Project documentation requirements and formats including; Basis of Design, Commissioning Plans and Reports, and the Systems Manual.
6. Training requirements for owner's operation and maintenance personnel and occupants.

The OPR documents the functional requirements of a project, and expectations of the building use and operation, as it relates to systems being commissioned. The document describes the physical and functional building characteristics desired by the owner, and establishes performance and acceptance criteria. The OPR is most effective when developed during predesign and used to develop the BOD during the design process. The level of detail and complexity of the OPR will vary according to building use, type and systems.

Template CF-1B provides an optional guide for collecting and documenting the information associated with the Commissioning Process activities. Other formats are acceptable.

OWNER'S PROJECT REQUIREMENTS COMPLIANCE FORM
CF-1B
Submitted with Permit Application if Required

Project Name:_____

Project Address:_____ Permit Number:_____

ITEM #	OWNER'S PROJECT REQUIREMENTS ITEMS	PAGE NUMBER IN OPR DOC.
	Project Program	
a	Facility size, location, user requirements, including space usage, occupancy, operation and project schedules and codes, standards and indoor environment requirements, including temperature, humidity, and ventilation.	
	Commissioning Process	
b	Commissioning process requirements, including logs, reviews, reports and listing of equipment, systems and assemblies requiring commissioning with installation evaluation and testing requirements.	
	Systems and Assemblies	
c	Commissioned equipment, systems and assemblies requirements, and warranty provisions including maintainability, access, and operational performance requirements.	
	Environmental Quality and Efficiency Requirements	
d	Environmental, sustainability, and efficiency goals and benchmarks for code requirements.	
	Documentation	
e	Project documentation requirements and formats including; Basis of Design, Commissioning Plans and Reports, and Systems Manual.	

Owner Acknowledgement

I have reviewed the OPR document and verified that it meets the owner's project requirements.

Name: _____

Company Name: _____

Signature: _____ Date: _____

Enforcement. At their discretion, the building official ~~shall~~ should confirm demonstrated compliance at plan intake by:

- Receipt of a copy of the OPR document; or
- Receipt of a form signed by the owner or owner's representative attesting that the OPR has been completed and approved by the owner.
- Receipt of other documents required by the applicable code

A.1.2 Basis of Design

Basis of Design

Basis of Design (BOD). The BOD should be completed at the start of the design phase of the building project, and updated as necessary during the design and construction phases.

Contents. The BOD document should include compliance with the requirements of the applicable code and the following:

1. Description of the design team's proposed technical method to meet the requirements;
2. Coordination of applicable technical and code requirements as well as the commissioning requirements for systems and assemblies being commissioned;
3. Design criteria and design assumptions in agreement with the OPR and code requirements;
4. Requirements for sustainable design and other certifications when required; and
5. Requirements that systems, assemblies, and equipment be located, installed, commissioned and maintainable, and that training be provided to operations and maintenance staff.

Template CF-1C provides an optional guide for collecting and documenting the information associated with the Commissioning Process activities. Other formats are acceptable.

BASIS OF DESIGN COMPLIANCE FORM CF- 1C Submitted with permit application if required		
Project Name:_____		
Project Address:_____ Permit Number:_____		
ITEM #	**BASIS OF DESIGN ITEMS**	**PAGE NUMBER IN BOD DOC.**

	Technical Approach	
a	Description of the design team's technical approach to each of the Owner's requirements.	
	Codes and Commissioning	
b	Coordination of applicable technical and code requirements as well as the commissioning requirements for the systems and assemblies being commissioned.	
	Assumptions	
c	Design criteria and design assumptions in agreement with the OPR and code requirements.	
	Sustainability and Related Criteria	
d	Requirements for sustainable design and other certifications when required.	
	Maintenance and Training	
e	Requirements that systems, assemblies, and equipment be located, installed, commissioned and maintainable, and that training be provided to operations and maintenance staff.	

Owner Acknowledgement

I have reviewed the Basis of Design and verified that it meet the owner's project requirements.

Name: _____

Company Name: _____

Signature: _____ Date: _____

Enforcement. At his discretion, the building official should confirm demonstrated compliance at plan intake by:

- Receipt of a copy of the BOD document;-or
- Receipt of a form signed by the architect, engineer or designer of record, attesting that the BOD has been completed and meets the requirements of the OPR.
- Receipt of other documents required by the applicable code

A.1.3 Commissioning Plan

Prior to construction permit issuance a commissioning plan should be completed to document how the project will be commissioned.

Commissioning Plan. The Preliminary Commissioning Plan and Final Commissioning Plan should be provided as required in Sections A.1.3.1 and A.1.3.2 and shall be specifically created for each individual project.

A.1.3.1 Preliminary Commissioning Plan. At the time of permit application, a Preliminary Commissioning Plan based on applicable codes should be provided. Contents of the Preliminary Commissioning Plan shall comply with applicable code requirements and include:

1. Overview of the proposed commissioning process;

2. Schedules developed for commissioning activities in the design, construction and occupancy phases of the project;

3. Roles and responsibilities for the Commissioning Team throughout the project. The responsibilities shall delineate the duties of the commissioning provider, commissioning specialists, owner, inspectors, contractors, suppliers, and other agencies;

4. Documentation of communication procedures including the distribution of the Commissioning Plan and other documentation during the design and construction processes, including the development and utilization of the Issues and Resolution Logs and a preliminary listing of required reports, reviews and approvals;

5. Design documentation review procedures, submittal evaluation procedures and report formats;

6. Preliminary list of operations, systems and assemblies that will be commissioned and/or inspected;

7. Format for commissioning checklists, commissioning testing forms and Commissioning Progress Reports;

8. Guidelines and formats that will be used to develop the Systems Manual, Training Plans, and Final Commissioning Report;

9. Procedures to be followed when evaluation results do not meet the code requirements or construction document requirements.

A.1.3.2 Final Commissioning Plan: The Final Commissioning Plan should be completed before the start of functional and performance testing. It should update the Preliminary Commissioning Plan as required and include the following information:

1. Detailed description of Commissioning Process activities, the schedule of activities and the list of operations, systems and assemblies that will be commissioned or inspected, including evaluation procedures and performance criteria.

2. Final listing of required reports including format, reviews and approvals.

3. Detailed testing procedures and checklists for functional testing and performance testing for all commissioned systems and assemblies, including verification of sequences of operation and, where relevant, conditions under which the testing has been performed.

   Template CF-2 provides an optional guide for collecting and documenting the information associated with the Commissioning Plan activities. Other formats are acceptable

COMMISSIONING PLAN COMPLIANCE FORM CF-2		
Project Name:_____		
Project Address:_____ Permit Number:_____		
ITEM #	**PRELIMINARY COMMISSIONING PLAN ITEMS Submitted with permit application**	**PAGE NUMBER IN Cx PLAN**
General Project Information		
a	Overview of the commissioning process and schedules developed for each phase of the project, from design through occupancy.	

Roles and Responsibilities		
b	General roles and responsibilities for the Commissioning Team throughout the project. The responsibilities shall delineate the duties of the commissioning providers, commissioning specialists, inspectors, contractors, suppliers, and other agencies.	
Communication Channels		
c	Documentation of general communication channels including the distribution of the Commissioning Plan and documentation during the design and construction processes. This includes the development and utilization of the Issues and Resolution Logs and a preliminary listing of required reports including format, reviews and approvals.	
Documentation and Submittal Review		
d	Project construction design documentation review and submittal evaluation procedures and report formats.	
Commissioned Equipment and Systems		
e	The preliminary list of operations, equipment and systems that will be commissioned and/or inspected, including performance criteria.	
Checklists, Forms, Logs and Reports		
f	Preliminary format for Commissioning checklists and testing forms and Commissioning Progress Reports.	
Systems Manual, Training Plans and Final Commissioning Report		
g	Guidelines and formats that will be used to develop the Systems Manual, Training Plans, and Final Commissioning Report.	
Resolution Process		
h	Procedures to follow whenever Commissioning Process evaluation results do not meet the code requirements or the construction document requirements.	
ITEM #	**FINAL COMMISSIONING PLAN ITEMS**	**PAGE NUMBER IN Cx PLAN**
a.	Detailed description of Commissioning Process activities, the schedule of activities and the list of operations, systems and assemblies that have been commissioned or inspected, including evaluation procedures and performance criteria.	
b.	Final listing of required reports including format, reviews and approvals.	
c.	Detailed testing procedures and checklists for functional testing and performance testing for all commissioned systems and assemblies, including verification of sequences of operation and, where relevant, conditions under which the testing has been performed.	
d.	All of the Preliminary Commissioning Plan items have been updated as required to reflect any project changes.	

Commissioning Provider Acknowledgement – Preliminary

I have reviewed the Preliminary Commissioning Plan and verified that it meets the requirements of this standard for code-required commissioning.

Name: _____

Company Name _____

Provider Signature: _____ Date: _____

Commissioning Provider Acknowledgement – Final

I have reviewed the Final Commissioning Plan and verified that it meets the requirements of this standard for code-required commissioning.

Name: _____

Company Name: _____

Provider Signature: _____ Date: _____

Enforcement. At his discretion, the building official confirms demonstrated compliance at plan intake by:

- Receipt of a copy of the preliminary commissioning plan; or
- Receipt of a form (see the *Commissioning Plan Compliance Form*) signed by the CxP attesting that the commissioning plan has been completed.
- Receipt of other documents required by the applicable code

A.1.4 Functional and Performance Testing

Commissioning Testing

Checklists and test procedures. The following should be established and fully documented prior to testing.

1. Project-specific construction checklists and commissioning testing procedures;
2. Where test data results are required for specific equipment or systems, there should be an item in the associated Construction Checklist for the test data to be submitted to the Commissioning Provider;
3. A listing of the entities responsible for executing each of the tests; and
4. A uniform and effective process to document Commissioning testing of and interaction between commissioned equipment and systems.

Evaluation. Evaluation of the equipment and systems shall include the following:

1. Verification that the installed equipment and systems match those defined in the construction documents and approved construction submittals;
2. Verification that the equipment and systems were properly installed and are accessible for testing and maintenance; and
3. Test results for the installed equipment and systems should be compared to the relevant requirements of the specifications, submittals and codes;

Test reports. Completed test reports including checklists and test procedures should be submitted to the project team for review and to the Commissioning Provider for evaluation and inclusion in the Commissioning Report.

Functional and Performance Testing (FPT). A documented test of the dynamic functioning operation of equipment and systems with the goal of verifying that the Project Owner's requirements are met. FPT is based on scope of work and contract documents. Test procedures are developed and results documented by the commissioning agency. FPTs shall demonstrate installation and operations of each operating components and system-to-system interface in accordance with the approved design plans and the owner's project requirements.

Code required functional and performance testing usually includes the following systems:

- HVAC systems
- Plumbing hot water systems
- Lighting systems
- Control systems for the above systems

Other systems may be added by the local codes, AHJ, owner, or design team.

The checklists on Appendix B-1 below show some of the possible systems to be commissioned by building type. The system and subsystem commissioning requirements selected in B-1 are listed in the B-2 checklists.

Prior to all functional testing, prerequisite/pre-functional verification and start-up documentation should be provided by the installing contractor and/or factory-trained personnel for each piece of equipment. This information ensures the operating success of each component and proper functionality of all system operations.

This information should contain, but is not limited to:

- Date and responsible party of installation start up.
- Manufacturer model and serial number.
- Design and actual operating information, such as voltage, amperage, wattage, motor nameplate information, sheave, pulleys, belts and air filters, revolutions per minute (RPM) of motors and fans, refrigerant operating conditions, temperature splits, gas pressures, water pressures, and test and balance report.
- Precautionary measures and methods of procedure regarding safety interaction with all personnel.

FPT documentation should address the step-by-step instruction sequence and modes of each operation with interconnecting safety interlocks, temperature sensors, pressure transducers, building management system (BMS) integration, lighting controllers, timers and manually controlled operations.

FPT reports should contain information addressing each of the building components tested; testing methods utilized; and include any readings and adjustments made.

The functional testing documentation should incorporate a signature block information format containing:

- Date.
- Responsible party identifier.
- Required testing instruments.

- Measurable pass-fail of testing sequence.
- Expected response of operating parameters.
- Results of testing that is performed.
- Operating condition of equipment status upon completion of each test sequence.

A deficiencies list shall be incorporated into the functional testing documentation; this list will track and clarify all failed operating sequences and components. The deficiencies list will act as a living document until all components or sequence of operation have been completed. The building department and building owner / owner's representative will require all parties to perform their duties to correct deficient items.

A.1.4.1 SAMPLE COMPLIANCE FORM FOR FUNCTIONAL TESTING

Template CF-3 provides an optional guide for collecting and documenting the information associated with the Commissioning Testing activities. Other formats are acceptable.

This Form is to be Completed at the Time of Inspection

COMMISSIONING TESTING COMPLIANCE FORM CF-3 Submitted before final inspection		
Project Name:_____		
Project Address:_____ Permit Number:_____		
ITEM #	**COMMISSIONING TESTING ITEMS**	**PAGE NUMBER IN Cx TESTING DOC.**
Checklists and Test Procedures		
a	Project-specific Construction Checklists and Commissioning testing procedures shall be established for review by Owner and appropriate team members.	
b	The test procedures shall list the entities responsible for executing each of the tests.	
c	Whenever a test data result is required for a specific system or assembly, there shall be an item in the associated Construction Checklist for the test data to be submitted to the Commissioning Provider.	
d	There shall be a uniform and effective process for documentation of testing to provide Commissioning testing of and interaction between commissioned equipment, systems, and assemblies. Commissioning team shall refer to applicable Commissioning technical resources tailored to their specific projects.	
Evaluation		
e	Vital information on the equipment or materials supplied. Information shall detail what equipment/material was specified and submitted. What was actually delivered on the site shall be documented and verified.	
f	Proper installation of the systems and assemblies. Evaluation shall focus on the physical installation of the systems and assemblies, on their ability to meet the contract documents requirements, and on accessibility for Commissioning, testing, and maintenance operations.	
g	Testing procedures, conditions and successful Commissioning testing results of systems and assemblies.	

Test Reports		
h	Completed test reports including checklists and test procedures shall be submitted to the project team for review and the Commissioning Provider for evaluation and inclusion in the Commissioning Report.	

Commissioning Provider Acknowledgement

I have reviewed the Commissioning Testing documents and verified that it meets the applicable code requirements.

Name: _____

Company Name _____

Provider Signature: _____ Date: _____

A.1.5 Issues and Resolution Log

Commissioning Issue and Resolution Logs

The Commissioning Provider and Commissioning Team shall develop an Issues and Resolutions Log with supporting documentation.

Contents. The contents of the Issue and Resolution Logs shall include:

1. All open and continuing items, with status and responsible person or organization for resolution;
2. Procedures to maintain and distribute the issues and resolution log throughout the project until all issues are resolved or acknowledged by the Owner; and
3. Resolution(s) shall be included in the log and acknowledged by the owner.

Template CF-4 provides an optional guide for collecting and documenting the information associated with the Issues and Resolution Log activities. Other formats are acceptable.

COMMISSIONING ISSUES AND RESOLUTION LOG COMPLIANCE FORM
CF-4
Submitted before final inspection

Project Name:_____

Project Address:_____ Permit Number:_____

ITEM #	COMMISSIONING ISSUES AND RESOLUTION LOG ITEMS	PAGE NUMBER IN Cx ISSUES LOG
General Project Information		
1	All open and continuing items, with status and responsible person or organization for resolution.	
Log Procedures		
2	Procedures to maintain the log throughout the project until all issues are resolved or accepted by the Owner.	
Log Distribution		
2	Procedures to distribute the logs to the Commissioning Team at intervals prescribed in the Commissioning Plan.	
Resolution		

3	Resolution of each issue in the log with final approval by owner.	

Commissioning Provider Acknowledgement

I have reviewed the Issues Log and verified that it meets the applicable code requirements.

Name: _____

Company Name: _____

Provider Signature: _____ Date: _____

A.1.6 Systems Manual

The systems manual documents information focusing on the operation of the building systems. This document provides information needed to understand, operate, and maintain the equipment and systems; and informs those not involved in the design and construction of the building systems. This document is in addition to the record construction drawings, documents, and the O&M manuals supplied by the contractor. The systems manual is assembled during the construction phase and is available during the contractors' training of the facility staff. The systems manual shall be submitted to the owner prior to project completion and if possible before issuance of the certificate of occupancy. The systems manual ~~shall~~ should include the following information for all commissioned systems:

1. Table of Contents;
2. Information for each commissioned equipment element or system including:
   - Manufacturer's operation and maintenance data for installed equipment, systems and assemblies including wiring diagrams and schematics;
   - Warranties, where provided;
   - Contractor, supplier, or service agency listing and contact information;
3. Facility Operations;
   - Facility guide, including operating plan, building and equipment operating schedules, setpoints and ranges, sequences of operation, and emergency procedures;
   - Maintenance plans, procedures, checklists, schedules and records;
   - Janitorial and cleaning plans and procedures where required.

SYSTEMS MANUAL

Template CF-5 provides an optional guide for collecting and documenting the information associated with the Issues and Resolution Log activities. Other formats are acceptable

SYSTEMS MANUAL COMPLIANCE FORM
CF-5

Submitted before Project Completion

Name:_____

Project Address:_____ Permit Number:_____

ITEM #	SYSTEMS MANUAL ITEMS	PAGE NUMBER IN SYSTEMS MANUAL
	Table Of Contents	
Code-Required Commissioning requirements		
a	Listing of all equipment and systems required by applicable codes to be commissioned.	
Record Documents Evaluation		
b	Construction record documents including; record plans, specifications and approved submittals.	
Systems and Assemblies Information		
c	Facility, systems and assemblies information including: 1. Manufacturer's operation and maintenance data for installed equipment. systems and assemblies including wiring diagrams and schematics. 2. Warranties, where applicable. 3. Contractor, supplier, or service agency listing and contact information.	
Operation Information		
d	A facility operations guide, including an operating plan, building and equipment operating schedules, setpoints and ranges, sequences of operation, system and equipment limitations and emergency procedures.	
	Maintenance Plans and Janitorial plans where required	
Training		
e	Where training is provided, training plans, materials and records shall be provided.	
Preliminary Commissioning Report		
f	A preliminary commissioning report including commissioning plans, FPT requirements and results, systems tested, listing and plans for equipment yet to be commissioned.	

Commissioning Provider Acknowledgement

I have reviewed the Systems Manual and verified that it meets the applicable code requirements.

Name: _____

Company Name: _____

Provider Signature: _____ Date: _____

A.1.7 Systems operations training.

The training of the appropriate maintenance staff for each equipment type and/or system should be documented in the commissioning report and should include the following:

- System/equipment overview (what it is, what it does, and with what other systems and/or equipment it interfaces).
- Review and demonstration of servicing/preventive maintenance.
- Review of the information in the systems manual.
- Review of the record drawings on the system/equipment.

Intent. The systems operation training verifies that a training program is developed to provide training to the appropriate maintenance staff for each equipment type and/or system, and that this training program is documented in the commissioning report. The systems operation training program is specified in the project specifications for the major systems listed. The systems manual, O&M documentation and record drawings are prepared and available to the maintenance staff prior to the implementation of any training or the development of a written training program. The training program is to be administered when the appropriate maintenance staff is made available to receive training. The written training program includes: (a) learning goals and objectives for each session; (b) training agenda, topics and length of instruction for each session; (c) instructor information and qualifications; (d) location of training sessions (on-site, off-site, manufacturer's or vendor's facility); (e) attendance forms; (f) training materials; and (g) description on how the training will be archived for future use.

Systems/equipment overview.

- Review the OPR and BOD related to the major systems and equipment.
- Describe system type and configuration.
- Explain operation all major systems and equipment, and how it interfaces with other systems and equipment.
- Describe operations of critical devices, controls and accessories.
- Review locations of the major systems and equipment.
- Describe operations of the control system for each system, location of critical control elements, and procedures to properly operate control system.
- Review recommendations for implementation to reduce energy and water use.

Review and demonstration of servicing/preventive maintenance.

- Explain location or delivery contact of the O&M manuals.
- Review of all manufacturers' recommended maintenance activities to maintain the warranty.
- Review and demonstrate frequent maintenance activities (air filter replacement, lubrication, fan belt inspection and/or replacement, condenser water treatment, etc.), and suggested schedule.
- Review and demonstrate typical servicing procedures and techniques (electrical current, pressure and flow readings, calibration procedures, point trending, power fail restart procedures, etc.).
- Locate, observe and identify major equipment, systems, accessories and controls.

Review emergency shutoffs and procedures.

Enforcement. At their discretion, the building official confirms demonstrated compliance during on-site enforcement by:

- Receipt of a copy of the written training program and completed attendance forms; and

- Receipt of a form signed by the owner or owner's representative attesting that the training program and delivery of training has been completed.
- Receipt of other forms required by the applicable code or AHJ

DOCUMENTATION AND TRAINING SAMPLE COMPLIANCE FORM

Training

Contract documents. The training of the operating and maintenance staff of the facility should be required in the contract documents and include the development and application of a training plan.

Contents. The contents of the training plan should include:

1. Outline of instructional topics that should address the design, construction, operation, and maintenance of commissioned systems, assemblies, and equipment. A review and utilization of the Systems Manual should be included in the training process;
2. Learning objectives and training delivery methods, training materials and instructor requirements locations and duration for each instructional topic in conformance to the OPR and commissioning Plan; and
3. Requirements and format for training reports, records and recording criteria.

Records. Archival of instruction, delivery of instruction, and training materials should be provided as specified in the Contract Documents and per the OPR and commissioning plan. A copy of the Training Plan, training materials, and records should be included in the final Systems Manual.

Template CF-6 provides an optional guide for collecting and documenting the information associated with the Training activities. Other formats are acceptable.

TRAINING COMPLIANCE FORM CF- 6		
Project Name:_____		
Project Address:_____ Permit Number:_____		
ITEM #	**TRAINING ITEMS**	**PAGE NUMBER IN TRAINING PLAN**
	General Training Information	
a	Outline of instructional topics should address the design, construction, operation, and maintenance of commissioned systems, assemblies, and equipment. A review and utilization of the Systems Manual ~~shall~~ should be included in the training process.	
	Objectives and Methods	
b	Learning objectives and training delivery methods, training materials and instructor requirements, locations and duration for each instructional topic in conformance to the OPR and commissioning Plan.	
	Materials and Records	
c	Requirements and format for training report, records and recording criteria.	

Commissioning Agency Acknowledgement

I have reviewed the training plan and verified that it meets the owner's project requirements.

Name: _____

Company Name: _____

Agency' Signature: _____ Date: _____

A.1.8 Commissioning report

Preliminary Commissioning Report. The preliminary commissioning report should be delivered to the owner and if required the code official prior to the final inspection or issuance of the Certificate of Occupancy and shall include the following:

1. Table of contents.
2. Documentation of the commissioning activities included in the commissioning plan and those required by code and by this standard, including any delayed testing.
3. The final commissioning plan, including functional test and performance test procedures used and the criteria for test acceptance.
4. The list of code-required commissioning and the design and submittal reviews required by the Commissioning Plan.
5. The results of all evaluations, start-up data, functional tests, and performance tests, and reports for code-required commissioning.
6. Issue logs and disposition of all deficiencies found during testing and evaluation, including corrective measures used or proposed.
7. A resolution plan identifying any tests that are deferred and issues that are unresolved or incomplete, plus the conditions for completion and the individuals responsible for completion.

Final Commissioning Report. The final commissioning report shall be delivered to the owner after final completion of the commissioning work required by code and by this guideline and should include the Commissioning Process activities occurring after issuance of the Certificate of Occupancy and the results from those activities, together with the contents of the Preliminary Commissioning Report.

COMMISSIONING REPORT SAMPLE COMPLIANCE FORM

Template CF-7 provides an optional guide for collecting and documenting the information associated with the Commissioning activities. Other formats are acceptable.

PRELIMINARY COMMISSIONING REPORT COMPLIANCE FORM
CF-7

Project Name:_____

Project Address:_____ Permit Number:_____

ITEM #	PRELIMINARY COMMISSIONING REPORT ITEMS	PAGE NUMBER IN Cx Report
Commissioning Scope		
a	Documentation of the commissioning activities included in the commissioning plan required by adopted codes and the OPR including delayed testing.	
Commissioning Plan		
b	A copy of the final commissioning plan, including functional and performance test procedures used during the commissioning process and measurable criteria for test acceptance.	
Design Documents and Reviews		
c	A copy of the design and submittal reviews as required by the commissioning plan.	
System Evaluations		
d	The results of all evaluations, start-up data, functional and performance tests, and reports by suppliers, contractors, inspectors, and commissioning providers.	
Issues and resolutions		
e	Issue logs and disposition of all deficiencies found during testing, including details of corrective measures used or proposed.	
Open Items		
f	A resolution plan approved by the owner or the owner's representative identifying the deferred tests and issues that are unresolved or incomplete and any required conditions for completion.	

Commissioning Agency Acknowledgement

I have reviewed the commissioning report and verified that it meets the owner's project requirements.

Name: _____

Company Name: _____

Agency' Signature: _____ Date: _____

Owner Acknowledgement

I have received and reviewed the preliminary commissioning report.

Name: _____

Company Name: _____

Signature: _____ Date: _____

Enforcement. At their discretion, the building official confirms demonstrated compliance by:

- Receipt of a copy of the commissioning report;-or
- Receipt of a form signed by the owner or owner's representative attesting that the commissioning report has been completed.

Receipt of other forms required by the applicable code or AHJ

APENDIX B.1
Commissioning Checklists for Building Types and Functions

B.1.1 Commercial and Office Building Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning depending upon project type, and budget. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO OFFICE FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems are shown in Appendix B-2 that follows.

Commercial and Office Building Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	**Equipment/System**	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems – code required			
3	Plumbing Systems			
4	Lighting and control systems – code required			
5	Electrical power systems			
6	Energy monitoring and management systems			

7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Roofing systems			
14	Computer and data rooms systems			
15	Security systems			
16	Telephone and communication systems			
17	Renewable Energy Systems			
18				
19				
20				
21				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.2 Health Care Facilities - Medical Office Buildings and Hospitals Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO MEDICAL FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems are shown in Appendix B-2 below

Medical Buildings and Hospitals Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	**Equipment/System**	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed -- Date
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems – code required			
3	Plumbing Systems			
4	Lighting and control systems-code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Computer rooms and data systems			
14	Security systems			
15	Telephone and communication systems			
16	Medical gas systems			
17	Steam Systems			
18	Central Plant			
19	Humidification systems			
20	Nurse call systems			
21	Renewable Energy Systems			
25				
26				

27				
28				
29				
30				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.3 Education Facilities – Schools PreK-12 Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO SCHOOL FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems are shown in B-2 below.

Education Facilities – Schools PreK-12 Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	**Equipment/System**	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed -- Date
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems – code required			

3	Plumbing Systems			
4	Lighting and control systems-code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Other Structures			
14	Computer and data rooms systems			
15	Security systems			
16	Telephone and communication systems			
17	Time clock and signaling systems			
18	Medical area and isolation systems			
19	Humidity Control Systems			
20	Laboratory Hoods and Exhausts			
21	Shop and Special Exhausts			
22				
23				
24				
25				
26				
27				
28				
29				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.4 Colleges and University Facility Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO UNIVERSITY FACILITIES SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 below.

Colleges and University Facility Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	Equipment/System	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed – Date
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems – code required			
3	Plumbing Systems			
4	Lighting and control systems – code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			

12	Building enclosures			
13	Computer rooms and data systems			
14	Security systems			
15	Telephone and communication systems			
16	Central plant and connected systems			
17	Shop and Special Exhausts			
18	Humidity control systems			
19	Central Plant			
20				
21				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.5 Municipal and State Buildings Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO MUNICIPAL and STATE FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 below.

Municipal and State Buildings Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	Equipment/System	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed -- Date
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems – code required			
3	Plumbing Systems			
4	Lighting and control systems – code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13				
14	Computer rooms and data systems			
15	Security systems			
16	Telephone and communication systems			
17	Public address systems			
18	Court Systems			
19	Detention areas			
20	Smoke Control Systems			
21	Library Systems			
22	Humidity Control Systems			
23	Fire Stations			
24	Shops and Special Exhaust Systems			
25	Police Stations Special Systems			
26				
27				
28				
29				
30				
31				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.6 Federal Buildings Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO FEDERAL FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 below.

Federal Buildings Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	Equipment/System	System Commissioning Required Yes/No	Integrated System Commissioning Required – Y/N	Commissioning Completed – Date
1	Air Conditioning and ventilation systems			
2	Plumbing hot water systems			
3	Plumbing Systems			
4	Lighting and control systems			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery			

	systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Roofing systems			
14	Computer rooms and data systems			
15	Security systems			
16	Telephone and communication systems			
17	Public address systems			
18	Court Systems			
19	Detention Facilities			
20	Smoke Control Systems			
21	Libraries			
22	Humidity Control Systems			
23	Fire Prevention and Operation			
24	Shops and Special Exhaust Systems			
25	Law Enforcement and Security Systems			
26				
27				
28				
29				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____
Company Name _____
Signature: _____ Date: _____

B.1.7 Industrial Facility Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO INDUSTRIAL FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 below.

Industrial Facility Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	**Equipment/System**	System Commissioning Required	Integrated System Commissioning Required	Commissioning Completed – Date
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems – code required			
3	Plumbing Systems			
4	Lighting and control systems – code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Roofing systems			
14	Computer rooms and data systems			
15	Security systems			
16	Telephone and communication systems			
17	Storage and transportation systems			
18	Manufacturing equipment and systems			
19	Exhaust Systems			
20	Refrigeration Systems			
21	Warehouse and Storage Systems			

22	Chemical Storage and Use			
23				
24				
25				
26				
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The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.8 High Rise Residential Building Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning depending upon project type, and budget. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO OFFICE FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 that follows.

Residential Building Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	**Equipment/System**	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed

1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems -code required			
3	Plumbing Systems			
4	Lighting and control systems – code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Roofing systems			
14	Security systems			
15	Telephone and communication systems			
16				
17				
18				
19				
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The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.9 Retail Building and Area Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. However, each building project selects specific systems to undergo commissioning depending upon project type, and budget. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each retail building type usually has unique systems, such as lighting, communication and air conditioning, that benefit from commissioning.

2. COMMISSIONING APPLICATION TO OFFICE FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 that follows.

Commercial and Office Building Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	**Equipment/System**	System Commissioning Required Yes/No	Integrated System Commissioning Required Y/N	Commissioning Completed
1	Air Conditioning and ventilation systems – code required			
2	Plumbing hot water systems if included – code required			
3	Plumbing Systems if included			
4	Lighting and control systems - code required			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Special communication systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators if included			
12	Building enclosures			
13	Roofing systems			

14	Computer and data rooms systems			
15	Security systems			
16	Telephone and communication systems			
17				
18				
19				
20				
21				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Commissioning Provider Name: _____

Company Name _____

Signature: _____ Date: _____

B.1.10 Justice Buildings Commissioning

1. INTRODUCTION

The Commissioning Process can be utilized on nearly all building systems. These projects may include detention, jail or prison buildings, courthouses, police facilities and other related facilities. Due to their special functions and safety requirements, there are unique systems include that must be commissioned. However, each building project selects specific systems to undergo commissioning. This is done at project inception during the development of the Owner's Project Requirements. This listing is used to plan and implement commissioning during the entire project. Each building type usually has unique systems that benefit from commissioning.

2. COMMISSIONING APPLICATION TO FEDERAL FACILITY SYSTEMS

The following chart can be used to make the initial selection of the systems to be commissioned. The extent of the selections will depend upon needs of the project, and budget and schedule limitations. The detail subsystem decision list for many of these systems is shown in Section B.2 below.

Justice Buildings Commissioning

Project:_____Address:_____

Owner:_____Email/Phone_____

Owner's PM_____ Email/Phone_____

CX Provider:_____Email/Phone_____

Date Initiated: _____Date Revised:_____

Item	Equipment/System	System Commissioning Required Yes/No	Integrated System Commissioning Required – Y/N	Commissioning Completed – Date
1	Air Conditioning and ventilation systems			
2	Plumbing hot water systems			
3	Plumbing Systems			
4	Lighting and control systems			
5	Electrical power systems			
6	Energy monitoring and management systems			
7	Outdoor air and energy recovery systems			
8	Landscape irrigation systems			
9	Fire protection and fire sprinkler systems			
10	Fire alarm systems			
11	Vertical transportation, elevators, escalators			
12	Building enclosures			
13	Roofing systems			
14	Computer rooms and data systems			
15	Security systems			
16	Telephone and communication systems			
17	Public address systems			
18	Court Systems			
19	Detention Facilities			
20	Smoke Control Systems			
21	Libraries			
22	Humidity Control Systems			
23	Fire Prevention and Operation			
24	Shops and Special Exhaust Systems			
25	Law Enforcement and Security Systems			
26				
27				
28				

The approval section below can be used if applicable to the planning process.

I have reviewed the equipment list and verified that it meets the owner's project requirements:

Commissioning Provider Name: _____

Company Name _____

Signature: _____ Date: _____

B.2 Commissioning Functional Systems Checklist

- The following are a list of equipment/items/components that should be tested/verified when installed or where applicable. These lists can be used to designate commissioning process items and tracking the completion of the process

B.2.1 Site development and land use

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Landscape Irrigation: • Landscape irrigation design. • Static pressure verification. • Point of connection. • Backflow prevention. • Flow meter. • O&M manual.	Verify the availability of required static pressure Backflow O&M manual
Irrigation Design and Systems:	
• Irrigation controllers with weather or moisture-based capabilities.	• Check irrigation controllers for compliance with the plans and specifications.
• Irrigation design.	Check for proper irrigation proper water spray coverage, and appropriate overlap and spacing in accordance with the plans
• Sprinkler head layout at perimeter of building:	• Check for correct sprinkler head emitters with appropriate head rotation to prevent over spraying onto building walls. • Verify sprinkler head per approved plans.

Outdoor Ornamental Fountains and Water Features:
• System Calibration System Performance Testing of system of related components in-pool items Testing of mechanical room Erosion Control Systems
	• Verify the following per plans
	  • Outdoor Ornamental Fountains and Water Features:
	  • Design of water feature or fountain.
	  • Available water source.
	  • Available electrical voltage.
	  • Electrical components.
	  • Mechanical components.
	  • Plumbing components.
	• Verify calibration of all components, including, but not limited to, pumps, filters, chemical controllers, motors, electrical panels, pipe installation, geo-membranes, surface materials.
	• Verify performance of Leakage tests.

	• Verify performance of the system as a unit. • Verify performance of all modes of operation. • Verify test of in-pool items, including, but not limited to, nozzles; suction and inlet fittings; overflows and weirs; control valves; lights; junction boxes; cord seals; and level sensors. • Verify test of mechanical room, including, but not limited to, control panel terminations, lighting panel, disconnects and ground-fault device wiring to all equipment, valve tags and flow directional arrows, piping and pressure gauges.

Site drainage	• Verify Storm water pollution prevention plan (SWPPP) , when required, is on site
	• Verify drainage system is installed in accordance with site drainage plan
	• Check when required by the plans:
	  • Silt fencing.
	  • Construction drive.
	  • Erosion control blankets.
	  • Erosion control straw logs.
	• Observation and documentation that all BMP pertaining to erosion control were successfully utilized.
	• Observation and documentation during construction that all elements of the erosion control plan are in place such that the soil on the site is contained with no chance of run-off.
	• Verification that collected water after a rain event will move through the site in accordance with the site drainage plan.
	• Verification and documentation that the drainage system components meet or exceed those specified in the site drainage plan.
	• Verification and observation that the O&M and systems manual as submitted meets the criteria and needs of the end user.

Topography and Grading (cut/fill): • Grading plan. • Soil analysis/compaction plan. • . • Site safety plan. • Tree removal/mitigation plan. • Soil stabilization and erosion control plan. • Re-vegetation plan, slope-control planting. • Equipment utilization plan. • Ground water and infiltration.	• Verify that soils reports are complete and in accordance with local rules and regulations • Verify site waste reduction plan is consistent with IgCC and/or local ordinance including tree removal • Verify vegetation meets the re-vegetation plan • Ensure air quality plan is part of SWPPP or soil erosion control plan • Check to ensure site safety plan is in place • Verify that earth-moving equipment has been maintained and repaired in accordance with the O&M manual pertaining to each piece of equipment. • Verify that all elements of site erosion control are monitored daily for deficiencies or necessary repairs. • Verify that areas of fill are compacted to a level that meets or exceeds the soil compaction plan. • Verify that sufficient soil samples representing a true cross section of the cut and fill areas, and of the material to be used as fill, have

	been taken and tested under the supervision of a certified soils engineer. • Verify of all field and laboratory tests of the land to be covered with fill to confirm that the characteristics of the soil, including its expansive qualities, and bearing value of the land, consolidation potential, can support the proposed fill and structures. • Verify laboratory analysis and related data support the proposals to replace, rework or blend, or to stabilize or modify with additives support the proposed work. • Periodic site inspections for verify that the previously disturbed areas are maintaining their slopes and compaction rates.
Land-clearing Debris and Soil Reuse: • Waste management communication plan. • Waste inventory. • Salvage. • Disposal. • Source-separated construction, demolition and land-clearing recycling. • Waste management report.	• Verify that the materials on the site are handled as outlined in the waste management plan. • Verify that the recyclables and salvage items are packaged for removal and transported as outlined in the waste management plan. • Verify that hazardous construction materials are handled as outlined in the construction waste management plan. • Verify that the waste management goals and the waste prevention goals meet the requirements of the waste management plan. • Verify that the waste inventory reconciles with all disposal manifests or weight tickets. • Verification and documentation that the waste management report correctly reflects the outcome of the waste management plan.
Heat Island Mitigation: • Energy consumption. • Air pollutant emissions. • Greenhouse gases. • Trees and vegetation.	• Verify cool roof complies with thermal emittance, solar reflectance, or SRI values per the code • Verify structural and vegetative elements of the green roof • Verification of the water quality as it pertains to the mitigation techniques utilized in the original construction of the site. • Verify that the O&M manual meets the needs of the property owner. • Check and document the energy consumption savings as they pertain to the mitigation techniques used in the construction of the site. • Check and document the decreased air pollutant emissions and greenhouse gases produced and released as they pertain to the mitigation techniques utilized in the original construction of the site. • Verification and documentation of the water quality as it pertains to the mitigation techniques utilized in the original construction of the site.
Lighting: • Site lighting. • Security lighting. • Area lighting. • Landscape lighting. • Sports lighting.	• Verify exterior lighting meets light pollution plan • Check and document that all fixtures are in compliance with the definitions as defined by the IESNA. • Check Peripheral vision enhancement. • Check and document that the smallest wattage lamp source available is used to meet the desired lighting levels. • Check and document that the ratios of illuminance and luminance

	values are in compliance with the IESNA's *9th Edition Handbook Recommended Standards*. • Verify that all fixtures installed have been either selected from the specified product group or submitted as approved alternatives, as approved by the governing body of the local area. • Check and document that primary entry lighting, exterior emergency egress lighting, service area lighting, surface parking, parking garage and roadways are in compliance with the final lighting commissioning plan. • Verification and documentation that the O&M manual meets the goals of the owner.
Brownfield Mitigation: • Baseline risk assessment. • Corrective action plan. • Remedial action plan. • Remedial investigation/feasibility study. •	• Verification and documentation that the baseline risk assessment clearly and correctly identified and evaluated the threat to human health and the environment. • Verification and documentation that the recommended cleanup criteria and alternatives for remediation are aligned with the extent of contamination on the site. • Observation, verification and documentation that the cleanup of the site is at a level determined to be health protective for its intended use.

B.2.2 Materials (architectural building assembly)

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Foundations subsoil drainage system.	Verify compliance with approved plans, specifications, and construction documents
Foundation damp proofing and waterproofing.	
Flashing at: exterior doors, skylights, wall flashing and drainage systems.	
Exterior wall coverings.	
Optional systems:	
• Moisture envelopes.	Meet OPR, BOD, Cx specifications.
• Exterior below-grade walls.	Check for proper drainage system at exterior wall perimeter to keep water from entering the building.
• External floor and soffits, slab-on-grade.	• Check for thermal resistance or insulation when required. • Check the IECC, when applicable. • Slabs: Check drainage for moisture penetration.
• Exterior walls.	• Check drawings for wall assembly requirements and any sound transmission class (STC) requirements in accordance with ASTM E 90 and ASTM E 413. • Check for compliance with applicable section of the International Building Code (IBC).
• Exterior glazed window fenestration: windows, glazed doors and skylights.	Drawing reviews and contractor submittal reviews: • Check that fenestration products are labeled with a *U*-factor (see NFRC 100) and a solar heat gain coefficient (SHGC) (see NFRC 200), and certification for the air infiltration requirement

	of 0.3 cfm/ft^2 or other approved standards. • Check for proper flashing and caulking at walls and roof assemblies. Glazed doors: • Check for proper flashing, and seals and gaskets; and proper pull force, if provided with a closer. • Check for proper door swing. • Check for STC requirements, if applicable.
• Site-built fenestration: curtain walls and store-front systems, and atrium roof systems.	• Check for a label certificate issued by the National Fenestration Rating Council (NFRC) or a label certificate issued by the glazing fabricator that meets the default U-factor of the SHGC; or an NFRC component modeling approach (CMA) label certificate or another approved standard. • Check for proper door swing. • Check for STC requirements, if applicable.
• Field-fabricated fenestrations: fenestration made at the site, not preformed or cut.	Check for compliance with the default *U*-factor and the default SHGC in accordance with the applicable approved standard.
• Exterior doors	• Check for proper flashing installation at header, walls and floor. • Check for U-factor requirements for swinging and non-swinging doors. • Check for appropriate manufacturer's referenced standard (American Architectural Manufacturer's Association (AAMA); Canadian Standards Association (CSA); and Window and Door Manufacturer's Association (WDMA) or other approved standard) product data sheets.
• Sealants, control joints and flashing (stationary and moveable).	• Check for proper installation in accordance with the manufacturer's written instructions. • Check for proper flashing installation.
• Shading devices (stationary and moveable).	• Check for proper anchoring to building with proper flashing at wall connections. • At mechanical devices: check for proper installation and controls.
• Structural systems.	Check for proper anchoring in accordance with construction documents, including metal connectors and beam supports.
• Materials and finishes.	• Check for compliance with allowed volatile organic compound limits and proper manufacturer's installation application • Review product data sheets.

For SI: 1 cubic foot per minute per square foot = 0.00508 m^3/(s · m^2).

Other Project Requirements

Structural systems.	Check for proper anchoring in accordance with the construction documents, including metal connectors and beam supports.

Structural requirements for mechanical systems and renewable energy systems.	Pre-functional checklists, site observations and construction testing.

B.2.3 Energy—Management and monitoring systems

• Workstation graphic displays.	Verify the following is consistent with the commissioning plan: • Systems design. • System specifications. • System submittals. • System installations. • System pre-startup inspection checklist. • System functional performance testing. • Systems training. • Device Point to Point checkout (Static Testing) • Device Point to Point checkout (Dynamic Testing) • Sensor calibration • Valve and damper stroke setup and check • Coil valve leak check • Isolation valve or system valve leak check
• Public display systems.	
• Central processing/monitoring hardware and software.	
• Network communications/alarm functions.	
• User interface with emergency medical services.	
• Monitoring functions required for facility operations.	
• Local control panels and individual monitoring points.	
Integrated Automation Instrumentation for HVAC Systems: • Actuators and operators. • Sensors and transmitters. • Control valves. • Control dampers. • Flow meters.	
Integrated Automation Instrumentation for Plumbing Systems: • Domestic water metering. • Grey water metering. • Fuel system (gas, oil) metering.	
Integrated Automation Instrumentation and Terminal Devices for Electrical Systems: • Power meters. • Kilowatt (kW) transducers. • Current sensors. • Battery monitors. • Lighting relays. • UPS monitors.	
Integrated Automation of Renewable Energy Systems: • Solar photovoltaic. • Wind generation. • Geothermal.	
• Building management systems.	
• Electrical systems.	
• Lighting systems.	

• Alternative power systems.	
• On-site renewable energy.	
• Whole-building energy analysis.	
• Controllability of lighting systems.	
• Controllability of thermal systems.	

B.2.4 Energy—HVAC Systems

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Instrumentation and Control for HVAC: • Actuators and operators. • Sensors and transmitters. • Control valves. • Control dampers. • Direct-digital control system.	(tasks included on previous page)
Unitary HVAC Equipment: • Packaged terminal air conditioners. • Room air conditioners. • Self-contained air conditioners. • Computer room air conditioners. • Split-system air conditioners. • Air-source unitary heat pumps. • Water-source unitary heat pumps.	• Verify air system balancing • Verify hydronic system balancing • Verify duct system testing. • Verify mechanical system manuals and construction documents required by the O&M manual are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system completion; documentation that construction documents require drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Humidity Control Equipment: • Humidifiers. • Heated-pan humidifiers. • Wetted-element humidifiers. • Atomizing humidifiers. • Direct-steam-injection humidifiers. • Jacketed, steam humidifiers. • Self-contained steam humidifiers. • Portable humidifiers, mechanical dehumidification units. • Outdoor, mechanical dehumidification units. • Indoor, mechanical dehumidification units. • Portable dehumidifiers. • Desiccant dehumidification units.	

Convection Heating and Cooling Units: • Chilled beams. • Air coils. • Fan coil units. • Unit ventilators. • Induction units. • Radiators convectors. • Finned-tube radiation heaters. • Unit heaters. • Cabinet unit heaters. • Propeller unit heaters. • Wall and ceiling unit heaters. Water-to-water heat pumps.	• Verify air system balancing • Verify hydronic system balancing • Verify mechanical system manuals construction documents required by the O&M and systems manual are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system completion; documentation that construction documents require drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Humidity Control Equipment: • Humidifiers. • Heated-pan humidifiers. • Wetted-element humidifiers. • Atomizing humidifiers. • Direct-steam-injection humidifiers. • Jacketed, steam humidifiers. • Self-contained steam humidifiers. • Portable humidifiers. • Mechanical dehumidification units. • Outdoor, mechanical dehumidification units. • Indoor, mechanical dehumidification units. • Portable dehumidifiers. • Desiccant dehumidification units.	
Radiant Heating Units: • Radiant-heating electric cables. • Radiant-heating electric mats. • Radiant-heating hydronic piping. • Radiant-heating electric panels. • Gas-fired radiant heaters. • Electric radiant heaters.	
Central Heating Equipment—Breechings, Chimneys and Stacks: • Draft control devices. • Draft-induction fans. • Vent dampers. • Barometric dampers. • Fabricated breechings and accessories. • Fabricated stacks. • Gas vents. • Insulated sectional chimneys. • Flue-gas filtration equipment. • Gaseous filtration.	• Verify air system balancing and a means for providing the system balancing. • Verify hydronic system balancing and a means for providing the system balancing. • Verify duct system testing. • Verify mechanical system manuals and construction documents required by the O&M manual are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system

• Particulate filtration.	completion; documentation that construction documents require drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Fuel-fired Heaters: • Fuel-fired duct heaters. • Oil-fired duct heaters. • Gas-fired duct heaters. • Gas-fired radiant heaters. • Fuel-fired unit heaters. • Oil-fired unit heaters. • Gas-fired unit heaters.	• Verify air system balancing and a means for providing the system balancing. • Verify hydronic system balancing and a means for providing the system balancing. • Verify duct system testing. • Verify mechanical system manuals and construction documents required by the O&M manual are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system completion; documentation that construction documents require drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Furnaces: • Electric-resistance furnaces. • Fuel-fired furnaces. • Gas-fired furnaces. • Oil-fired furnaces.	
Heat Exchangers for HVAC: • Steam-to-steam heat exchangers, steam-to-water heat exchangers. • Liquid-to-liquid heat exchangers. • Plate-type, liquid-to-liquid heat exchangers. • Shell-type, liquid-to-liquid heat exchangers. • Direct-geo-exchange heat exchangers.	
Heating Boiler Feedwater Equipment: • Boiler feedwater pumps. • De-aerators.	
Heating Boilers: • Electric boilers. • Condensing boilers. • Stainless-steel condensing boilers. • Aluminum condensing boilers. • Low-mass boilers. • Pulse combustion boilers. • Cast-iron boilers. • Water-tube boilers. • Finned water-tube boilers. • Steel water-tube boilers.	

• Copper water-tube boilers. • Fire-tube boilers. • Scotch marine boilers. • Steel fire-tube boilers. • Boiler blowdown systems.	
Solar Energy Heating Equipment: • Heating solar collectors. • Heating solar flat-plate collectors. • Heating solar concentrating collectors. • Heating solar vacuum-tube collectors. • Packaged solar heating equipment.	
Central Cooling Equipment: • Refrigerant compressors. • Centrifugal refrigerant compressors. • Non-condensable, gas-purge equipment. • Reciprocating refrigerant compressors. • Scroll refrigerant compressors. • Rotary-screw refrigerant compressors. • Compressor and condenser units packaged air/water-cooled refrigerant compressor and condenser units.	• Verify air system balancing and a means for providing the system balancing. • Verify hydronic system balancing and a means for providing the system balancing. • Verify duct system testing. • Verify mechanical system manuals and construction documents required by the O&M manual are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system completion; documentation that construction documents require drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Cooling Towers: • Forced-draft cooling towers. • Open-circuit, forced-draft cooling towers. • Closed-circuit, forced-draft cooling towers. • Natural-draft cooling towers. • Liquid coolers.	
Packaged Water Chillers • Absorption water chillers. • Direct-fired absorption water chillers. • Indirect-fired absorption water chillers. • Centrifugal water chillers. • Air-cooled centrifugal water chillers. • Water-cooled centrifugal water chillers reciprocating water chillers. • Scroll water chillers. • Rotary-screw water chillers.	
Thermal Storage: • Chilled-water thermal storage. • Ice thermal storage. • Ice-slurry thermal storage.	• Verify hydronic system balancing and a means for providing the system balancing. • Verify duct system testing. • Verify mechanical system manuals and construction documents required by the O&M manual are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system completion; documentation that construction documents require

	drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Air Outlets and Inlets: • Diffusers, registers and grilles. • HVAC gravity ventilators. • HVAC gravity dome ventilators. • HVAC gravity-louvered penthouse ventilators. • HVAC gravity up-blast ventilators.	• Verify air system balancing • Verify hydronic system balancing • Verify duct system testing. • Verify mechanical system manuals and construction documents required by the O&M and systems manuals are submitted. • Verify that functional performance testing of HVAC equipment and associated controls and control systems. • Verify acceptance of HVAC systems and equipment/system verification report. • Verify preparation and distribution of final HVAC system completion; documentation that construction documents require drawings, manuals, balancing reports and commissioning report are provided to the owner and that they have been provided. • Verify air-handling system access. • Verify air-handling system filters. • Verify temperature and humidity in occupied spaces. • Verify specific indoor air quality and pollutant control measures. • Verify listing, instillation and venting of fireplaces and combustion appliances. • Verify mechanical and emergency generator equipment located outside building or located where expose to exterior environment.
Air Terminal Units: • Constant-air-volume units. • VAV units.	
Electronic Air Cleaners: • Washable electronic air cleaners. • Self-contained electronic air cleaners.	
Gas-phase Air Filtration: • Activated-carbon air filtration. • Chemically impregnated adsorption air filtration. • Catalytic-adsorption air filtration.	
HVAC Air Cleaning Devices—Particulate Air Filtration: • Panel air filters. • Renewable-media air filters. • Washable air filters. • Extended surface filters. • High-efficiency particulate filtration.	
HVAC Air Distribution: • Dampers. • Volume-control dampers. • Fire dampers. • Smoke-control dampers. • Backdraft dampers. • Duct silencers. • Turning vanes. • Duct- access doors. • HVAC fans. • Axial HVAC fans.	

• Centrifugal HVAC fans. • HVAC power ventilators. • Air curtains.	
Special Exhaust Systems: • Dust-collection systems. • Sawdust collection systems. • Engine exhaust systems. • Positive-pressure engine exhaust systems. • Mechanical engine exhaust systems.	(Included in above tasks/comments) • Verify compliance with local codes
Ventilation Hoods: • Commercial kitchen hoods. • Listed commercial kitchen hoods. • Standard commercial kitchen hoods. • Fume hoods.	
HVAC Piping and Pumps; **Hydronic Piping and Pumps:** • Hydronic piping. • Underground hydronic piping. • Above-ground hydronic piping. • Ground-loop heat-pump piping. • Hydronic piping specialties. • Hydronic pumps. • In-line centrifugal hydronic pumps. • Base-mounted, centrifugal hydronic pumps. • Vertical-mounted, double-suction centrifugal hydronic pumps. • Vertical-turbine hydronic pump, automatic.	• Installed in compliance with contract document • Flushing and cleaning plan submitted and approved • System properly flushed and cleaned and temp piping removed • Piping pressure tested according to contract document • Isolation valves provided at all branches and main takeoffs as required by the contract documents • Valves installed in the proper direction • Valves that require a positive shut-off are verified to not leak when closed at normal operating pressure • Valves tagged and valve schedule submitted and displayed per contract documents • Temperature, pressure and flow gages and sensors installed • Piping gages, BAS and associated panel temperature and pressure readouts match
HVAC Water Treatment: • Water treatment for Closed-loop hydronic systems. • Water treatment for open hydronic systems. • Water treatment for steam system feedwater.	
Internal-combustion Engine Piping: • Internal-combustion engine remote-radiator coolant piping. • Internal-combustion engine exhaust piping.	
Refrigerant Piping: • Refrigerant piping valves. • Refrigerant piping specialties. • Refrigerant safety relief valve discharge piping. • Refrigerants.	

Steam and Condensate Piping and Pumps: • Steam and condensate pump units. • Steam and condensate heating piping. • Steam and condensate heating piping specialties. • Steam condensate pumps. • Electric-driven steam condensate pumps. • Pressure-powered steam condensate pumps.	

B.2.5 Energy—Lighting and electrical systems

Lighting and Electrical:	
• Automatic demand-reduction control system functionality.	• Devices installed per manufacturer's instructions and specifications
• Plug load controls.	
• Connection of appliances to switched receptacles.	
• Verification of transformer nameplate efficiency.	
• Lamps (lighting installations).	
• Ballasts (lighting installations).	
• Lighting control systems (low voltage).	• Verify a representative sample of zones for sweep warning effectiveness, override capability and zone size. • Test accuracy of schedule, sweep warning system and sweep override switches.
Automatic daylight harvesting.	• Verify photosensors are properly placed and aimed. • Verify daylight control zones correspond to available daylight. • Calibrate dimming set points without the presence of daylighting. • Calibrate dimming gain in presence of daylighting. • Calibrate switching dead-bands and set points. • Performance test a representative sample of daylight zones.
Occupancy and vacancy sensors.	• Calibrate sensitivity sensor and time delay adjustment. • Performance test a representative sample of control zones, including entry tests, hand-motion tests and perimeter tests.

Optional Items

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Medium-voltage: • Substations. • Switches. • Circuit breakers. • Switchgear. • Switchboards. • Panel boards.	• Verify coordination study is complete, and that breaker and relay settings are set in accordance with the study. • Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist. • Test transformers. • Test protective devices.

• Emergency systems.	• Test control circuits, e.g., potential transformers and current transformers. • Test switchgear, e.g., electrical and mechanical operations. • Test circuit breakers. • Local operational tests. • Remote operational tests, if applicable. • Verify training of operating personnel for O&M of equipment.
Low-voltage: • Substations. • Disconnects. • Circuit breakers. • Motor control centers. • Panel boards. • Emergency systems.	• Verify coordination study is complete, and that breaker and relay settings are set in accordance with the study. • Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present e.g., installer, factory representative, etc. • Review start-up checklist. • Test transformers. • Test protective devices, e.g., potential transformers and current transformers. • Test control circuits. • Test switchgear, e.g., electrical and mechanical operations. • Test circuit breakers. • Local operational tests. • Remote operational tests, if applicable. • Verify training of operating personnel for O&M of equipment.
Motors, motor starters and drives (VFD).	• Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist. • Verify motor and starter data match specification and each other. • Inspect the installation. • Take voltage and current reading; compare with nameplate and manufacture's specifications. • Test for proper motor rotation; if VFD, verify proper motor rotation when in VFD bypass mode. • Local operational tests. • Remote operational tests, if applicable. • Verify training of operating personnel for O&M of equipment. • Monitor operations.
Emergency generators and distribution systems.	• Verify coordination study is complete, and that breaker and relay settings are set in accordance with the study. • Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist and factory commissioning plan. • Inspect the installation. • Follow factory commissioning plan. • Local operational tests. • Remote operational tests, if applicable. • Load and duration tests (increasing loads over increasing durations).

	• Verify training of operating personnel for O&M of equipment. • Monitor operation.
UPS.	• Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist and factory commissioning plan. • Inspect the installation. • Follow factory commissioning plans (transfer testing, to generator, to bypass, to maintenance bypass, etc.). • Verify training of operating personnel for O&M of equipment. • Monitor operation.
Grounding equipment and building grounding systems.	• See IEEE 81. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Inspect the installation. • Verify training of operating personnel for O&M of equipment.
Lightning protection equipment and systems.	• Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Inspect the installation. • Ensure installer is listed by UL, and that a master label application is submitted to UL for the installation. • Ensure owner signs the master label application. • Ensure receipt of master label from the installer. • Place master label on the protected structure, as requested. • Take voltage and current reading; compare with nameplate and manufacture's specifications. • Test for proper motor rotation; if VFD, verify proper motor rotation when in VFD bypass mode. • Verify training of operating personnel for O&M of equipment. • Monitor operation.

B.2.6 Energy—Other electrical and Communication systems (communications, including telecom, intercom, public address, television, video, etc.)

- Optional items

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Medium-voltage: • Transformers. • Substations. • Switches. • Circuit breakers. • Switchgear. • Switchboards. • Panel boards. • Emergency systems.	• Verify coordination study is complete, and that breaker, fuse and relay settings are set in accordance with the study. • Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist. • Test transformers. • Test protective devices. • Test control circuits, e.g., potential transformers and current transformers. • Test switchgear, e.g., electrical and mechanical operation. • Test circuit breakers. • Local operational tests. • Remote operational tests, if applicable. • Test all mechanical connections using an infrared camera after initial energizing and after the system is loaded. • Verify training of operating personnel for O&M of equipment.
Low-voltage: • Transformers. • Substations. • Disconnects. • Bus duct. • Circuit breakers (air circuit breakers not molded case circuit breakers). • Motor control centers. • Panel boards. • Emergency systems.	• Verify coordination study is complete, and that breaker, fuse and relay settings are set in accordance with the study. • Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist. • Test transformers. • Test protective devices, e.g., potential transformers and current transformers. • Test control circuits. • Test switchgear, e.g., electrical and mechanical operation. • Test circuit breakers. • Local operational tests. • Remote operational tests, if applicable. • Test all mechanical connections using an infrared camera after initial energizing and after the system is loaded. • Verify training of operating personnel for O&M of equipment.

Motors, motor starters and drives (VFD).	• Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist. • Verify motor and starter data match specification and each other. • Inspect the installation. • Take voltage and current reading, compare with nameplate and manufacture's specifications. • Test for proper motor rotation; if VFD, verify motor proper motor rotation when in VFD bypass mode. • Local operational tests. • Remote operational tests, if applicable. • Verify training of operating personnel for O&M of equipment. • Monitor operation.
Emergency generators and distribution systems.	• Verify coordination study is complete, and that breaker, fuse and relay settings are set in accordance with the study. • Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist and factory commissioning plan. • Inspect the installation. • Follow factory commissioning plan. • Local operational tests. • Remote operational tests, if applicable. • Test all mechanical connections using an infrared camera after initial energizing and after the system is loaded. • Load and duration tests (increasing loads over increasing durations). • Verify training of operating personnel for O&M of equipment. • Monitor operation.
UPS.	• Witnessing of factory tests, as appropriate. • Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Review start-up checklist and factory commissioning plan. • Inspect the installation. • Follow factory commissioning plans (transfer testing, to generator, to bypass, to maintenance bypass, etc.). • Test all mechanical connections using an infrared camera after initial energizing and after the system is loaded. • Verify training of operating personnel for O&M of equipment. • Monitor operation.
Grounding equipment and building grounding systems.	• Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Inspect the installation. • Verify training of operating personnel for O&M of equipment.

Lightning protection equipment and systems.	• Ensure all necessary representatives are present, e.g., installer, factory representative, etc. • Inspect the installation. • Ensure installer is listed by UL and that a master label application is submitted to UL for the installation. • Ensure building owner signs the master label application. • Ensure receipt of master label from the installer. • Place master label on the protected structure, as requested. • Take voltage and current reading, compare with nameplate and manufactures specifications. • Test for proper motor rotation; if VFD, verify proper motor rotation when in VFD bypass mode. • Verify training of operating personnel for O&M of equipment. • Monitor operation.

B.2.7 Water—Plumbing systems (water distribution, sanitary/storm water, rainwater, gray water, etc.)

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Facility Water Distribution Piping: • Domestic water piping. • Domestic water piping specialties. • Domestic water pumps. • Domestic water-packaged booster pumps.	• Installed in compliance with contract document • Flushing and cleaning plan submitted and approved • Piping pressure tested according to contract document
Facility potable-water-storage tanks.	Installed in compliance with contract document
Facility Sanitary Sewerage: • Sanitary waste piping specialties. • Sanitary drains. • Fats, oils and grease disposal systems. • Grease removal devices. • Backwater valves. • Air admittance valves. • Sanitary waste interceptors and separators. • Sanitary sewerage pumps. • Wet pit-mounted, vertical sewerage pumps. • Submersible sewerage pumps. • Sewerage pump basins and pits. • Facility septic tanks. • Facility gray water tanks.	• Installed in compliance with contract document • Flushing and cleaning plan submitted and approved • System properly flushed and cleaned and temp piping removed • Piping pressure tested according to contract document • Valves installed in the proper direction • Valves that require a positive shut-off are verified to not leak when closed at normal operating pressure • Valves tagged and valve schedule submitted and displayed per contract documents
Facility Storm Drainage: • Facility storm drainage piping. • Sump pump discharge piping. • Sump pumps. • Submersible sump pumps. • Sump-pump basins and pits.	

• Packaged, pedestal drainage pump units. • Packaged, submersible, drainage pump units. • Rainwater storage tanks.	
General service compressed-air systems.	
Domestic Water Heat Exchangers: • Instantaneous domestic water heat exchangers. • Heating fluid-in-coil, instantaneous domestic water heat exchangers. • Domestic water-in-coil, instantaneous domestic water heat exchangers. • Heating fluid, instantaneous domestic water heat exchangers. • Circulating, domestic water heat exchangers. • Circulating, compact domestic water heat exchangers. • Circulating, storage domestic water heat exchangers. • Noncirculating, domestic water heat exchangers. • Noncirculating, storage domestic water heat exchangers. • Domestic water brazed-plate heat exchangers. • Domestic water frame-and-plate heat exchangers. • Domestic water heat reclaimers.	• Comply with manufacturer's recommended checkout and startup procedures • Manufacturer's recommended spare parts are provided • Equipment label permanently affixed • Pumps in place and properly supported • Pressure / temperature relief valves installed per contract documents • Shaft seal is leak free • Insulation installed per contract documents • All electrical connections are tight • Grounding installed and operational • Safeties installed and operational • Control system interlocks connected and functional • Pump rotates in correct direction • Temperature and pressure gages and sensors installed per contract documents

Domestic Water Softeners; **Domestic Water Filtration Equipment;** **Electric Domestic Water Heaters:** • Instantaneous electric domestic water heaters. • Flow-control, instantaneous electric domestic water heaters. • Thermostat-control, instantaneous electric domestic water heaters. • Electric domestic water heaters. • Small-capacity electric domestic water heaters. • Residential, storage electric domestic water heaters. • Collector-to-tank, solar-electric domestic water heaters. • Collector-to-tank, heat-exchanger-coil, solar-electric domestic water heaters. • Light-commercial electric domestic water heaters. • Commercial domestic water electric booster heaters. • Commercial domestic water electric booster heaters. • Commercial storage electric domestic water heaters.	• Comply with manufacturer's recommended checkout and startup procedures • Manufacturer's recommended spare parts are provided • Equipment label permanently affixed • Pumps in place and properly supported • Pressure / temperature relief valves installed per contract documents • Shaft seal is leak free • Insulation installed per contract documents

Fuel-fired Domestic Water Heaters: • Instantaneous, tankless, gas domestic water heaters. • Residential gas domestic water heaters. • Residential, atmospheric, gas domestic water heaters. • Residential, direct-vent, gas domestic water heaters. • Residential, power-vent, gas domestic water heaters. • Commercial gas domestic water heaters. • Commercial, atmospheric, gas domestic water heaters. • Commercial, power-burner, gas domestic water heaters. • Commercial, power-vent, gas domestic water heaters. • Commercial, high-efficiency, gas domestic water heaters. • Commercial, coil-type, finned-tube, gas domestic water heaters. • Commercial, grid-type, finned-tube, gas domestic water heaters. • Oil-fired domestic water heaters. • Large-capacity, oil-fired domestic water heaters. • Dual fuel-fired domestic water heaters.	• All electrical connections are tight • Grounding installed and operational • Safeties installed and operational • Control system interlocks connected and functional • Pump rotates in correct direction • Temperature and pressure gages and sensors installed per contract documents
Commercial Plumbing Fixtures: • Commercial water closets, urinals and bidets. • Commercial water closets. • Commercial urinals. • Commercial lavatories and sinks. • Commercial lavatories. • Commercial sinks. • Commercial bathtubs. • Commercial showers. • Commercial disposers. • Wash fountains. • Commercial faucets, supplies and trim. • Flushometers.	• Installation is per manufacturer's instructions • Pipe fittings complete and properly supported • Faucet / Flush handles secure and properly aligned • Associated trim and accessories consistent with contract documents • Joints between fixtures, walls and floors and counters sealed • Insulation installed per contract documents • Fixtures consistent with ADA • Water pressure meets contract documents • Hot Water temperature meets contract documents • Automatic flush valves and sensors verified for proper operation and sensitivity adjustment
Emergency Plumbing Fixtures: • Emergency showers. • Eyewash equipment. • Self-contained eyewash equipment.	• Installation is per manufacturer's instructions • Water pressure meets contract documents • Hot Water temperature meets contract documents

Drinking Fountains and Water Coolers: • Drinking fountains. • Pressure water coolers. • Water-station water coolers. • Remote water coolers.	• Installation is per manufacturer's instructions • Water pressure meets contract documents • Water temperature meets contract documents
Fountain Plumbing Systems: • Fountain piping. • Fountain pumps. • Fountain water treatment equipment. • Fountain equipment controls.	• Comply with manufacturer's recommended checkout and startup procedures • Manufacturer's recommended spare parts are provided • Equipment label permanently affixed • Pumps in place and properly supported • Pressure / temperature relief valves installed per contract documents • Shaft seal is leak free • Insulation installed per contract documents • All electrical connections are tight • Grounding installed and operational • Safeties installed and operational • Control system interlocks connected and functional • Pump rotates in correct direction
Swimming Pool Plumbing Systems: • Swimming pool pumps. • Swimming pool water treatment equipment. • Swimming pool equipment controls.	

B.2.8 Indoor environmental quality

- For IEQ requirements for individual systems see the following sections:
  - See Energy—HVAC systems.
- Optional systems
  - See Materials (architectural building assembly).

B.2.9 Water-Based Fire Protection systems

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
General:	Person must be familiar with the governing laws, codes, regulations, or standards.
• Building permit and building inspection record on site.	Verify type of system to be installed in accordance with governing laws, codes, regulations, or standards and the owner.
• Approved fire sprinkler plans/shop drawings, hydraulic calculations and architectural plans shall be on site.	Commissioning provider shall be proficient in all applicable codes. See NFPA 3, NFPA 4, NFPA 12, NFPA 12A ,NFPA 13, NFPA 13D, NFPA 13R, NFPA 14, NFPA 15, NFPA 16, NFPA 17, NFPA 17A,,NFPA 20, NFPA 22, NFPA 24, NFPA 25, NFPA 30, NFPA 30B, NFPA 33, NFPA 45, NFPA 54, NFPA 90A, NFPA 90B, NFPA 92, NFPA 96, NFPA 211, NFPA 214, NFPA 307 NFPA 409, NFPA 750, NFPA 853, and NFPA 2001.
• All materials and equipment.	Verify all materials and equipment used are listed and approved in

	accordance with the owner's needs as well as governing laws, codes, regulations or standard
Overhead piping:	See NFPA 13, *Standard for the Installation of Sprinkler Systems*
• All piping.	Witness hydrostatic test for all piping systems.
• Pipe sizing.	Verify pipe sizes are in accordance with the approved plans.
• Sprinklers.	Verify sprinkler spacing and positions are in accordance with the approved plans, listing and locally adopted codes.
• Hangers.	Verify spacing is in accordance with the approved plans and listing.
• Seismic bracing.	Verify spacing is in accordance with the approved plans and listing.
• Branch line supports	Verify spacing is in accordance with the approved plans.
• Flow switches.	Verify location, listing and operation.
• Inspector's test connection.	Witness operation and verify annunciation of alarm in required time.
• Sprinkler control valves and tamper switches.	Witness operation and verify annunciation of alarm in required time.
• Sprinkler Fire Alarm control panel indication.	Witness operation and verify annunciation of alarm in required time.
• Drainage for riser drain and inspector's test.	Verify drain pipe size.
Underground Piping:	See NFPA 24, *Standard for the Installation of Private Fire Service Mains*
• Underground pipe.	Witness hydrostatic test for all piping.
• Pipe size.	Verify pipe size installed in accordance with the approved plans, and in accordance with the owner's project documents as well as governing laws, codes, regulations or standard
• Depth of cover.	Verify pipe is installed to proper depth.
• Piping restrain.	Verify pipe is restrained properly.
• Fire department inlet connection.	Verify fire department connection (FDC) piping is properly sized.
• Back flush fire department inlet connections.	Witness flushing.
• Pipe flushing.	Witness flushing.
• Protection for mechanical damage.	Verify pipe is protected properly from mechanical damage.
Standpipe Systems:	See NFPA 14. *Standard for the Installation of Standpipe and Hose Systems*
• Underground piping.	Witness hydrostatic test.
• Pipe sizing.	Verify pipe size installed in accordance with the approved plans
• Hangers.	Verify hangers are installed in accordance with the approved plans and listing, and locally adopted codes.
• Seismic bracing.	Verify braces are installed in accordance with the approved plans and listing, and locally adopted codes.
• Standpipe.	Verify standpipe outlets are installed in accordance with locally adopted codes.
• Isolation valves and access.	Verify standpipe outlets are installed in accordance with locally adopted codes.
• Flush and flow test.	Witness test meets flow requirements in accordance with locally adopted codes.
• Hose connection and pressure rating.	Check for listing, damage, leakage, missing caps and obstructions.

Fire Pump Systems:	See NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*
• Certified curve for the fire pump.	Obtain certified curve from pump manufacturer.
• Fire pump identification number.	Compare approved plans and curve to pump nameplate.
• Pump room: floor drain, ventilation and rating.	Verify drainage, ventilation and rating of room is adequate inspection by others.
• Pipe hangers.	Verify hanger location in accordance with the approved plan and installed in accordance with locally adopted codes.
• Seismic bracing.	Verify braces in accordance with the approved plan and locally adopted codes.
• Test header outlets.	Verify location pipe size in accordance with the approved plan and installed in accordance with locally adopted codes.
• Relief valves	Verify size and location in accordance with the approved plans and installed in accordance with locally adopted codes.
• Jockey pump.	Verify suction and discharge is installed in correct locations in accordance with locally adopted codes.
• Controller and pressure-sensing piping.	Verify installation in accordance with locally adopted codes.
Water Storage Tank:	See NFPA 22, *Standard for Water Tanks for Private Fire Protection*
• Water in tank.	Check water level and water condition.
• Water level alarms.	Verify high- and low-level alarms.
• Water level indicators.	Verify location, accuracy and freedom of movement.
• Drain valve.	Verify flow.
• Tank vent.	Verify size in accordance with the approved plan and vent screen.
• Tank overflow.	Verify size in accordance with the approved plan.
• Supervised alarms.	Verify connection to a constantly attended location.
• Tank exterior.	Inspect damage exterior paint, foundation or supporting structure, catwalk or ladders.
• Area around the tank.	Free of combustible storage, trash, debris or other materials that could present a fire exposure hazard.
• Expansion joints.	Verify listing and check for cracks.
Pre-action Automatic Sprinkler Systems:	See NFPA 13, *Standard for the Installation of Sprinkler Systems*
• Control valves (locked or supervised).	• Verify listing. • Verify position.
• Water flow alarm devices.	• Operate to verify initiation and receipt of alarm. • Verify alarm test valve alignment and tamper switch.
• Pre-action valve and trim.	• Inspect exterior of valves, gauges and trim alignment. • Verify valve pressure and legibility of hydraulic nameplate.
• Main drain.	Conduct main drain test to verify supply (valve position).
• FDC.	• Verify accessibility and condition. • Check for obstructions, and missing or removed caps.
Deluge Sprinkler Systems:	See NFPA 13, *Standard for the Installation of Sprinkler Systems*
• Control valves (locked or supervised).	• Verify listing. • Verify position (open/close).
• Water flow alarms devices.	• Operate to verify initiation and receipt of alarm. • Verify alarm test valve alignment and tamper switch.
• FDC.	• Inspect exterior of valves, gauges and trim alignment. • Verify valve pressure and legibility of hydraulic nameplate.

• Main drain.	Conduct main drain test to verify supply (valve position).
• FDC.	• Verify accessibility and condition. • Check for obstructions, and missing or removed caps.
Dry Pipe Automatic Sprinkler Systems:	See NFPA 13, *Standard for the Installation of Sprinkler Systems*
• Control valves.	• Verify listing. • Verify position (open/close).
• Water flow alarm devices.	• Verify listing. • Operate to verify initiation and receipt of alarm. • Verify alarm test valve alignment and tamper switch.
• Dry pip alarm valve and trim.	• Verify listing. • Visually inspect exterior of valves, gauges and trim alignment. • Verify valve pressure and legibility of hydraulic nameplate.
• Main drain.	Conduct main drain test to verify supply (valve position).
• FDC.	• Verify accessibility and condition. • Check for obstructions, and missing or removed caps.

B.2.10 Fire alarms (See NFPA 72, *National Fire Alarm and Signaling Code*)

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Approved plans on-site.	
Pretest sheet completed.	Make sure forms are completed by installation contractors and field inspectors.
Permanent power to Fire Alarm (FA) system.	Verify permanent power is provided to FA and accessory systems.
Test booklet/list of devices on-site.	Verify FA device list is prepared, accurate and categorized by type of device and by floor.
Approved sequence of operations posted.	Verify the sequence of operation is accurate and posted adjacent to FA panel.
Operating instructions posted for FA system.	
Label all FA panels with the electrical circuit number.	Verify the presence of labels.
Lock-ons all FA electrical circuits.	Verify that circuits serving FA system have lock devices.
Date all batteries in FA system.	Verify all batteries have installation dates.
Approval of panel layout in fire control room.	Verify that layout accurately depicts location of life safety systems.
Inspect construction of fire control room.	Fire control room shall have the correct fire rating.
Access keys.	Obtain keys for building access; fire control room and FA panels/manual pull stations for key box. A lock box shall be provided at building entrance and at fire control room with required access keys.
Approval of matrix annunciator.	Verify the annunciator panel matches the approved plans.
Test operation of remote annunciators, if provided.	Verify that annunciation is synchronized with (matches) activated devices.
Fire alarm control panel (FACP) to monitor connection to matrix/remote annunciators.	Verify electrical supervision of circuits to remote annunciator.
FACP clear and trouble free prior to start of testing.	System shall be free of device and supervisory troubles.
FACP to monitor ground faults/power	Verify that ground-fault power supply/battery troubles/notification

supply-battery troubles. FACP to monitor troubles on initiating and notification circuits.	circuits annunciate as trouble signals to FACP.
FACP to monitor fire pump, water storage tank levels, fuel, emergency generator, smoke control panel switch status's supervisory signals.	Verify that FACP indicates trouble on non-normal status of these systems.
FACP to monitor elevator heat shunt trip breaker as supervisory signal. Primary and alternate floor elevator recall programming to be tested.	Verify proper operation to match approved fire department plans.
Central Station Signaling System (CSSS) to be tested.	Verify signals from FACP are properly sent by CSSS to monitor company and verify that the monitor company has correct jurisdictional contact.
24-hour battery test.	To be performed (5 or 15 minutes). Perform voltage check after discharge test.
Voice evacuation, where required.	Test all zones, elevators and stairwells to make sure they operate as indicated on the voice evacuation panel.
Voice evacuation/notification zones shall match each other and be tested.	Verify proper operation.
Fire-fighter communication system.	Shall be tested (sound powered, amplified, bi-directional antenna (BDA), etc.). Test handsets and input jacks.
Handsets.	Verify proper number of handsets is provided for fire-fighter communication system.
Initiating devices.	All initiating devices to be tested to verify programming and sequence of operations. All initiating devices to be installed in accordance with NFPA 72.
Subsequent alarm/sequence of operation.	Subsequent alarm/sequence of operation programming to be tested sequence of operations to be verified include: FACP programming, annunciation on matrix annunciator, signal sent to CSSS, smoke control activation, activation of notification devices, magnetic door holder release, activation of smoke/fire dampers, HVAC shutdown, audio-visual shunt, elevator recall, release of door locks in the path of egress, release of stairwell door locks, restoration of egress lighting in assembly occupancies.
Duct detectors.	Remote light-emitting diodes (LED's) for duct detectors to be tested.
Elevator lobby door locks.	Elevator lobby door locking systems to be tested.
Flow devices and tamper devices.	Test all water flow devices and tampers. Verify the correct signal to the FACP.
Special extinguishing systems, e.g., pre-action and deluge systems.	Test interaction/connection of special extinguishing systems to FACP.

Inspect signage on FA panels, doors to rooms with FA panels inside.	Ensure signage is in accordance with the approved plans.
Notification devices.	Inspect correct locations in accordance with the approved plans. Notification device candela ratings to be inspected. Audibility and Intelligibility levels to be tested for notification devices.
Mass notification systems.	Shall be tested for proper operation.

B.2.11 Elevators

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
Building permit and building inspection record on site.	Verify Documents
Approved elevator plans shall be on site.	
All materials and equipment shall be listed/approved.	
Elevator speed.	Verify contract speed.
Stopping zones.	Verify zones with the manufacturers testing procedures and specifications.
Door open speed.	Measure door open speed time.
Short hold open.	Verify door operation in accordance with the manufacturer's specifications.
Interrupted ray hold.	Verify operation of door reopening device.
Nudging hold open.	Verify operation.
Stall pressure.	Measure door torque.
Long hold open.	Measure door-open time in accordance with the manufacture's specifications.
Lanterns call notification.	Verify operation of hall lantern functions [in accordance with the Americans with Disabilities Act (ADA)].
Acceleration.	Verify car acceleration specification with the manufacturer.
Quality of stop.	Subjection to the manufacturer's specifications.
Door operation (how smooth).	Subjective to the manufacturer's specifications.
Door-open buttons.	Verify operation of door-open buttons.
Alarm buttons.	Verify operation of alarm buttons.
Emergency light.	Verify operation of emergency lighting.
Fire service, Phase 1.	Verify operation.
Fire service, Phase 2.	
Standby power.	
Telephone.	
Intercom.	
Car lighting guarded/mounted.	Car interior lighting in accordance with locally adopted codes and the manufacturer's specifications.
False call cancel.	If provide, verify operation.
Seismic operators.	Verify operation.
Door restriction.	

B.2.12 Escalators

RELATED SYSTEMS, EQUIPMENT, ASSEMBLIES AND COMPONENTS	TASKS/COMMENTS
General:	Verify Documents
• Building permit and building inspection record on site.	
• Approved escalator plans shall be on site.	
• All materials and equipment shall be listed/approved.	
External Evaluation:	
• Handrail.	Inspect condition, tracking and clearances.
• Handrail entry devices.	Inspect operation of safety devices.
• Comb-plate condition/contrast.	Inspect in accordance with the manufacturer's specifications.
• Indexing of steps/alignment in comb teeth.	Inspect in accordance with the manufacturer's specifications.
• Floor plates and landing plates.	Tripping hazards, lighting, mounted in accordance with the manufacturer's specifications.
• Deck.	Mounted, anti-slide, gaps and edge hazards in accordance with the specifications.
• Balustrade panels.	Mounted in accordance with the manufacturer's specifications.
• Skirt panels.	Check with locally adopted codes for compliance with the performance index and the manufacturer's specifications.
• Skirt brushes.	Inspect operation of safety devices.
• Emergency stop switches and audible alarms.	
• Start switches/direction reversal.	Inspect markings and operation of safety device.
• Comb-plate lighting.	Meet illumination requirements.
• Under-step demarcation lighting.	Verify operation of the demarcation (minimum two green lights).
• General lighting requirements.	Verify minimum illumination levels [5 foot-candles (53.82 lux)].
• Steps.	Check treads clearances.
• Ride quality.	Verify compliance with the manufacturer's specifications.
• Newel ends.	Check for entry guards and operations.
• Deck barricades.	Install in accordance with locally adopted codes: low-deck escalators.
• Ceiling guards at intersections.	Verify proper installation.
• Caution signage.	Verify location and verbiage.
Testing:	
• Measured speed steps.	Verify speed of steps within the manufacturer's specifications .
• Handrails.	Verify speed of handrail.
• Stop-slide directions, both directions if possible—load/no load.	Verify for consistency with the manufacturer's specifications.
• Stop-chain length—10 steps nose-to-nose.	In accordance with the manufacturer's specifications.
• Handrail—speed monitoring devices.	Inspect operation of safety devices in accordance with locally adopted codes.
• Skirt-to-step clearance.	Verify minimum and maximum required clearances.
Internal Evaluations:	

• Skirt switches.	Inspect operation of safety devices.
• Track pressure switches.	
• Machine—lubrication, gears, bearings and couplings.	In accordance with the manufacturer's specifications.
• Machine area stop switches.	Inspect operation of safety devices in accordance with locally adopted codes.
• Brakes.	In accordance with locally adopted codes and the manufacturer's specifications.
• Machine break torque.	Measure break torque.
• Handrail chain-tensioning systems.	Check tensioning devices.
• Handrail chain lubrication.	Check automatic lube in accordance with the manufacturer's specifications.
• Step chain lubrication.	
• Broken drive—chain devices.	Check operation of safety devices.
• Step rollers.	Check that it meets the manufacturer's specifications.
• Step up-thrust devices.	Inspect operation of safety devices.
• Pit light.	Verify operation and location.
• Pit receptacle.	
• Missing step devices.	Inspect operation of safety devices.
• Pit stop switches.	Inspect operation of safety devices.
• Step guard.	Verify position and materials.
• Broken step-chain devices (step-chain tension carriage switches).	Inspect operation of safety devices.
• Step level devices.	
• Comb-step impact devices.	
• Access cover switches.	
• Step lateral displacement devices.	

APPENDIX C

Commissioning Provider Skills and Qualifications

The following listings include sample skills, knowledge and abilities that Commissioning Providers and inspectors should have or be knowledgeable of to facilitate the commissioning process in the specific area listed. They should be knowledgeable in the tasks listed in the appropriate section in Appendix B-2 in this guideline.

C.1 Site development and land use

- **Knowledge of:**
    - Landscape design and systems.
    - Codes, standards and local regulations pertaining to landscape irrigation systems.
    - Codes, standards local regulations pertaining to outdoor fountains and water features.
    - Codes, principles and practice of controlling sediment, erosion and other storm water pollutants.
    - Hydrology, water quality, air quality, habitat conservation and site grading.
    - Codes, standards and principles pertaining to topography and site grading.
    - Codes, standards and local regulations pertaining to construction waste management.
    - Codes, standards and local regulations pertaining to heat island mitigation.
    - Codes, standards and local regulations pertaining to outdoor and site lighting.
    - Flood plain development.

- **The following is a list of qualifications that the Building Official may use in evaluating the CxP. The Building Official may consider one or more of the qualifications in this list:**
    - Third party certification acceptable to the AHJ
    - State licensure or reciprocity may not be a manufacturer of components; may not be the installer.
    - Prior experience within the landscape irrigation industry.
    - Civil Engineer.
    - National Pollutant Discharge Elimination System Level 1A Certification.
    - Civil engineer experienced and knowledgeable in the practice of soil engineering (soils engineer).
    - Professional Certification: International Waste Manager – Technical status or equal.
    - Building Commissioning Certifications with experience requirements

C.2 Materials (architectural building assembly)

- **Knowledge of:**
    - Third party certification acceptable to the AHJ

- The *International Building Code* (IBC®).
- Building assemblies
- Architectural detailing .
- Energy codes, ASHRAE 90.1.Related Standards
- Material Safety Data Sheets (MSDS) and other product verification.
- Egress requirements.

- NFPA 101, *Life Safety Code*

- **The following is a list of qualifications that the Building Official may use when evaluating the CxP. The Building Official may consider one or more of the qualifications in this list :**

  - Licensed architect.
  - Licensed engineer.
  - ICC certified inspector.
  - ICC certified CALGreen inspector.

C.3 Energy

- **Management and monitoring systems.**
  - Knowledge of:
    - Energy policy.
    - Codes and standards.
    - Energy audits.
      - Benchmarking.
      - General audit.
      - Investment-grade audit.
    - Life cycle analysis.
    - Energy financing, accounting and economics.
    - Building automation and control systems.
    - Energy procurement.
    - Green buildings, LEED and Energy Star.

- **The following is a list of qualifications that the Building Official may use in evaluating the CxP. . The Building Official may consider one or more of the qualifications in this list :**
  - Green Building Engineer certification or Licensed Engineer.

- **HVAC systems.**

  - Knowledge of:

    - Design and construction phase commissioning process
    - Construction communication protocol.
    - Facility requirements.
    - Sustainability and energy requirements.
    - Facility design and construction requirements.
    - Design conditions (climatic conditions, room conditions, temperature humidity levels, and pressure requirements, etc.).
    - Design methods, techniques and software applications.

- National, state and local building codes, standards and guidelines.
- Schematic, design development, construction phase documents.
- Design of mechanical, electrical and plumbing systems.
- Electrical—Power distribution, motor control centers, power monitoring, etc.
- Building automation systems, diagrams, points and sequences.
- Specification formats.
- Commissioned systems and equipment.
- Construction submittals.
- Installation requirements of mechanical, electrical and plumbing (MEP) equipment and systems.
- O&M requirements.
- Equipment manufacturer's start-up procedures.
- Mechanical/electrical equipment and system operation.
- BAS control diagrams, points, sequences and configuration.
- TAB process and procedures.
- O&M documentation.
- System manual components and assembly.
- Delivery of training.

o Record test data and results.
o Develop trending and analysis trend reports.
o Facilitate the FPT process.

- **The following is a list of qualifications that the Building Official may use in evaluating the CxP. . The Building Official may consider one or more of the qualifications in this list :**

  o Licensed Engineer
  o An independent third-party commissioning certification program

C.4 Lighting

- **Knowledge of:**

  o Skills and abilities to verify that the systems listed are designed, installed and operate as intended.
  o Lighting control systems
  o IEEE and IES standards.
  o NFPA 70.
  o Arc flash safety requirements.
  o Lockout tag-out procedures and medium-voltage power distribution equipment and controls.
  o Motors, starters and VFDs.
  o Generator systems and their associated subsystems [battery charging and starting; lubrication; fuel; ignition; cooling; prime-mover engine (Diesel/turbine); reduction gear; exciter ; and generator] of UPS systems and their associated subsystems (back-up generator; input/output switch gear; battery and charging).

- The following is a list of qualifications that the Building Official may use in evaluating the CxP**.** The Building Official may consider one or more of the qualifications in this list :

    - ~~o~~ Licensed Engineer
    - o Third party certification acceptable to the AHJ

C.5 Water

- **Knowledge of:**

- Verification that the systems listed are designed, installed and operate as intended.
- Plumbing Codes
- Plumbing system design
- Plumbing fixture performance criteria and testing

- **The following is a list of qualifications that the Building Official may use when evaluating the CxP. The Building Official may consider one or more of the qualifications in this list** :

    - o Licensed Engineer
    - o Third party certification acceptable to the AHJ

C.6 Indoor environmental quality

- See corresponding sections under HVAC, Lighting and Materials.

C.7 Fire suppression systems

- **Knowledge of the following as required for specific system designed and installed:**

    - o NFPA 3, *Standard for Commissioning of Fire Protection and Life Safety Systems*
    - o NFPA 4, *Standard for Integrated Fire Protection and Life Safety System Testing*
    - o NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*
    - o NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*
    - o NFPA 13, Standard for the *Installation of Sprinkler Systems*.
    - o NFPA 13D, Standard for *Installation of Sprinkler Systems in One- and Two family Dwellings*.
    - o NFPA 13R, Standard for the *Installation of Sprinkler Systems in Group R Occupancies Four or Fewer Stories*.
    - o NFPA 14, *Standard for the Installation of Standpipes and Hose Systems*.
    - o NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*
    - o NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*

- NFPA 17, *Standard for Dry Chemical Extinguishing Systems*
- NFPA 17A, *Standard for Wet Chemical Extinguishing Systems*
- NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*.
- NFPA 22, *Standard for Water Tanks for Private Fire Protection*.
- NFPA 24, *Standard for the Installation of Private Fire Service Mains and their Appurtenances*.
- NFPA 25, *Standard for the Inspection, Testing, Maintenance of Water-based Fire Protection Systems*.
- NFPA 30, *Flammable and Combustible Liquids Code*.
- NFPA 30B, *Code for the Manufacturing and Storage of Aerosol Products*.
- NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials*
- NFPA 45, *Fire Protection for Laboratories*.
- NFPA 54, ANSI Z223.1-2018 *National Fuel Gas Code*.
- NFPA 90A, *Standard for the Installation of Air-conditioning and Ventilation Systems*.
- NFPA 90B, *Standard for the Installation of Warm Air-heating and Air-conditioning Systems*.
- NFPA 92, *Standard for Smoke Control Systems*
- NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*.
- NFPA 211, *Standard for Chimneys, Fireplaces, Vents and Solid Fuel-burning Appliances.*
- NFPA 214, *Standard on Water-cooling Towers*.
- NFPA 307, Standard for the Construction and Fire Protection of Marine Terminals, Piers, and Wharves
- NFPA 409, *Standard on Aircraft Hangars*.
- NFPA 750, *Standard on Water Mist Fire Protection Systems*
- NFPA 853, *Standard for the Installation of Stationary Fuel Cell Power Systems*.
- NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*

- **The following is a list of qualifications that the Building Official may use when evaluating the CxP. The Building Official may consider one or more of the qualifications in this list :**
  - Licensed fire sprinkler contractor.
  - Registered or licensed Professional engineer in other disciplines with knowledge of the applicable fire protection or life safety systems included as part of the commissioning process.
  - Registered or licensed Fire Protection Engineer with knowledge of the applicable fire protection or life safety systems included as part of the commissioning process

- Third party certification acceptable to the AHJ

C.8 Fire alarms

- **Knowledge of:**
  - NFPA 72.
  - NFPA 70.
- **The following is a list of qualifications that the Building Official may use in evaluating the CxP. The Building Official may consider one or more of the qualifications in this list :**
  - Licensed Fire Alarm contractor.
  - Registered or licensed professional engineer in other disciplines with knowledge of the applicable fire protection or life safety systems included as part of the commissioning process.
  - Registered or licensed professional Fire Protection Engineer with knowledge of the applicable fire protection or life safety systems included as part of the commissioning process

C.9 Vertical conveyance systems

- **Elevators.**
  - Knowledge of:
    - ASME A17.1.
    - ASME A17.2.
    - ASME A17.3.
- **The following is a list of qualifications that the building official may use when evaluating the CxP:**
    - Qualified Elevator Inspector (QEI) certification.
    - Third-party license.
- **Escalators.**
  - Knowledge of:
    - ASME A17.1.
    - ASME A17.2.
    - ASME A17.3.
    - Speed measurements as related to escalators.
- **The following is a list of qualifications that the Building Official may use when evaluating the CxP. The Building Official may consider one or more of the qualifications in this list** :
    - QEI certification.
    - State licensing, if applicable.

INFORMATIVE APPENDIX D

ICC CODE COMMISSIONING REQUIREMENTS

The following is a summary of the requirements for or references to the commissioning process in the International Code Council Codes. See the current codes for updates and details.

D.1 IBC-2015 International Building Code

- International Building Code - 2015 includes Special Inspector Requirements 'to verify proper commissioning of Smoke Control Systems' in Section 909.3.
- Commissioning shall be by accepted engineering practice and published standards.
- 1703 Approved agency qualifications include: independence, adequate calibrated equipment, experienced personnel
- No ASHRAE Standards are referenced

D.2 IMC – 2015 International Mechanical Code

- Section 513.3 refers to special inspection to verify proper Commissioning of Smoke Control Systems as in IBC section 909
- Commissioning shall be IAW generally accepted engineering practice and published standards.
- ASHRAE Standards referenced = 15, 34, 62.1, 170, 180

D.3 IFC -2015 International Fire Code Acceptance Testing (not full commissioning)

- 510.5.3 Cx - Emergency responder radio coverage system
- 510.6.1 Re-Cx annual - Emergency responder radio coverage system
- 603.1.6 Cx - Oil-burning equipment
- 604.5 Cx - Emergency power systems
- 604.6.1 FRe-Cx - Emergency lighting systems (monthly)
- 606.6 Cx - Refrigeration systems
- 606.6.1 Re-Cx - Refrigeration systems: emergency systems
- 703.4 Re-Cx annual - Fire doors
- 901.6.1 FCx – Carbon dioxide systems, Halon 1301 systems, Dry-chemical fire extinguishing systems, Wet-chemical fire extinguishing systems, Water-based fire protection systems, Smoke and heat vents, Fire alarm and detection systems, Water mist systems, Clean-agent extinguishing systems, Stationary fire pumps
- 904.4.2 FCx - Fire alarm systems
- 904.4.3 FCx - Fire alarm system monitoring service connections
- 904.5.1 FRe-Cx - Wet chemical systems (^-month
- 904.6 FRe-Cx - Dry chemical systems (6-month)
- 904.7 FRe-Cx - Foam suppression systems (per NFPA 25)
- 904.8 FRe-Cx - Carbon dioxide systems (per NFPA 12 annual)
- 904.9 FRe-Cx - Halon systems (per NFPA 12A annual)
- 904.10 FRe-Cx - Clean agent systems (per NFPA 2001 annual)
- 904.11.3 FRe-Cx - Water mist per manufacturer's requirements and IFC 901.6.1
- 904.12.6 FRe-Cx - Commercial cooking systems

- 905.2 FCx - Standpipes per NFPA 14
- 905.2 FRe - Cx - Standpipes per NFPA 25
- 907.7 FCx - Fire alarm systems per NFPA 72
- 907.8.2 FRE-Cx - Fire alarm systems per NFPA 72
- 909.3 FCx - Smoke control systems
- 909.18 FCx - Smoke control systems
- 909.19 FCx - Smoke control systems
- 910.5.2.2 FCx - Mechanical smoke removal systems
- 915.5 FRe-Cx - Fire pumps per NFPA 25
- 913.5.1 FCx - Fire pumps per NFPA 20
- 2306.7.4 FCx - Fuel dispenser impact valves
- 2306.7.4 FRe-Cx - Fuel dispenser impact valves (annual)
- 2907.5 Cx - Organic coating manufacture process piping
- 3103.7 Cx - Tent, air-supported, air-inflated or tension membrane structures
- 3105.6 Cx - Temporary stage canopies
- 5003.2.9.1 Cx - Hazardous materials equipment: gas detection, automatic shutoff valves, limit control valves, emergency alarm systems
- 5003.2.9.2 ReCx - Previous list (annual)
- 5703.6.3 Cx - Flammable and combustible liquid pipe systems
- 5704.2.12 Cx - Flammable and combustible liquid tanks

D.4 IECC -2015 International Energy Conservation Code

- Building Commissioning : A process that verifies and documents that the selected building systems have been designed, installed, and function according to the owner's project requirements and construction documents, and to minimum code requirements.

- C408.2 Mechanical and Service Water Heating System Commissioning and Completion- Prior to final mechanical and plumbing inspections, the registered design professional or approved agency shall provide evidence of mechanical system commissioning and completion

    - Excludes air conditioning systems less than 40 tons
    - Excludes hotel room and apartments

- Construction documents must include commissioning requirements

- C408.2.1 Mechanical Systems Commissioning

  Commissioning Plan developed by registered design professional or approved agency

    - Narrative of activities and personnel included
    - Listing of equipment and systems
    - Functions to be tested
    - Test conditions
    - Measurable criteria

- C408.2.2 HVAC Systems Test and Balance

    - Test and Balance required to accepted engineering standards.
    - Air and water flow rates measured and adjusted to tolerances provided in product specifications
    - Air supply outlets and zone terminal devices shall be equipped with means for balancing.

- Hydronic heating and cooling coils shall be equipped with means for balancing and measuring flow
- Written test and balance report required
  - Should be reviewed by Commissioning Provider
  - Should be included in Systems Manual
  - Should be available for review by Building Official

- C405.2.3 Mechanical Systems Commissioning
  Functional Performance Testing – Equipment
  - - Installation and operation
  - - Sequence of operation
  - - Maintenance serviceability

  Controls and Economizers
  - - Calibrated
  - - Adjusted
  - - Operate to approved plans and specifications

- C408.2.4 Preliminary Commissioning Report
  - Preliminary Commissioning Report (by Design Professional or Approved Agency) with deficiencies, deferred testing and conditions required.
    - Owner shall certify receipt of the preliminary report prior to final inspection
    - Code official can request a copy

- C408.2.5 Documentation
  - DOCUMENTATION: Construction documents shall require delivery to owner within 90 days of Certificate of Occupancy:
    - Record Drawings with performance data
    - Systems Manual with submittals, O&M manuals, control system data with sequence of operation, service and maintenance data and schedules
    - Systems Balancing Report
    - Final Commissioning Report with functional and performance testing procedures, final results, and open issues

- C408.3 Lighting Commissioning
  - Lighting system functional testing- Prior to final inspection, registered design professional shall provide evidence of lighting control system testing including hardware and software programming and adjustment.
    - Occupant sensor controls
    - Time switch controls
    - Daylight responsive controls
  - This evidence shall be provided to the building official
  - Lighting System Construction documents shall require a final report to owner within 90 days of CO.
    NOTE: This report does not need to be presented to the Building Official unless requested.

- C502 Additions shall comply with new construction requirements
- C503 Alterations shall comply with new construction requirements with some variations
- C504 Repairs not normally required to comply.
- C505 Change in Occupancy requires IECC compliance if energy use is increased

D.5 IGCC-2015 International Green Construction Code

- Section 611: Energy System Commissioning- Prior to Final Inspection, Registered Design Professional or Approved Agency shall provide evidence of system Commissioning per IECC including:
  - Construction documents include commissioning
  - Commissioning Plan by RDP or Approved Agency
  - Air & Hydronic Systems Balancing and Reports
  - Functional and Performance Testing
  - Documentation – O&M
  - Preliminary Commissioning Report with written Owner letter acknowledging receipt.
  - Lighting and Building Enclosure Commissioning included
  - Final Commissioning Report at project completion.

- Section 902 – Special Inspection and Commissioning
  - The Registered Design Professional in Responsible Charge or Approved Agency Shall Perform Commissioning during Construction and After Occupancy per Table 902.1
    Approved Agency:(AHJ to approve Qualifications)
    - Objective, Competent and Independent from Contractor
    - Adequate, Calibrated Equipment
    - Experienced, Educated Personnel
  - Section 902 – Special Inspection and Commissioning includes detail requirements on:
    - Commissioning Plan
    - Pre-Certificate of Occupancy Report
    - Commissioning Performance Requirements
    - Final Commissioning Report
    - Systems Manual
    - Record Documents
  - Table 902.1 Commissioning Plan includes:
    - List of Construction or Systems requiring inspection, verification and commissioning of all the building systems in IGCC plus other items.
    - Methods and Occurrence /Scheduling

INFORMATIVE APPENDIX E

INDUSTRY COMMISSIONING RESOURCES

(Reference ASHRAE Standard 202)

The following organizations, documents, and web sites can provide additional guidance on the commissioning process:

PUBLICATIONS:

Comment [JK1]: Dates need to be verified immediately before publishing

ASHRAE Standard 202-2013, *The Commissioning Process for Buildings and Systems.* ASHRAE

ASHRAE. Guideline 0-2013, *The Commissioning Process*. Atlanta: ASHRAE.

ASHRAE. Guideline 0.2-2016, *Commissioning Process for Existing Buildings and Systems*. Atlanta: ASHRAE.

ASHRAE. Guideline 1.1-2007, *HVAC&R Technical Requirements for The Commissioning Process*. Atlanta: ASHRAE.

ASHRAE. Guideline 1.2-2018, *Commissioning Process for Existing HVAC&R Systems*. Atlanta: ASHRAE

ASHRAE. Guideline 1.3-2018*, Building Operation and Maintenance Training for the HVAC&R Commissioning Process*. Atlanta: ASHRAE.

ASHRAE. Guideline 1.4-2014, *Systems Manual for Facilities*. Atlanta: ASHRAE

ASHRAE. Guideline 1.5-2017, *The Commissioning Process for Smoke Control Systems*. Atlanta: ASHRAE.

ASHRAE. 2015. *ASHRAE Handbook—HVAC Applications*, Chapter 43, HVAC Commissioning. Atlanta: ASHRAE.

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Organizations

The following organization and agencies have produced publications and resources relating to the Commissioning Process that are available from the publishing organization. These publications and resources may or may not conform to the requirements of ASHRAE Standard 202-2013. This list is provided as a resource for those using and providing commissioning services. Since publications can change frequently, the organization websites are the best source of current documents.

AABC Commissioning Group (ACG), 1518 K Street, NW, Suite 503,Washington DC, *http://www.commissioning.org/commissioningguideline*.

ASTM International, 100 Bar Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 E2813-12, *http:// www.astm.org/DIGITAL_LIBRARY/index.shtml*.

Building Commissioning Association (BCA), 1600 NW Compton Drive, Suite 200, Beaverton, OR 97006, *http:// www.bcxa.org/knowledge-center*

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Energy Systems Laboratory, TAMU, College Station, Texas, *http://www.esl.tamu.edu/continuous-commissioning*.

Illuminating Engineering Society of North America (IESNA) 120 Wall Street, 17th floor, New York, NY 10005, https://www.ies.org/product/the-commissioning-process-applied-to-lighting-and-control-systems/

International Code Council (ICC), 500 New Jersey Ave. NW, 6th Floor, Washington, DC 20001, *http:// www.shop.iccsafe.org/icc-G4-2012-guideline-forcommissioning- 1.html*.

International Energy Agency (IES), Energy Conservation in Buildings and Community Systems (ECBCS) Programme, 9, rue de la Federation, 75739 Paris Cedex 15, France, *http://www.buildup.eu/en/explore/links/iea-ecbcs-annex-40-commissioning-building-hvac-systems-improving-energy-performance*

National Environmental Balance Bureau (NEBB), 8575 Grovemont Circle, Gaithersburg, MD 20877, *http:// www.nebb.org/resources/standards/*.

National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 82169, *http://nfpa.org/codes*.

National Institute of Building Science (NIBS)1090 Vermont Ave, Suite 700, Washington, DC, 20005, *http:// www.nibs.org* and *http://www.wbdg.org/project/buildingcomm.php*

Sheet Metal and Air Conditioning Contractors National Association (SMACNA) 4201 Lafayette Center Drive, Chantilly, VA, 20151, *http://www.smacna.org/technical*.

The State of Minnesota, Sustainable Building Guidelines, Design & Construction Phase Commissioning Plan Template, *http://www.msbg.umn.edu*.

University of Wisconsin – Madison, *https://epd.wisc.edu/*

United States Department of Veterans Affairs (VA), *https://www.cfm.va.gov/til/cx-rcx/cxmanual.pdf*

United States Army Corps of Engineers, *www.wbdg.org/project/buildingcomm.php*

United States Department of Energy (USDOE), *https://www.eere.energy.gov/femp/reconstructionguide/commprocess.html*

United States General Services Administration, (GSA), *http://www.gsa.gov/portal/category/21064*.

DAVIS CHAMBER OF COMMERCE
CULTIVATING LOCAL PROSPERITY

We are a membership organization whose mission is to promote, support, and advocate for the general economic vitality of our membership and the quality of life for our community.

April 3, 2019

Brett Lee, Mayor
City of Davis
23 Russell Blvd., Suite 1
Davis, CA 95616

Dear Mayor Lee,

On behalf of the Davis Chamber of Commerce (Chamber), we would like to express our appreciation for city staff addressing various concerns and clarifications we identified regarding amendments to the City's Green Building and Energy Efficiency Standards. Based on the comments from staff, the Chamber removes any remaining concerns initially outlined in the proposal.

The Chamber is encouraged by city staff's willingness to address issues that could have adverse impacts on the community's economic development and housing objectives. We know that the proposed ordinance strives to balance these economic realities with Davis' long held desire to be a leader at the local level. We are cognizant that providing more certainty to business owners and developers is the best path forward to achieving new construction that will serve the community.

With over 500 business members, the Chamber would like to continue our partnership with the city and continue an open dialogue on issues that impact the business community. Our members are willing to address these issues and provide meaningful feedback to the city on a wide variety of issues.

Again, we thank city staff and the council for listening to our concerns and responding in a positive way.

Sincerely,

Cory Koehler

Cory Koehler
Executive Director