CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A:
Additional Community Outreach Results and Surveys

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APPENDIX A:
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Community Inputs from First Community Meeting

The key takeaways from the meeting are as follows:

- The representative from California electric vehicle assistance program noted that the program was very well-received by the public. The financial assistance program might be extended from $5 million to $18 million and would likely include sustainability financing and support. The program targeted low to moderate income community with household income limits of $48,000 for single person, $53,000 for two-person family; $60,000-68,000 for 3 people family, and about $100,000 for a four-person family. The program was considering other financial support for car charging and was developing various concepts, such as mobile charging stations and integrating streetlights with charging ports.
- The representative from GRID Alternatives discussed the new solar panel program for multifamily units and expressed strong interest in developing community-scale solar program. They were planning some rural community solar projects. The representative noted that current State policy is unattractive and too complex for implementing a community solar program in Fresno and other urban areas, but further pointed out about the great potential of Fresno for community solar program because there are vast areas in West Fresno that have low land value. Further, the representative explained that about half of single-family homes interested in the solar program could not meet the basic installation requirement because a new roof and/or an electrical panel upgrade is needed. Each of these prerequisites would incur significant costs to the homeowner. A new roof or an upgrade may cost $10,000-$30,000, while an electrical panel upgrade may need $2,000-$3,000.
- Half of the meeting attendees (8 out of 15 participants) owned the homes they lived in, while the rests were renters. Most of the attendees (13 out of 15) lived in single-family homes, while the rests lived in multifamily homes.
- Many attendees (10 out of 15) indicated that they do not have central air conditioning system and about half (7 out of 15) indicated they do not use central heating system. Majority of the attendees' home (13 out of 15) used gas water heaters. More than half of the attendees expressed dissatisfactions with their heating and cooling systems during the winter and summer months, respectively.
- Forty-percent of the attendees (6 out of 15) were CARE program customers. Most of the homes (13 out of 15) did not have solar panel systems. Two-thirds of the attendees expressed concern with their energy costs.
- Most of the attendees (13 out of 15) owned a car, with average miles driven per day at 25 miles.

- Most of the attendees (more than 10 out of 15) were concerned about traffic pollution, outdoor air quality and industrial pollution, while about half (8 out of 15) were concerned about indoor air quality.
- During the breakout session, meeting attendees expressed their concerns for lack of access to various energy efficient solutions such as electric vehicles and solar panels. An attendee, who has solar panels installed at her home, described an increase in her monthly energy cost and was understandably upset.
- Meeting attendees noted that the public transportation coverage, such as buses, is rather limited in Fresno because of the routes and the long wait time. Regarding using lower cost shared services, such as electric scooters, there were lack of interests because travel distances in Fresno are too far for the option to work effectively.
- Other topic discussed was adapting to increasingly hot weather in Fresno areas. The attendees discussed some suggestions that promotes behavior changes, i.e. cooking earlier in day, closing windows and adding shades, and setting thermostatic control at 78-degree Fahrenheit.
- An attendee shared her concerns about high prevalence of respiratory illness in her household and the community. Her children were affected by asthmatic symptoms. She welcomed solutions to fix air quality issues in Fresno.
- A lesson learned from the community meeting was that many terminologies and technical concept should be presented in more layman terms or explained clearly. Some meeting attendees were unclear about solar photovoltaic system, community solar, climate equity, weather-stripping, and energy efficiency technologies/strategies. It seemed that the meeting attendees would benefit from a brief overview of the state's climate policy to understand the larger context of the study.

Results of Phone Interviews (Phase 2)

Home Characteristics and Home Heating and Cooling Equipment

The second phase of the study further confirmed the homeownership and home type distributions observed in the first survey. Eighty percent of the participants (73 out of 91 participants), who lived in the Winchell and Columbia districts, were renters. Within the renters category, 45% or 41 out of 91 participants lived in a single-family homes. The rest of the renters lived in apartment complex. All homeowners (18 out of 91) lived in single-family homes.

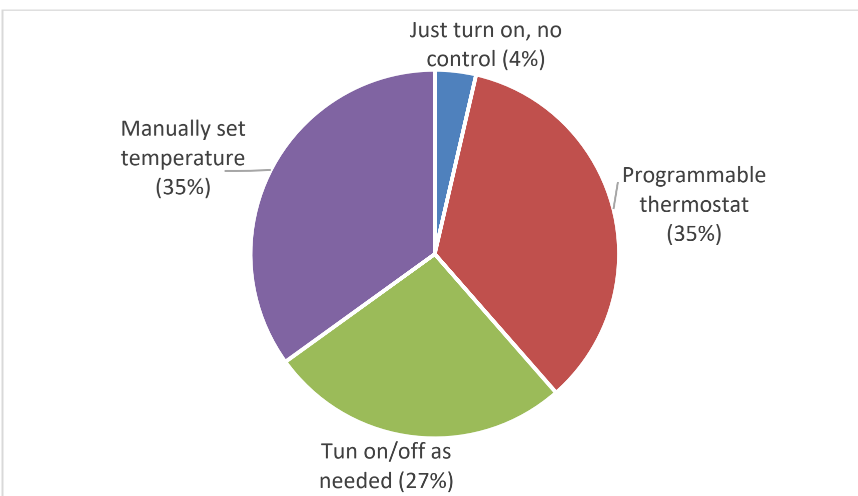
Table A-1 provides additional details regarding the participants' home characteristics including the use of heating or cooling systems. Most of the single-family homes (more than 75%) do not have attic and basement, and about half of the single-family home (50%) do not have an attached garage. Eighty-four percent of all the homes use heating during winter and almost all home (96%) use cooling during the hot summer months in Fresno.

Table A-1. Home Characteristics by Types of Home

Home Type (Number of homes: 91)	**Have Attic**		**Have Attached Garage**		**Have Basement**		**Use Heating during Winter**		**Use Cooling during Summer**	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Single-family house detached	14%	47%	32%	29%	10%	51%	47%	13%	57%	3%
Single-family house attached to other house	2%	2%	1%	3%	1%	3%	4%	0%	4%	0%
Apartment in a building with 2 to 4 units	0%	13%	0%	13%	0%	13%	12%	1%	12%	1%
Apartment in a building with 5 or more units	1%	18%	1%	18%	0%	19%	16%	2%	19%	0%
Mobile Home	0%	2%	1%	2%	0%	3%	3%	0%	3%	0%

Of all the homes that used heating, more than half of the homes (56%) used a central heating system (furnace). This is consistent with the previous phone survey (Phase 1). About 24% of the homes used built-in heaters, i.e. electric wall heaters, floor/wall pipeless furnace, or heater burning gas/oil. Less than 10% used portable electric heater as their primary heating equipment. When asked about the age of their heating equipment, most participants indicated they did not know, which is likely because of they were not the homeowner or owner of the equipment. Figure A-1 shows the equipment control mechanisms of all the heating systems. Most participants controlled their heating system by manually setting the temperature or programming their thermostat.

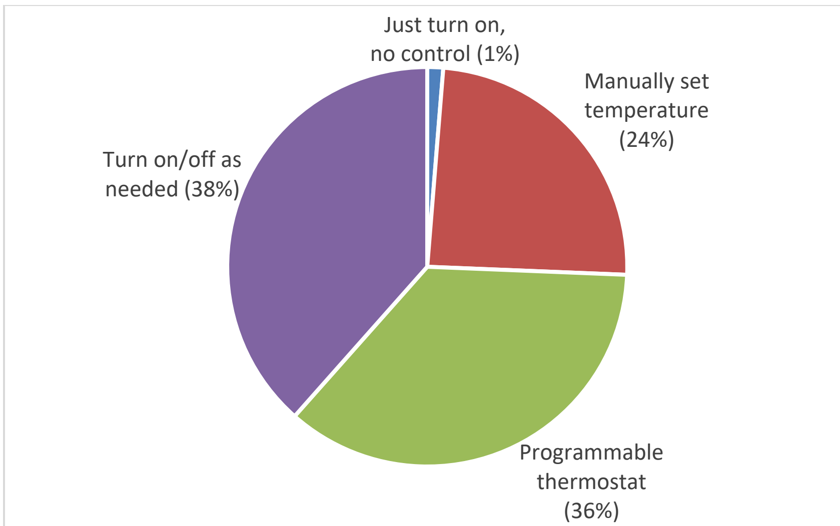
Figure A-1. Equipment Control and Temperature Setting of Heating Equipment



Source: LBNL Authors' figure

Of all the homes that used cooling, more than half of the homes (54%) used a central cooling system (central air conditioner), followed by 32% of the homes with window air conditioners. This finding is relatively consistent with the previous phone survey (Phase 1) results. Swamp coolers and portable air conditioners were used by 8% and 3% of the homes as primary cooling equipment, respectively. Similar to the heating equipment, when the participants were asked about the age of their cooling system, most participants indicated they did not know. Figure A-2 shows the equipment control mechanisms of the cooling systems. The participants turned on or off their cooling systems as needed (38%), used the programmable thermostat (36%), or manually set the temperature setpoint (24%). Looking at the control for heating and cooling systems, it shows that smart control system, such as a programmable thermostat, was not a common equipment control strategies used by the households or it is not available for their heating and cooling systems.

Figure A-2. Equipment Control and Temperature Setting of Cooling Equipment



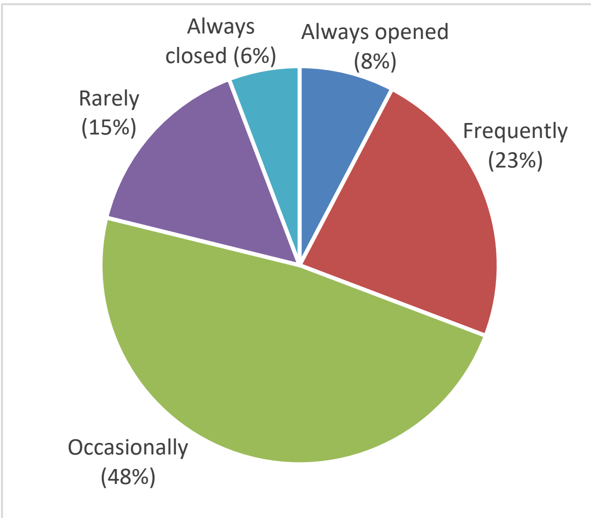
Source: LBNL Authors' figure

The survey reveals that more than two-thirds of the participants considered their heating systems to be insufficient for the coldest days (41%: sufficient but not on coldest days; 13%: somewhat sufficient but inconsistent and not enough for cold days; 11%: not sufficient at all, feeling cold all the time). For the cooling systems, 70% of the participants responded that it was insufficient for the hottest days (54%: sufficient but not on hottest days; 7%: somewhat sufficient but inconsistent and not enough for hot days; 9%: not sufficient at all, feeling hot all the time). This feedback indicates that many households in the Winchell and Columbia districts of Fresno require changes or improvements to their heating and cooling systems.

Ventilation and Air Quality Issues

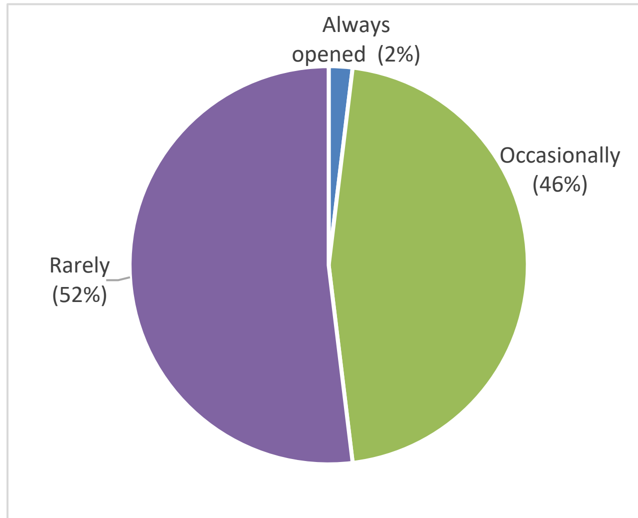
For ventilation purpose, most homes used fumehoods (59%) and bathroom fans (40%). Only one home mentioned using an additional window fan for ventilation. Figure A-3 and Figure A-4 depict the windows opening behavior of the households during summer and winter periods, respectively. Generally, the households opened their windows occasionally as needed disregard of the seasons. However, during summer, 30% of the households opened their windows frequently, even kept it opened continously. By contrast, during winter, more than half of the households opted to close their windows most of the time. Considering that half of the homes were situated near a main traffic route as reported by the participants, there could be negative health consequence because of entrainment of outdoor pollutants to indoor spaces when the windows were opened. Many participants indicated in their feedback that they were very concerned about outdoor air quality (72%). Only 12% and 16% of participants were somewhat concerned or not concerned about the outdoor pollution levels, respectively. On the other hand, the participants did not seem to be seriously concerned about their indoor air quality. Only 19% of participants were very concerned about their indoor air quality, while 31% were somewhat concerned and 50% were not concerned at all.

Figure A-3. Windows Opening Frequency during Summer Months



Source: LBNL Authors' figure

Figure A-4. Windows Opening Frequency during Winter Months



Source: LBNL Authors' figure

About 45% of the participants reported having household member(s) with asthma and allergies. Many indoor-related factors affecting the asthmatics were assessed in the survey. Aside from the dust particulates from outdoor sources, a main source of indoor particulates was the fireplace. Two-thirds of the homes did not have a fireplace. Of all the homes with a fireplace, about 70% of them were not vented, although the participants noted that they never or hardly ever used the fireplace. Further, most participants (87%) did not notice signs of water damages, mold, damp surfaces, condensation or leaks in their home. Participants reported that they had seen pests such as cockroaches (34%) and mice/rats (10%) in their home in the past year. Some participants considered their home ventilation and other measures to maintain indoor air quality to be very sufficient (37%), but many others noted that while sufficient they were not able to resolve major issues (47%). None of the participants used a portable air filtration system in their living space but would like to have one if provided. Participants were unable to provide information regarding the filter maintenance of their home air distribution system.

Passive and Active Energy Savings Measures

Window blinds and curtains were the most common passive energy savings feature reported by all the participants (45%). About 35% of the homes were installed with double-pane windows. Many participants also reported that their homes were under some shades from nearby buildings or trees at certain times of the day (84%). Most participants were unable to provide feedback about any weatherization program for their home.

A majority of the households were part of the PG&E CARE program and received a monthly discount (90%). However, despite the financial assistance, many households were still paying relatively high energy bills. About a third of the participants paid less than $100 electricity bills per month, more than half (56%) paid between $100 and $200, while the rests (20%)

paid more than $200, with some even paying as high as $500-$700 per month. For gas bill, most of the participants (85%) reported paying $50 or less per month with a few exceptions (12%) paying between $200-$250 per month. The high energy costs for some households would require further investigation to identify the problems so proper solution can be recommended.

Transportation Modes

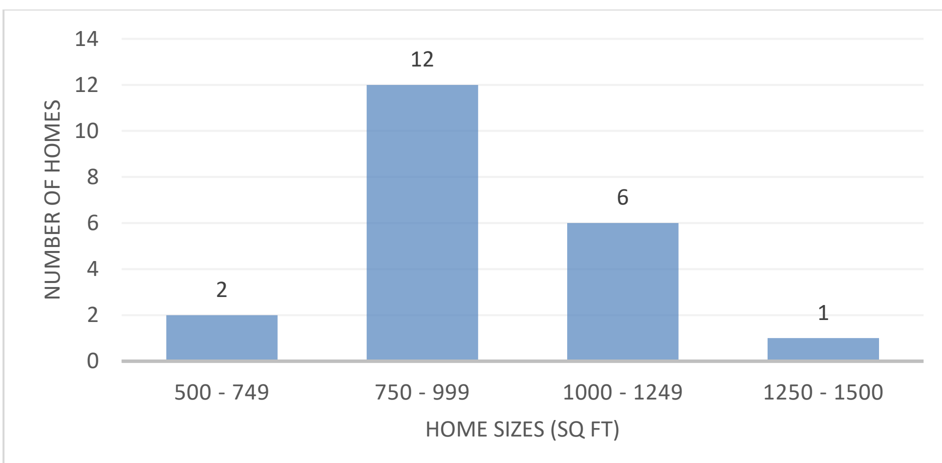
Eighty percent of the participants used car as their main transportation mode. All of them used gas as fuel with exception of one participant who electric car. About 15% of the participants utilized public transportation. About two-thirds of the participants drove 10 miles or less per day, 25% drove between 10 and 20 miles per day, and the rests drove more than 20 miles each day. The gasoline bills per month ranged between $30-$150 as reported by the participants. Eighty percent spent $100 or less a month, and the rests spent up to $150 per month on gas. Most of the participants (80%) were interested in an electric car if they were within their affordable price ranges.

Community outreach data summary results for virtual home walkthroughs (Phase 3) and the second (and final) community meeting are presented in Appendix A. In general, the responses across all the outreach phases were similar with fairly consistent findings.

Results of Virtual Walkthroughs (Phase 3)

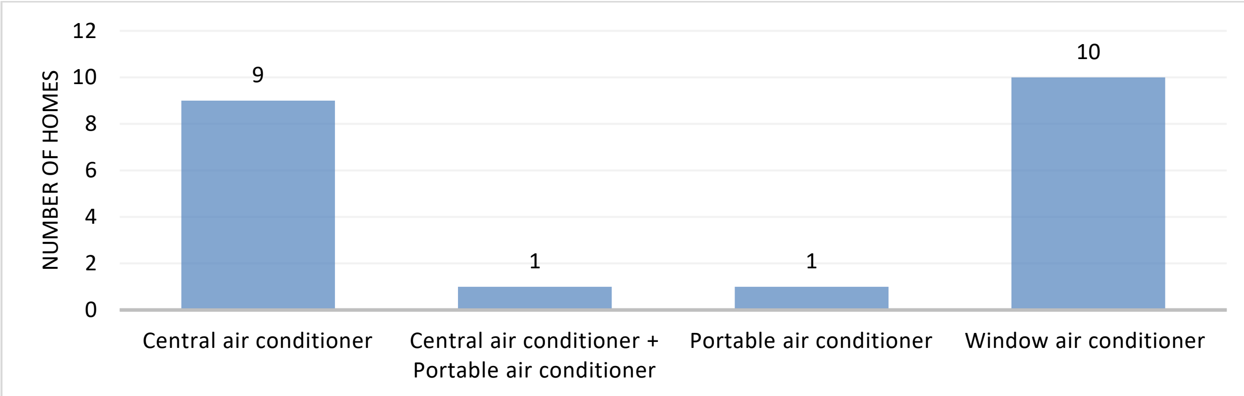
Figure A-5 shows the distribution of homes selected for the virtual walkthroughs by home sizes. Most surveyed homes were in the range of 750-1250 sq ft.

Figure A-5. Home Sizes Selected for Walkthrough Survey



Consistent with survey results earlier phases, the homes selected for the walkthrough also used a central air conditioner or window air conditioner for cooling, with one home also using a supplementary portable air conditioner (Figure A-6). One of the homes did not use centralized cooling and was only using portable air conditioner.

Figure A-6. Equipment Types for Space Conditioning



As seen in Figure A-7, central furnace systems and built-in wall heaters were most commonly used. The built-in wall-heaters were either fueled by electricity or gas. The distribution of equipment types was similar to the observed distribution from previous survey phases. The survey confirmed that all centralized systems (cooling and heating) supplied air through ducts connected to terminal air grilles located in various rooms, whereas the portable or built-in systems supplied air directly to the room where they are located.

Figure A-7. Equipment Types for Space Heating

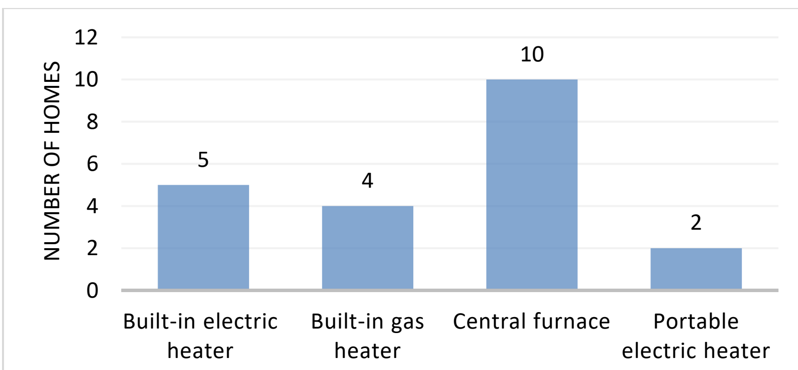
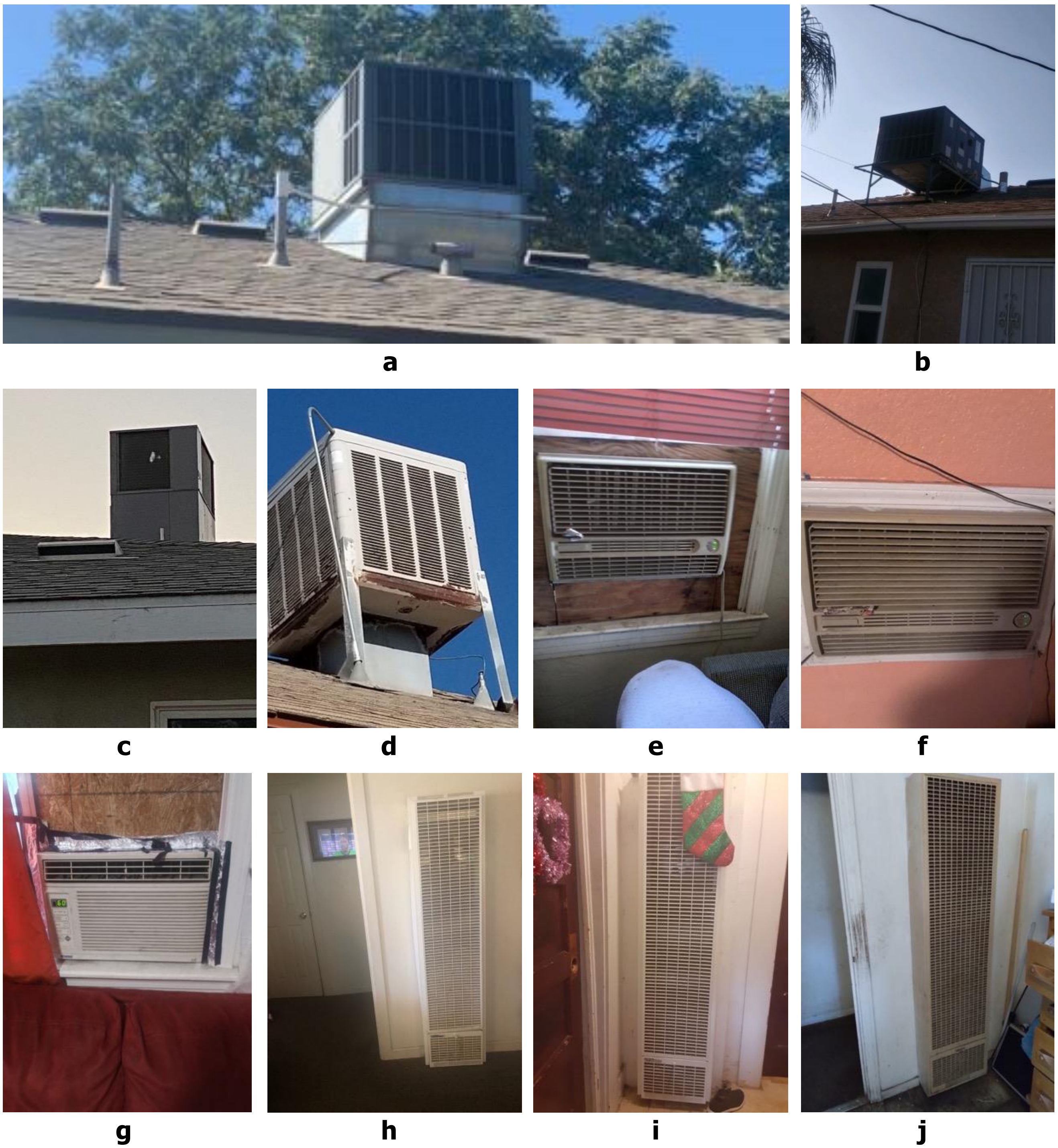


Figure A-8 shows a photo collage of various air conditioning and heating equipment installed in the homes. The survey revealed that many of the central systems were located on the rooftop, making future upgrade or replacement effort more challenging and potential costlier. Top-vent gas wall heaters were found in homes that relied on built-in heating unit.

About 30% (6 out of 21 participants) reported having children with asthma or respiratory health issues in their household. These participants attributed the illnesses to both indoor and outdoor air quality issues. Ninety percent of the participants (19 out of 21) used gas stoves for cooking. About half of the participants noted that their heating and cooling systems never had filter cleaning or replacement and the rests were unable to provide any feedback. Many of the homes (60%) were located near major traffic routes.

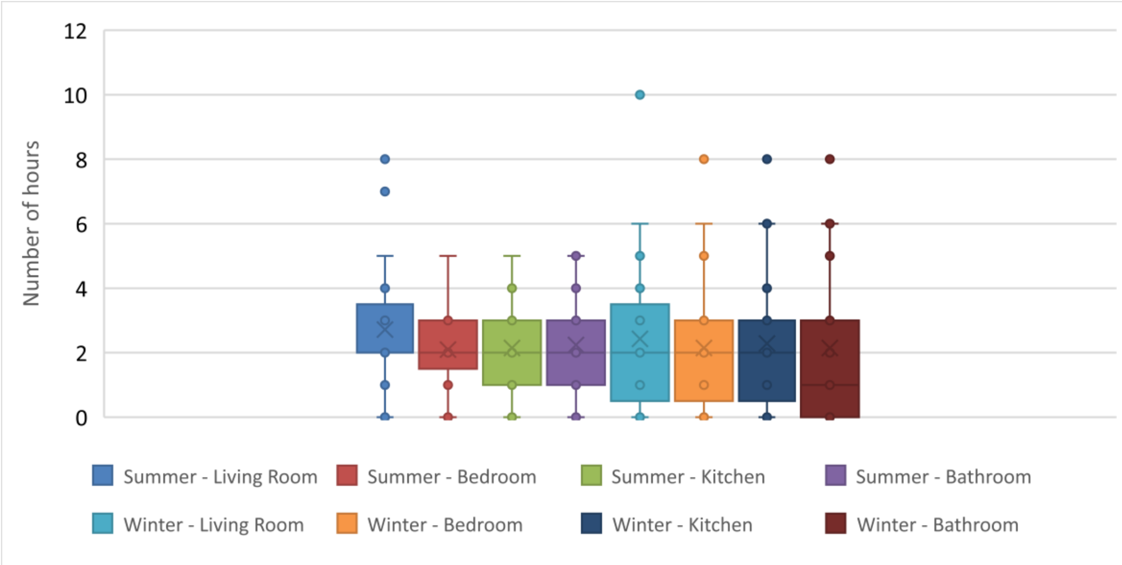
As shown in the Figure A-9, there was no difference in terms of hours of windows opening between the summer and winter periods. There were also no significant variations by room types. On average, the windows were opened for slightly more than 2 hours daily. All participants noted that the main purpose of opening or closing the windows and doors was to control the space temperature for comfort. In addition, 85% and 75% of the participants were attempting to save energy and improve room ventilation, respectively, by opening windows and doors. The participants noted various purposed for closing their windows/doors: 42% would like to keep outdoor air odor from getting into their homes, 30% would like to keep out the noise, 20% would like to keep out dust, smoke, pollen, or other allergens, and 15% indicated security reasons.

Figure A-8. Photos of Home Cooling and Heating Equipment



(Note: a-d are central AC installed on the roof; e-g show window air conditioners, and h-j depict typical built-in wall heaters)

Figure A-9. Hours Windows/Doors Opened in Summer and Winter



Based on the energy bills shared by participants, there was no significant difference in term of energy costs between heating and cooling months (Figures A-10 and A-11). Overall, electricity costs ranged between $50-$100 per month, reaching $350 per month in the cooling season; and gas bills ranged between $25-$50, reaching $150 in the heating season. The outliers indicate greater energy use using gas for heating equipment in the winter and electricity for air conditioning system in the hot summer days. These data confirm previous results from Phase 2 surveys.

Figure A-10. Energy Costs in Winter

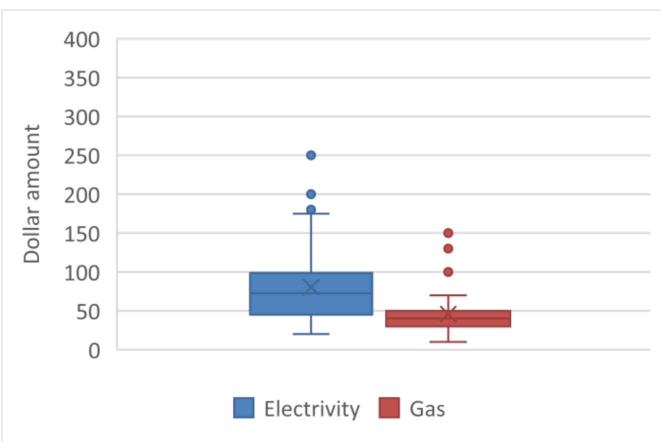
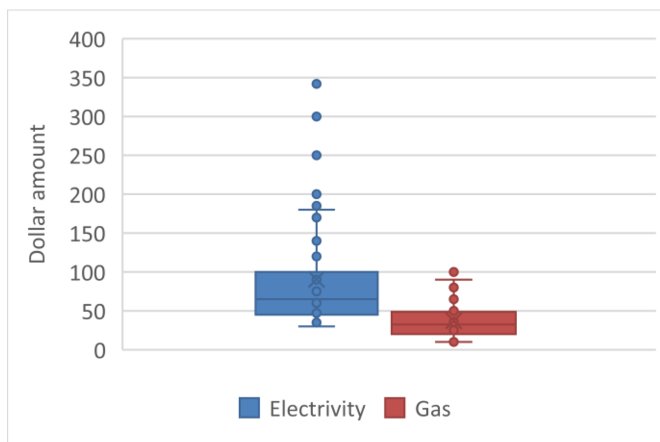


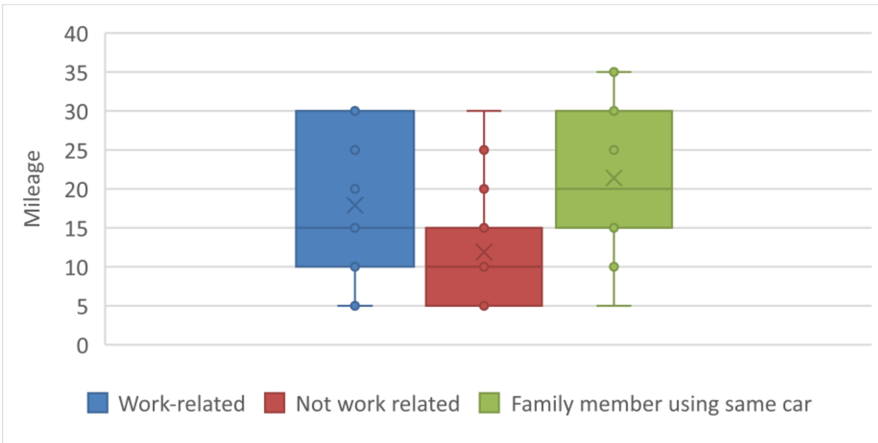
Figure A-11. Energy Cost in Summer



All the homes have roof surfaces with direct sunlight or without shades from surrounding trees and buildings. About 42% of homes had the largest area of their roofs facing the South, which suggest potential for solar panel program. All the roofs used asphalt shingles with exception of one which used clay tiles. Half of the participants did not know the age of their roofs, the rests indicated that their roofs were more than 10 years old. Some of the roofs would likely need an upgrade before solar panels can be installed. When asked if they would be willing to reach out to their landlords about installing solar PV in case they rented the home, all of the participants responded positively.

None of the participants used electric vehicles. About 85% of the participants used their car regularly for everyday activities such as going to work, getting groceries, and school pickups. All of them shared their car with other family members on daily basis. On average, the participants drove about 15-20 miles per day for work and 10 miles per day for non-work-related activities, with additional 20 miles per day by their family member (Figure A-12). (Median 45miles)

Figure A-12. Daily Driving Distances



When participants were asked if they would be willing to use other alternative ways to get around, all of them responded willingness to use bus and other public transportations. About half responded that they would be willing to carpool with family, friend, or co-worker. Another mode accepted as an alternative by about 30% of the participants was bike/scooter sharing, though this percentage of favorability to bike/scooter sharing was much lower in community meeting #1 and Phase 2 surveys.

For Phase 3 survey, access to the home's electrical panel was requested to assess the need for a panel upgrade if some of the home equipment such as new air conditioning system or heat pump were to be introduced in the homes. A total of 12 homes provided electric panel pictures of which authors estimate 3 to 5 or about 33% need panel replacement. Some examples of panels that would likely need an upgrade or replacement are shown in Figure A-13.

Figure A-13. Photos of Electrical Panels

Community Feedback from Second (Final) Community Meeting

The key takeaways from the meeting are as follows:

- Seventy-four percent of the attendees were renters, while the rests (26%) were homeowners. Sixty-six percent of the attendees lived in single-family homes, while the rest (34%) lived in apartments. The distribution has been consistent across all the surveys.
- Attendees selected their top three most helpful solutions to their energy-related needs as follows: much lower utility bills (86%), better air quality (66%), and much lower transportation costs such as gasoline and repair (63%).
- About 35% of the attendees still used swamp coolers for space cooling. This was common for homes that were built before 1980s.
- Almost all attendees (97%) were unaware of any air quality related programs or rebates for low-cost air filtration system. The attendees noted that they would be willing to purchase an air filtration system if the price after any rebates is $10 or less (55%), $11-20 (39%), or $21-30 (5%). The attendees were not familiar with any do-it-yourself low cost and portable filter fans that could help improve their air quality by means of local air filtration.
- Eighty-seven percent of attendees were unaware of Clean Vehicle Rebates. About 40% of the attendees confirmed that they drove more than 35 miles each day. 76% think that EVs are too expensive – so opportunity for used EVs + DAC rebates
    - Still concerns with range and charging availability
- Most attendees (80%) noted that they would be interested in owning an electric vehicle provided that the price is affordable. However, the attendees also noted some concerns with having an electric vehicle, such as high costs (76%), low driving range (56%), and lack of charging stations (56%).
- Most attendees (80%) were unaware of any solar installation programs and about 70% never heard of community solar programs. Most attendees (70%) expressed willingness to switch their home equipment from gas to electric if the upgrade or change incurred no cost to them.

Community Meeting #1 survey

Building Healthier and Energy Efficient Communities in Fresno

****

1. Do you rent or own the residence you are currently living in?
    - ☐ Rent
    - Own

2. What type of home do you live in most of the year?
    - single-family house
    - multi-family/ apartment building
    - mobile or manufactured home
    - something else:_____________

3. How long have you lived in this home? ______ years

4. How many people are living in your household? ________people (including children)

5. Which elementary school district is your home located in? __________________

6. What is your combined annual household income?
    - $0-$19,999 per year
    - $20,000-$39,999 per year
    - $40,000-$59,999 per year
    - $60,000-$79,999 per year
    - $80,000-$99,999 per year
    - $100,000-$119,999 per year
    - $120,000-$149,999 per year
    - $150,000-$199,999 per year
    - $200,000 or more per year
    - Don't know/Decline to state

7. Are you currently enrolled in the California Alternate Rates for Energy (CARE) program?
    - Yes
    - No

8. What is the main equipment used for space heating in your home? (refer to pictures at end)
    - Central Furnace
    - Central Heat Pump
    - Portable Heater
    - Wall Heater (tall, narrow)
    - Strip Heater (along the floor)
    - Rooftop unit
    - None or other: ________________

9. What is the fuel use for the main heating equipment?
    - Electric
    - Gas
    - Other: ________________

10. What is the main equipment used for space cooling in your home? (refer to pictures at end)
    - Central Air Conditioner
    - Central Heat Pump
    - Portable Air Conditioner
    - Window Air Conditioner
    - Ceiling Fan
    - Portable Fan
    - Rooftop unit
    - None or others: ________________

11. What is the fuel use for this cooling equipment?
    - Electric
    - Gas
    - Other: ________________________________

12. What type of water heater do you have and what fuel does it use? (refer to pictures at end)
    - Gas water heater with storage tank
    - Electric heat pump water heater with storage tank
    - Electric resistance water heater with storage tank
    - Gas water heater without tank (tankless)
    - Electric water heater without tank (tankless)
    - Other: ___________

13. Is your home installed with solar PV panels (providing electricity)?
    - Yes
    - No

14. What is your main transportation mode?
    - Car: ▪ gas ▪ diesel ▪ electric
    - Public transport: ▪ bus ▪ train ▪ both
    - Others: ______________

15. On average how many miles do you drive or transit each day? __________miles per day

16. How often are you uncomfortable in your household during cold season?
    - Rarely
    - Sometimes (once a week or so)
    - Often (2-4 times a week)
    - Very frequently (more than 5 times a week)

17. How often are you uncomfortable in your household during the hot season?
    - Rarely
    - Sometimes (once a week or so)
    - Often (2-4 times a week)
    - Very frequently (more than 5 times a week)

18. Do you have any concerns related to your monthly energy cost or utility bill? (check any that apply)
    - The bill is too high in winter
    - The bill is too high in summer
    - The utility bill in winter is increasing too fast
    - The utility bill in summer is increasing too fast
    - Other ____

19. Do you have any concerns associated with the air quality of your home and surrounding areas?

Indoor air quality:	▪ Seriously concerned	▪ Moderately concerned	▪ Not concerned
Outdoor air quality:	▪ Seriously concerned	▪ Moderately concerned	▪ Not concerned
Traffic pollution:	▪ Seriously concerned	▪ Moderately concerned	▪ Not concerned
Factory pollution:	▪ Seriously concerned	▪ Moderately concerned	▪ Not concerned
Other pollution:	▪ Seriously concerned	▪ Moderately concerned	▪ Not concerned

Other pollution source: ____

Additional details if any: ____

____

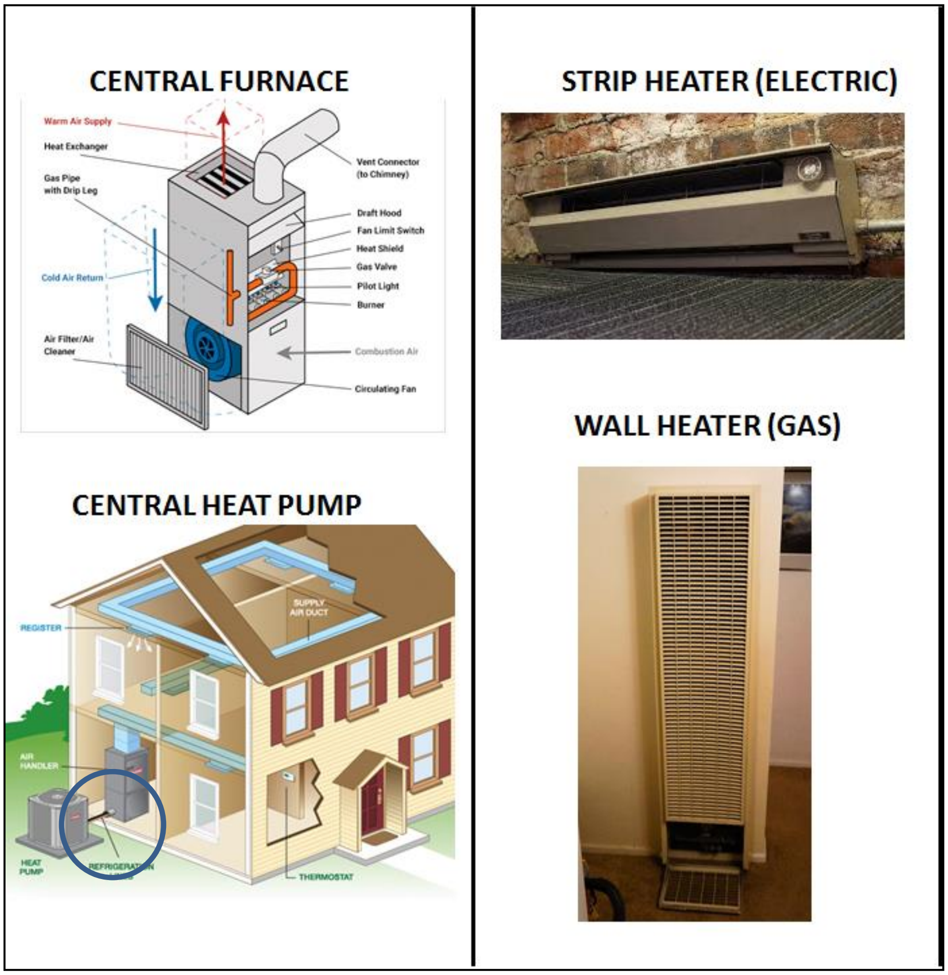
20. Do you feel you have access to the following?

Public transportation:	▪ Difficult to access	▪ Moderate difficulty	▪ Easy to access
Weather stripping your home:	▪ Difficult to access	▪ Moderate difficulty	▪ Easy to access
Energy efficient appliances:	▪ Difficult to access	▪ Moderate difficulty	▪ Easy to access
Rooftop solar PV:	▪ Difficult to access	▪ Moderate difficulty	▪ Easy to access
Zero emission vehicle:	▪ Difficult to access	▪ Moderate difficulty	▪ Easy to access

Other concerns: ____

____

SPACE HEATING TYPES:



AIR CONDITIONING TYPES:

CENTRAL AC	PORTABLE AC	WINDOW AC
		

WATER HEATING TYPES:

GAS WATER HEATER with TANK	TANKLESS GAS WATER HEATER
	
	TANKLESS ELECTRIC WATER HEATER
	

Phase 2 Survey Questions

California Community Health and Energy Efficient Residential System Survey (Cal-CHEERS)

Building Healthier and Energy Efficient Communities

Site ID#: **Date of data collection:** **Surveyor name:**

1 House Characteristics

a What is the floor area of your home (sq ft)? ___

b How many bedrooms? ___

c How many bathrooms? ___

d When was your home built? ___ (YYYY)

e Do you (or your family) own or rent your home?
○ Own ○ Rent

f What is the type of your home:
- ○ Mobile home
- ○ Single-family house detached from other house
- ○ Single-family house attached to other house
- ○ Apartment in a building with 2 to 4 units
- ○ Apartment in a building with 5 or more units

g Does your home have an attic? ○ Yes ○ No

h Does your home have an attached garage?
○ Yes ○ No

i Does your home have a basement? ○ Yes ○ No

j How long have you (and your family) lived in this home?
○ Less than 1 year ○ 1-5 years ○ 5-10 years
○ More than 10 years

k What is the address of your home? (We ask this information for the purpose of determining the census block. After this process, we will remove your address information.)
____

2 Heating Equipment

a Do you use heating during the winter?
- ○ Yes, most of the time
- ○ Yes, but only as needed (example during the night)
- ○ Yes, but very rarely used (only extreme cold days)
- ○ No, I do not have any heating equipment

b If you use heating, do you have any of the following heating equipment?

❑ Central furnace (typically in basement) that delivers hot air to vents in rooms

❑ Boiler (typically in basement) that delivers hot water to radiators in rooms

❑ Built-in electric heater installed in walls, ceilings, or floors, such as wall heater, baseboard heater

❑ Portable electric heater

❑ Electric fireplace

❑ Built-in gas/propane heater installed in walls, ceilings, or floors, such as wall furnace, floor furnace

❑ Gas hearth products (fireplace, gas logs, etc)

❑ Built-in room heater burning oil, wood, or kerosene

❑ Heating stove burning wood, coal, or solid fuel

c If more than one heating equipment is selected, which equipment you rely on the most as your main heating system? ________________

d What is the age of your main heating equipment?
- ○ Less than 2 years
- ○ 2 to 4 years
- ○ 5 to 9 years

○ 10 to 19 years ○ 20 or more years

e Where is your main heating equipment located? ________________________

f How well does it work on a scale of 1 to 5?
- ○ 1: does not work at all
- ○ 2: poorly controlled or provides weak flow of warm air
- ○ 3: experience warm air, but inconsistent and not enough warming during cold days
- ○ 4: works very well except on the coldest days
- ○ 5: works very well even on the coldest days

g Has this heating been repaired/replaced before? ○ Yes ○ No

h How do you control your main heating equipment?
- ○ Manually set temperature
- ○ Programmable thermostat
- ○ Just turn on (no control)
- ○ Turn on/off as needed

i If using a thermostat to set the temperature, how well does it work on a scale of 1 to 5?
- ○ 1: does not work at all
- ○ 2: poorly controlled, or not working well
- ○ 3: somewhat inconsistent performance
- ○ 4: works well most of the time
- ○ 5: works well all of the time

j Do you use secondary heating equipment?
○ Yes ○ No

k If using a secondary heating, what is the type (see the list from main heating, question 2b):

____

l On a scale of 1 to 5, is the overall heating in your home sufficient for you and your family?
- ○ 1: not sufficient at all, feeling cold all the time like no heating or warm air
- ○ 2: not sufficient, feeling cold most of the time
- ○ 3: somewhat sufficient warm air, but inconsistent and not enough during cold days
- ○ 4: sufficient but not on the coldest days
- ○ 5: very sufficient even on the coldest days

3 Cooling Equipment

a Do you use cooling equipment during the summer?
- ○ Yes, most of the time
- ○ Yes, but only as needed (example during the day)
- ○ Yes, but very rarely used (only extreme hot days)
- ○ No, I do not have any cooling equipment

b If you use cooling, do you have any of the following cooling equipment?

❑ Central air conditioner (a large air conditioning unit installed on rooftop)

❑ Central air conditioner (a large air conditioning unit but not installed on rooftop)

❑ Portable air conditioner (has wheels, movable and has duct tube usually connected to a window)

❑ Window air conditioner (usually installed in wall/window)

❑ Swamp cooler (evaporative cooler that generates cool mist)

❑ Ceiling fans

❑ Portable fans

❑ Other ___________________________

c If more than one cooling equipment is selected, which equipment you rely on the most as your main cooling system? ________________

d What is the age of your main cooling equipment?
- ○ Less than 2 years ○ 2 to 4 years ○ 5 to 9 years
- ○ 10 to 19 years ○ 20 or more years

e Where is your main cooling equipment located? ________________________

f How well does it work on a scale of 1 to 5?
- ○ 1: does not work at all
- ○ 2: poorly controlled or provides weak flow of cold air
- ○ 3: experience cold air, but inconsistent or not enough cooling on hot days
- ○ 4: works well except in heat waves
- ○ 5: works well even in heat waves

g Has this cooling equipment been repaired/replaced before? ○ Yes ○ No ○ I don't know

h How do you control your main cooling equipment?
- ○ Manually set temperature ○ Programmable thermostat
- ○ Just turn on (no control) ○ Turn on/off as needed

i If using a thermostat to set the temperature, how well does it work on a scale of 1 to 5?
- ○ 1: does not work at all
- ○ 2: poorly controlled, or not working well
- ○ 3: somewhat inconsistent performance
- ○ 4: works well most of the time
- ○ 5: works well all of the time

j Do you use secondary cooling equipment? ○ Yes ○ No

k If using a secondary cooling, what is the type (see the list from main cooling, question 3b): _______________

l Do you use passive cooling such as shading, blinds, trees to help cool your home? ○ Yes ○ No

m On a scale of 1 to 5, is the overall cooling in your home sufficient for you and your family?
- ○ 1: not sufficient at all, feeling hot all the time like no cooling
- ○ 2: not sufficient, feeling hot most of the time
- ○ 3: somewhat sufficient cool air, but inconsistent and not enough during hot days
- ○ 4: sufficient but not on the hottest days
- ○ 5: very sufficient even on the hottest days

4 <u>Water Heating Equipment</u>

a What is the type of your water heater?
- ○ Water heater with storage tank (water tank in basement, garage, or closet)
- ○ Tankless water heater (no water tank)
- ○ Central water heating system or boilers (for multifamily or apartment buildings)

b What fuel does your water heater use?
- ○ Natural gas ○ Propane ○ Electric ○ Other:______

c Where is your water heater located?
- ○ Garage
- ○ Indoor closet
- ○ Basement
- ○ Attic
- ○ Exterior closet
- ○ Other:__________________

d What is the age of your water heater?:
- ○ Less than 2 years
- ○ 2 to 4 years
- ○ 5 to 9 years
- ○ 10 to 19 years
- ○ 20 or more years

e Has this water heater been repaired/replaced before? ○ Yes ○ No ○ I don't know

f On a scale of 1 to 5, is the water heater providing sufficient hot water for you and your family?
- ○ 1: not sufficient at all, no hot water or always run out of hot water quickly during each bath or shower
- ○ 2: not sufficient, often run out of hot water during each bath or shower
- ○ 3: somewhat sufficient hot water, but inconsistent or occasionally not hot enough
- ○ 4: sufficient, but not for long and consecutive shower or bath events
- ○ 5: very sufficient, even for long and consecutive shower or bath events

5 <u>Home Ventilation and Air Quality</u>

a What type(s) of ventilation does your home have?

❑ Fume hood over stove

❑ Window fan (fan installed in windows)

❑ Bathroom fan

❑ Exhaust fans (in any room of the house, for example kitchen exhaust fan)

❑ Whole house fan (a type of fan commonly venting into a building's attic, designed to circulate air in a home)

❑ Other: _______________

b Do you or your family use your fume hood when cooking?
- ○ Always ○ Occasionally
- ○ Very rarely/never
- ○ I don't have fume hood

c Do you or your family use your kitchen exhaust fan when cooking?
- ○ Always
- ○ Occasionally
- ○ Very rarely/never
- ○ I don't have kitchen exhaust fan

d Do you or your family use your bathroom exhaust fan when bathing or showering?
- ○ Always
- ○ Occasionally
- ○ Very rarely/never
- ○ I don't have bathroom exhaust fan

e Does any type of ventilation not work? Please describe the issue:_______________________

f Is your fireplace vented?
- ○ Yes ○ No ○ I don't know ○ I don't have fireplace

g If you have fireplace, how often do you or your family use it?
- ○ Always ○ Occasionally ○ Very rarely/never ○ N/A

h During the summer, how often are windows opened for ventilation?
- ○ Always opened
- ○ Frequently
- ○ Occasionally, as needed
- ○ Rarely
- ○ Always closed

i During the winter, how often are windows opened for ventilation?
- ○ Always opened
- ○ Frequently
- ○ Occasionally, as needed
- ○ Rarely
- ○ Always closed

j Is your home located near main traffic routes or heavy traffic areas? ○ Yes ○ No

k Does any household member smoke inside your home? ○ Yes ○ No

l How often do you notice polluted air inside your home? (This is related to concerns about dust, smoke, or other chemical pollution in the air).
- ○ Never
- ○ Rarely
- ○ Occasionally
- ○ Often
- ○ Very often or always

m How much does outdoor air pollution affect the air quality inside your home?
- ○ No impact at all
- ○ Minimal impact/ almost unnoticeable
- ○ Some impact during a limited period
- ○ Frequent impact/ almost regularly
- ○ Strong negative impact all the time

n Does any household member have asthma or allergy? ○ Yes ○ No

o Do you see the following pests inside your home?
❑ Cockroaches ❑ Mice/rats ❑ Other insects

p Does your home show any of the following moisture relate issues?

❑ Water damages or leaks

❑ Mold

❑ Damp surfaces

❑ Condensations on windows

❑ Other:____________

q Do you use any of the following devices?

❑ Portable dehumidifier

❑ Portable humidifier

❑ Portable air cleaner or filter

r On a scale of 1 to 5, is your home ventilation and other measures to maintain or improve indoor air quality sufficient for you and your family?
- ○ 1: not sufficient at all, all air quality issues continue to be problem
- ○ 2: not sufficient, sometimes work but very inconsistent result
- ○ 3: somewhat sufficient, works on some air quality issues
- ○ 4: sufficient, but not able to resolve major issues
- ○ 5: very sufficient, good air quality is maintained all the time

6 <u>Energy Assessment</u>

a What is the type of roof on your home?
- ○ Asphalt shingle
- ○ Composition (flat)
- ○ Wood shake or wood shingle
- ○ Clay tile

○ Concrete tile
○ Metal
○ Other: ______

What is the age of the roofing on your house?
○ Less 10 years
○ 10-20 years
○ More than 20 years
○ Not sure

b What is the roof color on a scale of 1 to 5, where: 1 is white, 3 is yellowish-brown, and 5 is very dark/black [enter number from 1 to 5]?_________

c What is the type of exterior wall of your home?
○ Brick ○ Stucco ○ Siding ○ Other: _____

d What is exterior wall color on a scale of 1 to 5, where: 1 is white, 3 is yellowish-brown, and 5 is very dark/black [enter number from 1 to 5]?

____

e Do your windows have any of the following features?

❑ Blinds ❑ Curtains ❑ Outside shade covering

❑ Outside awning or overhang ❑ Temporary pop-ups

❑ Dual-pane windows ❑ Low-emissivity windows [windows with special transparent coatings to reduce amount of heat from the sun]

f Which of the following appliances have Energy Star logo on them?

❑ Clothes washer ❑ Clothes dryer ❑ Dishwasher

❑ Refrigerators ❑ Water heater

❑ Other:___________

g What type of lighting do you use in your home?

❑ LEDs ❑ CFLs (spiral fluorescent bulbs)

❑ Incandescent ❑ Fluorescent tubes

❑ Other: ________

h How many computers are actively used in your home? _____

i How many electronic game systems are actively used in your home? _______

j How many large screen TVs are actively used in your home (48” diagonal or larger)? _______

k How many refrigerators are inside your home (not including your garage)?______

l What is your typical monthly energy bill in summer?
○ Less than $150 ○ $150-249 ○ $250-349
○ $350-449 ○ $450 or greater

m What is your typical monthly energy bill in winter?
○ Less than $150 ○ $150-249 ○ $250-349
○ $350-449 ○ $450 or greater

n Do you receive a monthly discount on your PG&E bill?
○ Yes ○ No

o If yes, are you enrolled in any of the following?

❑ CARE ❑ Medical Baseline ❑ Life Support

p Do you have solar panels on your roof?
○ Yes ○ No

Would you like to have solar PV on your roof if it would not increase your utility bill?
○ Yes ○ No

Does you home need repainting?
❍ Yes ❍ No

q Has your home been weatherized recently?
❍ Yes ❍ No

r If yes, how many years ago? ___

s What measures were installed?
❑ Wall insulation ❑ Attic insulation
❑ Floor insulation ❑ Sealed or replaced ducts
❑ Duct insulation ❑ LED light bulbs ❑ Compact fluorescent light bulbs ❑ Window shades
❑ Window films ❑ Curtains ❑ Fans ❑ New windows ❑ New AC ❑ New heating system
❑ New hot water system

❑ Other: ______________

7 <u>Transportation</u>

a What is your daily mode of transportation?

❑ Car ❑ Motorcycle ❑ Battery-powered bike/ scooter ❑ Bicycle or scooter ❑ Rideshare
❑ Public transportation (bus)
❑ Other:____________

b If using car, what is the vehicle fuel?

❑ Gas ❑ Electric ❑ Hybrid

c If using car, what is the age of your car (years)?______(YYYY)

d If using car, what is the estimated average miles driven per day? ___________

e If using car, what is the range of your gasoline bills per month?
○ Less than $150 ○ $150-249 ○ $250-349
○ $350-449 ○ $450 or greater

f If not using a car, what is the biggest barrier for not using a car?

❑ Cost ❑ Inconvenience ❑ Safety ❑ Other:__________

g What price would you be able to willing to spend for your next car?

❑ Under $1000 ❑ $1000-2000 ❑ $2000-3000

❑ More than $3000

h Have you heard about clean vehicle rebates?
❍ Yes ❍ No

i Would you be interested in an electric car if it were within your price range above?
❍ Yes ❍ No

j If no, why not? ❑ Lack of range ❑ Not familiar
❑ Safety ❑ Other

8 Demographic Information

a What is the number of occupants in household (do not include anyone just visiting, those away in the military, or children at college? You may decline to answer.

Age 0-19:	Age 30-39:	Age 50-59:	Age 70+:
Age 20-29:	Age 40-49:	Age 60-69:	Age Unknown:

b What is the total gross annual household income? You may decline to answer.

				❍	$80,000-$99,999	❍	$150,000-$199,999
❍	$ 0-$19,999	❍	$40,000-$59,999	❍	$100,000-$119,999	❍	$200,000+
❍	$20,000-$39,999	❍	$60,000-$79,999	❍	$120,000-$149,999	❍	Decline to state

c What are the races of your household members? You may decline to answer.

☐	Hispanic/Latino	☐	South Asian	☐	Native American
☐	Caucasian	☐	African or African American	☐	Some other race
☐	East Asian	☐	Southeast Asian or Pacific Islander	☐	Decline to state

d What is the highest education level in your household? You may decline to answer.

				❍	Master's degree (MA, MS, MBA)
❍	No schooling completed	❍	Some college, no degree	❍	Professional degree (MD, JD)
❍	Grades K-12 (no diploma)	❍	Associate's degree (AA, AS)	❍	Doctoral degree (PhD, EdD)
❍	High school diploma or GED	❍	Bachelor's degree (BA, BS)	❍	Decline to state

Phase 3 survey questions

First, we would like to ask about the **cooling and heating equipment** in your home.

How many square feet is your home? (estimation is fine) ____

Are you using any of the following equipment? (check all that apply)

For cooling:

❑ Central air conditioner (a large air conditioning unit installed on rooftop)
❑ Central air conditioner (a large air conditioning unit but **not** installed on rooftop)
❑ Portable air conditioner (has wheels, movable and has duct tube usually connected to a window)
❑ Window air conditioner (usually installed in wall/window)
❑ Swamp cooler (evaporative cooler that generates cool mist)

For heating:

❑ Central furnace (typically in basement) that delivers hot air to vents in rooms
❑ Boiler (typically in basement) that delivers hot water to radiators in rooms
❑ Built-in electric heater installed in walls, ceilings, or floors, such as wall heater, baseboard heater
❑ Portable electric heater
❑ Electric fireplace
❑ Built-in gas heater installed in walls, ceilings, or floors, such as wall furnace, floor furnace
❑ Gas hearth products (fireplace, gas logs, etc)
❑ Built-in room heater burning oil, wood, or kerosene
❑ Heating stove burning wood, coal, or solid fuel

Could you take a photo for each of the equipment that you are using for cooling and heating your home? Please make sure your photos show the entire unit. If the unit is outside or on the roof, please take the photos from a distance that is convenient to you. (wait for a few minutes to ensure photos are taken, resolve any questions about photo taking)

Thanks for taking the photos. At the end of this survey, I will end the call so that you can send the photos to our email [insert email address]. After receiving your email, I will call you back to confirm.

If the space heating equipment in your home uses natural gas, will you be willing to replace it with an electric equipment such as a heat pump unit? Yes/No/NA

Now, I am going to ask some questions related to your **home air quality**.

Do any children in your household have asthma problem or other respiratory health issue? Yes/No

Do you know or feel health issues among the children are attributed to indoor air quality issues? Yes/No

What type of cooking equipment do you use in your homes? Gas stove/Electric stove/Induction stove/Other: _____

What fuel does your cooking equipment use? Natural gas/Propane/Electricity/Other: _____

(If household uses gas stove) Will you be willing to replace your gas stove with an electric stove? Yes/No

Is your home located near (less than a mile of) a major traffic route? Yes/No

Is your home located near a large industrial site (less than a mile) such as a factory or a processing plant? Yes/No

Do you know or feel health issues among the children are attributed to outdoor air quality issues? Yes/No

In Summer, what is the average number of hours each day that any windows or doors are open more than an inch in the: living room____; bedroom____; kitchen____; bathroom____?

In Winter, what is the average number of hours each day that any windows or doors are open more than an inch in the: living room____; bedroom____; kitchen____; bathroom____?

For what reasons do you typically open windows or doors to the outdoors (allow multiple selections): to cool / warm the house____; to remove odors / moisture / smoke (from cigarettes, fireplace, and woodstove etc.____; for air circulation____; to save energy___; other reasons____?

For what reasons do you typically close windows or doors (allow multiple selections): to maintain comfortable indoor temperature____; to keep out noise____; to keep out dust, smoke, pollen or other allergens, insects____; to keep out odor from outside___; security / privacy reasons___; other reasons____?

How many months ago was the last time your space heating or cooling equipment have a filter cleaning or replacement service? ____/never/don't know

Next we would like obtain information about your **energy bills**. For research purpose, we would like to request that you provide photos or files of your monthly energy bills including electric and gas. At least one month of data during the heating months (December, January, February, and March) AND one month of data during the cooling months (June, July, August, September) is preferred. When taking photos of the bills, please include the energy use breakdown pages for the electricity and gas usage. Please exclude your name and address from the photos whenever possible.

If paper or electronic bills are not available, we would like to request for downloaded energy use data from your account. We can provide a step-by-step guidance to you to access the information using Green Button feature on your utility account.

1. Sign in to account
2. Click on energy use details
3. Find the Green Button link
4. Select export bill for all bills or select the bill period; select format in CSV
5. Click export and save the file

Please send us the file you have just downloaded at the end of this call together with other photos you have taken earlier.

Next, we would like to ask about your roof structure in relation to **PV panel installation**.

Is your roof without obstructions such as vents, antennas, skylights, or a chimney? Yes/No

Is your roof receive enough sun or without shades from surrounding trees and buildings? Yes/No

Is the main or largest area of your roof facing: South/West/East/North?

What is the type of roof on your home? Asphalt shingle/Composition (flat)/Wood shake or wood shingle/Clay tile/Concrete tile/Metal/Other: ______

[b/c did not get good responses]

What is the age of the roofing on your house? Less 10 years/10-20 years/More than 20 years/Not sure

How would you describe your roof? Flat roof that lacks precipitation run off/Flat roof with precipitation run off/Steep roof

If you are a renter in an apartment building or complex, would you be willing to contact your neighbors to see if they are also interested in solar PV installation and eventually propose it to your landlord? Yes/No

Now we would like to ask you some questions related to your **transportation**. (only participant who uses car should be interviewed)

Do you use your car regularly for everyday activities such as going to work, getting groceries, school pickups? Assume a typical day not affected by COVID. Yes/No

How many miles do you drive every day on average for work? _____

How many miles do you drive every day on average for activities not related to work? _____

What is the vehicle fuel? Gas/Electric/Hybrid

(If using gas) Would you be willing to switch to an electric vehicle? Yes/No

(If no) What is your reason for not willing to switch?________

What is the price range you would be willing to pay for an electric vehicle?______

We have reached the end of our interview. Thanks very much for discussing these questions with us. Do you have any questions or other relevant information you'd like to share with me?_____________

As mentioned before, I'd like to ask you to send us the photos or files that you took earlier. Here is the email address to use: [insert email]. I repeat [insert email]. I will end this call so you can prepare and send the files. Once I receive the information, I will call you back to confirm or you can call me at [insert phone number].

Community Meeting #2 survey questions

[General] What would help you out the most? Please choose top 3 choices
¿Que te ayudara mas? Por favor seleccionan 3 opciones

a. Much lower utility bills / Servicios públicos como PG&E mucho más bajas
b. Much lower transportation costs (gasoline costs, repair costs) / Gastos de transportación mucho más bajo (por ejemplo lo de gasolina, de reparación)
c. Greater comfort at home in the summer / Sentir mas cómodo en casa en el tiempo de verano
d. Greater comfort at home in the winter / Sentir mas cómodo en casa en el tiempo de invierno
e. A more reliable car / Un auto más dependiente
f. Better air quality in my home / Mejor calidad del aire en mi hogar.
g. Fixing another appliance at home (for example refrigerator, dishwasher, or other appliance) / Arreglar otro aparato de mi casa (por ejemplo la refrigerador, lava platos, o otro aparato)

2. Are you a renter or owner? Renter/Owner
   ¿Rentas o estas comprando su casa? Rentando/Comprando
3. Do you live in an apartment or a single family home? Apt/ Single family home
   ¿Vives en un apartamento o en una casa? Apartamento / Casa

Electric Vehicles (3)
Vehículos Electrónicas

1) Have you applied for a Clean Vehicle rebate? Y/N
   ¿Ha solicitado un reembolso por vehículo limpio? Si / No
2) What if any concerns might you have with owning an electric vehicle?
   ¿Qué te preocupa de ser dueño un vehículo eléctrico?
   1) Too expensive / Muy carro
   2) Too small / Muy peuquino
   3) Can only drive limited distances / Tiene distancia limitado
   4) No place to charge my car / No tengo por donde cargar mi coche electrónico
   5) Other ___________________________ / Algo mas __________________________
3) If you were able to afford an electric vehicle, would you be interested in owning one? Y/N
   ¿Si pudiera pagar un vehículo eléctrico, le interesaría tener uno? Si / No

Indoor Air Quality (3)
Calidad de aire Interior

1) Do you have a portable fan that is box shaped? Y/N
   ¿Usted Tiene un ventilador portátil con forma de caja cuadrado? Si o No
2) Have you seen any programs or rebates for low cost air filters as described here? Y/N
   ¿Has visto algún programa o reembolso por filtros de aire de bajo costo como se describe aquí? Si o No

3) If the filter were not free but available at a discount (online price $30-40), how much would you be willing to pay
¿Si el filtro no fuera gratuito, pero estuviera disponible con un descuento (precio en internet $ 30-40), cuánto estaría dispuesto a pagar?
    1) $0
    2) $0- 10
    3) $11-20
    4) $20-30

Solar PV/ Electric Heating (3)
Paneles Solar / Calentamiento Electronico

1) If you are a homeowner, are you aware of incentive programs for installing solar PV? Y/N
Si eres dueno de una vivienda, ¿conoce los programas de incentivos para la instalación de paneles solar? Si o No
2) Have you heard of Community Solar programs or incentives? Y/N
¿Has escuchado de programas o incentivos de Solar Communitario? Si o No
3) For your home's water heating and heating system to keep your home warm in the winter, would you be willing to test an upgrade to all-electric heating if it were free?
Para que el sistema de calentar su casa y sistema de calentar la agua de su hogar mantenga su hogar caliente en el invierno, ¿estaría dispuesto a probar una actualización a la calefacción totalmente eléctrica si fuera gratis?
    1) Yes / Si
    2) No / No
    3) I don't know enough to answer this / No sé lo suficiente para responder a esto

Cooling (2)
Enfriamiento

1) Do you only have a swamp cooler in your home and no air conditioning? Y/N
¿Solamente tienes un cooler de agua en su casa? Si o No
2) Would you be willing to test a solar control window film in your home if it were free? Y/N
¿Estaría dispuesto a probar una tapa de ventanas solar en su hogar si fuera gratis? Si o No

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B:

Measures and Technologies Considered for Climate Equity Action Plan

November 2023 | CEC-500-2024-001-APA-G

APPENDIX B: Measures and technologies considered for climate equity action plan

Table B-1. Measures and technologies considered for climate equity action plan. Shaded options in orange those modeled by the research team.

Area	Measure/ Technology	Opportunity	Barriers/ considerations
Energy supply	Rooftop solar PV – Single Family (SF)	Reduce electricity bill esp. for subsidized PV	SF: "50% of home do not qualify since older roofs; ~30% owner occupied SF homes ==> ~15% eligible SF homes. This is a key policy gap: providing affordable PV for rental SF homes
Energy supply	Rooftop solar PV – Multi-family (MF)	Reduce electricity bill esp. for subsidized PV	MF units represent fewer building in Fresno DAC neighborhoods of focus
Energy supply	Community solar or shared solar	Brownfield/empty lots in SW Fresno; Workforce training and	City concerned about lock-in of site over PV lifetime; usually grid connected so no resilience benefit during outage; only moderate interest from Fresno Housing Authority
Energy supply	Central solar PV plants		Large price drops over last 10 years; out of scope
Energy supply	Energy storage		Policies for no-cost storage can play a role, but need PV first, so this seems less accessible; SGIP has LINC programs; lower priority
Energy supply	Microgrids for resilience	Islanded microgrid provides resilient power during power outage/PSPS event	Inputs from multiple stakeholders including Fresno Sustainability Office are that extended outages not a key priority for Fresno; historically not seen PSPS or extended outages; recent utility upgrades; redundant transmission lines; lower priority

Area	Measure/ Technology	Opportunity	Barriers/ considerations
Energy supply	"Resilience hubs"	Adding solar PV/storage to 4 existing community cooling centers (2 of 4 are emergency response centers) for extended emergency response; wildfire smoke, heat wave, power outages	We are collecting physical parameters, equipment types, and critical loads for PV/storage modeling of costs and resilience benefits
Energy supply	Local community choice aggregator like Marin Clean Energy (MCE)	Provide greater choice to residents and options for cleaner electricity	Have not explored this option; but this seems to be more indirect benefit to city in terms of electricity sector emissions. Marin Clean Energy offers some innovative electrification programs.
Residential buildings	Deferred maintenance	Improve baseline for older homes to facilitate weatherization, fuel switching, rooftop PV	See rooftop PV for example. There are some programs with no-cost loans but these seem to be limited to commercial or MF units and appears to be a policy gap for SF homes.
Residential buildings	EE upgrades: insulation, HVAC (non-fuel switching)	Reduce utility bills, increase comfort and equity	Installing new gas-based appliances can create technology lock-in for another 20 years; not consistent with 40% GHG reduction target in 2030
Residential buildings	Upgrades to more energy efficient appliances	e.g. Electric stove, electric clothes dryer or washer/dryer combo	Currently lower priority since energy use dominated by HVAC and water heating
Residential buildings	General heat resilience measures	Passive measures can improve heat resilience during worst case heat waves and during temporary power outages	[Will refer to SGC CAL THRIVES project & quote a few key results for Action plan] Solar window films - can be reflective; need some care in selecting proper film; not favored by Fresno EOC Roof insulation: costly and not typically covered in weatherization - see barriers above
Residential buildings	Swamp cooler to air conditioners for heat resilience	Swamp coolers ineffective at extreme temperatures above about 95F; switch to AC for better comfort and heat resilience	Existing weatherization programs (e.g. TCC-Fresno EOC) typically do like-for-like replacements; AC might require extra work or cost

Area	Measure/ Technology	Opportunity	Barriers/ considerations
Residential buildings	Electrification of HVAC-Water heating e.g. Gas furnace and central air conditioning to air-source or mini-split heat pumps for equipment consolidation and reduction of on-site combustion	First cost savings from replacing 2 systems (furnace and AC) with 1 heat pump system	Utility bill cost needs to be quantified; Panel upgrades ($2000-$4000 and electric circuit upgrade(s) ($500-$1500) are additional cost; also combining building electrification with rooftop PV and vehicle electrification scenarios
Residential buildings	Electric resistance water heater (ER WH) to heat pump water heater	Sharply reduce electricity consumption and bills	HP water heater up to 3X more efficient; LiHEAP/LiWIP can do fuel switching but not PG&E ESA and TCC-weatherization; but do not seem to have many ER WH in SW Fresno
Residential buildings	Lower Voltage 120V plug-in ready HP HVAC and WH	Sharply reduce or eliminate cost for panel upgrades and circuit upgrades	Still to be modeled; may not be appropriate for households with high number of occupants
Residential buildings	"Smart panels" or smart circuits	Sharply reduce or eliminate cost for panel upgrades and circuit upgrades	Still to be modeled
Transportation	EVs or used EVs/ PHEVs	Residents have older cars - EV/PHEV would be win for equity, GHG, and air quality/health benefits	Most residents' budget is less than $3000, so new EVs are not accessible; MF charging access a barrier but fewer MF; Lower operating costs means that residents can have greater mobility (can drive more for same fuel or electricity and maintenance budget); BEV range limitations [Plan to have develop scenarios/AQ benefits using EMFAC vehicle data and 2 closed form health models (InMAP and EASIUR) in Q2'21]
Transportation	EV charging infrastructure	Improve access by providing more charge ports in MF units	Can be challenging (costs, ADA/ trees, etc.) Key learnings from LA, Berkeley, Sacramento. Most homes are SF homes and L1 charging is possible at the least.

Area	Measure/ Technology	Opportunity	Barriers/ considerations
Transportation	Two wheeled transport e.g. electric bikes, scooters	Low GHG alternatives to ICE passenger vehicles	Some pilots on these, but far distances and hot weather can be limiters for adoption and usage; lack of "biking culture" (Fresno Housing Authority); Survey respondents did not seem to favor these; lower priority
Transportation	EV ride share fleet	Less reliance on ICE passenger vehicles	Team is tracking plans by Lyft, Uber; ride sharing is apparently less common in these DAC areas - lower priority
Transportation	Active transportation	Reduced GHG from less driving	Walking, biking may be tough in hot season and in winter; not prioritized
Transportation	Expanded transit for bus system	Lack of coverage in Southwest Fresno, infrequent stops	Will be included in Action plan but this is generally out of scope (typically limited by local/county funding)
Transportation	Truck electrification (local small to medium duty trucks e.g. delivery trucks)	Reduce GHG and improve local AQ, especially when fossil-fuel truck idling	Delivery trucks; local fleets – research team to follow up on this item
Air Quality (Energy related)	More Zero Emission Vehicles	Improved local air quality, lower GHG, improved equity	In the past have used "closed form" models to estimate health benefits (e.g. EASIUR model). Will extend to include higher spatial resolution InMAP model
Air Quality (Energy related)	DIY Air filters with fans + MERV filter	Improved AQ during wildfire event with high smoke	Would need some program to replace filters; e.g. annual community drive to update; may be best for acute AQ like wildfires; uses energy + noise; Outreach item
Air Quality (Energy related)	Improved fume hood or no combustion from stove	Improved air quality from better ventilation or elimination of combustion	Will be a follow up for outreach efforts for follow up survey questions or (e.g. zoom calls) actual monitoring (less likely); humidifiers for dry air?
Air Quality (Energy related)	Furnace filter replacement	Improve indoor air quality from regular replacement	If upgrading to new furnace, going to 4" filter panel most cost effective for improved air quality; outreach/ education opportunity for Action Plan

Area	Measure/ Technology	Opportunity	Barriers/ considerations
Air Quality (Energy related)	Pursue energy efficiency upgrades and Healthy Homes at same time	Weatherization can improve in-home conditions for better health (Information only; weatherization programs well established in Fresno)	Refer to literature: BPI's Healthy Home Evaluator (dry, clean, pest-free, safe, contaminant-free, ventilate, maintain, and energy efficiency); Action steps here but not all energy focused (mold, lead, CO, water, pesticides, local toxics, home safety)
Air Quality (Energy related)	Carbon monoxide monitors (ovens/heaters)	Health and safety measure for dangerous CO levels	Baseline item for Fresno EOC weatherization – outreach/education opportunity for safety
Air Quality (Energy related)	Local truck fleets e.g. delivery trucks? Keep away zones	Improve local AQ by preventing	Potential area for modeling but lack data on size of private truck fleet (e.g. delivery trucks)
Air Quality (Energy related)	Outdoor AQ monitoring	Provide early warning to residents for unhealthy AQ	Local effort in 2017 here
Air Quality (Energy related)	Indoor AQ monitoring	Quantify CO2, $PM_{2.5}$ levels in homes	Important to do but deemed out of scope for this project
Policy/ Air Quality	AB617 Community AQ plans	Leverage any funding or data here (Info only)	Info here
Policy	Energy Saving Assistance Programs for low income residents (PG&E, CPUC)	Achieve cost savings for residents from conventional energy efficiency retrofit measures	Currently do not have energy efficiency goals and do not support fuel switching (mainly like-for-like equipment replacement). More high level finding for action plan.
Policy	Consolidation: Set up 1-stop registration for all programs and incentives	Streamline enrollment, efficiency, effectiveness of EE/equity programs	SoCal Edison EmPOWER program (outreach) an example; Propose some combo of rooftop PV, used EV, EE retrofits, and electrification pilots in Action Plan.
Policy	On Bill financing	Innovative policy; do not need high credit score; 3rd party financing for upgrades that save on utility bills	Policy recommendation for action plan
Policy	Clean vehicle rebate programs	Lower cost of new or used cleaner vehicle	More outreach/education for action plan

Area	Measure/ Technology	Opportunity	Barriers/ considerations
Policy	Community solar or shared solar	Highlight existing programs and projects/enrollment if available	More outreach/education for action plan
Follow up pilot/demo	Propose integrated packages to demonstrate upgrades/benefits/resident feedback/Indoor AQ monitoring	Learn how to scale up programs; explore block-level upgrades e.g. 10-15 homes; integrate EE/electrification/ solar PV/vehicle electrifycation for decarbonization in support of 2030 40% GHG reduction goal, equity goal and improved indoor AQ	Programs should not increase residents' overall energy bills; MF buildings have generally high turnover; contingency planning if residents do not like the new technology

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX C:
Key Policy-Related Findings and Recommendations

November 2023 | CEC-500-2024-001-APA-G

APPENDIX C:
Key Policy-related findings and recommendations

TRANSPORTATION

Improving Local Air Quality & Increasing Access to Electric Vehicles

Clean Cars 4 All

Clean Cars 4 All (CC4A) is a statewide program to help low-income families exchange their old vehicle for a newer model. It is implemented via local air districts throughout the state. The San Joaquin Valley Air Pollution Control District (SJVAPCD) is the local implementer for Fresno and markets their CC4A program as part of their Drive Clean in San Joaquin program. Qualified residents can receive a larger grant if they purchase an Electric Vehicle (EV). For this program hybrids, plug-in hybrids (PHEV), and zero emission vehicles (ZEV) are considered to be EV's. To qualify for the program an individual's household income must be at or below 400% of the Federal Poverty Level (FPL).

Opportunities

City of Fresno

DAC Engagement

The City of Fresno can work with SJVAPCD to increase community participation in the program. This can be done through a variety of methods such as; city approved joint mailers sent to eligible households, community workshops focused on EV and program education, and public EV charging demonstrations.

Regional Agencies

Car Model

By increasing the model year range of an eligible car (i.e. reducing the eligible age of cars), more residents will be able to participate in the program, resulting in a potential increase of DAC participation.

EV/PHEV Focus

Fuel efficient combustion vehicles are eligible as a replacement vehicle, thus, the program may be more effective at reducing localized air pollution if EV/PHEVs were the only replacement option. There is a triple win for vehicle electrification: 1) equity and access to clean energy technologies; 2) improved local air quality and associated health benefits; and 3) lowering operating and maintenance costs for EV/PHEV. The latter factor could improve equity by providing more personal transportation service available to residents for the same transportation budget, i.e. residents can use their car more for the same fuel and maintenance budget that would have been incurred for a gasoline vehicle.

Used Vehicles

As the EV market expands, purchasing a used EV becomes more of a viable option. Used EV's are currently not considered as an eligible purchase under the Drive Clean in San Joaquin program. Expanding eligibility to used EV's can decrease consumer costs, increase program participation, and increase accessibility for low-income residents.

California Electric Vehicle Infrastructure Project (CALeVIP)

CALeVIP is a rebate program designed to create a statewide infrastructure for electric vehicles (EVs) by facilitating the purchase and installation of EV chargers. Due to the public access requirement an applicant must be a business, non-profit organization, tribal government, or government entity. Private single-family residences are not eligible for the program. Eligible locations are also determined on the type of EV charger to be installed; a Level 2 Charger or DC Fast Charger. Under the CALeVIP program, DC Fast Chargers can be installed for residential multi-family properties. Along with chargers, eligible costs include energy storage equipment, transformers, extended warranties, and signage. CALeVIP has two programs available for Fresno; the Fresno County Incentive Project (FCIP) and the San Joaquin Valley Incentive Project (SJVIP). SJVIP explicitly allocates 25% of funding to disadvantaged communities.

San Joaquin Valley Incentive Project

As the administrator of CALeVIP, the Center for Sustainable Energy (CSE) subcontracts with Central California Asthma Coalition (CCAC**)** to facilitate local program implementation. Kevin Hamilton from CCAC described the implementation method in two steps; step one focused on installing DC Fast Chargers in DAC's along the Highway 99 corridor. Step two focused on installing Level 2 Chargers in communities isolated from the interstate, with an emphasis on local businesses. As of May 2020, all SJVIP funding has been reserved for projects. Although 25% of funding was designated for DAC's, only 4% of issued incentives were allocated towards charger installation within disadvantaged communities.

Opportunities

City of Fresno

DAC Engagement

The City of Fresno can work with CCAC to increase the participation rate for DACs. A variety of methods can be used such as assistance in identifying eligible sites, joint mailers, and educational events. Partnering with community groups and neighborhood associations is one way to reach a larger audience.

Public Agency Participation

City and public agencies within Fresno County can apply to the program in order to increase EV charging capacity at public buildings and other city owned properties. For example, the Fresno Housing Authority is eligible for these funds and installs EV chargers at their sites in priority neighborhoods, which would increase accessibility of this infrastructure to low-income residents and DAC's.

Regional Agencies

Financing
Applicants who are interested in participating may not have sufficient capital for the upfront costs of purchasing and installing an EV charger. Providing alternative options such as zero-money down financing or grants may help reduce this barrier.

ENERGY

Increasing access to local renewable energy

Disadvantaged Communities-Single-Family Affordable Solar Homes (DAC-SASH)
Modeled after the Single-family Affordable Solar Housing (SASH) program, DAC-SASH provides incentives for qualified homeowners to receive a PV solar system. The program also provides workforce training and consumer education on energy efficiency. This statewide incentive is administered by the non-profit GRID Alternatives via their Energy for All program. To qualify for DAC-SASH, applicants must meet the following requirements:

- Live in the top 25% of disadvantaged communities based on CalEnviroScreen.
- Receive electrical service from Pacific Gas & Electric (PG&E), Southern California Edison (SCE), or San Diego Gas & Electric (SDG&E).
- Reside in a single-family home in which they own.
- Have their annual household income meet the California Alternate Rates for Energy (CARE) or Family Electric Rate Assistance (FERA) guidelines.

Eligible households may not receive a solar PV system if their home requires structural upgrades. Common upgrades needed can include a main service panel or roof replacement, both of which are costly. It is common for eligible families to drop out of the program due to their inability to afford these structural upgrades.

GRID Alternatives Central Valley (GRID CV) is the regional office responsible for implementing the Energy for All program within Fresno. The office has a strong history of working with DACs in Fresno, which has enabled the organization to build and maintain a robust understanding of the local communities they serve. They are able to identify eligible households through their effective outreach efforts, which includes canvassing, referral reward programs, and partnerships with other community-based organizations (CBOs). GRID CV also works to ensure non-English speaking applicants have a full understanding of the program by providing paperwork in the applicants' native language and translation services, as well as hiring multilingual outreach staff. As a result, families who received a system through GRID often refer their friends and other family members to the program.

Results from SASH's implementation indicates DAC-SASH has the potential to be a successful program. Under SASH, GRID CV has installed 307 PV solar systems for single-family homes in Fresno. As a result, disadvantaged communities in Fresno are able to produce 1066 kW hours of solar energy, prevent 17,745 lbs. of carbon being released into the atmosphere, and generate an estimated $8.6 million in savings for low-income families.

Opportunities

City of Fresno

Community Engagement
The City of Fresno can work with GRID CV to send a joint mailer to eligible households and organize educational workshops. This strategy is often used by regional GRID offices to reach a broader audience in DACs. The City can also partner with CBOs to identify funding to help cover the cost of upgrades that prevent a household from receiving a PV solar system.

Permit Cost
Fresno's Building Department can reduce or waive building permit fees explicitly for GRID solar installations completed through the DAC-SASH program. If reducing permit costs is not a viable option, a policy can be put in place to expedite the approval process of said permits.

Regional Agencies

Partnerships
GRID CV and the San Joaquin Valley Air Pollution Control District can provide information on their complementary services to their audiences. For example, GRID CV can refer their qualified homeowners to apply to the Drive Clean in San Joaquin program. Homeowners with newly installed PV solar systems may have more incentive to apply to the program and elect a plug-in hybrid or all electric vehicle as their trade in option.

Community Solar Green Tariff (CSGT)

The Community Solar Green Tariff (CSGT) is designed to increase access to solar energy for low-income households. Implemented by PG&E, pilot projects will consist of community solar arrays installed in areas in which households are located in DACs or in the San Joaquin Valley (SJV). Along with local power generation, eligible customers will receive a 20% discount on their electricity bill. For a pilot project to be eligible it must meet the following requirements:

- Sponsored by a local community organization, can be a non-profit or government agency.
- Support local workforce development by hiring residents to participate in project installation.
- Located within the top 25% of DAC's or within 40 miles of SJV.
  - PG&E designates SJV as: Allensworth, Alpaugh, Cantua Creek, Fairmead, Lanare, Le Grand, Seville, and La Vina.
- Array size not to succeed 4.26 MW
- A minimum of 50% enrolled customers are CARE/FERA (Family Electric Rate Assistance) eligible.

Under these requirements, the City of Fresno is eligible to have pilot programs under the DAC or SJV designation.

Recommendations

City of Fresno

Building Permits
Fresno's Building Department can reduce or waive building permit fees explicitly for community solar installations completed through the CSGT program. If reducing permit costs is not a viable option, a policy can be put in place to expedite the approval process of said permits.

Regional Agencies

Community Engagement
Pilot projects can be used as a method to educate community members on the local impacts of renewable energy and energy efficiency. It can also be used to showcase other programs in which residents are eligible for such as DAC-SASH and Clean Cars 4 All.

FINANCING

Increasing access to energy efficient upgrades

Tariffed On-Bill Financing (Tariffed OBF)

Tariffed on-bill financing allows for utilities to invest in cost-effective energy efficiency upgrades for residential customers. An example of an eligible upgrade is the installation of an energy efficient heating and cooling unit. Investment costs are recovered through a dedicated charge on a customer's utility bill. The charge is designed to be less than the estimated savings of the energy efficiency improvements to preserve customer affordability. Tariffed OBF is associated with the utility meter of a residential property, therefore the tariff will remain in place until the cost of the investment is fully recouped, regardless of residential occupants. This model is more accessible than conventional On-Bill Financing because it does not require consumer loans, credit checks, nor proof of homeownership. As a result, it is a variable option for financing energy efficiency upgrades for low-income households and rental properties.

Tariffed OBF programs have been successfully implemented in eight states by 18 utilities, including investor owned, cooperative, and municipal utilities. More than $30 million has been invested in energy efficiency and renewable upgrades at 5,000 locations. State examples include the Town of Windsor and the City of Hayward.

Windsor, CA
The Town of Windsor's Windsor Energy PAYS® program allows residents and businesses to finance water and energy saving upgrades with no up-front cost and immediate savings on utility bills. Average customer savings amount to $30 per utility bill, 10% reduction in energy use, and 20% reduction in indoor water use, generating estimated annual savings of 9.2 million gallons of water, 88,000 kWh, and 25,000 therms. This program was funded by a $665,000 grant from the U.S. Department of Energy BetterBuildings Neighborhood Program given to the Sonoma County Regional Climate Protection Authority (RCPA) for an on-water-bill financing pilot.

Hayward, CA

The City of Hayward's Green Hayward PAYS® program allows multifamily property owners to get immediate savings on their water and energy utility bills by installing efficiency improvements with no up-front cost.

Opportunities

City of Fresno

Tariffs for DACs

The City can work with PG&E to create a On-Bill Financing tariff focused on disadvantaged communities. Census tract data can be utilized to determine the eligibility of specific areas within Fresno. The potential tariff could be applied to single family and multi-family residences with a shared electrical infrastructure.

City Pilot Program

The City of Fresno can apply to grant funding to launch a municipal led Tariffed OBF pilot program similar to those seen in the Town of Windsor and the City of Hayward. If a pilot program were to occur, prioritizing households already qualified for Low-to-Moderate Income (LMI) programs can ensure accessibility.

Potential CCA Services

If the City of Fresno moves forward with joining a Community Choice Aggregate (CCA), providing Tariffed OBF as a service can help ensure accessibility to energy efficiency services.

Regional Agency

Regional Pilot Program

A regional agency such as San Joaquin Valley Clean Energy Organization may apply to larger sources of funding such as the Federal Department of Energy to offer pilot funding for Tariffed OBF programs in their territory.

- Sonoma County Regional Climate Protection Authority (RCPA) offered financing for OBF pilots to all of their member jurisdictions.
- San Joaquin Valley Clean Energy Organization currently offers Technical Assistance on OBF to its members in either SCE or PG&E territory.

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX D1:
Integrated Building Modeling Assumptions

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APPENDIX D1: Integrated building modeling assumptions

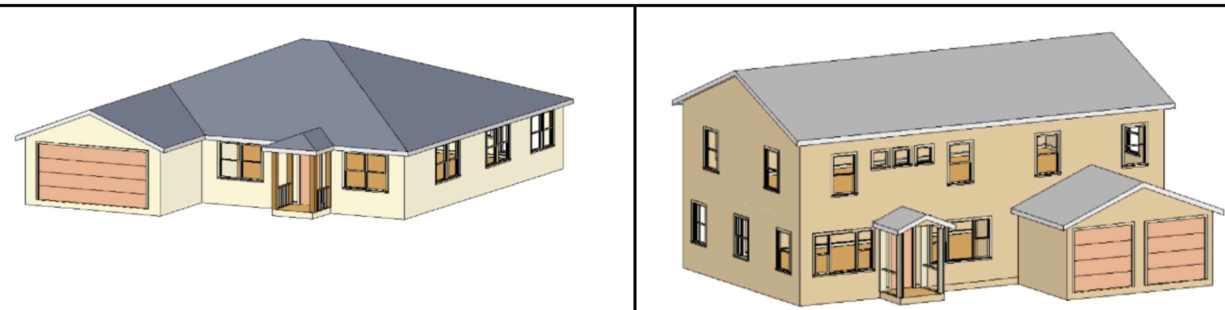
1.1. Baseline Model Definition

In the selected DAC neighborhoods, more than 95% of the buildings are single-family homes and low-rise multi-family homes. Therefore, we focus mainly on the modeling of residential buildings in this study.

The prototype models are designed to represent existing buildings and were calibrated in terms of energy usage based on CBECC-RES[1] (California compliance software for the residential buildings) and IECC (International Energy Conservation Code) prototype models. For the district scale modeling, the prototype models were modified to reflect the actual floor area of each building in the building stock and our best estimates of in-place equipment.

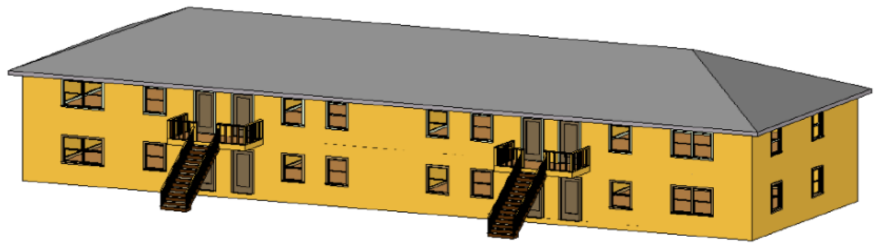
There are three major types of residential buildings in the studied neighborhoods: one-story single-family homes, two (or more) story single-family homes, and low-rise multi-family homes. Their geometries are based on the California Title 24 Alternative Calculation Method (ACM) (California Energy Commission, 2016a), as shown in Figure D1-1. The one-story and two (or more)-story single-family homes are both assumed to have pitched roofs, an unconditioned attic under the roof, and an unconditioned ground-level garage that is attached to the living zone. Low-rise multi-family buildings have pitched roofs and unconditioned attics, but do not have attached garages.

Figure D1-1. Illustrative 3D geometry of three types of residential buildings from Title 24 ACM



(a) One-story single-family house	(b) Two-story single-family house

[1] CBECC-Res is a free computer program developed by the California Energy Commission for use in demonstrating compliance with the California Residential Building Energy Efficiency Standards [https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency-2].



(c) Low-rise multi-family building

The 1-story single family house is modeled as a single conditioned thermal zone. The 2-story single family house is modeled as two thermal zones, one for the first/bottom floor and the other for the second/upper floor. Each apartment unit of the multi-family building is modeled as a thermal zone. The attic and garage are modeled as unconditioned spaces.

The envelope properties, internal loads, and HVAC efficiencies are derived from Title 24 minimum efficiency requirements, as shown in Table D1-1. Buildings constructed in different years are assumed to comply with Title 24 energy efficiency standards of the corresponding vintages (Title 24 is updated every three years, (California Energy Commission, 2016b)). For buildings constructed before California building energy codes were developed, i.e. before 1978, it is not uncommon that some buildings have been retrofitted to improve the thermal performance by adding insulation to top-floor ceiling and/or exterior walls. Therefore, two scenarios are assumed for the prototype buildings constructed before building codes: (1) no retrofit has been done, (2) building has been retrofitted with ceiling and wall insulations added. The insulation values in the first scenario are based on 2019 Title 24 Residential Compliance Manual (California Energy Commission, 2018b), while those in the second scenario are based on energy audits and site surveys to the local communities in Fresno (Fresno Economic Opportunities Commission, 2020; Fresno Housing Authority, 2020; Mazur-Stommen and Gilbert, 2020). On the district scale, we assume that the percentage of pre-1978 buildings with both upgraded ceiling insulation and wall insulation is 10%, and that with only upgraded ceiling insulation is 6%, according to local energy audits and surveys in the Fresno DACs.

According to the Fresno Economic Opportunities Commission (EOC), which conducts energy audits and weatherization in Fresno, the most commonly used types of air conditioning systems in the Fresno DACs are evaporative coolers, window air conditioners, and central air conditioners. Evaporative coolers, sometimes called “swamp” coolers, cool outdoor air by passing it over water-saturated pads, drawing sensible heat from the air to evaporate the water (U.S. Department of Energy, 2020a). We assume homes using evaporative coolers are ducted systems. They are most suitable for areas with low humidity as evaporating water into the air provides a natural and energy-efficient means of cooling. Window air conditioners cool individual rooms rather than the entire home (U.S. Department of Energy, 2020b). Central air conditioners, comprising an outdoor condenser and compressor, an indoor evaporator coil, and supply fan, circulate cool air through a system of supply and return ducts. Supply ducts and registers (i.e., openings in the walls, floors, or ceilings covered by grills) carry cooled air from the air conditioner to the home. This cooled air becomes warmer as it circulates through the home, then flows back to the central air conditioner through return registers and ducts (U.S. Department of Energy, 2020c). In residential buildings constructed before 1978 in the Fresno DACs, our estimates of the proportions of the homes using evaporative coolers, window air conditioners, and central air conditioners are 25%, 50%, and 25% respectively for single-family homes, and 25%, 25%, and 50% respectively for multi-family homes (one per unit). Nearly all buildings constructed after 1978 are equipped with central air conditioners. We assume that each building equipped with window AC and swamp cooler uses natural gas fired wall heaters for space heating, and the buildings equipped with central air conditioners use gas furnaces for central space heating. These estimates are based on surveys and focus groups conducted by researchers in the project team (Mazur-Stommen and Gilbert, 2020), and inputs from two knowledgeable community stakeholder groups in the Fresno area (Fresno Economic Opportunities Commission, 2020; Fresno Housing Authority, 2020).

We assume that refrigerant leakage and coil fouling reduce the capacity and efficiency of each HVAC system over time. To capture these effects, we assume a degradation factor of 2% per year for both the cooling capacity and cooling efficiency (coefficient of performance, abbreviated COP) of the cooling equipment. We chose the average maintenance frequency according to review of the literature (Fenaughty and Parker, 2018; Hendron, 2006). Based on a maximum HVAC system service life of 20 years (Althoff, 2020, p. 20; Princeton Air, 2019), buildings constructed over 20 years ago should already have replaced their HVAC systems at least once; therefore, we assign an HVAC system age of 10 years. Otherwise, the HVAC system age is assumed to be the same as the building age. The HVAC degradation may lead to insufficient cooling supply during extreme heat events, which will cause the indoor air temperature to exceed the thermal comfort range.

Per the Fresno EOC, the overwhelming majority of homes use natural-gas storage water heaters for domestic hot water as with most of the state's homes and because natural gas is less expensive than electricity in California. Each single-family home and each unit in the multi-family building is equipped with its own water heater.

Table D1-1. Key assumptions of the baseline models of the three studied vintages (single-story single-family home as example)

Property	1976	2004	2015
Gross floor area [m²]	236		
Conditioned floor area [m²]	195		
Window-to-wall ratio [-]	Non-north: 0.288; North: 0.2		
Roof area [m²]	303		
Wall assembly U-factor [W/m²·K]	No Retrofit: 2.02 Retrofitted: 0.58	0.42	0.37
Wall cavity insulation [m²·K/W]	No Retrofit: R0 Retrofitted: R2.29	R3.35	R2.64 cavity + R0.70 continuous
Top-floor ceiling cavity insulation [m²·K/W]	No Retrofit: R1.94 Retrofitted: R5.28	R6.69	R6.69
Window thermal transmittance [W/m²·K]	3.69	3.69	1.82
Window SHGC [-]	0.4	0.4	0.25

Property	1976	2004	2015
Cooling equipment efficiency (considering replacement and degradation)			
Central AC: COP [-]	2.63	2.19	2.96
Window AC: COP [-]	2.63	2.19	2.96
Swamp cooler: Cooling saturation efficiency [%]	69.5	61.5	76.8
Gas furnace efficiency [-]	0.78	0.8	0.8
Gas water heater efficiency [-]	0.72	0.8	0.82
Lighting power density [W/m²]	6.25	3.07	1.95
Plug load power density [W/m²]	7.91	7.91	7.91

Title 24 requirements for air changes per hour (ACH) at a pressure difference of 50 Pa (ACH_{50}) in residential buildings can be converted to ACH under a natural pressure difference of 4 Pa (ACH_4) via Eq. (1):

$$ACH_4 = ACH_{50} \times \left(\frac{4}{50}\right)^n \quad (1)$$

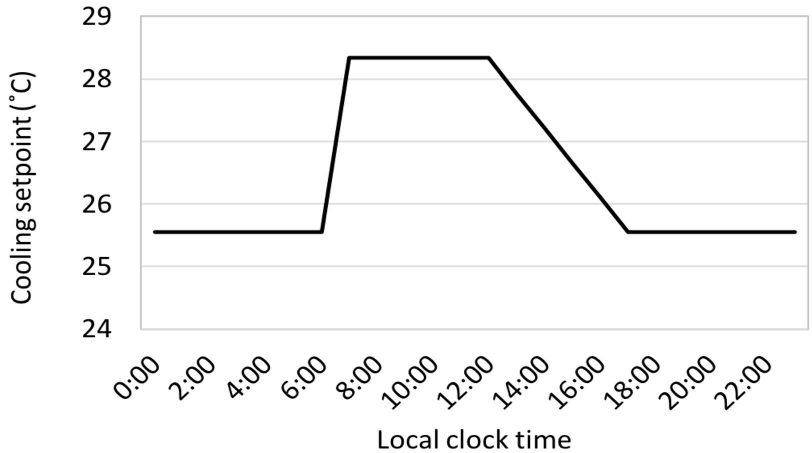
Here exponent n is based on the characteristic shape of the orifices of the building, and ranges from 0.5 (perfect orifice) to 1.0 (very long and thin crack). We assume $n = 0.75$, yielding the air-change rates shown in Table D1-2.

Table D1-2. Infiltration rates (ACH_4) for single- and multi-family homes by year of construction, extrapolated from Title 24 specifications of ACH50

Year of construction	Air changes per hour at 4 Pa (ACH_4) in a single-family home	Air changes per hour at 4 Pa (ACH_4) in a multi-family home
Before 2005	1.29	1.45
2006 to 2013	1.00	1.12
2014 to present	0.75	1.05

The cooling setpoint adopts the assumption from the Title 24 residential ACM (California Energy Commission, 2016a). It is set to a constant value of 25.6 °C during the weekend. The setpoint schedule on the weekdays is shown in Figure D1-2, assuming the occupants are not at home during the daytime.

Figure D1-2. Residential cooling setpoint schedule on weekdays

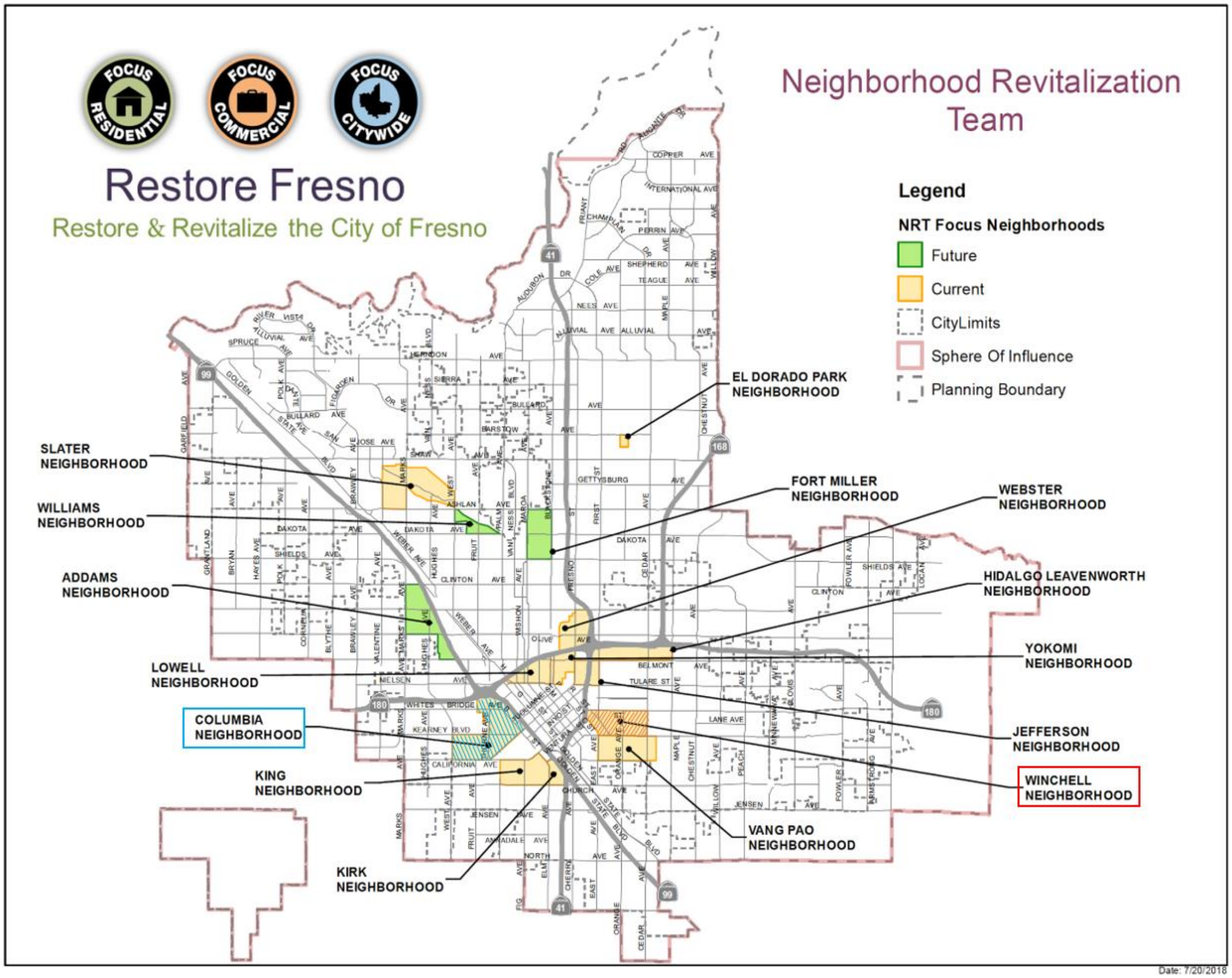


For schedules related to internal loads, the lighting schedule and the plug load schedule are from the 2019 Title 24 prototype model in CBECC-RES, while the occupancy schedule is the BEopt default for the residential buildings. BEopt (Building Energy Optimization Tool) is a free software developed by National Renewable Energy Laboratory that provides capabilities to evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy (National Renewable Energy Laboratory, 2018). The number of occupants is calculated from the number of bedrooms based on the BEopt default, and the number of bedrooms is estimated based on the floor area of the home from the Residential Energy Consumption Survey (RECS) 2015 data (U.S. Energy Information Administration, 2015). RECS is a multi-year effort led by the U.S. Energy Information Administration, consisting of a household survey phase, data collection from household energy suppliers, and end-use consumption and expenditures estimation (U.S. Energy Information Administration, 2020).

1.2. Buildings dataset development

The Columbia and Winchell neighborhoods are selected as the study DAC districts for this project (shown in Figure D1-3) as representative neighborhood that are also areas proposed by the City of Fresno for neighborhood revitalization.

Figure D1-3. Map of neighborhoods in Fresno

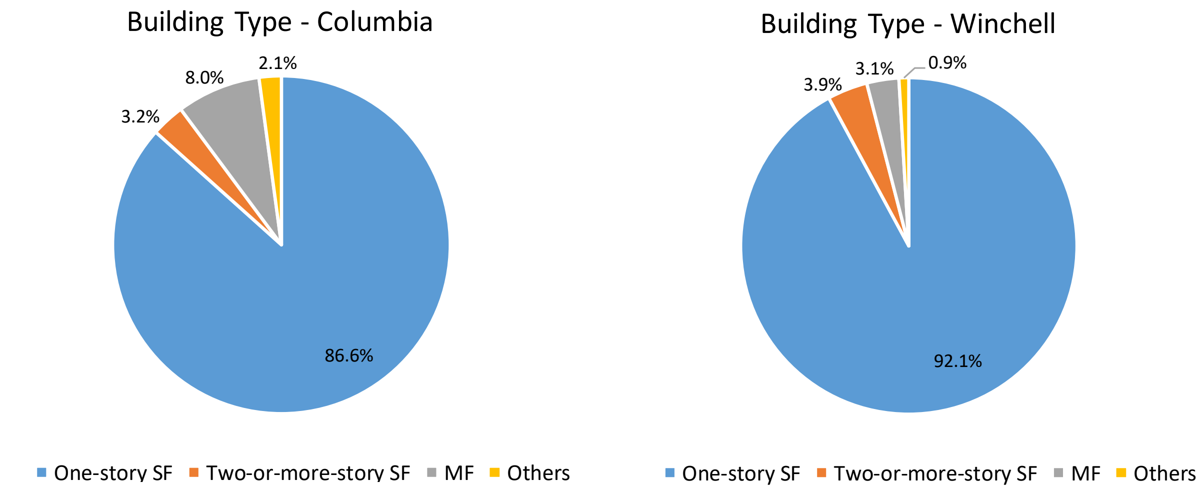


The target neighborhoods Columbia and Winchell are highlighted in blue and red respectively.

Building properties are collected from several sources for creating the dataset to be used in CityBES, and include the building footprints, use type, height, number of stories, and the year of built. The building footprints are extracted from the Microsoft Building Footprint database (Microsoft, 2019) with the boundaries of the neighborhoods, and year of built, use type, and number of stories are mainly from query results using the Atom API. We did not locate a valid data source for the height of the buildings, so we assumed a height of 3m per floor for all the buildings.

1406 buildings and 1166 buildings are collected for Columbia and Winchell districts, respectively. Figures D1-4 through D1-6 show the distribution of residential building types. The majority of the buildings in these two districts are one-story single-family homes. There are more multi-family homes in Columbia than in Winchell. More than 95% of buildings in the Winchell district are single-family homes.

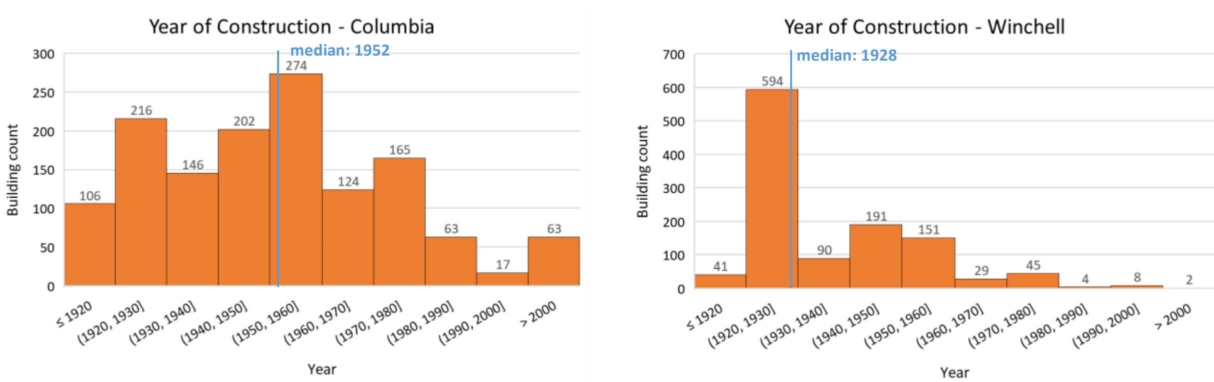
Figure D1-4. The distribution of building types for (a) Columbia neighborhood and (b) Winchell neighborhood



(a) (b)

As for the building vintage, most of the residential buildings in Winchell were built between 1920-1930, while in Columbia, the building vintages spread more evenly between 1920 to 1980 and there are more old residential homes built before 1920.

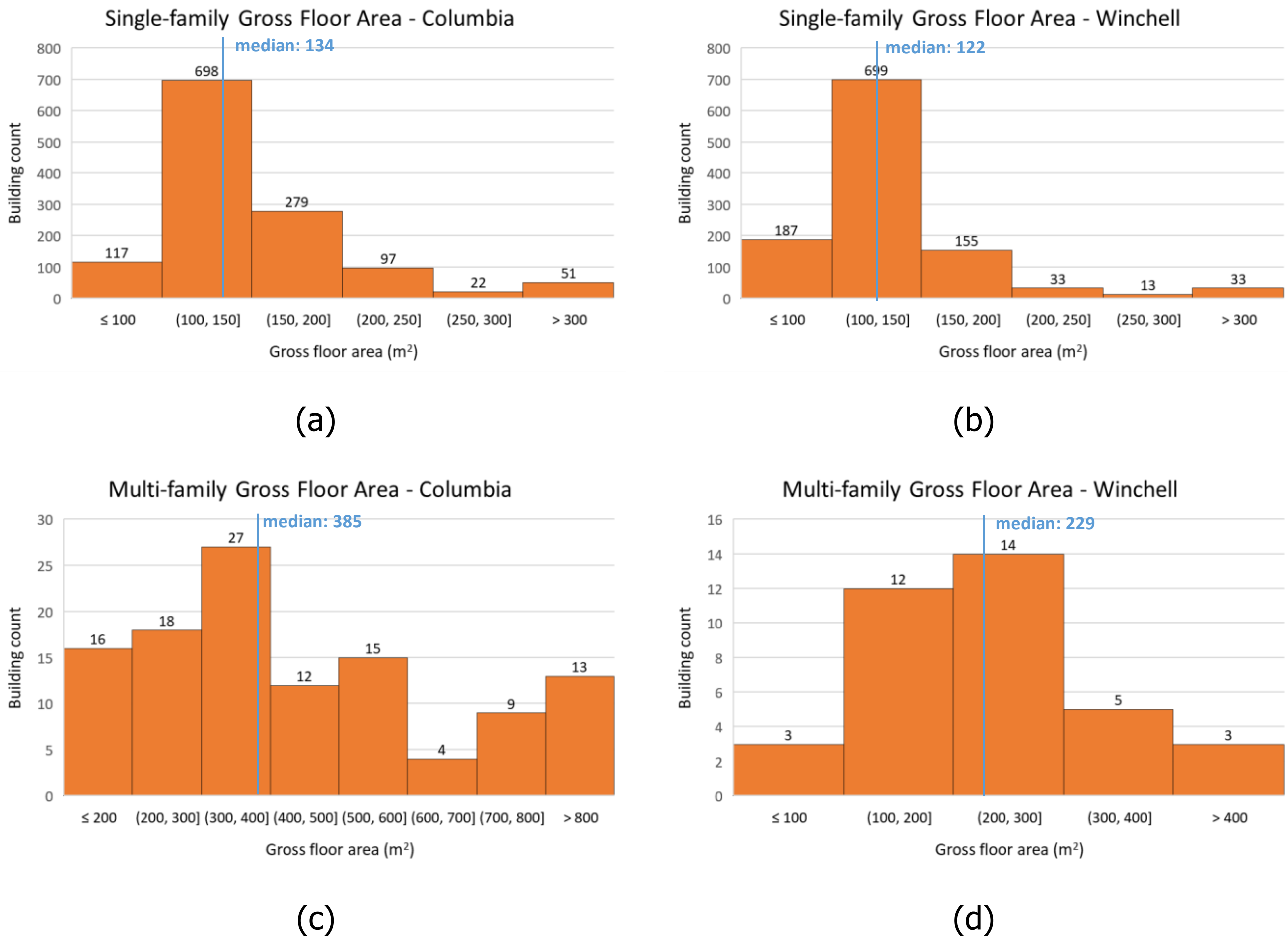
Figure D1-5. The distribution of residential building vintages for (a) Columbia neighborhood and (b) Winchell neighborhood



(a) (b)

The distributions of the gross floor area of single-family buildings in these two districts are pretty similar. Most of the buildings fall into the range of 50-250 m^2 (538-2691 ft^2). For multi-family homes, Columbia has more large multi-family buildings than Winchell. The median size of the multi-family homes is also much larger than that of Winchell.

Figure D1-6. The distribution of residential building gross floor area for (a) single-family homes in Columbia neighborhood, (b) single-family homes in Winchell neighborhood, (c) multi-family homes in Columbia neighborhood and (d) multi-family homes in Winchell neighborhood



Based on the research team's survey conducted in the city of Fresno, buildings built before 1978 are equipped with various HVAC system types apart from our universal assumptions of the residential prototypes as the central split system. For single-family buildings, around 50% use window ACs and 25% use swamp coolers, while for the multi-family buildings, around 25% use window ACs and 25% use swamp coolers. Others use the central split system. Window AC and swamp coolers are coupled with gas furnace wall heaters, and central split system uses centralized gas furnace as the heating source. Hence, we randomly sample the buildings in the datasets to change their HVAC system types based on this distribution.

1.3. Evaluation of energy efficiency measures

A total of 22 energy efficiency measures (EEMs) were selected and modeled in this study, which cover (a) space cooling and heating improvement, such as upgrading to an air-source heat pump or mini-split heat pump system from gas-based heating, or efficiency upgrade of gas furnace; (b) domestic hot water system replacement, such as efficiency upgrade of gas storage water heater, improving water tank insulation, and fuel switching (and efficiency upgrade) to an electric storage heat pump water heater; (c) envelope performance improvement, such as adding wall insulation, adding window film, and adding air sealing to seal any leaks in the building's exterior surfaces; (d) increasing air circulation, such as adding ceiling fan, adding portable fan, and adding attic fan; (e) lighting system improvement, such as replacing existing lighting with LED fixtures; (f) improving operation and maintenance, such as reducing duct leakage; and (g) replacing gasoline vehicles with electric vehicles. More detailed information on EEMs, modeling assumptions and methods are described in Section 1.7.

The goal of EEM evaluation is to figure out the top performing EEMs and EEM packages that can maximize energy savings, maximize energy cost savings, minimize CO_2 emissions, or minimize payback period. The payback is calculated by dividing the total investment cost by annual energy cost savings. The DAC dataset developed in Section 1.2 was used to create baseline models for the building stock in CityBES. The baseline models were then applied with selected EEMs from Section 1.3 individually, and their effectiveness was evaluated and ranked according to the goals above. The EEMs were then combined as packages based on their categories and performance. The packages were further modeled and analyzed. For different performance goals, different packages were selected as appropriate. Typical meteorological year (TMY) weather data is used in EnergyPlus simulations for EEM evaluation.

The CO_2 emission factor for electricity is 420.4 lbs CO_2/MWh in California (190.7 kg CO_2/MWh), based on the Emissions & Generation Resource Integrated Database (eGRID) (U.S. Environmental Protection Agency, 2018) and for natural gas is 399.5 lbs CO_2/MWh (181.3 kg CO_2/MWh). With SB100 legislation, electricity emissions factors are decreasing with time so our CO_2 emissions savings are a lower bound on lifetime savings.

1.4. Electrification

We explored the viable pathways towards electrification by evaluating the performance and cost-effectiveness of electrification measures. Out of the above 22 EEMs, four measures were selected and evaluated for the fuel switching purpose: (1) upgrade to an air-source heat pump system; (2) upgrade to mini-split heat pump system; (3) upgrade to heat pump water heater; (4) replace internal combustion-based passenger vehicle with electric vehicle. The electric vehicle measure is discussed in detail in 2.4.1.

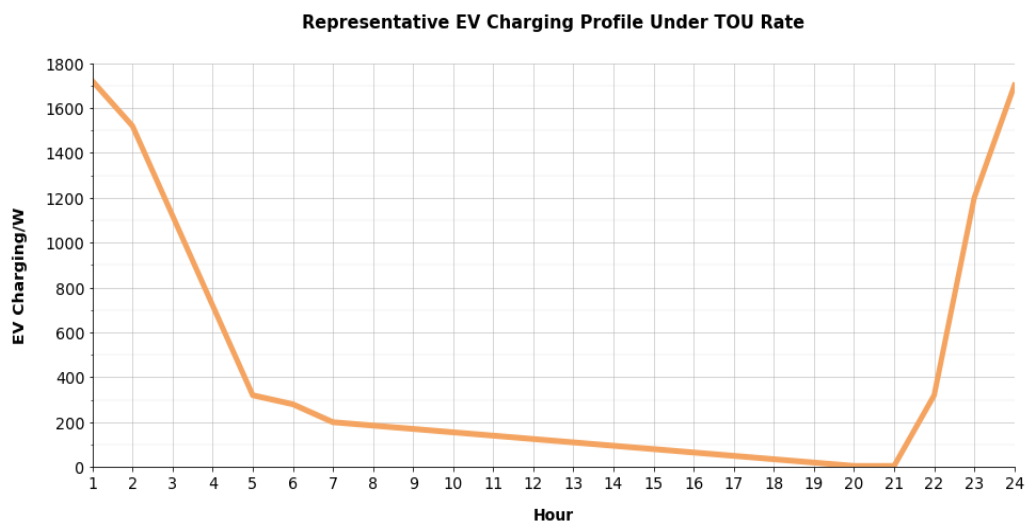
We also analyzed the incremental cost of electrification measures over the traditional weatherization programs, which generally do like-for-like retrofits at the end of equipment service life. The goal is to understand how much more the residents and policy makers need to invest to adopt clean energy and if there are additional energy savings.

1.4.1. Electric vehicles

Szinai et al. from Lawrence Berkeley National Lab modeled the added grid load under different EV adoption rates and charging scenarios (Szinai et al., 2020). We referred to the simulation results of 2.5 million EV adoption scenario (median adoption rate assumption) and adopted the modeled EV charging profile under the time-of-use (TOU) scenario in our study, as shown in Figure D1-7. This is compatible with the PG&E utility rates. We also compiled individual vehicle charging profiles based on the same underlying source, EVI-Pro from NREL, but those profiles generally showed charging starting around 4:30 pm which would correspond to peak time rates, so we chose to adopt the charging profile in Figure D1-7. A more aggressive scenario would shift to the PG&E EV rate and EV charging at periods of minimum electricity prices between 12am and 3pm.

Other related assumptions include the annual mileage, fuel car efficiency (mile per gallon or MPG), and gasoline price. According to the statistical data of the U.S. Department of Transportation, the annual mileage per vehicle in the Fresno Columbia and Winchell districts is 9000 (U.S. Department of Transportation, 2021a). The survey data in the Fresno local communities indicate that the median car age is 13 years. Based on prior research by Lawrence Berkeley National Lab, the average fuel efficiency for 2007 new cars in California is 22.2 mpg (Wei et al., 2012). We assume a 5% degradation in fuel efficiency over 13 years (since 2007) due to poor maintenance, and arrived at 21 mpg as the fuel efficiency assumption for the existing gasoline vehicles. Considering that the vehicles in the DAC areas tend to be older than other communities, this assumption is consistent with the statistical data from the U.S. Department of Transportation, which shows the national average light duty vehicle fuel efficiency is 22.3 mpg in 2017 (U.S. Department of Transportation, 2021b). The gasoline retail price in California during the last three years (2018-2020) is estimated at $3.40 per gallon per U.S. Energy Information Administration (U.S. Energy Information Administration, 2021a). This value is relatively low compared with historical data (U.S. Energy Information Administration, 2021b) and with worldwide gasoline prices (GlobalPetrolPrices.com, 2021). In fact, the average price per gallon of gasoline is Fresno was climbing toward $6 in early May 2022 (https://www.autoblog.com/fresno-ca-gas-prices/), and our quoted fuel savings from vehicle electrification may be a low-end estimate if these high prices persist.

Figure D1-7. Typical daily EV charging profile under the TOU rate



1.4.2. Incremental cost analysis

The incremental cost of an electrification measure is defined as the investment cost difference between this measure and the basic like-for-like retrofit measure. Like-for-like retrofit mostly happens in the end of the equipment service life to maintain the basic functionality.

For example, in a building equipped with window AC system, when the window AC reaches the end of its service life, a basic like-for-like retrofit normally just replaces the old equipment with a new window AC, while for the electrification scenario, a new heat pump system might be installed, and the investment cost difference between these two types of retrofits is the incremental cost of the heat pump measure. Similarly, incremental energy savings and energy cost savings, and incremental payback years are also evaluated. Incremental payback is calculated by dividing incremental investment cost by annual incremental energy cost savings, which is different from payback definition based on the upfront cost of the energy efficiency measure.

We modeled each like-for-like upgrade and electrification measure and analyzed the incremental cost for individual measures, then combined HVAC and DHW measures as packages and analyzed the incremental cost for retrofit packages. The modeling scenarios for packages are illustrated in Table D1-3 below. The efficiency assumptions of baselines and all measures are listed in Table D1-5.

Table D1-3. Modeling scenarios for like-for-like and electrification packages' incremental cost analysis

Baseline		Like-for-like upgrade		Electrification package 1	Electrification package 2
HVAC	DHW	HVAC	DHW		
Swamp cooler + wall heater	Gas storage water heater	Swamp cooler + wall heater efficiency upgrade	Gas storage water heater efficiency upgrade	Air-source heat pump + heat pump water heater	Mini-split heat pump + heat pump water heater
Window AC + wall heater		Window AC + wall heater efficiency upgrade			
Central AC + furnace		Residential central AC efficiency upgrade			

1.5. ZNE analysis

We evaluated the ZNE potential of the DAC districts by assuming additions of rooftop PV systems to their buildings and integrating them with energy retrofit measures. Three scenarios of building conditions are analyzed: baseline with no retrofits, energy saving retrofit package, and electrification package. Two PV roof coverage scenarios, 15% and 30% of the gross roof area, are considered to estimate the PV capacity requirement to reach ZNE. The modeling scenarios are summarized in Table D1-4. We assume that the homes are roof-ready in that no further roof repair is required to install solar PV.

Table D1-4. ZNE analysis scenarios

Scenarios	Measures	Sensitivity cases (Pct. of roof area covered by solar PV)
Baseline	Baseline HVAC, Baseline Domestic hot water	PV 0% (no PV)
		PV 15%
		PV 30%

Scenarios	Measures	Sensitivity cases (Pct. of roof area covered by solar PV)
Energy saving retrofit	Mini-Split Heat Pump, Heat Pump Water Heater, LED, Roof Insulation, Wall Insulation, Interior Storm Window, Window Film	PV 0%
		PV 15%
		PV 30%
Electrification	Mini-Split Heat Pump, Heat Pump Water Heater, Electric Vehicle	PV 0%
		PV 15%
		PV 30%

In this ZNE analysis, we adopted the PG&E's Net Energy Metering 2.0 Policy (NEM 2.0 Policy), which is a residential solar PV tariff policy that helps reduce customers' monthly electric bill by generating their own electricity through a private solar rooftop energy system (Pacific Gas and Electric Company, 2021a). The NEM program calculates the net electricity and utility bill for each customer. The value for net electricity is obtained by subtracting electricity consumed from electricity produced. If the value of electricity produced is larger than electricity consumed, the generated electricity surplus is sold back to the grid and customers will have credit for their utility bill. On the other hand, if the value of electricity consumed is larger than electricity produced, electricity not provided by PV is purchased from the grid as usual with the normal rate and customers will have to pay for their utility bill.

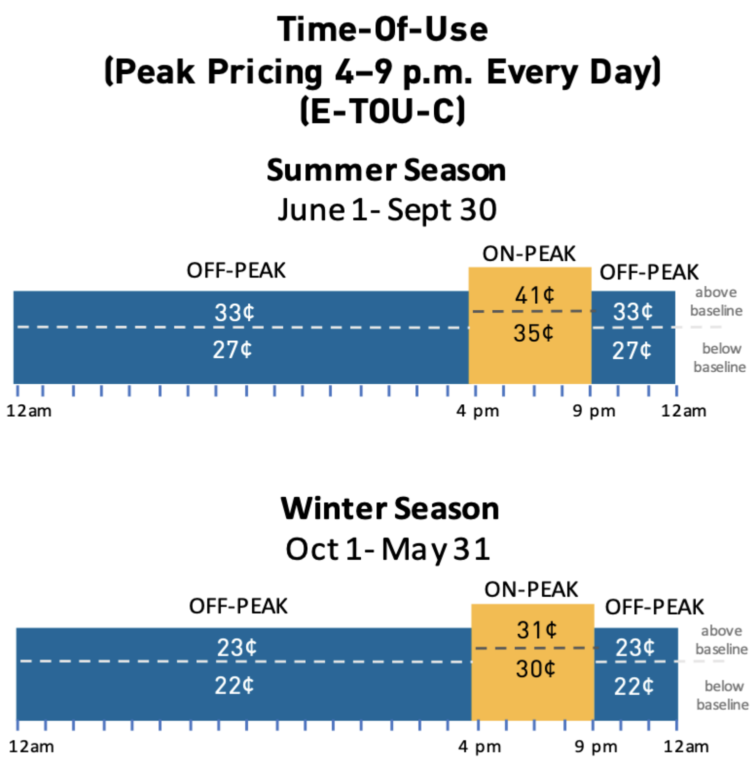
The NEM Program uses the 12-month billing cycle in which each customer will receive a monthly statement that specifies the amount due from the monthly delivery charges and monthly NEM charges (or credit). The monthly delivery charge is $10 for general users, and $5 for PG&E's CARE (California Alternate Rates for Energy) program users (Pacific Gas and Electric Company, 2021b). We are using the latter for this analysis as most residents in the DAC neighborhoods qualify for the CARE program. At the end of each 12-month billing cycle, customers will receive an annual statement called True-Up statement that reports the net energy charges or credit for the entire year. The balance remaining in the report is the amount due that customers need to pay. Bill credit that accumulates in any given month can offset the charges in other months. Any balance surplus electricity generation in the True-Up statement is sold back at Net Surplus Compensation (NSC) rate rather than retail rate. The NSC rate is set based on a 12-month rolling average of energy retail rate, which is approximately $0.02 - $0.03 per kWh (Pacific Gas and Electric Company, 2021a). For this ZNE analysis, we are using the average NSC value from 2019 from PG&E at $0.033521 per kWh. Additionally, at the beginning of the NEM program, customers are also required to pay a one-time interconnection fee of $145 for PG&E utility.

1.6. Time-of-use rate

Throughout all our simulations and analyses, Time-Of-Use Rates (TOU Rate) from PG&E are used for calculating the electricity cost (Pacific Gas and Electric Company, 2021c). This rate plan calculates energy cost based on the time the energy is used. The utility rate is higher during peak hours than non-peak hours. Ultimately, customers who adopt the TOU rate plan can shift their energy use from peak hours to non-peak hours to reduce their utility bill and save money. Therefore, the TOU rates encourage the most efficient use of the system and can reduce the overall costs for both the utility and customers.

There are two different TOU Rates adopted for the analyses: E-TOU-C (Pacific Gas and Electric Company, 2021d) and EV2-A rate (Pacific Gas and Electric Company, 2021e). For the E-TOU-C rate plan, energy is charged at a higher price (peak pricing) between 4 – 9 p.m., while the price is lower (off-peak) beyond that period. The E-TOU-C rate plan uses pricing tiers to bill the customers' electricity usage. The lowest pricing tier is called the baseline allowance where electricity is charged at a lower price. However, when the accumulated electricity usage on a monthly basis has surpassed the baseline allowance, the electricity is charged at a more expensive price. This information is illustrated in Figure D1-8, where the cost of electricity varies depending on the time of use, baseline allowance, and season.

Figure D1-8. PG&E's E-TOU-C rate plan



Baseline allowance varies with the regions where customers live (Baseline Territory, Figure D1-9). Different Baseline Territories have different sets of daily amount limits (Table D1-5), which need to be multiplied by the number of billing days in a month to obtain the customers' monthly baseline allowances. The daily amount within each Baseline Territory also differs according to the heating system. The "Basic Electric" daily amount is used if the homes do not have any permanently installed electric heating system, while the "All Electric" daily amount is used if the homes include a permanently installed electric heating system. In our simulations, we used the Baseline Territory R where the city of Fresno is located, which has the "Basic Electric" daily amount of 18.6 kWh in summer and 11.3 kWh in winter and the "All Electric" daily amount of 20.9 kWh in summer and 28.1 kWh in winter. The "Basic Electric" E-TOU-C plan is used in majority of our simulations, while the "All Electric" E-TOU-C plan is used for simulations that involve electrification of the HVAC system with measures like air-source heat pump or mini-split heat pump.

Figure D1-9. PG&E's baseline territory to determine baseline allowance for E-TOU-C rate plan

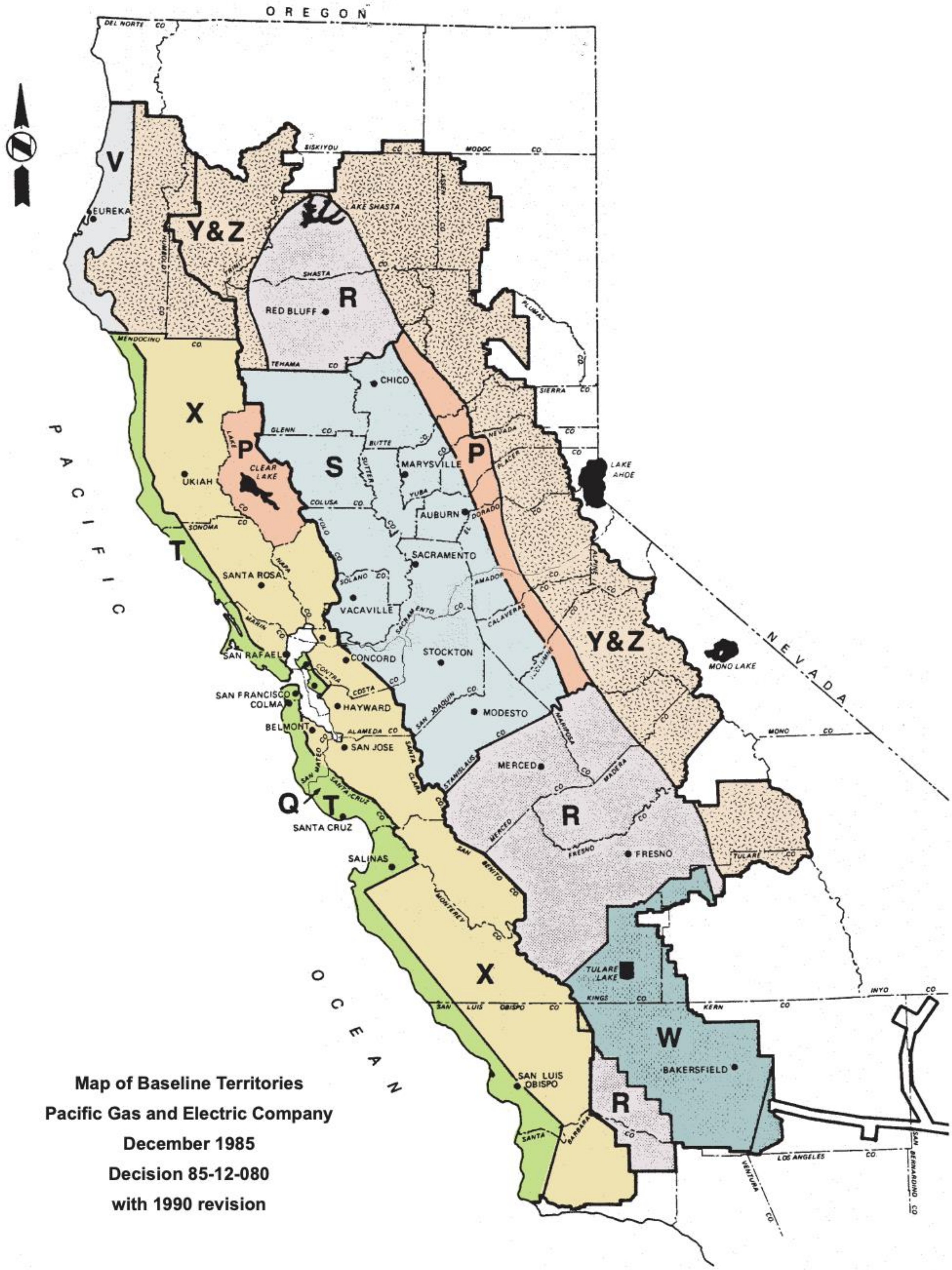


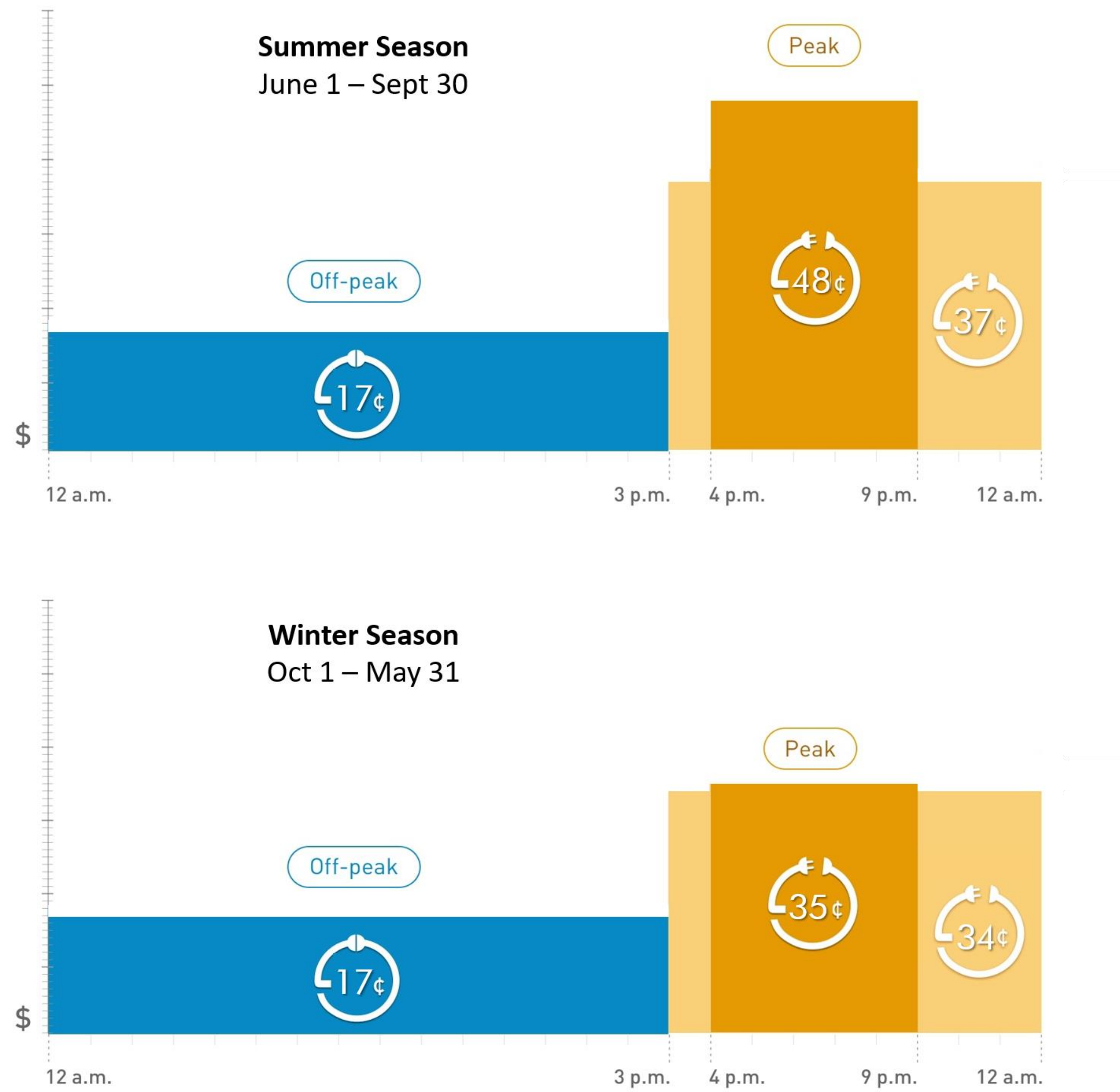
Table D1-5. Baseline Allowances for E-TOU-C Rate Plan

TERRITORY	TIERED-RATE (E1) or TIME-OF-USE (Peak Pricing 3-8 p.m. Weekdays Peak Pricing 4-9 p.m. Every day)		TIME-OF-USE (E6)		GAS
	S Summer: Jun 1 - Sep 30 W Winter: Oct 1 - May 31		S Summer: May 1 - Oct 31 W Winter: Nov 1 - Apr 30		S Summer: Apr 1 - Oct 31 WOP Winter Off Peak: Nov 1 - Nov 30, Feb 1 - Mar 31 WP Winter Peak: Dec 1 - Jan 31
	Basic Electric	All Electric	Basic Electric	All Electric	Residential Gas Service
P	S: 14.2 W: 12.0	S: 16.0 W: 27.4	S: 13.0 W: 12.5	S: 15.2 W: 29.2	S: 0.39 WOP: 1.88 WP: 2.16
Q	S: 10.3 W: 12.0	S: 8.9 W: 27.4	S: 9.9 W: 12.5	S: 8.7 W: 29.2	S: 0.59 WOP: 1.55 WP: 2.16
R	S: 18.6 W: 11.3	S: 20.9 W: 28.1	S: 16.5 W: 11.1	S: 19.2 W: 29.4	S: 0.36 WOP: 1.28 WP: 1.97
S	S: 15.8 W: 11.1	S: 18.7 W: 24.9	S: 14.3 W: 11.1	S: 17.3 W: 26.3	S: 0.39 WOP: 1.38 WP: 2.06
T	S: 6.8 W: 8.2	S: 7.5 W: 13.6	S: 6.8 W: 8.4	S: 7.7 W: 14.4	S: 0.59 WOP: 1.38 WP: 1.81
V	S: 7.5 W: 8.8	S: 10.9 W: 16.9	S: 7.6 W: 9.2	S: 11.2 W: 18.5	S: 0.62 WOP: 1.51 WP: 1.84
W	S: 20.2 W: 10.7	S: 23.6 W: 20.0	S: 17.8 W: 10.1	S: 21.1 W: 19.9	S: 0.39 WOP: 1.18 WP: 1.84
X	S: 10.3 W: 10.5	S: 8.9 W: 15.4	S: 9.9 W: 10.7	S: 8.8 W: 16.2	S: 0.49 WOP: 1.55 WP: 2.16
Y	S: 11.0 W: 12.1	S: 12.6 W: 25.3	S: 10.7 W: 12.7	S: 12.6 W: 26.8	S: 0.69 WOP: 2.15 WP: 2.65
Z	S: 6.2 W: 8.1	S: 7.0 W: 16.5	S: 6.1 W: 8.9	S: 7.0 W: 18.0	

Aside from E-TOU-C, we also used the EV2-A TOU rate, which is an electric vehicle rate plan for the residential buildings. The EV2-A plan categorizes the time of use pricings into three tiers: peak, partial peak, and off peak. The peak pricing occurs during 4-9 pm just like the E-TOU-C. However, the off-peak pricing only spans between 12am and 3pm in which the electricity cost is at its lowest price. Between those two periods, there is the partial peak pricing during 3-4pm and 9pm-12am. During this partial peak time period, the electricity cost is between the highest and lowest price. Aside from the time of use, the electricity cost also differs between seasons: higher in the summer and lower in the winter, as illustrated in Figure D1-10. Unlike E-TOU-C, the EV2-A rate plan does not include the baseline allowance thresholds. The EV2-A rate plan is used specifically in our simulations that include the electric vehicle measure.

For both E-TOU-C and EV2-A plans, there is also a monthly electricity delivery fee. It is $10 for general users and $5 for the CARE program users. The latter is adopted in this analysis for DACs.

Figure D1-10. PG&E's EV2-A rate plan



The natural gas price in the TOU plan also has two tiers, differentiated by the baseline allowances defined in Table D1-5. The natural gas rate varies slightly from month to month. For simplification, we adopted the annual average from 2020 in simulation, which is $1.46/therm within the baseline allowance and $1.99/therm for beyond (Pacific Gas and Electric Company, 2021f).

We also note that the CARE program provides at least 20% discount on the electricity and natural gas bill (Pacific Gas and Electric Company, 2021g). For the two studied DAC neighborhoods, we applied 20% discount on electricity and gas bills.

1.7. Description of EEMs and Modeling Method

A total of 22 EEMs are selected for modeling and analysis in this study. This section describes basic assumptions, key inputs, and modeling methods of each EEM. The key assumptions and cost information related to each EEM are summarized in Table D1-6. The EEM costs are mostly based on Homewyse, which is a vendor-neutral, comprehensive online reference for the house and home. Some cost data was also drawn from online home improvement retailers like The Home Depot and Lowe's. Although the research team spent significant efforts on obtaining the cost data for new measures and updating the cost data of existing measures, costs are very dynamic and dependent on many factors such as supply chain issues, fuel costs, and labor availability, among other factors. Thus, these costs are a snapshot, and all results of course will be sensitive to these input assumptions. More details for each EEM are described as follows.

Table D1-6. Summary of key inputs and assumptions of the baseline models and EEMs

Measures	Baseline model assumptions	EEM assumptions	Cost unit	Installed Cost per unit	Capacity[a]
Gas furnace efficiency upgrade	Thermal efficiency: Pre-1978 (majority): 0.78	Thermal efficiency: 0.95	$/kBTU	25.1	
Upgrade to air-source heat pump system	Pre-1978 (majority): Cooling COP: 1.99; Heating efficiency: 0.78	Cooling COP: 3.22 Heating COP: 3.3	$/ton	2789; 2191; 1574[b]	2; 3; 5[b]
Upgrade to mini-split heat pump system	Pre-1978 (majority): Cooling COP: 1.99; Heating efficiency: 0.78	Cooling COP: 3.66 Heating COP: 3.7	$/ton	437*ton + 4962[c]	
Efficiency Upgrade of the Gas Storage Water Heater	Thermal efficiency: Pre-1978 (majority): 0.78	Thermal efficiency: 0.93	$/DHW_gallon	49.3; 32.7[d]	30; 50[d]
Improve Water Tank Insulation	Loss coefficient to ambient temperature: 6W/K	Loss coefficient to ambient temperature: 3.7W/K	$/DHW_tank	86.0	
Upgrade to Electric Storage Water Heater	Gas storage water heater => Thermal efficiency: Pre-1978 (majority): 0.78	Electric storage water heater => Thermal efficiency: 0.95	$/DHW_gallon	71,46[d]	30,50[d]
Upgrade to heat pump water heater	Gas storage water heater => Thermal efficiency: Pre-1978 (majority): 0.78	Heat pump water heater => COP: 3.3	$/DHW_gallon	107.9; 79.5[d]	30; 50[d]
Add Ceiling Fan	Cooling setpoint is 25.56°C when occupied. Indoor air velocity is 0.2m/s	Cooling setpoint raised to 28°C when occupied. Indoor air velocity is raised to 0.8m/s. Extra fan energy use	$/sf	0.821	
Attic fan	Infiltration only in the attic	Extra ventilation from attic fan with air change rate per hour about 10	$	550	
Add portable fan	Cooling setpoint is 25.56°C when occupied. Indoor air velocity is 0.2m/s	Cooling setpoint raised to 28°C when occupied. Indoor air velocity is raised to 0.8m/s. Extra fan energy use	$/person	50	
Add Air Sealing to Seal Leaks	See Section 1.1	30% reduction on baseline infiltration rate	$/sf	1.9	
Add Duct Sealing to Minimize Duct Leakage	Duct leakage rate: 10%	Duct leakage rate: 5%	$/sf	0.18	
Add window film	No window film	Apply window film to the interior surface of the existing window	$/sf window area	7.76	
Add interior storm window	No storm window	Add an interior storm window layer, which is assumed as a 3mm low-e glass	$/sf window area	10.4	

Measures	Baseline model assumptions	EEM assumptions	Cost unit	Installed Cost per unit	Capacity[a]
Add wall insulation	Pre-1978 (majority): wall insulation R8.4	Add insulation layer to wall to reach R-21	$/sf wall area	3.87	
Reroof and Add Roof Insulation	Roof doesn't have insulation layer	Add insulation layer of R-24.83 to roof	$/sf roof area	7.84	
Apply Top Floor Ceiling Insulation	Applicable for buildings built before 1992, whose ceiling has insulation layer of R16.67	Improve the insulation layer to R-38	$/sf ceiling area	2.19	
Replace existing lighting with LED upgrade	See Section 1.1	Replace existing lighting to LEDs with 1.346 W/m2 for the living zone, 0.545 W/m2 for the garage	$/sf	0.60	
Upgrade cooling equipment to window air conditioner	Pre-1978 (majority): Cooling COP: 1.99	Cooling COP: 3.19	$/ton	820	
Residential central AC system cooling efficiency upgrade	Pre-1978 (majority): Cooling COP: 1.99	Cooling COP: 3.28	$/ton	3048; 2315; 1610[b]	2; 3; 5[b]
Swamp cooler efficiency upgrade	Direct saturation efficiency: 85%	Direct saturation efficiency: 95%	$/cfm	0.69; 0.46; 0.38[e]	3000; 5000; 6500[e]
Replace fuel vehicle with used electric vehicle	Gasoline vehicle: Annual mileage: 9000; Mile per gallon: 21 Gasoline price: $3.4/gallon	Electric vehicle: Charging profile see section 2.4.1	$	10,000	

Notes:

[a] Capacity is only applicable if the cost unit is per capacity and cost per unit has multiple stages.

[b] The unit cost is segmented based on cooling capacity. The unit cost is lower with higher capacity. Taking the measure "Upgrade to heat pump system" as an example, the cost unit is "$/ton", the cost per unit is "2663; 2082; 1490", the capacity is "2; 3; 5". This means that the unit cost is 2663 $/ton for capacity ranging from 0 to 2 ton, 2082 $/ton for capacity ranging from 2 to 3 ton, and 1490 $/ton for capacity from 3 to 5 ton and above.

[c] The cost of installing mini-split heat pump was fitted to a linear regression of refrigeration tons based on Homewyse data, i.e., cost = a * tons + b, where a = $437/ton and b = $4962.

[d] The unit cost is segmented based on the water tank storage capacity of the water heaters. The unit cost is lower with higher capacity. Taking the measure "Efficiency Upgrade of the Gas Storage Water Heater" as an example, the cost unit is "$/DHW_gallon", the cost per unit is "47.3; 31.0", the capacity is "30; 50". This means that the unit cost is $47.30 /gallon for water tank storage capacity ranging from 0 to 30 gallons, and $31.0 /gallon for capacity ranging from 30 to 50 gallons and above.

[e] The unit cost is segmented based on the system air flow rate. The unit cost is lower with higher flow rate. Taking the measure "Swamp cooler efficiency upgrade" as an example, the cost unit is "$/cfm", the cost per unit is "0.67; 0.45; 0.36", the capacity is "3000; 5000; 6500". This means that the unit cost is $0.67 /cfm for system air flow rate ranging from 0 to 3000 cfm, $0.45 /cfm for system air flow rate ranging from 3000 to 5000 cfm, and $0.36 /cfm for system air flow rate ranging from 5000 to 6500 cfm and above.

(1) Gas Furnace Efficiency Upgrade

This measure replaces the gas furnace for space heating with a higher efficiency furnace. The original thermal efficiency is 0.78 for pre-1978 baseline models, and the upgraded thermal efficiency is 0.95 for a condensing furnace. This measure aims to reduce the natural gas consumption from space heating. In EnergyPlus, this is modeled via modifying the thermal efficiency input of the gas heating coil.

(2) Upgrade to air source heat pump system

This measure replaces the existing space cooling and heating system with an efficient heat pump system. The pre-1978 baseline models are equipped with three types of cooling systems: evaporative coolers, window air conditioners, and central air conditioners. The space heating system for the first two cooling types is assumed to be a gas-based wall heater, and a gas furnace for the third cooling type.

The heat pump system is simulated by constructing an HVAC air loop in EnergyPlus with a DX cooling coil, a DX heating coil, a supplemental electric heating coil, and a constant speed fan.

(3) Upgrade to mini-split heat pump system

Similar to (2), this measure replaces the existing HVAC system with an efficient ductless mini-split heat pump system to serve both cooling and heating. Mini-splits are made of an indoor and outdoor unit connected with some wiring and tubing. They are usually less complicated to install than adding a central system with new ductwork and make a HP solution possible when there is no room or difficulty to install ductwork. They are also quite energy-efficient with proper installation and operation. The main advantage over ducted centralized systems is that there are no ducts, which minimizes the loss of energy through air leaks and heat exchange (Air Conditioning Installation, 2017). It should be noted that compared with window AC or portable AC units, ~~generic heat pump~~ systems mini-splits heat pumps are much more expensive but mini-splits also providing heating.

In EnergyPlus, there is no special object that models mini-split systems but the variable refrigerant flow (VRF) system module is currently available. Since mini-split systems basically operate on the same principle like the VRF system, the major difference is that the outdoor unit of VRF can support more than one indoor unit. Therefore, mini-split can be modeled using the VRF object by customizing the connection between indoor and outdoor units, as well as the performance curves.

(4) Efficiency Upgrade of the Gas Storage Water Heater

This measure replaces the existing gas storage water heater with a higher efficiency water heater. The original thermal efficiency is 0.72 for baseline models of pre-1978, and the upgraded thermal efficiency is 0.93. This measure aims to reduce the natural gas consumption from domestic hot water systems. In EnergyPlus, this is modeled via modifying the thermal efficiency input of the water heater object.

(5) Improve Water Tank Insulation

This measure improves the insulation properties of the domestic hot water tank to reduce its heat loss to the ambient environment. The original loss coefficient to ambient temperature is set as 6W /K, while the coefficient after insulation upgrade is reduced to 3.7W /K. In EnergyPlus, this can be modeled via modifying the loss coefficient of the water heater object.

(6) Efficiency Upgrade to Electric Storage Water Heater

This measure replaces the existing gas storage water heater with an electric storage water heater with higher efficiency based on resistive heating. The original thermal efficiency is 0.78 for baseline models of pre-1978, and that of the electric water heater is 0.95. While this measure can not only reduce the site energy use of water heaters, but also enable the electrification of domestic hot water systems, it would also sharply increase water heating energy costs because of electricity's much higher cost per unit of energy than natural gas. In EnergyPlus, this can be modeled via modifying the fuel type of water heater.

(7) Upgrade to heat pump water heater

This measure replaces the existing gas storage water heater with a heat pump water heater. The original thermal efficiency is 0.78 for baseline models of pre-1978, while COP of the heat pump water heater can reach 3.3. Similar to measure (6), this measure can not only reduce the site energy use, but also enable the electrification of domestic hot water systems. Because of the much higher energy efficiency, water heating costs would be impacted much less than in switching from a gas storage water heater to an electric storage water heater (#6 above).

This system is more complicated to model in EnergyPlus. A "WaterHeaterHeatPump" object has been created to represent the heat pump, whose major component is a "CoilWaterHeatingAirToWaterHeatPump". A "WaterHeaterMixed" object is also created to represent the storage tank, and these two objects are connected via pipes.

(8) Add Ceiling Fan

This measure aims to raise the upper boundary of the occupants' comfort zone by increasing the air circulation through ceiling fans. The original cooling setpoint is 25.56˚C when occupied, and indoor air velocity is 0.2 m/s. Studies show that an air speed of 0.8 to 1.05 m/s could maintain comfort between 28°C and 29.5°C at 50% relative humidity (Burton et al., 1975; McIntyre, 1978; Rohles et al., 1983; Scheatzle et al., 1989). In our study, we assume that indoor air velocity is raised to 0.8 m/s with installed ceiling fans, and the cooling setpoint can be raised to 28˚C when occupied. Ceiling fans draw a modest amount of power. We assume the adoption of DC motor-driven ceiling fans, which consume about 0.36 W/m² floor area during normal operation. This is based on the specs of a number of relatively affordable EnergyStar certified products from Home Depot, and the finding from previous research that the average power when the ceiling fans were running was between 20-25% of max (Miller et al., 2021).

In EnergyPlus, ceiling fans are modeled by increasing the surrounding air velocity of the People objects and adding extra fan objects. At the same time, the cooling setpoint is elevated to 28°C. The fan objects are added to the entire conditioned living zone (i.e., garage and attic not included). As we didn't model detailed zoning of the homes due to lack of information, it is a limitation that we are not able to identify the exact area of the rooms that use ceiling fans, such as living rooms, dining rooms, and bedrooms. However, we did consider a demand factor of 0.66 to reflect the physical differentiation and concurrent usage among multiple rooms based on recommendations from the National Electrical Code (National Fire Protection Association, 2020; Parmar, 2018). The size and cost of the ceiling fan depend on the room area. The larger the room is, the higher flow rate and ceiling fan cost.

(9) Attic fan

This measure aims to improve the thermal environment of attics by increasing ventilation rate in the attics. During a summer day, the temperature in the attics can easily reach 110-120˚F, even as high as 150˚F while the outside temperature is lower than 100˚F (Bunns HVAC, 2017; Parker and Sherwin, 1998). By increasing the attic exhaust ventilation, the attic temperature can be significantly decreased, which in turn will reduce the heat gain from the ceiling. It should be noted that attic fans also add extra fan energy.

In EnergyPlus, the attic fans are modeled by adding an extra ventilation object in the attic zone, which is controlled by indoor and outdoor temperature. More specifically, we assume that the attic fans are operate only when attic indoor temperature rises above a certain threshold (i.e., 75.2˚F) and outdoor temperature doesn't drop below a certain threshold (i.e., 68˚F) to avoid overcooling. Fan pressure rise and efficiency is associated with the ventilation object to account for the extra fan energy for attic fan operation.

(10) Portable fan

The working mechanism of portable fans are very similar to the ceiling fans. The assumptions of their impact on air velocity and thermal comfort range are the same, as well as the modeling method. The only difference is that we assume that the number of portable fans are associated with the people rather than rooms in the home. In other words, each person in the home is equipped with a fixed-size portable fan, so the cost varies with the number of people in the home rather than the size of the home.

(11) Add Air Sealing to Seal Leaks

This measure aims to reduce air infiltration via the envelope by sealing the windows. The original setting on air infiltration is described in Section 1.1. With air sealing, we assume the infiltration rate is reduced by 30%. This is modeled in EnergyPlus by modifying the rated infiltration value of the infiltration object. A side benefit of this measure is improved air quality when the outside air quality is harmful.

(12) Add Duct Sealing to Minimize Duct Leakage

Air duct leakage is very common in homes, which can lead to a 30-40% thermal loss (Jump et al., 1996; Modera, 1993; Wray and Sherman, 2010). This measure adds duct repair and sealing to reduce the leakage, which assumes application of aluminum duct tape to duct holes and mastic over the aluminum duct tape. The duct leakage rate of the baseline is assumed to be 10% and is assumed to be reduced to 5% after repair and sealing (Wray and Sherman, 2010).

In EnergyPlus, duct leakage is simulated using the Simple Duct Leakage Model, developed by Lawrence Berkeley National Lab (Wray and Sherman, 2010). The model assumes that the leaks are in the supply ducts and go to the return path, so this part of the supply does not reach the conditioned zones. This configuration is modeled with heat and mass balance equations. It should be noted that the model accounts for loss of cooled air through holes in the ductwork, but not conduction of heat through the duct walls. This is because EnergyPlus can model detailed duct systems only by using the AirflowNetwork model, which simulates natural ventilation or forced air distribution systems but is rarely used in real applications due to its complexity. Duct leakage rate is specified in the object "air distribution unit".

(13) Add Window Film

This measure applies a window film to the interior surface of the existing windows. The film properties are based on an example solar control film product from LLumar Vista series (LLumar, 2020).

The simulation method is similar to that of the interior storm window, i.e., (1) the simple input properties of the existing windows are translated into detailed properties for a "Representative Layer", (2) the window film layer is attached to the interior side of the "Representative Layer", and (3) updated properties are calculated.

(14) Add Interior Storm Window Layer

This measure adds an interior storm window layer to the existing windows. The storm window properties and simulation method are basically identical to those of the exterior storm window, the only difference is that this measure adds the storm window layer to the interior side of the windows.

(15) Add Wall Insulation

This measure aims to improve the exterior wall thermal properties by applying an extra insulation layer to the wall cavity. Insulation provides resistance to heat flow, taking less energy to heat/cool the space. The original wall insulation for baseline models of pre-1978 is R-8.4, and the upgraded wall insulation is R-21. This is modeled in EnergyPlus by modifying the thickness of the insulation layer.

(16) Reroof and Add Roof Insulation

As roof insulation is not mandatory in California low-rise residential buildings until Title 24-2016, it is not included in buildings that were built before 2016 in CityBES. This measure will remove existing roof, install insulation with R-value of 24.8 ($°F·ft^2·h/BTU$) and reroof to reduce unwanted heat gain/loss. This measure is most applicable to older roofs in need of re-roofing. This is simulated by adding an extra layer with R24.8 to the roof construction in the EnergyPlus model.

(17) Apply Top Floor Ceiling Insulation

This measure installs insulation (R38) to the ceiling (attic floor) or beneath the existing roof (if no attic). According to Title 24 standards, for buildings built before 1992, the ceiling insulation is R16.67 for all California climate zones; while after 1992, the ceiling insulation is R-30 for climate zone (CZ) 2 to 10, and R-38 for CZ1 and CZ 11-16. Therefore, this measure is mostly applicable for older buildings, and also for newer buildings in certain climate zones. This is simulated by adding to the existing insulation layer to achieve a R-38 insulation layer to the attic above the top floor in EnergyPlus.

(18) Replace existing lighting with LED

This measure replaces existing lighting to LEDs with 0.125 W/ft^2 for the living zone, 0.0506 W/ft^2 for the garage. The lighting power density is estimated based on the luminance requirement and efficacy assumption. The referenced luminance requirements for residential rooms are shown in Table D1-7 (Wilson et al., 2014). The bedroom requirement of 12.5-foot candles (where a foot-candle equals one lumen per square foot), as a mid-tier value, was selected as the residential home average requirement. An efficacy of 100 lumens/watt was assumed for LED bulbs (LLumar, 2020).

Table D1-7. Single- and Multi-family Homes Lighting Levels by Room Type (Wilson et al., 2014)

Room Type	Lighting Requirements (fc)	Room Type	Lighting Requirements (fc)
Bathroom	17.5	Hall, stairway, foyer	3.0
Bedroom	12.5	Kitchen, breakfast nook	19.0
Closet	5.0	Living room, great room	6.0
Dining room	6.5	Home office, den, study	11.8
Family room, recreation room	8.8	Utility room	17.5
Garage	5.0	Other, library	12.5
Unfinished basement	5.0	–	–

LEDs consume less power and last longer than fluorescent lamps. A retrofit kit is recommended for converting fluorescent lighting ballasts, which allows certain types of LEDs to leverage existing ballasts without changing the entire fixture. Replacement may also improve lighting quality and controllability in some cases.

(19) Upgrade cooling equipment to window air conditioner

This measure assumes that the existing cooling equipment is replaced with a new window air conditioner, which usually happens when the existing equipment is malfunctioning or has reached the end of its service life. The cooling efficiency is assumed to be EER 10.9 (COP 3.19). This is based on the fact that the U.S. Department of Energy requires that the manufacturers of residential room air conditioners must comply with the energy conservation standards specified in the Code of Federal Regulations 10 CFR 430.32(b) (The Code of Federal Regulations (CFR), 2021).

(20) Residential central AC system cooling efficiency upgrade

This measure assumes that the existing central air conditioning unit (split air conditioner) is replaced with a higher efficiency cooling unit of the same type. The cooling efficiency is assumed to be EER 11.2. The efficiency assumptions are based on the 2016 Title 24 efficiency requirement for unitary air conditioners and condensing units (Table 110.2-A) (California Energy Commission, 2016b).

(21) Evaporative cooler (swamp cooler) efficiency upgrade

This measure upgrades the existing swamp cooler to a higher efficiency swamp cooler. The direct saturation efficiency is assumed to be 95%. The efficiency assumption is based on the 2020 ASHRAE Handbook (ASHRAE, 2020). The swamp cooler unit is simulated in EnergyPlus using the object "EvaporativeCooler:Direct:ResearchSpecial".

(22) Replace passenger vehicle with electric vehicle

This measure replaces the existing gasoline vehicle with an electric vehicle. The detailed assumptions of this measure are elaborated in section 2.4.1. In summary, the annual mileage is 9000 miles for the two Fresno districts, average fuel efficiency of the gasoline vehicles is 21 mile per gallon, and the average gasoline price is $3.40/gallon. The charging profile of electric vehicles is illustrated in Figure D1-7. This measure is analyzed outside EnergyPlus through a separate set of calculations.

CALIFORNIA ENERGY COMMISSION

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX D2:
Additional Integrated Building Modeling Results

November 2023 | CEC-500-2024-001-APA-G

APPENDIX D2:
Additional integrated building modeling results

1.1. Results for individual energy efficiency measures

21 out of the 22 selected EEMs (excluding EV) were modeled in CityBES to explore potential solutions to reduce energy consumption and CO_2 emission from the previously described baseline homes. Additionally, these EEMs are also evaluated from a financial perspective, which help the residents and policy makers make informed decisions. The performance of each EEM is evaluated and ranked according to four goals: maximizing site energy savings, maximizing CO_2 emission reduction, minimizing payback year, and minimizing investment cost. These EEMs are ranked by the median value of the results. Figure D2-1 reveals the ranking of these measures based on site energy use reduction and CO_2 emission reduction. Finally, these EEMs are organized into a ranking for each category as data shown in Figures D2-3, D2-4, and D2-5. In all of these rankings, the air source heat pump EEM indicated with an asterisk does not include baseline homes with window ACs since we assume that homes with window ACs lack ducting and installing new ducts in homes without ducting would be prohibitively expensive.

Figure D2-1. Ranking of individual measures by site energy saving and GHG reduction for the residential buildings in the Winchell neighborhood

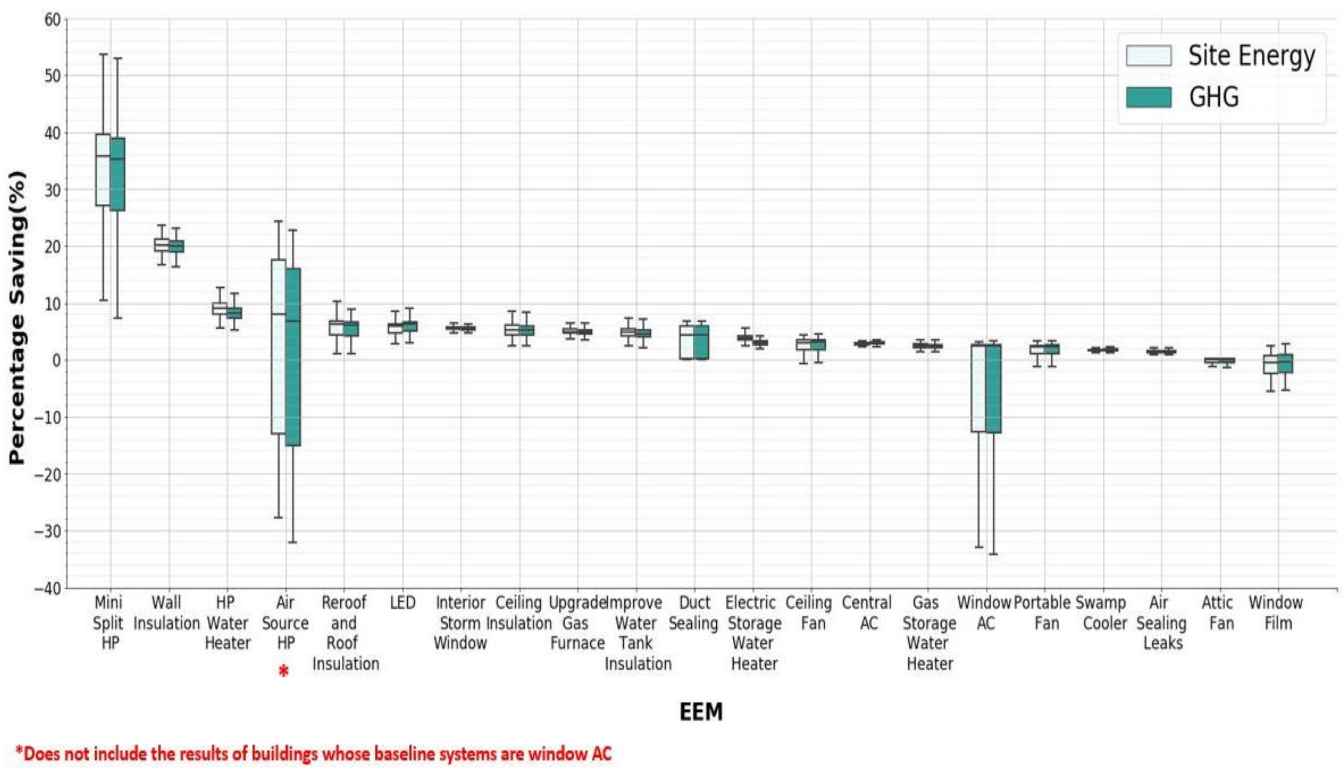
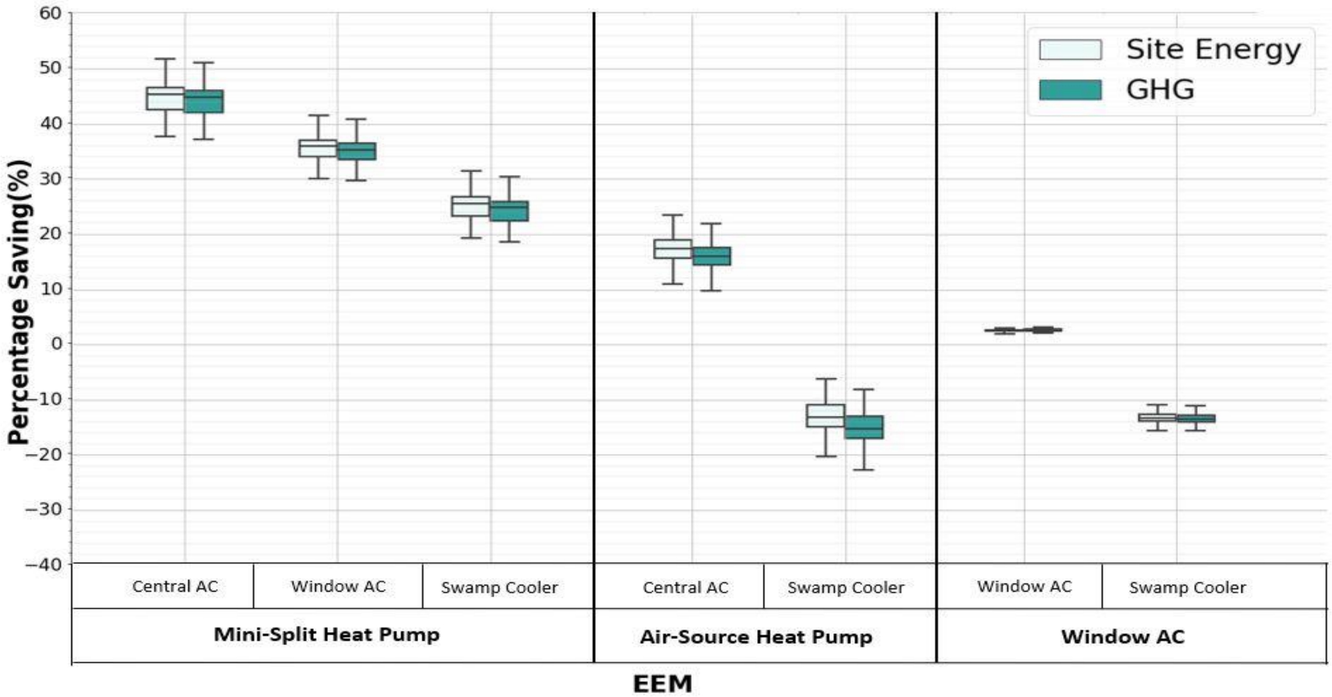


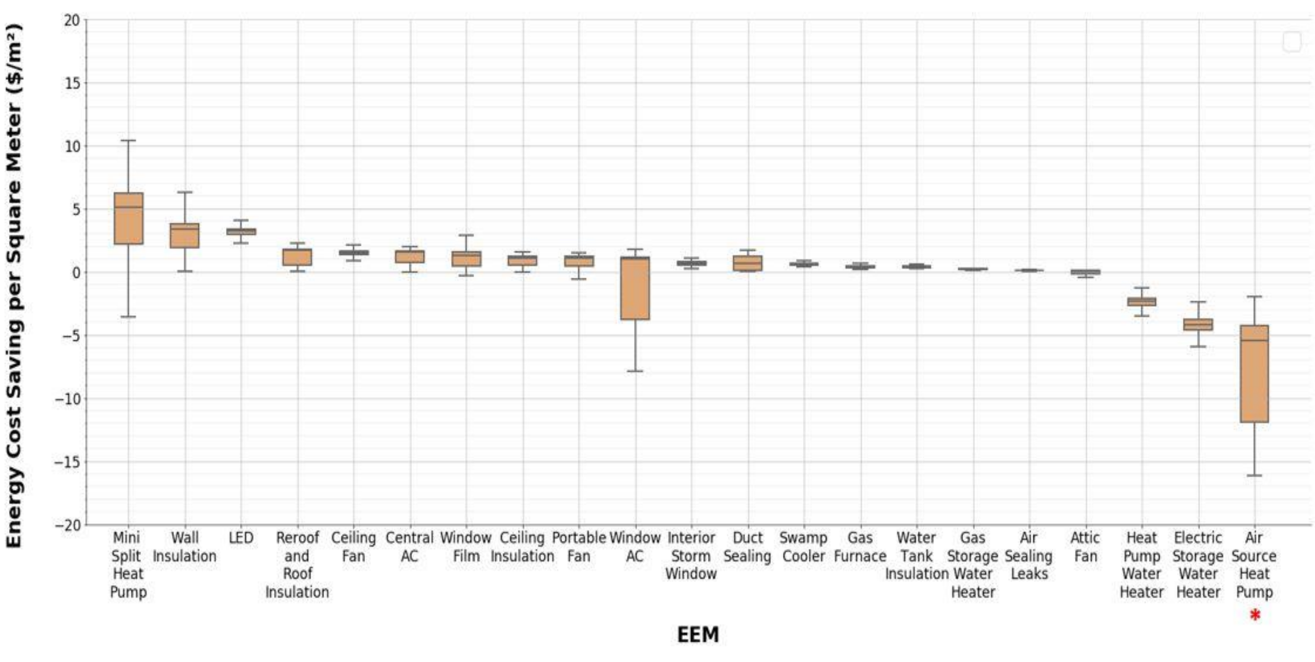
Figure D2-2. Breakdown of site energy use saving and GHG emission reduction of EEM according to baseline HVAC type. The non-bolded cooling equipment refers to the home's initial cooling equipment



According to the ranking shown in Figure D2-1, the five most high-performing measures for site energy-saving, in descending order, are upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating), applying wall insulation (R-21), upgrading to heat pump water heater (COP 3.3), upgrade to air source heat pump (11.0 EER, 3.3 COP), and reroof with insulation (R-24.83). For CO_2 emission reduction, Figure D2-1 shows the same ranking as the site-energy ranking. This is mainly due to the similar CO_2 emission factors for electricity and natural gas in California. For both energy savings and CO_2 emission reduction, the measure of upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating) outperforms others by a large margin. The mini-split heat pump saves much cooling energy from its high cooling COP. It also eliminates natural gas use for heating and minimizes heating electricity consumption with high heating COP, leading to an additional site energy saving. Upgrading to heat pump water heater is another high-performing electrification measure with excellent energy savings and CO_2 emission reduction. The fuel switching measures will reduce more GHG emissions in the future as the electricity emission factor gets lower, and even zero in extreme case when electricity generation from the grid is zero carbon. Figure D2-2 further breaks down the performance of three HVAC EEMs according to the baseline HVAC types, for the following two reasons: (1) the HVAC upgrade EEMs are not all applicable/appropriate to the three baseline HVAC systems in the DAC context. For example, upgrading to air-source heat pump is not suitable to window AC baseline as it will trigger addition of new duct system, which is generally not affordable in DAC. As another example, upgrading to window AC is not applicable to central AC baseline system, as it doesn't make sense to give up existing duct system and spend money and efforts to install a new system that doesn't have significantly higher cooling COP; (2)The impacts of these EEMs vary significantly with the baseline system types. The trend follows a descending order where most saving occur with central AC and least saving occur with swamp cooler. Swamp coolers has the least energy saving because it consumes the least amount of energy as it only uses fan to provide cool energy without the compressor energy needed for air conditioning units. Thus, when the swamp cooler system is upgraded to a new HVAC system, there is less energy saving compared to the other two conventional vapor compression-based baseline HVAC systems. As for the other two baselines, upgrades from central AC are more energy saving than window AC upgrades, as central AC consumes more energy than window AC due to higher fan energy consumption from supplying cooled air throughout the whole building via ducts rather than only circulating within each room for window AC.

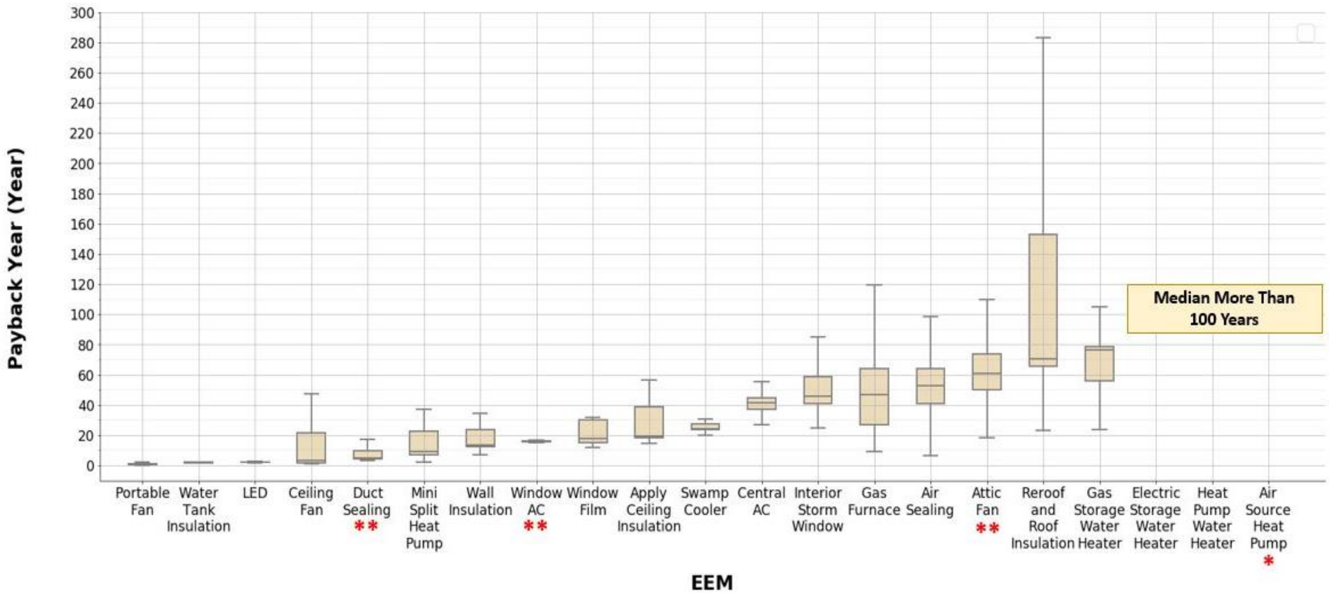
As shown in Figure D2-3, the ranking of top five high-performing measures for maximizing energy cost saving, from most savings to least savings are upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating), applying wall insulation (R-21), replacing existing lighting with LED (0.6W/sf), reroof and roof with insulation (R-24.83), and adding ceiling fan. Since mini-split heat pump overall saves the most site energy use, it ultimately saves the most energy cost as well. However, three measures have negative energy cost saving: upgrading to heat pump water heater (COP 3.3), upgrading to electric storage water heater (0.95), and upgrading to air-source heat pump (3.22 COP cooling, 3.3 COP heating). Although they save overall site energy use, there is an increase in electricity use. In California, the cost of grid electricity is much more expensive than the cost of natural gas, so these measures end up not saving energy cost even though they save overall site energy use and eliminate use of natural gas for that application.

Figure D2-3. Ranking of individual measures by energy cost savings for the residential buildings in the Winchell neighborhood



*Does not include the results of buildings whose baseline systems are window AC

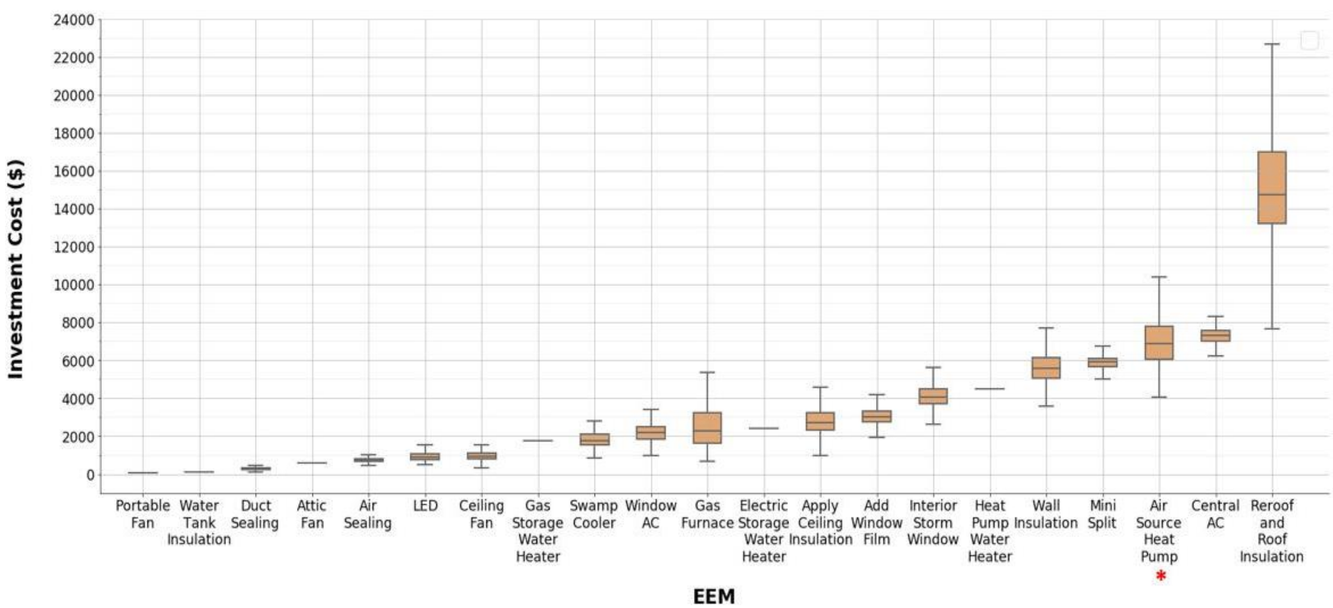
Figure D2-4. Ranking of individual measures by payback year for the residential buildings in the Winchell neighborhood



*Does not include the results of buildings whose baseline systems are window AC

**Does not include the results of buildings whose baseline systems are swamp coolers, because their energy savings are negative. However, there are significant uncomfortable hours in these baseline buildings, which can be reduced by the ECMs.

Figure D2-5. Ranking of individual measures by investment cost for the residential buildings in the Winchell neighborhood



*Does not include the results of buildings whose baseline systems are window AC

As shown in Figure D2-4, the top five most high-performing measures for minimizing payback year, from short to long payback period, are adding portable fans, improving water tank insulation, replacing existing lighting with LED (0.6 W/sf), adding ceiling fans, and adding duct sealing for leakage. For this payback analysis, some measures, such as adding ceiling fans, do not include the swamp cooler baseline because the energy savings are negative.

However, there are significant number of uncomfortable hours in the baseline buildings, which can be reduced by the EEMs. For minimizing the investment cost, Figure D2-5 shows that the top five measures from low to high investment cost are adding portable fans, improving water tank insulation, adding duct sealing for leakage, adding attic fan, and adding air sealing for leakage. For both categories, the measure for adding portable fans (together with thermostat setback in the summer) is the most effective one for having the least payback year of only half-a-year and the least median investment cost of $54 per fan. Thus, with its low investment cost, this measure effectively compensates its initial cost within half a year before saving additional energy costs in the following years. By contrast, despite its relatively high investment cost, the mini-split heat pump measure has the fifth shortest payback period. Being highly energy-saving, as previously explained, it can compensate for its initial capital cost within a median of 12 years. Therefore, the payback year and investment cost metrics provide two aspects of accounting for financial benefits of all the measures.

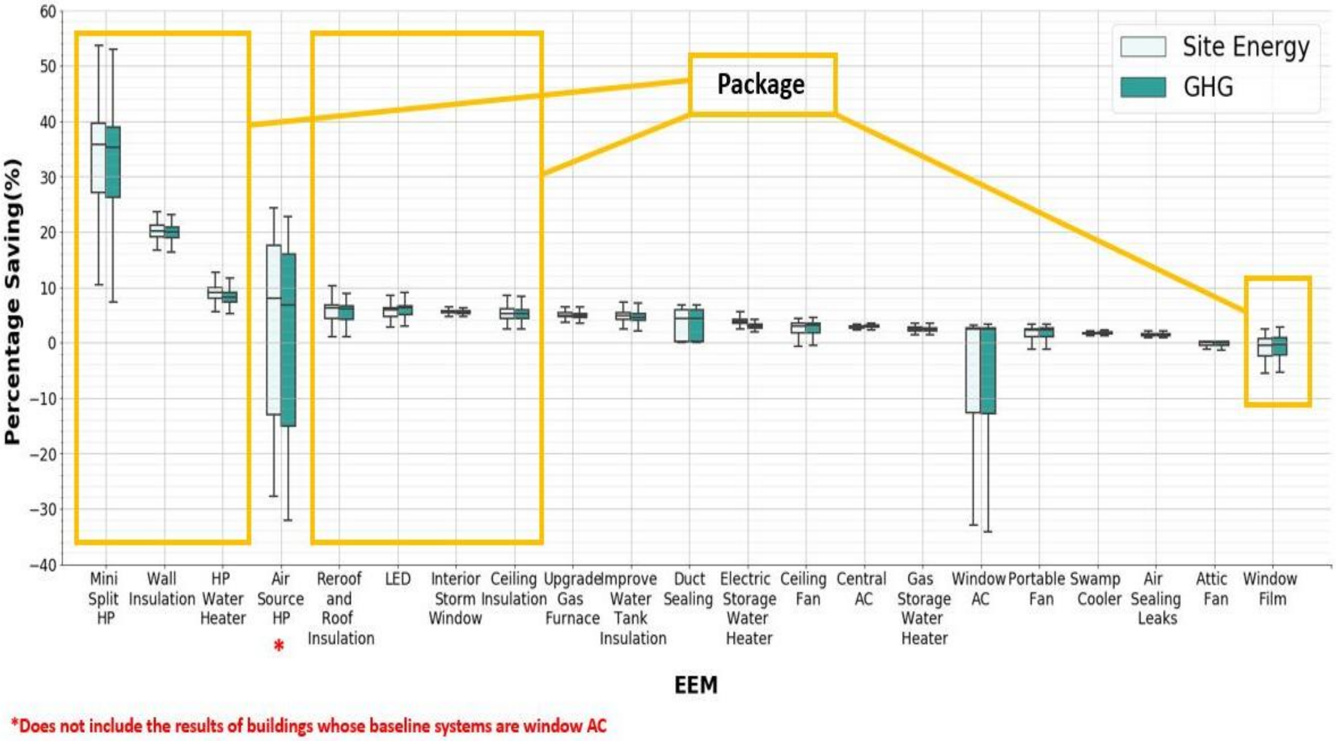
1.2. Results for packages of energy efficiency measures

Following the assessment of each individual measure, the most high-performing ones of each category are selectively combined and simulated together to create multiple packages of measures according to different goals. Similar to the four categories for evaluating individual measures, the measure packages are selected for the purposes of maximizing one of the following: site energy savings, CO_2 emission reduction, energy cost savings; minimizing payback year, or minimizing investment cost.

1.2.1. Optimal package for energy savings and CO_2 emission reduction

After running a series of simulations with different combinations of measures, the measure package with the most energy savings is selected, as illustrated in Figure D2-6. It includes a total of eight high-performing measures: replacing existing lighting with LED (0.6 W/sf), applying ceiling insulation (R-38), upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating), upgrading to heat pump water heater (COP 3.3), reroofing and roof with insulation (R-24.83), adding an interior storm window layer, applying wall insulation (R-21), and adding window film. For the goal of maximizing CO_2 emission reduction, the selected optimal measure package turns out to be the same as the energy saving package. This is mainly due to the similar CO_2 emission factors for electricity and natural gas in California. However, while the measure package can achieve large energy savings and CO_2 emission reduction, the package has high initial investment cost and generally long payback period.

Figure D2-6. Selected measure package for maximizing site energy saving and GHG reduction for the residential buildings in the Winchell neighborhood



To achieve this optimal measure package, the process began with evaluating and ranking individual measures according to their energy-saving and CO_2 emission reduction performance (4.2). From this ranking, high-performing passive measures, such as applying wall insulation (R21), reroofing and roof with insulation (R24.83), applying ceiling insulation (R38), and adding an interior window storm layer were first selected and incrementally combined to effectively reduce the heating and cooling load of the HVAC system. Then active measures were incrementally added to the package, including mini-split heat pump (3.66 COP cooling, 3.7 COP heating), heat pump water heater (COP 3.3) and LED upgrade (0.6W/sf). These active measures improve the efficiency of the HVAC, domestic hot water, and lighting systems which result in lower energy consumption and CO2 emission. Upgrade to air source heat pump (11.0 EER, 3.3 COP) was not selected for the measure because mini-split heat pump largely outperforms the gas furnace measure in terms of both energy savings and CO2 emission reduction.

During this simulation process, lower-performing measures were also simulated alternatively to add to the package (as the eighth measure). The interaction among these measures can create different results between individual performance and package performance. The result reveals that the addition of window film measure to the package improves the package performance, despite being the lowest performing measure based on the individual ranking. This happens because window film saves energy in summer by reducing heat gain in the building but increases energy consumption in winter by lowering the amount of heat entering the building. However, when integrated with improving roof insulation and wall insulation, the heating load of the building gets smaller and the heating energy increased by window film is curtailed. However, beyond this combination of eight measures, the addition of other measures will only lower the package's energy saving and CO_2 emission reduction because the energy savings of some measures get limited when the basic load is significantly reduced. For example, adding portable fans can reduce cooling energy use but will bring extra fan energy use. However, when the basic cooling load is already cut down by measures like adding wall, ceiling, and roof insulations, adding window film and storm window, and upgrading to LED, the reduction in cooling energy use from adding portable fans may not be large enough to compensate for its additional fan energy use.

As shown in Figure D2-7, the measure package can reduce the energy consumption by a median of 63%, from the initial distribution of site energy consumption ranging between 75-275 kWh/m² annually to a new distribution ranging between 25-125 kWh/m². Moreover, the CO_2 emission also follows the trend of a median of 63% reduction, shifting its range of values from 15-50 kg/m² to mostly 5-25 kg/m², as shown in Figure D2-8. These savings are due to the combination of active and passive measures in the package. For the active measures, the upgrade to LED reduces electricity consumption from interior lighting, while the mini-split heat pump and heat pump water heater upgrades the HVAC and domestic hot water system respectively to eliminate natural gas usage from these two end-uses. Whereas passive measures like roof insulation, wall insulation, ceiling insulation, and interior window storm layer are applied to reduce heat gain in summer and heat loss in winter through the envelope, which can reduce cooling and heating load. Subsequently, the window film is a passive cooling measure to decrease buildings' solar heat gains through the windows, which can further reduce cooling load in summer. Therefore, the combination of these eight measures in the package results in 60% reduction of the annual site energy use and CO_2 emission.

However, while the measure package can achieve large energy savings and CO_2 emission reduction, they are usually associated with high initial investment cost and long payback period. As shown in Figure D2-9, the payback period of the energy saving package ranges mostly from 12 to 100 years, depending on individual buildings' characteristics. Two peaks are identified in the distribution, the minor peak with longer payback period is caused by buildings equipped with swamp cooler systems. The swamp cooler system consumes much less energy than the other two system types (central AC and window AC) because it cools and supplies the outdoor air with fan and water only. As a result, the energy saving of the mini-split heat pump only occurs on the heating energy, leading to lower energy cost saving and longer payback. If the residents have limited investment capability or expect a quick payback, other packages should be considered and investigated too, which are discussed in 4.3.2 - 4.3.4.

Figure D2-7. The change of site energy use distribution from baseline to energy saving measure package for the residential buildings in the Winchell neighborhood

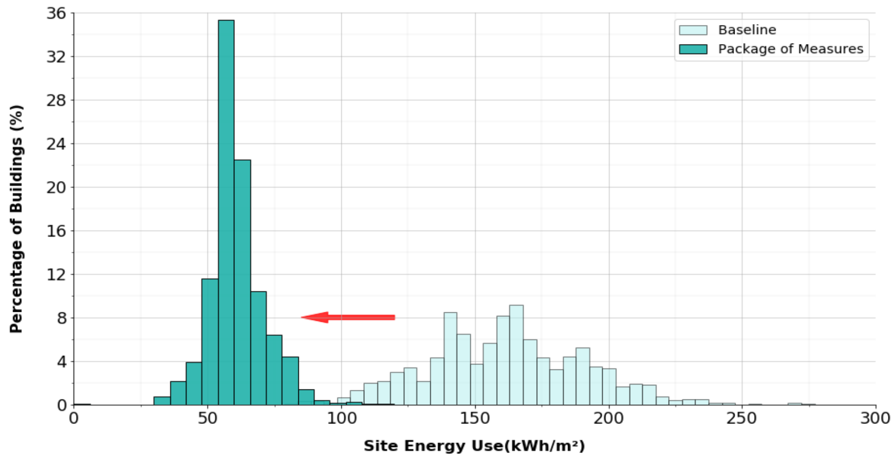


Figure D2-8. The change of operational GHG emission distribution from baseline to energy saving measure package for the residential buildings in the Winchell neighborhood

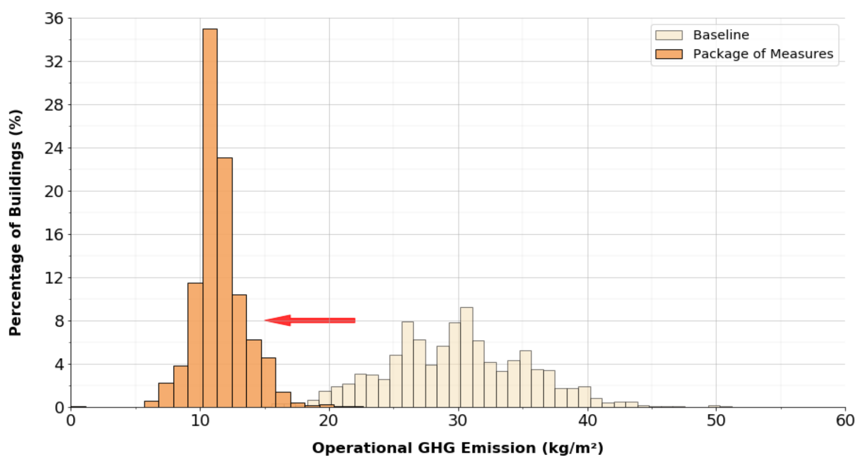
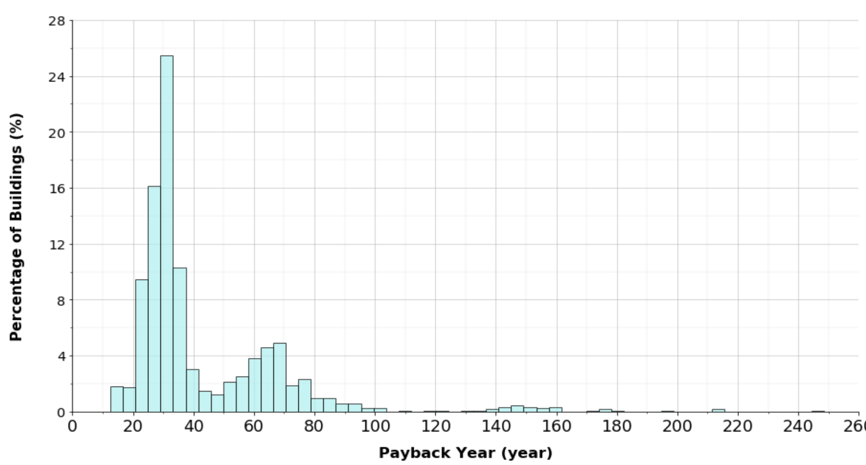


Figure D2-9. Distribution of payback years of the energy saving package for the residential buildings in the Winchell neighborhood



1.2.2. Optimal package for utility bill savings

The optimal package for energy cost savings or utility bill savings aims to maximize the amount of cost saved per square meter as a result of saved energy consumption. Based on PG&E's TOU rate (Appendix D1, Section 1.6), electricity is more expensive than natural gas in the City of Fresno. Thus, to maximize energy cost savings, the optimal package includes the six top-performing measures based on energy saving, specifically targeting at electricity usage reduction: upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating), replacing existing lighting with LED upgrade (0.6 W/sf), applying wall insulation (R-21), reroof and roof with insulation (R-24.83), applying top floor ceiling insulation (R-38), and adding portable fans. As shown in Figure D2-11, this package saves up to $16/m² annually, with the median at approximately $10/m². This high energy cost saving is due to the high electricity saving of up to 55% as illustrated in Figure D2-10. Therefore, because of the high price of electricity, maximizing electricity saving results in optimized energy cost savings.

Similar to Figure D2-9, two peaks are identified in both Figures D2-10 and D2-11. This is also caused by the discrepancies of baseline energy consumptions among different HVAC system types.

Figure D2-10. Distribution of annual electricity saving percentage with selected measure package

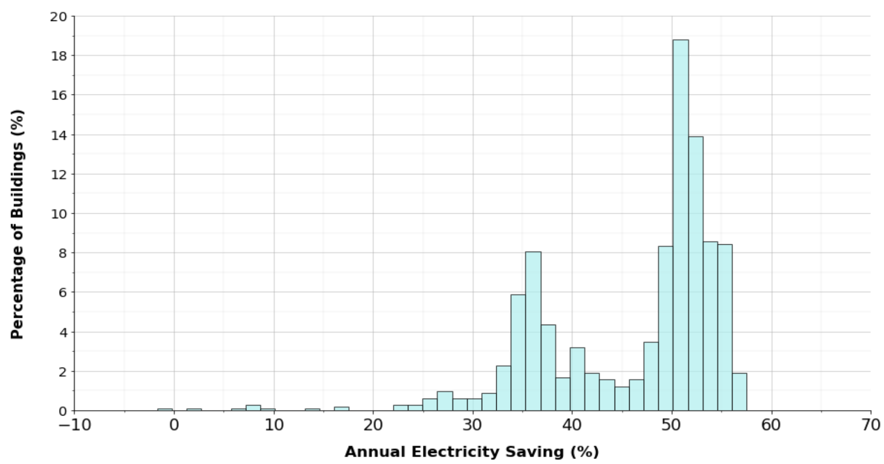
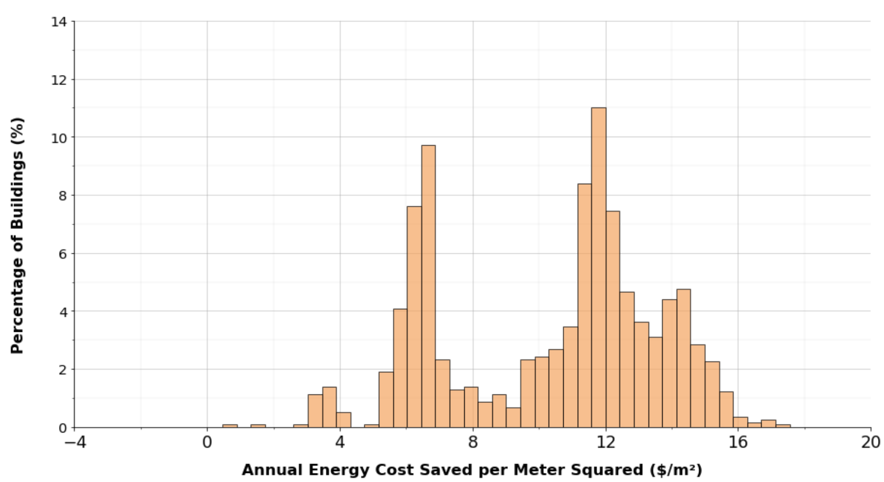


Figure D2-11. Distribution of annual energy cost saving per square meter with selected measure package



1.2.3. Optimal package for investment cost

This section focuses on minimizing the initial cost of retrofitting the buildings using measures with the least initial cost. Two packages were selected to achieve this goal depending on the limit of investment capability. The first package, as shown in Figure D2-12, has a $1000-limit of initial investment that includes three measures: adding portable fans, improving water tank insulation, and adding air sealing to seal leaks. The second package in Figure D2-13 has a $5000-investment limit, and this package includes four measures: adding portable fans, improving water tank insulation, replacing existing lighting with LED upgrade (0.6 W/sf), and upgrading gas furnace efficiency (AFUE 95). For the first package, the majority of the buildings only need approximately $600-1000 to retrofit, and this could save up to 12% of annual energy consumption (median 8%). For the second package, which has a more distributed investment cost range, needs an average of $1000-5000 of investment cost as presented in Figure D2-13. Figure D2-14 reveals that because the $5000 limit package includes more high-performing energy-saving measures, such as the LED upgrade and gas furnace efficiency upgrade, it can save up to 20% of annual energy consumption. Currently, we have investigated incentive and rebate programs from the state, utility, and local communities, but we discovered that none of the incentives and rebates are applicable to our measures. In fact, we also discovered that many of the applicable incentive and rebate programs had expired or no longer accepted any applications at this moment.

Figure D2-12. Distribution of residential buildings' initial investment cost with a $1,000-limit measure package in the Winchell neighborhood

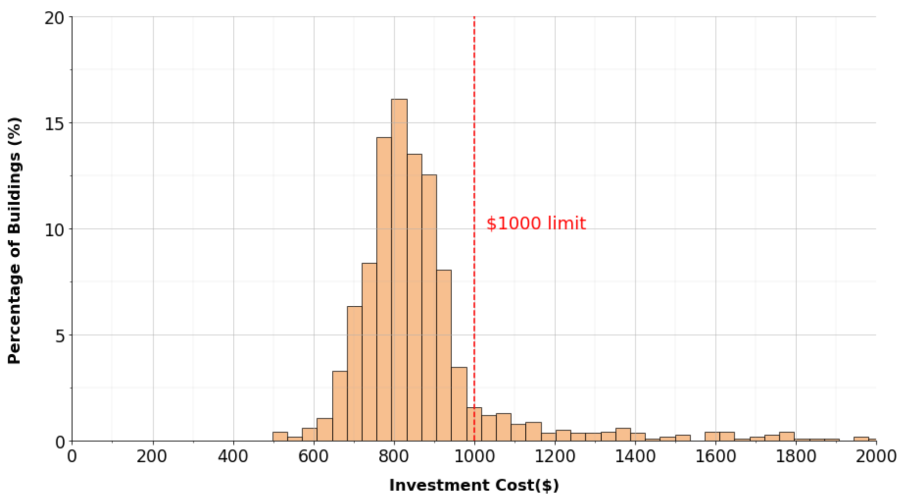


Figure D2-13. Distribution of residential buildings' initial investment cost with $1,000-limit and $5,000-limit measure packages in the Winchell neighborhood.

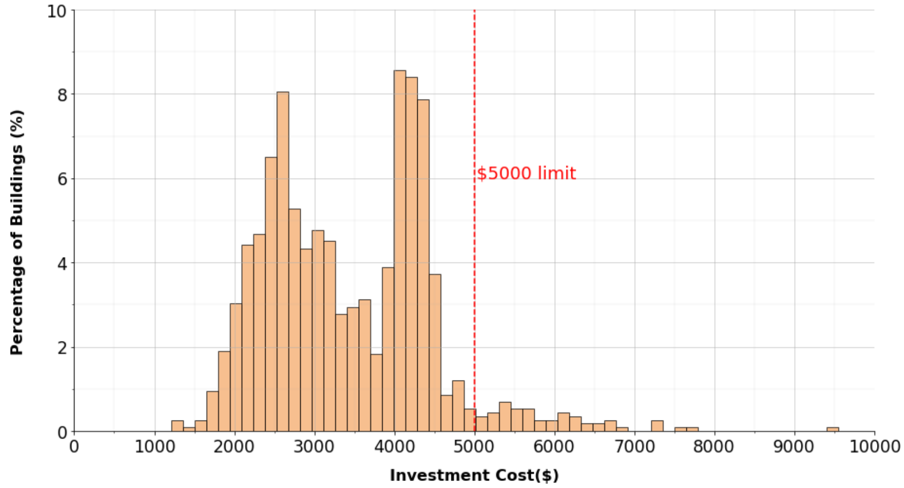
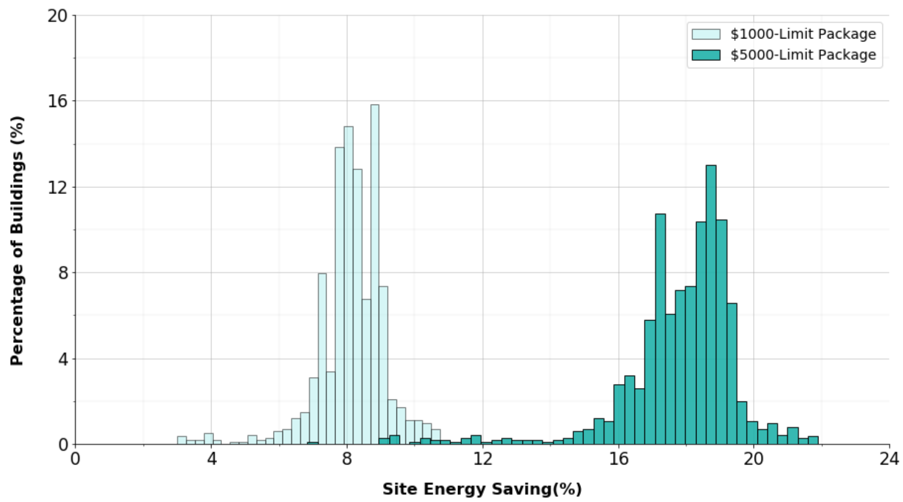


Figure D2-14. Distributions of annual energy saving percentage on the $1,000-limit and $5,000-limit measure packages for the residential buildings in the Winchell neighborhood.



1.2.4. Optimal package by payback year

This section aims to minimize the number of years needed to compensate for its initial investment of the measures through annual energy cost savings. There are two optimal packages according to the year limit as shown in Figure D2-15. When constraining the payback year within the 5-year limit, it includes a combination of four high-performing measures which is exactly the same as the package with $5000-limit of investment cost: replacing existing lighting with LED (0.6 W/sf), adding portable fans, and improving water tank insulation. This combination allows other high-performing measures to balance out the payback year of the package and achieve approximately two years of payback year.

For the 10-year limit, it is a combination of the same three high-performing measures and with the addition of measure of upgrading to mini-split heat pump system. With the 10-year limit package, other measures also balance out the high investment cost of the mini-split heat pump, which then constrains the payback year to mostly in the range of 4-8 years.

Buildings that surpass the 10-year limit are the ones with swamp cooler systems. As noted above, the swamp cooler system consumes much less energy than the other two system types (central AC and window AC). As a result, the energy saving of the mini-split heat pump only occurs for heating energy, leading to lower energy cost saving and longer payback. According to Figure D2-16, although it has a slightly longer payback, the 10-year limit package can save up to 60% of energy consumption compared to the 5-year limit package of up to only 18% of energy-saving. This difference is caused by the high energy saving from the mini-split heat pump compared to the gas furnace.

Figure D2-15. Comparison of payback years between 5-year limit package and 10-year limit package for the residential buildings in the Winchell neighborhood.

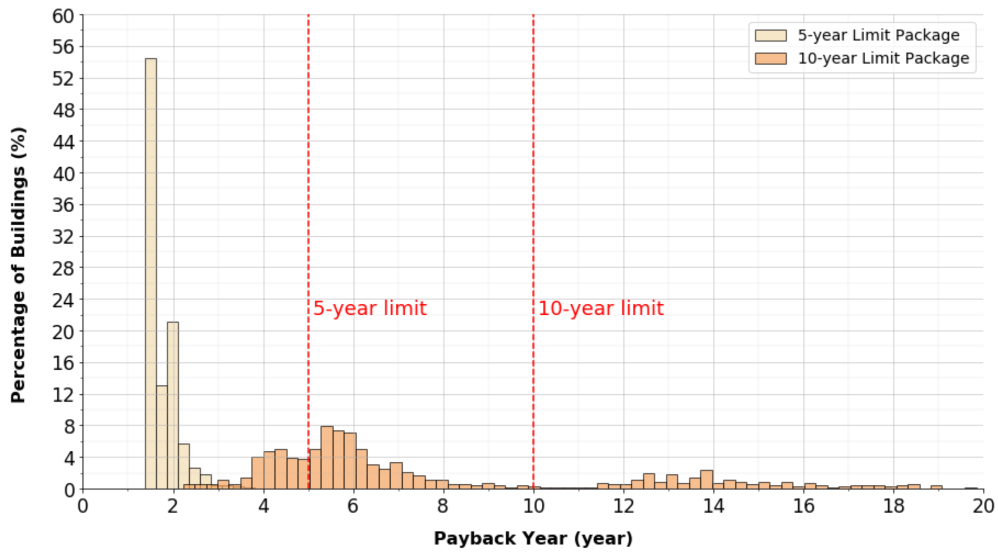
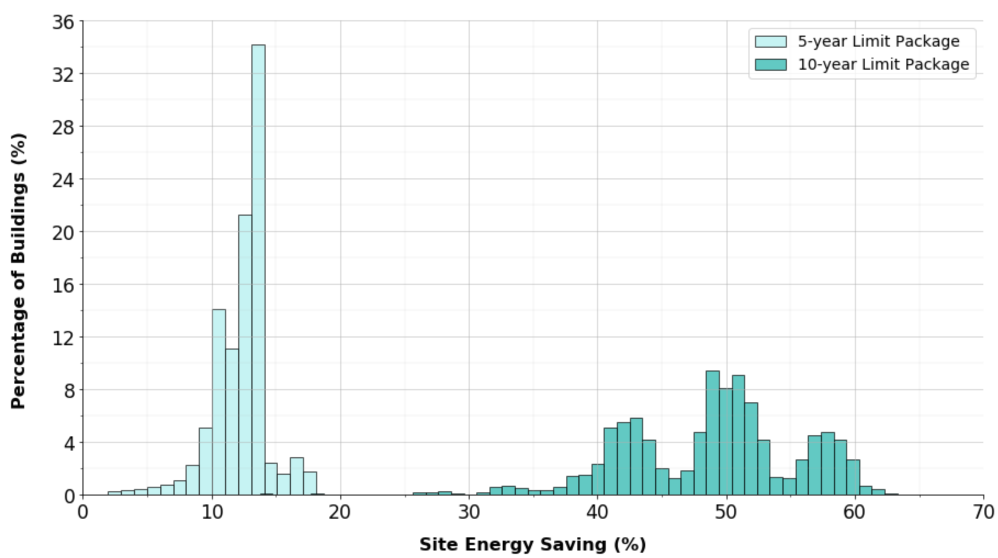


Figure D2-16. Comparison of annual site energy saving percentages between 5-year limit package and 10-year limit package for the residential buildings in the Winchell neighborhood.



Electrification Analysis

Incremental Analysis - Individual measures

Table D2-1 summarizes the different scenarios of incremental cost analysis for individual measures. There are three different baseline HVAC systems and one domestic hot water system, all of which consume natural gas for either space heating or water heating. For the like-for-like upgrade, these systems are upgraded to the same equipment type with a higher efficiency. For the electrification cases, all of the baseline HVAC systems are upgraded to mini-split heat pumps or to air source heat pump (except for the window AC baseline), which consume electricity rather than natural gas for space heating. The domestic hot water system is electrified by replacing the gas storage water heater with a heat pump water heater.

Table D2-1. Scenarios of incremental cost analysis for individual measures

<table>
<tr><th>Baseline</th><th>Like-for-like upgrade</th><th>Electrification 1</th><th>Electrification 2</th></tr>
<tr><td>Swamp Cooler + Wall Heater</td><td>Swamp Cooler + Wall Heater Efficiency upgrade</td><td rowspan="2">Air-Source Heat Pump</td><td rowspan="3">Mini-Split Heat Pump</td></tr>
<tr><td>Central AC</td><td>Residential Central AC Efficiency Upgrade</td></tr>
<tr><td>Window AC + Wall Heater</td><td>Window AC + Wall Heater Efficiency Upgrade</td><td>-</td></tr>
<tr><td>Gas Storage Water Heater</td><td>Gas Storage Water Heater Efficiency Upgrade</td><td>Heat Pump Water Heater</td><td>Heat Pump Water Heater</td></tr>
</table>

Figure D2-17 illustrates the incremental investment cost and incremental energy saving percentage of each system. The lowest incremental cost is between the central AC like-for-like upgrade and upgrading to the mini split heat pump. The negative incremental cost indicates that instead of paying more to electrify the HVAC system, the mini split heat pump actually cost less than the central AC efficiency upgrade. The 40% incremental energy saving result points out that the mini split heat pump can save more energy than the like-for-like upgrade. The result also reveals that among the 3 baseline HVAC systems, the incremental cost to mini-split heat pump is lower than to air-source heat pump as the investment cost for mini-split heat pump is lower. Moreover, the mini-split heat pump is more efficient than the air-source heat pump, especially at partial load conditions which happen most of the time, so it ultimately results in higher incremental energy saving up to more than 40%. Additionally, the incremental CO_2 emission reduction percentages of these measures are quite similar to their incremental energy saving percentages, as shown in Figure D2-18, which reflects another significant incremental benefit brought by the electrification measures.

Figure D2-17. Incremental energy saving percentage and incremental investment cost of individual measures for the residential buildings in the Winchell neighborhood

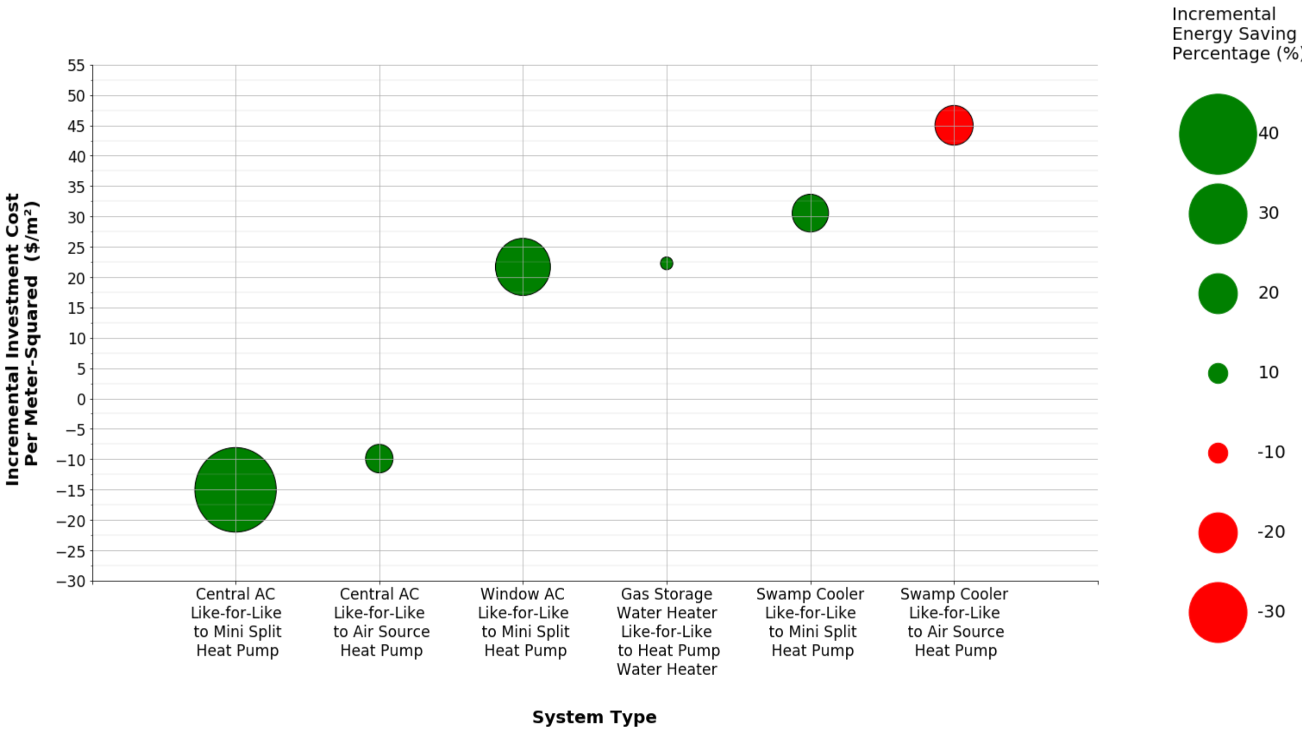
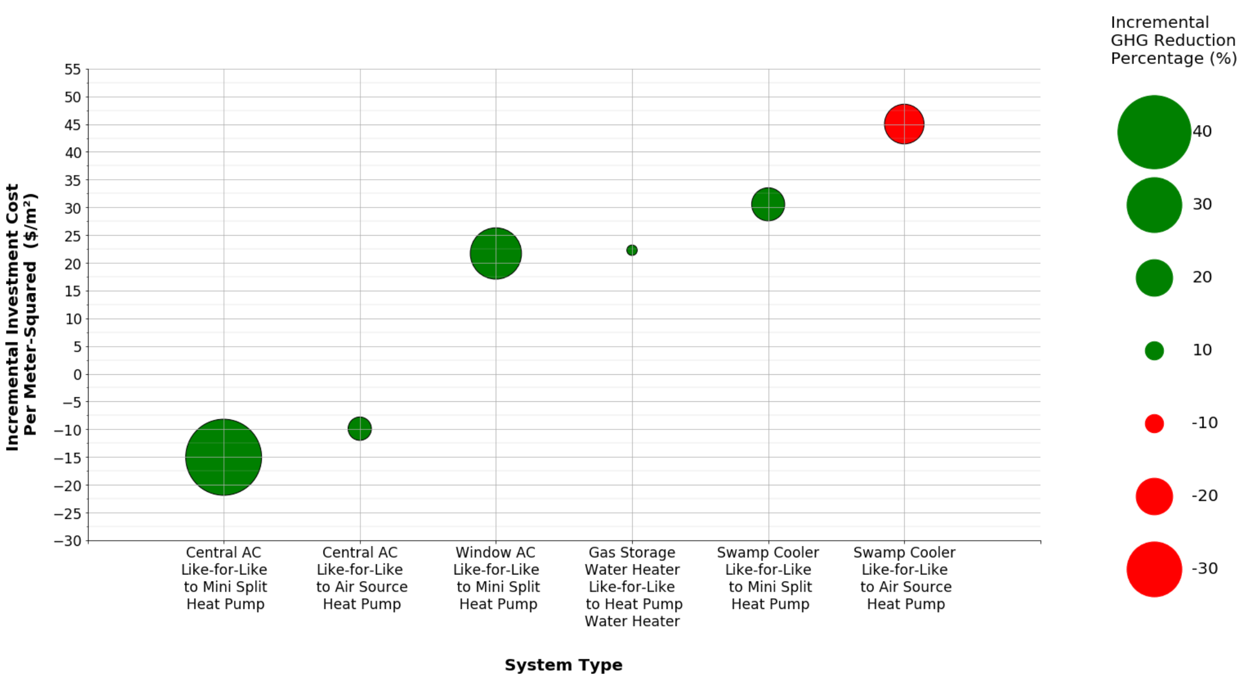
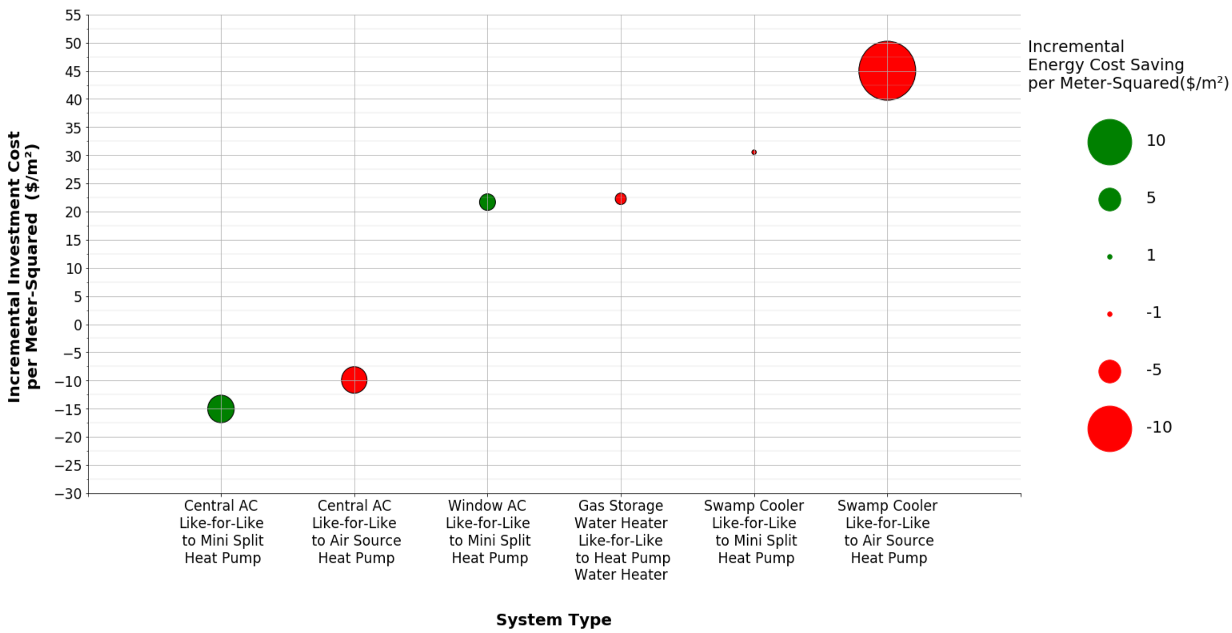


Figure D2-18. Incremental GHG reduction percentage and incremental investment cost of individual measures for the residential buildings in the Winchell neighborhood



In terms of energy cost saving, a general trend shown in Figure D2-19 reveals that most incremental costs do not result in a positive energy cost saving. In fact, only two scenarios, which are from central AC efficiency upgrade to mini-split heat pump and from window AC efficiency upgrade to mini-split heat pump, result in positive incremental energy cost saving. This is because electricity is relatively more expensive than natural gas in Fresno, which does not favor electrification.

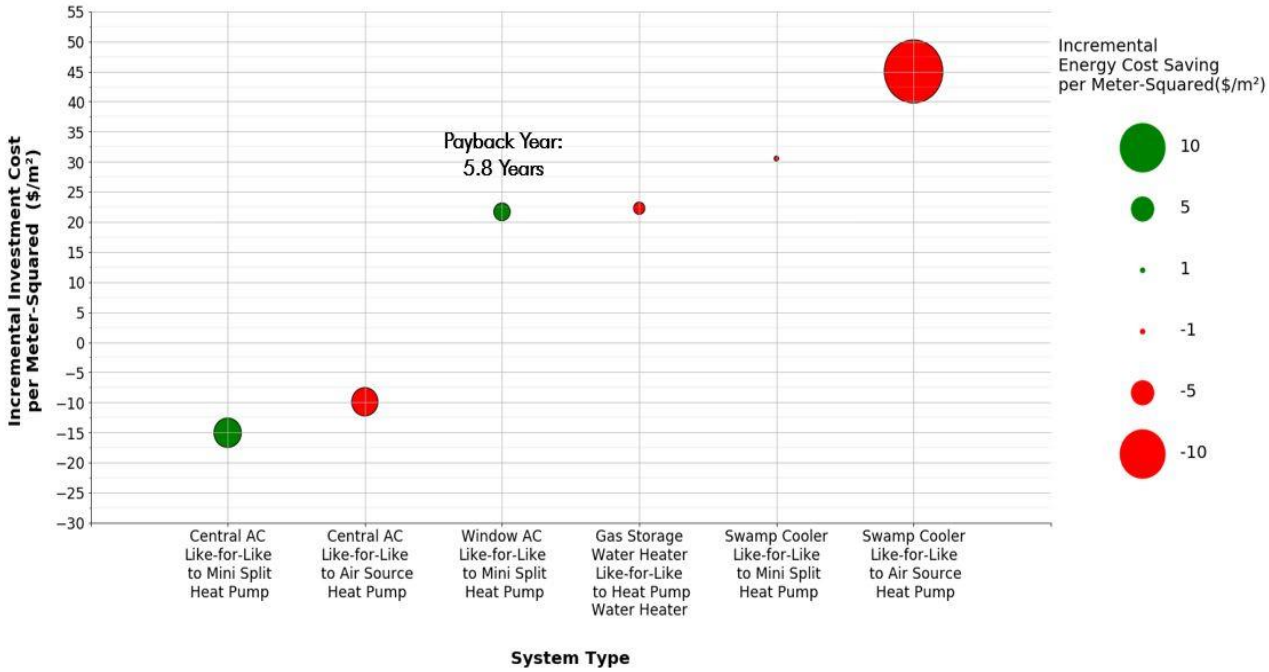
Figure D2-19. Incremental energy cost saving percentage and incremental investment cost of individual measures for the residential buildings in the Winchell neighborhood



As shown in Figure D2-20, incremental payback year is not applicable to the first scenario since the incremental cost is negative, which means the electrification upgrade is even cheaper than the like-for-like upgrade. Another four scenarios do not have payback year because the incremental energy cost saving is negative. Thus, the incremental investment cost in these scenarios can never be paid back. Finally, there is only one scenario that have a positive incremental payback year. The window AC like-for-like upgrade to mini-split heat pump, the payback period is 5.8 years due to high incremental cost and low incremental energy cost saving. If a panel upgrade and electric circuit upgrade is required, assuming the main panel upgrade costs $4000 and a circuit upgrade costs $500, the mean payback period will be increased to about 15.7 years.

It should be highlighted that, if the existing HVAC system is central air conditioner and has reached the end of service life, replacing it with a mini-split heat pump can save much more energy, investment cost, and energy cost, and reduce more GHG emission than a like-for-like retrofit with the same equipment type, and it doesn't have a payback year since the incremental investment cost is negative. If a panel upgrade and electric circuit upgrade is required, assuming the main panel upgrade costs $4000 and a circuit upgrade costs $500, the incremental cost will be positive but the payback time is still reasonable at an estimated 3.6 years.

Figure D2-20. Incremental payback year, incremental energy cost savings percentage, and incremental investment cost of individual measures for the residential buildings in the Winchell neighborhood



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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX E:
Resilience Hub Modeling Assumptions

November 2023 | CEC-500-2024-001-APA-G

APPENDIX E:
Resilience hub modeling assumptions

Nomenclature for PV and battery storage system

General	
LIBs	Lithium ion batteries
Sets	
K	Technologies (PV, storage, inverter and battery converter), indexed by k = {pv, s, in, cc}
T	Set of hours in a year indexed by t
τ	Set of hours during an outage event indexed by τ
Variables	
inv	Annualized investment cost ($/year)
op	Operation cost ($/year)
cap_k	Capacity of technology k to be installed (kW or kWh)
i_k	Binary decision of installing technology k
ui_t	Utility imports at time t
ue_t	Utility exports at time t
soc_t	Battery energy state of charge at time t (kWh)
ch_t, dch_t	Battery charging and discharging power at time t (kW)
pv_t	PV generation at time t (kW)
Parameters	
$CFix_k$	Fixed cost of technology k ($)
$CVar_k$	Variable? cost of technology k ($/kW or $/kWh)
$Cmax_k$	Maximum capacity allowed of each technology k
Ann_k	Annualization ratio of technology k
r	Discount rate
L_k	Lifetime of technology k
EC_t	Energy costs at time t ($/kWh)
FI_t	Solar compensation at time t ($/kWh)
ηch, ηdch	Battery charging and discharging efficiencies (%)
MiSOC	Minimum state of charge (%)
PCr	Battery power capacity ratio
AG	Battery aging ratio

ηcc, ηinv	Converter and inverter efficiencies (%)
SR_t	PV productivity profile (% of PV capacity)
Ld_t	System load at time t

Economics and objective function

The objective of the sizing PV and storage sizing exercise is to minimize the overall investment and operation costs. The investments of each technology (1) is expressed - using fixed and variable costs - as a function of the capacity (*cap*) together with a binary (*i*) that expresses the existence of the technology in the investment portfolio. The relationship between these 2 variables is imposed in (2), using the max capacity of each technology (*k)* considered (PV, storage, inverters and converters). The technology investments are annualized using a discount rate (*r*) and considering the lifetime (*L*) of each technology (3). The second part of the objective function is given by the annual operational costs described in (4). This function considers the costs of the utility imports (*ui*) and exports (*ue*) for each time (*t*). Considering these two components, the objective function is presented in (5).

$inv = \sum_{k \in K} (CFix_k . i_k + CVar_k . cap_k)\, Ann_k$	(1)
$cap_k \leq i_k . Cmax_k$	(2)
$Ann_k = \frac{r}{1 - (1 + r)^{L_k}}$	(3)
$op = \sum_{t \in T} (ui_t . EC_t + ue_t . FI_t)$	(4)
$min\ c = inv + op?$	(5)

Storage equations

The operation of the storage system is given by the equations below. The battery energy flows must respect the storage energy balance, described by a typical reservoir model, considering charge and discharge efficiencies (ɳ), as shown in (6). The battery state of charge is constrained by minimum requirements of operation and by the capacity of storage installed (7). Charging and discharging rate are also limited by the power conversion ratio of the battery (PCr). Using the approach of equation (8), the number of hours needed to charge the battery at full capacity is 1/PCr. Depending on the efficiencies (ɳ), there is a possibility that simultaneous charging and discharging becomes a viable solution from a mathematical point of view. To avoid this situation to happen, and keep our model realistic, we explicitly prevent simultaneous charging and discharging using a binary variable (α) in equations (9) and (10). Equation (11) limits the use of the battery, with the objective of approximating the battery aging phenomenon, based on a linearization methodology presented in (ref). According to the methodology, AG is the aging coefficient calculated based on the targeted lifetime of the battery together with physical parameters associated with the battery technology. Finally, the capacity of the battery converter (cc) imposes a limit to the battery charging and discharging in each period.

We assume two cases: (1) no storage rebate is available and (2) the SGIP rebate was modeled as an 85% discount in the investment cost (SGIP Equity Rebate, SGIP 2021 handbook)

$soc_t = soc_{t-1} + ch_{t,}.\eta ch - \frac{dch_t}{\eta dch}$	(6)
$MiSOC \cdot cap_s \leq soc_t \leq cap_s$	(7)
$ch_t , dch_t \leq cap_s \cdot PCr$	(8)
$ch_t \leq \alpha M$	(9)
$dch_t \leq (1-\alpha) M$	(10)
$\sum_{t \in T} dch_t \leq cap_s \cdot AG$	(11)
$dch_t + \frac{ch_t}{\eta cc} \leq cap_{cc}$	(12)

PV technologies and energy balances

The generation from the PV panel at each time (*t*) is limited by the installed capacity (*cap*) and the solar radiation hourly productivity profile (*SR*), as shown in equation (13). The power flow between DC and AC is given by the hourly PV generation together with the battery charging profile. This flow is limited by the inverter capacity, as shown in (14), and impacts the energy balance on the AC side according to (15). Besides the flow to the DC bus, the AC energy balance includes the building load (*Ld*) as well as imports from and exports to the utility.

$pv_t \leq cap_{pv} \cdot SR_t$	(13)
$pv_t + dch_t + \frac{ch_t}{\eta cc} \leq cap_{in}$	(14)
$Ld_t = ui_t - ue_t + \eta in \cdot (pv_t + dch_t - \frac{ch_t}{\eta cc})$	(15)

Utility exports (*ue*) are limited by the PV production, as shown in (16), to prevent the system from exporting energy from the battery and profit from energy arbitrage. These exports cannot be higher than the imports at the end of the year, as described in equation (17).

$ue_t \leq \eta in \,.\, pv_t$	(16)
$\sum_t (ui_t - ue_t) >= 0$	(17)

Cost assumptions

Parameters		Value
$CFix_{pv}$	Fixed cost of PV technologies ($)	*4200*
$CFix_s$	Fixed cost of storage technologies ($)	*2500*
$CFix_{cc}$	Fixed cost of the converter ($)	*50*
$CFix_{in}$	Fixed cost of the inverter ($)	*1800*
$CVar_{pv}$	Variable costs of PV technologies ($/kW)	*3000*
$CVar_s$	Variable cost of storage technologies ($/kWh)	*650 (- 85% rebate)*
$CVar_{cc}$	Variable cost of the converter ($/kW)	*140*
$CVar_{inv}$	Variable cost of the inverter ($/kW)	*550*
$Cmax_{pv}$	Maximum PV capacity (kW)	*500*
r	Discount rate	*3%*
L_{pv}	Lifetime of PV technologies	*25*
L_s	Lifetime of storage installations	*10*
L_{cc}	Lifetime of the converter	*15*
L_{inv}	Lifetime of the inverter	*15*
EC_t	*Energy costs at time t ($/kWh)* *PG&E Tariff B-10 (accessed in 9/1/2021)*	*Summer (June -Sept)* *Peak 4 - 9 PM* — *0.27142* *Part-peak 2 - 4 PM 9 - 11 PM* — *0.20973*

<table>
<tr><th colspan="2">Parameters</th><th>Value</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>off-peak
All others</td><td>0.17716</td></tr>
</table>
Winter (Oct - May)
<table>
<tr><td>Peak 4 - 9 PM</td><td>0.19515</td></tr>
<tr><td>Super Off-Peak
9 AM - 2 PM</td><td>0.15967</td></tr>
<tr><td>Off-peak
All others</td><td>0.12333</td></tr>
</table>
</td></tr>
<tr><td>FI_t</td><td>Solar compensation at time t ($/kWh)</td><td>Net-metering compensation
EC_t - Non-bypassable charges
(0.023/kWh)</td></tr>
<tr><td>ηch, ηdch</td><td>Battery charging and discharging efficiencies (%)</td><td>90</td></tr>
<tr><td>MiSOC</td><td>Minimum state of charge (%)</td><td>0</td></tr>
<tr><td>PCr</td><td>Battery power capacity ratio</td><td>0.3 (approx a 3 hours battery)</td></tr>
<tr><td>AG</td><td>Battery aging ratio</td><td>150.03</td></tr>
<tr><td>ηcc, ηinv</td><td>Converter and inverter efficiencies (%)</td><td>95</td></tr>
<tr><td>SR_t</td><td>PV productivity profile (% of PV capacity)</td><td>Calculated based on TMY3 radiation profile for Fresno area, considering panel tilt equal to the latitude.</td></tr>
<tr><td>Ld_t</td><td>System Load at time t</td><td>Obtained from the building simulation</td></tr>
<tr><td>Lc_t</td><td>Critical system Load at time t</td><td>All electric load was considered critical: $Lc_t=Ld_t$</td></tr>
</table>

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APPENDIX F:
Light Duty Vehicle Health Damage Modeling Additional Details

November 2023 | CEC-500-2024-001-APA-G

APPENDIX F: Light duty vehicle health damage modeling additional details

Alongside notably high exposure to air pollution from industrial and agricultural activities, Fresno County has high levels of pollution from on-road vehicle emissions, in particular exposure to $PM_{2.5}$ (Reichmuth, 2019), the pollutant most directly responsible for respiratory health issues (Xing et al. 2016). These impacts have shown to be inequitably distributed across the county between demographic groups, most visibly within the City of Fresno (CalEPA, 2021). Fresno neighborhoods, such as those in the west area of the city, have seen the health impacts of vehicle pollution disproportionately impact Black and Latino communities (Lee and Crowder, 2017), many of whom are low-income and living near highways, such as Highway 99 (Ayres and Eisinger, 2016).

A recent Executive Order calls for the transition of all new passenger vehicles to zero-emission vehicles (ZEVs) by 2035 (CA, 2020) and seeks to improve vehicle charging infrastructure to 250,000 charging stations (CPUC, n.d.). SB (Senate Bill) 350, the Clean Energy and Pollution Reduction Act of 2015 is another recent statute that aims to alleviate health issues caused by vehicle pollution in California by supporting the increased adoption of electric vehicles (EVs) across the state, alongside addressing other key environmental goals, such as a reduced dependence on carbon-intensive fossil fuels (CPUC, n.d.). SB 350 and its Transportation Electrification programs call for state partnerships with investor-owned utilities (IOUs) to implement financing mechanisms for making the acquisition of EVs more accessible and affordable to low and middle-income residents who may have not initially considered driving an EV, given the high upfront costs (CPUC, 2021; DOE, n.d.). Through its Transportation Electrification framework, SB 350 supports more equitable adoption of EVs, recognizing the many significant barriers that prevent certain communities from accessing an EV (Muehlegger and Rapson, 2017; Ju, Cushing, and Morello-Frosch, 2020; Eilert et al., 2016).

California initiatives such as the California Electric Vehicle Infrastructure Project (CALeVIP) and the Electric Vehicle Charging Station Financing Program offer rebate incentives and loan support for property owners and small business that implement on-site EV charging infrastructure for public access, with additional support offered for projects located in disadvantaged communities (DACs) (DOE, n.d.). Projects such as the Clean Vehicle Rebate Program (CVRP) offer rebates directly to California residents who have purchased or leased a ZEV and are deemed as being low-income (based on gross annual income). The Clean Cars 4 All program offers similar rebate incentives to low-income Californians for purchasing a ZEV, but with the added directive the recipient will subsequently retire their older, more pollution-prone vehicle in exchange (DOE, n.d.). There is an additional push for state organizations such as California Air Resources Board (ARB) to increase awareness of these programs in DACs. While certain financing mechanisms, such as these rebate and incentive programs, have lowered some of the financial barriers to accessing EVs, there is still an additional need to identify where state resources, such as financial assistance and charging infrastructure, should be allocated and prioritized to produce the greatest overall health benefits for communities most heavily impacted by vehicle-borne pollution.

Efforts to model the health and monetized impacts resulting from vehicle emissions have taken quantitatively rigorous approaches to estimating how increasing degrees of exposure to different pollutants lead to a range of health consequences, demonstrated with the APEEP (Air Pollution Emissions Experiments and Policy) modeling tool [Muller and Mendelsohn, 2006]. The EASIUR (Estimating Air pollution Social Impact Using Regression) modeling tool builds upon conventional chemical transportation modeling to further to show the social costs of exposure to pollution (Heo and Adams, 2015).

The two tools above (and the InMAP tool used in this report) are classed as "reduced-complexity" models, which entails the use of pre-defined relationships between emissions at source sites and pollution impact at receptor sites to be applied across a grid with certain environmental parameters and inputs already embedded within, allowing for high-order health impacts to be estimated with relatively little computational power required. The use of these models lie in contrast to the use of full-form emissions impact models that capture the individual photochemical and atmospheric processes involved in emissions transport and accumulation to a more complete extent, factoring in detailed environment-specific inputs and accordingly requiring a higher degree of user expertise and computational power (Gilmore et al. 2019; Baker et al.) Due to the many complex and nuanced variables involved in understanding how pollution uniquely affects different people with different underlying conditions, as well representing the uncertainty in how vehicles travel, it has shown to be very challenging to produce quantitatively rigorous modeling tools that can accurately predict health impacts. Still, while these models are favorable for both their health impact estimating power and simultaneous ease-of-use and accessibility, the resolution of the findings is not immediately resolved to the specific neighborhoods within counties that need the most attention.

Whereas numerous studies have employed various modeling methodologies to demonstrate the dire health situation concerning on road emissions and exposure to particulate matter in California's Central Valley region (Foy and Schauer, 2019; Lee and Park, 2020; Samuelsen et al., 2021), efforts to most effectively roll out ZEV adoption in California and Fresno County to maximize health benefits will require a means to accurately report not just total county-wide health impacts, but further which neighborhoods are most at risk and where polluting vehicles are most in need of replacement. This will specifically require the use of input emissions data that detail not only the specific within-county locations of source vehicles, but further ensure they are the exact types of vehicles covered by clean transportation programs in California.

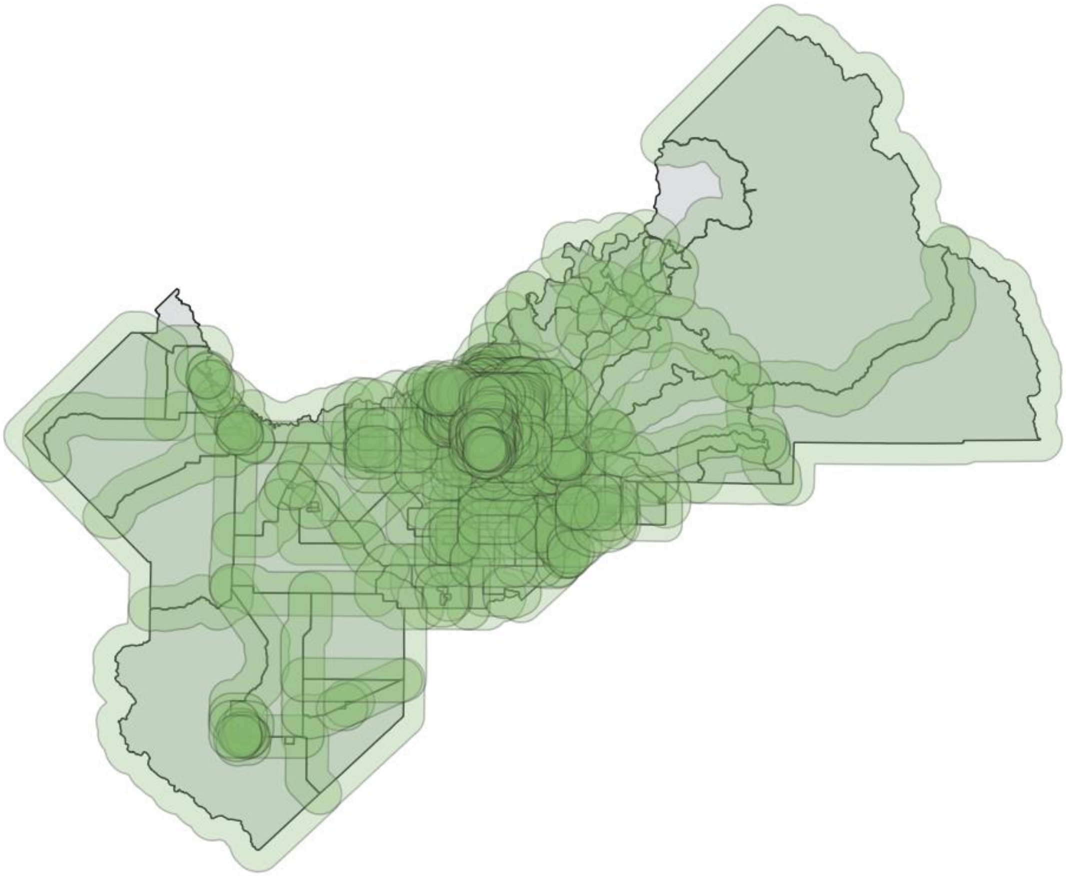
This study is an effort to identify the specific needs for meeting these modeling goals and address shortcomings in resolution by developing a quantitative approach for spatially allocating source emissions from light-duty vehicles to the block group level, producing county-level health impacts that can provide information where within the county vehicle replacement should be prioritized. Given their dire health situation and position to benefit substantially from increased ZEV adoption, we apply our methods to Fresno County to reveal the degree to which increased replacement of gasoline-fueled vehicles can lead to the most significant health improvements. These types of modeling efforts that could inform state policy pertaining to which census block groups and overlapping neighborhoods are most impacted by LDV vehicle pollution and help policy makers decide where ZEV adoption support programs should be most prioritized.

Complex Method

The complex method of emissions allocations seeks to more accurately capture the spatial resolution of allocated EMFAC EI relative to where vehicles are actually being driven throughout Fresno County

This requires additional layers of calculation that allow us to allocate county-level emissions quantities down to block groups and then distribute across road segments contained within and across block groups. Additionally, we account for variation in this travel between different vehicle types. Compared to the simplified method where emissions quantities were distributed to each block group, the complex method first seeks to identify emissions per VMT rates attributed to each block group, where these rates are the averaged VMT values of all vehicles of all light-duty types associated with each block group, allowing for variation in vehicle type to be accounted for. To account for vehicle travel across counties, we use average one-way trip distances obtained from the EMFAC EI dataset as a proxy for how far each vehicle type will likely travel beyond the boundary of its origin block group. To capture these travel distances, variable-distance buffers were drawn around each block group polygon according to the average one-way trip travel distances associated with the vehicle populations situated in each block group, accounting for vehicle type. This showed how far each block group's associated emissions rate traveled beyond its boundaries, consequently creating a multitude of overlapping regions that contained emissions rates corresponding to many block groups, as portrayed in Figure F-1. The basic idea in allocating emissions down to road segments is simply to multiply the emissions per VMT rates associated with each block group by the VMT quantities attributed to each road segment contained within that block group to ultimately reveal emissions quantities for each road segment.

Figure F-1. Buffer-distance polygons drawn around each county block group, where buffer distance for each block group is the average one-way travel distance for all vehicle types associated with that block group



Given the high degree of overlap between these buffer polygons, there is significant challenge presented in deciding which emissions rates should be attributed to produced overlap regions and just where exactly the boundaries of these overlap regions should be drawn, often made up of dozens of overlapped buffer polygons, as previously displayed. Consequently, the simple goal of multiplying each buffer polygon's emissions rate by its underlying road segments becomes uncertain when there are simultaneously many polygons laying on top of those same roads segments. This task thereby becomes exceedingly complex for simple calculations between vector geometries and accordingly impelled us to employ strategies in raster analysis, whereby the county layer is viewed as a grid of pixels, rather than shapes. For our purposes, each pixel is attributed to an emissions rate. The goal of implementing raster analysis here is to average the pixels of overlapping buffer polygons together, allowing for emissions values from overlapping polygons to neatly be averaged between vertically aligned pixels, rather than across excessively numerous geometries. Whereas these emissions rates needed to be averaged, an additional consideration that needed to be addressed involved determining how averaged pixels from overlapping buffers should be weighted, primarily asserting that buffer polygons corresponding to higher vehicle population counts should hold larger influence in an average than buffer polygons corresponding to lower vehicle population counts. To solve this issue, we weighted emissions rates by vehicle population by simply multiplying the associated average emissions rates of each block group buffer with its associated vehicle population count.

To find the population-weighted average of each emissions rate corresponding to each pixel, each buffered polygon was rasterized as its own layer and summed. Alongside, the vehicle population counts corresponding to each buffered polygon were similarly rasterized as their own layers and summed. Lastly, summed population-weighted average rasters for each emissions type were divided by the population sum raster to produce for each emissions category a raster portraying the population-weighted emissions rates across the county, as described in Equation (1) below. The resulting calculation produces a pixelated raster layer of emissions rates for each species depicting variation in emissions rates across the County, as displayed in Figure F-2. The next step in distributing emissions along roads segments involved finding the average representative emissions rate for each emissions species to attribute to each roads segment, shown in Figure F-3. Accordingly, a roads network layer was buffered to 12ft to account for typical road length, with the average pixel value recorded within each of these road segments through zonal statistics, a method used to calculate summary statistics of raster pixels contained within vector polygons.

(1)

$$W_s = \frac{\sum_{i=1}^{n} p_i X_i}{\sum_{i=1}^{n} p_i}$$

where

W = population-weighted average

s = emissions species

p = population

X = emissions rate

N= number of block groups in county

Figure F-2. Population-weighted raster of SOx occurring on a scale from 3.33e-09 to 5.63e-09 tons $PM_{2.5}$ per VMT (black to white)

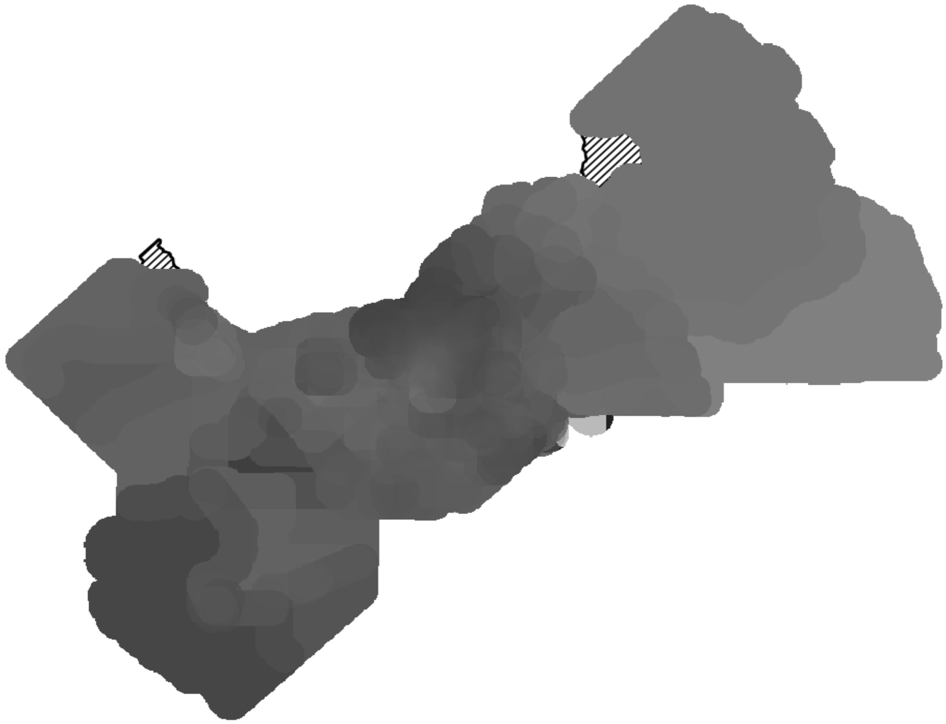
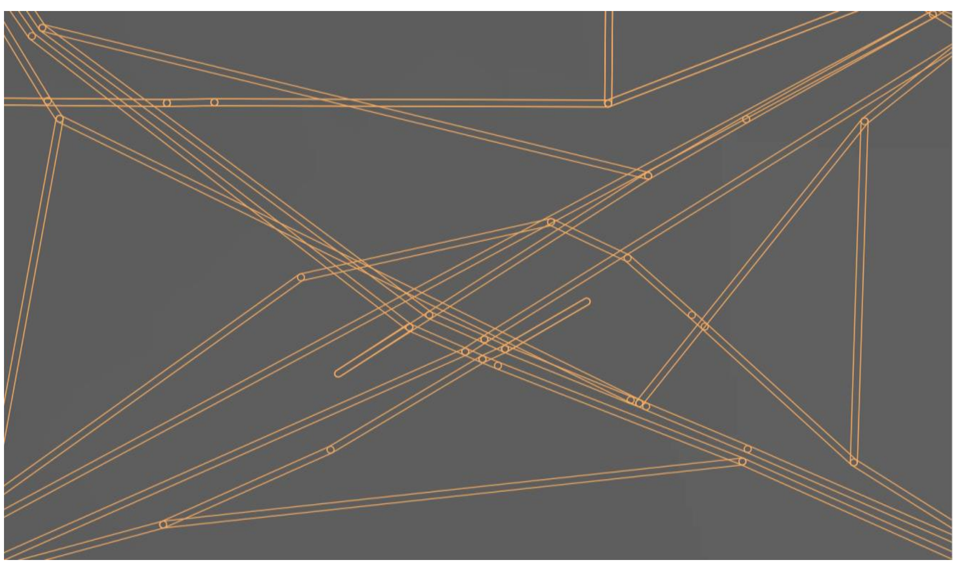
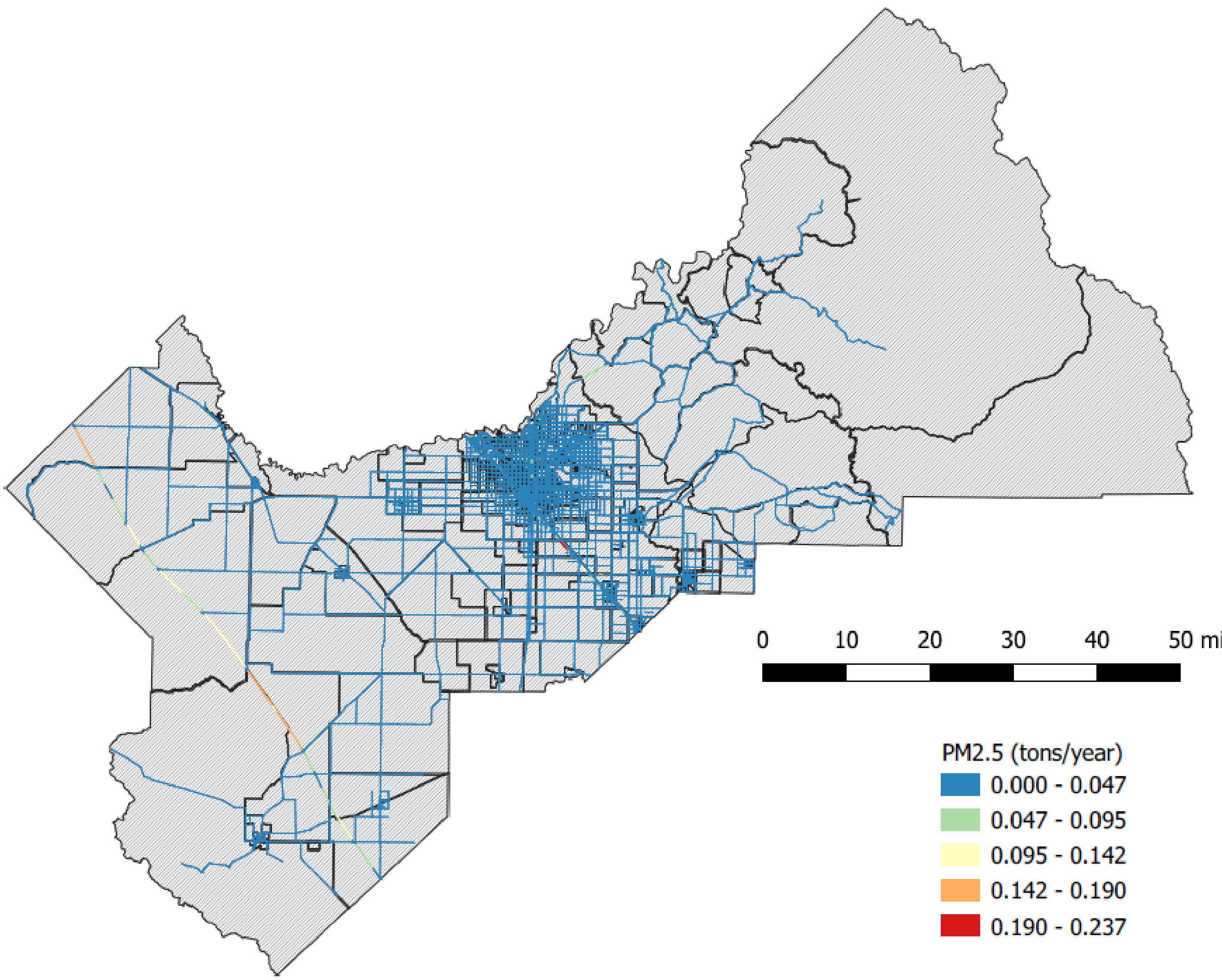


Figure F-3. 12 ft. buffered roads used for taking average emissions values via zonal statistics



The total VMT contained for each road segment was then multiplied by the emissions rates for each road segment to ultimately produce a total tons emission value for each road segment, as shown in Figure F-4. Once this was complete and tons emissions values for NOx, SOx, $PM_{2.5}$, NH3, and VOC were entered for each road segment, the subsequently produced shapefile was entered into InMAP as the required input emissions data. We specifically utilize a variation of the InMAP model, the InMAP Source Receptor Matrices (ISRM), which is a dataset containing quantitative relationships between the $PM_{2.5}$ concentrations at emissions "source" sites and the "receptor" sites where source emissions travel to. In other words, for every emissions source location in the InMAP grid, there is a given change to the concentration of those emissions at its receptor location. Once source emissions are mapped to their receptor locations, the ISRM is accessed to calculate how the concentrations of these emissions have changed and evolved into the secondary emissions that determine $PM_{2.5}$ exposure, based on linear relationships. Since these relationships are already provided, this provides a much quicker means for obtaining health impact damages from an input emissions shapefile than running the full InMAP model and individually calculating these relationships from the beginning.

Figure F-4. Input Emissions Shapefile showing PM2.5 produced through the complex method

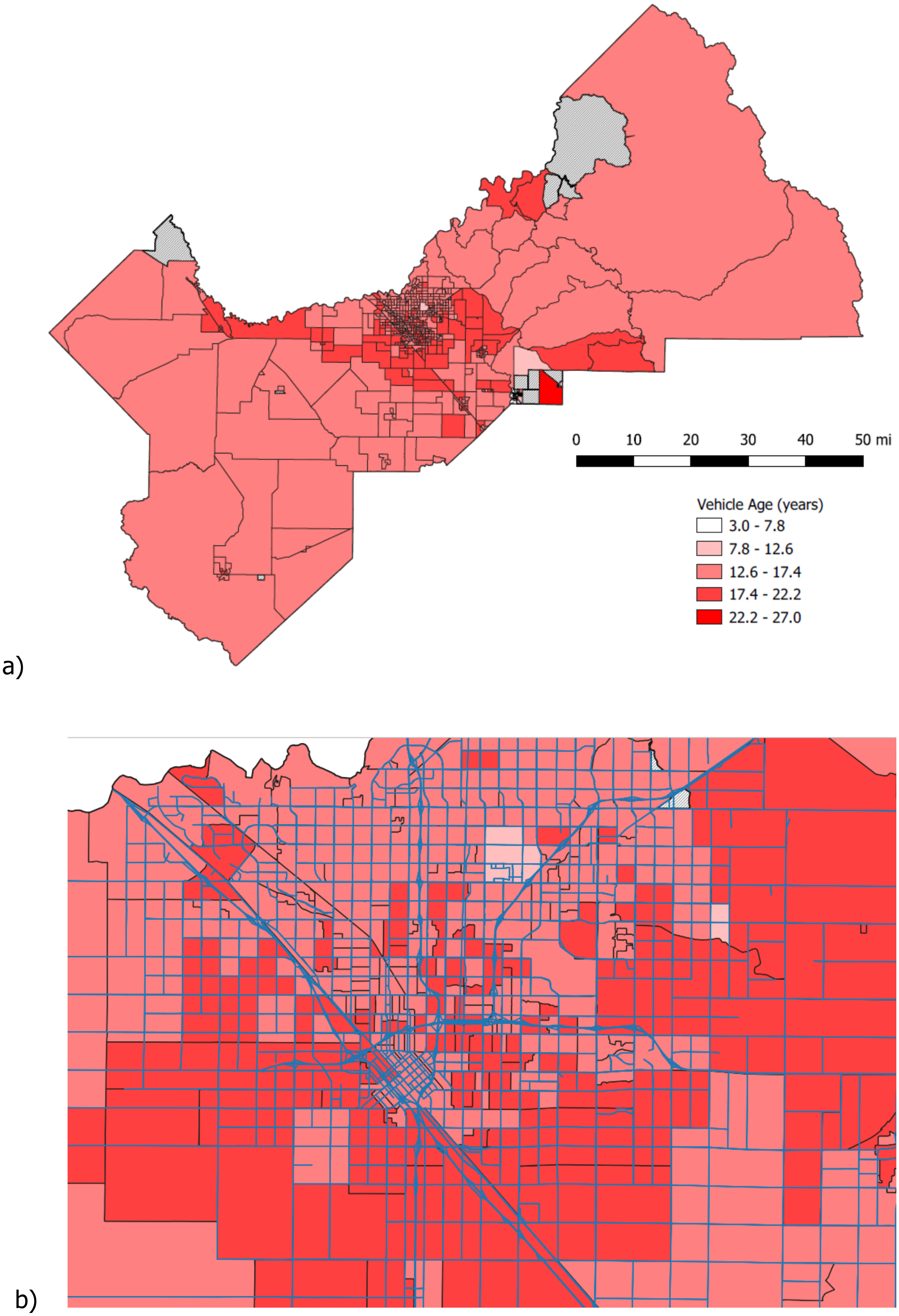


Vehicle Ages

We then look at the distribution of vehicle age across Fresno County as shown in Figure F-5.

The south parts of the city and areas east of the city have an older vehicle population with average vehicle ages between 17.4 and 22.2 years.

Figure F-5. Vehicle age across Fresno County in years with a) across the county and b) at the urban core



CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX G:
Action Plan Key Takeaways

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APPENDIX G:
Action Plan Key Takeaways

The outreach, building modeling, resilience hub modeling, and health modeling from ZEV passenger vehicles were used to help formulate the companion action plan, from which key takeaways are reproduced below.

Policy Gaps

1. Gaps in extreme heat resilience are that (a) there are no requirements for maximum temperatures indoors or minimal cooling requirements in building codes and standards; and (b) an estimated 15% of homes lack air conditioning, which can lead to dangerous indoor conditions during extreme heat waves which are growing in severity, duration, and frequency.
2. A disconnect among policies focusing on different aspects of buildings (energy, decarbonization, resilience, health, safety) and from different agencies.
3. Addressing deferred maintenance upgrades in DAC homes (e.g. roof repairs, electric panel upgrades, and kitchen and bathroom ventilation fans) is an equity priority for resident health and safety, independent of decarbonization and electrification policy goals. For example, about half of single-family homes are not "solar PV-ready" and there is no program to address this (repairing dilapidated roofs and upgrading old electric panels).
4. There is a lack of adequate financing programs for upgrading homes in DAC areas to meet decarbonization, equity, and climate resilience goals.
5. A substantial fraction of residents are renters in single family homes, and many clean energy programs are open only to homeowners. This is a major gap in equitable financing programs. For example, a large fraction of homes in South Fresno (70%) are single family homes and about 2/3 of those are rentals. These renters are not able to install and benefit from rooftop solar PV since renters are not eligible for solar PV rebates.

Recommendations

1. The state should enact design standards for maximum allowed temperatures in all buildings, and all residents of Fresno should have access to an air conditioner at home. Mechanisms would be needed to ensure that resident utility bills are not increased with more electricity consumption.
2. There is the need for more integrated pilots and demonstration projects in DACs to "learn-by-doing" and develop best practices. More demonstration and pilot projects in the residential sector combining energy efficiency, electrification of heating, EVs, and solar PV, are needed to determine what works best for residents and to develop best practices for inspection, implementation, and monitoring. Such pilots would provide essential data collection and fill data gaps in installation costs and highlight the interactions between measures for improving cost-benefit analysis. Rather than having several serial interventions, integrated programs can help develop pathways to

scale up DAC decarbonization, equity, and resilience efforts. There are elements that include some of the above (e.g., EV and charging programs) but no integrated program for DAC areas.

   a. Upgrading DAC homes to rooftop solar PV and to cleaner end-uses (such as electric heat pumps for HVAC and water heating and used electric vehicles) is an opportunity to meet multiple policy objectives such as decarbonization, equity, resilience, and improved public health.

3. Existing programs for weatherization and energy efficiency are natural starting points to build greater capacity and implement broader home upgrades to better enable scaling up of decarbonization, equity, and resilience efforts in DAC homes.
   a. Current weatherization programs do "like-for-like" upgrades (e.g. old gas water heater upgrade to new gas water heater or old evaporative cooler upgrade to new evaporative cooler) and should be broadened to include electrification upgrades to heat-pump based space and water heating and upgrades from evaporative coolers to air conditioners.
   b. Expansion of energy efficiency audits to include other assessments such as building electrification readiness and extreme weather resilience audits/assessments, rooftop PV readiness, and EV readiness could improve overall efficacy of achieving policy goals, improve equity, and increase the speed of deployment. Current home audits, recommended measures for installation, and estimated benefits in energy efficiency programs could be broadened to become "comprehensive climate audits" including electrification and resilience assessments, recommended measures, and estimated energy and non-energy benefits of recommended measures.
   c. Investment is needed in expanding the capacity and requirements for this broadening of energy efficiency programs such as training, handling legal issues such as data protocols and privacy, program organization, cost-benefit quantification of resilience measures, and decision support tools.
4. Innovative finance and incentive programs
   a. Single family renters are not eligible for rooftop solar PV incentives and would benefit from more attractive community solar programs; or if solar PV is installed on rental homes with PV incentives for property owners, there would need to be property owner agreements or covenants to constrain any future rent increases.
   b. More work is needed on developing financing options and pathways for DAC residential upgrades particularly to meet the high up-front costs of building and passenger vehicle electrification and related home infrastructure upgrades (electric panels and electric circuit upgrades).
   c. Rooftop solar PV and battery storage with Self-Generation Incentive Program (SGIP) incentives for storage are an attractive opportunity with favorable economics for Fresno cooling centers to be upgraded to more all-around "resilience hubs" for emergency event support, assuming that the City is eligible for SGIP Equity incentives for storage.

5. Promote low-cost yet effective interventions
    a. Low-cost Do-it-yourself (DIY) fans with MERV13 air filters can improve indoor air quality especially during wildfire events with smoky air and are an opportunity for program and outreach expansion.
    b. Used EVs can be an attractive option for many residents, and residents would benefit from more programs, higher incentives, and greater community outreach.
6. More consolidated implementation programs are needed to reduced transaction cost barriers and improve equity among residents.
    a. Program consolidation would minimize the transaction costs to residents and provide greater access to existing programs, rebates, and incentives and in principle could reduce transaction costs for program administrators as well. For example, program consolidation would require residents to be aware of a single clean energy program rather that the current patchwork of programs across energy efficiency, EVs, solar PV, air quality, healthy homes, etc.
    b. Program consolidation would also maximize benefits to residents and provide more opportunities reduce their energy bills. For example, combining measures such as solar PV and heat pump electrification can bring resilience benefits and stabilize utility bills; and combining used EVs and heat pump electrification can better reduce overall energy bills from the operating cost savings of EVs versus older gasoline-based vehicles.
7. More outreach is needed to improve resident awareness of existing programs. The project found a general lack of awareness among residents for existing programs in community solar, rooftop PV, and clean cars. As highlighted above, more "one-stop shop" models for incentive and deployment programs would help to address issues in awareness/education and transactional costs.

Summary of key community outreach findings

- Most residents are not comfortable in their homes in hot (70%) or cold weather (60%) at least once a week. This is an area to improve equity – to provide better indoor comfort during the summer and winter without increasing energy bills.
- About 45% of the participants reported having household member(s) with asthma and allergies. Although residents did not report excessive concern with indoor air quality, the prevalence of indoor air filters seems very low and residents seem quite open to adopting low cost Do-It-Yourself air filters. More education on HVAC furnace/AC filter cleaning or replacement is another opportunity.
- Common concerns for energy related services include high utility bills, poor outdoor air quality, and transportation fuel costs and access
- Awareness of existing rooftop solar PV and clean vehicle rebate programs appears low (80% or more unaware of these programs) and is an opportunity for greater outreach and/or more program consolidation to avoid missing residents who may inquire about a specific energy efficiency/PV or EV program.

- There is a general lack of interest in e-scooters sharing, and bike sharing due to long travel distances with more interest in carpooling.
- For personal transportation, an estimated 60% or more of residents drive less than 35 miles per day and thus electric vehicles (EV) with Level 1 charging is an option instead of a gasoline vehicle. The dominant fraction of people was willing to adopt an electric vehicle if it was affordable.