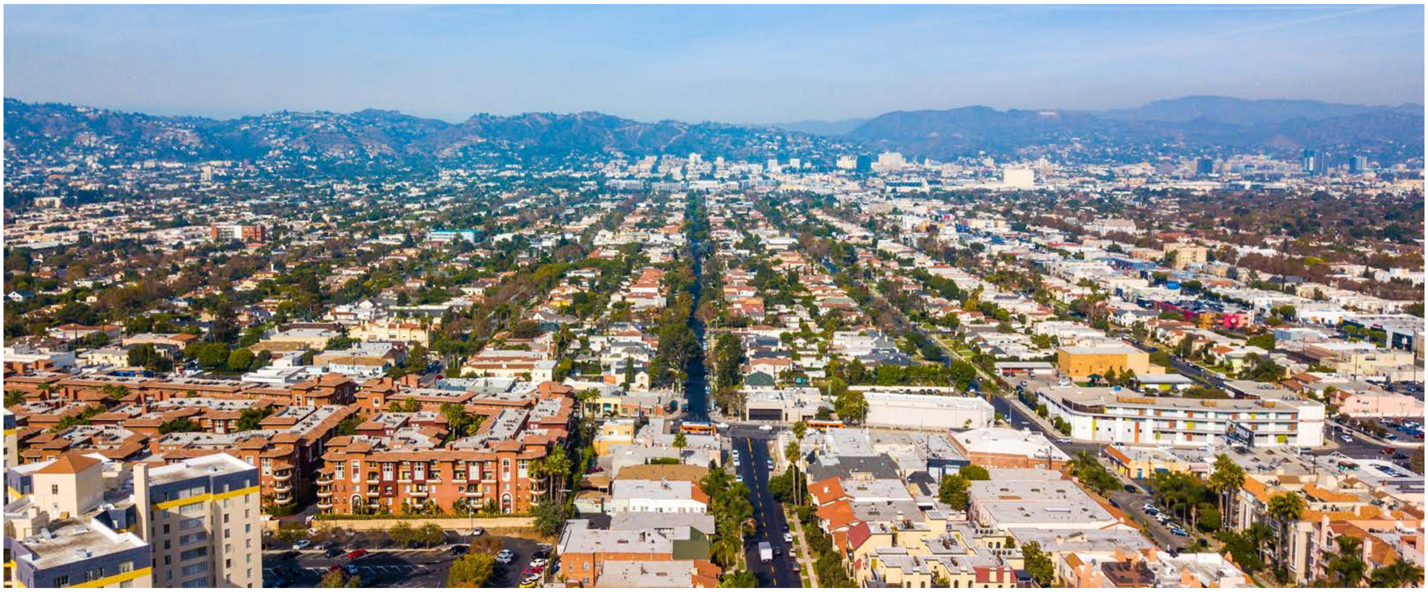
LA100 EQUITY STRATEGIES



Chapter 7: Housing Weatherization and Resilience

FINAL REPORT: LA100 Equity Strategies

Katelyn Stenger, Philip White, Anthony Fontanini, Lixi Liu, Janet Reyna, Noah Sandoval, Ry Horsey, Joseph Robertson, and Jeff Maguire

LA DWP

NREL Transforming ENERGY

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LA DWP

NREL Transforming ENERGY

LA100 EQUITY STRATEGIES

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Preface

The Los Angeles 100% Renewable Energy Study, or LA100, revealed that although all communities in Los Angeles will share in the air quality and public health benefits of the clean energy transition, increasing equity in participation and outcomes will require intentionally designed policies and programs. The LA100 Equity Strategies project was specifically designed to help Los Angeles identify pathways to such policies and programs in the form of equity strategies. The project aimed to do this by incorporating research and analysis to chart a course toward specific, community-prioritized, and equitable outcomes from the clean energy transition outlined in the LA100 study.

The Project Partners

The Los Angeles Department of Water and Power (LADWP), the National Renewable Energy Laboratory (NREL), and the University of California Los Angeles (UCLA) partnered on the LA100 Equity Strategies project to develop strategies for engaging communities, funding equitable technology and infrastructure investments, expanding existing programs, and designing new programs and policies to improve equity by incorporating what community members themselves know is needed to achieve a more equitable energy future.

The Project Approach

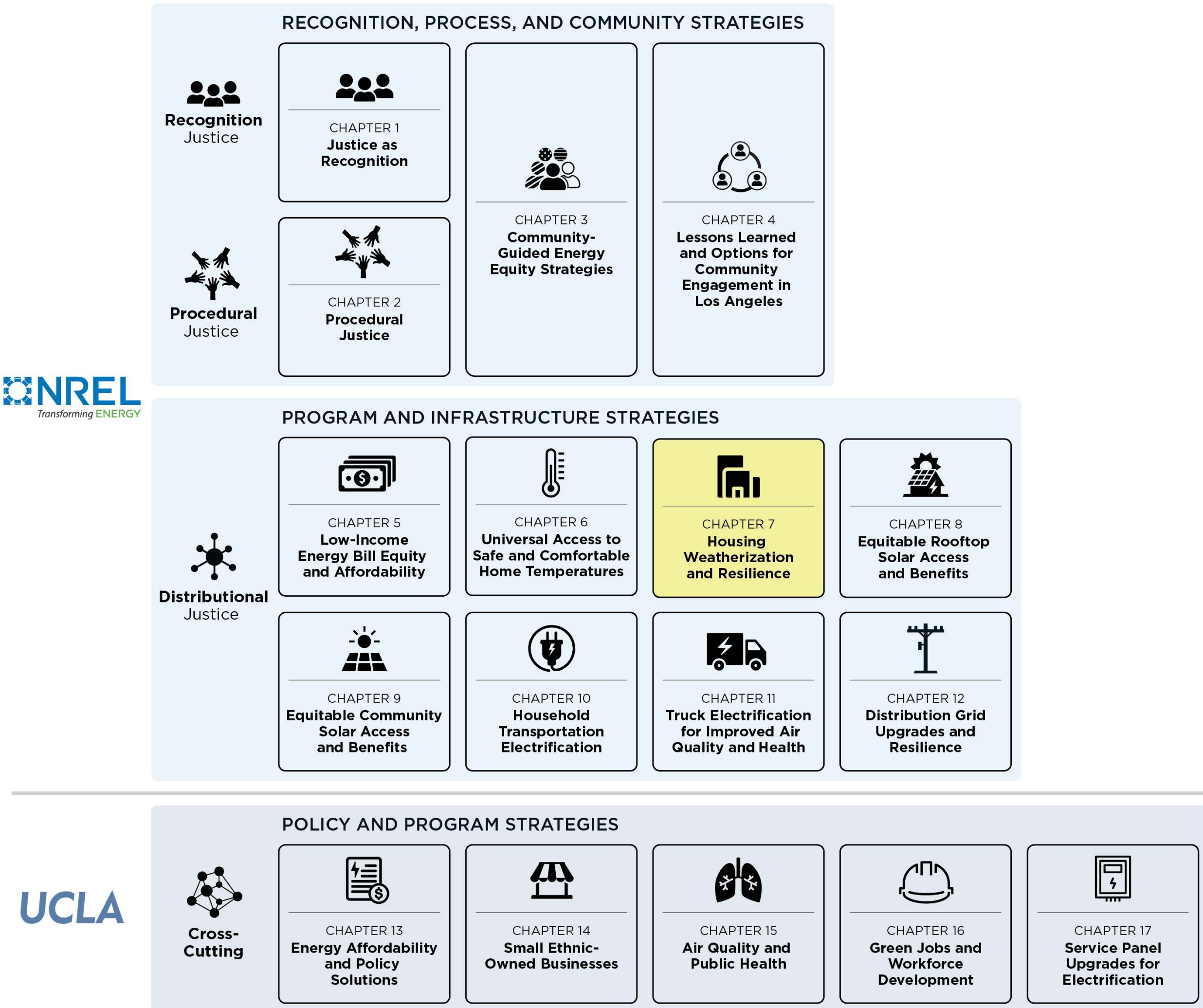
LA100 Equity Strategies employs a unique mixed-methodological approach utilizing three distinct—but connected—research efforts. Through these efforts, NREL and UCLA developed a range of strategy options for increasing equity in LA's transition to 100% clean energy.

A Project Summary

To get a high-level overview of the project, you can dive into the executive summary, interactive data visualizations, and more on the LA100 Equity Strategies website at maps.nrel.gov/la100/equity-strategies.

The Full Report

NREL's final full report for the LA100 Equity Strategies project encompasses seventeen chapters. The first twelve chapters, authored by NREL, are organized around the three tenets of justice. Chapters 1–4 address recognition and procedural justice, while Chapters 5–12 address distributional justice. The final five chapters, authored by UCLA, provide crosscutting policy and program strategies. Each chapter provides data, methods, insights, and strategies to help LADWP make data-driven, community-informed decisions for equitable investments and program development.



NREL Chapters

Chapter 1: Justice as Recognition

Chapter 2: Procedural Justice

Chapter 3: Community-Guided Energy Equity Strategies

Chapter 4: Lessons Learned and Options for Community Engagement in Los Angeles

Chapter 5: Low-Income Energy Bill Equity and Affordability

Chapter 6: Universal Access to Safe and Comfortable Home Temperatures

Chapter 7: Housing Weatherization and Resilience

Chapter 8: Equitable Rooftop Solar Access and Benefits

Chapter 9: Equitable Community Solar Access and Benefits

Chapter 10: Household Transportation Electrification

Chapter 11: Truck Electrification for Improved Air Quality and Health

Chapter 12: Distribution Grid Upgrades for Equitable Resilience and Solar, Storage, and Electric Vehicle Access

UCLA Chapters

Chapter 13: Energy Affordability and Policy Solutions Analysis

Chapter 14: Small Ethnic-Owned Businesses Study

Chapter 15: Air Quality and Public Health

Chapter 16: Green Jobs Workforce Development

Chapter 17: Service Panel Upgrade Needs for Future Residential Electrification

List of Abbreviations and Acronyms

AMI	area median income
AMY	actual meteorological year
CAIDI	Customer Average Interruption Duration Index
CARE	California Alternative Rates for Energy
DAC	disadvantaged community
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
HEIP	Home Energy Improvement Program
HOMES	Home Owner Managing Energy Savings
HVAC	heating, ventilating, and air conditioning
IRA	Inflation Reduction Act of 2022
LADWP	Los Angeles Department of Water and Power
LEED	Leadership in Energy and Environmental Design
LMI	low- and moderate-income
MF	multifamily
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database
PUMA	Public Use Microdata Area
RASS	Residential Appliance Saturation Study
SET	standard effective temperature
WBGT	wet-bulb globe temperature

Executive Summary

The LA100 Equity Strategies project integrates community guidance with robust research, modeling, and analysis to identify strategy options that can increase equitable outcomes in Los Angeles' clean energy transition. This chapter focuses on housing weatherization and access to cooling as means to achieve more equitable resilience to heat waves during unplanned power outages.

Specifically, NREL used weather, housing, and socioeconomic data to characterize LA's residential building stock. We developed a residential building stock model to simulate the energy use of 50,000 dwellings representing the diversity of housing types, appliances, climate zones, and household incomes across Los Angeles. We then simulated and evaluated the impacts of 10 building envelope and cooling upgrades on indoor temperature—a main cause of heat-induced health risks—over a 4-day power outage during a heat wave. We examined occupant exposure to extreme heat and how heat exposure changes with each upgrade across income, tenure (renter/owner status), building type, and disadvantaged community (DAC) status. We also examined upgrade costs and utility bills.

Based on the results of our analysis and community guidance, we identified building envelope upgrades and cooling strategies that could save lives and maintain safe home temperatures for LA's low-income households in the event of a planned or unplanned power outage during a summer heat wave.

Research was guided by input from the community engagement process, and associated equity strategies are presented in alignment with that guidance.

Community Guidance

Guidance from the LA100 Equity Strategies Steering Committee, community meetings, and listening sessions with community members cohosted with community-based organizations included the following:

Community Concerns

- The next power outage and heat wave in Los Angeles will have negative effects.
- Upgrades (i.e., weatherization and increased cooling access) will raise rents and cause displacement.
- The cost of energy efficiency upgrades will be unaffordable for some homeowners.
- Lack of access to safe and comfortable locations during heat waves.
- Energy inefficient housing, lack of approval to change cooling infrastructure, and cost of operating cooling systems can result in health risks for renters.

East LA Resident:

"So, the mayor says to go to a local library or senior center to cool off, right? The closest library here, which is only a block away from where I work, has been closed for three years … So where are the seniors supposed to go? It'd been closed since the pandemic … before that the air-conditioning had gone down. I had called the mayor and told them, you know what, if it would be somewhere in West Hollywood, they would fix it like this (snaps fingers)."

- Mistrust of energy efficiency service providers prevents some residents from improving housing efficiency.

Equity Strategies Steering Committee member on how they handled a recent heat wave:

"I have a window [AC] unit and it's in a different room than what I spend most of my time in. It was quite difficult. I would just go sit in my car for relief."

Community Priorities

- More diversified and community-tailored outreach and support (e.g., feedback channels) to co-develop, access, and utilize energy efficiency program benefits
- Affordable program options that do not require up-front costs
- Support for home improvements needed for upgrades, such as electrical panels or mold abatement
- Amended eligibility requirements for equity-deserving ratepayers that do not fit current criteria (e.g., moderate-income household eligibility)
- Maintenance and safety upgrade support
- Revised LADWP programs that address the split incentive problem between renters and homeowners
- Development of apprenticeship programs for energy efficiency retrofits that build on local knowledge and skillsets.

Distributional Equity Baseline

Equitable distribution of energy efficiency improvements can lead to more equitable resilience to power outages during heat waves. Distributional equity analysis found that LADWP residential energy efficiency investments between 2005 and 2021 disproportionately benefited non-disadvantaged, mostly White, mostly non-Hispanic, mostly home-owning, and mostly above-median-income communities (Figure ES-1).

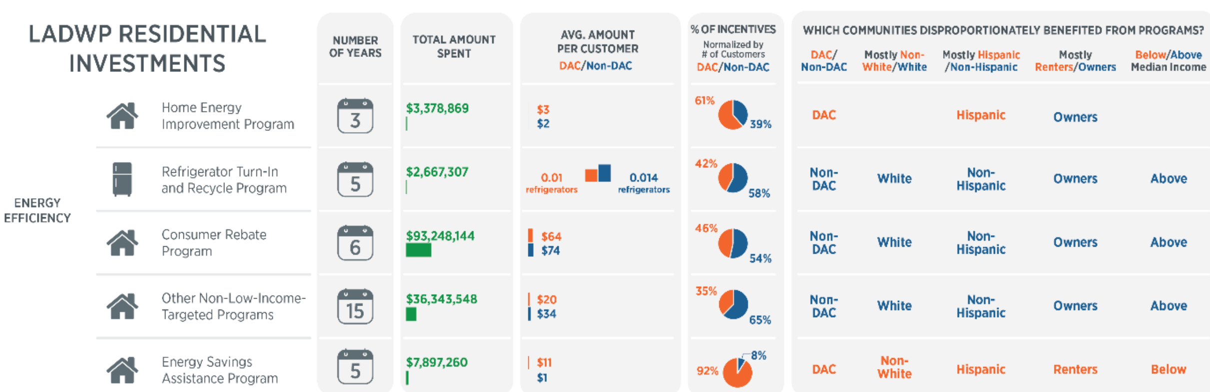
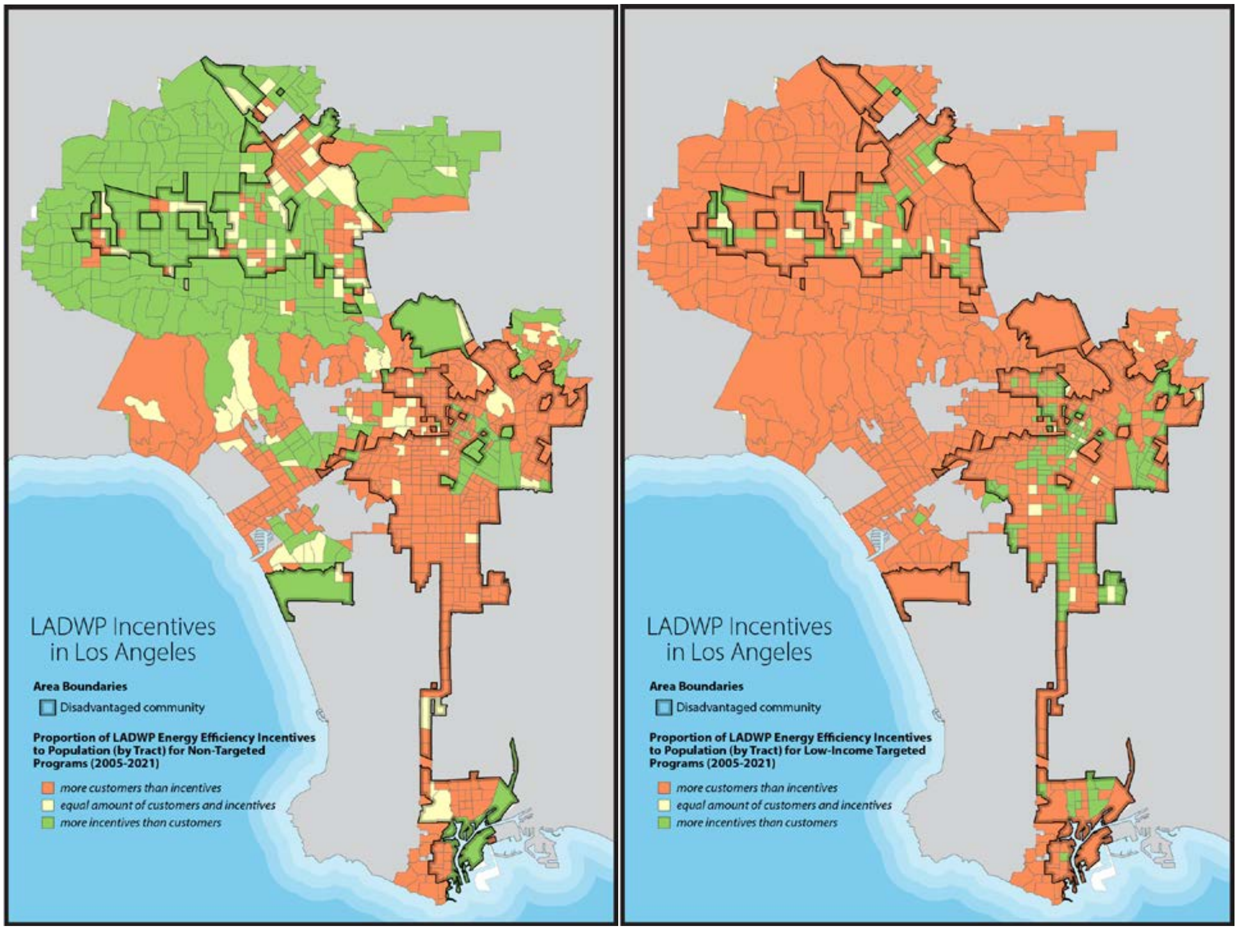


Figure ES-1. Statistical analysis of LADWP energy efficiency investments (2005–2021)

Of the 14 residential energy efficiency programs analyzed, one program—the Energy Savings Assistance Program—targeted low-income households and proportionately benefited DACs. Relevant to cooling access, LADWP increased rebates for small, window-unit air conditioners to $225 as part of the Cool LA program (LADWP 2022). For the other 13 energy efficiency programs that did not target low-income households, areas such as South LA did not receive energy incentive benefits proportional to their populations (Figure ES-2).



(a) (b)

Figure ES-2. (a) Distribution of LADWP incentives for programs not targeting low-income households and (b) Distribution of LADWP incentives for programs targeting low-income households

Key Findings

Modeling results showed using air conditioning before a power outage occurs can mitigate heat-induced health risks. Occupants can also employ strategies such as closing blinds during sunny conditions or opening windows when temperatures are cooler outside.

Modeling indicated many low-income households would start a power outage at unsafe temperatures, either because of a lack of access to or use of a cooling system. Access to and use of cooling, combined with robust building envelope improvements such as insulation, air sealing, and window replacements, reduces dangerous indoor heat exposure by 84%–96% over a four-day power outage; and in the first day of the outage, households reaching dangerous temperatures decreases from 85% to 33%. The duration of safe temperatures for low-income households increases from 0 hours in the baseline condition to 24 hours when cooling is used.

Both DACs and non-DACs have significant potential to increase resilience through broader cooling access and building weatherization; therefore, identifying policy and program actions that lower barriers to realizing the resilience benefits in these communities is key for equitable outcomes in Los Angeles.

Key takeaways include:

- *Multifamily building residents, which are predominantly renters, are disproportionately negatively impacted by heat exposure*. Multifamily households without cooling (or those that do not use cooling) started and remained at unsafe temperatures throughout the simulated power outage. Less than one-half of renters use cooling (Palmgren et al. 2021), placing them at a higher risk of unsafe heat exposure before and during an outage.
- *Access to and use of cooling reduces exposure to extreme heat* for all income levels, building types, and tenures. Cooling use with Title 24 envelope improvements, which are required for all new housing units in California, decrease average 4-day heat exposure between 84% and 96%.
- *Cooling use alone is insufficient in reducing dangerous heat exposure in single-family dwellings during an outage*. 74% of all dwelling types with cooling use reach unsafe indoor air temperatures within the first 24 hours of the outage. Cooling use decreases the starting temperature for most single-family dwellings by approximately 9°F. However, by the end of the first day of the power outage, single-family dwellings with cooling use prior to the outage follow similar indoor air temperature profiles as single-family dwellings without cooling.
- *Cooling use is effective and cooling use combined with Title 24 envelope upgrades are most effective at increasing the time before extreme heat exposure is reached*, particularly for low-income households. In the baseline condition, 85% of Los Angeles housing stock reaches the dangerous temperature threshold (86°F) in the first 24 hours of the outage. 37% of low-income households start the outage at the dangerous temperature threshold—meaning there are 0 hours until unsafe temperatures are reached. With a Title 24 envelope, 57% of the Los Angeles housing stock reaches dangerous temperatures within the first 24 hours, compared to 33% with cooling use and a Title 24 envelope. For the low-income dwellings included in this 33%, the hours until unsafe temperatures are reached are extended from 0 hours in the baseline to 24 hours when using cooling with Title 24 envelope. More time until unsafe temperatures are reached means more time for households and the city to plan and act.
- *Envelope improvements do not substantially reduce dangerous heat exposure for five or more unit multifamily building residents (who are predominantly renters).* Low-cost envelope improvements provide, on average, a 33% decrease in heat exposure for homeowners, but a 10%–12% decrease for renters. More than three-quarters of renters live in multifamily dwellings, and those dwellings have less natural ventilation, more thermal mass, and more insulated shared walls, resulting in more heat retention throughout the day. On average, Title 24 envelope improvements reduced exposure by 41% for renters and 77% for owners, whereas cooling use reduced exposure by 31% for owners and by 41% for renters across income levels. These findings suggest the need for differentiated strategies between renters and multifamily building residents and owners and single-family home residents.

Housing resilience equity metrics include:

- Level and duration of exposure to unsafe home temperatures (>86°F)
- Upgrade costs and utility bill impacts
- Household income
- Renter or owner occupancy status
- Housing type (multifamily, single-family)

- *Dangerous heat exposure can be reduced at the lowest cost in multifamily buildings*. Upgrade costs are lower in multifamily dwellings compared to single-family dwellings because these dwellings are generally smaller and better insulated (including by adjacent units), resulting in smaller cooling system sizes and, therefore, costs.
- *Inflation Reduction Act of 2022 (IRA) rebates can reduce or eliminate the cost of upgrades for low- and moderate-income households*. With IRA Section 50122 rebates, LADWP could install cooling with mini-split heat pumps in low-income (0%–80% area median income [AMI]) households without households incurring any debt by using a direct install program. However, IRA program budgets are limited, and current funds would cover upgrades in less than 1% of 0%–150% AMI households in Los Angeles.

Equity Strategies

Modeling, analysis, and community engagement identified the following strategies for achieving more equitable outcomes in building weatherization and cooling for resilience:

- *Target cooling access and envelope improvements by housing type*, where multifamily homes receive cooling access to address their greater exposure to dangerous temperatures, and single-family homes receive building envelope improvements to mitigate their increased exposure to outside temperatures.
- *Combine federal funding from the IRA or Weatherization Assistance Program* with existing LADWP rebates to augment existing programs—particularly the Home Energy Improvement Program (HEIP) and Cool LA program—to expand opportunities for direct installation of cooling through heat pumps and lower-cost building weatherization upgrades for low-income households. Expand LADWP's HEIP to include funding for renovations and electrical upgrades necessary to support cooling through a heat pump, when feasible, by leveraging up to $6,500 in IRA rebates for low-income households.
- *Shift to direct install* instead of rebates for low- and moderate-income households.
- *Fund and staff program outreach and technical assistance* in partnership with community organizations through neighborhood resource centers as well as door-to-door outreach approaches targeting areas that historically received disproportionately fewer efficiency incentives.
- *Mitigate the potential for LADWP-supported weatherization and cooling upgrades to increase rents and contribute to displacement among low- and moderate-income renters*.
    - Partner with the Housing Authority to install upgrades in public housing.
    - Identify mechanisms to mitigate rent increases for nonpublic housing receiving low-income-qualified cooling and weatherization interventions. Options include renter protections, "right to return" provisions if renovations temporarily displace renters, and mechanisms to prevent short-term rent increases for multifamily rental properties receiving utility-supported upgrades. Add cooling access by leveraging up to $8,000 in IRA rebates for low-income households.
- *Support apprenticeship programs in DACs* for HVAC entrepreneurship and educational opportunities by coordinating IRA funds for workforce development (IRA Section 50123) (see Chapter 12 for details).

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1 Introduction

The LA100 Equity Strategies project seeks to increase equity in Los Angeles' transition to 100% clean energy. This report focuses on identifying strategies to increase equity in the distribution of benefits from building weatherization and cooling upgrades that can maintain safe temperatures within Los Angeles households in the event of a power outage during a heat wave.

1.1 Community Guidance

Analysis incorporated guidance from the LA100 Equity Strategies Steering Committee, community meetings, and Listening Sessions with community members cohosted with community-based organizations. The community expressed concerns and priorities related to resilience to power outages during heat waves.

Community concerns include:

- The next power outage and heat wave in Los Angeles will have negative effects.
- Upgrades (i.e., weatherization and increased cooling access) will raise rents and cause displacement.
- The cost of energy efficiency upgrades will be unaffordable for many homeowners.
- Lack of access to safe and comfortable locations during heat waves.
- *Energy inefficient housing, lack of approval to change cooling infrastructure, and cost of operating cooling systems can result in health risks for renters*. Many low- and moderate-income Angeleno renters live in energy inefficient housing conditions that can increase health risks due to extreme heat or cold. Furthermore, renters are often unable to change the cooling and heating infrastructure within their homes (i.e., they need homeowner approval and/or investment to install ceiling fans and air conditioning). In addition, if the existing equipment provided to the renter is inefficient or poorly maintained, then operating that equipment could be cost-prohibitive for the renter. For these reasons, the resulting unconditioned housing environment can become detrimental to the residents' health.
- *Mistrust of energy efficiency service providers prevents some residents from improving housing efficiency*. As Chapter 2 discusses in more detail, some residents mistrust Los Angeles Department of Water and Power (LADWP) subcontracted service providers—such as those providing ratepayers with energy efficient appliances—because they have received poor-quality products and service from LADWP contractors in the past. In the absence of accountability, this leads to community mistrust, dissuading residents from seeking efficiency upgrades and causing them to question the benefits of clean and efficient energy technologies and services more generally.

Community priorities include:

- More diversified and community-tailored outreach and support (e.g., feedback channels) to co-develop, access, and utilize energy efficiency program benefits
- Affordable program options that do not require up-front costs
- Support for home improvements needed for upgrades, such as electrical panels or mold abatement
- Amended eligibility requirements for equity-deserving ratepayers that do not fit current criteria (e.g., moderate-income household eligibility)
- Maintenance and safety upgrade support

- Revised LADWP programs that address the split incentive problem between renters and homeowners
- Development of apprenticeship programs for energy efficiency retrofits that build on local knowledge and skillsets.

1.2 Modeling and Analysis Approach

The National Renewable Energy Laboratory (NREL) modeled how indoor temperature, a main cause of heat-induced health risks, changes with building envelope and cooling upgrades in a power outage during a heat wave. Figure 1 provides an overview of the modeling workflow. The applied methods, which were developed with input from the LA100 Equity Strategies Steering Committee and community members, are described in detail in the appendix.

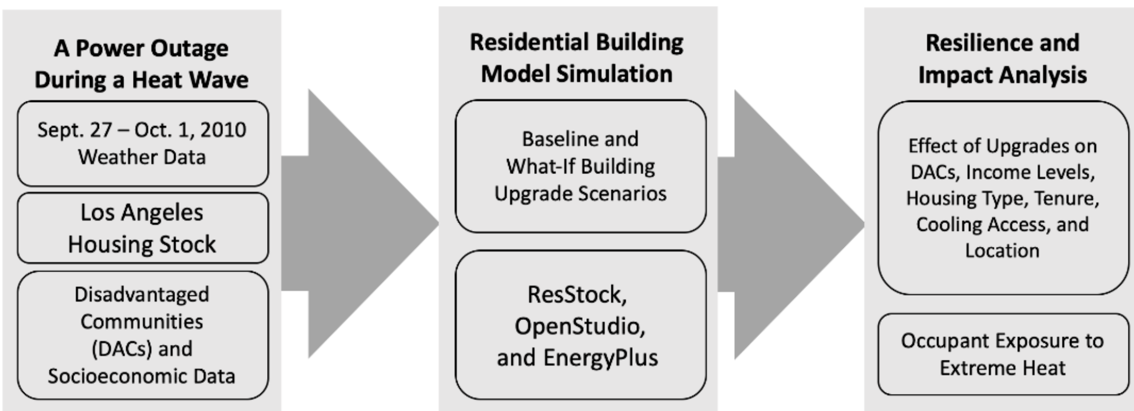

Figure 1. Residential building power outage modeling workflow

The modeling and analysis approach uses weather, housing, and socioeconomic data to characterize Los Angeles' residential building stock. The data informed representative building energy models via ResStock™ (Wilson et al. 2017), which uses EnergyPlus® to simulate the representative buildings. The baseline models are then modified and re-simulated to evaluate various building upgrades and investment scenarios. NREL examined occupant exposure to extreme heat and how heat exposure changes with each upgrade and across income, tenure (renter/owner status), building type, and disadvantaged community (DAC) status. Our approach aligns with energy resilience assessment methodologies described by Anderson et al. (2019).

We modeled eight conditions, described in detail in the appendix:

- Baseline
- Cooling use
- Cooling use, cool roof, and shading
- Cooling use and low-cost envelope improvements
- Cooling use and Title 24 envelope improvements
- Cool roof and shading
- Low-cost envelope improvements
- Title 24 envelope improvements.

The building upgrades are applied as what-if scenarios to Los Angeles' housing stock, and then compared to assess their performance in a power outage during a heat wave. We modeled heat pumps for cooling because they deliver cooling with similar or lower total purchase and operational costs than room air conditioning (Booten et al. 2022) and will be eligible for the widest selection of federal rebates, while other options are not. The model sized heat pumps after applying the effect of other building improvements. In addition, we modeled the resilience effect of increasing envelope robustness through low-cost envelope improvements and Title 24 envelope improvements that meet standards upheld by the California Energy Commission and are required for all new housing units (California Energy Commission 2023). See Table A-2 in the appendix for a summary of modeled upgrade specifications.

1.2.1 Simulating Resilience to a Power Outage During a Heat Wave

Extreme heat index days are expected to increase in frequency during the next century (Dahl et al. 2019). A power outage during a heat wave is considered a disaster, and being resilient to disasters through building weatherization is imperative to ensuring the health and safety of the public (National Research Council 2012). Communities also use resilience strategies, such as cooling centers, natural ventilation, and window coverings, to decrease heat exposure. NREL modeled a heat wave in 2010 using Actual Meteorological Year (AMY) weather data in Los Angeles County.

Two power outages were analyzed. First, NREL analyzed a 4-day outage, from September 27, 2010, at 15:00, through October 1, 2010, at 21:00, which is the hottest four-day period of the year in the weather data. While a four-day outage is extremely rare, modeling a long-duration power outage allows assessment of the impacts of building weatherization and cooling upgrades as living space temperatures increase in dwellings during the outage. Second, a power outage of 180 minutes was analyzed, results of which can be found in the appendix. The reported Customer Average Interruption Duration Index (CAIDI) for LADWP reliability reporting was 183 minutes in 2021 (EIA 2022). We assume all dwellings do not have access to back-up power supplies. In Chapter 8, the resilience benefits of microgrids and back-up power are investigated.

1.2.2 Measuring Risk Due to Heat Exposure

NREL measured exposure to extreme heat by both magnitude of temperature (how hot the air in the building is) and duration (how long a person is exposed). These passive survivability metrics indicate the ability to shelter in place during extreme weather such as a heat wave. Standard effective temperature (SET) and SET degree-hours were used to measure passive survivability, which is a measure derived from air temperature and air velocity. We use the Leadership in Energy and Environmental Design (LEED) Pilot Credit IPpc100 – *Passive Survivability and Back-Up Power During Disruptions* to quantify risk due to heat exposure, which specifies a SET threshold above 86°F SET for residential buildings and a 216 SET°F-hours limit for the duration of heat exposure (USGBC 2023). SET-hours describe the magnitude above the threshold as well as the duration over the 4-day power outage. For example, if an indoor living temperature reached 96°F SET for 3 hours each day, the household would experience 120 SET°F-hours ([96°F–86°F] × 3 hours/day × 4 days). A representational diagram showing the methodology for SET°F-hours is provided in the appendix. We analyze how many hours a dwelling would have until the indoor living space temperature reaches 86°F SET, and the maximum number of hours above the 86°F SET threshold. The passive survivability metrics are simulated using EnergyPlus (version 22.2.0).

1.2.3 Developing Community-Informed Strategies

In addition to the modeling, NREL collected input on concerns related to power outages during heat waves and potential solutions from the LA100 Equity Strategies Steering Committee and Listening Sessions with community members cohosted with community-based organizations, as well as community meetings, as described in Chapter 2. The analysis was tailored to incorporate guidance related to resilience to power outages during heat waves.

2 Modeling and Analysis Results

Table 1 presents the effects of building weatherization upgrades during a power outage in a heat wave. The lower (25%), middle (50%), and upper quartile (75%) effects are shown to provide statistical context. For each upgrade, we calculate the exposure in 4 days, the average change in four-day exposure, the exposure in the first 24 hours of the outage, the exposure by CAIDI, and the maximum number of hours above the 86°F threshold for each upgrade relative to the baseline.

The results in Table 1 indicate that the exposure to extreme heat in the first 96 hours decreases most significantly with a combination of robust building envelope improvements and cooling access and use, enabling households to start the outage at lower temperatures. Combining building envelope improvements with cooling use reduced exposure by at least 90%. The median exposure by the fourth day of the outage is reduced by 97% across LA's housing stock when robust building envelope improvements (i.e., Title 24) are provided to dwellings. The results indicate that the median exposure is reduced by 56% when cooling is used or when dwellings have cool roofs and shading.

Table 1. Effects of Building Weatherization Upgrades on Exposure to Extreme Heat

Upgrade	4-Day Exposure (SET°F-hours)			Exposure in 24 hours (SET°F-hours)			Exposure by CAIDI (SET°F-hours)			Max. Hours Above Threshold (hours)		
	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%
Baseline + outage only	11	79	170	0.6	24	77	0.0	9.0	23	6.8	13	22
Cooling use	0.0	35	110	0.0	1.6	26	0.0	0.0	4.5	0.0	8.3	12
Cooling use, cool roof, and shading	0.0	5.8	53	0.0	0.0	13	0.0	0.0	1.8	0.0	5.5	9.8
Cooling use and low-cost envelope	0.0	7.3	67	0.0	0.0	8.9	0.0	0.0	0.4	0.0	5.8	11
Cooling use and Title 24 envelope	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
Cool roof and shading	0.3	35	110	0.0	13	58	0.0	4.8	19	1.8	9.8	17
Low-cost envelope	0.8	44	140	0.0	13	65	0.0	4.6	19	3.0	12	22
Title 24 envelope	0.0	2.2	58	0.0	0.1	35	0.0	0.0	10	0.0	5.0	15

2.1.1 A Power Outage During a Heat Wave by Building Type

We examined the effects of four distinct upgrade scenarios—baseline, cooling use, cooling use and Title 24 envelope improvements, and Title 24 envelope improvements—by building type (single-family versus multifamily), as shown in Figure 2 and Figure 3. The vertical dotted lines indicate when the outage starts and ends, with the outage period shaded in white. The black line shows the outdoor air temperature, and the blue and purple shaded regions represent the 25%–75% quartiles in indoor air temperature. The horizontal line indicates the dangerous temperature threshold (86°F). The goal of the upgrades is to ensure indoor air temperatures remain below the 86°F threshold.

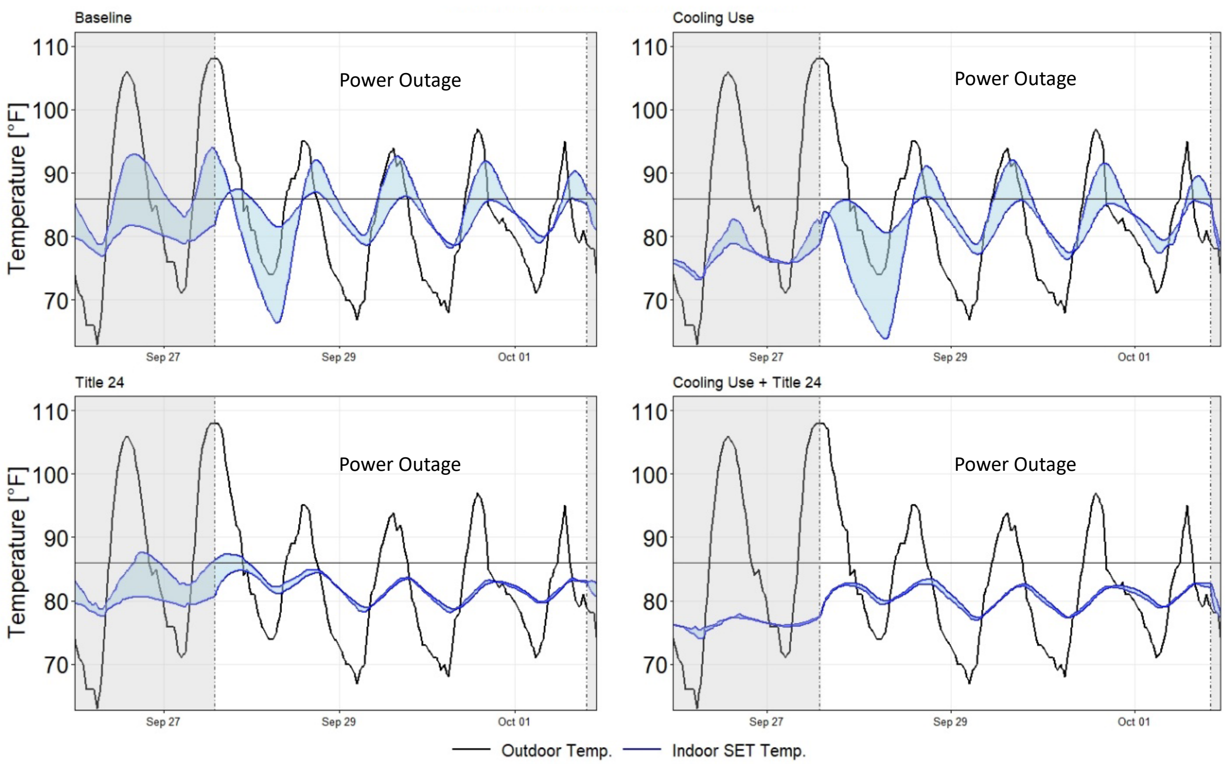

Figure 2. Indoor and outdoor air temperature during a power outage in single-family dwellings

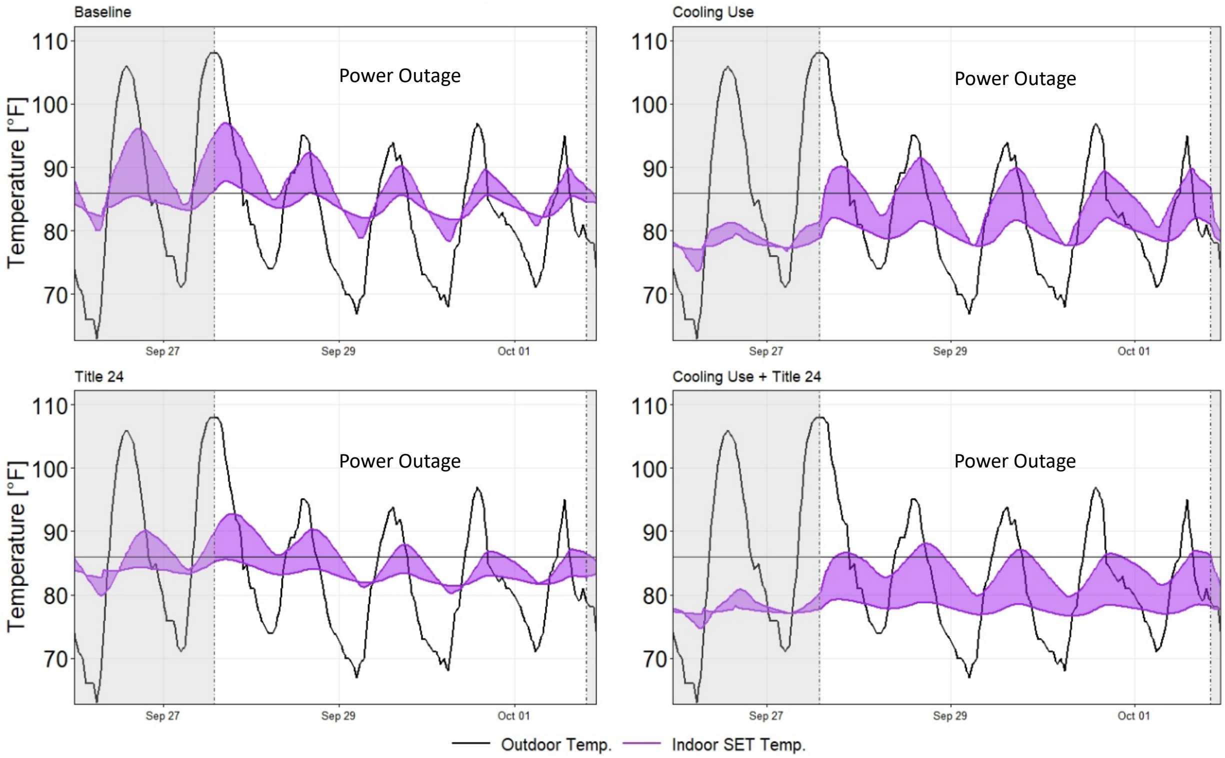

Figure 3. Indoor and outdoor air temperature during a power outage in multifamily dwellings

Results show multifamily dwellings experience slightly greater exposure to dangerous temperatures than single-family dwellings, both before and immediately after the simulated power outage for the baseline case; 57% of multifamily dwellings are at or above the threshold of 86°F SET, while 54% of single-family dwellings are at or above the 86°F threshold.

Title 24 envelope improvements alone reduce heat exposure below the dangerous threshold in nearly all hours in single-family dwellings but are not as effective in multifamily dwellings. Sixty percent of single-family dwellings with a Title 24 envelope improvement remain at safe indoor living conditions because of efficient natural ventilation. In comparison, the Title 24 envelope improvements result in 32% of multifamily dwellings remaining at safe indoor living conditions. Single-family dwellings naturally ventilate accumulated heat more quickly than multifamily dwellings. Single-family dwellings have larger window areas and multiple facades to allow for ventilation, while multifamily dwellings have smaller window areas and only one or two facades to allow for ventilation. On average, multifamily dwellings have 41% of the natural ventilation that single-family dwellings have in the baseline condition, and 47% of the natural ventilation that single-family dwellings have with the Title 24 envelope upgrades on a cubic-foot-of-air per minute basis. A summary and analysis of natural ventilation and infiltration rates can be found in the appendix.

In single-family dwellings, cooling use is insufficient in reducing heat exposure below the dangerous threshold. For single-family dwellings, cooling use decreases the starting temperature in the upper quartile (75%) by approximately 9°F. However, by the end of the first day of the power outage, single-family dwellings with cooling use before the outage follow similar indoor air temperature profiles as single-family dwellings in the baseline condition. For multifamily dwellings, cooling use is sufficient for the lowest quartile of multifamily dwelling temperatures (25%), which remain at a safe indoor living condition (i.e., below 86°F). However, the highest quartile frequently exceeds the 86°F dangerous threshold.

The most effective solution is a combination of cooling use and Title 24 envelope improvements, which decreases dangerous heat exposure above 86°F (SET) for 68% of single-family and multifamily dwellings. However, this solution is also the costliest, as described in the appendix.

We examined the effects of the upgrades by building type, as shown in Figure 4, segmented by single-family dwellings (Single-Family), multifamily units in a building with two to four units (MF 2–4 Units), and multifamily units in a building with five or more units (MF 5+ Units). For context, approximately 56% of the Los Angeles population lives in multifamily buildings, and 44% live in single-family (mobile homes included) buildings.

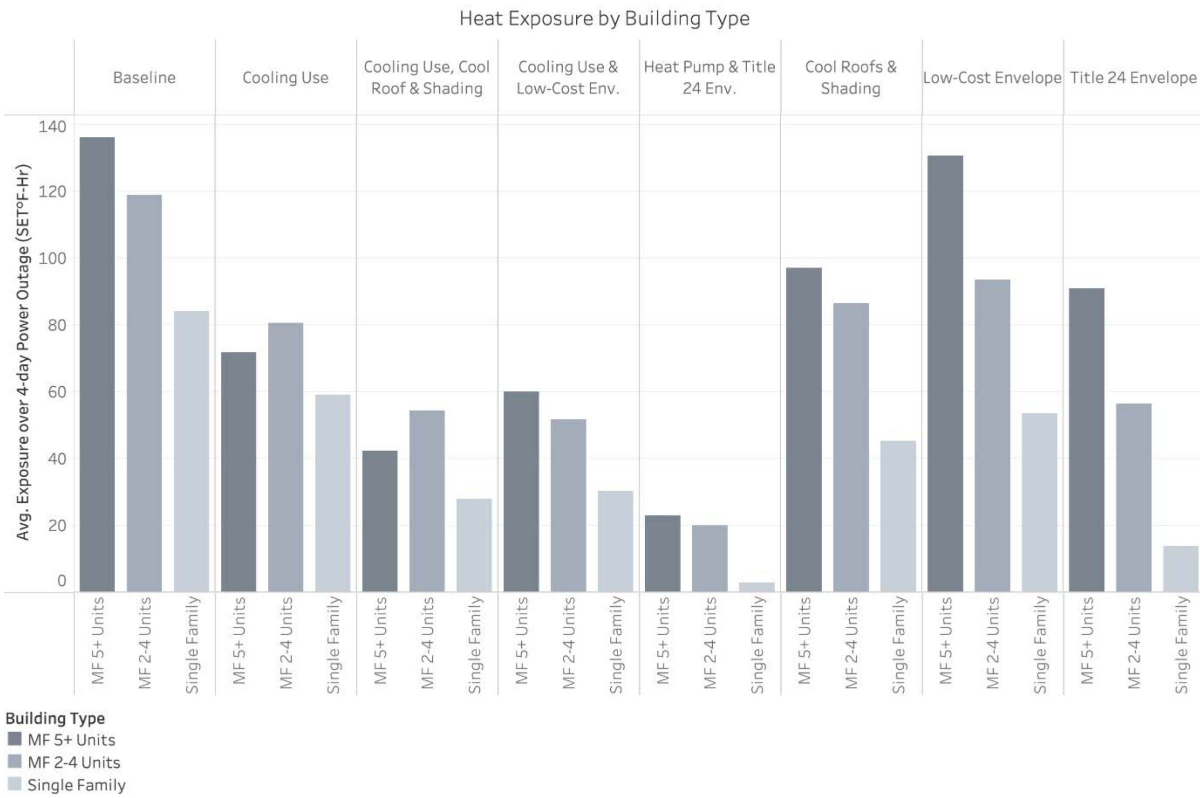

Figure 4. Average heat exposure during 4-day outage by building type

MF = multifamily

Without upgrades, households living in multifamily buildings with five or more units experience substantially greater exposure to dangerous temperatures than households in smaller multifamily buildings and single-family homes. Using cooling more effectively reduces exposure than envelope improvements in MF 5+ units, whereas robust envelope improvements more effectively reduce exposure than cooling access in single-family dwellings. A combination of cooling use and building weatherization reduced exposure across all building types. Consistent with previous findings, cooling use and Title 24 envelope improvements resulted in the greatest reduction in exposure, where single-family detached residences decreased from 84 SET°F-hours to

0.3 SET°F-hours on average, and MF 5+ units decreased from 136 SET°F-hours to 7.9 SET°F--hours.

Multifamily and single-family dwellings exhibited different magnitudes in decreased exposure as a result of building upgrades. In MF 5+ units, low-cost envelope improvements marginally decreased exposure by 4%, whereas in single-family buildings, low-cost envelope improvements decreased exposure by 37%. In single-family dwellings, robust envelope improvements, such as Title 24, significantly reduced exposure by an average of 84%. By contrast, in MF 5+ units, exposure was reduced by only 44% with Title 24 envelopes. Cool roofs and shading reduced exposure for MF 5+ units by 29% and decreased exposure in single-family dwellings by 46%. Cooling use reduces exposure by 53% in MF 5+ units, but by only 30% in single-family dwellings.

2.1.2 Cooling Access and Use

Using cooling increases the resilience of a household during a power outage. From the ResStock Los Angeles residential building stock energy model,[1] the percentages of Los Angeles households that have access to cooling, along with the percentages of Los Angeles households that use that cooling, are shown in Figure 5 by percentage area median income (AMI).

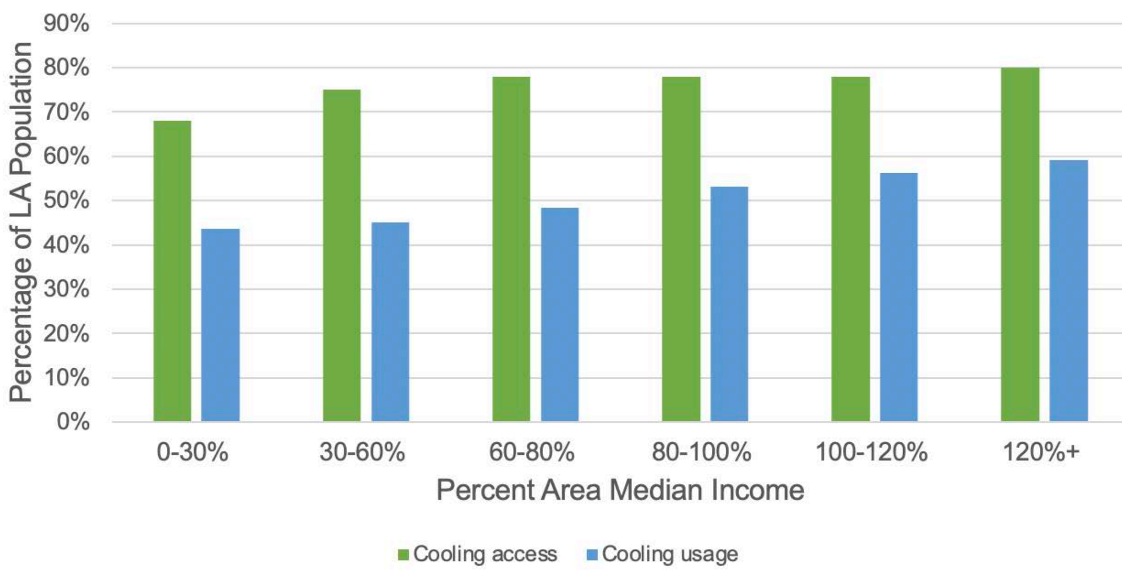

Figure 5. Percentage of population with cooling access and use by % AMI for Los Angeles

Cooling access and use generally increase as income increases. Less than one-half of extremely low-income (0%–30% AMI), very low-income (30%–60% AMI), and low-income (60%–80% AMI) households use cooling. Only 70% of extremely low-income households have access to cooling. See the appendix for more information about access to cooling.

In LA100 Equity Strategies Listening Sessions, participants identified several barriers they experience to accessing and using cooling technologies in their homes. Barriers include the cost

[1] Informed by RASS 2019.

of the equipment, the cost to run the equipment, limitations in existing housing infrastructure (i.e., old wiring and/or electrical panels), and housing tenure. Tenure affects Angelenos' eligibility for energy efficient cooling technologies, such as LADWP's Cool LA initiative. Renters are disqualified from most energy efficiency housing benefits, which prioritize homeowners. Homeowners with low to moderate incomes who struggle to pay their bills and monthly expenses are often disqualified because of income eligibility limits. Participants highlighted that access is not only about having the cooling technology available in the home, but also having the ability to use that technology affordably and safely. Broadening eligibility requirements related to income restrictions as well as tenure status could increase access to and use of cooling. For more information on community-informed solutions, see Chapter 13. Table 2 presents the percentage of households with space conditioning by tenure, building type, and DAC status.

Table 2. Percentages of Households with Space Conditioning by Demographic

Original Space Conditioning	Tenure		Building Type		DAC	
	Renter	Owner	Single Family	Multifamily	Yes	No
No Cooling or Space Conditioning	26%	20%	22%	25%	26%	21%
Partial Space Conditioning	18%	17%	20%	16%	19%	16%
Full Space Conditioning	56%	63%	58%	59%	55%	62%

2.1.3 Income and Tenure

We examined how the effects of upgrade scenarios differ across household income levels and tenure statuses, as shown in Table 3 and Table 4. 37% of low-income households (10,000 of 27,000 models representing low-income households) start the outage at dangerous temperatures.

Renters experience much higher exposure to dangerous temperatures than homeowners in baseline conditions. Results differ by tenure, primarily because more than 70% of renters live in multifamily buildings with two or more units, and more than 85% of owners live in single-family attached or detached dwellings. Cooling use and Title 24 envelope improvements reduce heat exposure the most, regardless of income or tenure. Title 24 envelope improvements decrease exposure by between 41% and 46% for renters and 77% and 79% for owners. Cooling use decreases exposure by between 41% and 43% for renters and 31% and 33% for owners. Cool roofs and shading reduce exposure by between 30% and 33% for renters and 44% and 45% for owners.

Table 3. Four-Day Exposure (SET°F-hr) by Income and Tenure

Upgrade	4-Day Exposure (SET°F-hour)					
	Renter			Owner		
	0%–80% AMI	80%–120% AMI	120%+ AMI	0%–80% AMI	80%–120% AMI	120%+ AMI
Baseline	140	120	110	92	85	73
Low-cost envelope	120	110	93	62	57	49
Cool roofs and shading	96	83	71	51	47	41
Title 24 envelope	80	67	57	21	19	15
Cooling use	78	71	60	62	59	50
Cooling use, cool roof, and shading	46	41	34	30	28	23
Cooling use and low-cost envelope	59	53	44	33	32	26
Cooling use and Title 24 envelope	21	18	14	5.3	4.5	2.7

Table 4. Percent Change in 4-Day Exposure by Income and Tenure

Upgrade	Change Relative to Baseline (%)					
	Renter			Owner		
	0%–80% AMI	80%–120% AMI	120%+ AMI	0%–80% AMI	80%–120% AMI	120%+ AMI
Low-cost envelope	10	11	12	33	33	33
Cool roofs and shading	30	32	33	44	44	45
Title 24 envelope	41	44	46	77	78	79
Cooling use	43	41	43	33	31	32
Cooling use, cool roof, and shading	66	66	68	68	67	68
Cooling use and low-cost envelope	57	56	58	64	63	64
Cooling use and Title 24 envelope	84	85	87	94	95	96

Exceeding the cumulated heat exposure of 216°F-hour indicates a high amount of exposure that poses a serious threat to building occupants during a 4-day power outage. A total count of households that exceeded the threshold that did not have cooling in the baseline condition were calculated by income and building type.

Table 5. Dwellings Without Cooling Exceeding the Limit of Passive Survivability in 4-Day Outage

Dwelling Type	0%–80% AMI	80%–120% AMI	120%+ AMI
Multifamily	58,000	11,000	14,000
Single-family	11,000	2,600	4,700

Low-income multifamily dwellings have the most households exceeding passive survivability limits of 58,000. To provide context, the distribution of building type and income level was investigated for household in Los Angeles.

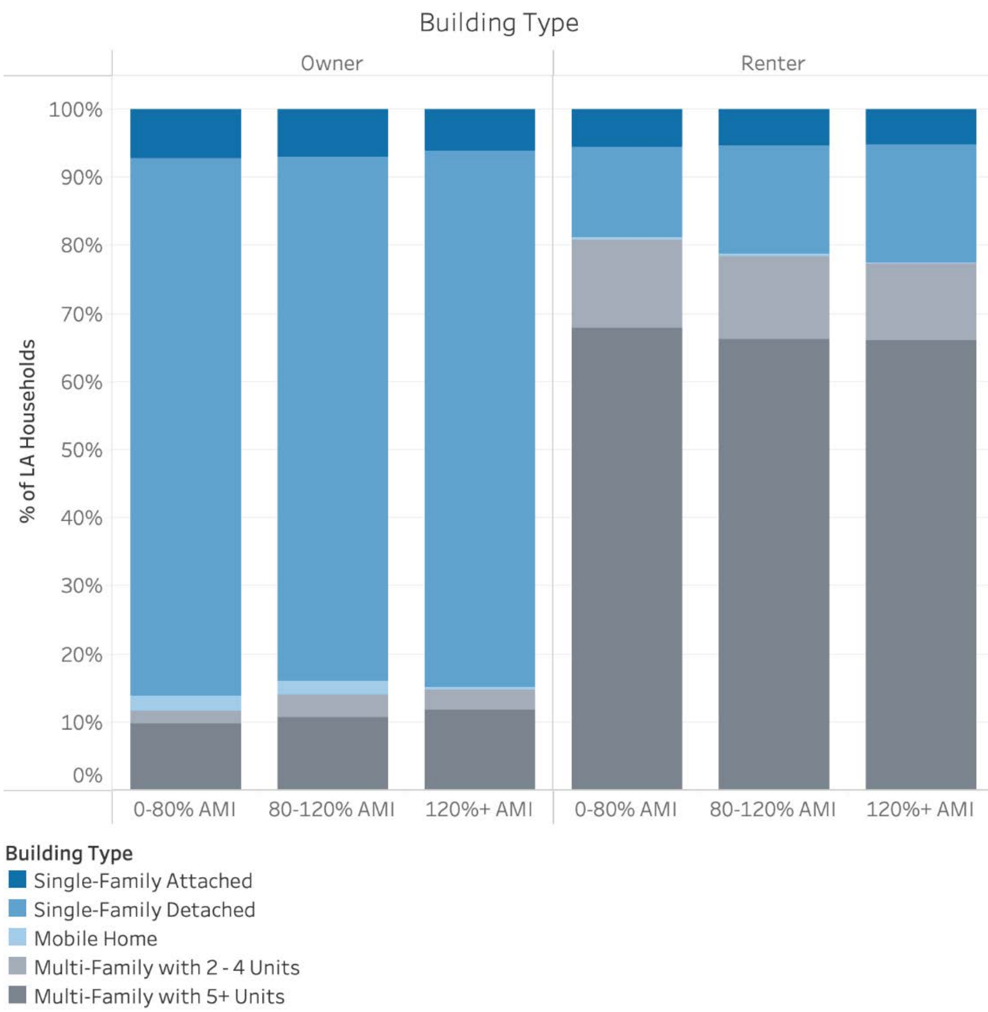

Figure 6. Housing type by tenure in Los Angeles

As income increases, exposure generally decreases across all baseline and upgrade scenarios. Low-income renters experience the highest exposure, which suggests a one-size-fits-all approach to residential building technology deployment may reproduce existing inequities in exposure.

Upgrades that decrease the amount of difference between income levels support more equitable outcomes (i.e., where exposure is similar regardless of income). When considering building weatherization and cooling separately, Title 24 envelope upgrades reduce income-based exposure differences the most to 5.6 SET°F-hours for owners, whereas cooling use reduces income-based exposure differences the most to 17.6 SET°F-hours for renters. Combining cooling upgrades and envelope upgrades minimizes the income-based differences between 6.5 to 15 SET°F-hours for low-cost envelopes and heat pumps. Conversely, low-cost envelope upgrades alone have the largest inequity in upgrade impacts, with an exposure range of 30 SET°F-hours between low- and higher-income renters and 19 SET°F-hours between low- and higher-income owners.

For context, Los Angeles households are approximately 64% renters and 36% owners (see the appendix for analysis). Of the renters with cooling access, 47% regularly use cooling equipment, whereas 58% of owners with cooling access regularly use cooling equipment. The average heat exposure (SET°F-hours) was calculated for each upgrade by tenure, as shown in Figure 7.

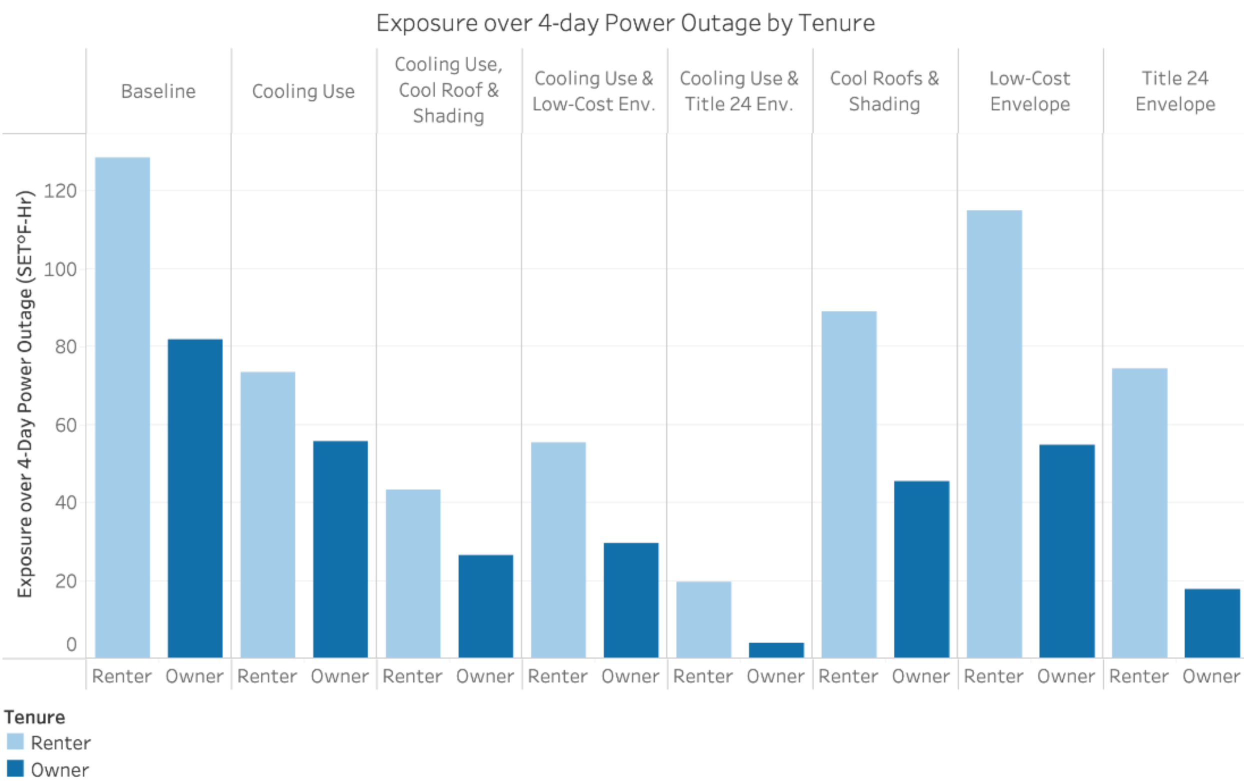

Figure 7. Average SET°F-hours over a 4-day power outage in Los Angeles by tenure

Renters experience higher exposure to heat than owners in the baseline condition and across upgrade scenarios—again, primarily because renters live in multifamily buildings, which retain heat and have less effective natural ventilation more than single-family buildings. On average, cooling use decreases renters' heat exposure from 130 SET°F-hours to 73 SET°F-hours and Title

24 envelope improvements decrease exposure to 74 SET°F-hours. In comparison, owners decrease exposure from 82 SET°F-hours in the baseline to 55 SET°F-hours with cooling access, and 18 SET°F-hours with a Title 24 envelope improvement.

2.1.4 Hours Until Threshold

In the baseline condition, 85% of the Los Angeles housing stock reach the dangerous temperature threshold (86°F) in the 4-day outage period, as shown below in Table 6. Upgrades reduce the percent of dwellings that reach this threshold, with combined cooling use and Title 24 envelope upgrades providing the greatest reduction, and low-cost envelope improvements providing the least reduction.

Table 6. Percentage of Housing Stock Reaching Dangerous Threshold of 86°F in First 24 hours

Upgrade	Households Reaching Threshold	% Housing Stock
Baseline + outage only	1,300,000	85
Cooling use	1,200,000	74
Cooling use, cool roof, and shading	970,000	62
Cooling use and low-cost envelope	980,000	62
Cooling use and Title 24 envelope	510,000	33
Cool roof and shading	1,200,000	77
Low-cost envelope	1,200,000	78
Title 24 envelope	890,000	57

More time until unsafe temperatures are reached means more time for households and the City of Los Angeles to plan and act. For the dwellings that reach dangerous temperatures, Table 7 shows the number of hours until this threshold is reached.

For the housing stock that reached dangerous temperatures in the first 24 hours, cooling use was the main determinant in extending the number of safe hours. Modeling indicates many low-income households start an outage at unsafe temperatures, either because these households lack access to cooling, or they do not use cooling because of the cost of running inefficient air conditioners. When cooling is available and used before an outage, the number of hours households remain at a safe temperature following the power outage increases from 0 hours in the baseline condition to 2.5 hours for low-income, multifamily dwellings. Cooling use and envelope improvements, such as Title 24 envelopes, increase the number of hours households remain at a safe temperature from 0 hours in the baseline condition to 23 hours or more across all building types and income levels. Cooling use and low-cost envelope improvements increase the number of safe hours from 0 to 5.5 hours for low-income, multifamily dwellings. Upgrades that do not include cooling remain at a median of 0 hours, meaning most dwellings start the power outage at dangerous temperatures.

Table 7. Median Hours Until Dangerous Temperatures by Income and Building Type

Upgrade	0%–80% AMI		80%–120% AMI		120%+ AMI	
	Multifamily	Single Family	Multifamily	Single Family	Multifamily	Single Family
Baseline	0.0	0.0	0.0	0.0	0.0	0.0
Cooling use	2.5	1.5	2.0	1.3	2.5	1.3
Cooling use, cool roof, and shading	2.8	1.8	2.5	1.8	2.8	1.5
Cooling use and low-cost envelope	5.5	3.0	4.0	2.5	5.8	2.5
Cooling use and Title 24 envelope	23	24	23	24	24	24
Cool roof and shading	0.0	0.0	0.0	0.0	0.0	0.0
Low-cost envelope	0.0	0.0	0.0	0.0	0.0	0.0
Title 24 envelope	0.0	0.0	0.0	0.0	0.0	0.0

2.1.5 Federal Funding for Upgrades

Using federal rebates and funding can enable more low-income households to adopt technologies that provide long-term savings but have higher up-front costs. The Inflation Reduction Act of 2022 (IRA)[8] funds rebates, administered through state energy offices, for homeowners to decrease home energy consumption (IRA Section 50121) and electrify their homes (IRA Section 50122). The U.S. Department of Energy (DOE) allocated $292,000,000 for the Home Owner Managing Energy Savings (HOMES) rebate program and $290,000,000 for the Home Electrification rebate program for the State of California (DOE 2022a). If Los Angeles receives a budget proportional to its population (approximately 10%), and 20% is allocated for program administration, technical assistance, and outreach, LA households could anticipate receiving $23 million in HOMES rebate funding and $23 million in Home Electrification funding. For the HOMES rebate program, all households, regardless of income, are eligible for funding, but 0%–80% AMI households receive higher rebates. For the Home Electrification program, 100% of the funds are allocated for 0%–150% AMI households and 0%–80% AMI households receive a higher rebate.

Table 8 shows the distribution of income and eligibility for IRA rebates by low- and moderate-income households in Los Angeles. If all 0%–80% AMI households receive the maximum combined rebate of $8,000 from HOMES and $14,500 from Home Electrification, this would cost $19.2 billion. If all 80%–150% AMI households received the maximum combined rebate of $4,000 from HOMES and $14,500 from Home Electrification, this would cost $4.8 billion. Given the program budgets, HOMES could fund retrofits in approximately 0.12% of 0%–150% AMI households, and Home Electrification could fund retrofits in approximately 0.48% of 0%–150% AMI households. Therefore, significant additional funding would be required to supplement federal funding.

Approved projects for the Home Electrification rebates could be a part of new construction, replace nonelectric appliances, or be first-time purchases, and could include electric heat pumps for space heating and cooling (up to $8,000); insulation, air sealing, and material to improve ventilation (up to $1,600); electric wiring (up to $2,500), and electric panel upgrades (up to $4,000). For the lowest income households (0%–80% AMI), 100% of the project costs can be covered.

Table 8. Distribution of Eligibility for IRA Rebates by Low- and Moderate-Income Households

	Household Income	
	0%–80% AMI	**80%–120% AMI**
Eligible LA Renter (number of households)	665,000	152,000
Eligible LA Owner (number of households)	187,000	108,000
Total Eligible Households	**852,000**	**260,000**
IRA Section 50121 HOMES rebate: 20%–35% savings	80% of cost up to $4,000	50% of cost up to $2,000
IRA Section 50121 HOMES rebate: 35%+ savings	80% of cost up to $8,000	50% of cost up to $4,000
IRA Section 50122 Home Electrification rebate	100% of cost up to $14,000 plus $500 for installation	50% of cost up to $14,000 plus $500 for installation

With IRA Section 50122 rebates, LADWP could generally install mini-split heat pumps—at an average cost of $7,000 per pump—in low-income households (0%–80% AMI) without incurring any debt or payment plans through a direct installation plan. For more information on using IRA rebates with building technologies and the potential for a pay-as-you-save program, see Chapter 4 (Bowen et al. 2023).[9]

In addition, the federal Weatherization Assistance Program reduces energy costs for low-income households by increasing the energy efficiency of their homes while ensuring their health and safety. The program supports 8,500 jobs and provides weatherization services to approximately 35,000 homes every year using U.S. Department of Energy funds. In 2023, the average cost-per-unit limit for cost-effective upgrades, such as air sealing, shell, and heating and cooling measures in low-income, single-family, and multifamily dwellings was $8,250 (DOE 2022b). The Weatherization Assistance Program also provides training and resources for workforce development.[10]

IRA Section 50123 provides $200 million to reduce the cost of training, testing, and certifying contractors, as well as partnering with nonprofit organizations to develop and implement a program. Recruiting and prioritizing individuals from disadvantaged communities (DACs) can be a strategic and equitable approach to deploying and building energy efficiency programs. Using fiscal year 2022 allocations from the Department of Energy, California may receive approximately 6.8%, or $13,500,000, of IRA Section 50123 contractor education and training funding. If Los Angeles receives a budget proportional to the city population (approximately 10%), approximately $1,400,000 would be available for contractor education and training in Los Angeles.

3 Equity Strategies Discussion

Both DAC and non-DAC communities have significant potential to increase resilience through building weatherization, but the analysis of distributional equity in energy efficiency incentives shows residential energy efficiency programs disproportionately benefit non-disadvantaged, mostly White, mostly non-Hispanic, mostly home-owning, and mostly above-median-income communities. Therefore, identifying policy actions that prioritize DACs, as well as addressing factors that lower barriers to realizing the resilience benefits in these communities, is key for equitable outcomes in Los Angeles.

This analysis modeled building weatherization and resilience impacts during a power outage in a heat wave. By simulating 10 upgrade options, our analysis finds that significant technical potential exists to reduce dangerous heat exposure. Applying a combined upgrade package of cooling access and a Title 24 building envelope upgrade decreased exposure between 85% and 96%. Combining cooling and robust envelope upgrades provides the greatest opportunities to reduce heat exposure during a power outage across income levels, tenure, and building type.

Lack of access to cooling—most acute among lower-income households and renters—increases exposure to unsafe temperatures significantly. Providing access to cooling reduces heat exposure by between 31% and 43%, decreases the percentage of the housing stock experiencing unsafe temperatures by 11%, and reduces exposure for a lower cost than most other upgrades modeled for low-income households. Low-cost envelope improvements reduce heat exposure in owner-occupied buildings by 33% and renter-occupied buildings by 11%. These differences in benefits require crafting different, targeted program interventions for the different populations.

Based on community guidance and modeling and analysis, the following strategies were developed to achieve more equitable outcomes in building weatherization and cooling for resilience:

- *Target cooling access and envelope improvements by housing type:*
    - *Deploy cooling systems* in low- and moderate-income, multifamily households with no cooling or heating to address their greater exposure to dangerous temperatures. Within this category, prioritize multifamily renters. Window-unit heat pumps could be deployed as property of the renter, avoiding the split incentive, the risk of rent increases, and increasing equity.
    - *Deploy cooling systems and envelope upgrades* in low- and moderate-income, single-family households without cooling to mitigate their increased exposure to outside temperatures. Within this category, prioritize very-low-income (0%–30% AMI), owner-occupied, single-family housing with upgrades, as these households experience the highest energy burdens.
- *Partner with the Housing Authority to provide upgrades in public housing*. Establish mechanisms to mitigate rent increases due to upgrades in nonpublic housing. More than 95% of low-income households living in multifamily buildings are renters. Options include renter protections, "right to return" provisions if renovations temporarily displace renters, and mechanisms to prevent short-term rent increases for multifamily rental properties receiving utility-supported upgrades.
- *Combine federal funding from the IRA and Weatherization Assistance Program with existing LADWP rebates* to augment existing programs, particularly the Home Energy Improvement Program (HEIP) and Cool LA program, to expand opportunities for direct installation (in lieu of rebates) of cooling

through heat pumps and lower-cost building weatherization upgrades for low-income households. Expand LADWP's HEIP to include funding for renovations and electrical upgrades required to add cooling access by leveraging up to $6,500 in IRA rebates for low-income households.

- *Fund and staff program outreach and technical assistance* in partnership with community organizations through neighborhood resource centers, as well as door-to-door outreach approaches targeting areas that received disproportionately fewer LADWP efficiency incentives.
- *Support apprenticeship programs* in DACs for HVAC entrepreneurship and educational opportunities by coordinating IRA funds for workforce development (IRA Section 50123).

Table 9 summarizes the expected benefit and cost (where known) of each strategy, as well as the timeline for implementation (short or long term), the party responsible for implementing the strategy, and metrics for measuring the success of the strategy. The estimated costs summarize the materials and labor costs for each dwelling to receive the upgrade for the demographic as described in the equity strategy.

Table 9. Equity Strategy Benefit, Cost, Timeline, Responsible Party, and Evaluation Metrics

Equity Strategy	Benefit/Impact	Cost	Timeline	Responsible Party	Metric
Deploy cooling in low- and moderate-income, multifamily households with no cooling	Reduce dangerous indoor heat exposure by 84%–100% and increase duration of safe temperatures from 0 to 24 hours in a 24-hour outage 58,000 low-income and 11,000 moderate-income multifamily households have no cooling and are at risk of dangerous heat exposure during a 4-day outage	$430 million – cumulative upgrade costs including materials and labor for adding whole-home cooling to LMI multifamily households without cooling and exceed 216 SET °F-hours in 4-day outage; offset by ~$23 million in IRA 50122 funds	Short-term	LADWP	-Number of systems deployed in LMI households -Percent of LMI multifamily households with cooling
Deploy cooling and envelope upgrades in low- and moderate-income single-family households without cooling	Reduce dangerous indoor heat exposure by 84%–100% and increase duration of safe temperatures from 0 to 24 hours in a 24-hour outage 11,000 low- and 2,500 moderate-income single-family homes without cooling and are at risk of dangerous heat exposure during a 4-day outage	$230 million – cooling and envelope upgrade costs for LMI single-family households without cooling and exceed 216 SET °F-hours in 4-day outage; offset by ~$23 million IRA HOMES funds	Short-term	LADWP	-Number of systems deployed in LMI households -Percent of LMI single-family households with cooling and envelope upgrades
Partner with the Housing Authority to provide upgrades in public housing. Establish mechanisms to mitigate rent increases due to upgrades in nonpublic housing	More than 95% of low-income LA households living in multifamily buildings are renters Improve health and resilience without increased rent	Potentially limited to administrative costs for implementing rent increase restrictions post-upgrade	Short-term	LADWP	-Number of public housing units with LADWP-supported upgrades -Number of LADWP-supported upgrades with rent increase mitigation measures
Use federal funding to expand direct installation of cooling and weatherization upgrades for low-income households	Increased deployment of cooling and weatherization upgrades and increased safety in emergency outages IRA 50122 covers up to $8,000 for heat pumps in low-income households.	Administrative costs, IRA funding, and unknown additional costs	Short-term	LADWP	-Federal funding accessed -Number of upgrades implemented with federal funding in LMI households

The synthesis of baseline equity conditions, community solutions guidance, and modeling and analysis key findings into equity strategies is shown in Figure 8. These strategies were shared with the LA100 Equity Strategies Steering Committee and Advisory Committee and were revised based on their feedback and guidance.

Baseline Equity

- Less than 50% of low- and moderate-income households use cooling. More than 30% of extremely low-income households lack access to cooling.
- More than 26% of households in disadvantaged communities have no cooling or space conditioning.
- Three of the five LADWP residential energy efficiency programs analyzed disproportionately benefited non-disadvantaged, mostly White, mostly non-Hispanic, mostly homeowning, and mostly above-median-income communities.

Community Solutions Guidance

- Ensure LADWP-supported improvements do not increase rents or cause displacement.
- Transparent explanation of benefits and costs of weatherization measures.
- Simplified application materials and methods.
- Deliver benefits to low- and moderate-income, renter, and energy-burdened households and households in multifamily housing.
- Consistent disadvantaged customer support for safety and comfort maintenance and efficiency upgrades.

Modeling and Analysis Key Findings

- Low-income multifamily renters have highest exposure to dangerous temperatures in an outage.
- Whole-home cooling access and use before an outage decreases extreme heat exposure by 34%, increases the average hours until unsafe temperatures to 15, and decreases exposure to similar levels in single-family and multifamily homes.
- Combining cooling and robust envelope improvements decreases exposure to dangerous temperatures to a median of 0 across tenure and income levels.

Equity Strategies

- Modify the Comprehensive Affordable Multifamily Retrofits program to provide direct install cooling for households at greatest risk of dangerous heat exposure: low-income, multifamily building renters without cooling.
- Provide rebates for heat pumps through Cool LA and auto-enroll low-income rebate recipients in bill assistance to mitigate energy burdens.
- Deploy cooling and envelope improvement in coordination for single-family homes without cooling.
- Partner with the Housing Authority to install upgrades in public housing. Establish a mechanism to mitigate rent increases from upgrades in non-public housing.

Figure 8. Equity strategies for resilience through strategic deployment of cooling access and weatherization

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Appendix. Buildings Modeling and Analysis Methodology and Detailed Results

A.1 Data Sources

Table A-1. Summary of Building Weatherization and Resilience Modeling Data Sources

Data	Source	Description	Resolution	Vintage
Disadvantaged Communities (DACs)	SB 535	DACs are identified as tracts with the highest 25% CalEnviroScreen scores.	Census tract	2022
Residential Energy Consumption Survey (RECS)	U.S. Energy Information Administration	Residential building geometries, characteristics, building types, building technologies, etc.	California	2009 and 2015
California Residential Appliance Saturation Study (RASS)	RASS 2019	Residential building stock and appliance saturation study for the LADWP service territory	LADWP service territory and other building stock segments	2019
American Community Survey (ACS)	U.S. American Community Survey	Income, tenure (renter/owner), Federal Poverty Level, % Area Median Income	Public Use Microdata Area (PUMA)	2015–2019
Weather	AMY 2010	Weather data	California Energy Commission Climate Zones	2010
LADWP Low Income Assistance Program Eligibility	LADWP	Low-income eligibility for LADWP assistance programs	Census tract	2022
California Alternative Rates for Energy (CARE) Eligibility	California Public Utility Commission	CARE eligibility	Census tract	2022

Data	Source	Description	Resolution	Vintage
eTRM	California Technical Forum	Wall insulation, ceiling insulation, water heating, cooking range, clothes drying, HVAC (ASHP), MSHP, furnace, wall/floor furnace, AC, room AC	Material costs, labor costs, labor hours	2012
LBNL Cost Data	LBNL	Water heating, air sealing, wall insulation, ceiling insulation, windows, clothes drying, HVAC (ASHP, MSHP, NG furnace, AC)	Total project costs	2020
National Residential Efficiency Measures Database	NREL	Water heating, cooking range, clothes drying, air sealing, wall insulation, ceiling insulation, windows, HVAC (ASHP, baseboards, boilers, MSHP, furnaces, wall/floor furnaces, AC, room AC)	Total project costs	2010
RSMeans data	RSMeans	Water heating, wall insulation, ceiling insulation, lighting, windows, HVAC (boiler, furnace, fan coil AC, ASHP)	Material cost, differentiated labor hourly rate, labor hours, location material and labor factors	Varied

HVAC = heating, ventilating, and air conditioning; AC = air conditioning; ASHP = air-source heat pump; MSHP = mini-split heat pump; NG = natural gas; LADWP = Los Angeles Department of Water and Power; LBNL = Lawrence Berkeley National Laboratory; NREL = National Renewable Energy Laboratory.

A.2 Modeling and Analysis

Modeling Los Angeles' Housing Stock Using ResStock

ResStock is a physics-simulation tool for generating statistically representative households (Wilson 2017). The tool considers the diversity in the age, size, construction practices, installed equipment, appliances, and resident behavior of the housing stock across U.S. geographic regions. ResStock enables a new approach to large-scale residential energy analysis by combining large public and private data sources, statistical sampling, and detailed sub-hourly building simulations. The tool generates a group of statistically representative building simulation models from a housing parameter space derived from existing residential stock data.

Each residential building model is based on building and sociodemographic characteristics, including building geometries (e.g., single-family versus multifamily), building technologies, cooling technologies, tenure (i.e., renter versus owner), and income. Los Angeles' housing stock is modeled using ResStock, as described in the following sections.

Stock Characterization

Public data sources, such as the U.S. Energy Information Administration Residential Energy Consumption Survey, are queried for conditional probability distributions for building stock characteristics and demographics. This approach leverages a robust classification suitable for building stock energy models in energy policymaking, where the different data sources are combined and mapped together using shared parameters such as location, building type, and year (Langevin et al. 2019).

Sampling

ResStock uses deterministic quota sampling, with probabilistic combination of non-correlated parameters. For Los Angeles, 50,000 samples were used in ResStock to represent 1,571,692 dwelling units (a ratio of approximately 1:31).

The residential building modeling team downselected the national ResStock model Los Angeles using the spatial geographies defined by the 2010 U.S. Census geographies and city boundaries. The down-selected residential model represents 1,600,000 dwelling units (U.S. Census Bureau 2021). The dwelling units were distributed to census tracts by the combined use of the 2020 Census Redistricting Data (U.S. Census Bureau 2021), the National Historical Geographic Information System (NHGIS) 2020 to 2010 block crosswalk file (IPUMS NHGIS 2020), and the ACS 2016 5-year dwelling unit counts. ResStock dwelling unit distributions are specified by census tract based on the ACS 2016 5-year survey. A mapping of the dwelling units from census tracts to census blocks was performed using census tract to census block distributions from the 2020 Redistricting Data. We mapped the 2020 Redistricting Data to 2010 U.S. Census geographies using the NHGIS 2020 to 2010 block crosswalk file. The dwelling units were then reaggregated by census tract based on the census blocks in Los Angeles.

The finest geographic granularity of the national version of ResStock is by Public Use Microdata Area (PUMA). PUMAs are a collection of census tracts with an average population of 200,000 and a minimum of 100,000. For the LA100 Equity Strategies study, census tracts were also added into the model for increased geographic specificity of the dwelling unit representative models.

Physics Simulation

The samples inform physics-simulation models, specifically EnergyPlus (EnergyPlus 2023). Model construction and articulation are facilitated by the OpenStudio® software development kit and associated residential modeling workflows.

Calibration and Validation

We use 2010 AMY weather data, which are a combination of ground-based measurement from the National Oceanic and Atmospheric Administration (Smith, Lott, and Vose 2011) and satellite-derived solar radiation data from the National Solar Radiation Database (NREL 2021).

Calibration involved numerous improvements to model input data and refinement of probability distribution dependencies.

Model Outputs and Post-Processing

Model outputs include both annual and hourly or sub-hourly time series energy use outputs for each sample for major and minor end uses (e.g., electricity and on-site natural gas, propane, and fuel oil use). Outputs for each sample also include HVAC system capacities and the hours the heating and cooling setpoints were not met, time series indoor zone air (i.e., dry-bulb) temperature, outdoor dry-bulb temperature, indoor Standard Effective Temperature (SET), mean radiant temperature, relative humidity, and derivative outputs specific to passive survivability, such as SET and heat index.

The building simulations use 2010 AMY, which serve as inputs into the EnergyPlus model to reflect the extreme weather events in this study.

Upgrades

The physics simulation answers questions in what-if scenarios; for example: *What if homes with no wall insulation were retrofitted with dense-packed cellulose? What if homes in disadvantaged communities were retrofitted to Title 24?* Outputs include annual and sub-hourly energy use (and home conditions such as indoor/outdoor temperature and humidity) for the baseline home and the hypothetical upgraded home. We analyzed eight potential building weatherization upgrades, as described in detail in Table A-2.

Equity Metrics

DACs, as defined by SB 535 CalEnviroScreen data, were integrated and used to consider inequities within Los Angeles. In addition, household income and tenure (renter/owner status) were added to ResStock. Using income, occupant count (household size), and U.S. Department of Housing and Urban Development-generated income guidelines, several income disparity metrics were derived, which include the Federal Poverty Level, AMI, California Alternate Rates for Energy (CARE) eligibility, and LADWP low-income eligibility. Having these metrics readily available in ResStock allows for segmentation of simulated building loads in a manner that is consistent with the means-testing requirement of existing federal, state, and local assistance programs.

Measuring Passive Survivability

Passive survivability metrics estimate the risk of heat exposure, primarily through measures of heat index, wet-bulb globe temperature (WBGT), or SET. The modeling team selected the SET approach detailed by LEED Pilot Credit IPpc100 (USGBC 2023). The cooling should not exceed 216 SET°F-hours above 86°F SET for residential buildings. For heat waves, the credit specifies that SET-hours should be calculated by the sum of the difference between the zone-calculated SET and 86°F, only if the zone SET is greater than 86°F, for all hours of the power outage.

Figure A-1 shows a heat wave over a 4-day period. The regions shaded in red indicate SET temperatures exceeding the 86°F SET. The summed area (i.e., integral) of the instances is the duration of the exposure, measured by SET-hours.

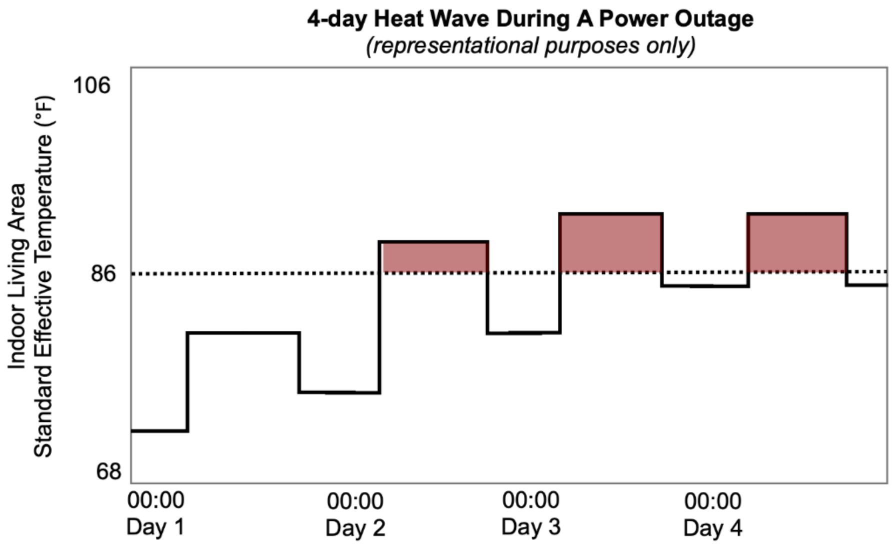

Figure A-1. A representational diagram showing the methodology for exposure (SET°F-hours)

Dimensional Blending

NREL implemented dimensional blending to ingest multiple sources of data. Dimensional blending resolves conditional distributions where many of their dependency combinations have small sample sizes. This often happens when a distribution is conditional to many dependencies and/or a survey has few datapoints, thus making the segmentation of the data by dependency combination too thin. Dimensional blending splits the required dependency set into two or more subsets "blending" together the distribution created from each subset of dependencies. The blending method assumes that dependency subsets are conditionally independent of each other, given the housing characteristics, and ignores possible interactions between them.

Upgrades

Table A-2 provides the detailed building upgrades modeled. In this appendix, cooling use is represented as "heat pump" upgrades.

Table A-2. Building Upgrades

Upgrade	Heat Pump	Window U-Factor	Window SHGC	Ceiling R-Value	Wall R-Value	Infiltration	Floor R-Value	Foundation Wall R-Value	Slab Edge R-Value	Duct Leakage	Duct Insulation	Shading and Roofing
Baseline	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Heat Pump	Air-source heat pump (ASHP) SEER 26.1, 11 HSPF Mini-split heat pump (MSHP) SEER 33.1, 13.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Heat Pump, Cool Roof, and Shading	ASHP SEER 26.1, 11 HSPF MSHP SEER 33.1, 13.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Space-dependent Tree shading Roof replaced with light-colored or white materials
Heat Pump and Low-Cost Envelope	ASHP SEER 26.1, 11 HSPF MSHP SEER 33.1, 13.5	N/A	N/A	N/A	Wood Stud: R-13	25% reduction	N/A	N/A	N/A	N/A	N/A	N/A

Upgrade	Heat Pump	Window U-Factor	Window SHGC	Ceiling R-Value	Wall R-Value	Infiltration	Floor R-Value	Foundation Wall R-Value	Slab Edge R-Value	Duct Leakage	Duct Insulation	Shading and Roofing
Heat Pump and Title 24 Envelope	ASHP SEER 26.1, 11 HSPF MSHP SEER 33.1, 13.5	0.37	0.3	Single Family Wood Stud: R-30 (CEC CZ 6); R-2 (CEC CZ 8, 9, & 16) Single Family Concrete Masonry Unit (CMU)/Brick: R-13 (CEC CZ 6, 8, & 9) R-17 (CEC CZ 16) Multifamily: R-22	Single Family Wood Stud: R-15 (CEC CZ 6); R-2 (CEC CZ 8, 9, & 16) Single Family CMU/Brick: R-13 (CEC CZ 6, 8, & 9); R-17 (CEC CZ 16) Multi-Family Wood Stud: R-13 Multi-Family CMU/Brick: R-2	5 ACH50	N/A	N/A	N/A	N/A	N/A	N/A
Cool Roof and Shading	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Space-dependent Tree shading Roof replaced with light-colored or white materials
Low-Cost Envelope	N/A	N/A	N/A	N/A	Wood Stud: R-13	25% reduction	N/A	N/A	N/A	N/A	N/A	N/A

Upgrade	Heat Pump	Window U-Factor	Window SHGC	Ceiling R-Value	Wall R-Value	Infiltration	Floor R-Value	Foundation Wall R-Value	Slab Edge R-Value	Duct Leakage	Duct Insulation	Shading and Roofing
Title 24 Envelope	N/A	0.37	0.3	Single Family Wood Stud: R-30 (CEC CZ 6); R-2 (CEC CZ 8, 9, & 16) Single Family CMU/Brick: R-13 (CEC CZ 6, 8, & 9) R-17 (CEC CZ 16) Multifamily: R-22	Single Family Wood Stud: R-15 (CEC CZ 6); R-2 (CEC CZ 8, 9, & 16) Single Family CMU/Brick: R-13 (CEC CZ 6, 8, & 9); R-17 (CEC CZ 16) Multi-Family Wood Stud: R-13 Multi-Family CMU/Brick: R-2	5 ACH50	N/A	N/A	N/A	N/A	N/A	N/A

Natural Ventilation Modeling

Natural ventilation (i.e., outside airflow into the dwelling via windows) is modeled for all dwellings before, during, and after the outage. When an outage is not active, natural ventilation flow during cooling months will occur if the outdoor temperature is lower than the indoor temperature, the outdoor relative humidity is less than 0.7, and the outdoor humidity ratio is less than 0.0115. During an outage, the humidity constraints of natural ventilation availability are dropped, and natural ventilation will occur exclusively if the outdoor temperature is less than the indoor temperature. The model calculated the available window area by taking a fraction of the window's operable window area (i.e., how much the window could feasible be open), which ranges between 0.2 and 0.5. The 0.5 fraction accounts for the assumption that 50% of the area of an operable window can be open, and the 0.2 fraction accounts for the assumption that 20% of the openable window area is open. Further details on natural ventilation assumptions can be found in Wilson et al. (2014, Section 4.2.1).

Within the analysis, we noticed an increase in heat exposure in MF 5+ units with only envelope-based improvements. We hypothesized this increase is caused by the lack of ventilation available (particularly in middle units without access to operable windows or cross-ventilation). The model outputs of natural ventilation and infiltration by the mean, standard deviation, and 25%, 50%, and 75% quartiles help to confirm this hypothesis, as shown in Table A-3 and Table A-4.

Table A-3. Natural Ventilation in Multifamily Buildings

	Mean Natural Ventilation (cfm)		
	Baseline	**Low-Cost Envelope**	**Title 24**
Mean	98	97	84
Std	77	77	65
25%	43	42	38
50%	77	75	67
75%	130	130	110
	Mean Infiltration (cfm)		
	Baseline	**Low-Cost Envelope**	**Title 24**
Mean	29	22	8.7
Std	22	17	7.3
25%	14	10	5.1
50%	23	17	7.4
75%	37	28	11

Table A-4. Natural Ventilation in Single-Family Buildings

	Mean Natural Ventilation (cfm)		
	Baseline	**Low-Cost Envelope**	**Title 24**
Mean	240	220	180
Std	190	180	150
25%	120	110	82
50%	190	170	140
75%	300	290	230
	Mean Infiltration (cfm)		
	Baseline	**Low-Cost Envelope**	**Title 24**
Mean	60	45	20
Std	41	31	15
25%	33	25	12
50%	50	37	16
75%	77	58	23

Single-family dwellings see larger amounts of natural ventilation and infiltration, regardless of upgrade, than multifamily dwellings. On average, multifamily units have 41% of the natural ventilation that single-family buildings have in the baseline condition. Similarly, infiltration in multifamily buildings is 47% of that in single-family homes in baseline conditions. Multifamily dwelling units generally have fewer exterior walls and windows compared to single-family dwellings.

Outage Considerations, Including Temperature Capacitance

Outage simulation is achieved in this work by adjusting availability schedules to 0 for the duration of a specified date range. This method leaves the indoor temperature of the dwellings to "float" with no set-point control. The simulated heat capacity of air in the node being solved by the EnergyPlus software can influence the rate of change of indoor temperature heavily. This heat capacity can be modified by its default value via the Zone Sensible Heat Capacity Multiplier to stabilize the simulation or better calibrate the simulation to empirical data. In a survey of literature about the Zone Sensible Heat Capacity Multiplier, a range of values has been chosen for similar analyses: from 3.0 to 15 (Chintala, Winkler, and Jin 2021; German and Hoeschele 2014). This study used a value of 7.0 based on recently performed experiments that matched a value of 7.0 for a thoroughly characterized existing house (Sparn et al. 2014).

Exposure in Disadvantaged Communities

We investigated the impacts of upgrades on DACs and non-DACs. Figure A-2 shows the average 4-day exposure.

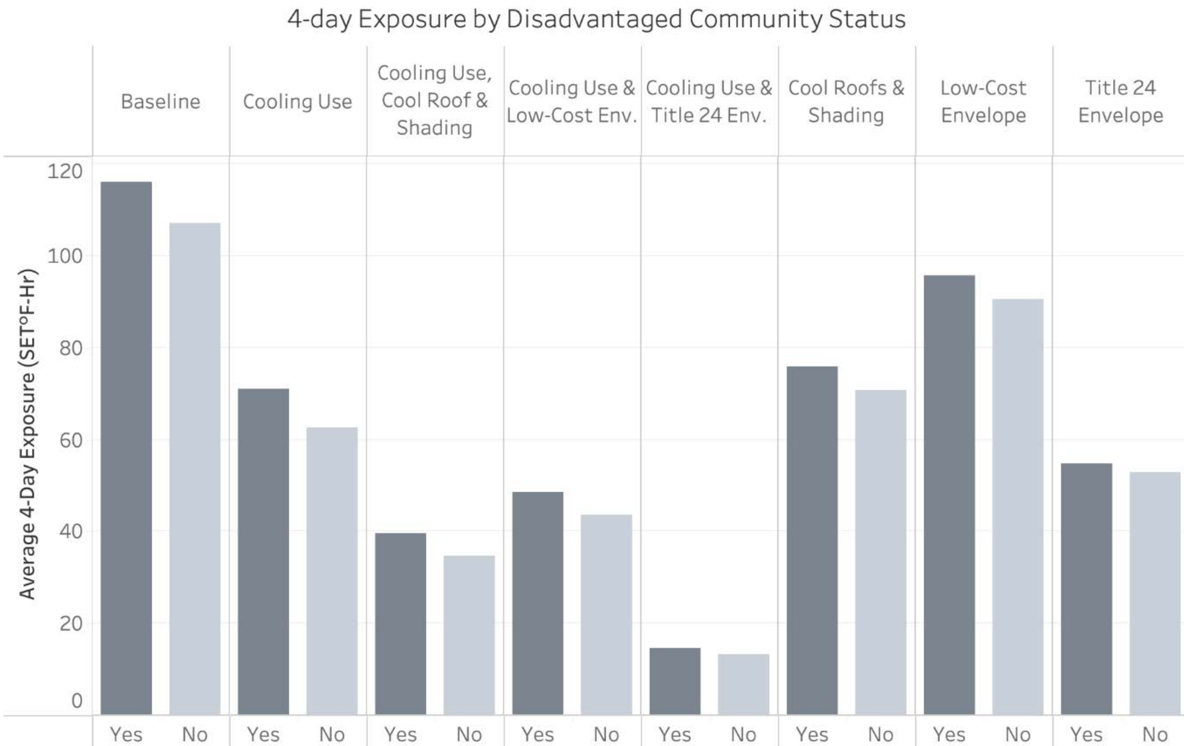

Figure A-2. 4-day exposure by DAC status

We noticed limitations in measuring DACs, as indicated by the small difference of exposure shown in Figure A-2. Across all scenarios, DACs were exposed to higher levels of dangerous temperatures than non-DACs. The data informing the housing characteristics are specified at the PUMA level or larger. PUMAs are a collection of census tracts, and DACs are census tracts. Since DACs are defined at a smaller geography than PUMAs, we believe the distribution of DACs becomes obfuscated in our modeling. Throughout the report, we investigate other demographics to identify equitable pathways for building weatherization and resilience.

Exposure During an Average Power Outage

We measured exposure during the heat wave at the time of an average power outage (i.e., CAIDI with major events) for Los Angeles. At 180 minutes, the exposure for different scenarios is shown in Table A-5.

In the baseline condition, low-income renters experience the highest amount of exposure during an average power outage (14 SET°F-hours), whereas owners in 120%+ AMI experience the lowest amount of exposure (10 SET°F-hours). A combination of cooling use and Title 24 envelope decreases the exposure to approximately zero across income levels and tenure status.

Table A-5. Exposure (SET°F-hours) at 180 Minutes During a Power Outage

Upgrade	Owner			Renter		
	0%–80%	80%–120%	120%+	0%–80%	80%–120%	120%+
Baseline	13	12	10	14	13	12
Low-Cost Envelope	9.2	8.0	6.9	13	11	9.9
Cool Roofs and Shading	9.2	8.1	7.0	12	11	9.6
Title 24 Envelope	3.7	3.2	2.4	8.9	7.5	6.5
Heat Pump	3.1	2.6	2.0	8.0	6.4	5.8
Heat Pump, Cool Roof and Shading	2.2	2.3	1.9	2.1	2.1	1.9
Heat Pump and Low-Cost Envelope	1.6	1.6	1.3	1.6	1.7	1.5
Heat Pump & Title 24 Envelope	0.3	0.2	0.1	0.5	0.5	0.4

Cost for Upgrades

For a complete description of the labor and equipment costs for upgrades, see Chapter 5. We examined the costs relative to the benefits of these improvements, as shown in Table A-6. The costs of upgrades were generated using the total costs, which include the material costs as well as the labor costs to install upgrades. The details of the costing methodology are provided in detail in Chapter 5. We calculated the benefits by subtracting the cumulative 4-day exposure simulated with an upgrade, as measured in SET°F-hours, from the exposure in the baseline condition in an outage for each of the 50,000 building models. We omitted dwellings that showed no change in exposure because they resulted in an infinite value, which primarily resulted from dwellings who received cooling use in the upgrade but had cooling used in the baseline condition.

In low- and moderate-income (0%–120% AMI) households, providing cool roof and shading was the lowest cost per reduced heat exposure in multifamily and single-family dwellings. Yet, the benefits of tree shading are often only available after multiple years of growth. Low-cost envelope improvements provide the lowest cost for immediate benefit across income and housing types. Cooling use provides cost-effective, immediate benefits for single-family dwellings, whereas Title 24 envelopes provide more cost-effective, immediate benefits for multifamily dwellings. Heat pump and Title 24 envelope improvements were the most expensive for the reduction in exposure across all housing and income types. This analysis approximates the relative costs to benefits for resilience. For more analysis on the utility bill effects and other economic effects, see Chapter 5.

Table A-6. Median Cost Relative to Reduced Exposure ($-2022/SET°F-hour) by Income and Housing Type

Upgrade	Single-Family			Multifamily		
	0%–80% AMI	80%–120% AMI	120%+ AMI	0%–80% AMI	80%–120% AMI	120%+ AMI
Cooling Use	260	330	350	79	91	98
Cooling Use, Cool Roof, and Shading	260	340	430	99	120	140
Cooling Use and Low-Cost Envelope	240	310	390	95	110	130
Cooling Use and Title 24 Envelope	250	310	400	110	130	150
Cool Roof and Shading	140	170	210	34	39	43
Low-Cost Envelope	110	130	160	61	69	79
Title 24 Envelope	170	200	250	91	99	110

Multifamily dwellings have lower costs than single-family dwellings. Lower-income households have lower costs than higher-income households. Low-income, multifamily dwellings have the lowest costs relative to the resilience benefits across all upgrades.

A.3 Demographics of Los Angeles

Tenure and Income

More than 70% of renters in Los Angeles live in multifamily buildings with two or more units, as illustrated in Figure A-3. More than 85% of owners live in single-family attached or detached dwellings.

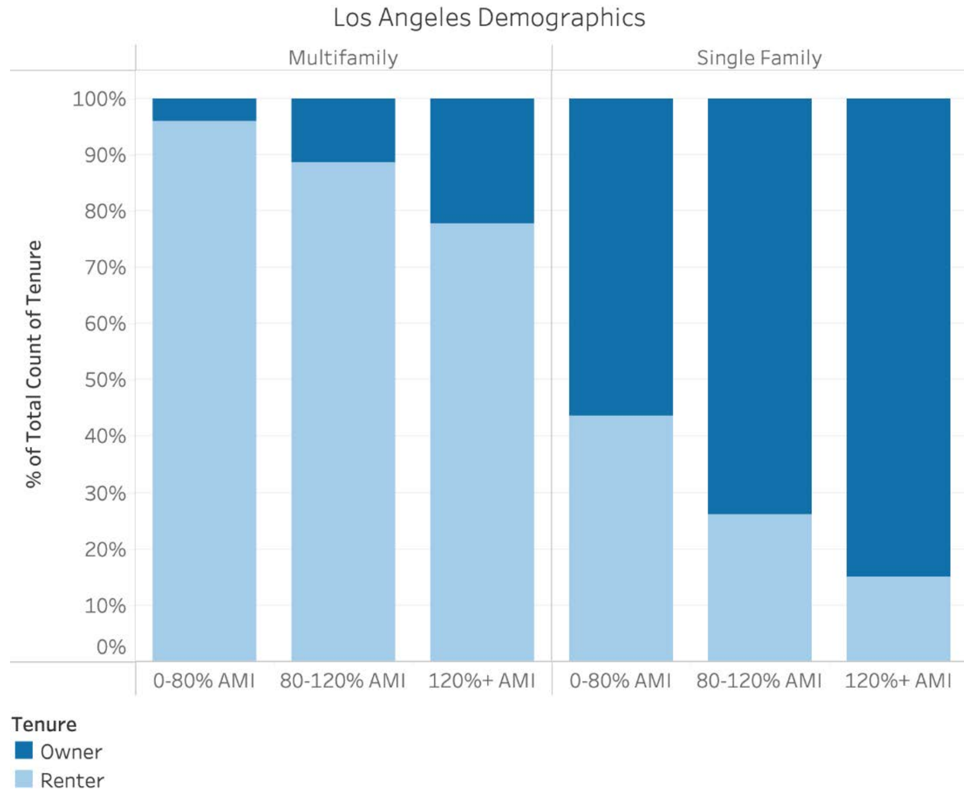

Figure A-3. Los Angeles demographics by tenure, income, and building type

Access to Cooling

We calculate access to cooling in the baseline condition across demographics, as shown in Table A-7. More than 25% of renters, DAC residents, and multifamily building units have no cooling or space conditioning—a key risk factor for heat exposure in an outage, as these households start an outage at unsafe temperatures. Partial space conditioning includes cooling equipment such as small window AC units and mini-split heat pumps that only cool one or two rooms. Full space conditioning includes cooling equipment that is generally centralized and distributed throughout the dwelling.

Table A-7. Percentages of Population with Space Conditioning by Demographic

Original Space Conditioning	Tenure		Building Type		DAC	
	Renter	Owner	Single Family	Multifamily	Yes	No
No Cooling or Space Conditioning	26%	20%	22%	25%	26%	21%
Partial Space Conditioning	18%	17%	20%	16%	19%	16%
Full Space Conditioning	56%	63%	58%	59%	55%	62%

Use of Cooling

We calculate use of cooling by tenure and building type, as shown in Figure A-4.

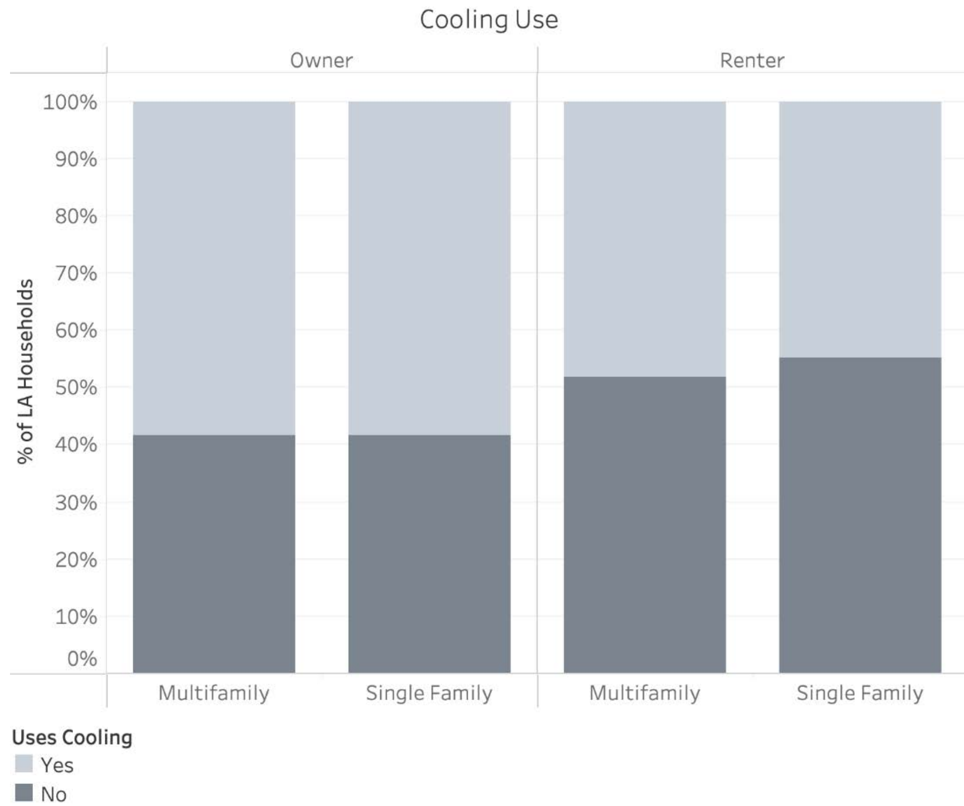

Figure A-4. Cooling use in Los Angeles by tenure and building type

Less than half of all renters use cooling for both multifamily and single-family dwellings. Cooling use provides safe and comfortable living temperatures during heat waves.

Heating Type

We examined the percentage of Los Angeles dwelling units using heating fuel types by tenure and income levels, as shown in Figure A-5.

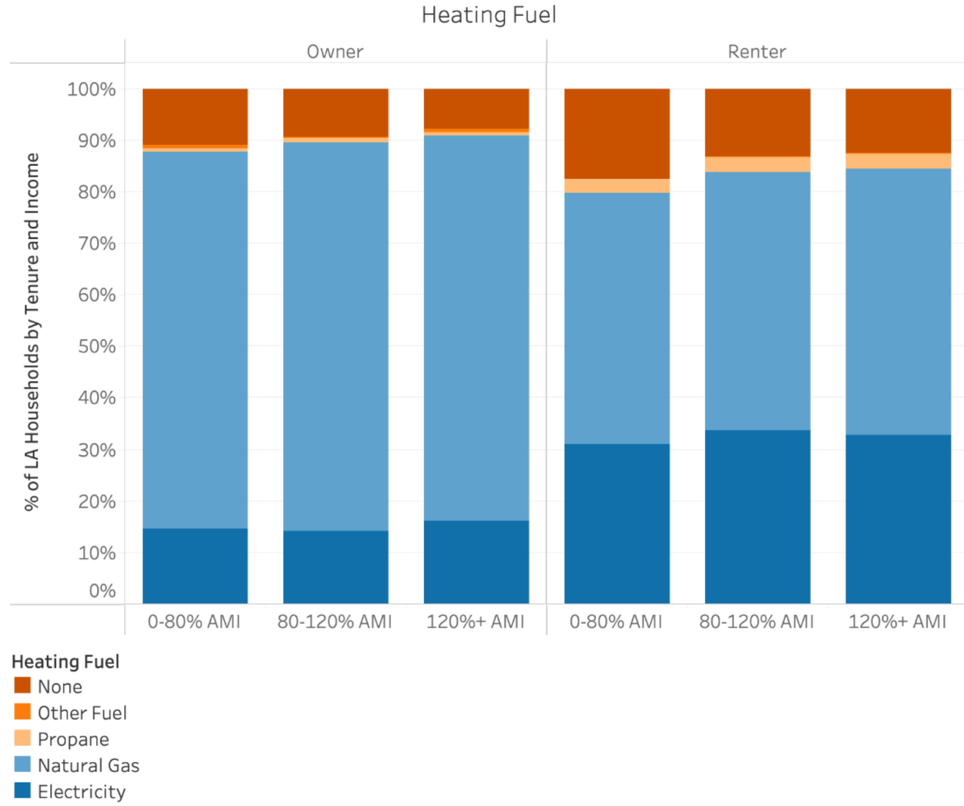

Figure A-5. Heating fuel by income and tenure

Twenty percent of low-income renters either do not have heating fuel or use propane or another type of fuel. Natural gas has the highest usage for heating fuel—over 70% for owners across all income bands and 50% for renters across all income bands. The high use of fossil fuel (or lack of heating) supports the additional benefits of switching to heat pump technologies, which provide cooling during warm temperatures and heating during cool temperatures.

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