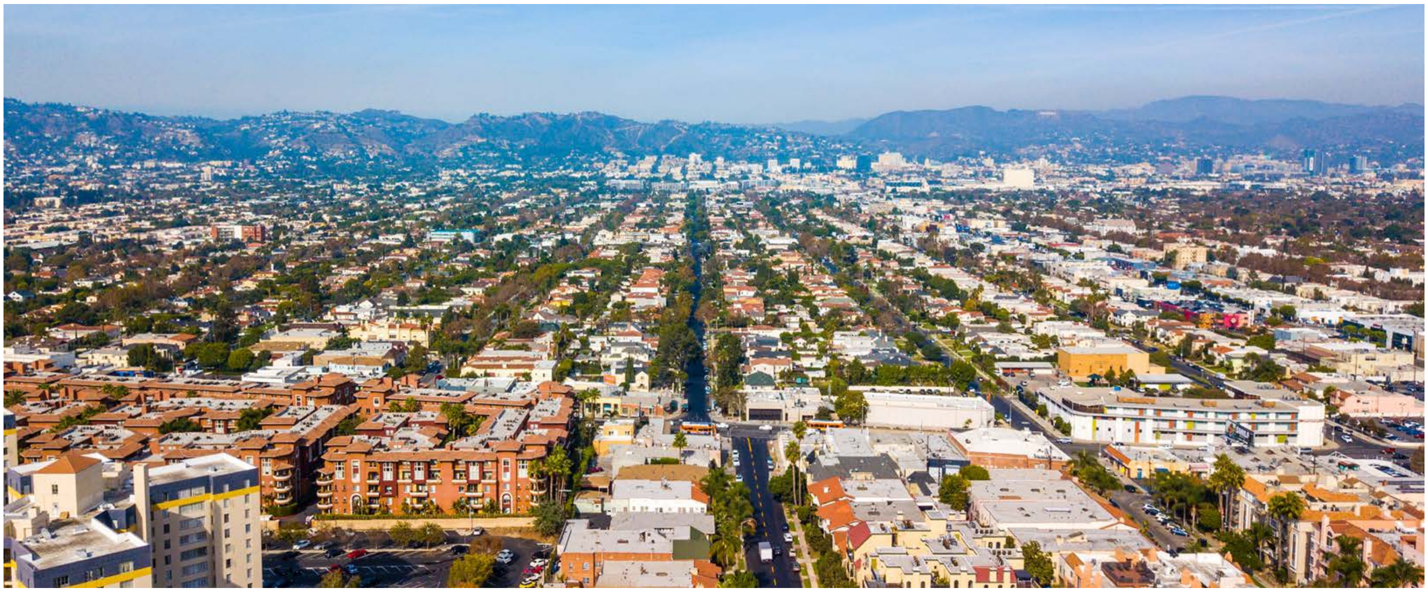
LA100 EQUITY STRATEGIES



Chapter 6: Universal Access to Safe and Comfortable Home Temperatures

FINAL REPORT: LA100 Equity Strategies

Noah Sandoval, Katelyn Stenger, Anthony Fontanini, Lixi Liu, Janet Reyna, Philip White, Ry Horsey, Patricia Romero-Lankao, and Nicole Rosner

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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

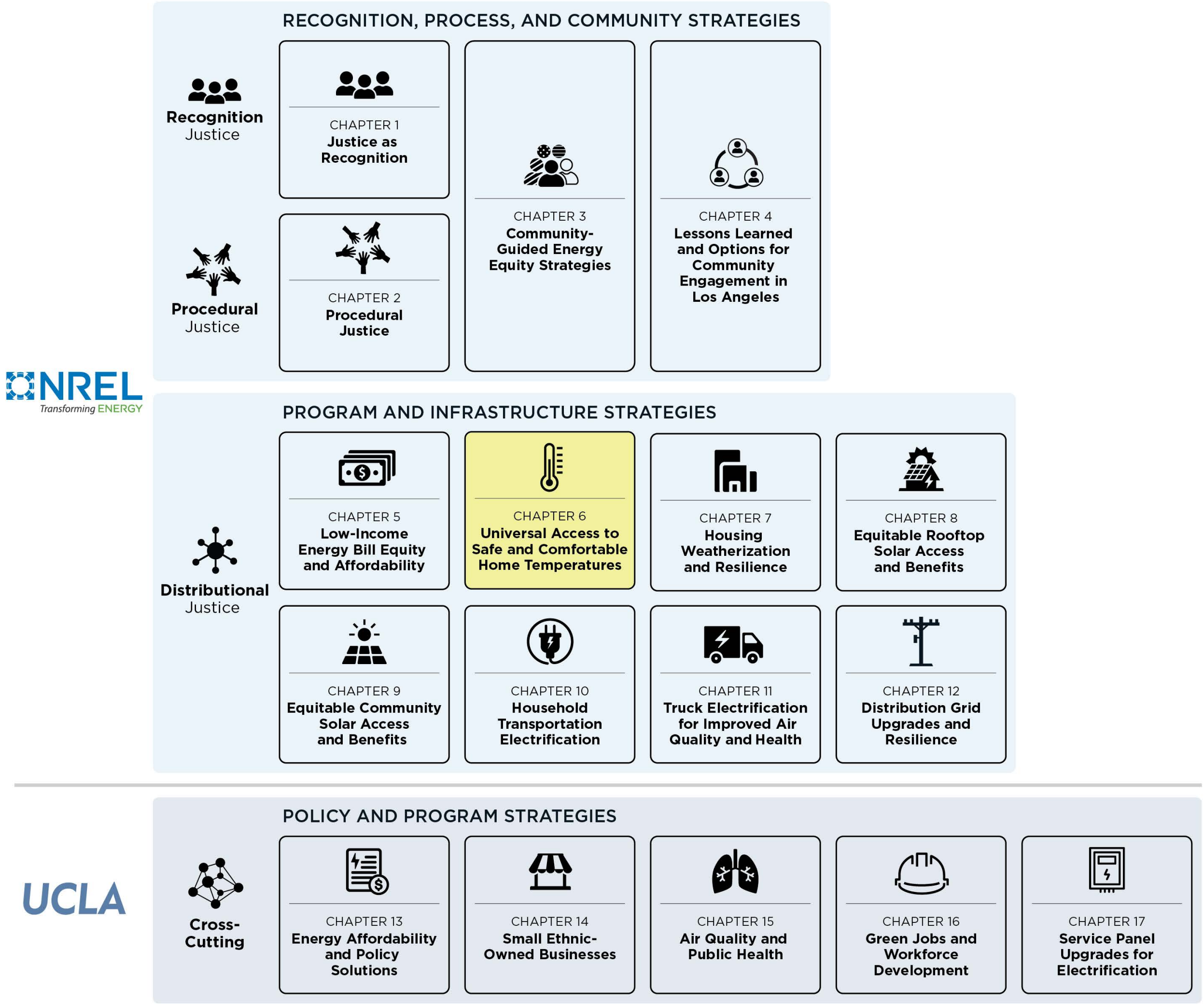
LA100 Equity Strategies employs a unique mixed-methodological approach utilizing three distinct—but connected—research efforts. Through these efforts, NREL and UCLA developed a range of strategy options for increasing equity in LA's transition to 100% clean energy.

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

AC	air conditioning/air conditioner
ACCA	Air Conditioning Contractors of America
AMI	area median income
ASHP	air-source heat pump
CEC CZ	California Energy Commission climate zone
CMU	concrete masonry unit
DAC	disadvantaged community
eTRM	electronic technical reference manual
GWh	gigawatt-hours
HEIP	Home Energy Improvement Program
HOMES	Home Owner Managing Energy Savings
HSPF	heating seasonal performance factor
HUD	Housing and Urban Development
HVAC	heating, ventilating, and air conditioning
IRA	Inflation Reduction Act of 2022
LADWP	Los Angeles Department of Water and Power
LBL	Lawrence Berkeley National Laboratory
LEAD	Low-Income Energy Affordability Data
NREL	National Renewable Energy Laboratory
NREMDb	National Residential Efficiency Measures Database
NYSERDA	New York State Energy Research Development Authority
PUMA	Public Use Microdata Area
SGHC	solar heat gain coefficient

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 cooling technologies as means to increase access to safe and comfortable home temperatures. Lack of cooling access and use can have severe health impacts on building occupants during heat waves.

Specifically, NREL developed and used 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 compared a baseline scenario with seven upgrade scenarios. Five scenarios cooled the entire household and featured cooling systems at varying efficiency levels with various improvements to the envelope, roof, and shading, and two scenarios cooled a single room in a household with no prior cooling using either a room air-conditioning or a heat pump system. For each scenario, we evaluated impacts on utility bills, payback periods, and changes in energy burdens, as well as ability to achieve safe and comfortable temperatures. We also examined the effects of building types (multifamily vs. single-family) on indoor air temperatures.

Based on the results of modeling, analysis, and community guidance, we identified six short-term and two long-term strategies for improving access to building envelope upgrades and cooling strategies that could save lives and maintain safe home temperatures for Los Angeles' low-income households during heat waves.

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

Community Guidance

Analysis was tailored to incorporate guidance from the LA100 Equity Strategies Steering Committee, listening sessions with community-based organizations and community members, and community meetings. The following community concerns and priorities relate to universal cooling and comfort:

Steering Committee member:

"Passive cooling is critical, not just air conditioning. Reflective surfaces, cool roofs, insulation, planting trees on the southwest corner of homes should all be considered."

- The need for safe living conditions
- Concerns that upgrades will raise rents and cause displacement
- More diversified and community-tailored outreach and support, such as feedback channels
- Affordable program options that require fewer upfront costs
- Maintenance and safety upgrade support for home improvements needed for upgrades like electrical panels or mold abatement
- Amended eligibility requirements for ratepayers experiencing disadvantages that do not fit current criteria (e.g., moderate-income household eligibility)
- Revised Los Angeles Department of Water and Power (LADWP) programs that address the split incentive problem between renters and property owners
- Need for apprenticeship programs and local knowledge.

> **Steering Committee member:**
>
> "We have a housing crisis throughout the city with a burgeoning homelessness crisis … landlords are flipping people out of buildings, using temperature/climate to push tenants out by diminishing the habitability, or they will pass costs on to tenants to increase rents. We need a code that no public money will be given to landlords without tenant protections. It has to be written into any strategies from this work—legal mechanisms to ensure habitability without increasing rent or utility burden."

Distributional Equity Baseline

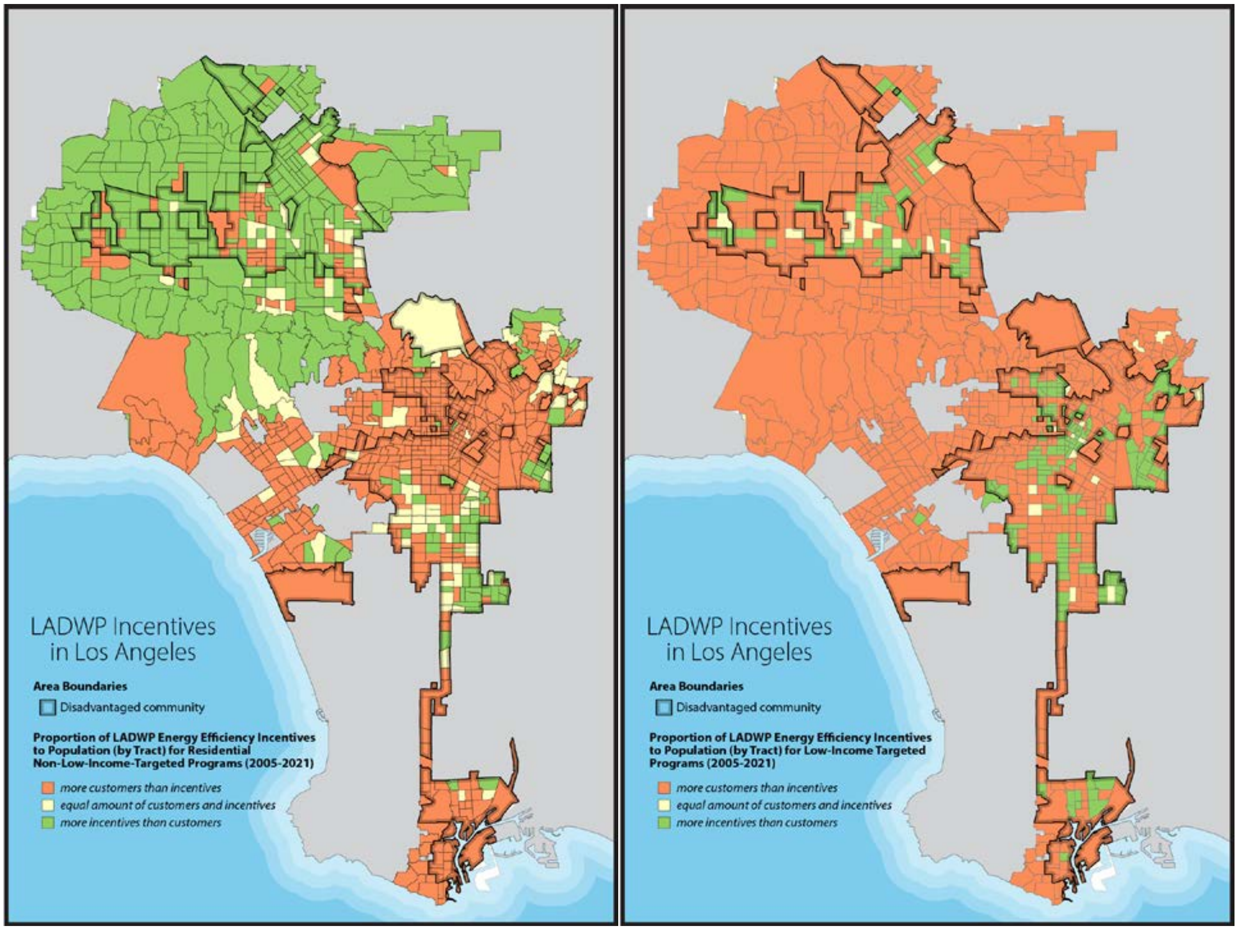
Distributional equity analysis found that most LADWP residential energy efficiency programs analyzed disproportionately benefited non-disadvantaged, mostly White, non-Hispanic, mostly home-owning, and mostly above-median-income communities (Figure ES-1).

LADWP RESIDENTIAL INVESTMENTS		NUMBER OF YEARS	TOTAL AMOUNT SPENT	AVG. AMOUNT PER CUSTOMER DAC/Non-DAC	% OF INCENTIVES Normalized by # of Customers DAC/Non-DAC	WHICH COMMUNITIES DISPROPORTIONATELY BENEFITED FROM PROGRAMS?				
						DAC/ Non-DAC	Mostly Non-White/White	Mostly Hispanic /Non-Hispanic	Mostly Renters/Owners	Below/Above Median Income
ENERGY EFFICIENCY	Home Energy Improvement Program	3	$3,378,869	$3 $2	61% 39%	DAC		Hispanic	Owners	
	Refrigerator Turn-In and Recycle Program	5	$2,667,307	0.01 refrigerators 0.014 refrigerators	42% 58%	Non-DAC	White	Non-Hispanic	Owners	Above
	Consumer Rebate Program	6	$93,248,144	$64 $74	46% 54%	Non-DAC	White	Non-Hispanic	Owners	Above
	Other Non-Low-Income-Targeted Programs	15	$36,343,548	$20 $34	35% 65%	Non-DAC	White	Non-Hispanic	Owners	Above
	Energy Savings Assistance Program*	5	$7,897,260	$11 $1	92% 8%	DAC	Non-White	Hispanic	Renters	Below

* Low-Income Targeted

Figure ES-1. Statistical analysis of LADWP residential energy efficiency investments (2007–2021)

Of the residential energy efficiency programs analyzed, one program, the Energy Savings Assistance Program, targeted low-income households and, by design, benefited disadvantaged communities (DACs)[1]. Areas such as Central Los Angeles, Northeast Los Angeles, Boyle Heights, Lincoln Heights, and the Harbor saw disproportionately fewer benefits from energy efficiency programs that did not target low-income households (Figure ES-2).



(a) **(b)**

Figure ES-2. Distribution of LADWP residential efficiency incentives not targeted to low-income households (a) and distribution of LADWP residential efficiency incentives targeting low-income households (b), where number of incentives are compared to number of customers

Areas in orange indicate a lower number of incentives per customer, and areas in green indicate a higher number of incentives per customer.

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[1] Disadvantaged communities are identified by CalEPA based on criteria defined in Senate Bill (SB) 535, as described here: https://oehha.ca.gov/calenviroscreen/sb535

Key Findings

NREL developed a building stock model that simulated the energy use of 50,000 representative dwellings.[2] These dwelling units represent the diversity of housing types, appliances, climate zones, and household incomes across Los Angeles. A baseline scenario was compared with seven upgrade scenarios. Five upgrade scenarios cool the entire household and feature cooling systems at varying efficiency levels with various improvements to the envelope, roof, and shading. Two upgrade scenarios cool one room in a household without cooling in the baseline by using either a room air conditioner (AC) or mini-split heat pump system.

Economic impacts, as well as a dwelling unit's ability to achieve safe and comfortable temperatures, were evaluated for each scenario. Key findings include:

- More than 27% of low-income (0%–80% AMI) households in Los Angeles lack access to cooling and are projected to experience the equivalent of nearly two months of exposure to dangerous indoor temperatures in 2035. Cooling one room with a room AC for 230,000 households would have an installed cost of $160 million total or $13 million per year between 2024 and 2035.[3]
- In the baseline scenario, households in multifamily buildings are projected to experience more than a month of dangerous indoor heat exposure in 2035 compared to households in single-family homes, which are projected to experience a median of less than one day of dangerous temperatures. More than 95% of low-income renters live in multifamily dwellings.[4]
    - *Providing cooling for the entire dwelling eliminated exposure to dangerous indoor temperatures* regardless of income, building type, or access to cooling before upgrades. However, these upgrades have high initial costs of $6,000–$16,000.

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)

- *Cooling use alone dramatically improves access to safe and comfortable home temperatures*. Whole-home cooling with a heat pump reduces the maximum living space temperature by an average of 13°F and reduces hours above the dangerous temperature threshold (86°F) by over 99% for low-income, multifamily households.

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[2] A dwelling is a place of residence.

[3] Assuming a set point between 74°F and 78°F, this would increase annual average per household utility costs by $181. NREL cannot verify how much partial cooling will meet the cooling set point, decrease the maximum indoor home temperature, or decrease the number of hours above 86°F that a dwelling unit will experience. Temperatures are modeled for whole-home cooling systems, which are more effective at delivering comfort but increase costs.

[4] See Chapter 7: Housing Weatherization and Resilience (Stenger et al. 2023) for additional Los Angeles housing data by income, tenure, and building type.

- *In Los Angeles' mild climate, additional envelope efficiency upgrades do not reduce exposure to dangerous temperatures*. While improved insulation, air sealing, and window performance can increase energy efficiency and utility bill savings, whole-home cooling equipment access and use is the most effective way to reduce exposure to dangerous temperatures.
- *13% of Los Angeles households are energy-burdened and extremely low-income.* Providing low-income households that do not have cooling with a whole-home, maximum efficiency cooling system increases the number of energy-burdened households by 12,000—this increased burden is a result of the added cooling service and resulting energy demand. Providing whole-home, maximum efficiency cooling to low-income households with existing whole-home cooling, however, reduces energy-burdened households among this group by 15,000, because more efficient cooling saves on utility bills.
- Minimum efficiency cooling systems for the whole home have the shortest payback period across income levels among whole-home cooling upgrade scenarios evaluated. Low-income owners have a simple payback period of 16 years, and renters have a simple payback period of 24 years. Using the Inflation Reduction Act of 2022 (IRA) rebates reduces the simple payback to less than a year. However, limited IRA program budgets can fund systems in less than 1% of 0%–150% area median income (AMI) households. Where funding is insufficient to provide whole-home cooling, partial space conditioning can provide some cooling at 65%–90% lower costs to dwellings without any cooling.

Equity Strategies

Modeling, analysis, and community engagement identified the following strategies for achieving more equitable outcomes in the distribution of benefits and burdens in Los Angeles' transition to clean energy and universal cooling.

- **Short Term:** Provide affordable access to whole-home cooling through a heat pump before envelope improvements, particularly in multifamily residential buildings.
- **Short Term:** Deliver direct installation to cool one room in extremely low-income households (0%–30% AMI) or deploy rebates used at point of purchase.
- **Short Term:** Issue rebates for heat pumps as part of the Cool LA Program to provide up to 29% more energy-efficient cooling for total lifecycle costs equivalent to current rebates for window-unit ACs.
- **Short Term:** Reduce application time and/or auto-enroll extremely low-income households who receive Cool LA rebates for partial conditioning (i.e., room AC) into a bill assistance program to avoid increased energy burdens.
- **Short Term:** Combine federal IRA or Weatherization Assistance Program funding with existing LADWP rebates to augment LADWP's Home Energy Improvement Program (HEIP), Cool LA program, and other programs to lower the equipment costs of heat pumps and envelope efficiency upgrades for low-income households.

- **Short Term:** Expand LADWP's HEIP (LADWP 2023) to include funding for necessary renovations and electrical upgrades to ensure the ability to install a heat pump.
- **Long Term:** Evaluate contractors representing DACs in current LADWP contracts and support apprenticeship programs in DACs for heating, ventilating, and air conditioning (HVAC) entrepreneurship and educational opportunities—importantly, heat pump installation training and demonstrations.
- **Long Term**: Partner with the Housing Authority to install upgrades in public housing and establish a mechanism to mitigate rent increases due to LADWP-supported upgrades elsewhere.

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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 identifies strategies to increase access to safe and comfortable home temperatures through housing weatherization and cooling technologies.

1.1 Modeling and Analysis Approach

To provide universal access to safe and comfortable home temperatures in Los Angeles, the National Renewable Energy Laboratory (NREL) explored the impact of universal access to cooling along with building envelope improvements using the ResStock™ model. 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 in Los Angeles, are described in detail below.

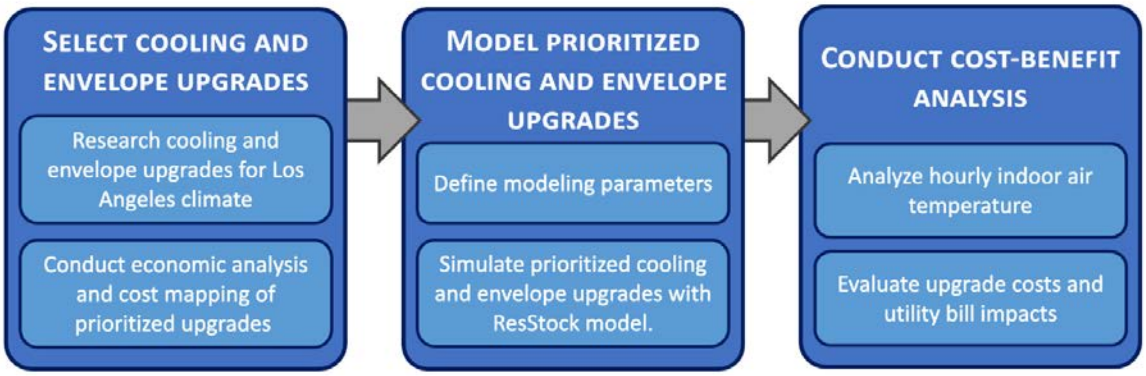

Figure 1. Modeling workflow for the analysis

1.1.1 Cooling and Building Envelope Upgrade Scenario Selection and Modeling

NREL chose eight combinations of cooling systems and building envelope upgrades—or upgrade scenarios—to model indoor air temperatures and utility usage changes:

- Baseline
- Whole-Home Cooling
    - Max. Efficiency Cooling System
    - Min. Efficiency Cooling System
    - Min. Efficiency Cooling System, Cool Roof, and Shading
    - Min. Efficiency Cooling System and Low-Cost Envelope Improvements
    - Min. Efficiency Cooling System and Title 24[5] Envelope Improvements
- One-Room Cooling
    - Min. Efficiency Partial Space Conditioning

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[5] "Building Energy Efficiency Standards: Title 24," California Energy Commission, https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards.

- Max. Efficiency Partial Space Conditioning.

We modeled cooling to the entire dwelling under maximum[6] and minimum[7] efficiency conditions. We selected heat pumps for cooling because they provide up to 29% more energy-efficient cooling for equivalent total lifecycle costs compared to window-unit air conditioners (Booten, Winkler, and Faramarzi 2022) and will be eligible for the widest selection of federal rebates. LA100 Equity Strategies Steering Committee input and current LADWP policies informed the envelope efficiency upgrades that were modeled in combination with entire dwelling cooling.

In addition to the upgrades listed above, NREL investigated the effects of providing cooling to one room for dwellings that would otherwise not have any cooling. These upgrades and results are discussed in Section 2.2 (page 17).

Cooling can be achieved through methods other than the ones presented in these upgrade scenarios. The focus of this analysis was to provide cooling through central air-source and mini-split air-source heat pumps. It is also possible to lower indoor air temperature through traditional AC systems, shading, or mechanical ventilation. Given the mild climate of Los Angeles, measures taken by residents to cool their dwelling units, such as precooling homes on off-peak hours or installing operable windows, may be cost-effective. Furthermore, some dwelling units may be best served by individual, less costly envelope upgrades (e.g., increased ceiling insulation) rather than full envelope retrofits. Another cooling technology being explored by LADWP to improve equity through demand response is internet-connected AC systems. This technology was not investigated in this report.

1.1.2 Cost Analysis

We conducted a cost analysis for whole-home cooling technology and building envelope upgrades. We reviewed the data from various technology cost databases (see Appendix C) and summarized costs for each upgrade by technology type, fuel type, efficiency, capacity, total project costs, material costs, labor costs, hourly labor rates, and labor hours. Next, costs were compared to costs from local hardware retailers and online wholesalers and suppliers (see Appendix C) to determine whether the costs were reasonable for the LA area. If upgrade costs were unavailable or if costs were outside an acceptable range compared to local hardware retailer or wholesaler and supplier prices, we used the lowest cost from the retailer or wholesaler for the material price. Labor costs were included in total project costs if they were available. If not, labor costs were calculated by determining the type of labor needed (e.g., electrician), the associated hourly rate for that labor type, and the labor hours based on RSMeans data (Doheny 2021). Upgrade cost information is in Section C.2 in Appendix C (page 39). All cost data are in 2022 dollars (2022$).

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[6] For ASHP (SEER 26.1, 11 HSPF), for MSHP (SEER 33.1, 13.5 HSPF)

[7] Based on DOE guidelines, for ASHP (SEER 15, 9.0 HSPF); for MSHP, same as maximum because MSHP costs do not vary with efficiency, but rather system size. Thus, installing a lower efficiency model would be cost the same but consume more energy.

2 Modeling and Analysis Results

2.1 Whole-Home Cooling

Table 1 presents the median home temperature and economic effects of cooling and envelope improvement upgrades simulated in the baseline and first five (whole-home cooling) upgrade scenarios.

Table 1. Median Effect of Building Upgrade Scenarios (2035)

Upgrade Scenario	Hours Above 86°F	Maximum Indoor Air Temperature for a Single Hour (°F)	Annual Utility[a] Bill (2022$)	Upgrade Cost (2022$)
Baseline	590	93	1,100	—
Max. Efficiency Cooling System	0	79	1,100	11,000
Min. Efficiency Cooling System	0	80	1,200	7,900
Min. Efficiency Cooling System, Cool Roof, and Shading	0	79	1,200	10,300
Min. Efficiency Cooling System and Low-Cost Envelope	0	80	1,200	9,700
Min. Efficiency Cooling System and Title 24 Envelope	0	80	1,200	14,000

[a] Maximum indoor air temperatures rise a few degrees above the cooling sets points even with highly insulated and air sealed dwelling units in part because mechanical ventilation expels conditioned air to ensure indoor air quality when building envelopes are tight, and there are limitations of sizing heat pumps using ACCA Manual J/S to size for cooling loads (ACCA Manual J 2016).

[b] Utility refers to the combination of electricity and natural gas energy services.

[c] A positive value indicates utility bill savings.

Adding cooling to the entire dwelling through a heat pump reduced the maximum temperature from a dangerous indoor temperature of 93°F to safe temperatures of 79°F and 80°F for maximum and minimum efficiency cooling systems, respectively. Though utility bills generally increase, this is a result of increased access to and use of cooling, which is discussed in detail in the utility bill impacts sections, which start on page 8.

Of the upgrades selected for analysis, the minimum efficiency cooling systems have the lowest median upgrade cost ($7,900).

2.1.1 Universal Access to Safe and Comfortable Home Temperatures

We measured access to safe and comfortable home temperatures by determining the maximum living space temperature over a year and the number of hours above the dangerous temperature threshold, 86°F described in Chapter 7 (Stenger et al. 2023).

2.1.1.1 Maximum Indoor Temperatures

The maximum indoor temperature of a dwelling characterizes the warmest temperature experienced by a dwelling unit throughout the entire year. Figure 2 shows the maximum living space temperature by area median income (AMI) across upgrade scenarios.

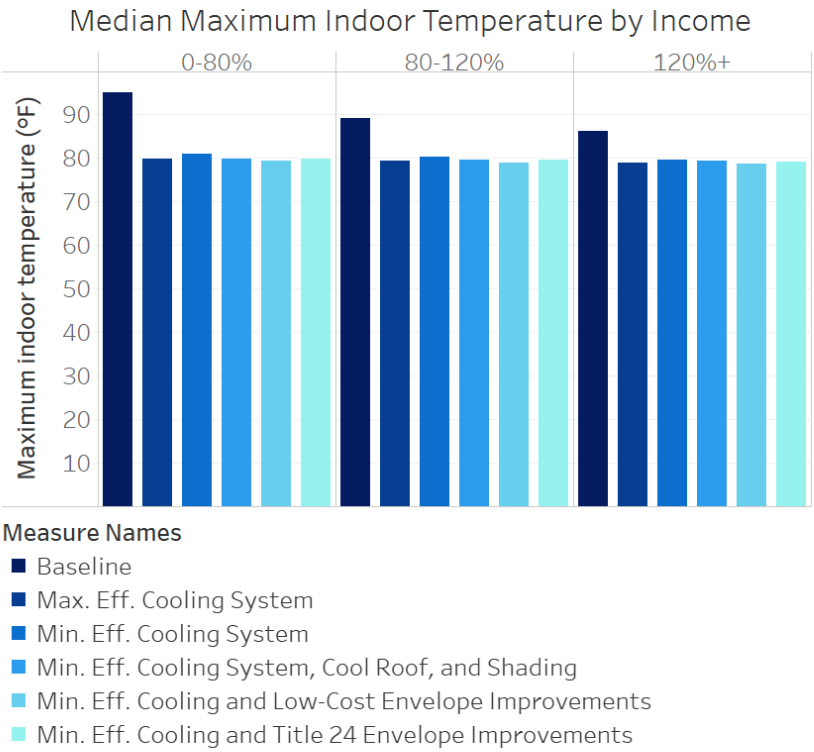

Figure 2. Maximum living space temperature by percentage AMI (2035)

In the baseline scenario, more than half of low-income (0%–80% AMI) households will experience dangerous indoor air temperatures of 95°F at least once a year by 2035, which exceeds the safe indoor temperature threshold of 86°F. Regardless of upgrade or efficiency level, providing cooling decreases maximum indoor temperatures to below the dangerous temperature threshold for low-income households. Additional results for maximum indoor air temperatures are provided in Appendix B.

2.1.1.2 Hours of Dangerous Temperatures

The number of hours at dangerous temperatures is shown in Table 2, which indicates the median number of hours above 86°F for the baseline and each upgrade by income level.

Table 2. Median Number of Hours Above 86°F Annually by Percentage AMI (2035)

Upgrade Scenario	0%–80% AMI	80%–120% AMI	+120% AMI
Baseline	1,400	100	2
Max. Efficiency Cooling System	0	0	0
Min. Efficiency Cooling System	0	0	0
Min. Efficiency Cooling System, Cool Roof, and Shading	0	0	0
Min. Efficiency Cooling System and Low-Cost Envelope	0	0	0
Min. Efficiency Cooling System and Title 24 Envelope	0	0	0

Table 2 shows that each upgrade scenario eliminates dangerous temperature exposure for dwelling units across income levels. In the baseline condition, low-income households (0%–80% AMI) experience dangerous temperatures 16% of the year (1,391 of 8,760 hours) and moderate-income (80%–120% AMI) households experience dangerous temperatures 1.2% of the year (104 of 8,760 hours). All upgrades, regardless of cooling system efficiency level, presence of cool roofs, shading, or improvements in envelope, reduced the median number of hours above 86°F to zero across all income levels.

We also examined the effects of building types. In the baseline condition, multifamily buildings experience dangerous temperatures 14% of the year, 1,235 more hours than single-family buildings. However, with any upgrade, the median number of hours above 86°F drops to zero for both building types (Table 3).

Table 3. Median Number of Hours Above 86°F Annually by Single-Family/Multifamily and Upgrade (2035)

Upgrade Scenario	Single-Family	Multifamily
Baseline	15	1,300
Max. Efficiency Cooling System	0	0
Min. Efficiency Cooling System	0	0
Min. Efficiency Cooling System, Cool Roof, and Shading	0	0
Min. Efficiency Cooling System and Low-Cost Envelope	0	0
Min. Efficiency Cooling System and Title 24 Envelope	0	0

2.1.2 Economic Impacts

We also examined the economic impacts on utility bill savings, upgrade costs, simple payback periods, and changes in energy burden. These results provide context for the costs and benefits of the upgrades simulated.

2.1.2.1 Upgrade Costs

Upfront capital costs prevent many households, particularly low- and moderate-income households, from installing energy-efficient building technologies that often result in utility bill savings (Dadzie et al 2018; Klöckner and Nayum 2017). Table 4 shows the median upgrade cost in 2022$ disaggregated by income level. We provide the lower (25%) and upper (75%) quartiles to provide statistical context. Upgrade costs differ by household income because higher-income households tend to have larger homes; therefore, larger floor, wall, and ceiling areas in these homes increase the amount of insulation or the size of a cooling system required. Importantly, the upgrade costs are highly variable for cooling systems because costs are a function of both efficiency level and system size. More information about upgrade costs is provided in Appendix C.

Table 4. Upgrade Costs by AMI (2022$)

Upgrade Scenario	0%–80% AMI			80%–120% AMI			120%+ AMI		
	Lower Quartile Upgrade Cost	Median Upgrade Cost	Upper Quartile Upgrade Cost	Lower Quartile Upgrade Cost	Median Upgrade Cost	Upper Quartile Upgrade Cost	Lower Quartile Upgrade Cost	Median Upgrade Cost	Upper Quartile Upgrade Cost
Max. Efficiency Cooling System	$5,700	$10,300	$12,000	$9,600	$12,000	$15,000	$11,000	$13,000	$16,000
Min. Efficiency Cooling System	$5,700	$7,200	$9,000	$6,900	$8,400	$11,000	$7,300	$9,600	$12,000
Min. Efficiency Cooling System, Cool Roofs, and Shading	$7,000	$8,900	$13,000	$8,000	$11,000	$17,000	$8,900	$14,000	$20,000
Min. Efficiency Cooling System and Low-Cost Envelope Improvements	$7,000	$8,800	$11,000	$8,200	$10,000	$14,000	$8,900	$12,000	$17,000
Min. Efficiency Cooling System and Title 24 Envelope Improvements	$9,800	$13,000	$18,000	$11,000	$15,000	$22,000	$12,000	$18,000	$26,000

Across all income levels, upgrades without incentives required an investment between $5,700 and $26,000.

The lowest cost whole-home cooling system upgrade for all income levels is the minimum efficiency cooling system, which increases access to safe and comfortable indoor air temperatures. The second-lowest cost upgrade is the minimum efficiency cooling system with low-cost envelope improvements. Chapter 7 (Stenger et al. 2023) finds that cooling access and use and envelope improvements increase the passive survivability of households during a power outage.

2.1.2.2 Utility Bill Impacts by Cooling Access

Impacts on monthly utility bills were a primary concern voiced during LA100 Equity Strategies Steering Committee meetings, community listening sessions, and community meetings. Increases in utility bills have serious consequences for households that struggle to pay their utility bills and can result in utility shutoffs, which pose both immediate and lasting health and economic repercussions (Hernández 2013; Cook et al. 2008).

We approximated utility bills using a fixed rate, which is a flat rate that all customers must pay each year to simply receive utility service, and a volumetric rate, which is the price per unit of energy, kilowatt-hour or therm, for electricity and natural gas respectively. For each of the 50,000 representative households, we multiplied modeled annual electricity and natural gas consumption by the respective volumetric rates and then added to this the flat rate. The fixed and volumetric rates we used for this calculation are shown in Table 5, which is a simplification of utility bills to approximate impact in 2022$.

Table 5. Fixed and Volumetric Rates for Electricity and Natural Gas

Utility Service	Rate Type	Rate	Source
Electricity	Fixed rate ($/year)	$27.6	OpenEI n.d.a.
	Volumetric rate ($/kWh)	$0.187	OpenEI n.d.b.; LADWP
Gas	Fixed rate ($/year)	$59.2	SoCalGas 2022
	Volumetric rate ($/therm)	$1.87	SoCalGas 2022

Utility bill change is the baseline utility bill minus the upgrade scenario utility bill; therefore, a positive value is a decrease in a utility bill (i.e., bill savings) from the baseline to the upgrade scenario. See Chapter 4 (Bowen et al. 2023), for detailed utility bill modeling.

We analyzed results by dwellings that use cooling systems and dwellings that do not have or use cooling. Adding and using a new cooling system increases energy demand, and therefore cost, while also increasing comfort and safety. Figure 3 shows utility bill change in 2022$ across upgrades disaggregated by income (AMI), where a positive value indicates bill savings, and a negative value indicates a bill increase.

Table 6. Annual Utility Bill Change by Income and Cooling Use

Upgrade Scenario	Uses Cooling in Baseline	0%–80% AMI (HUD)	80%–120% AMI (HUD)	120%+ AMI (HUD)
Max. Efficiency Cooling Systems	No	-$120	-$160	-$190
	Yes	$120	$170	$210
Min. Efficiency Cooling System	No	-$160	-$220	-$270
	Yes	$26	$23	$25
Min. Efficiency Cooling System, Cool Roofs, and Shading	No	-$130	-$180	-$230
	Yes	$59	$71	$84
Min. Efficiency Cooling System and Low-Cost Envelope Improvements	No	-$150	-$210	-$250
	Yes	$29	$34	$45
Min. Efficiency Cooling System and Title 24 Envelope Improvements	No	-$190	-$230	-$260
	Yes	$9	$35	$67

Dwellings that have and use cooling in the baseline scenario save on utility bills due to the increased efficiency of the heat pump systems modeled, whereas dwellings without cooling increase utility bills due to increased cooling area served (i.e., none to whole-home cooling) and therefore energy demand. Maximum efficiency cooling systems save $120–$210 compared to minimum efficiency savings of $23–$26 annually. Therefore, while the higher efficiency systems are more expensive initially, they provide greater utility bill savings.

2.1.2.3 *Utility Bill Impacts by Dwelling Size*

Utility bills for dwellings with cooling use in the baseline were normalized by the size of the dwelling to explore utility costs per square foot by housing type, as shown in Figure 3.

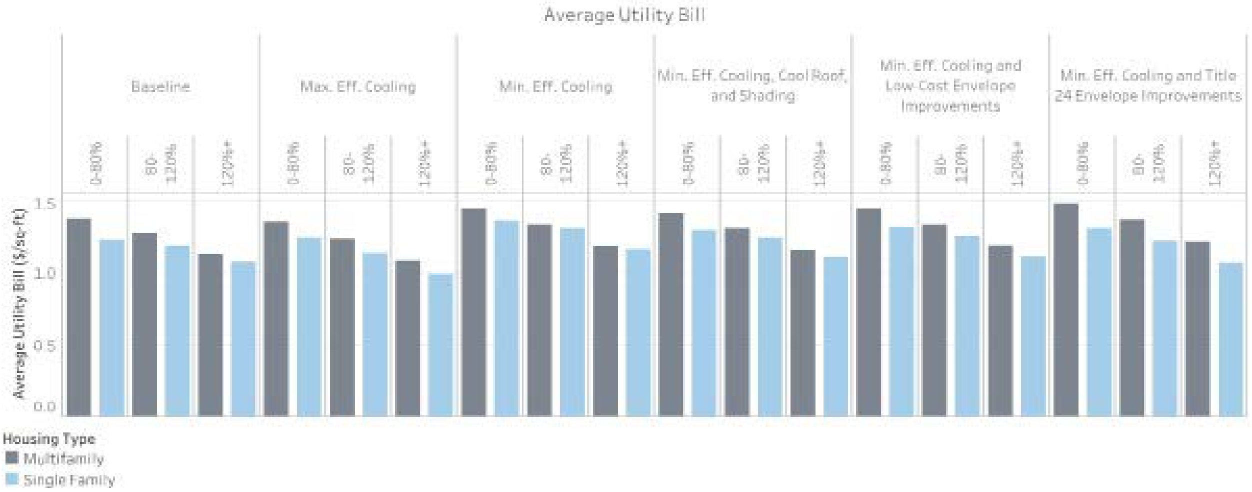

Figure 3. Annual utility bill change by income and cooling access

Multifamily dwelling units have higher utility bills per square foot than single-family units regardless of upgrade type, in part, because of fixed utility charges. It is important to note that multifamily dwelling units have a lower median annual utility bill compared to single-family dwelling units; approximately $910 and $1550 for multifamily and single-family, respectively. Single-family dwelling units are larger than multifamily dwelling units, which is a key driver of utility bills.

2.1.2.4 Impact of Federal Funding

Using federal rebates and funding can enable more low-income households to adopt technologies that provide long-term savings but have higher upfront 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 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 7 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.

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[8] "H.R.5376: Inflation Reduction Act of 2022," https://www.congress.gov/bill/117th-congress/house-bill/5376/text

Table 7. 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

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[9] We do not consider the measured energy savings of 15%–20% as specified in the HOMES rebate because leadership in the Department of Energy's State and Community Energy Programs, the office administering the IRA rebate program, expressed concerns that it may require a complicated system of verification that will be difficult for municipalities and utilities to implement. https://www.energy.gov/scep/ira-home-energy-rebate-programs-informational-webinar-text-version

[10] "Workforce Development Toolkit for the Weatherization Assistance Program," U.S. Department of Energy, https://www.energy.gov/scep/wap/workforce-development-toolkit-weatherization-assistance-program.

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.

2.1.2.5 Simple Payback Period

We calculated the simple payback period for whole-home cooling upgrade scenarios for dwellings with existing cooling access in the baseline case. Some dwellings without cooling access might never see a payback because the added cooling equipment increases electricity use (and cost) by providing a service that was initially unavailable. In Table 8, we show the median simple payback period for households that have cooling access in the baseline condition. We segment cooling access by dwellings in the baseline condition with full space conditioning (i.e., whole-home cooling) and dwellings with partial space conditioning. Simple payback period is calculated by dividing the total upgrade costs by the annual utility bill savings. These payback periods are conservative estimates because they do not consider the avoided costs of replacing the baseline heating and cooling systems. In addition, we do not consider the health benefits of increased comfort or decreased exposure to heat.

Table 8. Simple Payback Period (years) by Income, Tenure, and Initial Cooling Access Type

		Owner		**Renter**	
Upgrade Scenario	**Income (% AMI)**	**Full Space Conditioning**	**Partial Space Conditioning**[a]	**Full Space Conditioning**	**Partial Space Conditioning**[a]
Max. Cooling Efficiency System	0%–80%	31	N/A	40	26
	80%–120%	31	20	40	23
	120%+	30	19	41	15
Min. Cooling Efficiency System	0%–80%	16	N/A	24	N/A
	80%–120%	15	N/A	24	N/A
	120%+	17	N/A	25	N/A
Min. Cooling Efficiency System, Cool Roofs, and Shading	0%–80%	29	N/A	33	32
	80%–120%	29	N/A	32	26
	120%+	30	N/A	34	N/A
Min. Cooling Efficiency System and Low-Cost Envelope Improvements	0%–80%	23	N/A	28	N/A
	80%–120%	23	N/A	28	N/A
	120%+	23	N/A	28	N/A
Min. Cooling Efficiency	0%–80%	36	N/A	39	N/A
	80%–120%	35	N/A	36	N/A

		Owner		Renter	
Upgrade Scenario	**Income (% AMI)**	**Full Space Conditioning**	**Partial Space Conditioning**[a]	**Full Space Conditioning**	**Partial Space Conditioning**[a]
System and Title 24 Envelope Improvements	120%+	36	N/A	36	N/A

[a] N/A means there was no simple payback period because of increased service (and thus an increased utility bill) from partial to full space conditioning.

The whole-home minimum cooling efficiency upgrade provides the quickest payback of any upgrade, which aligns with similar analysis for Southern California (Booten, Winkler, and Faramarzi 2022). For this upgrade, low-income owners have the quickest payback period of 16 years, whereas renters have a simple payback of 24 years. Across all whole-home upgrades, owners generally have a lower payback period than renters because owners have a higher utility bill savings than renters, largely due to larger dwelling sizes. In most scenarios, these conservatively estimated payback periods exceed system lifetimes for Los Angeles. Therefore, we examined the effects of IRA rebates and partial cooling for dwellings without cooling.

We evaluated the simple payback period of the same whole-home upgrades with IRA rebates. We examined two different rebates, the Home Energy Performance-Based, Whole-House rebate of the HOMES program and the High-Efficiency rebate of the Electric Home program. We applied the HOMES rebate to dwelling units over 120% AMI, based on energy saved, and the High-Efficiency Electric Home rebate to dwellings under the 120% AMI level.

Table 9. Simple Payback Period (years) with Maximum IRA Rebates

		Owner		Renter	
Upgrade Scenario	**Income (% AMI)**	**Full Space Conditioning**	**Partial Space Conditioning***	**Full Space Conditioning**	**Partial Space Conditioning***
Max. Efficiency Cooling System	0–80%	2.6	2.7	3.7	3.7
	80%–120%	2.4	2.2	3.5	2.8
	120%+	2.3	2.2	3.7	3.6
Min. Efficiency Cooling System	0%–80%	0.4	0.3	0.45	0.63
	80%–120%	0.4	0.4	0.19	0.23
	120%+	0.3	0.3	0.45	0.56
Min. Efficiency Cooling System, Cool Roof, and Shading	0%–80%	2.7	2.6	3.8	4.1
	80%–120%	2.4	2.1	3.0	3.1
	120%+	2.3	2.2	3.8	4.1

Upgrade Scenario	Income (% AMI)	Owner		Renter	
		Full Space Conditioning	**Partial Space Conditioning***	**Full Space Conditioning**	**Partial Space Conditioning***
Min. Efficiency Cooling System and Low-Cost Envelope Improvements	0%–80%	0.94	0.75	1.2	1.5
	80%–120%	0.88	0.67	0.76	0.53
	120%+	0.72	0.67	1.1	1.4
Min. Efficiency Cooling System and Title 24 Envelope Improvements	0%–80%	4.3	4.3	6.2	6.5
	80%–120%	4.1	4.3	5.4	5.8
	120%+	3.8	3.7	6.0	5.8

With IRA rebates, the simple payback period for whole-home cooling decreases to 0–6 years across all upgrades, income levels, and tenure, which is well under the expected lifetimes of the technologies included in the upgrades. However, rebate program budgets are limited and can fund retrofits in less than 1% of 0%–150% AMI households. Therefore, significant additional funding or alternative implementation strategies would be required to supplement federal funding.

2.1.2.6 Energy Burden

Energy burden measures utility bills as a percentage of household income, where 6% is considered high energy burden and needs attention or intervention (Colton 2011). Figure 4 shows the average energy burden by upgrade scenario and income level.

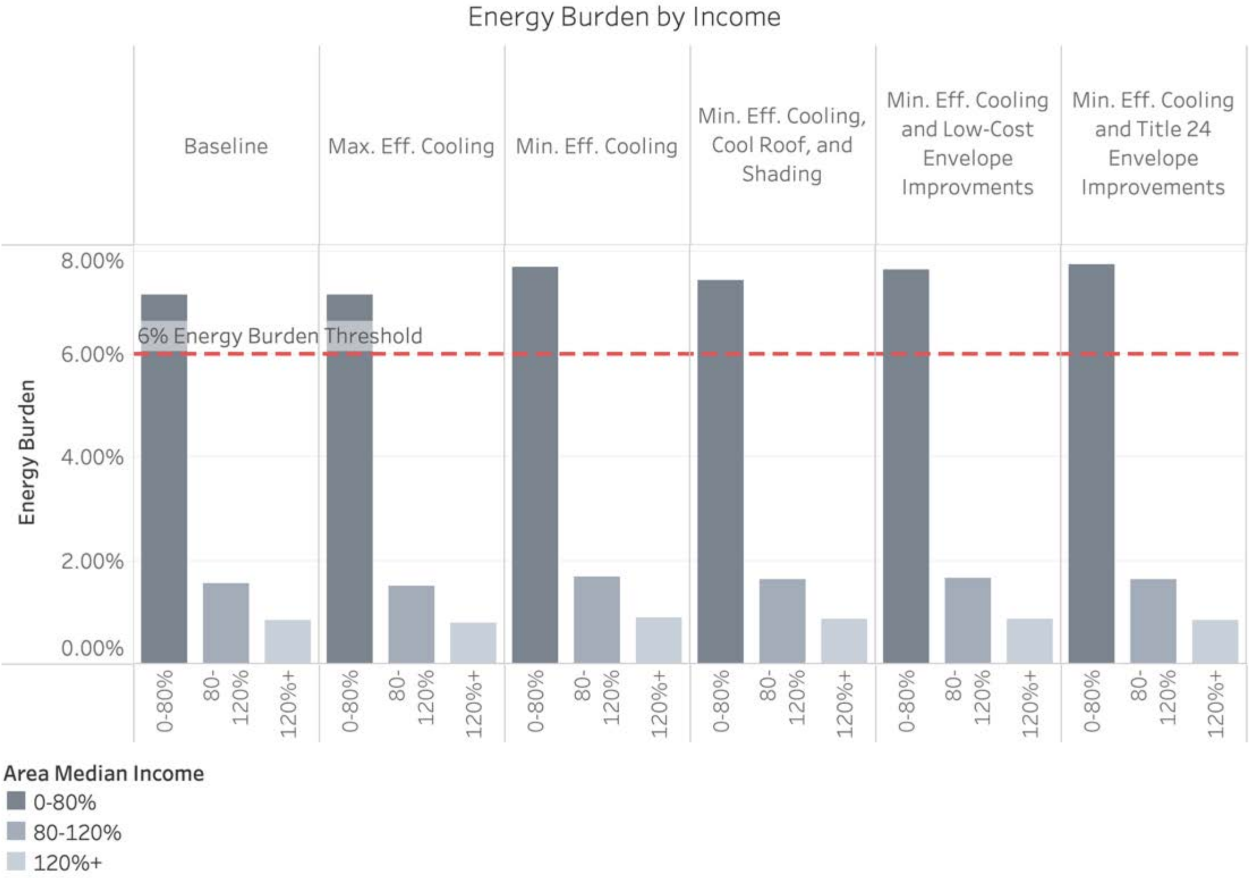

Figure 4. Average energy burden by income under the five whole-home cooling upgrade scenarios

On average, low-income households (0%–80% AMI) are above the 6% energy burden threshold regardless of whole-home cooling upgrade scenario, whereas moderate- and higher-income households are below the threshold.

The upgrades slightly increased the average energy burden for low-income dwellings, in part because of increased cooling access and use. For low-income households, we estimated the number of Los Angeles households that were energy-burdened by type of cooling access for the baseline and minimum efficiency cooling access.

When a household increases access to cooling, electricity demand and utility bills can increase. Given that low-income households are most energy-burdened, the number of low-income (0%–30%, 30%–60%, and 60%–80%) dwellings in the baseline and minimum effeciency cooling system upgrade scenarios that are above this 6% threshold are shown in Table 10.

Table 10. Estimated Number of Los Angeles Households Above Energy Burden of 6.0%

Baseline Cooling Access	Income (% AMI)	Dwelling Units in Baseline Scenario	Dwelling Units in Max. Efficiency Cooling System Upgrade Scenario	Percentage Change from Baseline to Min. Efficiency Cooling System
None	0%–30%	59,000	69,000	17%
	30%–60%	1,300	2,800	120%
	60%–80%	63	63	0%
Partial Space Conditioning	0%–30%	39,000	41,000	5%
	30%–60%	2,200	2,400	7%
	60%–80%	250	220	-13%
100% Conditioned	0%–30%	110,000	104,000	-7%
	30%–60%	13,000	6,700	-48%
	60%–80%	880	350	-61%

Currently, 13.4% of Los Angeles households are both energy-burdened and extremely low-income (0%–30% AMI), including an estimated 59,000 households without cooling access. When maximum efficiency cooling (through a heat pump that cools and heats 100% of the dwelling floor area) is provided for these households with no existing cooling, extremely low-income, the number of energy-burdened households increases by 17%, yet when households who already have whole-home cooling receive a maximum efficiency cooling, energy burden decreases by 7%. Providing maximum efficiency, whole-home cooling to 30%–60% and 60%–80% AMI households with cooling can reduce energy burden by 48% and 61%, respectively. In short, the increase in area of a dwelling cooled and duration of cooling increases both energy usage and energy burden. Yet, more efficient whole-home cooling systems for low-income households with whole-home cooling reduces energy burden relative to the baseline.

Low-income families will more likely have less disposable income to spend on these upgrades, and less access to low-interest financing and credit (Albanesi, DeGiorgi, and Nosal 2017). Because their basic survival needs are met, high-income households have the flexibility for upfront capital expenditures with deferred savings. Low-income households do not have this flexibility because they are driven to meet basic needs and might be confined to technologies with a rapid return and opt out of technologies with larger long-term savings potential (Newell and Siikamaki 2015).

2.2 Cooling One Room for Those Without Cooling

Nearly a quarter of LA households have no cooling technologies in their dwellings. As shown in Section 2.1.2.2 (page 8), adding whole-home cooling for dwelling units without cooling access means high upfront costs and can increase utility bills. The purpose of this analysis is to understand the costs of providing cooling to one room in a dwelling through a window/individual room cooling unit to a critical area of a dwelling unit, such as a bedroom or a living room.

We modeled a minimum and maximum efficiency system for dwelling units that did not have access to cooling in the baseline scenario. The minimum efficiency system models the lowest efficiency and least expensive room AC unit available on the market. The maximum efficiency system models a mini-split heat pump that only provides cooling to a single room and is somewhat less expensive than sizing a mini-split heat pump to cool an entire dwelling. To approximate cooling access for a single, critical room in the dwelling unit, we varied the percentage of conditioned space based on the number of bedrooms in each dwelling unit.

Cooling is provided year-round as needed, regardless of cooling season. Normally, a set of buildings has a wide range of cooling set points. We found that cooling set point is highly correlated with building type. To replicate this distribution, we assigned the following cooling set points:

- Single-family attached, single-family detached, and mobile homes were assigned a cooling set point of 76°F.
- Multifamily buildings with two to four units were assigned a cooling set point of 74°F.
- Multifamily buildings with more than four units were assigned cooling set point of 78°F.

Table 11 shows the upgrade costs associated with the minimum and maximum efficiency partial space conditioning cooling systems modeled for the lower quartile (25%), median, and upper quartile (75%).

Table 11. Upgrade Costs by Income to Cool One Room

	0%–80% AMI			80%–120% AMI			120%+ AMI		
Upgrade	25%	50%	75%	25%	50%	75%	25%	50%	75%
Min. Efficiency Partial Space Conditioning (2022$)	530	660	800	530	700	920	550	750	1,000
Max. Efficiency Partial Space Conditioning (2022$)	2,200	2,800	3,500	2,200	3,000	4,200	2,300	3,300	4,800

Cooling one room costs much less than whole-home cooling with minimum efficiency systems. The maximum and minimum efficiency partial space conditioning systems are approximately 65% ($4,400) and 90% ($6,500) less expensive, respectively, than minimum efficiency whole-home cooling systems, Table 4 (page 7).

Table 12 shows estimated labor and equipment costs if LADWP provided one-room cooling for all households without cooling by income.

Table 12. Estimated Costs to Cool One Room in Dwellings Without Cooling Access

Upgrade	0%–80% AMI	80%–120% AMI	120%+ AMI
Number of LA households without cooling	230,000	56,000	87,000
Min. Efficiency Partial Space Conditioning	$160,000,000	$44,000,000	$74,000,000
Max. Efficiency Partial Space Conditioning	$720,000,000	$190,000,000	$330,000,000

Table 13 shows the annual utility bill change for both maximum and minimum efficiency partial space conditioning systems (a negative number indicates a bill increase).

Table 13. Median Annual Utility Bill Change (2022$) for Partial Space Conditioning by Income

Upgrade Scenario	0%-80% AMI	80%-120% AMI	120%+ AMI
Min. Efficiency Partial Space Conditioning	-180	-170	-160
Max. Efficiency Partial Space Conditioning	-150	-150	-140

For low-income (0%–80% AMI) households, both partial space conditioning upgrades increase the annual utility bill. As income level decreases, utility bills increase. This may be, in part, because low-income households tend to be older and less insulated than higher-income households, which results in more energy to cool. Cooling one room is less expensive in upfront costs than cooling the entire household but delivers only a fraction of the cooling load. Because of model limitations, we cannot determine whether the systems will maintain the cooling set point in the room in which they are located.[11]

Cooling one room for low-income (0%–80% AMI) households without cooling in the baseline increases utility bills by $150 for maximum efficiency partial cooling and $180 for minimum efficiency partial cooling. In comparison, cooling the entire dwelling for the same group increases utility bills by $120 for maximum efficiency cooling systems and $160 for minimum efficiency cooling systems. In short, whole-home cooling with a heat pump, while having higher upfront costs, is generally less costly to operate than cooling one room.

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[11] Modeling results for cooling one room cannot be compared directly to the costs and benefits delivered by providing whole-home cooling.

3 Equity Strategies Discussion

Residential building stock modeling indicates extremely low-income households will experience dangerous indoor temperatures for roughly one-third of the year by 2035. Lack of access to and use of cooling is a key driver of dangerous temperature exposure among low- and moderate-income households: less than 50% of low-income households in Los Angeles use cooling and more than 30% of extremely low-income (0%–30% AMI) households lack access to cooling. Risk of dangerous temperature exposure is much higher for multifamily building residents, and most low-income households live in multifamily buildings.

Our modeling indicates access to and use of cooling could be a critical strategy to maintain safe and comfortable home temperatures, especially as the climate warms. Combining envelope improvements with cooling systems was found to not provide added benefits for maintaining safe temperatures but added substantial upfront costs. Utility bill savings from heat pumps, as well as heat pumps combined with envelope improvements or cool roofs and shading interventions, were found to be substantially higher for owner-occupied, single-family homes than for multifamily homes.

Our modeling results align with Chapter 7 (Stenger et al. 2023), which describes findings on resilience in a power outage during a heat wave. Access to cooling through a heat pump enables households to start a power outage at safe temperatures.

To improve equitable outcomes in LA's transition to clean energy, the following strategies synthesize baseline equity analysis, community guidance, and integrated housing stock and sociodemographic modeling:

- **Short Term**: Provide affordable access to whole-home cooling through a heat pump before envelope improvements for households most at risk for dangerous heat exposure: low-income households in multifamily residential buildings.
- **Short Term**: Deliver direct installation to cool one room in extremely low-income households (0%–30% AMI) or deploy rebates used at point of purchase.
- **Short Term**: Issue rebates for heat pumps as part of the Cool LA Program to provide up to 29% more energy-efficient cooling for equivalent total lifecycle costs than the current rebates for window-unit ACs.
- **Short Term**: Reduce application time and/or auto-enroll extremely low-income households who receive Cool LA rebates for partial conditioning (i.e., room AC) into a bill assistance program to mitigate increased energy burdens.
- **Short Term**: Combine federal IRA or Weatherization Assistance Program funding with existing LADWP rebates to augment LADWP's Home Energy Improvement Program, Cool LA program, and other programs to lower the equipment costs of heat pumps and envelope efficiency upgrades for low-income households.
- **Short Term**: Expand LADWP's Home Energy Improvement Program (LADWP 2023) to include funding for necessary renovations and electrical upgrades to ensure the ability to install a heat pump.

- **Long Term**: Evaluate contractors representing DACs in current LADWP contracts, and support apprenticeship programs in DACs for HVAC entrepreneurship and educational opportunities—importantly, heat pump installation training and demonstrations.

Table 14 (page 21) 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.

Equity strategies to provide program outreach and technical assistance and to support apprenticeship programs are discussed in detail in Chapter 3 (Romero-Lankao, Blanco, and Rosner 2023).

The synthesis of baseline equity conditions, community solutions guidance, and modeling and analysis key findings into equity strategies is shown in Figure 5 (page 23). These figures were shared with the LA100 Equity Strategies Steering Committee and Advisory Committee and were revised based on their feedback and guidance.

Table 14. Equity Strategy Benefit, Cost, Timeline, Responsible Party[12], and Evaluation Metrics

Equity Strategy	Benefit/Impact	Cost	Metric
Short term: Deliver direct installation to cool one room in extremely low-income households (0%–30%) or deploy rebates used at point of purchase.	Extremely low-income households are projected to experience more than two months of exposure to dangerous indoor temperatures in 2035. Providing whole-home cooling eliminates dangerous heat exposure.	Whole home min. efficiency cooling system upgrade costs are $5,700–$9,000 and one-room minimum efficiency cooling costs for low-income households are $530–$800 per home. Installing Min. Efficiency cooling for one room in all extremely low-income households without cooling would cost $79 million.	110,000 extremely low-income LA households lack cooling $7.2 million/year 2024–2035
Short term: Issue rebates for heat pumps as part of the Cool LA Program to provide up to 29% more energy-efficient cooling for equivalent total lifecycle costs than the current rebates for window-unit ACs.	32% of extremely low-income (0%–30% AMI) households in Los Angeles lack access to cooling. Cool LA provides up to $225 on new cooling units and a $25 rebate to dispose of an old AC system.	If the City of Los Angeles provided the maximum Cool LA rebate for the purchase of a new AC system and the removal of an old system ($250) for every extremely low-income household without cooling, it would cost $58 million.	230,000 0%–80% AMI LA households without cooling
Short term: Auto-enroll extremely low-income households who receive Cool LA rebates for a room AC unit into a bill assistance and level pay programs to mitigate increased energy burdens.	Assuming a set point between 74°F and 78°F, cooling one room of dwelling would increase annual average utility costs between $140 and $180.	If LADWP covered 20% of utility bills for low- and moderate-income households with an energy burden of 6% or more, it would cost $4 million per year.	Percentage of eligible households enrolled in program. Average bill assistance enrollment time of less than 10 minutes on a smart phone.
Short term: Install upgrades in public housing where upgrades will not increase rents. Establish a mechanism to mitigate rent increases from upgrades elsewhere.	Improve comfort and health without increased rent. More than 95% of low-income households living in multifamily buildings are renters.	Potentially limited to administrative costs for implementing rent increase restrictions post-upgrade.	Number or percent of upgrades implemented in public housing.

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[12] LADWP is the primary responsible party for the equity strategies.

Equity Strategy	Benefit/Impact	Cost	Metric
Short term: Combine IRA or Weatherization Assistance Program funding with LADWP rebates to augment LADWP's Home Energy Improvement Program, Cool LA, and other programs to lower heat pump and envelope efficiency upgrade costs for low-income households.	The Weatherization Assistance Program covered an average of $8,250 per dwelling in low-income households for energy efficiency upgrades. IRA Section 50122 covers up to $8,000 for heat pumps in low-income households.	A total of 1,500 low-income (0%–80% AMI) households could be covered by federal funding available through IRA Section 50122. Providing the $250/dwelling rebate would reduce upfront cost of low-income households (0%–80% AMI) by 3.7%.	Number of households with upgrades a result of rebates.
Short term: Expand LADWP's Home Energy Improvement Program[a] to include funding for necessary renovations and electrical upgrades to ensure the ability to install a heat pump.	Cooling through heat pumps can require electrical panel upgrades. IRA Section 50122 provides rebates up to $2,500 for electrical wiring and $4,000 for electrical panel upgrades.	Electric panel upgrade costs were estimated to be between $1,300 and $5,000 (NV5 2022).	Number of electrical panel upgrades as a result of energy efficiency and cooling improvements.
Long term: Support apprenticeship programs in DACs for HVAC entrepreneurship and educational opportunities, especially heat pump installation training and demonstrations.	If Los Angeles receives a budget proportional to the city population (approximately 10% of California population), approximately $1,350,000 would be available for contractor education and training from IRA Section 50123.	Implementing apprenticeship programs requires effective coordination with existing trade unions and contractors to demonstrate effective technologies. Centering DACs within these trades will require investments with educational systems to recruit and retain talent.	Number of apprentices enrolled in supported programs from DACs. Number and percentage of contractors representing DACs in LADWP contracts.

[a] "LADWP's 'Cool Roof' Rebates Reduce Costs and Save Energy," LADWP, accessed April 14, 2023, https://www.ladwpnews.com/ladwps-cool-roof-rebates-reduce-costs-and-save-energy/.

Baseline Equity

- Less than 50% of low-income households (0–80% AMI) use cooling. More than 30% of extremely low-income (0–30% AMI) households lack access to cooling.
- The majority of LADWP residential energy efficiency programs analyzed disproportionately benefited mostly White, mostly non-Hispanic, mostly home-owning, 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, energy-burdened households and households in multifamily housing.
- Consistent disadvantaged customer support for safety and comfort maintenance and efficiency upgrades.
- Funded, staffed, culturally informed, and consistent outreach and communication through door-to-door, promotora-type approach

Modeling and Analysis Key Findings

- Low-income (0%-80% AMI) households in Los Angeles are projected to experience nearly two months of exposure to dangerous indoor temperatures by 2035.
- Adding whole-home cooling decreases maximum indoor air temperatures from 93°F to 80°F across all dwelling units.
- Providing cooling for one room with a room AC in every Los Angeles low-income household without cooling would increase annual average utility costs by $181.
- Compared to the baseline, households with cooling access save on their utility bills for all upgrades, income levels and housing types.

Equity Strategies

- **Short term:** Deliver direct installation to cool one room in extremely low-income households or deploy rebates used at point of purchase.
- **Short term:** Issue rebates for heat pumps as part of the Cool LA Program to provide up to 29% more energy-efficient cooling for equivalent total lifecycle costs than the current rebates for window-unit ACs.
- **Short term:** Auto-enroll extremely low-income households who receive Cool LA rebates for a room AC unit into a bill assistance and level pay program to mitigate increased energy burdens.

Figure 5. Synthesis of baseline equity conditions, community solutions guidance, and modeling and analysis key findings into equity strategies

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Appendix A. Data Sources and Assumptions

Table A-1 describes the modeling input data sources.

Table A-1. Summary of Universal Cooling Modeling Data Sources

Data	Source	Description	Resolution	Vintage
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 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	U.S. American Community Survey	Income, tenure (renter/owner), Federal Poverty Level, % AMI	Public Use Micro Area (PUMA) data	2015–2019
Weather File	AMY3	Weather data used for forecasting into 2035	ZIP code	2012
LADWP Low-Income Assistance Program Eligibility	LADWP	Low-income eligibility for LADWP assistance programs	Census tract	2022
California Alternative Rate for Energy eligibility	California Public Utility Commission	Income eligibility and limits	Census tract	2022
California electronic Technical Reference Manual (eTRM)	California Technical Forum	Wall insulation, ceiling insulation, water heating, cooking range, clothes drying, HVAC (air-source heat pump, mini-split heat pump, furnace,	Material costs, labor costs, labor hours	2012

Data	Source	Description	Resolution	Vintage
		wall/floor furnace, AC, room AC)		
LBL Cost Data	Lawrence Berkeley National Laboratory (LBL)	Water heating, air sealing, wall insulation, ceiling insulation, windows, clothes drying, HVAC (ASHP, mini-split heat pump, natural gas 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, mini-split heat pump, 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

ASHP = air-source heat pump, LADWP = Los Angeles Department of Water and Power, LBL = Lawrence Berkeley National Laboratory, NREL = National Renewable Energy Laboratory.

A.1 Assumptions

Table A-2 provides the detailed building upgrades modeled for full space conditioning.

Table A-2. Characteristics of Full Space Conditioning Upgrades Modeled

Upgrade	Heat Pump	Window U-Factor	Window SHGC	Ceiling R-Value	Wall R-Value	Infiltration	Shading and Roofing
Baseline	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum Efficiency Heat Pump	ASHP SEER 26.1, 11 heating seasonal performance factor (HSPF) Mini-split heat pump SEER 33.1, 13.5	N/A	N/A	N/A	N/A	N/A	N/A
Minimum Efficiency Heat Pump	ASHP SEER 15, 9.0 HSPF Mini-split heat pump SEER 33.1, 13.5	N/A	N/A	N/A	N/A	N/A	N/A
Min. Efficiency Heat Pump, Cool Roof, and Shading	ASHP SEER 15, 9.0 HSPF Mini-split heat pump SEER 33.1, 13.5	N/A	N/A	N/A	N/A	N/A	South side, Space-dependent Tree shading Roof replaced with reflective materials
Min. Efficiency Heat Pump and Low-Cost Envelope	ASHP SEER 15, 9.0 HSPF Mini-split heat pump SEER 33.1, 13.5	N/A	N/A	N/A	Wood Stud: R-13	25% reduction	N/A

Upgrade	Heat Pump	Window U-Factor	Window SHGC	Ceiling R-Value	Wall R-Value	Infiltration	Shading and Roofing
Min. Efficiency Heat Pump and Title 24 Envelope	ASHP SEER 15, 9.0 HSPF Mini-split heat pump 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 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) Multifamily Wood Stud: R-13 Multifamily CMU/Brick: R-2	5 ACH50	N/A

SGHC = solar heat gain coefficient, CEC CZ = California Energy Commission climate zone, CMU = concrete masonry unit

A.2 Upgrade Technologies

Heat pumps were sized following the Air Conditioning Contractors of America's Manual J (Rutkowski 2016), and after envelope upgrades were applied to the building model. The minimum efficiency heat pumps were selected, as described by California[13] and federal energy codes (DOE 2022c).

LA100 Equity Strategies Steering Committee members emphasized the importance of passive means to achieve cooling (e.g., shading and cool roofs) so as not to increase the energy usage and thus utility bills. Furthermore, cool roofs were considered because on January 1, 2023, the Los Angeles Municipal Building Code required cool roofs to be installed on new and refurbished homes to reduce AC loads and the possibility of heat-related injuries or death. Along with this, LADWP offers a cool roof rebate program that offsets \$0.20/ft^2 and \$0.30/ft^2 of roof material cost at or above building code requirements respectively (LADWP 2023).

In terms of envelope improvements, NREL investigated the energy efficiency effect of increasing envelope robustness through two distinct envelope improvements: (1) low-cost envelope improvements including R13 insulation for dwelling units with stud wall construction and 25% reduced infiltration for all dwelling units and (2) Title 24 envelope improvements standards required by the California Energy Commission for all new housing units.

Cooling one room of dwelling (i.e., partial space conditioning) was modeled for dwellings without cooling access in the baseline condition. We modeled a low-efficiency room air conditioner (EER 10.7) and a high-efficiency, cooling-only mini-split heat pump (SEER 20.0).

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[13] "Building Energy Efficiency Standards: Title 24," California Energy Commission, https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards.

Appendix B. Modeling Universal Cooling Access in Los Angeles Housing Stock Using ResStock

We developed upgrade scenarios for cooling use and various kinds of building upgrades. To ensure universal access to cooling, we changed two key upgrade parameters in the ResStock model. First, we stipulated that every dwelling unit in Los Angeles receive whole-home cooling through either an air-source heat pump or mini-split heat pump based on whether the unit did or did not have ducts, respectively. With this change, all units, regardless of whether they had cooling access in the baseline, would be upgraded to a whole-home cooling with a highly efficient heat pump. Second, we adjusted a parameter that controls whether cooling is used in units where a cooling technology is present. This parameter is used to represent those units that choose to not turn on their cooling systems to save on energy and utility costs. For all upgrades, we switched this parameter so that all units that have cooling systems use those systems to cool the units when needed.

For each upgrade category (e.g., wall insulation), we ensured that units in the Los Angeles building stock were addressed regardless of unit characteristics (e.g., wood stud, concrete masonry unit, or brick wall construction). In this way, we could specify the upgrades for units with different types of wall construction, ceiling construction, foundation construction, and floor construction, along with units in different California Energy Commission climate zones and those of different building types.

The second step to modeling universal cooling access in Los Angeles was to simulate the energy consumption of these units. Simulating this energy consumption was done following this sequence:

1. Create a custom version of the ResStock model.
2. Generate a representative building stock for Los Angeles.
3. Model and calibrate the energy consumption of the representative building stock.
4. Model the energy consumption of the representative building stock with the specified upgrades.

A custom version of ResStock was created by querying public data sources for conditional probability distributions of the building stock characteristics based on national data used in the original ResStock model (e.g., the U.S. Energy Information Administration Residential Energy Consumption Survey) along with more granular data (listed below). And we made the following ResStock updates to enable the use of simulated residential building loads for equity strategy analyses using these more granular data:

- Integrated income (in 2019 U.S. dollars) and housing tenure (renter/owner status) metadata from the 2019 5-year American Community Survey from the U.S. Census Bureau
- Downscaled model geography from the U.S. Census Bureau Public Use Microdata Areas (PUMAs; ResStock's native resolution) to a census tract level using crosswalks weighted by housing unit counts from the 2020 Census Redistricting data

- Calculated income measures using 2019 federal, local, and other relevant program income definitions: AMI, Federal Poverty Level, California Alternate Rate for Energy eligibility, LADWP Low-Income Eligibility, and Disadvantaged Community (DAC)
- Updated appliance saturation and housing characteristic distributions using the 2019 California Residential Appliance Saturation Study[14] to capture the income and tenure differentiation as well as the diversity specific to Los Angeles.

This approach leverages a robust classification suitable for building stock energy models in energy policymaking, where different data sources are mapped together using shared parameters such as location, building type, and year (Langevin et al. 2019).

ResStock uses deterministic quota sampling, with probabilistic combination of non-correlated parameters. For Los Angeles, ResStock used 50,000 samples to represent 1,600,000 dwelling units (approximately 1:31). The samples inform physics-simulation models, specifically EnergyPlus®.

Model construction and articulation are facilitated by the OpenStudio® software development kit and associated residential modeling workflows. We used 2012 TMY3 weather data and forecasted weather to 2035 using the methodology described in the LA100 study (Cochran et al. 2021). Climate zones were specified at the ZIP code level by the California Energy Commission to generate granular weather patterns. Calibration involved numerous improvements to model input data and refinement of probability distribution dependencies.

With the calibrated model, it was possible to apply a specified upgrade and model the energy consumption of the building stock. The building upgrades were applied as what-if scenarios to Los Angeles housing stock and then compared to assess their performance in reducing the maximum living space temperature, thus reducing the time and magnitude of the living space temperature above the cooling set point along with a number of economic analyses of costs associated with these upgrades.

Model outputs include both annual and 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 along with hourly outdoor and living space temperatures for the baseline home and the hypothetical upgraded home.

B.1 Residential Housing Stock

ResStock is a physics-simulation tool that generates statistically representative households (Wilson 2017). It 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 subhourly

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[14] "2019 Residential Appliance Saturation Study," CEC, https://www.energy.ca.gov/data-reports/surveys/2019-residential-appliance-saturation-study.

building simulations. The tool generates a group of statistically representative building simulation models from a housing parameter space derived from existing residential stock data.

We down-selected the national ResStock model to Los Angeles using the spatial geographies defined by the 2010 U.S. Census Bureau geographies and city boundaries. The down-selected residential model represents 1,500,000 dwelling units, which were taken from the Los Angeles City Planning website (LA City Planning 2023). The dwelling units were distributed to census tracts by the combined use of the 2020 Census Redistricting Data, National Historical Geographic Information System 2020-to-2010 block crosswalk file, and the American Community Survey 2016 5-year dwelling unit counts. ResStock dwelling unit distributions are specified by census tract based on the American Community Survey 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. The 2020 Redistricting Data were mapped to 2010 U.S. Census geographies using the National Historical Geographic Information System 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 Micro Area. PUMAs are a collection of census tracts with an average population of 200,000 and a minimum of population 100,000. For the LA100 Equity Strategies study, census tracts were also added to the model to increase the geographic specificity of the dwelling unit representative models.

For more information about equity metrics, measuring building performance, dimensional blending, impacts of upgrades on DACs, and access to cooling, see Chapter 6 (Stenger et al. 2023).

B.2 Impact of Upgrades in Multifamily Buildings

In Figure B-1, we can see that multifamily dwelling units experience much higher maximum indoor temperatures than single-family dwelling units. However, all upgrades decrease the median maximum indoor temperature significantly. With all upgrades median maximum indoor temperatures are under 82°F, which is under the dangerous temperature threshold of 86°F.

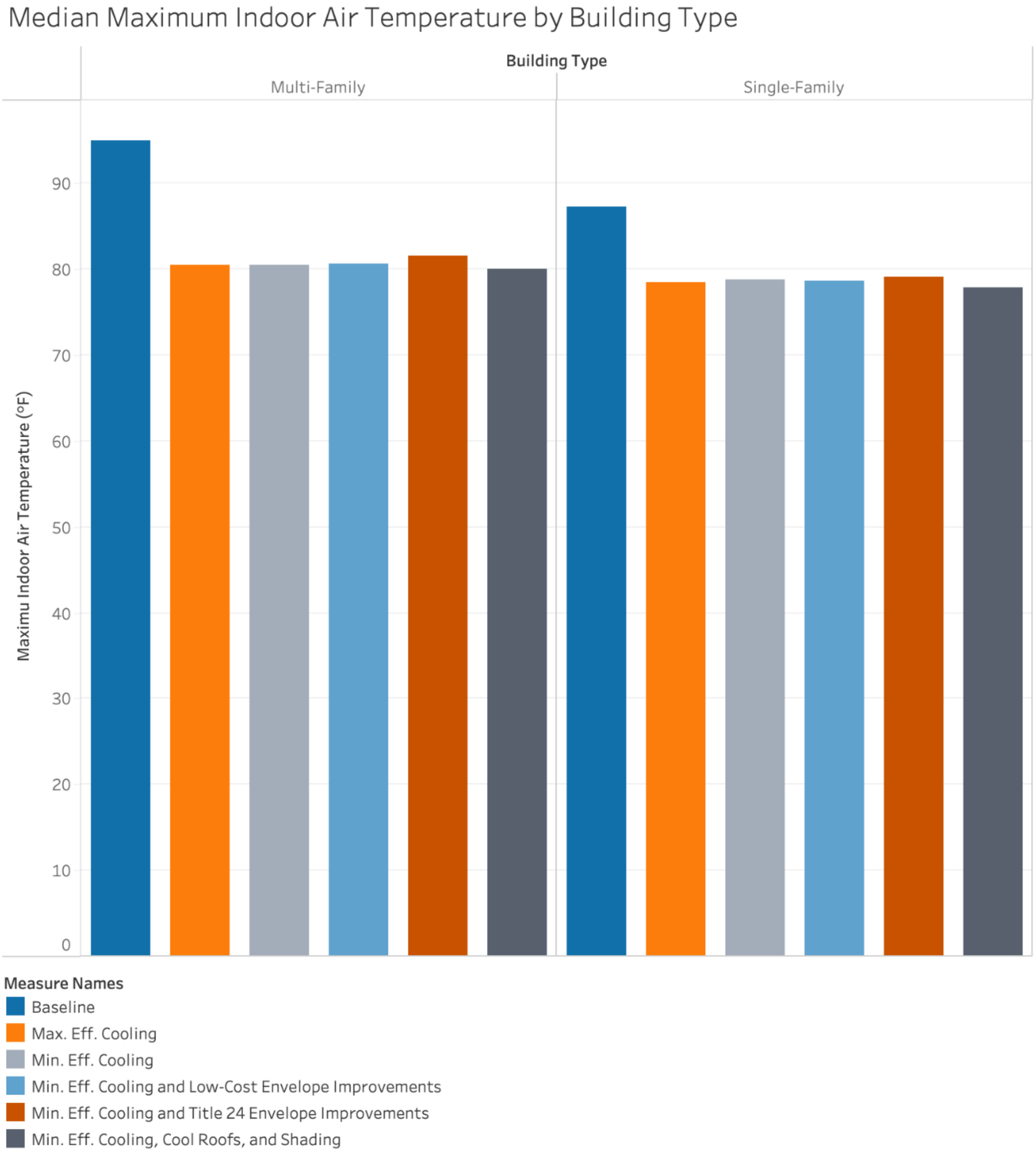

Figure B-1. Maximum indoor temperature by building type

In the baseline upgrade scenario, multifamily dwelling units experience indoor temperatures above 86°F nearly 15% of the year. Regardless of upgrade scenario, the number of hours above 86°F drops to zero for the median value in the building stock simulations.

B.3 Impact of Upgrades by Baseline Access to Cooling

In Table B-1, the average number of hours above 86°F is shown for the baseline and each upgrade, disaggregated by units that used their cooling systems in the baseline compared to those who either did not use their cooling system or who did not have access to cooling in the baseline.

Table B-1. Average Hours Above 86°F by Cooling Use in the Baseline

Upgrade	Uses Cooling	Does Not Use Cooling
Baseline	400	2,700
Heat Pumps	12	12
Heat Pumps, Cool Roofs, and Shading	11	11
Heat Pumps and Low-Cost Envelope Improvements	14	14
Heat Pumps and Title-24 Envelope Improvements	15	170

For all upgrades, units experience a decrease in hours above 86°F regardless of whether cooling was in the baseline. Improved envelope characteristics do not provide for marked improvements in access to safe and comfortable home temperatures, in terms of decreasing the hours above 86°F.

An important consideration in any building upgrade study is the change in fuel consumption. In our analysis, we only applied upgrades to dwelling units connected to the utilities providing electricity and natural gas. Table B-2 and Table B-3 show the median annual electricity and natural gas consumption per dwelling unit.

Table B-2. Median Annual Electricity Consumption (kWh) per Dwelling Unit

	Multifamily			Single-Family		
	0%–80%	80%–120%	120%+	0%–80%	80%–120%	120%+
Baseline	4,400	4,700	4,500	6,900	8,000	8,900
Max. Efficiency Cooling	4,300	4,500	4,300	7,100	7,800	8,300
Min. Efficiency Cooling	4,500	4,600	4,400	6,800	7,300	7,700
Min. Efficiency Cooling, Cool Roof, and Shading	4,700	4,900	4,800	7,900	9,100	9,900
Min. Efficiency Cooling and Low-Cost Envelope Improvements	4,500	4,800	4,600	7,500	8,600	9,300
Min. Efficiency Cooling and Title 24 Envelope Improvements	4,700	4,900	4,800	7,600	8,700	9,500

Table B-3. Median Annual Natural Gas Consumption (therms) per Dwelling Unit

	Multifamily			Single-Family		
	0-80%	80-120%	120%+	0-80%	80-120%	120%+
Baseline	93	88	92	200	230	240
Max. Efficiency Cooling	91	83	88	160	180	180
Min. Efficiency Cooling	90	83	87	160	180	180
Min. Efficiency Cooling, Cool Roof, and Shading	91	83	88	160	180	180
Min. Efficiency Cooling and Low-Cost Envelope Improvements	91	83	88	160	180	180
Min. Efficiency Cooling and Title 24 Envelope Improvements	90	83	87	160	180	180

Based on the upgrades, electricity consumption stays within approximately 15% of the original value regardless of building type or income level, both increasing and decreasing based on the specific upgrade. Single-family buildings have a larger increase due to their larger average sizes, and we see that the Minimum Efficiency Cooling and Title 24 Envelope Improvements show the greatest increase in electricity demand. For natural gas, consumption decreases for dwelling units regardless of upgrade, income level, or building type because space heating is electrified in all dwelling units. Though the largest increases in electricity consumption are in single-family buildings, these dwelling units see a commensurate decrease in natural gas consumption. Again, this is due to energy savings from heating larger spaces.

B.4 Impact on Electrical Grid

One key consideration in building upgrades is the resultant impact on the grid. A shift to electric technologies could create a substantial increase in demand for electricity. This increased demand could impact the grid's ability to provide reliable electricity and could require expansion or upgrade of the grid to support this new, larger load. We sum the total electricity use for all the dwelling units under each upgrade scenario and then compare this total across scenarios. Table B-4 shows the total annual electricity use for all dwelling units for each upgrade scenario.

Table B-4 shows that the baseline modeled LA housing electricity demand will total 9,270 megawatt-hours (MWh) in 2035. The minimum efficiency cooling upgrade scenario increases the total annual electricity demand by slightly more than 10%.

Table B-4. Total Annual Electricity Use for LA Housing Stock in 2035 (MWh)

Baseline	Max. Eff. Cooling	Min. Eff. Cooling	Min. Eff. Cooling, Cool Roofs, and Shading	Min. Eff. Cooling and Low-Cost Envelope Improvements	Min. Eff. Cooling and Title 24 Envelope Improvements
9,300	9,100	10,300	9,800	10,100	10,000

Appendix C. Upgrade Cost Data and Cost Databases

This appendix synthesizes the upgrade cost data for the cooling and envelope efficiency upgrades. For each technology, a table lists the total costs that account for material costs, labor costs, and estimated labor hours. We provide sources for these estimations as well as granularity when costs vary based on square footage or the current state of the dwelling's technology (i.e., insulation). Tables are detailed for cost databases, hardware and online retailers, material costs for air sealing, wall insulation, roof material, tree shading, mechanical ventilation, foundation insulation, windows, attic insulation, HVAC heat pumps, and partial space conditioning.

The cost databases in Table C-1 were used to estimate labor costs, labor hours, and material costs across different envelope efficiency upgrades.

Table C-1. Cost Databases

Name	Who (Where)	Data Collection/Year	Type of Cost Data	Technologies
eTRM	California Technical Forum (California)	Various (Itron Report 2010-2012; RSMeans, various). Data collected from online retailers, wholesalers, suppliers, and others.	Material costs Labor costs Labor hours	Wall insulation, ceiling insulation, HVAC (ASHP, mini-split heat pump)
LBL Cost Data	LBL (Primarily California, Massachusetts, and North Carolina with data from 12 other states)	Survey to contractors with incentives for completion, 2020	Total project costs	Air sealing, wall insulation, ceiling insulation, windows, mechanical ventilation, HVAC (ASHP, mini-split heat pump)
National Residential Efficiency Measures Database	NREL (Nationwide)	2010	Total project costs	Air sealing, wall insulation, ceiling insulation, windows, mechanical ventilation, HVAC (ASHP, mini-split heat pump)
Navigant	Navigant Consulting (MA)	Contractor survey, "webscraping," rebate program invoices, 2018	Total project costs	HVAC (furnace, boiler)
Building construction costs with RSMeans data	RSMeans, (Nationwide)	2022	Material cost, differentiated labor hourly rate, labor hours, location material and labor factors	Wall insulation, ceiling insulation, lighting, windows, HVAC (ASHP)

C.1 Local Hardware Retailers and Online Wholesalers and Suppliers

Table C-2 lists the hardware retailers, online wholesalers, and suppliers whose websites were used to inform the upgrade costs, particularly the equipment costs.

Table C-2. Hardware and Online Retailers

Local Hardware Retailers	Online Wholesalers/Suppliers
Home Depot	AC Wholesalers
Lowes	Consumers Supply Company
	Craft Supply
	eComfort
	HighSEER
	National Pump Supply
	Oswald Supply
	Supply House
	The Furnace Outlet

C.2 Technologies

Air Sealing

Air sealing data were only available in the National Residential Efficiency Measures Database (NREMDb) and from the Lawrence Berkeley National Laboratory (LBL) Cost Database. However, only some of the LBL data had pre- and post-ACH50 values, and of that data, few data entries aligned with the project upgrades we specified. The NREMDb had data for some of, but not all, the project upgrades we specified; however, these data were more consistent than the LBL data. Therefore, we chose to use NREMDb data along with a regression to estimate data for the missing project upgrades.

Table C-3. Material Costs for Air Sealing

Labor costs are included in material costs. Unit costs are not applicable. NREMDb is the source of the cost data.

Technology	Variable Cost ($/ft^2)	Source
50 to 37.50 ACH50	2.17 (2010$)	NREMDb[a,b]
40 to 30 ACH50	1.78 (2010?)	NREMDb[a,b]
30 to 22.5 ACH50	1.39 (2010$)	NREMDb[a,b]
25 to 18.75 ACH50	1.20 (2010$)	NREMDb[a,b]
20 to 15 ACH50	1.20 (2010$)	NREMDb[a,b]
15 to 11.25 ACH50	1.20 (2010$)	NREMDb[a,b]
10 to 7.5ACH50	0.63 (2010$)	NREMDb[a,b]
8 to 6 ACH50	0.52 (2010$)	NREMDb[a,b]
7 to 5.25 ACH50	0.52 (2010$)	NREMDb[a,b]

Technology	Variable Cost ($/ft^2)	Source
6 to 4.5 ACH50	0.41 (2010$)	NREMDb[a,b]
5 to 3.75 ACH50	0.31 (2010$)	NREMDb[a,b]
4 to 3 ACH50	0.31(2010$)	NREMDb[a,b]
3 to 2.25 ACH50	0.31 (2010$)	NREMDb[a,b]
2 to 1.5 ACH50	0.31 (2010$)	NREMDb[a,b]
6 to 5 ACH50	0.31 (2010$)	NREMDb
7 to 5 ACH50	0.52 (2010$)	NREMDb
8 to 5 ACH50	0.73 (2010$)	NREMDb
9 to 5 ACH50	0.97 (2010$)	NREMDb, NREMDb[c]
10 to 5 ACH50	1.20 (2010$)	NREMDb
15 to 5 ACH50	2.20 (2010$)	NREMDb
20 to 5 ACH50	3.30 (2010$)	NREMDb
25 to 5 ACH50	4.30 (2010$)	NREMDb
30 to 5 ACH50	5.37 (2010$)	NREMDb[a]
40 to 5 ACH50	7.48 (2010$)	NREMDb[a]
50 to 5 ACH50	9.59 (2010$)	NREMDb[a]
2 to 1 ACH50	0.31 (2010$)	NREMDb
3 to 1 ACH50	0.52 (2010$)	NREMDb
4 to 1 ACH50	0.73 (2010$)	NREMDb
5 to 1 ACH50	0.94 (2010$)	NREMDb
6 to 1 ACH50	1.20 (2010$)	NREMDb
7 to 1 ACH50	1.40 (2010$)	NREMDb
8 to 1 ACH50	1.60 (2010$)	NREMDb
9 to 1 ACH50	1.80 (2010$)	NREMDb, NREMDb[c]
10 to 1 ACH50	2.00 (2010$)	NREMDb
15 to 1 ACH50	3.00 (2010$)	NREMDb
20 to 1 ACH50	4.10 (2010$)	NREMDb
25 to 1 ACH50	5.10 (2010$)	NREMDb
30 to 1 ACH50	6.16 (2010$)	NREMDb[a]
40 to 1 ACH50	8.24 (2010$)	NREMDb[a]
50 to 1 ACH50	10.32 (2010$)	NREMDb[a]

[a] Costs are not exact numbers from the National Residential Efficiency Measures Database, but rather are based on a regression of the available data.

[b] The value used was the original value from the NREMDb, which is in 2010$.

[c] A model linearly interpolated at the starting condition of 8 ACH50 and 10 ACH50 to the upgrade value.

Wall Insulation

For this upgrade, two costs were considered: the cost to upgrade from no insulation to R-19 and the cost to upgrade from either R-7, R-11, or R-15 to R-19. The latter set of insulation upgrades was costed at the same amount. Wall insulation data were available from NREMDb, RSMeans, and the LBL Cost Data. However, only some of the LBL data had pre- and post-insulation values, and wall area was not reported. RSMeans had the most up-to-date data, but it only included batt insulation and sprayed-on insulation. NREMDb had data for the first cost (uninsulated to R-19) for both fiberglass and cellulose insulation. These costs were averaged for the final cost used in this analysis. We assumed the cost to upgrade from an uninsulated wall to a partially insulated wall (R-7, R-11, and R-15 to R-19) would be half the cost to upgrade an uninsulated wall to R-19.

Table C-4. Material Costs for Wall Insulation

Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs. Unit costs are not applicable. Costs vary based on area of dwelling unit exterior walls (ft^2).

Technology	Variable Cost ($/$\text{ft}^2$, 2019$)	Source
Wood Stud Insulation (Loose fill)	$3.00[a]	NREMDb[b]
Brick Insulation (Loose fill)	$4.40[a]	NREMDb[b]
CMU Insulation (Loose fill)	$4.40[c]	NREMDb[b]
Wood Stud (Uninsulated to R-13)	$2.24[c]	Less 2021
Wood Stud (R-7 or R-11 to R-13)	$0.83[c]	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (Uninsulated to R-20)	$3.10	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (R-7, R-11, R-15, or R-19 to R-20)	$1.65	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (Uninsulated to R-30)	$4.95d	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (R-7 to R-30)	$3.80d	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (R-11to R-30)	$3.14d	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (R-15 to R-30)	$2.48d	NREMDb: Retrofit Measures for Wood Stud
Wood Stud (R-19 to R-30)	$1.82d	NREMDb: Retrofit Measures for Wood Stud

[a] These values are an average of cellulose and fiberglass for the insulation material. The value used was the original value from the NREMDb, which is in 2010$.

[b] These values were available from NREMDb in August 2022. However, these upgrade options are not available in the most recent version of NREMDb.

[c] This is the same value used for the brick insulation (loose fill).

[d] A regression based on two wall insulation levels.

Roof Material

Roof material upgrade data were only available from NREMDb. It had data for some of, but not all, the project upgrades we specified. Missing data were estimated based on similar data that were available.

Table C-5. Material Costs for Roof Material

Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs. Unit costs are not applicable. Costs vary based on area of dwelling roof (ft^2).

Technology	Variable Cost (2019$)	Source
Asphalt single, white or cool colors	$3.2[a]	RSMeans
Metal, white	$4.0	RSMeans
Tile, white	$9.0[a]	RSMeans

[a] Used for asphalt and composition shingle types.

Tree Shading

Cost information for this upgrade was not available from any of the cost databases nor any of the local hardware retailers and online wholesalers/suppliers (Table C-2). For this upgrade, we researched tree varieties local to the Southern California region that are commonly used in residential areas, and we researched the most affordable trees and suppliers. See Table C-6 for details on the tree we selected, its supplier, and cost. Trees take multiple years to reach mature age for shading a dwelling, which should be taken into account when evaluating this upgrade for potential implementation.

Table C-6. Material Costs for South Shading

Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs.

Technology	Cost Breakdown	Value (2019$)	Source	Notes
South Shading	Unit cost	$600	Pulled	This is the cost of a Coast Live Oak (*Quercus agrifolia*) sapling in a 24” box (5-10’ tall). The Coast Live Oak is native to Southern California, does well in hardiness zones 9 and 10 and does well in full sun.
	Variable cost	N/A		
	Variable unit			

Mechanical Ventilation

Mechanical ventilation upgrade data were only available from NREMDb and LBL. LBL had records of 65 projects, which included mechanical ventilation; however, these were split among low-cost exhaust fan, energy recovery ventilation, and heat recovery ventilation units, and the LBL records cited only the median heat recovery ventilation unit cost. The NREMDb, on the other hand, gave both a unit and variable cost based on the size of the unit so, we used the data from NREMDb.

Table C-7. Material Costs for Heat Recovery Ventilation

Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs.

Technology	Cost Breakdown	Value (2019$)	Source
Heat recovery ventilation (70%)	Unit cost	$1,300	NREMDb: Retrofit Measures for Mechanical Ventilation
	Variable cost	3.6	
	Variable unit	Flow Rate (cfm)	

Foundation Insulation

Foundation upgrade data were only available from NREMDb. It had data for some of, but not all, the project upgrades we specified; missing data were estimated based on similar data that were available. These substitutions are documented in the Notes column.

Table C-8. Material Costs for Foundation Insulation

Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs.

Technology	Cost Breakdown (Value 2019$)	Source	Notes
Slab insulation (uninsulated to R-14)	Unit cost: N/A Variable cost: $2.6 ft^2 roof	NREMDb: Retrofit Measures for Slab	This cost is associated with R15 exterior, extruded polystyrene, rigid foam board insulation
Foundation wall insulation (uninsulated to R-14)	Unit cost: N/A Variable cost: $2.2 ft^2 roof	NREMDb: Retrofit Measures for Crawlspace	This cost is associated with R15 exterior, extruded polystyrene, rigid foam board insulation
Foundation wall insulation (R-5 to R-14)	Unit cost: N/A Variable cost: $1.41 ft^2 roof	NREMDb: Retrofit Measures for Crawlspace	This cost is based on a regression from the Uninsulated to R-14 value
Foundation wall insulation (R-10 to R-14)	Unit cost: N/A Variable cost: $0.62 ft^2 roof	NREMDb: Retrofit Measures for Crawlspace	This cost is based on a regression from the Uninsulated to R-14 value

Windows

Window upgrade data were available from NREMDb, RSMeans, and the LBL Cost Data. However, some of the LBL data reported only the number of windows replaced and not the window area replaced. The NREMDb includes a cost for the type of window we specified in the upgrade, but these data are not very current. The best data we found were from RSMeans. The cost data were given by specific window type and dimensions. From the window dimensions, we were able to determine the cost per square foot (ft^2) of window for each window in each size and type. For the analysis, we averaged the costs of picture, single-hung, and double-hung windows. Labor costs were estimated based on the type of labor, rate of labor, and number of hours, which are included in the material costs.

Table C-9. Material Costs for Windows

Labor cost included in material cost. Unit cost is not applicable. Costs vary based on area of dwelling windows (ft^2).

Technology	Variable Cost (2019$)	Source
Low-E Double, Non-metal, Air, L-Gain Windows	$31.3	RSMeans
Passive Standard Window (Low-E, Triple, Non-metal, L-Gain)	$46.0	NREMDb: Retrofit Measures for Windows

Attic Insulation

Ceiling insulation data were available from NREMDb, RSMeans, and the LBL Cost Database. However, only some of the LBL data had pre- and post-insulation values, and attic area was not reported. RSMeans had the most up-to-date data, but those data gave only information for batt insulation and sprayed-on insulation. The NREMDb has a variety of datapoints, but those data only correspond with some of the upgrade values in which we were interested. To determine the costs that were unavailable, known values were averaged to get approximate costs. It is important to note that floor insulation was also considered for this study. In multistory buildings, floor and ceiling insulation have the same meaning for dwelling units not on the ground floor. Therefore, these costs are the same where applicable. Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs.

Table C-10. Material Costs for Attic Insulation

Unit costs are not applicable. Costs vary based on area of attic ceiling (ft^2).

Technology	Variable Costs (2019$)	Source
Uninsulated to R-49	$2.82	Averaged NREMDb costs
R-7 to R-49	$2.31	Averaged NREMDb costs
R-13 to R-49	$2.05	Averaged NREMDb costs
R-19 to R-49	$1.66	Averaged NREMDb costs
R-30 to R-49	$1.05	Averaged NREMDb costs
R-38 to R-49	$0.61	Averaged NREMDb costs
Uninsulated to R-30	$1.50	NREMDb: Ceilings/Roofs
R-7 to R-30	$1.00	NREMDb: Retrofit Measures for Unfinished Attic
R-13 to R-30	$0.77	NREMDb: Retrofit Measures for Unfinished Attic
R-19 to R-30	$0.48	NREMDb: Retrofit Measures for Unfinished Attic
Uninsulated to R-38	$1.90	NREMDb: Retrofit Measures for Unfinished Attic
R-7 to R-38	$1.40	NREMDb: Retrofit Measures for Unfinished Attic

Technology	Variable Costs (2019$)	Source
R-13 to R-38	$1.10	NREMDb: Retrofit Measures for Unfinished Attic
R-19 to R-38	$0.87	NREMDb: Retrofit Measures for Unfinished Attic
R-30 to R-38	$0.87	NREMDb: Retrofit Measures for Unfinished Attic
Uninsulated to R-22	$1.00	NREMDb: Retrofit Measures for Unfinished Attic
R-7 to R-22	$0.54	NREMDb: Retrofit Measures for Unfinished Attic
R-13 and R-19 to R-22	$0.27	NREMDb: Retrofit Measures for Unfinished Attic
Uninsulated to R-60	$2.90	NREMDb
R-7 to R-60	$2.40	NREMDb
R-13 to R-60	$2.10	NREMDb
R-19 to R-60	$1.90	NREMDb
R-30 to R-60	$1.40	NREMDb
R-38 to R-60	$0.99	NREMDb
R-49 to R-60	$0.49	NREMDb

HVAC Heat Pumps

Though several data sources had information on HVAC heat pumps, their cost data were for models that were significantly less efficient than the upgrades we used. The only source with heat pumps with efficiencies close to what we used was a regression created with the LBL Cost Data. For ASHPs, this regression was based on heating seasonal performance factor (HSPF) and capacity; mini-split heat pump costs were based on only capacity. Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs.

Table C-11. Material Costs for Heat Pumps

Labor costs are included in material costs.

Technology	Cost Breakdown	Value (2019$)	Source
Max. Efficiency ASHP (SEER 26.1, 11 HSPF)	Unit cost	$9,400 (2022$)	Chan, Less, and Walker 2021
	Variable cost	$160 (2022$)	
	Variable unit	kBtu-h	
Min. Efficiency ASHP (SEER 15, 9 HSPF)	Unit cost	$5,700 (2022$)	Chan, Less, and Walker 2021
	Variable cost	$160 (2022$)	
	Variable unit	kBtu-h	
Mini-split heat pump (all efficiencies)	Unit cost	$2,330 (2022$)	Chan, Less, and Walker 2021
	Variable cost	$300 (2022$)	
	Variable unit	kBtu-h	

Partial Space Conditioning

Though several data sources had information on HVAC heat pumps, their cost data were for models that were significantly less efficient than the upgrades we used. The only source with heat pumps with efficiencies close to what we used was a regression created with the LBL Cost Data. For ASHPs, this regression was based on HSPF and capacity; mini-split heat pump costs were only based on capacity. Labor costs estimated the type of labor, rate of labor, and number of hours, which are included in the material costs.

Table C-12. Technology Cost Assumptions

Technology	Cost Type	Cost Breakdown	Value (2019$)	Source
Min. Efficiency Partial Space Conditioning Cooling System (Room AC, EER 10.7)	Material costs	Unit cost	$530 (2022$)	AC wholesalers
		Variable cost	$15.8 (2022$)	
		Variable unit	kBtu-h	
	Labor costs	Labor type	Skilled worker	eTRM
		Labor hours	2	
		Hourly rate	$75	
Max. Efficiency Partial Space Conditioning Cooling System (mini-split air conditioner)	Material costs	Unit cost	$1130 (2022$)	AC wholesalers
		Variable cost	$80 (2022$)	
		Variable unit	kBtu-h	
	Labor costs	Labor type	Electrician/ plumber	eTRM
		Labor hours	7.5	
		Hourly rate	$138.50	

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