Chapter 17. Service Panel Upgrade Needs for Future Residential Electrification

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LA100 EQUITY STRATEGIES

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FINAL REPORT: LA100 Equity Strategies

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1 Introduction

This chapter details the results of an analysis conducted by the California Center for Sustainable Communities at UCLA into the anticipated need for future electric service panel upgrades within the residential building sector to support future decarbonization targets introduced in the LA100 plan. All of the different transformation pathways explored in the original LA100 feasibility study assumed significant increases in the future adoption of electric vehicles as well as electrification of existing gas-powered end-uses. However, both of these technology transformations will potentially result in significant increases in the demand for electrical energy and power. One significant barrier to increasing the service capacity for LADWP customers in order to facilitate this transition is the rated capacity of their electrical service panels. These are pieces of customer owned hardware that function as the interface between the utility distribution network and the building's internal energy system. Experience has shown that undersized service panels can be a significant barrier to customer efforts to electrify their existing gas loads or add major new ones, such as for electric vehicle (EV) charging.

1.1 Analysis Goal and Scope

The overarching goal of this analysis is to understand the landscape of existing customer owned electric service panel hardware within the city of Los Angeles. Perhaps surprisingly to some, most utilities do not track the rated capacity of the load center hardware components that are installed on the customer side of the meter. Rather, they typically only record the service voltage and amperage associated with each premise's interconnection agreement and use those figures for distribution and transmission system capacity planning purposes. This represents a significant blind spot in terms of potential barriers to future electrification efforts that are likely to emerge from the need for customer owned infrastructure upgrades.

As a part of the LA100 Equity Strategies initiative, this analysis is explicitly focused on the equity implications associated with the anticipated need for future upgrade of this customer owned interconnection hardware. All of the different transition pathways that were previously analyzed as part of the original LA100 analysis assume significant electrification of existing gas appliances and increased light duty EV adoption with varying levels of at-home charging. As a reflection of the importance that electrification is expected to play in this transition, the outputs of this analysis include parcel level estimates of the rated nameplate capacity of electricity interconnection hardware "as-built" at the time of the building's construction and estimates of the "existing" capacity following subsequent infrastructure upgrades that are either known or inferred to have occurred in the intervening years.

For the single-family context the analysis will further include estimates of the range of anticipated costs associated with these upgrades, aggregated to the census tract level throughout the city, as well as average annual rates at which these upgrades will need to be accomplished in order to adhere to the technology adoption trajectory implied by the LA100 transition timeline. For the multi-family context, similar estimates of the "as-built" and "existing" rated service capacity of panels will be generated per dwelling unit. However, as discussed previously, the range of uncertainty around the costs and technical challenges associated with future upgrades necessary to support full electrification within this sector is so great that cost estimates will not be considered.

2 Background

2.1 Electric Service Panel Fundamentals

2.1.1 *Service Panel Functions*

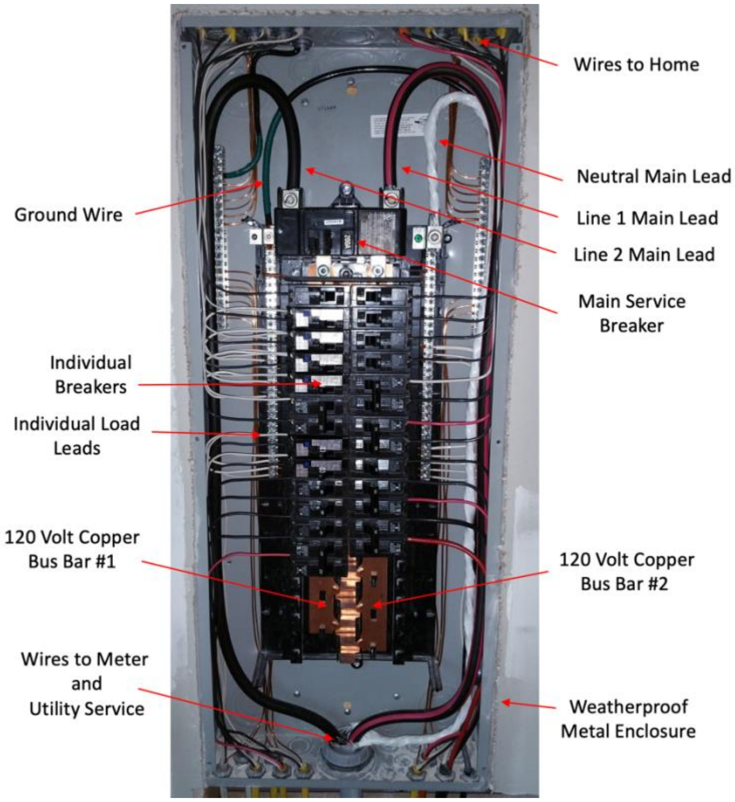
An electric service panel (also commonly referred to as a load center) is a piece of customer owned equipment which partially determines the rate at which electricity can be consumed within a building. The service panel serves following essential functions:

- Interconnect to the utility distribution system.
- House main and branch circuit breakers which provide overcurrent protection.
- Integrate with utility owned metering equipment that is used to record electricity consumption for the purpose of billing.

National Electrical Code (NEC) guidelines for calculating the size of an electrical service panel's rated capacity depend upon the year in which the structure was built, and both the number and type of electrical loads in service at the time of construction. (NEC-70 220.80, 2023) These NEC load calculation methods take into account the voltage, amperage, and reactive power demands of all the building's electrical end-use equipment. They also incorporate assumptions about the need for and sizing of certain types of equipment (i.e., lighting) as a function of building square footage, the likelihood and severity of potential concurrent loads, the need for back-up equipment to support certain critical loads, and whether or not a given load is meant to be operated continuously or in a more intermittent fashion. Service panel capacities are typically discussed in terms of their maximum rated amperage. This refers to the maximum volume of electricity which can instantaneously flow through the panel before the main service breaker is caused to "trip," automatically severing the connection to the supply of utility power.

2.1.2 *Service Panel Components*

If the volume of electrical current flowing into a conductor (wire) or piece of end-use equipment exceeds its rated capacity, then there can be a build-up of heat from resistance that creates a significant fire risk. Circuit breakers provide an essential safety function by shunting the flow of electricity in these types of situations. In a service panel, the individual end-use loads within a building are organized into physically isolated units called "branch circuits." These each have their own breaker and can be independently disconnected from utility service either manually, by flipping the breaker's switch, or automatically, if the breaker's capacity threshold is exceeded. Multiple different end-use loads can be wired together into a single branch circuit, so long as their combined amperage draw does not exceed the rated capacity of its associated breaker. Figure 1 provides a photograph of the inside of a typical 100-Amp rated single-family residential electrical service panel, with key components labeled.



[1]

Figure 1: Photograph of the inside of a typical 100-Amp single-family residential electric service panel with key components labeled.

Service panels provide two tiers of load isolation – (1) at the main breaker level and (2) at each individual branch circuit. The rated capacity of the main breaker determines the overall service capacity which can be delivered to the premises. Exceeding this rated capacity from either side of this main breaker – such as with a surge in the supply power on the utility side or a surge in the demand from loads on the customer side – will cause the breaker to trip, temporarily disconnecting the flow of power, requiring a manual reset. This same premise applies to the individual branch circuit breakers. However, when one of these trips, only the subset of loads which have been wired together will be de-energized and not the whole structure.

Beneath the main breaker, branch circuits are typically grouped into 15-Amp unit increments which are most commonly operated at 120 Volts. Within most residential structures, the ubiquitous three-prong, duplex (dual port) wall-outlets that serve most plug loads are typically wired into 15 Amp breakers that operate at 120 Volts. Other types of loads, which require higher voltages or amperages, such as for major appliances or dedicated electrical motors can require different outlet receptacles and larger amperage capacity / higher voltage breakers. These loads frequently also require larger gauge wiring to physically connect the outlet receptacles to their associated breakers within the service panel. Importantly, these larger capacity breakers occupy more physical space within the panel, taking up either 2 or 4 standard 15 Amp slots, for 30- and 60-Amp breakers, respectively. For these types of larger loads, higher voltages can sometimes

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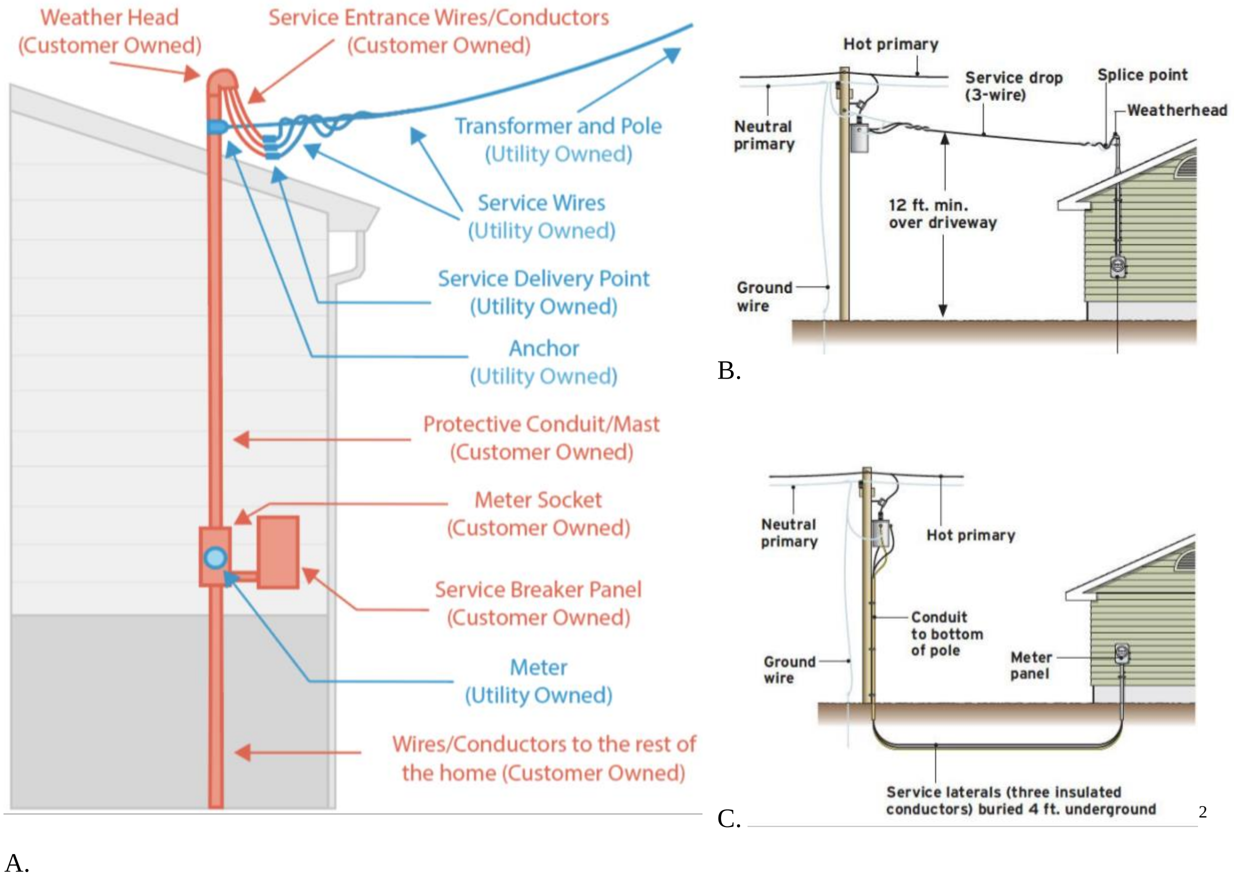
[1] Image Source: https://www.verobeachelectrical.com/wp-content/uploads/2017/08/200amp.jpg

also be required. Within the panel, voltage doubling, from 120 to 240 Volts, is achieved by connecting a single breaker to two separate 120 Volt bus bars. As a result of this, the number of 240 Volt loads which can be installed within a structure is limited by the physical configuration of breaker slots relative to the bus bar layout within a given piece of panel hardware.

2.1.3 *Service Panel Configurations*

From an ownership standpoint, the electric service panel is the last piece of complex electrical hardware residing on the customer side of a utility service interconnection point. (LADWP, 2005) This is the location at which customer owned energy equipment installed within a building interfaces with utility owned equipment considered part of the electric power distribution network. Figure 2A provides a graphical illustration of a typical above ground residential utility service interconnection point, with customer owned equipment shown in blue and utility owned equipment shown in red. (Redwood Energy, 2022) The volume of electricity that can be delivered to a building is only partially determined by the size rating of the customer's panel.



[2]

Figure 2: Graphic depiction of the divisions between customer (Red) versus utility (Blue) equipment ownership at the service delivery point (A) and comparative illustrations of the differences between above ground (B) and below ground (C) electric utility service connections.

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[2] Image Source: https://uploads-ssl.webflow.com/62b110a14473cb7777a50d28/6396bf323a8b1154fc57f221_Service%20Upgrades%20for%20Electrification%20Retrofits%20Study%20Final%20Report.pdf

The other important determinant of a utility customer's service capacity is the capacity of the upstream utility infrastructure that is part of the distribution and transmission networks. As part of each customer's service agreement, the utility will guarantee the allocation of sufficient capacity within these systems to ensure the continuous delivery of some maximum specified quantity of electrical power. Typically, for customers on normal residential tariffs that are inter-connected to normal distribution feeders, this service capacity limit will not exceed 600 Amps without the need for special consideration. (LADWP 2018)

2.1.4 *Single-Family Panel Upgrades*

The total costs associated with increasing the service capacity at a given premise encompass both customer owned and, potentially also, utility owned infrastructure upgrades. (Redwood Energy, 2022) For both parties, these costs can vary significantly depending upon a host of site-specific considerations. From the typical single-family residential customer's perspective, increasing the number and/or power rating of installed loads within a structure will frequently necessitate the installation of a new, larger capacity service panel, as well as, potentially, making modifications to the building's existing wiring and plug layout.

Recently published empirical data from panel upgrade projects completed under the TECH incentive program place the current average costs of performing a panel upgrade for a typical single-family home, using conventional hardware, range between $2,000 - $4,500. (TECH Program, 2023) Of course, the actual specific costs of any given project are determined by the capacity of the type and capacity selected panel hardware, the need to modify or replace other electrical components or systems within the building in order to achieve code compliances, as well as permitting, and labor. (Building Decarbonization Coalition, 2020) Here the "type" of a panel refers to whether or not it possesses digital monitoring and communications capabilities to both instrument and control the flow of electricity through individual breakers.

These "smart panels," as they are commonly referred to, are a relatively recent innovation in the building energy infrastructure space and currently command a price premium of an additional $3,000 – $4,000 above the previously quoted cost figures for fully integrated systems, with lower costs for individualized "smart breakers" with more circumscribed capabilities. For this added expense however, these new technologies provide a number of extremely useful capabilities that allow for finer grained and more dynamic control of power flows within a building. The implications of these new smart panel/breaker hardware capabilities for utilities and customers alike shall be discussed in greater detail within subsequent sections of this report.

From the utility's perspective, when a customer chooses to increase the size of their service panel, this can potentially lead to a need to increase the capacity of upstream infrastructure components. These include distribution system hardware such as feeder circuit conductors, step-down transformers, capacitor banks, protection equipment, and various others, leading all the way back to the local substation. If enough distribution circuits become similarly impacted, there can also eventually come the need to expand capacity on the transmission network which serves the local region. The sizing of these infrastructure components is such that the multiple customers within a given area will usually be able to upgrade their service capacity without issue. However, there will eventually reach a point when a single additional customer upgrade will cross some threshold tolerance, beyond which numerous upstream components must be replaced.

The sheer number and diversity of these hardware components, as well as where their different capacity/performance thresholds exist, makes it extremely difficult for utilities to accurately estimate the costs associated with supporting an arbitrary number of service capacity upgrades that are only vaguely defined in both space and time. Utility infrastructure upgrade costs can only be accurately evaluated on the margin, as they are determined by incremental differences in the rated capacities of the next larger-sized versions of available vendor equipment offerings or, otherwise not explicitly known as in the case of bespoke hardware. It is useful to note that these types of questions were considered as part of the original LA100 analysis and are again being revisited here as part of this Equity Strategies follow on study. And while more work certainly will need to be done understanding these issues – from a qualitative perspective, we can say that future distribution and transmission system upgrades will be necessary to support the LA100 initiative and the equity implications associated with their costs should be continuously evaluated.

A final set of important upgrade cost considerations are those associated with the physical accessibility of supply hardware components, and thus, their ease of replacement. For example, as illustrated in Figure 2B & C, utility service can either be provided to a customer through an above or below ground connection, with LADWP having significant numbers of both in its service territory. Increasing the service capacity for customers with below ground connections can be significantly more expensive for the utility if the component upgrades required necessitate the excavation and replacement of sub-surface equipment. This is an issue which could have significant equity implications if the locations of capacity constrained below ground infrastructure are found to meaningfully correlate with the locations of disadvantaged communities.

2.1.5 *Multi-Family Load Center Upgrades*

When compared to the single-family context, multi-family structures exhibit a much wider range of variation in the type, size, and configuration of their electricity service interconnection and load center hardware. This is due to the fact that the multi-family building classification encompasses structures that vary widely in the number of units, from small duplexes and triplexes housing a handful of customers, to multi-floor/multi-building structures with hundreds of occupants. More than just this variation in size however, multi-family buildings can also differ significantly with respect to the presence and configuration of individually (unitary) versus collectively metered (communal or house) loads, as illustrated by the picture in Figure 3. All units within a multi-family structure are required to have their own individual sub-panel which houses the branch circuits that serve their in-unit equipment. Typically, these sub-panels will each have their own independent disconnect switches before being routed to a load center that functions as the utility service interconnection point for the whole building. However, other configurations are also possible.

[3]

Figure 3: Image of a load center at a typical mid-sized multi-family property with separate sub-panels for each dwelling unit as well as building-wide communally metered loads.

At the larger end of the size spectrum, the electrical power requirements in the multi-family sector can significantly exceed those that would typically be encountered in single-family residential structures. Oftentimes, these types of larger sized multi-family structures will be directly supplied by 3-phase current which, when connected to a dual bus-bar load center, results in an effective operating voltage of 208 Volts - instead of the typical 240 Volts commonly available within the single-family context. (StopWaste, 2021) This difference in voltage can have significant implications for the types of compatible end-use equipment that are available as well as their overall amperage requirements.

Additionally, the step-down transformer that are necessary to step down the, generally higher, voltages encountered on 3-phase distribution feeders are typically pad mounted (as opposed to pole-top mounted) and can present a whole different set of upgrade challenges if they too must be added or replaced to facilitate expanded service capacity. This is because these equipment must be housed in dedicated enclosures and possess more robust and specialized safety and load monitoring/management capabilities. Moreover, when these types of distribution system upgrades must be made to support an increase in the service capacity that only benefits a single customer or premise, then that customer will be required to shoulder the bulk of their cost.

The goal of this preceding discussion has been to emphasize the important differences between the single and multi-family sectors with respect to this issue. Within the multi-family sector, one is far less likely to encounter a single, monolithic "service panel" in the same way that they typically exist within single-family structures. Thus, multi-family properties should be expected

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[3] Image Source: https://erwinelectric.com/wp-content/uploads/Multi-Family-Erwin-Electric1.jpg

to have a much more complex and integrated set of customer owned interconnection hardware upgrade requirements. Despite these challenges however, the multi-family context remains extremely important to understand from an equity standpoint, as the majority of households within disadvantaged communities live within multi-family buildings.

2.2 The Role of Service Panels in Building Decarbonization

2.2.1 *Electrification*

A core component of Los Angeles' future decarbonization strategy is the electrification of end-use energy equipment within buildings that have historically been powered by fossil fuels. At present, electricity can more easily and cost-effectively be produced from renewable sources than can other liquid/chemical hydrocarbon-based fuels at the scale required to facilitate this transition. (E3, 2019) According to the results of the California Energy Commission's (CEC's) most recent Residential Appliance Saturation Survey (RASS), gas remains the most common fuel used for water and space heating within the city. (Palmgren et al., 2021) These two end-uses alone typically comprise roughly half to the total primary energy use with the average residential structure. Consequently, future replacement of gas equipment with electric alternatives (such as electric heat-pump water heaters and HVAC units) is expected to significantly increase the overall power consumption of residential structures, thus necessitating corresponding increases in service capacity in many cases.

In addition to the projected increases in electric power demand from the gas appliance electrification, rapid growth in the adoption of light-duty electric vehicles (EVs) is also expected to significantly contribute to the future need for expanded residential service capacities. Relative to this ongoing EV transition, an important milestone was recently passed with Governor Newsom's executive order authorizing the California Air Resource Board (CARB) to implement a new statewide policy which will effectively ban the sale of Internal Combustion Engine (ICE) powered light duty vehicles by the year 2035. (Executive Department of the State of California, 2020) Given the popularity of at-home EV charging, this means that residential buildings are likely to subsume a significant portion of the primary energy flows that were previously associated with the transportation sector. This sectoral shift represents a profound structural change in the timing and geography of primary energy flows within our entire energy economy and its implications for the electric power system cannot be overstated.

For example, the current generation of light-duty EV batteries commonly range in size from 10-100 kWh and are charged at rates from between 3-22 kW within residential settings. (EV-Database.org, 2023) [4,5] For a typical single-family home, with normal driving and charger usage

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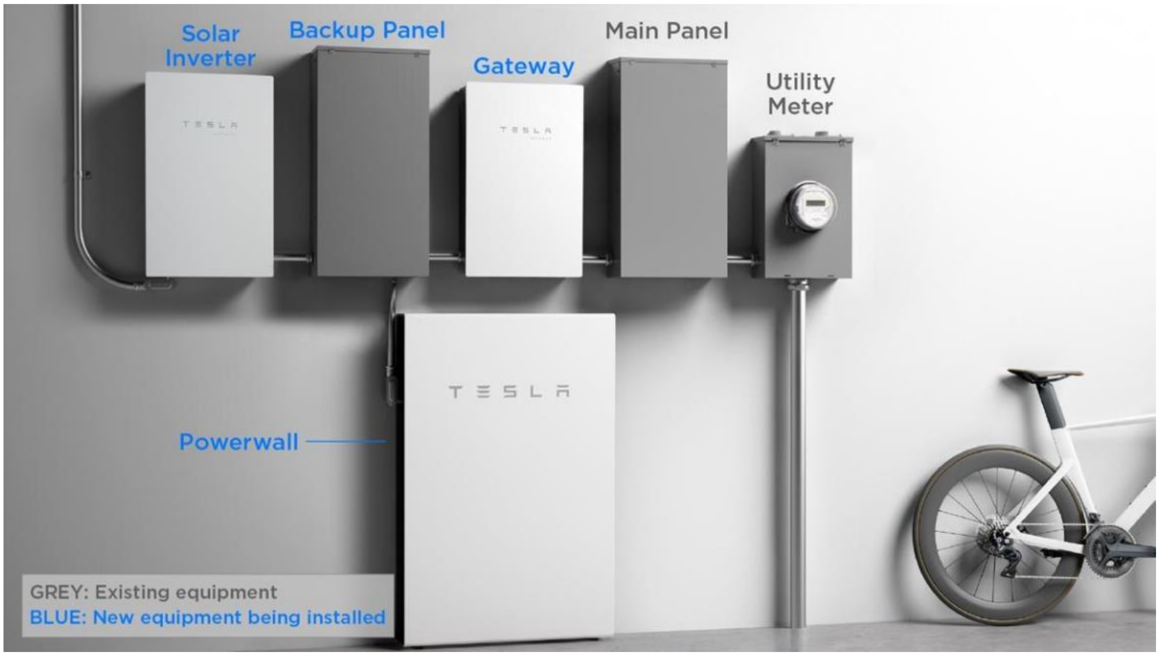
[4] Quoted battery size ranges come from a survey of vehicles on https://ev-database.org/. It should be noted that a small number of newer-model EVs, such as the luxury Lucid Air or sport utility GM Hummer EV, contain battery packs as large as 200 kWh. However, these have been excluded here as they are not representative of the average.

[5] Quoted charging rates are for the current generation of Level 2 fast charging equipment most commonly found in residential applications. Upgraded battery technologies in future generations of EVs may be designed to operate at much higher voltages, enabling much more rapid EV charge cycles (minutes instead of hours). The challenge associated with such rapid charging rates is their enormous power requirements. Current generations of Level 3 DC-Fast Chargers can range from 150-300 kW. A load of this magnitude would dramatically exceed the rated service capacity of the average residential home.

behaviors, the installation of a single Level-2 fast charger can result in a doubling of its historical annual energy consumption and as much as a 5x increase in its previous instantaneous peak power demand. Detailed consumption data collected from a large number of fully electrified homes has revealed that more common electrical appliances (i.e., plug loads, lighting, refrigeration, etc.) typically only amount to 1/3rd of their total annual consumption; with the remaining 2/3rd being roughly evenly split between the usage from electrified heating equipment (i.e., water heaters, air heaters, clothes dryers, stove/ranges, etc.) and EV charging.

2.2.2 *Distributed Energy Resources*

An additional consideration, in terms of the role that electricity service panels are likely to play in future decarbonization efforts, has to do with the potential for households to add distributed energy resources (DER) such as rooftop solar PV panels or home battery energy storage systems (BESS) in the future. Installation of net-metered DER equipment will often trigger the need to upgrade not only a home's electrical service panel but also the need to install various other pieces of supporting safety and monitoring equipment as well. Some examples of which include a dedicated utility meter, a home energy gateway, an essential loads sub-panel, and/or an automatic disconnection switch. These types of additional components are depicted in the rendering provided in Figure 4, produced as marketing material for the installation of Tesla Solar Roof + Powerwall systems.



[6]

Figure 4: Sample illustration of additional energy management equipment that is necessary to install/upgrade when adding a rooftop solar PV paired with a battery energy storage system.

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[6] Image Source: https://static.mistergreen.nl/Tesla_Powerwall_MisterGreen_intrinsic.jpeg?v=2020-06-17T11:55:33+00:00

2.3 Sizing Service Panels for Future Building Electrification

2.3.1 *Composition of the Building Stock*

The City of Los Angeles' residential building stock encompasses structures that were built as early as 1833, a year which predates the founding of LADWP itself and indeed, even the very concept of utility operated electrical service. These types of older buildings, which are still occupied and in operational use, have almost certainly been retrofitted to support the use of electrical power, and potentially multiple times, over the intervening years. Their existence is a good illustration of the fact that although electric infrastructure is deeply embedded within the design and construction of buildings, it can, and regularly will be modified and upgraded.

Across the entire residential building stock, increases in the number, diversity, and power requirements of common domestic electrical appliances have led to steady increases in the average size of the electric service panels over time. Yet despite these capacity increases, historically, service panels have overwhelmingly been sized so as to minimally serve the needs of the electrical equipment installed within the building at the time of its construction. The main reason for this is to save costs, as increasing the size of the panel's rated capacity can often necessitate other cost increases, such as for installing larger gauge internal wiring within the building to make it possible to actually use the increased panel capacity in the future.

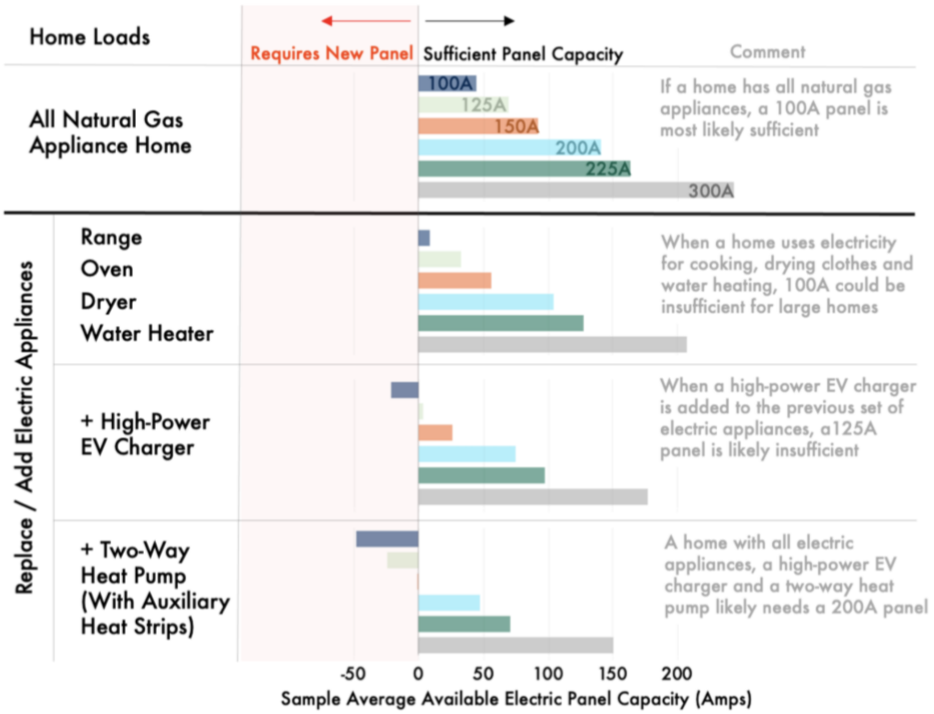
2.3.2 *Evolution of Panel Size Guidelines*

It has only been relatively recently that code requirements have evolved so as to mandate the installation of larger sized service panels than are strictly necessary in the present time. The current iteration of the California Building Electric Code requires that newly constructed single-family residential homes include 200 Amp panels, at minimum. (California Building Standards Commission, 2023) Additionally, there are currently ongoing discussions about raising this requirement to a 225 Amp minimum in subsequent iterations of the code. These capacity increases are being mandated in order to provide the additional headroom needed to support significant expansion in both the number and size of on-site loads anticipated from the aforementioned electrification trends.

Determining the actual NEC recommended service panel size that is necessary to support the full electrification of all of an existing building's energy end-uses, including the electrification of existing gas appliances and the addition of EV charging, requires detailed information about the number and type of equipment that will eventually be installed on-site. This presents something of a challenge from an analytical standpoint, in terms of efforts to potentially try and estimate the overall need for future electric service panel upgrades throughout Los Angeles. Adding to this complexity are uncertainties around whether or not the panel sizing calculations/assumptions that have historically been used will persist into the future. For example, many new smart-panel/breaker systems allow for the fine-grained control of the power demand of sub-loads within a structure such that their combined power draw does not exceed some specified threshold limit. This capability suggests that panels with larger numbers of circuits, but smaller overall capacity ratings, may be viable if the loads which are connected to them can be more intelligently managed to avoid worst case usage scenarios. EV charging provides a good example of the potential benefits of such an approach, as it can potentially have huge power demands, but is also quite flexible in terms of timing during which that consumption can be allowed to take place. It is possible to temporarily throttle back the power draw of an EV charger while other household loads are in use, particularly during peak periods. Doing so is likely not much of an issue for customers, so long as their EV’s battery eventually gets charged to a desired level by the time of the vehicle’s next intended use.

2.3.3 *Expectations Based on Previous Work*

In terms of previous work on this topic, a recent analysis published by the consulting firm Pecan Street, provides some relevant insights into what can be expected in terms of the panel size ratings that should be considered sufficient to support the electrification of different combinations of end-use equipment (EUC) within a typical residential structure. (Pecan Street, 2021) This analysis is based upon metered data from a large sample of real-world homes in Texas, possessing different EUC combinations including EV chargers and heat-pump based air and water heating units. As Figure 5 illustrates, for the homes within their sample, in nearly all cases 200-Amp service was deemed sufficient to support the full electrification of existing gas equipment and the addition of a single level-2 EV charger. In some instances of partial electrification, lower panel capacities were also deemed sufficient. However, 150 Amps was found to be the minimum required panel rating necessary to support the addition of either a single EV fast-charger or the electrification of major gas end-use appliances, particularly among larger sized (3,000+ ft^2) homes.



[7]

Figure 5: Results from a recent Pecan Street analysis into the size of electric service panels necessary to support different types of residential end-use equipment electrification.

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[7] Image Source: https://www.pecanstreet.org/publications/addressing-an-electrification-roadblock-residential-electric-panel-capacity/

It is important to note that the results depicted here are representative of the service panel capacity requirements associated with the average sized home within the sample dataset (i.e., 1,500 - 2,500 ft^2). The City of Los Angeles is unique in the sense that it hosts a significant number of residential properties which are vastly larger in size than this. Moreover, the overwhelming majority of these larger homes tend to be occupied by affluent households, which are also among the most likely to adopt new electrified technologies first. It is important therefore, to be aware of the extent to which these patterns of early adoption within affluent communities can potentially trigger the need for utility side infrastructure upgrades to provide additional service capacity and, consequently, the extent to which the cost of these utility infrastructure upgrades, whose benefits are localized to the households able to purchase new electric equipment and vehicles, may perhaps be distributed across the entire customer rate base. Such an inequitable distribution of costs to benefits would be an important equity concern and is a theme that will be revisited in later portions of this report.

As was previously mentioned, the three types of EUCs that are most likely to trigger the need for a panel capacity upgrade are Heat Pump air heating/conditioning units, water heaters, and EV chargers. Table 1 provides a view of the most recently collected survey data on the penetration of different EUCs among LADWP residential customers with the aforementioned categories highlighted in red. Here we can see that current penetration levels among them are quite low throughout the city, ranging from 5-6%. And even if these numbers have improved significantly in the intervening years (perhaps rising in the low double digits in some places), the lack of this equipment further bolsters the expectation that panel upgrade requirements are likely to be a significant issue with the utility’s service territory.

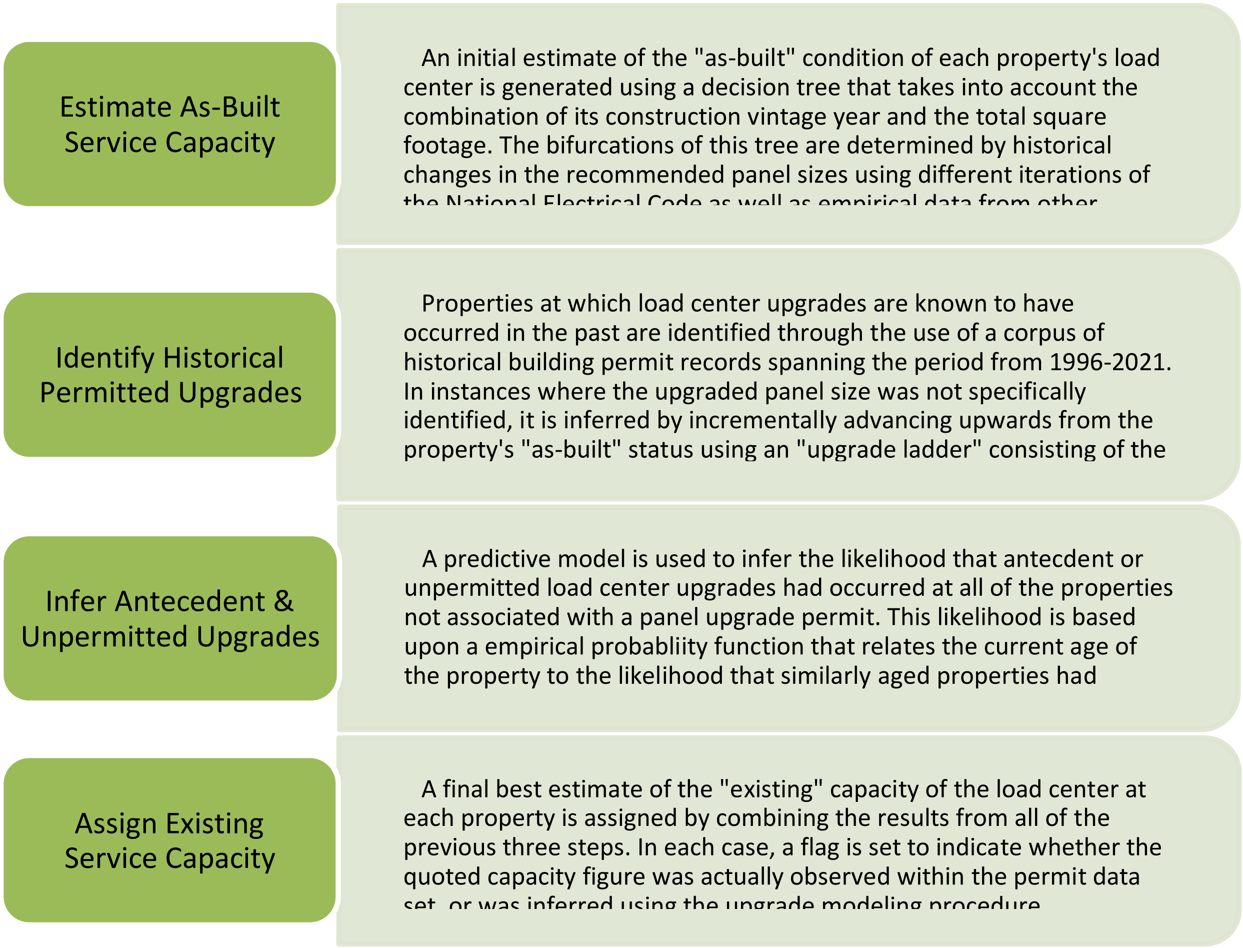
Table 1: LADWP customer electrical end use equipment (EUC) penetration rates from the 2019 Residential Appliance Saturation Survey (RASS)

Electrical End Use Equipment Category	LADWP Customer Penetration Rate
Conv. Heat	14%
Heat Pump	**6%**
Aux. Heat	8%
Furnace Fan	46%
Attic Ceiling Fan	1%
Central Air Conditioning	52%
Room AC	29%
Evap. Cooler	9%
Water Heat	**5%**
Solar Water Heat	0%
Dryer	17%
Clothes Washer	62%
Dishwasher	51%
First Refrigerator	100%
Second Refrigerator	20%
Freezer	10%
Pool Pump	7%
Spa	4%
Outdoor Lighting	46%
Range/Oven	36%
TV	65%
Spa Electric Heat	2%
Microwave	82%
Home Office	19%
PC	80%
Well Pump	1%
Electric Vehicle	**6%**
Miscellaneous	100%
Conv. Heat	14%

3 Methodology

3.1 Overview

In order to estimate the capacity of existing customer owned load center hardware, and the potential need for hardware upgrades in order to support future electrification, we developed a quantitative methodology that draws upon a combination of data from historical electrical code requirements, literature analyses, local parcel level building attributes, and historical building construction permit applications throughout the city. The four key components in this methodology are summarized by the block diagram in Figure 6 below.



Estimate As-Built Service Capacity

An initial estimate of the "as-built" condition of each property's load center is generated using a decision tree that takes into account the combination of its construction vintage year and the total square footage. The bifurcations of this tree are determined by historical changes in the recommended panel sizes using different iterations of the National Electrical Code as well as empirical data from other

Identify Historical Permitted Upgrades

Properties at which load center upgrades are known to have occurred in the past are identified through the use of a corpus of historical building permit records spanning the period from 1996-2021. In instances where the upgraded panel size was not specifically identified, it is inferred by incrementally advancing upwards from the property's "as-built" status using an "upgrade ladder" consisting of the

Infer Antecedent & Unpermitted Upgrades

A predictive model is used to infer the likelihood that antecdent or unpermitted load center upgrades had occurred at all of the properties not associated with a panel upgrade permit. This likelihood is based upon a empirical probabliity function that relates the current age of the property to the likelihood that similarly aged properties had

Assign Existing Service Capacity

A final best estimate of the "existing" capacity of the load center at each property is assigned by combining the results from all of the previous three steps. In each case, a flag is set to indicate whether the quoted capacity figure was actually observed within the permit data set, or was inferred using the upgrade modeling procedure

Figure 6: Process flow block diagram illustrating key elements of the methodology that was developed to estimate the future need for electric service panel upgrades for all of the single-family housing stock in the City of Los Angeles.

3.2 Defining Disadvantaged Communities

As part of the LA100 Equity Strategies project's stakeholder engagement process, CCSC researchers participated in monthly Steering Committee meetings and bi-monthly Advisory

Committee meetings which were held to discuss various aspects of the research methodology and solicit feedback about values, preferences, and concerns on a wide range of related issues. During these meetings, our team presented on the various different existing metrics and indicators that are commonly used to quantify community disadvantage throughout the state. Based upon subsequent discussions with both LADWP staff and Steering/Advisory committee members it was concluded that the definition of Disadvantaged Communities (DACs) that would be used for this analysis would be based upon version 4.0 of the California Office of Environmental Health Hazard Assessment (Cal-OEHHA) CalEnviroScreen (CES) Scores.

CES scores are index values that are computed at the census tract level for all of the populated regions throughout the state. They provide a composite measure of environmental pollution burden, socio-economic disadvantage, and other aspects of structural disadvantage. The composite scores are normalized to range from 1-100 with higher values indicating higher levels of overall disadvantage. For this analysis, the percentile ranking of these composite scores were used. These percentile rankings provide an indication of the degree of disadvantage at any given tract relative to that of the other tracts throughout the state. Specifically, the 75th percentile value was selected as the threshold demarcation point at which a census tract was defined as a DAC vs. non-DAC. This percentile threshold is commonly used by a number of other state energy agencies for such purposes as conducting similar equity analyses, establishing DAC focused funding program eligibility requirements, etc.

It is worth noting that the conversation about what constitutes a disadvantaged community – both from an energy perspective and specifically within the City of Los Angeles – is one that should remain open. The choice of metrics and indicators used for establishing these definitions should be able to be continually debated and updated, revised, and refined because of their extreme import in guiding the outcome not only of these types of analyses but also the programs and policies which they ultimately inform. In order to stimulate this conversation CCSC even developed an interactive web-map, that was presented at one of the project's Steering Committee meetings, which was designed to help illustrate salient overlaps / differences between the geographic range of DACs throughout LA according to different types of indicators and metrics of community disadvantage. We hope that through continued engagement, and the use of similar types of novel, interactive tools, that these conversations can continue in pursuit of outcomes and definitions that resonate with the needs and experiences of the city's disadvantaged populations.

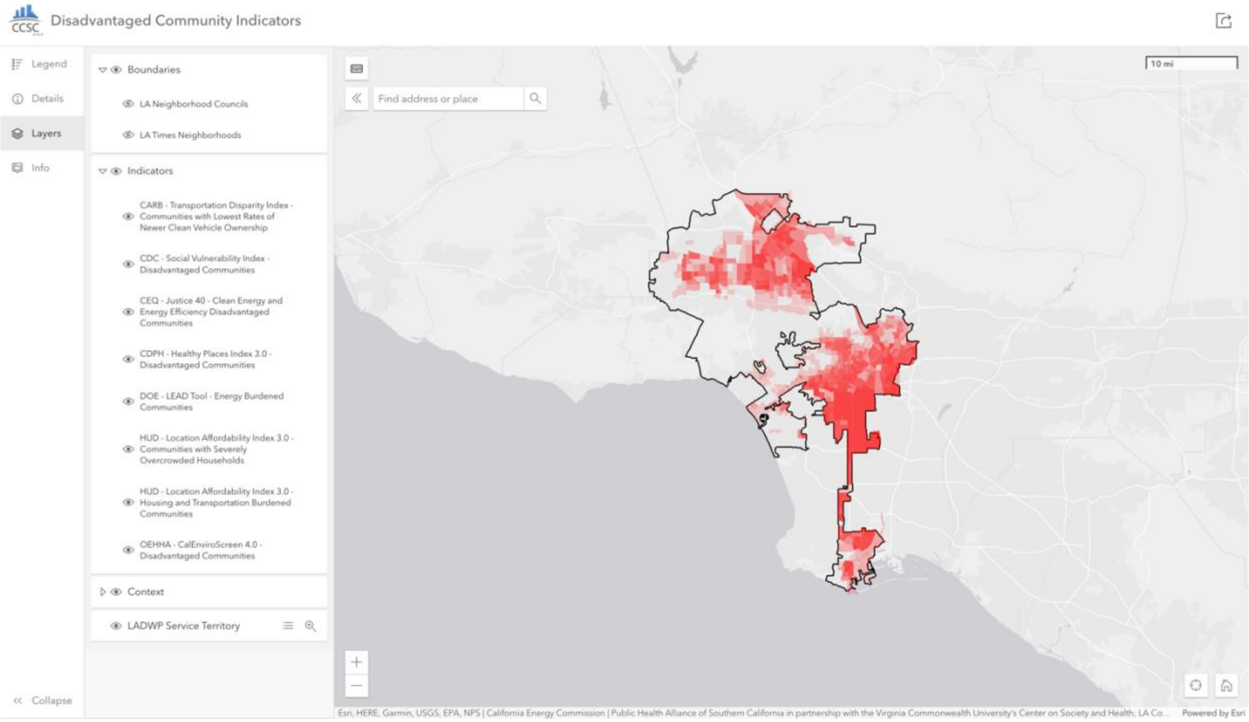


Figure 7. Screenshot of a web-map developed to illustrate the use of different metrics and indicators would influence the number and location of census tracts defined as DACs throughout LADWP service territory.

3.3 Estimating As-Built Panel Ratings from Building Attributes

The first key step in our quantitative methodology involves developing an initial estimate for the size of the electrical panel "as-built" for each property. Such an estimate for the size of the panel at the time of a building's initial construction is important as a baseline, as it is highly unlikely that the service capacity at any given location would be incrementally reduced over time. The as-built value therefore functions as the floor against which subsequent upgrades, whether they be permitted or inferred, are able to be used as reference.

3.3.1 *Single-Family Context*

Parcel attribute data for all of the detached single-family homes in the City of Los Angeles were obtained from the LA County Tax Assessor's Office Parcel Database. These records include building attributes such as construction vintage year, square footage, and others, which are regularly updated for tax assessment purposes. In total, the parcel attribute dataset used for this analysis encompassed 572,321 individual parcels comprising a total of 1,017,507,005 ft^2 of combined floor area. In terms of their attributes, Los Angeles' stock of single-family homes is extremely diverse, encompassing buildings with construction vintages which span from 1833 to the present day and floor areas that range from ~100-100,000+ ft^2, an impressive 4 orders of magnitude. Overall, the average single-family home in Los Angeles is 1,777 ft^2 in size and was constructed in 1957. The figures in Table 2 provide a more detailed breakdown of the differences in the count frequency and average size of homes grouped by ten-year construction vintage year range increments.

Table 2: Property statistics for single-family homes in LADWP service territory by ten-year construction vintage range increments.

Construction Vintage Range (Year)	Properties (Count)	Average Size (ft^2)
1830-1840	1	3,136
1840-1850	0	NA
1850-1860	0	NA
1860-1870	2	1,307
1870-1880	27	1,592
1880-1890	397	1,525
1890-1900	1,176	1,477
1900-1910	14,132	1,503
1910-1920	19,229	1,504
1920-1930	68,300	1,523
1930-1940	36,669	1,847
1940-1950	85,138	1,575
1950-1960	124,369	1,727
1960-1970	56,937	2,007
1970-1980	59,277	1,707
1980-1990	46,040	1,757
1990-2000	16,133	2,570
2000-2010	31,129	2,176
2010-2020	13,041	2,931

From an equity standpoint, the age and size of single-family homes are both strongly correlated with the DAC status of the census tracts in which they are located. These trends are clearly illustrated by the joint distribution plot shown in Figure 8. As the figure shows, single-family homes within DACs are both significantly older and smaller than the ones in their non-DAC counterparts. For example, the average DAC single-family home is 1,427 ft^2 and was constructed in 1948 while the average non-DAC home is 2,094 ft^2 and was built in 1960. This means that the non-DAC homes are 46% larger and 12 years newer than their DAC counterparts. As we shall later see, these differences in traits will likely have important equity implications in terms of the need for panel upgrades to support future decarbonization of the residential sector. Moreover, previous research has shown that though these newer homes are more energy efficient per square foot, their much larger size significantly dilutes the conservation gains, in terms of reduced overall energy consumption, that might otherwise be expected. (Fournier et al., 2019)

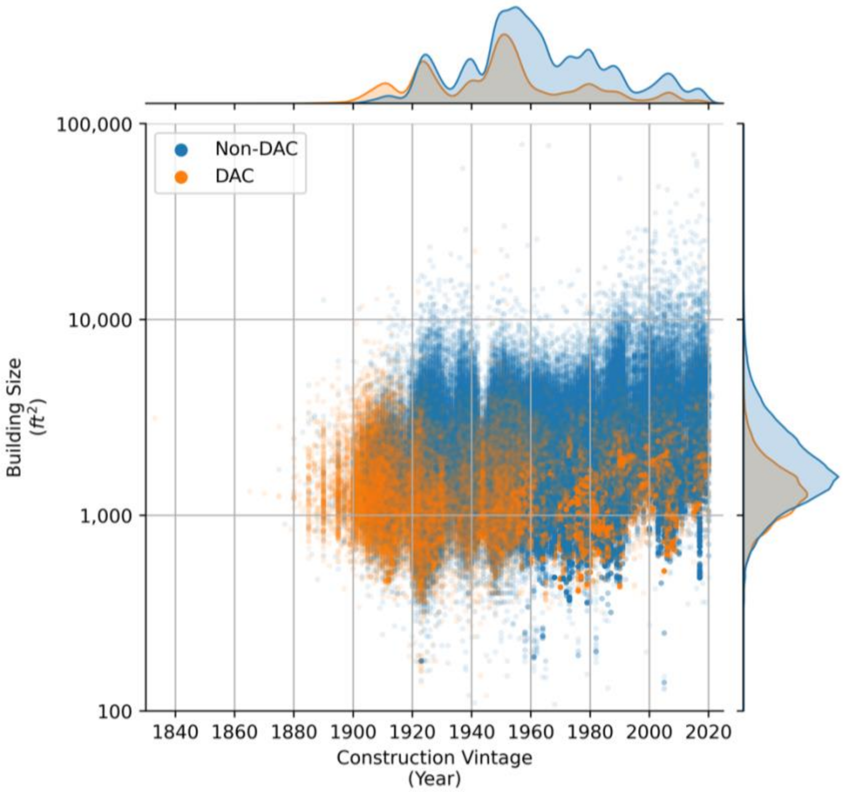


Figure 8: Joint distribution plot of the relationship between construction vintages and building square footages for all single-family residential properties in LADWP service territory, separated by DAC status.

In addition to differences in the physical characteristics of the single-family homes between the city's DAC vs. non-DAC communities, another important factor to remain aware of throughout the discussion of the results of this analysis are the differences in the sheer number properties between the two. Only 34% of the single-family homes in Los Angeles are located within DAC census tracts, despite the larger number of such tracts and their greater overall population. This is due to the higher density of occupation within DACs and larger proportion of renter households living in multi-family complexes. The map shown in Figure 9 clearly illustrates this discrepancy by plotting the geographic distribution of the number of single-family homes aggregated by census tract and colored by DAC status.

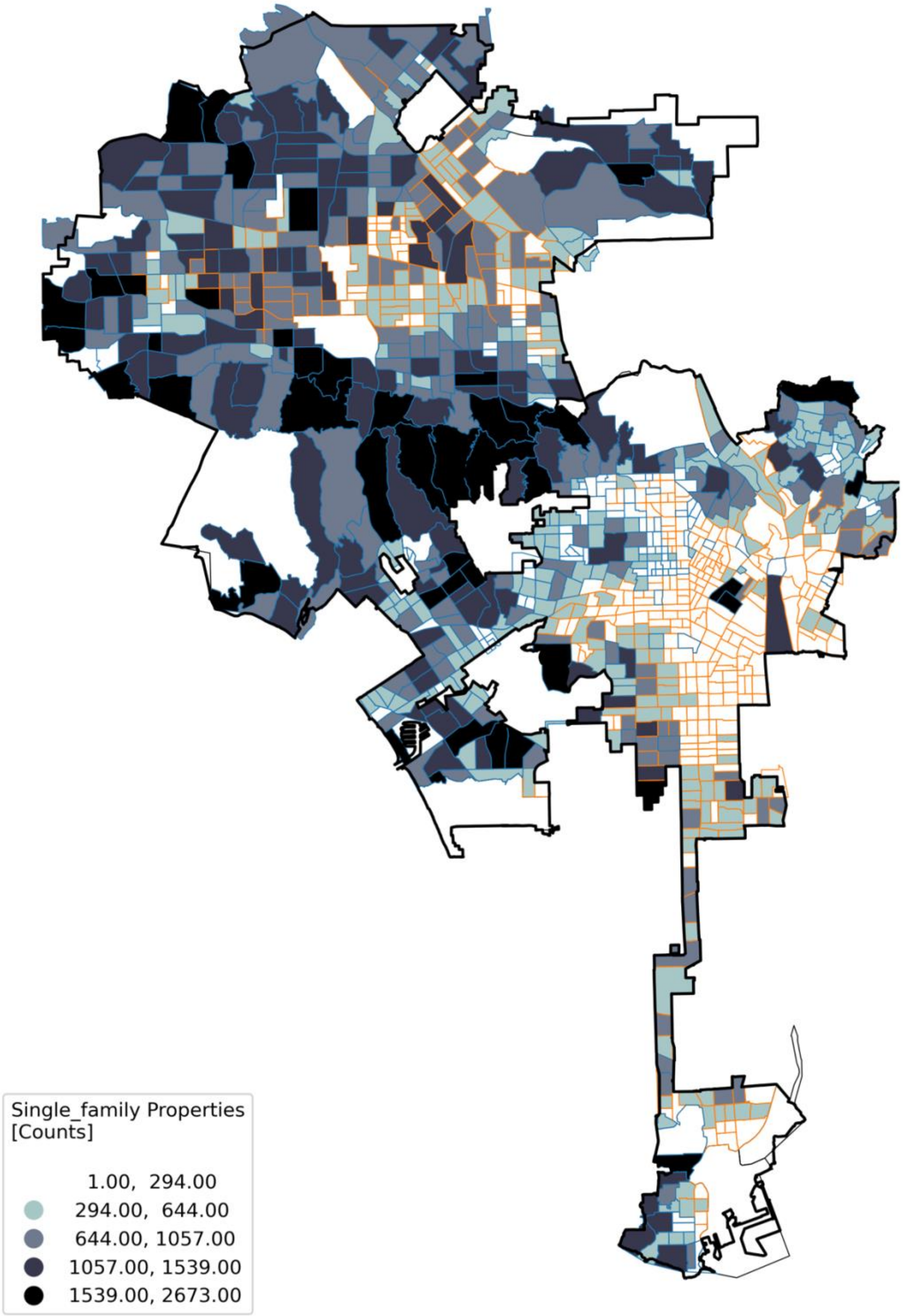


Figure 9: Map of the numbers of single-family properties by census tract and DAC status.

3.3.2 *Multi-Family Context*

Building attribute data for multi-family were sourced from the same County Assessor parcel database discussed previously in the single-family context. In total, there are 42,194 multi-family properties in LADWP service territory comprising a total of 357,577 individual units (not all of which are occupied) and 297,106,854 ft^2 of combined floor area. Overall, the average multi-family structure in the city of Los Angeles comprised a total of 7,041 ft^2, was constructed in 1950, contains 9 units, each with an average size of 844 ft^2.

The data presented in Table 3 summarizes the total number of properties, their average size, number of units, and the average size of each individual unit multi-family structures binned according to ten-year construction vintage year ranges. As these data show, there has been a steady increase in the average total size and the total number of units in the city's multi-family structures over time. This is perhaps indicative of most newly constructed multi-family buildings consisting of a larger proportion of luxury units, which have been designed to appeal to a higher income pool of potential renter households.

Table 3: Property statistics unit for multi-family structures in LADWP service territory by ten-year construction vintage range increments.

Construction Vintage Range (Year)	Properties (Count)	Average Total Size (ft^2)	Average Units (Count)	Average Unit Size (ft^2)
1850-1860	4	2,642	4	750
1860-1870	3	5,935	6	1,092
1870-1880	3	4,193	4	1,211
1880-1890	106	4,311	5	799
1890-1900	187	3,158	4	849
1900-1910	1,590	3,307	4	827
1910-1920	2,207	3,766	5	856
1920-1930	7,910	4,605	6	822
1930-1940	2,579	4,150	5	866
1940-1950	4,060	4,317	6	766
1950-1960	8,241	5,868	8	762
1960-1970	6,834	8,618	11	851
1970-1980	1,543	13,010	16	891
1980-1990	3,530	13,063	15	929
1990-2000	581	14,933	15	1,040
2000-2010	754	17,170	16	1,099
2010-2020	936	18,138	14	1,241

As was mentioned previously in the discussion of the single-family context, there are significantly more multi-family properties and total units within the city's DAC census tracts. In terms of differences between the distribution of characteristics in the multi-family building stock between DACs and non-DACs, the joint distribution plot shown in Figure 10 reveals that the two cohorts are actually quite similar, structurally, save for there being a much larger number of properties in the Pre-1930 / 1,000-10,000 ft^2 size category within DAC census tracts. This high concentration of older vintage, small to mid-sized, multi-family units within these DAC census tracts is also clearly visible in the property count map provided in Figure 11.

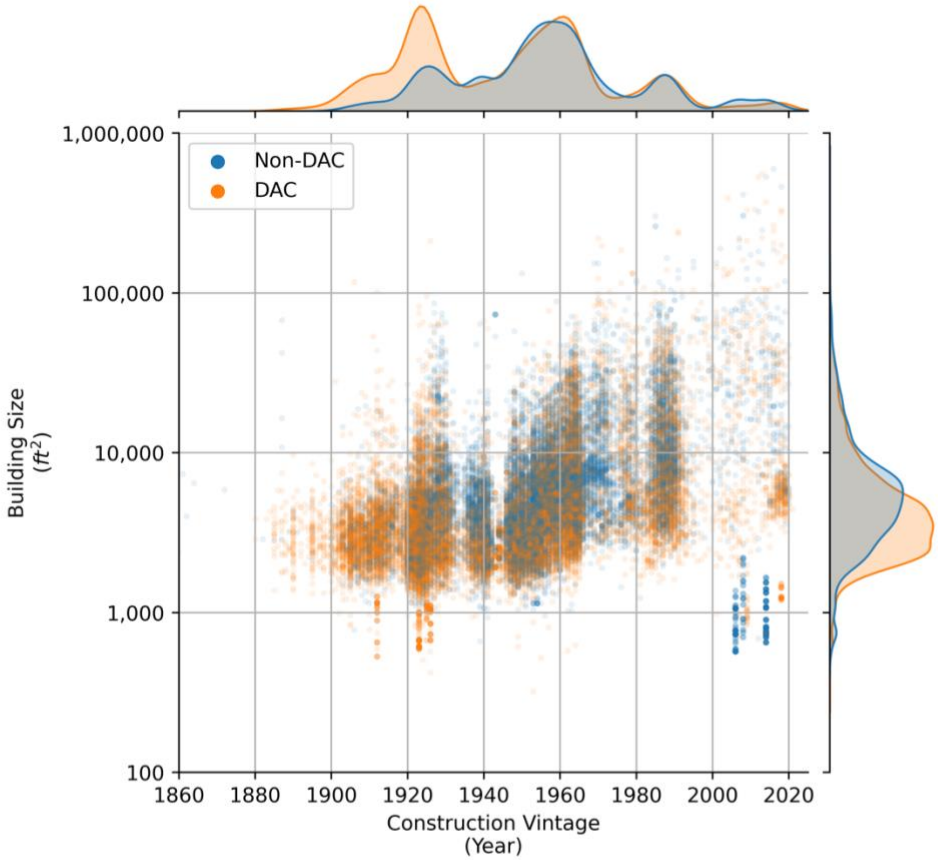


Figure 10: Joint distribution plot of the relationship between construction vintages and building square footages for all multi-family residential properties in LADWP service territory, separated by DAC status.

There are some differences in the physical characteristics of multi-family units between DAC and non-DAC census tracts; however, they are not so great as the differences in the size of the average single-family homes between the two cohorts that were discussed previously. For example, the average unit size in DAC multi-family buildings is 806 ft^2 and 890 ft^2 in their non-DAC counterparts, a difference of only 10.3%. This supports the conclusion that multi-family buildings are perhaps more uniform in their characteristics, and thus typical energy usage patterns and future service capacity needs, than are the stock of single-family buildings throughout the city.

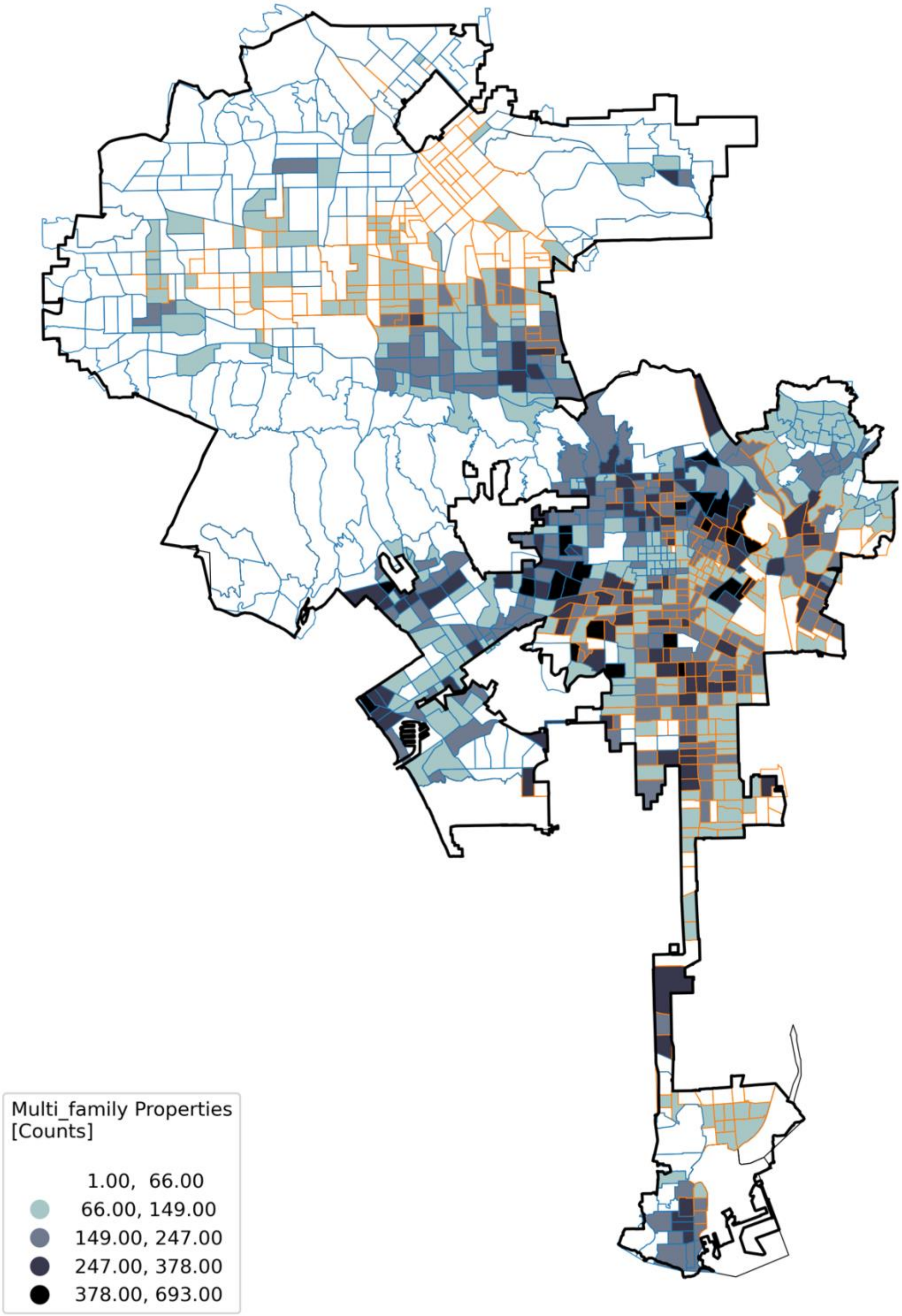


Figure 11: Map of the numbers of multi-family properties by census tract and DAC status.

3.4 As-Built Panel Sizing Assumptions

3.4.1 *Single-Family Context*

In order to establish the as-built capacity of the service panels installed at single-family properties, a decision tree was created which operates on information about the construction vintage year and size classification of each home. This structure of this decision tree was created by taking into account historical information about the recommended size of service panels within different historical iterations of the NEC as well as empirical data on the real-world size of the electrical panels at various properties referenced in different literature studies. (NEC 70, 2023) In terms of changes over time, the following are important demarcation points around which the recommended sizes of service panels for single-family homes are known to have changed significantly:

- Firstly, 1950 is an important year as it marked the beginning of the period of mass market availability of residential central air-conditioning (AC) systems. (Biddle, 2008) AC systems remain among the primary drivers of overall residential electrical power demand, thus necessitating larger panel sizes than what had been used previously for lighting and simple domestic appliances alone.

- Next, 1978 stands out for being the first year in which California's Title-24 building energy efficiency codes came into effect. (CEC, 2023) Prior to this period, the as-built rated capacity of the electrical service panel for the typical single-family home (1,000-3,000 ft^2) would likely range from 60-100 Amps. In addition to marking the onset of smarter, more energy efficient appliances, with intelligent digital controls, this period from 1978-2010 also marked the dawn of the consumer electronics era, with dramatic increases in the number and diversity of plug load electrical equipment found within homes. (Mahajan et al., 1999; Appel & Muller, 2021)

- Finally, the most recent era, spanning from 2010 to the present, represents a period in which new technologies enabling the full electrification of all end-uses within homes have become available and begun to grow in favor for their improved efficiencies, performance, and climate benefits. During this most recent period, we see fairly substantial increases in recommended panel sizes due to the large energy requirements from air/water heating and EV charging loads.

Table 4 provides a view of the predicted as-built rated panel capacity for single family homes of nine different size classifications built across the four major vintage period previously discussed.

Table 4: Table of values for the as-built panel size ratings that were assigned to single-family residential properties with different construction vintages and size classifications.

Size Classification	Pre-1950 *	1950-1978	1978 - 2010	Post-2010
< 1,000 ft^2	30 Amps	30 Amps	100 Amps	150 Amps
1,000 ft^2 – 2,000 ft^2	40 Amps	60 Amps	125 Amps	200 Amps
2,000 ft^2 – 3,000 ft^2	60 Amps	100 Amps	150 Amps	225 Amps
3,000 ft^2 – 4,000 ft^2	100 Amps	125 Amps	200 Amps	320 Amps
4,000 ft^2 – 5,000 ft^2	125 Amps	150 Amps	225 Amps	400 Amps
5,000 ft^2 – 8,000 ft^2	150 Amps	200 Amps	320 Amps	600 Amps
8,000 ft^2 – 10,000 ft^2	200 Amps	320 Amps	400 Amps	800 Amps
10,000 ft^2 – 20,000 ft^2	320 Amps	400 Amps	600 Amps	1000 Amps
> 20,000 ft^2	400 Amps	600 Amps	800 Amps	1200 Amps

* Note: The as-built condition of all buildings with construction vintages which pre-date 1882, the year in which the first municipal electric generation plant serving the city of Los Angeles was commissioned (which even predates the founding of LADWP itself) are assumed to be zero.

3.4.2 *Multi-Family Context*

While the load center design criteria for multi-family buildings are much less uniform than within the single-family context, a recent survey and analysis conducted by Sacramento Municipal Utility District (SMUD), an early leader in electrification initiatives, provides a number of useful insights about the common sizes of the service panels associated with individual tenants' sub-panels. (Davis, 2022) According to the SMUD report's findings, the overall size of a multi-family structure is far less significant as a determinant of panel size rating than it is within the single-family context. This is because larger multi-family structures tend to simply consist of more units and not necessarily larger ones. As evidence of this in Los Angeles, consider that the standard deviation of average unit sizes across all of the multi-family structures is 382 ft^2. By comparison, the standard deviation of the sizes of the single-family homes within the city is 1,294 ft^2 – a factor of 4x larger.

Table 5 provides a summary of the estimated panel capacity ratings that were used to establish the as-built rated panel capacity, per-unit, for multi-family structures based upon their construction vintage year classification. Here again, the classification boundaries remain the same, reflecting the same structural determinants of historical changes in energy use referenced previously in the single-family discussion.

Table 5. Table of values for the as-built panel size ratings that were assigned to multi-family residential units with different construction vintages.

Construction Vintage Classification	Rated Panel Capacity Per Unit
Pre-1950 *	40 Amps
1950-1978	60 Amps
1978-2010	90 Amps
Post-2010	150 Amps

* Note: The as-built condition of all buildings with construction vintages which pre-date 1882, the year in which the first municipal electric generation plant serving the city of Los Angeles was commissioned (which even predates the founding of LADWP itself) are assumed to be zero.

3.5 Identifying Historical Panel Upgrades

The Department of Building and Safety issues permits for the construction, remodeling, and repair of buildings and structures in the City of Los Angeles. Permits are categorized into building permits, electrical permits, and mechanical permits (which include plumbing, HVAC systems, fire sprinklers, elevators, and pressure vessels). Historical data with detailed information about these permits are publicly available for download through the city's open data portal. The permit data corpus used for this analysis includes records for projects with permit issue dates which span the period from August 1996 to August 2022. This means that the annualized statistics computed for each of these two bookend years should be considered incomplete.

Pre-processing of this data set involved the identification of electrical work permits which were explicitly pulled for service panel upgrades as well as permits pulled for other types of projects for which panel upgrades are explicitly required or were highly likely to be necessary. These include such things as major HVAC system overhauls, solar PV and battery energy storage system installs, and the addition of level-2 EV chargers. This filtering was accomplished by keyword string matching on the work permit description text. These descriptions are free-form text fields that are completed by the permit applicant, thus there is a high degree of variation which must be accounted for in terms of their content and completeness. It is worth noting that within the multi-family context there is an additional element of uncertainty associated with whether or not the referenced panel upgrade was applicable to one, some, or all of the units within the complex. In these cases, best efforts were made to account for this issue; however, fundamental uncertainties remained in many instances, hence a focus on the estimated average panel rating per unit within the multi-family throughout the analysis.

Each of the identified panel upgrade permits was then associated property records from the parcel database by joining common Assessor Parcel Identification numbers. Following this join, the size of the destination panel, in its existing condition following from the upgrade, must be established. In instances where the Amperage capacity rating of the destination panel has been explicitly stated in the permit's work description text field, these values are used directly. In instances where these values are not explicitly mentioned, they must be inferred. This process of inference takes into account information about both the estimated as-built size of the panel at the property in question as well as available information about the type of permitted work (i.e., EV charger vs. PV system vs. HVAC system installs). Using the combination of the work classification and the as-built panel rating for a given property, the existing panel rating is calculated by advancing an appropriate number of units up a defined "upgrade ladder." This is a table that consists of an order set of amperage ratings that are commonly occurring in panel hardware used within single-family residential applications.

3.6 Spatial and Temporal Patterns in Permitted Upgrades

3.6.1 *Single-Family Context*

Figure 12 provides a pair of time series plots which illustrate both the annual (top) and cumulative total (bottom) numbers of permitted panel upgrades that were able to be extracted from the building permit dataset. The average annual number of permitted panel upgrades over this period are 2,189 per year and 4,234 per year among DAC and Non-DAC households, respectively. This corresponds to a roughly ~2x faster rate of turnover within the non-DAC census tracts. The rates at which the number of annual upgrades is occurring has been steadily increasing over time. For example, from 1996-2022, the annual number of permitted panel upgrades have increased by an average of 42% year over year within DACs and 34% within non-DACs. However, it is unlikely that this pace will be sustained over the long term as these types of new technologies tend to diffuse according to a sigmoidal growth pattern; one which is characterized by high rates of initial growth, that then level off, and later continue to decline as the technology approaches full saturation within the population.

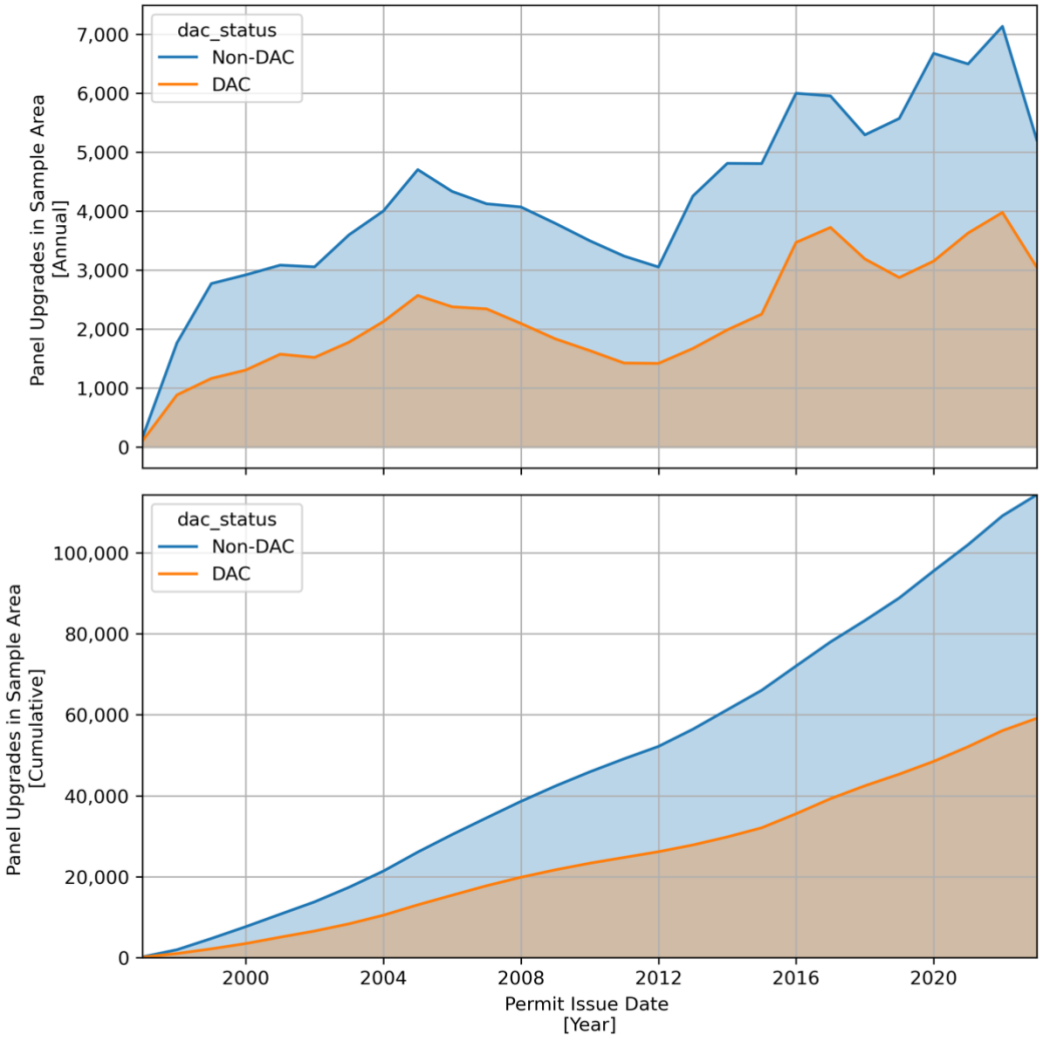


Figure 12. Time series plots of the annual (top) and cumulative total (bottom) permitted single-family property panel upgrades within LADWP service territory for a permit data corpus spanning from August 1996 to August 2021.

Figure 13 plots the total number of panel upgrade permits between DAC and non-DAC census tracts over the entire data availability period. Here we can see that the figure is again, roughly ~2x larger within the non-DAC cohort. Figure 18 unpacks these data spatially, with a map showing the geospatial distribution of cumulative permitted panel upgrades throughout LADWP service territory, with each census tract outline colored according to its DAC status. As this map shows, the highest concentration of permitted upgrades has occurred within the city's more affluent coastal, hills, and inland valley neighborhoods. When studying this figure however, it is important to recall the previous point which was raised about the differences in the sheer number of single-family properties between DAC and non-DAC census tracts, which in this case, would lead to an expectation of larger count totals within the non-DAC tracts, even if the rates of occurrence, as a percentage of the total number of properties, were the same between the two (which they are not).

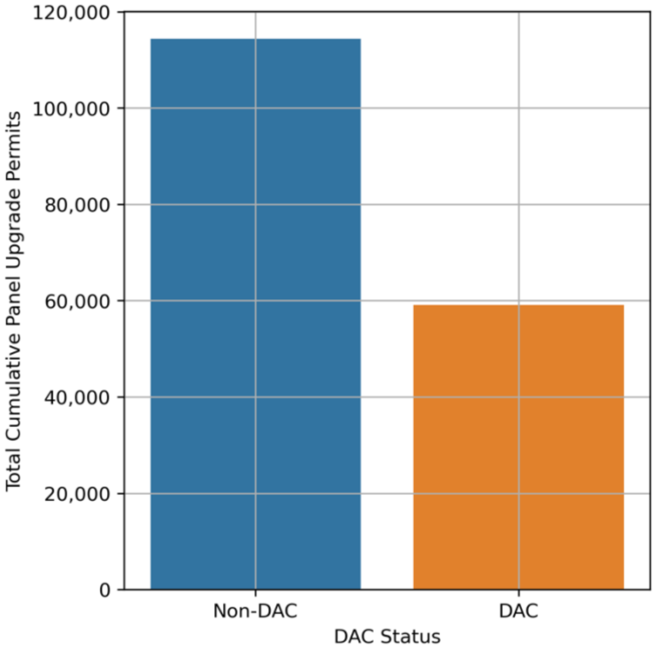


Figure 13: Bar plot of estimated total number of single-family home service panel upgrades (explicitly permitted + otherwise) by DAC status.

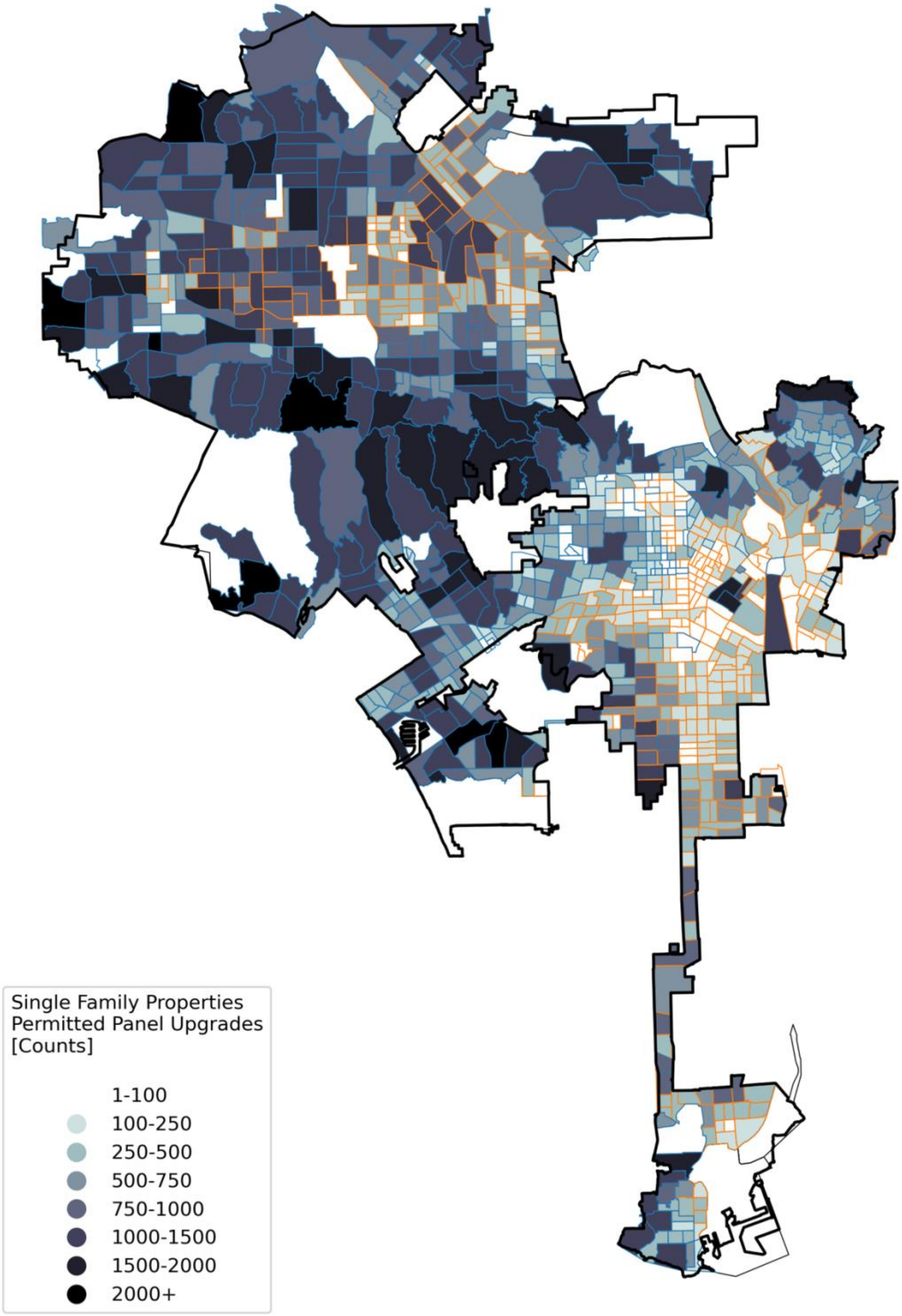


Figure 14: Map of the numbers of single-family property permitted panel upgrades by census tract and DAC status.

3.6.2 *Multi-Family Context*

Figure 15 provides a similar time series view of panel upgrade permits within the multi-family sector. Here again, the top plot depicts the annual number of permits issued per year and the bottom plot shows the cumulative sum over the sample timeframe. Overall, the average annual rate of multi-family upgrades over the permit data period is vastly lower than what was seen in the single-family context, with only around ~200 properties being upgraded each year in the most recent periods. These annual rates of permitted upgrades do not appear to have increased significantly over time either, suggesting there is less of an appetite for adopting electric appliances within this sector. Additionally, in terms of the balance of upgrades between DACs and non-DACs, we can see somewhat opposite trends to those which were present in the single-family context, with a larger overall number of permitted upgrade projects occurring within DAC census tracts. A likely explanation for this is the significantly larger number of such properties overall within DACs.

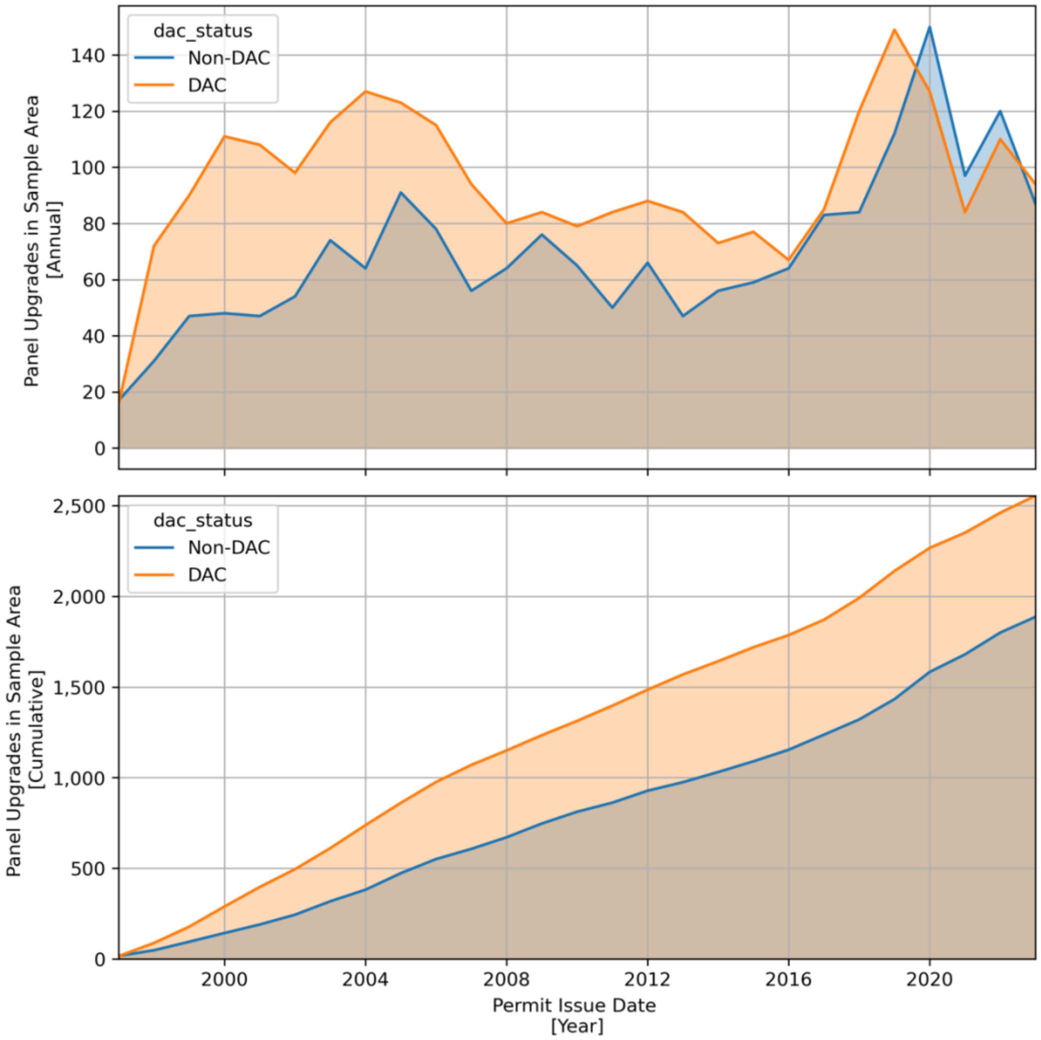


Figure 15. Time series plots of the annual (top) and cumulative total (bottom) permitted multi-family property load center upgrades within LADWP service territory for a permit data corpus spanning from August 1996 to August 2021.

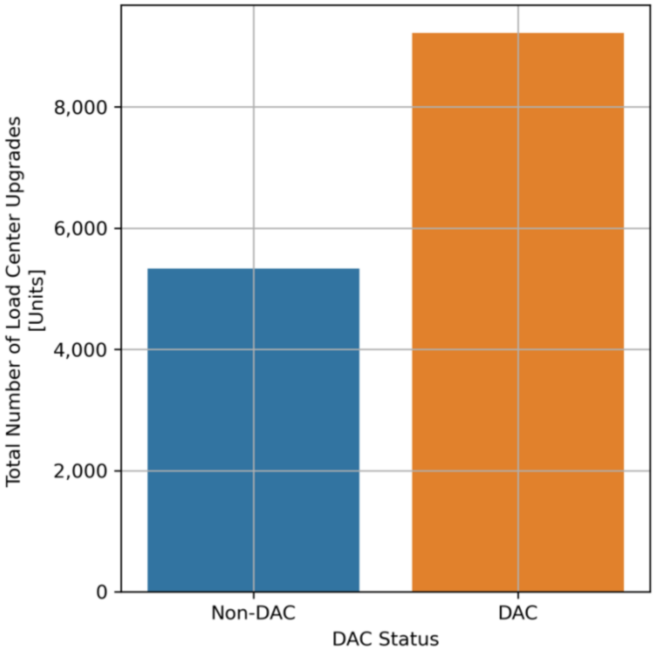


Figure 16: Bar plot of estimated total number of multi-family property load center upgrades (permitted + otherwise) by DAC status.

To the previous point, Figure 16 above provides a simple bar chart depicting the total cumulative number of units affected by these permitted upgrades separated by the DAC status of the census tracts in which they are located. Here we can once again see that even when considered on the basis of the number of upgraded units, the numerical superiority within the DAC cohort is retained. Finally, Figure 17 provides a map illustration of the geographic distribution of these 25 years' worth of permitted multi-family upgrades throughout the city. Some interesting spatial trends include higher concentrations occurring in properties along the East-West running Expo Line light rail corridor. There is also evidence of significant change which has occurred in Mid-City and the Eastern Foothill communities as well as in the Harbor Gateway and San Pedro.

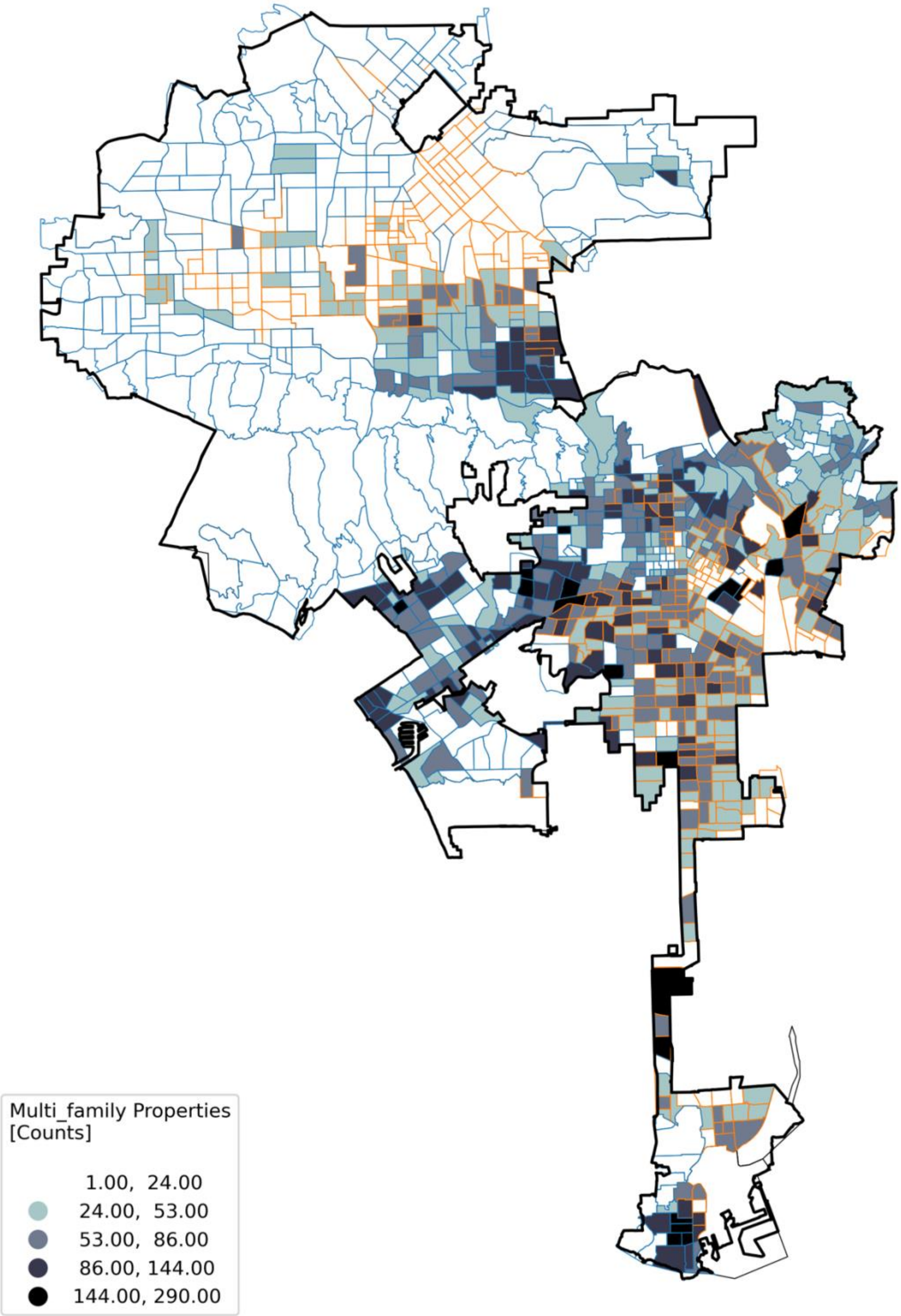


Figure 17: Map of the numbers of multi-family property permitted load center upgrades by census tract and DAC status (Note: There may be multiple upgrades per property).

3.7 Inferring Antecedent and Unpermitted Upgrades

After the historical database of building permits was ingested and all of the relevant panel upgrade permits and their new panel size ratings were assigned to the relevant properties, there still remain two important challenges. These related to the need to address (1) the possibility of permitted panel upgrades having occurred prior to the window of data availability and (2) the possibility of panel upgrades having been completed, at any time, in an unpermitted manner. In an effort to account for both of these confounding circumstances, a simple simulation model was built using the corpus of panel upgrade permit data as a training dataset.

The mechanics of this model are based upon the empirical cumulative density function (ECDF) derived from the permit records. This ECDF relates the probability of an upgrade having occurred to the age of a property at the time it was upgraded. Relative to each permit data record, these ages are computed as the difference between the property’s construction vintage date and the date when the panel upgrade permit was finaled. For the purposes of this analysis, two separate ECDF’s were fitted, one each for the DAC and Non-DAC census tract cohorts.

For each property in which a permitted panel upgrade was not available, the age of the building is provided as an input to the appropriate ECDF, depending upon the DAC status of the tract in which it is located. The output of the ECDF is a probability value (ranging from 0 to 1) that a panel upgrade had otherwise occurred. In this way, older buildings, despite not having panel upgrades in the permit dataset, would be assigned higher probabilities (approaching 1) for a panel upgrade having otherwise occurred. This probability would then be fed to a pseudo-random number generator that would produce a binary output representing the current upgrade status of the property. Based upon this simulation output, an appropriate destination existing panel size rating would then be assigned by incrementing from the property’s “as-built” condition, upwards, using the same “upgrade ladder” of common panel hardware size classifications discussed previously.

Figure 18 plots the two ECDF’s that were fit for the DAC and non-DAC cohorts of panel upgrade permit records for both the single-family (top) and multi-family (bottom) property cohorts. The shape of these functions provides some extremely relevant information in terms of understanding expected future trends in naturally occurring panel upgrades within the city’s building stock. This is because they depict changes in the expected residence time of a piece of installed panel hardware as a function of a building’s age. For example, looking at the top plot, for the single-family case, we can see that within non-DAC census tracts, there is a >50% chance of a panel upgrade having already occurred if a property is at least 60 years old. In DAC’s this age increases to 66 years before the 50% probability threshold is crossed.

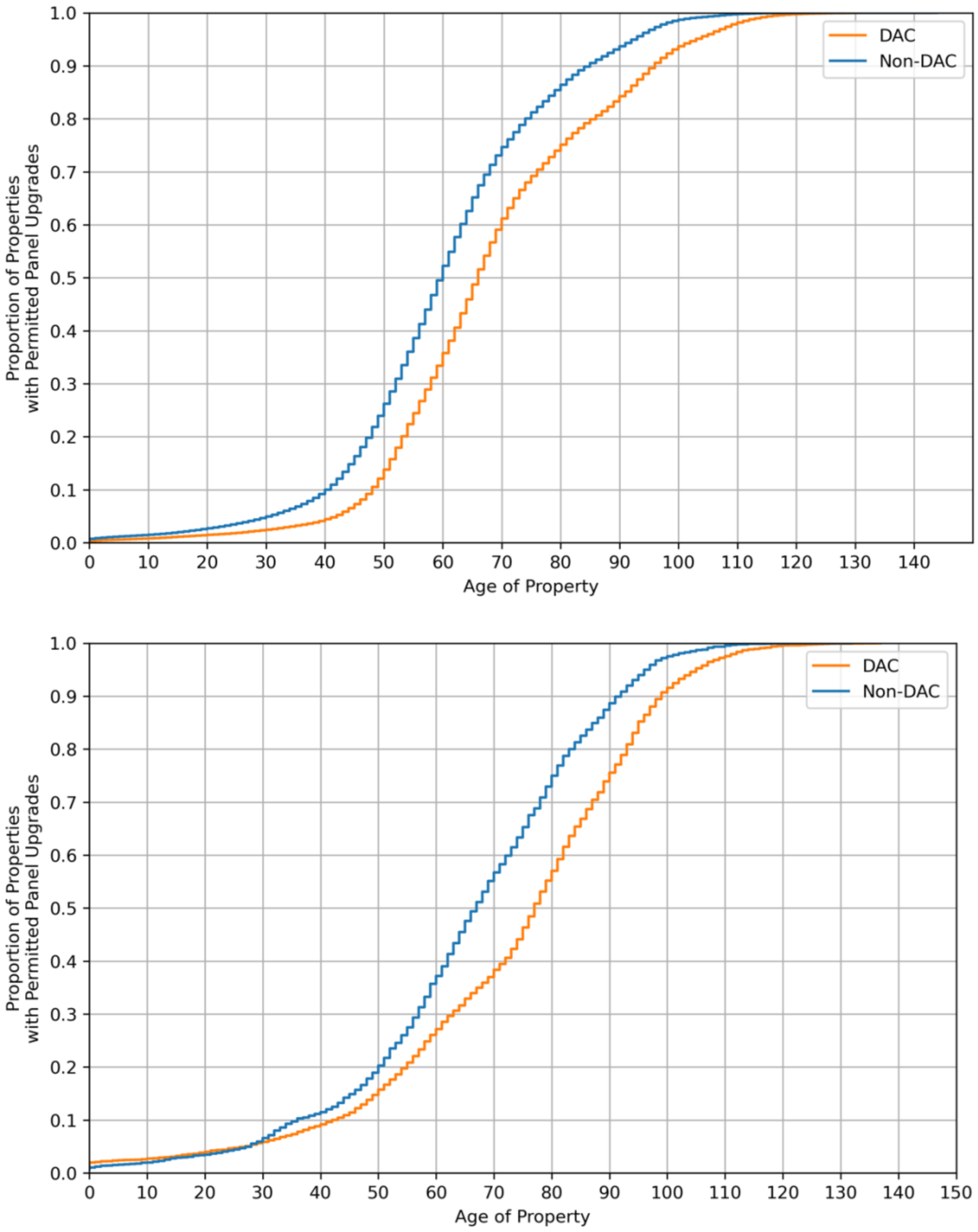


Figure 18: Empirical Cumulative Density Function (ECDF) plots illustrating the proportion of properties/units having received permitted panel upgrades as a function of their age and DAC status for the single-family (top) and multi-family (bottom) cohorts.

4 Results

4.1 As-Built Service Panel Ratings

4.1.1 Single-Family Context

Figure 19 plots the count frequency distributions for the estimated as-built size of electrical service panels installed in all of the single-family homes in LADWP service territory, disaggregated by their DAC status. As this plot shows, it is estimated that the largest component of the single-family housing stock was constructed with service panels that have a 60 Amp rated capacity. Also, it is important to note that very few of the single-family homes within DAC census tracts are expected to have been built with panels with greater than or equal to 200 Amp capacity. As discussed previously, 200 Amps represents an important size threshold in determining the feasibility of whole-home electrification efforts without the need for panel upgrades in the average sized single-family property.

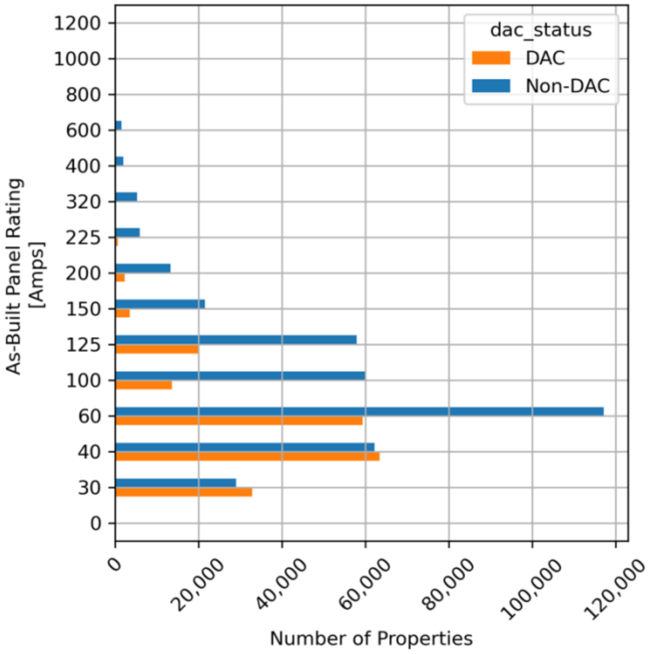


Figure 19: Count frequency histogram of the estimated "as-built" service panel ratings of single-family properties by DAC status.

The pair of joint histogram plots shown in Figure 20 provide an alternative view of these same data, illustrating differences in the number of single-family homes with service panels of each rating size classification, between the DAC (left) and non-DAC (right) cohorts. As these figures show, the long tail of larger single-family home sizes, particularly within the non-DAC cohort, leads to significant growth in the expected size ratings of electrical service panels – with a non-trivial number of properties expected to have been built with service interconnection hardware supporting >400 Amps of capacity.

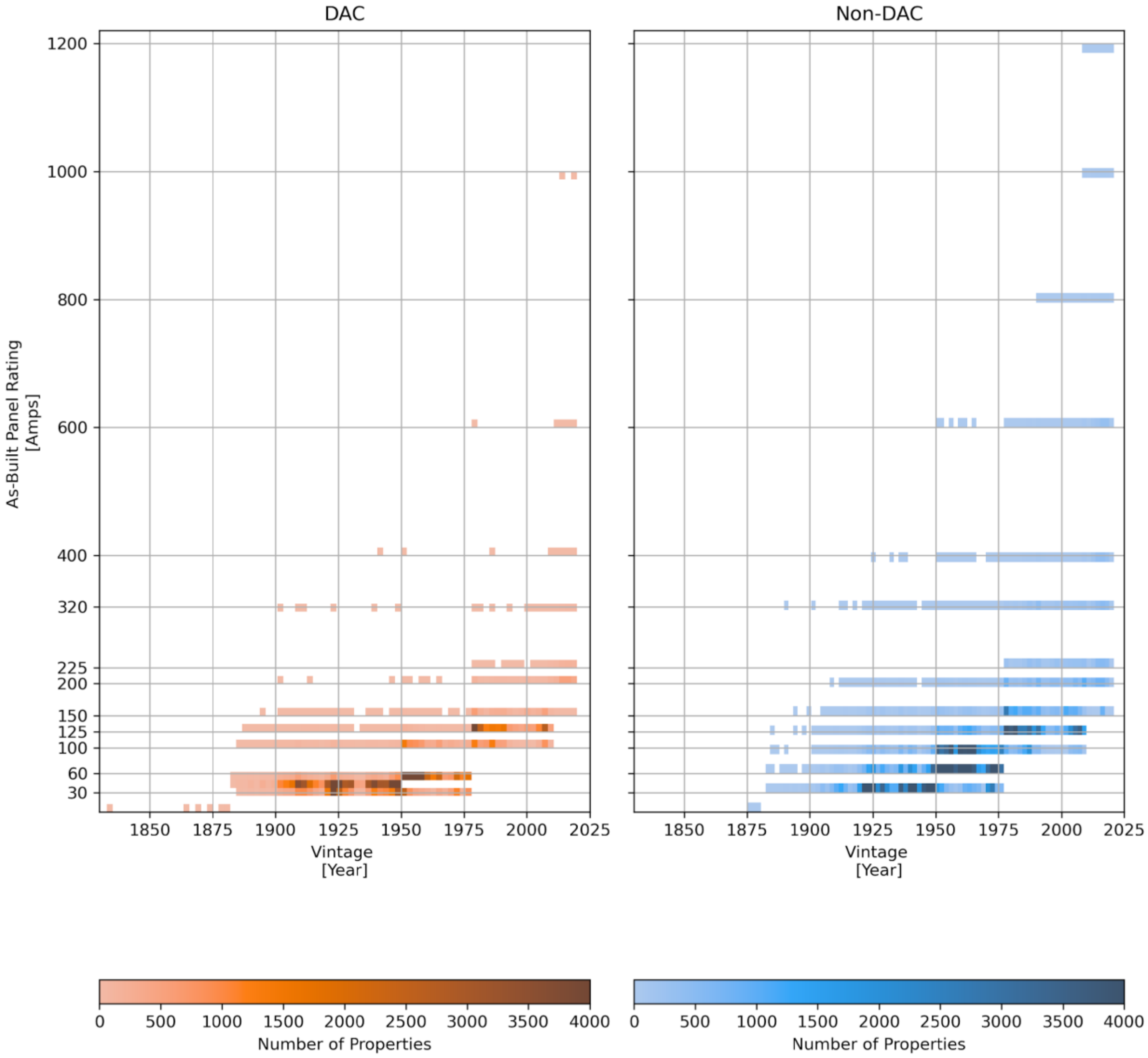


Figure 20: Joint histogram plots illustrating the numbers of single-family properties by as-built service panel size rating and construction vintage year, separated by DAC status.

The map plotted in Figure 21 shows the geographic distribution of the average as-built panel size rating for all of the single-family homes in each of the city's census tracts. The trends visible in this map conform to expectations based upon local knowledge about the distribution of affluence in Los Angeles. For example, the census tracts with the largest average capacity ratings are those located in the affluent hillside communities of Bel-Air, the Hollywood Hills, and surrounding areas which play host to many of the city's wealthiest households, who also tend to live in the largest and most recently constructed homes.

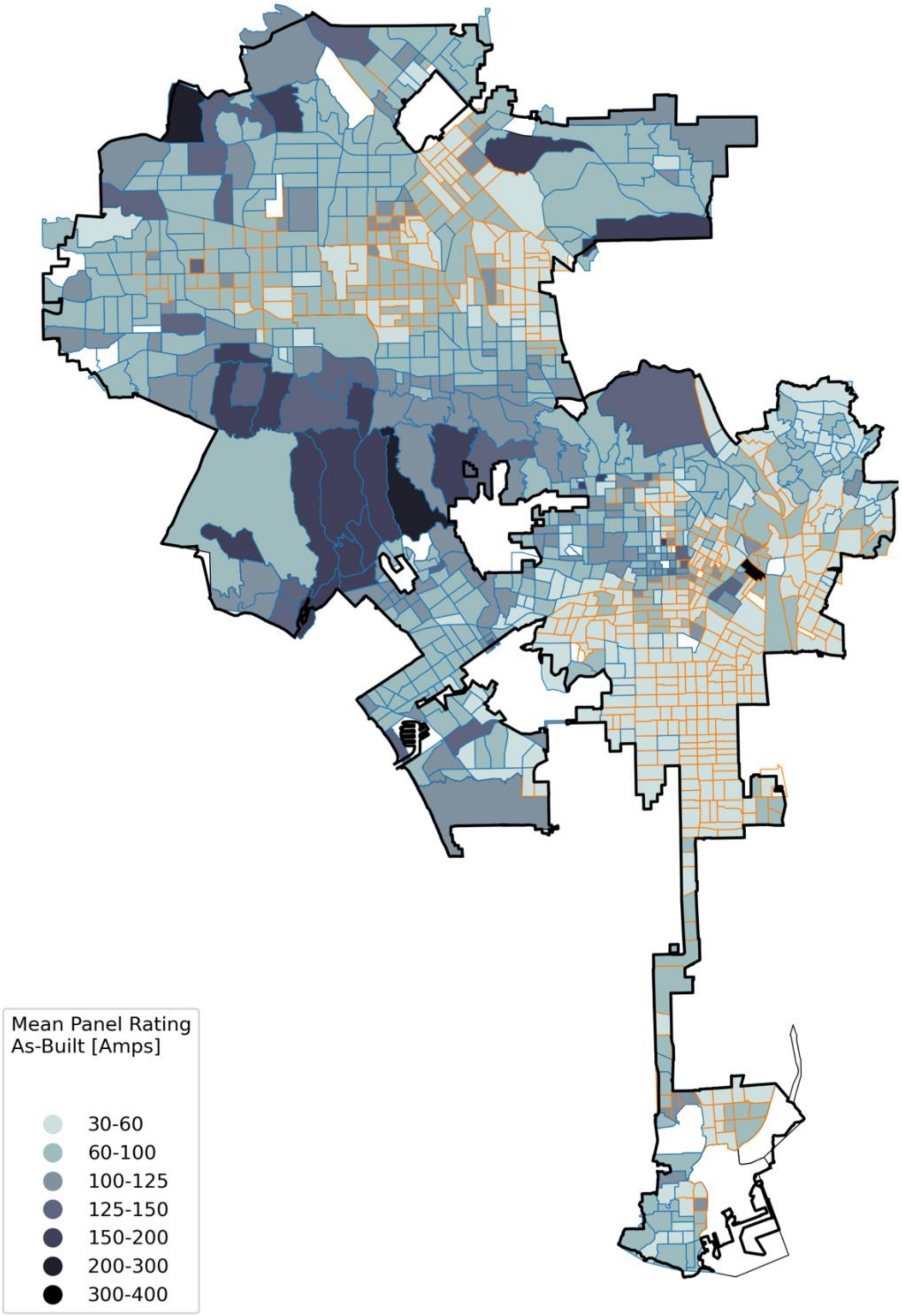


Figure 21: Map of the average estimated as-built size ratings of single-family home electrical service panels by census tract and DAC status.

4.1.2 *Multi-Family Context*

The plot shown in Figure 22 illustrates the estimated total numbers of multi-family units with different rated load center capacities, as-built. Here we can see that the majority of multi-family units throughout the city are expected to have been built with rated capacities of between 40-90 Amps. In terms of the breakdown of these estimates between the DAC and non-DAC cohorts, it is interesting to note that the majority of the units in the smallest rating classification (40 Amps / Unit) are located within DACs. This is likely due to the older average construction vintages of multi-family properties within the city's DAC regions.

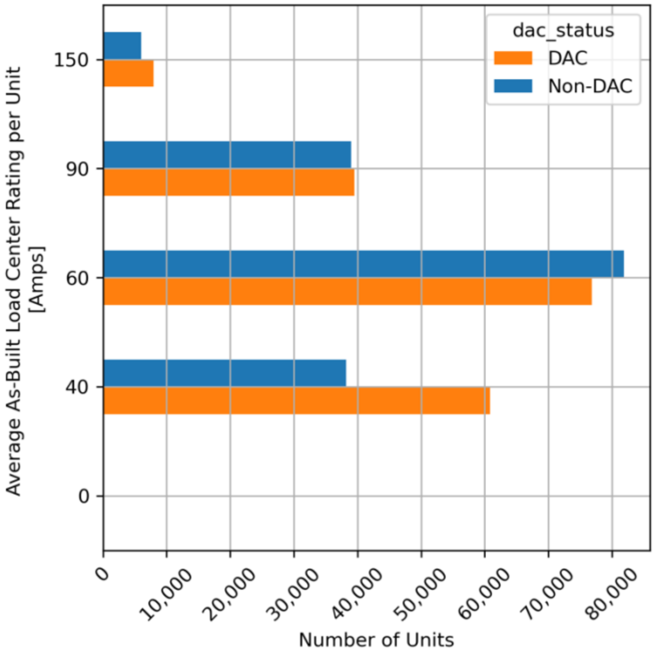


Figure 22: Count frequency histogram of the estimated as-built service panel ratings for the average unit of multi-family properties by DAC status.

Figure 23 provides a view of the number of multi-family properties disaggregated by the estimated size of their dwelling unit load centers and by construction vintage year. In both the DAC and non-DAC cases, the trend is towards larger panel sizes in the more newly constructed buildings. This is a product of the assumptions described in our methodology for estimating as-built panel sizes within the multi-family sector from construction vintage years alone. Here the relatively small number of properties with larger capacity load centers speaks to the lack of new development of new multi-family buildings in recent years compared with previous historical periods.

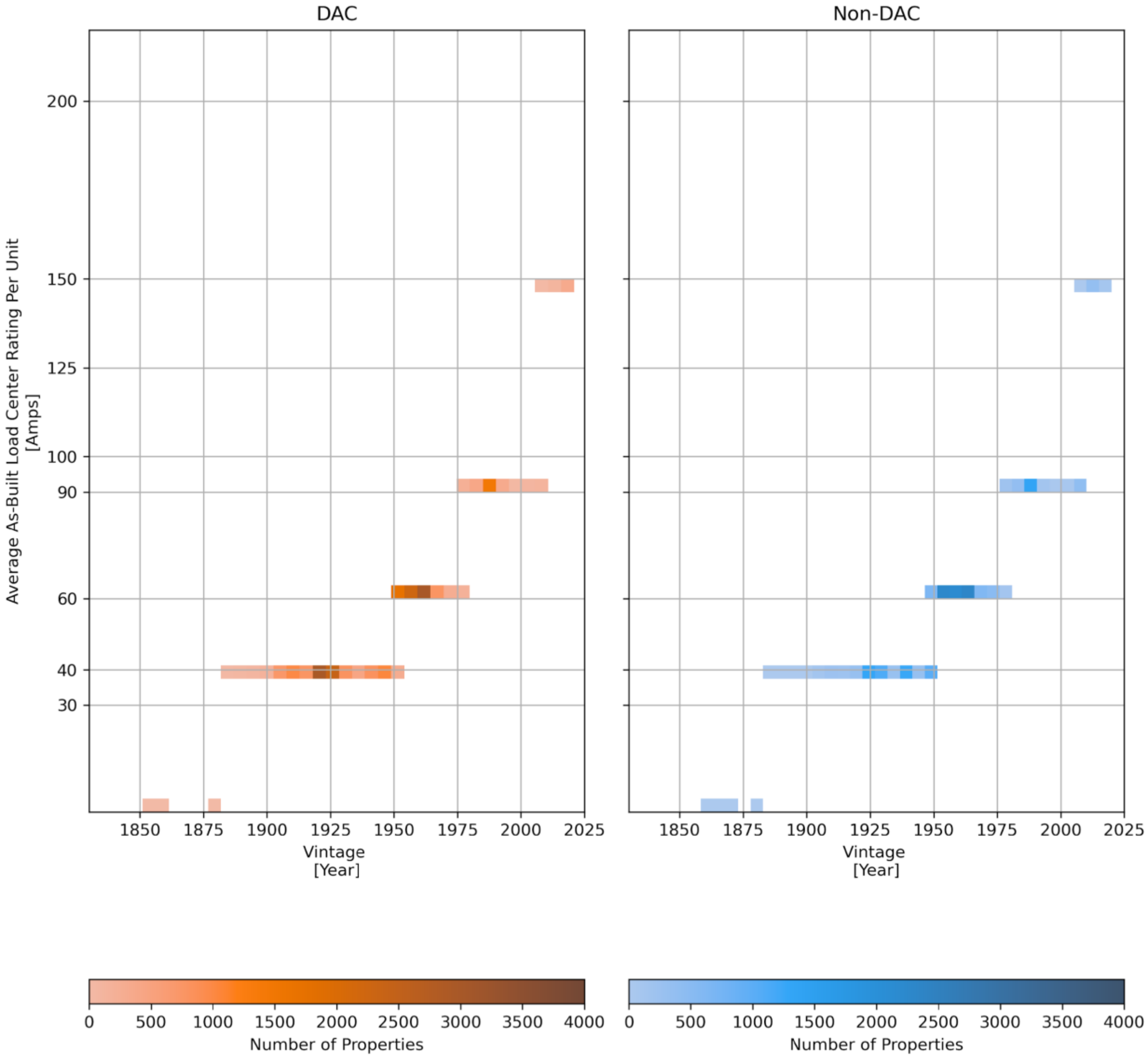


Figure 23: Joint histogram plots illustrating the numbers of multi-family properties by the as-built service panel size rating for the average unit and construction vintage year, separated by DAC status.

Figure 24 plots the geographic distribution of the average estimated capacity of load-centers among the multi-family structures within each census tract throughout the city. Once again, because the methodology for assigning these as-built ratings was simpler in the multi-family case than it was for the single-family, only taking into account the building vintage year, this map can largely be understood as a composite view of the average age of the multi-family structures in these different geographies. This situation will of course become much more complex, and more interesting, in subsequent results which will depict the estimated existing condition of the load centers as these locations – as those findings will take into account the historical permitted upgrades which have occurred over the intervening 25 years as well as inferred antecedent and unpermitted upgrades.

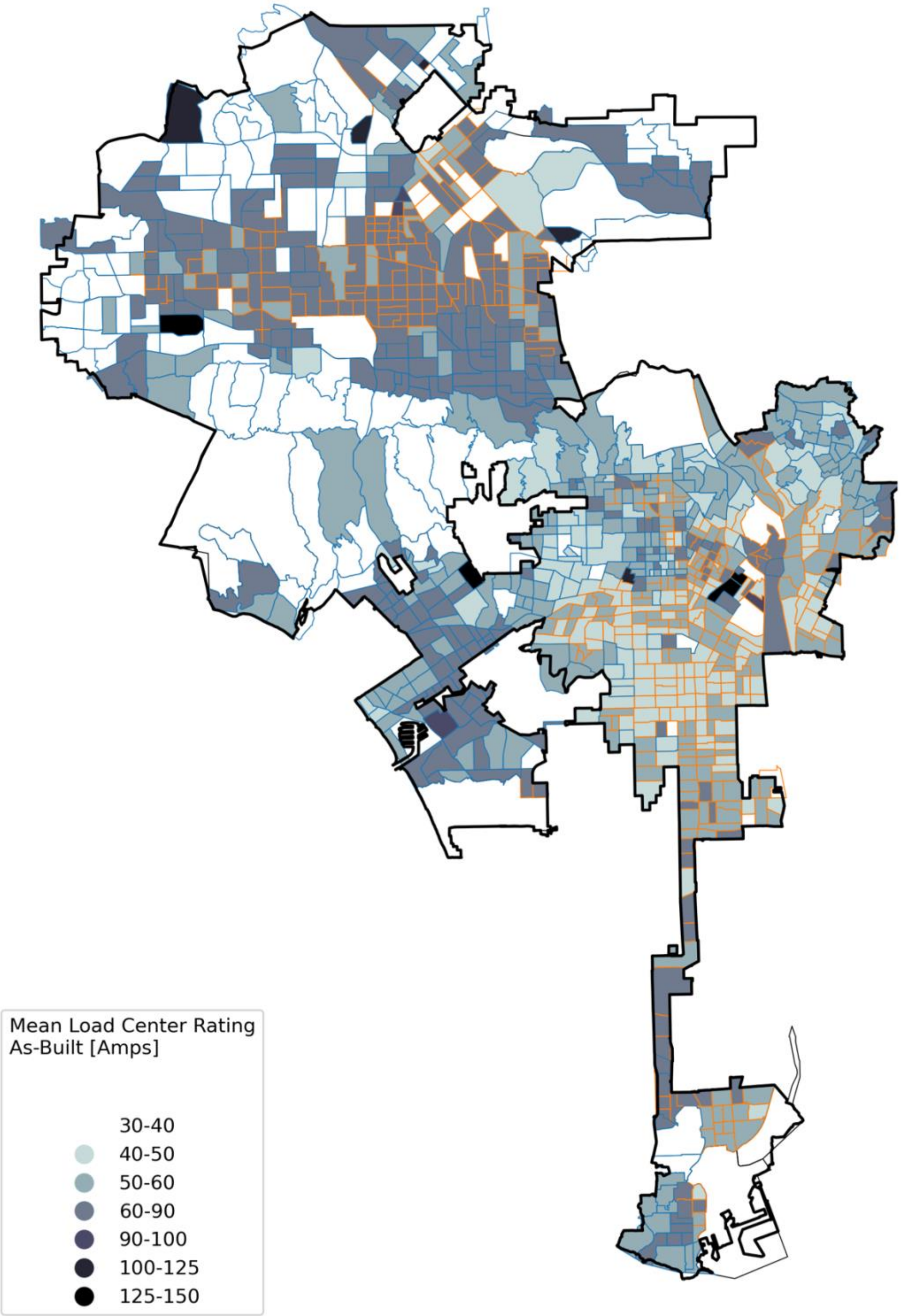


Figure 24: Map of the estimated as-built size rating per unit for multi-family property load centers (per unit) by census tract and DAC status.

4.2 Historical Permitted Panel Upgrades

4.2.1 *Single-Family Context*

Table 6 shows the proportion of single-family properties having already received panel upgrades, including both those which were explicitly permitted and those which were inferred, relative to the percentage of properties with panel's that are likely still in their as-built condition. Interestingly, the percentage of properties within DACs that have permitted panel upgrades is shown as being higher than those in the non-DAC census tracts. Though this may initially seem counter-intuitive, it actually makes sense when one considers the fact that DAC census tracts have a far lower number of newly constructed homes. The much higher prevalence of more newly constructed buildings within the non-DAC tracts means that the panels, as-built, at those properties tend to already have much greater capacity, reducing the need for upgrades. According to this line of reasoning therefore, while the non-DAC tracts have a larger proportion of properties that are not expected to have been previously upgraded (40%), we can assume that a large fraction of those, not yet upgraded, properties are in-fact new enough to have been built with service panels that have sufficient capacity to support full home electrification in the future.

Table 6: Overall single-family residential property panel upgrade statistics.

Property Cohort	DAC Census Tracts	Non-DAC Census Tracts
Properties with Permitted Panel Upgrades	25.53%	23.09%
Properties with Inferred Panel Upgrades	41.66%	36.71%
Properties without Panel Upgrades	32.81%	40.20%

4.2.2 *Multi-Family Context*

Table 7 provides similar high-level overview statistics for the multi-family load center upgrades assessed as part of this analysis. Again, the figures are disaggregated by the DAC status of the census tracts in which properties are located. Here, we can see that the proportion of properties that are expected to have received permitted panel upgrades from their original as-built status is actually slightly higher within the DAC areas – 12% in DACs versus 11% in non-DACs. However, these percentages of properties with actual permitted panel upgrades are a factor of two lower than within the single-family context. This is an important finding, as it speaks to differences in the rates that building upgrade projects occur within the multi-family sector throughout the city and the potential challenges that are likely to be encountered in terms of stimulating future development within this sector.

Table 7: Overall multi-family residential property load center upgrade statistics.

Property Cohort	DAC Census Tracts	Non-DAC Census Tracts
Properties with Permitted Panel Upgrades	12.11%	11.04%
Properties with Inferred Panel Upgrades	46.85%	45.15%
Properties without Panel Upgrades	41.04%	43.81%

4.3 Existing Service Panel Ratings

4.3.1 *Single-Family Context*

After applying all of the steps in our analytical methodology, the following set of final output results were generated which consist of best estimates for the existing panel size rating for every single-family property in LADWP service territory. The data presented in Table 8 and Figure 25 illustrate the frequency distribution of single-family properties by their estimated existing panel size ratings, differentiated by DAC status. As the figure and table both illustrate, the combination of new construction and historical panel upgrades have proceeded to such an extent that 27% of all of the single-family homes within city are now expected to possess panels with >=200 Amps of rated capacity – a value widely considered a safe minimum threshold to support future whole home electrification efforts. On the flip side however, 32% of all properties have panel sizes <100 Amps, meaning that they are likely going to require panel upgrades to be able support full electrification in the future. Among these, the larger total number are located within non-DACs, however as a proportion of the total single-family housing stock, the fraction is larger within DACs.

Table 8: Count frequencies of single-family properties by existing panel ratings and DAC status.

Panel Size Rating [Amps]	DAC Properties [Counts]	Non-DAC Properties [Counts]
0	NA	NA
30	6,719	7,934
40	25,535	19,399
60	57,447	70,126
100	35,169	79,358
125	21,022	65,978
150	3,707	24,283
200	45,241	91,396
225	800	7,528
320	206	5,290
400	59	2,493
600	32	1,698
800	NA	377
1000	3	190
1200	NA	37
1400	NA	1

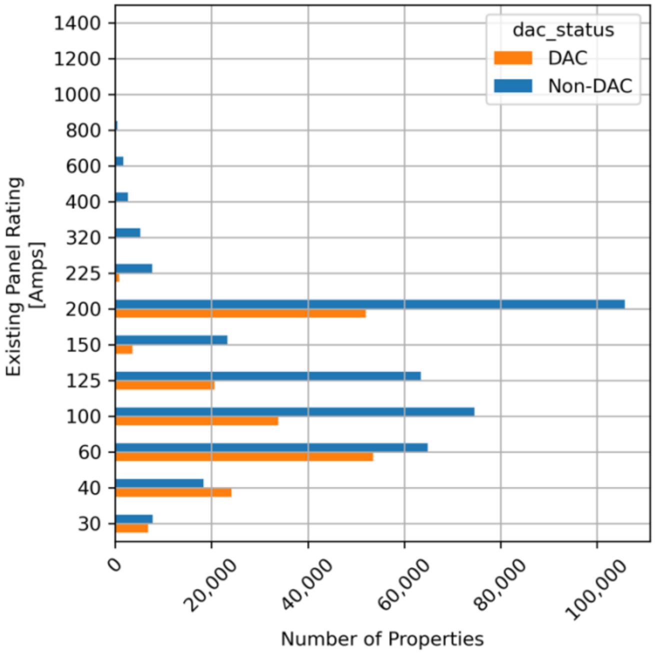


Figure 25: Count frequency histogram of single-family properties by estimated existing panel size rating and DAC status.

Figure 26 elaborates on these aggregated counts, showing the frequency distribution of different panel sizes by the properties' construction vintage years. Here we can see the effects of the transition towards a new "standard" panel size rating of 200 Amps. The majority of the properties within non-DAC census tracts are expected to have 200 Amp panels. The number of 200 Amp panels within these non-DAC census tracts is roughly double that with the DAC tracts.

The map plotted in Figure 27 shows the average single-family home's service panel capacity aggregated at the census tract level throughout the city of Los Angeles. Here we can see a continuation of the same geographic trends that were observed previously, when discussing the predicted as-built condition of the service panel hardware throughout the city. Once again, the most affluent, non-DAC tracts have significantly higher estimated average existing panel capacities. In this instance, this is due not only to their newer and larger homes, but also their higher rates of historical panel upgrades, both permitted and inferred.

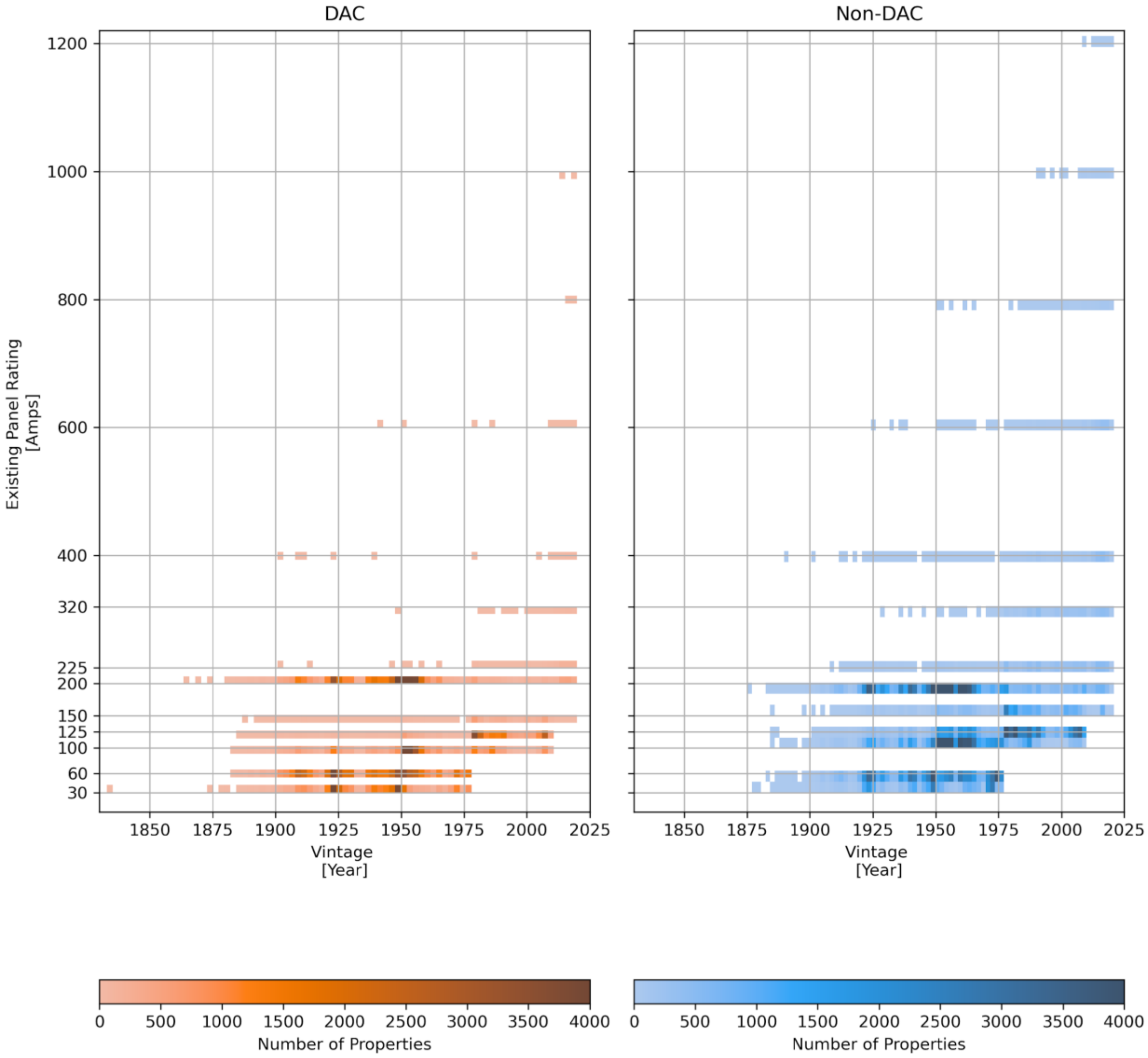


Figure 26: Count frequency histograms of single-family properties by existing service panel rating, construction vintage year, and DAC status.

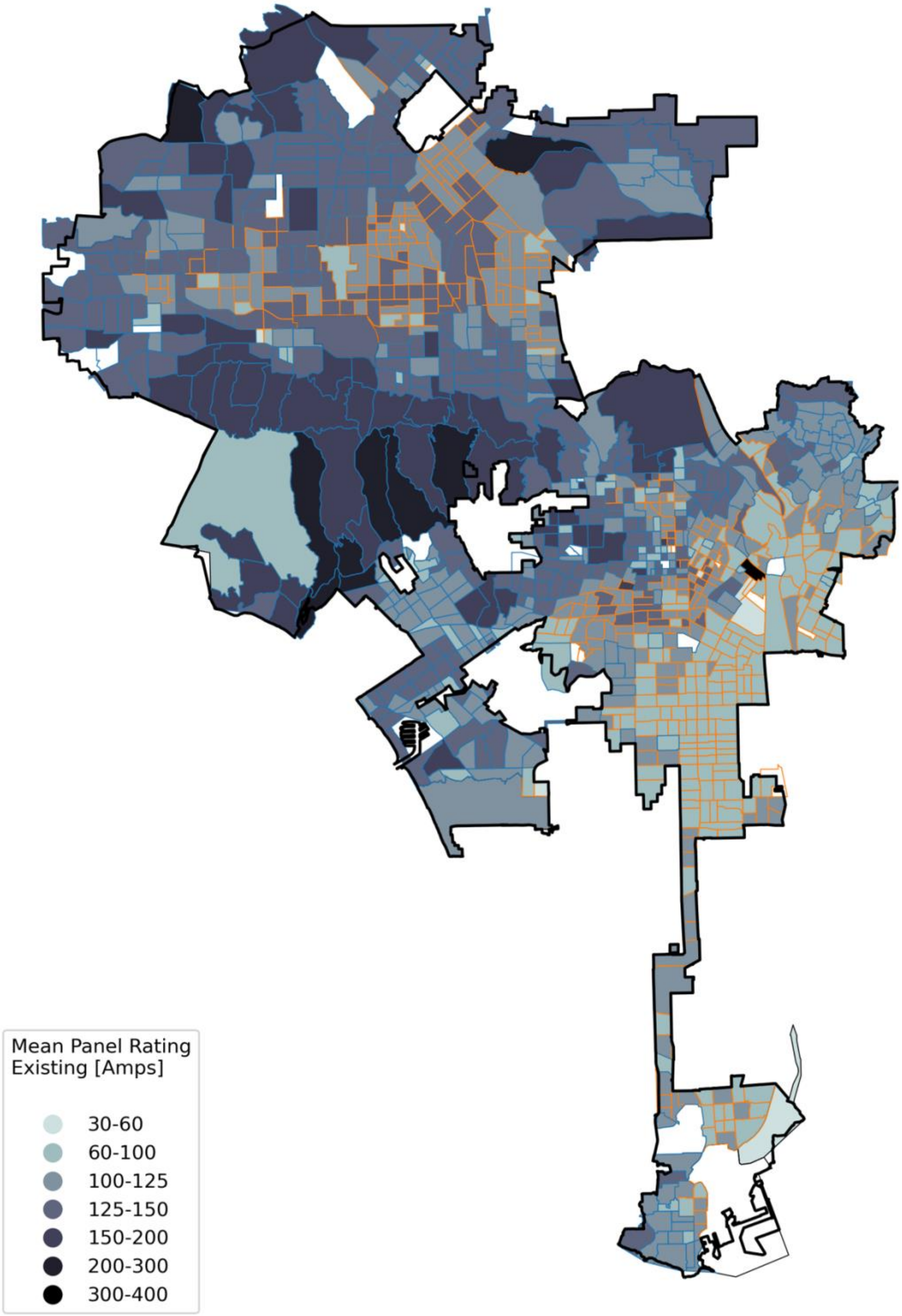


Figure 27: Map of estimated average existing single-family property service panel ratings by census tract and DAC status.

4.3.2 *Multi-Family Context*

Within the multi-family sector, estimates for the existing capacity of load center hardware were restricted to the average size of the sub-panel for each dwelling unit. As a reminder, the main service panel serving the house loads for the entire building, was considered out of the scope of this analysis due to the inherent variability of end-use load configurations within different multi-family structures. As we can see from the figures provided in Table 9, which are also visualized graphically in Figure 28, there are not actually huge differences in the total number of units with different rated load center capacities between the DAC and non-DAC cohorts of buildings. The vast majority of these units are expected to have unitary load center capacities of between 60-90 Amps, a range that would likely be considered deficient relative to the requirements of many different electrification measures.

Table 9: Count frequencies of multi-family units by existing average load center ratings per unit and DAC status.

Average Load Center Size Rating Per Units [Amps]	DAC Units [Counts]	Non-DAC Units [Counts]
40	16,082	8,818
60	180,380	141,033
90	97,543	118,282
100	4,217	3,460
125	588	890
150	47,195	43,748
200	5,803	5,563

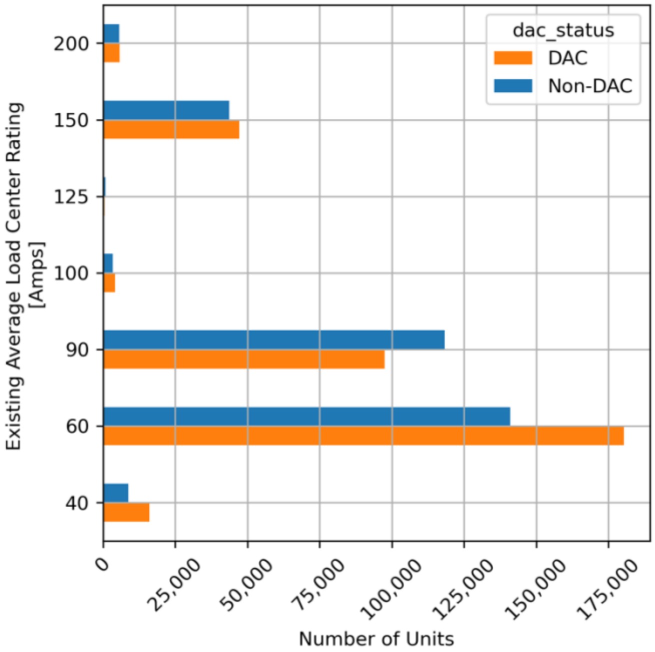


Figure 28: Count frequency histogram of multi-family units by estimated existing average load center rating and DAC status.

Moving on to Figure 29 we can see that the existing panel ratings within multi-family dwellings remain correlated with construction vintage year even after upgrades have been taken into account. The largest number of buildings with larger capacity load centers have been constructed since 2000, and among these, a slight majority in terms of the number of total properties are located within the non-DAC census tracts. These new properties, in general, also tend to be larger in size – both in terms of ft^2 per unit as well as the total number of units.

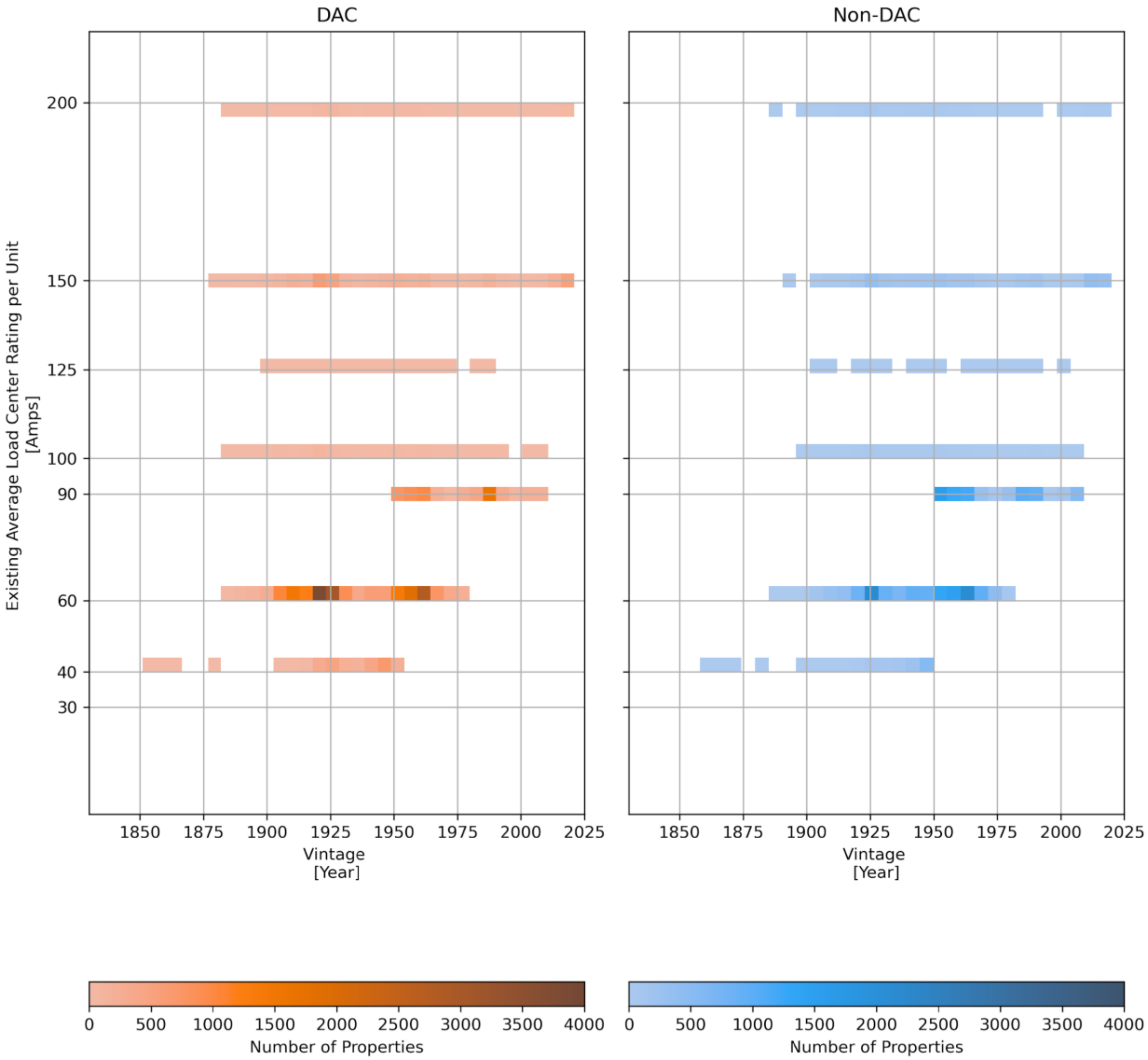


Figure 29: Count frequency histograms of multi-family properties by existing load center average ratings per unit, construction vintage year, and DAC status.

The map shown in Figure 30 illustrates the geographic distribution of the average load-center size, per dwelling unit, for multi-family properties throughout the city. Here, we can see the same evidence of there being far less variation in the condition of the multi-family structures between the DAC and non-DAC cohorts, with relatively low average capacities reported throughout.

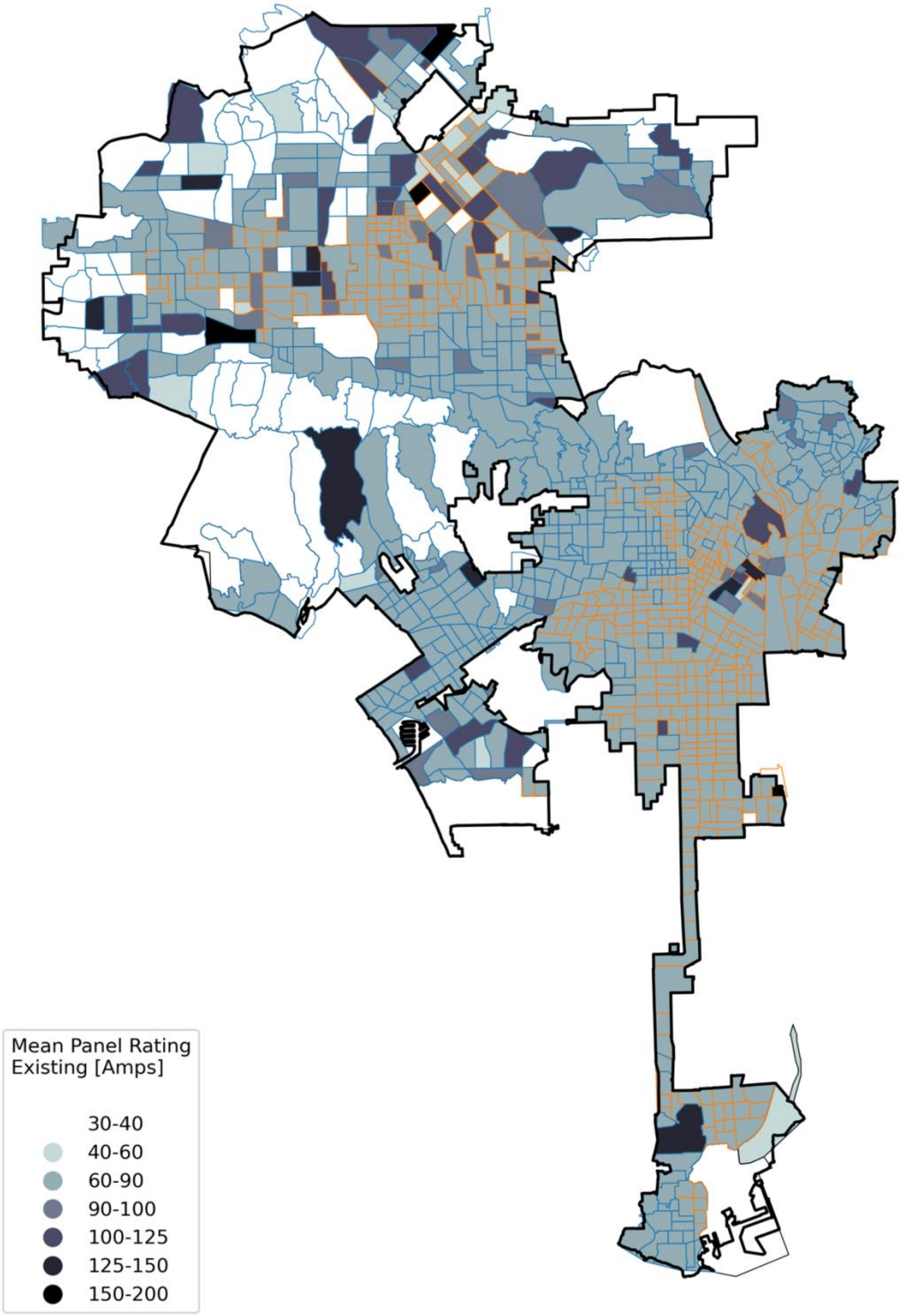


Figure 30: Map of multi-family property estimated average existing load center ratings by census tract and DAC status.

4.4 Future Upgrade Requirements

4.4.1 *Single-Family Context*

Table 10 provides a high-level summary overview of the distribution of these estimated existing panel size ratings between the city's DAC and non-DAC census tracts. Within this table, properties have been grouped into three size classifications that are most commonly referenced within the literature. Here, properties with panel size ratings that are <100 Amps are deemed "likely" to need to be upgraded to support full home electrification in most cases. While properties with size ratings >=100 Amps & <200 Amps are considered "potentially" candidates for upgrades. And finally, properties with panel size ratings in >=200 Amps are considered "unlikely" to require upgrades in most cases, going forwards. According to these thresholds, nearly half of the single-family properties in Los Angeles' DAC neighborhoods (46%) are likely to require service panel upgrades going forward if they are to be able to support full home electrification measures. This is as compared to 26% within non-DACs.

Table 10: Overall estimates of single-family homes requiring panel upgrades to support full electrification measures in the future separated by DAC status.

Panel Rating Classification	Upgrade Required for Future Full Electrification?	DAC Properties [Percentage]	Non-DAC Properties [Percentage]
<100 Amps	Likely	45.78%	25.91%
>=100 Amps & <200 Amps	Potentially	30.57%	45.10%
>=200 Amps	Unlikely	23.65%	28.99%

While the perspective taken above is somewhat useful in terms of anticipating the scale of the upgrade challenges that will be faced in the coming years, it can be a potentially dangerous oversimplification to think of the problem in terms of needing to achieve a single target minimum panel rating across all single-family buildings, regardless of their size. A likely more realistic perspective is to pose the problem in terms of the target number of Amps per square foot that will be needed, as larger buildings inherently possess more end-use loads and have greater heating and cooling energy requirements, necessitating increased service capacities.

Figure 31 provides an illustration of the problem from this alternative perspective. Here, relative to both the DAC and non-DAC cohorts, the normalized existing panel rating Amperage per ft^2 are plotted relative to property size for groups of homes both with and without permitted panel upgrades. The differences in the centers of these distributions, along the y-axis, illustrate the extent to which panel upgrades result in an increase in the number of Amps per ft^2 (note the use of Log10 scale). If we presume that the upgraded panels have been correctly sized for the loads that are present within the structures, we can use these mean values as scaling coefficients with which to estimate the likely target panel size for each property that has not yet been upgraded. For DACs and non-DACs, the groups with panel upgrades both appear to exhibit a negative relationship between the size of homes and their area normalized panel ratings. This indicates a decreasing rate of power demanded per unit building area, with incremental increases in building size. Critical values from this analysis as well as regression model fit parameters for these relationships are presented alongside the figure, in Table 11.

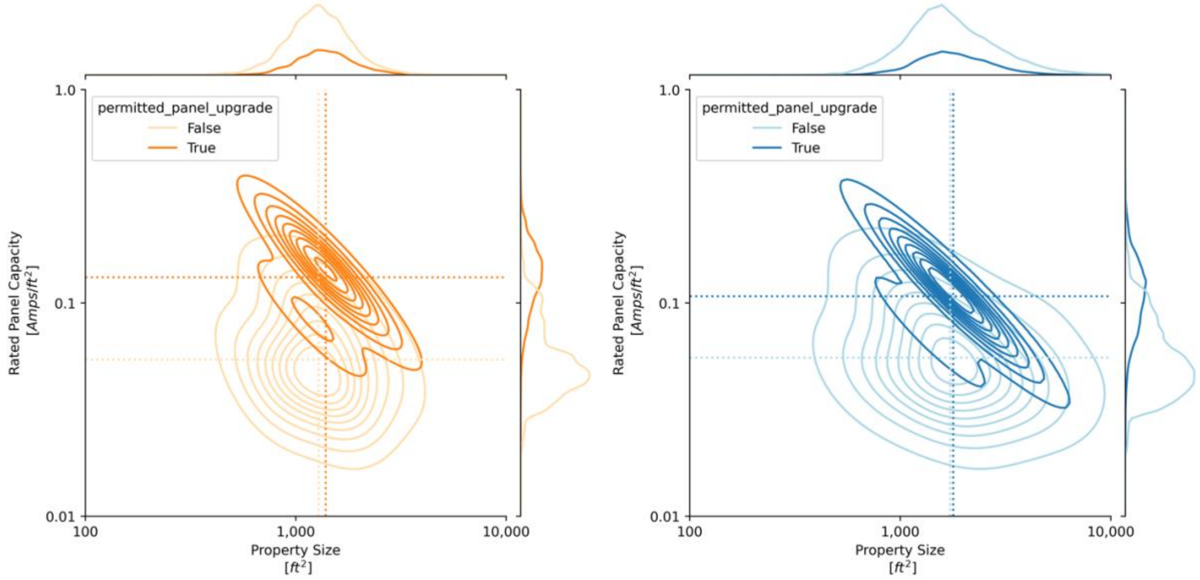


Figure 31: Joint kernel-density plots illustrating the differences in the area normalized existing panel capacity ratings (Amps / ft^2) by property size (ft^2) between single-family properties with permitted panel upgrades (dark color) vs. those without (light color) for both the DAC and non-DAC single-family property cohorts (orange and blue, respectively). Mean values are plotted in broken lines for each group across each axis.

Table 11: Table of critical values or area normalized amperage ratings for single-family properties with and without permitted panel upgrades.

DAC Status	Permitted Panel Upgrades	Mean Normalized Existing Panel Size [Amps / ft^2]	Model Fit Parameters [y = log10(Amps / ft^2), x = log10(ft^2)]
DAC	True	0.1319	y = -0.86548510 (x) + 1.84004711
	False	0.0543	N/A
Non-DAC	True	0.1076	y = -0.83308823 (x) + 1.74075343
	False	0.0554	N/A

Using these model fit equations, we can estimate that a total of 66.72% of the homes in non-DAC cohort and of the homes 71.36% in the DAC cohort have existing panel ratings that are deficient with respect to the capacity of the hardware that would most likely be installed if an upgrade were to be performed today. This calculation, of course, assumes that the same recommended panel sizing calculation methods which have been historically used would remain unchanged. This is not to say that this proportion would or necessarily should need to be upgraded to attain this level of capacity going forward however, especially not if the capabilities of new smart panel/breaker hardware are more fully embraced and more formally incorporated into standard code recommended panel sizing calculation methods. More discussion of this issue shall appear in the conclusions and recommendations sections of this report.

Looking at these total needs for upgrades, we can begin to think about potential future changes in the rate at which upgrades will need to occur. As was mentioned previously, recent year-over-year increases in the annual rate of new permitted panel upgrades have been encouragingly brisk, particularly within non-DACs, but these annual percentage figures need to be interpreted with an air of cautious realism. For example, in the single-family context, over the 25-year sample timeframe, the calculated year-over-year rate of increase was 50% for the DAC cohort and 59% for the non-DAC. One major reason for such strong rates of growth is that these types of panel upgrades were relatively uncommon 25 years ago - as there simply weren't the types of end-use appliances and equipment available that might justify a need for them. Suffice it to say however, that these growth rates will be extremely difficult to sustain. And though predicting the extent of their future decline is beyond the scope of this analysis, much about the future will likely depend on new pressures and stimuli that will be provided as part of the comprehensive LA100 implementation strategy.

4.4.2 *Multi-Family Context*

Table 12 provides a similar high-level summary overview of the scale of the anticipated panel upgrade requirements within the multi-family context. Here, different threshold values are used to differentiate between the "likely", "potential", and "unlikely" upgrade likeliness categories. The differences between these thresholds and those which appear in the single-family context largely reflect the lack of anticipated EV loads being wired to individual dwelling unit meters within most multi-family contexts, as these loads are more commonly metered collectively.

As the figures in this table clearly illustrate, we project the multi-family sector is behind the single-family context in terms of electrification readiness at this point in time. Only 13.94% and 13.66% of the DAC and non-DAC multi-family properties, respectively, are expected to have currently existing load center hardware capable of readily supporting full electrification of existing domestic energy end-uses. Moreover, 66.85% and 56.30% of the multi-family properties, in DACs vs. non-DACs, have estimated existing panel ratings that will likely need to be upgraded to support full electrification. This represents a significant challenge from an equity perspective, as the majority of the city's DAC population reside within these types of multi-family structures. Devising innovative ways to accelerate the expansion of the service capacity available at these types of properties should be considered a top strategic priority going forward.

Table 12: Overall estimates of multi-family units requiring panel upgrades to support full electrification measures in the future separated by DAC status.

Panel Rating Classification	Upgrade Required for Future Full Electrification?	DAC Properties [Percentage]	Non-DAC Properties [Percentage]
<90 Amps	Likely	66.85%	56.30%
>=90 Amps & <150 Amps	Potentially	19.21%	30.04%
>=150 Amps	Unlikely	13.94%	13.66%

Once again, within the multi-family context, we can also look at the problem from the perspective of the distribution of load center Amp ratings per ft^2 within the average unit, in a similar way as was done previously for the single-family cohort. This alternative perspective is illustrated by the plots contained in Figure 32 which shows the difference in the relationships between the average unit size and the area normalized load center capacity rating (Amps/ft^2) between properties with permitted upgrades and those without. Here we can see a similar trend to that which was identified in the single-family context, wherein the size of panels in newly upgraded properties increases with the average unit size but at a decreasing rate. Once again, critical values and coefficients for linear model fits for these relationships are provided in Table 13 just as they were previously for the single-family context.

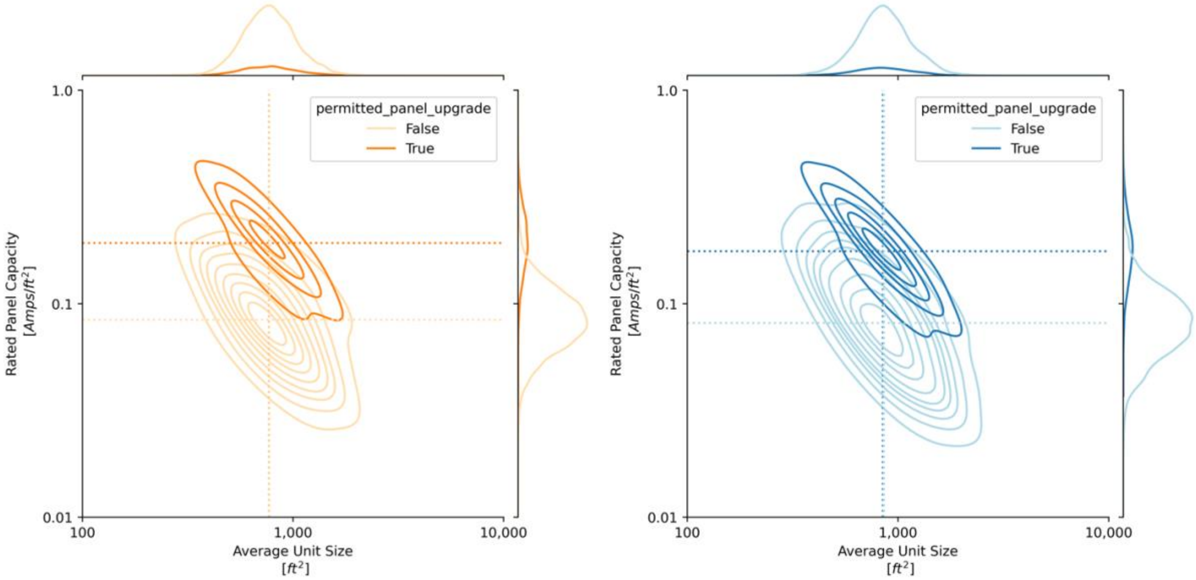


Figure 32: Joint kernel-density plots illustrating the differences in the area normalized existing panel capacity ratings (Amps / ft^2) by property size (ft^2) between multi-family properties with permitted panel upgrades (dark color) vs. those without (light color) for both the DAC and non-DAC single-family property cohorts (orange and blue, respectively). Mean values are plotted in broken lines for each group across each axis.

Table 13: Table of critical values or area normalized amperage ratings for multi-family properties with and without permitted panel upgrades.

DAC Status	**Permitted Panel Upgrades**	**Mean Normalized Existing Panel Size [Amps / ft^2]**	**Model Fit Parameters [y = log10(Amps / ft^2), x = log10(ft^2)]**
DAC	True	0.1924	y = -0.97473655 (x) + 2.09758752
	False	0.0842	N/A
Non-DAC	True	0.1763	y = -1.00395727 (x) + 2.18689792
	False	0.0812	N/A

4.5 Future Panel Upgrade Cost Estimates

4.5.1 *Single Family Context*

Recent published data from California's TECH program provides useful information about the range of costs that can be expected to upgrade the service panel within single-family residential homes. It bears mentioning, that the vast majority of the homes which have participated in the TECH program identify as being located within non-DACs; a feature which, no-doubt, is a source of bias in the data. Despite this, we do not have any reason to expect, a-priori, that there should be structural differences in the costs of completing such a project in DACs versus non-DACs. Thus, we proceed here, using the previously disclosed range of cost estimates for single-family panel upgrades ($2,000-4,500) to roughly estimate the overall cost burden of future upgrades throughout the single-family housing stock in Los Angeles, based upon the existing condition of service panels reported in this analysis.

The assumptions underpinning the figures reported in Table 14 consist of the following:

1) A property's service panel is considered "deficient" in size if its existing capacity is less than 80% of the value predicted by the linear model fit described in Table 12, based upon the property's square footage.

2) The low/high range cost estimates for a single service panel upgrade, based upon an analysis of TECH program data are $2,000 and $4,500, respectively.

3) Future versions of the national electrical code continue to use the same panel sizing requirements / calculation methodologies as those which currently exist.

Table 14: Total estimated costs associated with upgrading all deficient single-family residential service panels, disaggregated by DAC status.

		DACs	Non-DACs
Total Deficient Properties		139,985	251,002
Combined Upgrade Cost Estimate	Low-Range	$279,970,000	$502,004,000
	High-Range	$629,932,500	$1,129,509,000

As these figures show, the total combined cost of upgrading properties with deficient panels within the single-family context are expected to be significant. It is possible that many of these panel upgrades can be avoided, or at least deferred, if intelligent electrification strategies are pursued and code mandated panel sizing calculations can be updated to accommodate the capabilities of new technologies and more realistic load assumptions.

4.5.2 *Multi-Family Context*

As noted in the introductory discussion of the scope of the analysis, cost estimates will not be provided for the multi-family upgrade context due to the heterogeneity of the load center hardware and communal/unitary load configurations involved.

5 Conclusions

- **Generally, 200 Amps per single-family property and 150 Amps per multi-family unit, should be considered the target size for load center hardware upgrades in existing buildings.**

  It is important to recognize that the threshold capacity values of what constitutes "electrification readiness" can vary significantly depending upon the detailed characteristics of the properties in question. We make a best effort in this report to better quantify this variation by fitting linear models which relate the size of permitted panel upgrade hardware to a property's size, separately within the DAC/non-DAC cases, for both the single-family and multi-family cohorts. There are real downside risks associated with overbuilding excess panel capacity. Doing so can promote undesirable long term load patterns and can also require the need to similarly overbuild capacity of hardware on the distribution networks. This is because the capacities of customer owned hardware and utility owned grid infrastructure are dynamically coupled.

- **Panel upgrades can be avoided in many cases through the selection of low power appliances and the use of innovation power management strategies and systems.**

  New panel hardware capabilities, circuit management equipment, and low voltage appliance options have created opportunities to perhaps avoid panel upgrades when electrifying individual appliances. Unfortunately, even with the availability of these new options, it is unlikely that full home electrification retrofits would be able to be achieved in most instances without a panel upgrade investment of some kind. This is especially true with the requirements of EVs and other types of advanced behind-the-meter DERs are taken into consideration.

- **The majority of the single-family homes that will need to receive panel upgrades in order to support future electrification are actually in non-DAC census tracts.**

  This is down to the fact that there are simply many more single-family homes within these non-DAC neighborhoods. It is important to recognize, therefore, that households may still need to access financial or other forms of logistical support to facilitate panel upgrades regardless of whether or not they fall within a DAC census tract. This will be necessary to ensure that a sufficient number of homes are able to electrify core appliances on the timelines that are dictated by the LA100 transition pathway.

- **While there are a smaller total number of single-family homes within DACs that are likely to need panel upgrades the proportion of them within those communities is greater, as is the average size of the gap between their existing capacity and what will be required in the future.**

  This finding supports the conclusion that properties within DAC census tracts are more likely to encounter obstacles to electrification retrofits than their non-DAC counterparts due to insufficient panel capacities. Moreover, the financial costs associated with undertaking these panel upgrades are more likely to be prohibitive for these property owners without assistance due to their more limited available resources.

- **Very few census tracts in the city have average load center size ratings across all of their properties that are large enough to suggest they would currently be able to support widespread full-electrification. Moreover, nearly all of the census tracts that are close to these threshold readiness levels are within non-DAC areas.**

  The histograms plotted in Figure 33 illustrate the size of the transformation that will need to be affected if the target panel ratings are to be comprehensively achieved across both the stock of single-family and multi-family residential buildings within the city of Los Angeles. It is important to note that these histograms reflect census tract counts and not the actual numbers of properties within the different contexts.

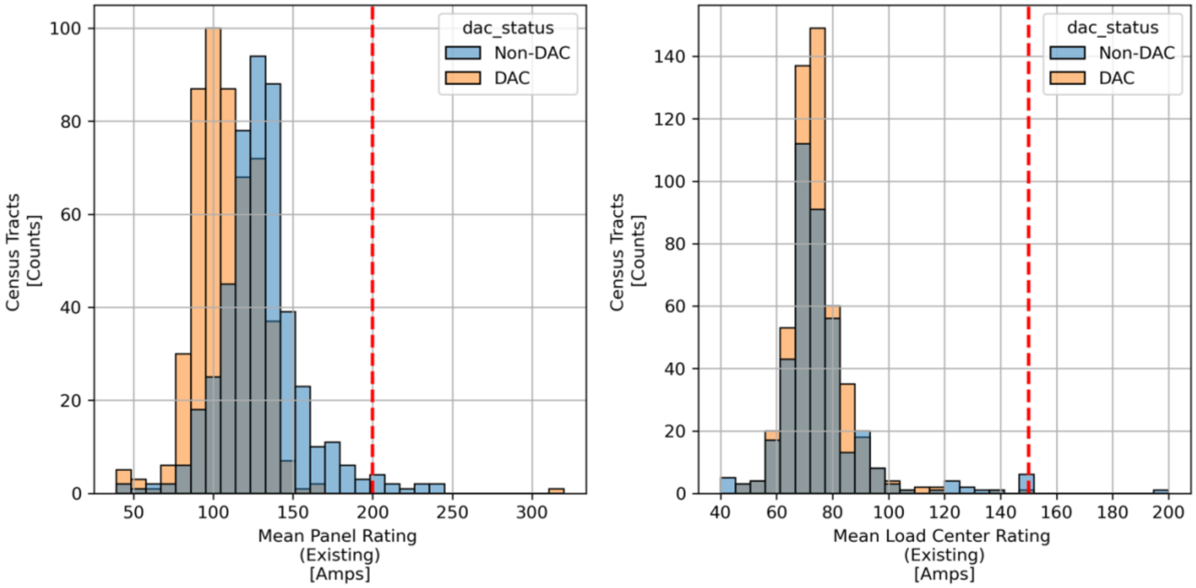


Figure 33: Histogram plots of the mean panel / load center rating per census tract for single-family (left) and multi-family (right) properties by DAC status.

- **A significant majority of the multi-family properties within the city (~60%) are likely to need load center upgrades to support the full electrification of their end-use equipment.**

The size and complexity of the interconnection hardware installed at many multi-family properties suggests that it will be more costly and difficult to accomplish these multi-family sector upgrades than it will be for most typical single-family structures. This, combined with the split incentives between renters and property owners indicates that this is likely to be a major equity concern that will require the allocation of significant effort and resources to address.

6 Equity Strategy Recommendations

- **Support efforts to retrofit the capacity of the load centers at existing residential buildings to 200 Amps for single-family homes and 150 Amps for multi-family units. Resist the temptation to support further capacity increases however, due to upstream implications for the transmission and distribution systems.**

  Mandating larger capacity hardware be included in newly constructed residential buildings is essential and will be an important part of the transition going forward. However, due to the gross disparities in the rates of new construction between DACs and non-DACs, this cannot be considered a viable equity strategy in and of itself. Parallel strategies must be developed and implemented to facilitate hardware upgrades within existing buildings, across the wide variety of retrofit contexts that will be encountered. An important issue to keep aware of is that rapidly increasing the average service capacity of customer load center hardware can accelerate the timetables of distribution and transmission infrastructure capacity upgrades. This can have major cost implications for the utility if these equipment need to be replaced before their useful service life is up. If history is any guide, such costs are most likely to be amortized in the form of future rate increases distributed across the entire customer base, despite the fact that the majority of these customer load center upgrades tend to occur first and most frequently within affluent communities, where the rates of new construction are highest.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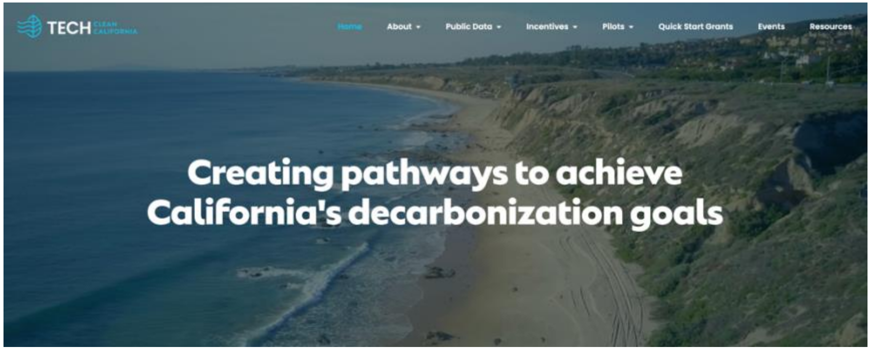
[8] Image Source: https://www.cloverelectric.com/images/blog/electrical-panel-upgrades.jpg

- **Leverage different sources of external funding support for panel upgrades that are currently being made available at both the state and federal levels, especially those recently created as part of California's TECH program and the Federal Inflation Reduction Act (IRA).**

  The Inflation Reduction Act contains specific provisions which explicitly provide funding support to customers pursuing electrical service panel upgrades, as described here, in language from the White House's published guidebook on IRA incentives titled "Building a Clean Energy Economy":

  > *The Energy Efficiency Home Improvement Credit provides up to $3,200 annually in tax credits to lower the cost of energy efficient upgrades by up to 30 percent, including the purchase of heat pumps, insulation, efficient doors and windows, electrical panel upgrades, and energy audits. Heat pumps alone can save households up to $500 in energy costs every year.*

  These and other funding sources, such as those currently provided by the state of California's TECH program should be aggressively leveraged by LADWP to assist qualifying low-income and disadvantaged community households and property owners in securing financial assistance to conduct electrical service panel upgrades.



Creating pathways to achieve California's decarbonization goals

[9,10]

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[9] Image Source: https://techcleanca.com/

[10] Image Source:

- **Support the revision of standard methods for calculating the required capacity of load center hardware to take into account more realistic assumptions about concurrent loads as well as the dynamic load management capabilities of new smart panel/breaker systems.**

  Previous studies have shown that the vast majority of customers who have undertaken panel capacity upgrades rarely, if ever, utilize anywhere near the full rated service capacity of their new load center hardware even after fully electrifying all of their appliances. (Pecan Street, 2021) This is because existing code recommended panel sizing calculations assume unrealistic worst-case concurrent load scenarios. These methods should be revised to better account for seasonal differences in the usage of electric heating vs. cooling appliance usage as well as the supreme flexibility of EV charging loads. Moreover, they should also make allowances for the peak load management capabilities of new smart panel/breaker hardware. For instance, it may be the case that a customer requires 300 Amps worth of breaker space within their service panel in order to physically connect all of their electric loads; however, the combined power draw from these loads at any one time can be limited to some arbitrary lower value through the use of automated load management software controls.

- **Incentivize the adoption of new smart-panel and smart breaker software-controlled load center hardware.**

  Currently, there is a general lack of awareness among both customers, and even many electrical contractors, about the long-term benefits of adopting new intelligent load center hardware. Both of these groups need to be educated about the importance of choosing these types of hardware over more traditional, albeit dated, alternatives when doing new construction and renovation projects. This is especially true given this study’s findings about the relatively lengthy half-life of these hardware components (60-70 years, on average). One way to promote a change in behavior is to create and advertise incentives for making the switch. Such programs could have a tiered structure to disproportionally allocate resources to residents of DACs which are most in need of support.

[11,12]

- **Begin tracking both the capacity and command/control capabilities of customer installed load center hardware.**

  As a general rule, the more intermittent renewable generation supplying a power system, the greater the need for active load management to ensure the most efficient utilization of expensive generation, storage, transmission, and distribution assets. If loads are unconstrained, all of these infrastructure systems will have to be overbuilt, at significant cost. As LADWP advances in its pursuit of 100 percent renewable generation, it will therefore become increasingly important to develop better intelligence about both the capacity and command & control capabilities of customer installed load center hardware. Historically, this type of customer owned hardware has been considered out of a utility's scope and thus, not something which must be tracked. However, this

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[11] Image Source: https://www.solarpowerworldonline.com/wp-content/uploads/2021/01/Span-panel.jpeg

[12] Image Source: https://www.absmarthealth.com/wp-content/uploads/2020/03/Schneider-Electric39s-smart-health-connected-electrical-panel.jpg

will need to change going forward. This is because the load center constitutes the most logical touchpoint for the implementation of dynamic load management programs, both from the customer's and the utility's perspective. The alternative to this strategy is to try to dynamically control each individual end-use load, a strategy which would require either the replacement or addition of intelligent controls to all of the load hardware, something which may not be feasible or desirable in many contexts.

- **Incentivize the installation of 120 Volt electric appliances and/or circuit splitting hardware when pursuing electrification retrofits.**

  Another important way in which the need for load center capacity upgrades can be avoided all-together is through the selection of appliances that operate at lower-voltages, have "soft-start" capabilities (reducing reactive power demand), or are able to be wired through load splitting devices which can alternate the appliances that use with the same breaker. To the extent to which these types of appliances and devices are able to adequately provision the same quantity and quality of end-use energy service desired by the customer, they should be considered the first option, and incentivized as such through the use of different programs and financial support mechanisms. This is especially true among DACs where the financial and logistical barriers associated with panel upgrade projects are likely to be most acutely experienced.

[13,14]

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[13] Image Source: http://www.truenorthenergyservices.com/wp-content/uploads/2015/05/geospring-pro.jpg

[14] Image Source: https://m.media-amazon.com/images/I/81jmgzPEPpL._AC_SL1500_.jpg

- **Pilot demand response programs specifically focused on customers who already possess intelligent load center hardware.**

  It is an open question as to whether or not the optimal long-term solution to the demand management needs of LADWP in a high renewable future should be accomplished through the use of more dynamic pricing mechanisms or direct “command and control” types of demand response programs. In either case, a move towards more widespread deployment of advanced metering infrastructure will likely be necessary as a prerequisite.

- **Advocate for new City, State, and Federal programs which provide more direct funding support for multi-family property load center upgrades with detailed prescriptions for how costs/incentives will be split between tenants and property owners.**

  Multi-family properties combine a number of characteristics which suggest that they will be obdurate to change as the pressure to electrify ramps up. These include the size and complexity of their load center / service interconnection hardware, the split incentives between renters and property owners, and the balance of unitary versus communal electrical end-use equipment. There has recently been some recent anecdotal evidence that insurance companies are beginning to put pressure on multi-family property owners to upgrade service panels due to the fire risk posed by aging equipment. However, steps need to be taken to further codify such requirements to ensure not only tenant safety but also equitable access to affordable, high quality energy services.

- **Study properties that have recently received panel upgrades / electrification measures to understand the extent to which new panel capacity is fully / efficiently being used.**

  Previous studies by Pecan Street and other have argued that antiquated sizing assumptions and a desire to “future proof” homes against and uncertain growth in the power consumption requirements of electrical loads is leading to many customers to install service panels with unnecessarily large capacities that are likely to go unused for the majority of the time, if ever.

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