Let Me Upgrade You: An Analysis of the Electrification Readiness of Homes as part of the Massachusetts Residential Baseline Study

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Abstract

An analysis of the electrification readiness of single-family homes is critical to understand how residential dwellings and their occupants consume energy, and will answer the question: How ready are single-family homes for electrification?

The main determinant of whether a home can accept additional electric loads, such as heat pumps, electric stoves, and electric vehicle (EV) chargers is the remaining capacity of the electrical service as determined by National Electrical Code service load calculations. To determine available capacity, this study first collected photographs of electrical panels through residential customer surveys to identify panel breakers and their loads. Any loads associated with electrification, such as electric heating, cooking, and EV chargers were cataloged. Then, calculations were performed to estimate whether the current electrical service was sufficient for electrification of the home.

This study was completed in Fall 2023. The data and associated analyses provide foundational information for cost-saving, energy efficiency measures related to electrical panel capacity upgrades and smarter panels; informs policy makers on the true cost of electrification; and supports electrification program enhancements and new designs.

Introduction

With growing interest in reducing the carbon footprint of homes, there is a need to replace fossil fuel consumption with electricity. Heat pumps that can offer site efficiencies three or more times that of onsite fossil fuel combustion. This effort goes by several terms, including beneficial electrification. Although most discussion of beneficial electrification centers on heat pumps and EV charging, it also can include replacing fossil fuel-driven clothes drying, cooking, and water heating. For instance, replacing a space heating boiler that also provides hot water with an air-to-air heat pump requires the installation of an additional water heater, such as a heat pump water heater.

To support beneficial electrification efforts, Guidehouse, on behalf of the Program Administrators in Massachusetts, analyzed the electrification readiness of homes in Massachusetts as part of the Residential Building Use and Equipment Characterization Study[1] (residential baseline study). To determine if existing electrical panels have sufficient capacity for

[1] https://ma-eeac.org/wp-content/uploads/Residential-Building-Use-and-Equipment-Characterization-Study-Comprehensive-Report-2023-12-22.pdf

various levels of electrification, the Guidehouse team used service load calculations from the 2023 edition of the National Electrical Code (NEC). Through the study survey, the team collected photos of participants' electrical panels to provide inputs to the service load calculations. Additionally, the team reviewed 1-minute and 15-minute frequency electrical data from the metered homes in the study to determine the actual loading of homes and compared that with the nominal capacity of the home's electrical service.

The Growing Need for Panel Capacity

The decision of whether to electrify a home is not a binary one, as all homes have some number of electrical appliances, even where the home is on an existing natural gas service. For example, many homes with natural gas service have electric clothes dryers and some have electric cooking ranges. Some homes have existing electric resistance water heaters, and more and more homes are converting from electric resistance and fossil fuel water heating to heat pump water heaters. More recently, homes have been adding heat pumps for cooling, supplemental heating, and whole home heating. Therefore, most homes have some level of electrical appliances and varying amounts of remaining electrical capacity.

A home's electrical service capacity is rated by the number of Amperes (amps) of current that it can carry at peak load. This capacity depends on the age of the home (older homes are more likely to have smaller services), the decision of the builder, and whether the home's electrical service has been upgraded.

The need for electrical capacity in homes has grown with the addition of loads, such as air conditioners (AC), appliances, and electronics. Service panels installed as late as the early 1960s held fuses and had capacities of 60 amps. Homes built in the 1970s and later had service panels with circuit breakers and commonly had capacities of 100 amps. In the 1990s and later, 200-amp electrical services became more common. Today, most homes are built with 200-amp electrical services, and some have services as large as 400 amps.

The Electrical Panel Upgrade Federal Tax Credit[2], part of the federal Inflation Reduction Act, offers opportunities to reduce the cost to homeowners of upgrading a home's electrical capacity. This 30% project cost credit (maximum of $600) can apply to any improvement or replacement of an electrical panel, subpanel, or associated wiring, with a load capacity of not less than 200 amps that is installed in conjunction with, and enables the use of, any qualified energy efficiency improvements or any qualified energy property. This study outlines electrification improvements that would likely qualify for this tax credit.

Methodology from the Study

With a goal to determine the electrification readiness of homes, the Massachusetts residential baseline study first collected photographs of electrical panels through residential customer surveys to identify panel breakers, major appliances, and their associated loads. Existing loads associated with electrification, such as electric heating, cooking, and EV chargers were cataloged. Next, calculations were preformed to estimate whether the current electrical service was sufficient for electrification or whether it needed to be upgraded. The team used the 2023 edition of the NEC recently adopted by Massachusetts.

[2] https://www.energystar.gov/about/federal-tax-credits/electric-panel-upgrade

Error! Reference source not found.1, an example photograph collected during the study, shows the main breaker size, the sizes of one and two-pole breakers, and labeling of the circuits. In cases where there was no labeling, the sizes of the breakers and knowledge of the home's loads were used to match breakers to loads.

The number of free breaker spaces can be a consideration in determining a home's ability to accept more loads. The team found that on average 100-amp panels had 2.55 free breaker spaces, which means one additional two-pole breaker or one 240Volt load could be added. On average, 200-amp panels had 5.05 free breaker spaces, which means two to three additional two-pole breakers, or two to three 240Volt loads could be added. Because subpanels can be added to the main panel for a relatively low cost, overall capacity was considered more critical to the analysis than the number of free breaker spaces.

Determining the remaining capacity of a panel is more complicated than adding up the ratings of the breakers in the panel for three reasons:

1. A home would likely never have all of its loads on at once.
2. The load is based on the nameplate rating of the appliance, not on the rating of the breaker.
3. The smallest breaker size is typically 15 amps, and these breakers can serve multiple outlets that are seldom used, and the breaker might only be loaded at 1 or 2 amps at maximum.

The 2023 edition of the NEC[3] addresses #1 and #2 above by counting the first 8 kVA at 100% and remaining loads at 40%, based on the optional calculation for adding load to an existing dwelling unit. The NEC[4] addresses #3 by assigning 3 volt-amps (0.025 amps at 120V) per square foot for miscellaneous lighting and receptacle loads.

The team used the portion of the NEC (Section 220.83) that applies to existing homes to calculate available capacity for new loads. This section requires general lighting and receptacle load to be calculated at 3 volt-amps per square foot, 1,500 volt-amps for each small appliance branch circuit (typically two per home), and 1,500 volt-amps for the laundry branch circuit. It also requires the nameplate ratings for all appliances that are fastened in place, permanently connected, and located to be on a specific circuit. For this study, while nameplate information was not available for every item listed in the section, on average, the team found that the nameplate was about 75% of the rating of the breaker. Therefore, the team used this value where the nature of a breaker's load was not fully known. Given the diversity of loads in a home, this approach is likely a conservative one.

Section 220.83 also requires nameplate ratings of cooking equipment, clothes dryers not on the laundry branch circuit (such as electric dryers), and water heaters. Because nameplate ratings for each home were not always available, the team used an average of 9,000 volt-amps for electric ranges, 4,000 volt-amps for wall ovens, 5,100 volt-amps for cook tops, 5,500 volt-amps for clothes dryers, and 5,000 volt-amps for electric water heaters. This section also requires the larger of the heating and/or cooling at 100% of its nameplate rating. Again, the team found that the average nameplate was approximately 75% of the breaker rating. For simplicity and consistency, the team uses this value for all breakers associated with HVAC loads.

[3] 2023 NEC, https://www.nfpa.org/70, Tables 220.83(A) and (B).
[4] 2023 NEC, Section 220.83(A)(1) and 220.83(B)(1).

Figure 1. Example of a Panel Photograph.
Source: Massachusetts RBUECS Study Phase 7.

Findings and Implications from the Study

Of the photographs that the team received, 201 represented single-family homes and were of sufficient quality to determine overall capacity. As **Error! Reference source not found.** shows, half of the homes had 100-amp panels and half had 200-amp panels. Of these panels, 86 of the 100 amp and 73 of the 200-amp panels had enough details to study.

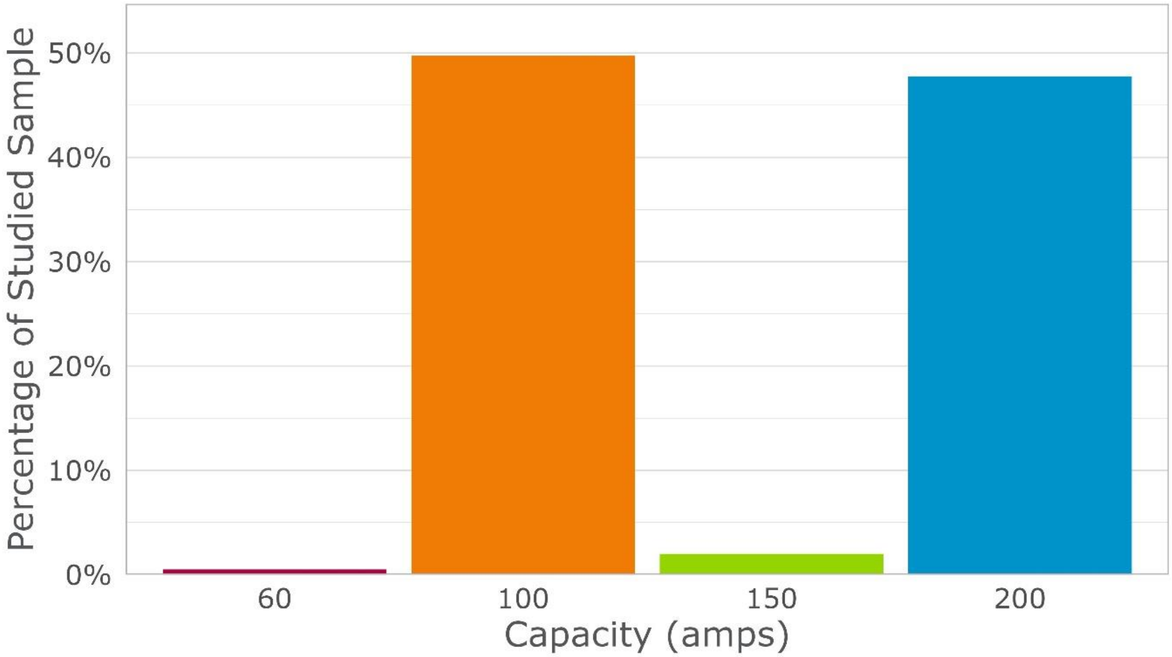

Figure 2. Panel Capacities in Studied Sample. *Source: Massachusetts RBUECS Study Phase 7.*

Error! Reference source not found.3 shows the load and capacity of the 100-amp panels. Most had remaining capacity even with some level of electrical appliances and HVAC; however, about 10% were already over code capacity, and another 10% were so near capacity that no additional major loads could be added.

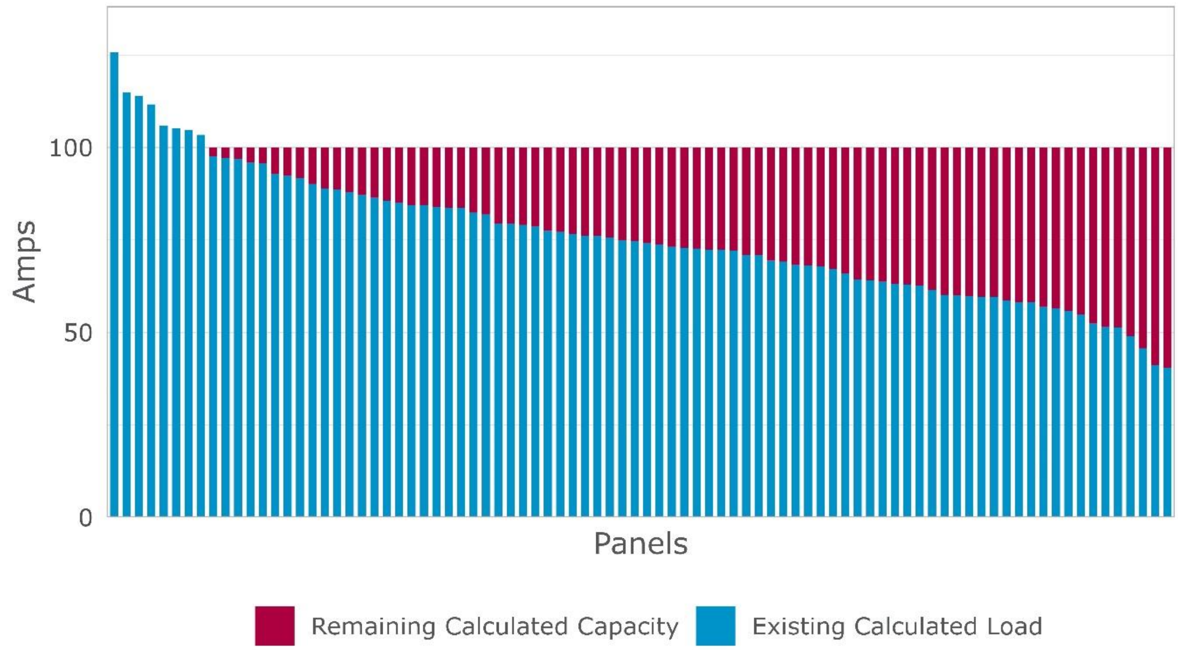

Figure 3. 100-amp Panel Existing Capacities (n = 86). *Source: Massachusetts RBUECS Study Phase 7.*

Examining these panels further, the team added loads to represent electrification of the home. The team first added electrical capacity for heating the home with heat pumps. When a home already had heat pumps or had a central AC, capacity was added based on square footage to approximate a whole home heat pump system. To approximate the capacity, and therefore amperage of heat pumps, the team used 1 ton of heat pump heat capacity per 450 square feet and 9 amps of current draw per ton at peak based on manufacturer engineering data.[5] This assumption results in 0.02 amps per square foot of electrical capacity needed for heat pumps. With this change, around 40% of panels evaluated are over capacity with full heating from heat pumps, and another 15% are near capacity, as shown in Figure 4.

The team then added capacity for a heat pump water heater if a home had no electric water heat and added capacity for an electric range if a home had no existing electric cooking.[6] At this level of electrification, 85% of the homes are over their 100-amp capacity. Finally, the team added a 40-amp electric car (EV) charger to the panel, which is a conservative estimate given that an increasing number of level 2 chargers are larger than this level. With this level of electrification, all the 100-amp panels are over capacity, with a majority at 50% over capacity, as shown in **Error! Reference source not found.**4.

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[5] Calculating the actual heat loss of homes was beyond this study's scope and the data the team collected. Actual heat pump loads should be calculated using ACCA Manual J, and manufacturers data; however, this approach aligns with the team's field observations of heat pump installations and the capacity needed.

[6] The team used 30A and 50A breakers to represent heat pump water heaters and electric cooking, respectively.

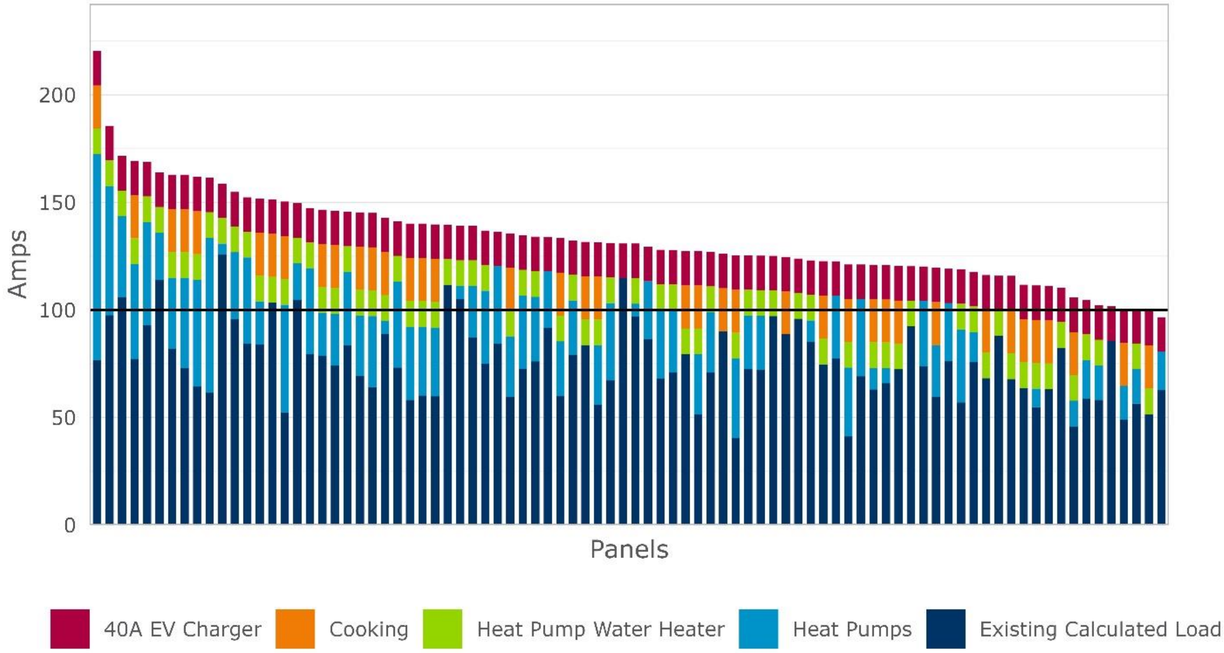

Figure 4. Capacity of 100-amp Panels with Full Home Heat Pumps, Heat Pump Water Heater, Cooking, and EV Chargers. (n =86). *Source: Massachusetts RBUECS Study Phase 7.*

Error! Reference source not found.5 shows the existing capacity of the 200-amp panels, all of which had remaining capacity even with some level of electrical appliances and HVAC. The 200-amp panel homes had higher existing loads than the 100-amp panel homes.

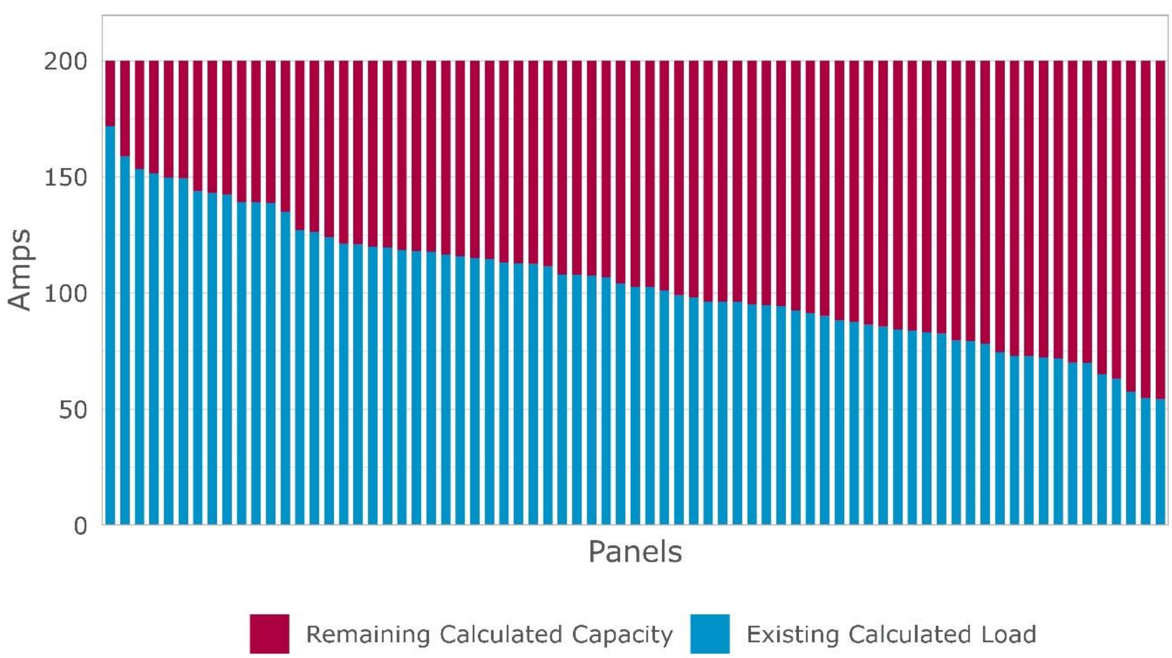

Figure 5. 200-amp Panel Existing Capacities. (n = 73). Source: Massachusetts RBUECS Study Phase 7.

Examining these panels further, the team first added electrical capacity for heating the home with heat pumps using the same approach as with the 100-amp panels. None of the 200-amp panels were over capacity with full home heat pumps. Similarly, heat pump water heaters and electric cooking were added following the 100-amp panel approach, and again, all 200-amp panels were within capacity at this level of electrification.

Finally, the team added a 60-amp electric car (EV) charger to the 200-amp panels. This addition is larger than the 40-amp EV charger added to the 100-amp panel, for reasoning that a homeowner would be unlikely to add a 60-amp charger to a 100-amp panel without upgrading first. With this level of electrification, about 5% of these homes are slightly overcapacity and about 19% are near capacity, as **Error! Reference source not found.**6 shows. If most homes will have two EVs in the future, an additional EV charger was included in Figure 7. With full home heat pumps, a heat pump water heater, electric cooking, and 2 60-amp EV chargers, about 40% of homes are overcapacity by as much as 20%, and an additional 10% are near capacity, as **Error! Reference source not found.**7 shows.

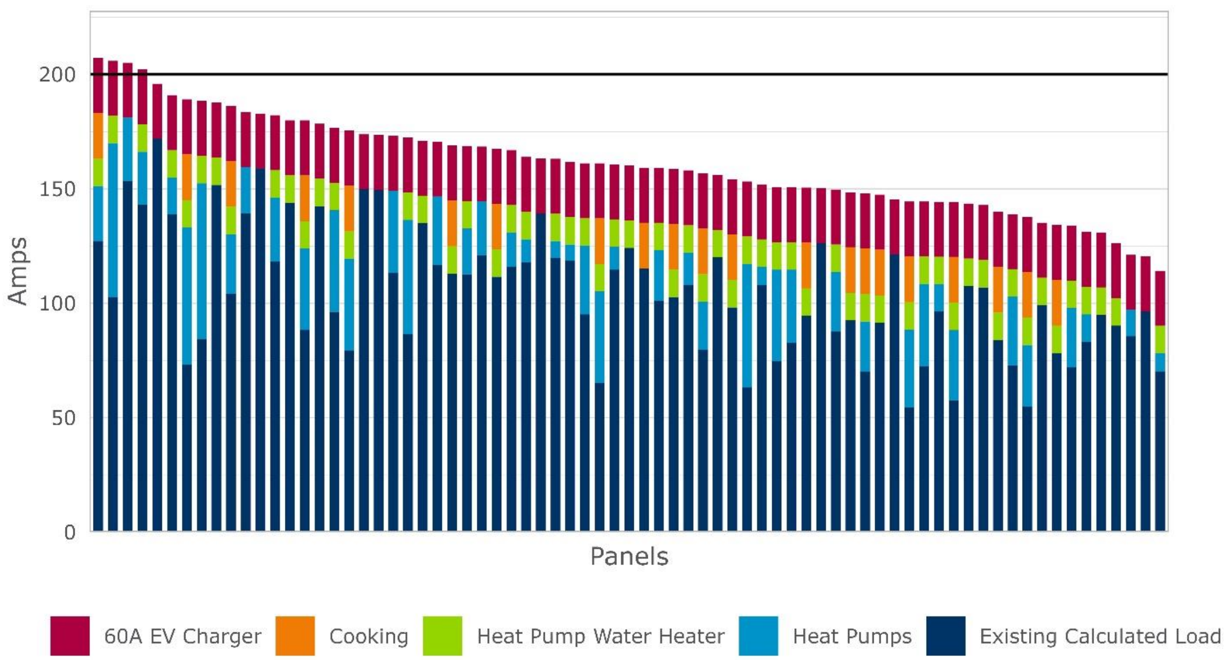

Figure 6. Capacity of 200-amp Panels with Full Home Heat Pumps, Heat Pump Water Heater, Cooking, and EV Charger. (n = 73). *Source: Massachusetts RBUECS Study Phase 7.*

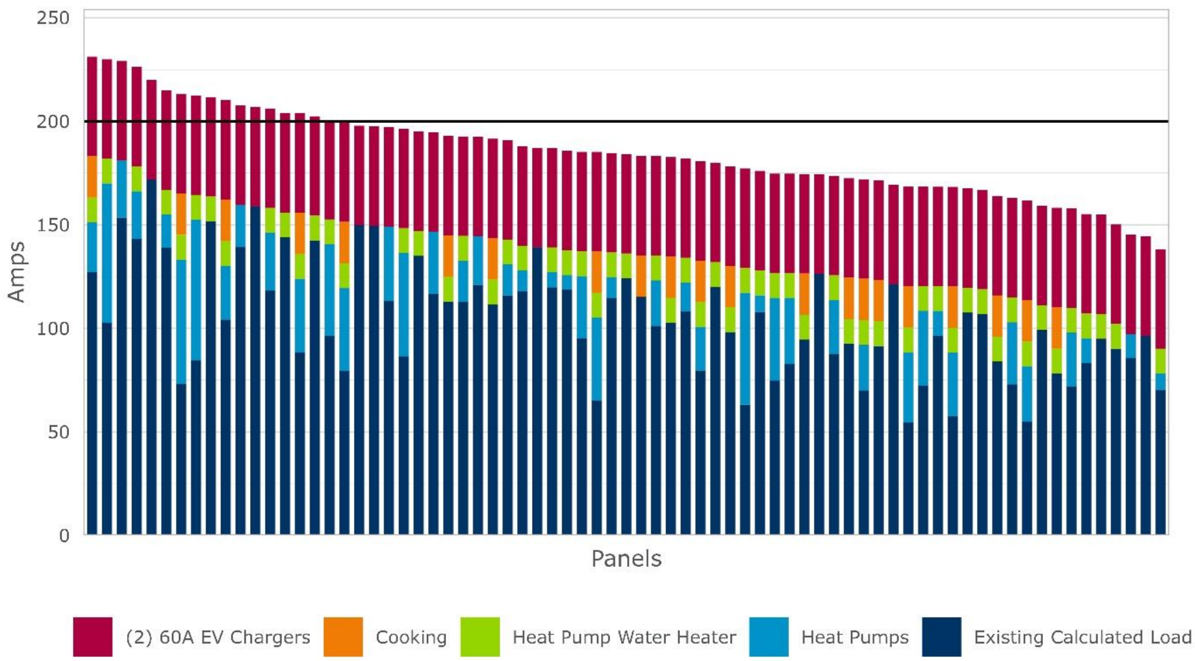

Figure 7. Capacity of 200-amp Panels with Full Home Heat Pumps, Heat Pump Water Heater, Cooking, and 2 EV Chargers. (n = 73). *Source: Massachusetts RBUECS Study Phase 7.*

Comparing Actual Electrical Loads to Existing Home Panel Ratings

In addition to calculating panel capacity, and specifically remaining electrical capacity using the NEC, the team compared metered maximum 1-minute load data from the metered sites in the Massachusetts residential baseline study to the rated panel capacity. The team used metered data from 105 of the 100-amp panels and 71 of the 200-amp panels. This metered data came directly from sites in the Massachusetts baseline study that had clearly labeled main breakers. The panels considered for the actual metered data analysis were different than the panels used for the service load calculation.

One-minute data was chosen because it is the setting of the supplemental power meters deployed. Depending on the specific thermal characteristics of residential panel breakers, the breaker will trip at about 200% of nominal capacity after 1 minute of overload. For this reason, using a 1-minute load is conservative. The team also plotted 125% of the maximum 15-minute data. The NEC 220.87 allows the use of 15-minute data and specifies that the permissible load is 125% of the actual 15-minute load, plus 100% of a new load (e.g. heat pumps).

In Figure 8, 1-minute peak load on homes with a 100-amp panels are on average around 50 amps, with one home reaching 100 amps. No panels had readings over 100 amps when using 125% of the 15-minute metered data and the average of the 15-minute maximum draws was 38 amps.

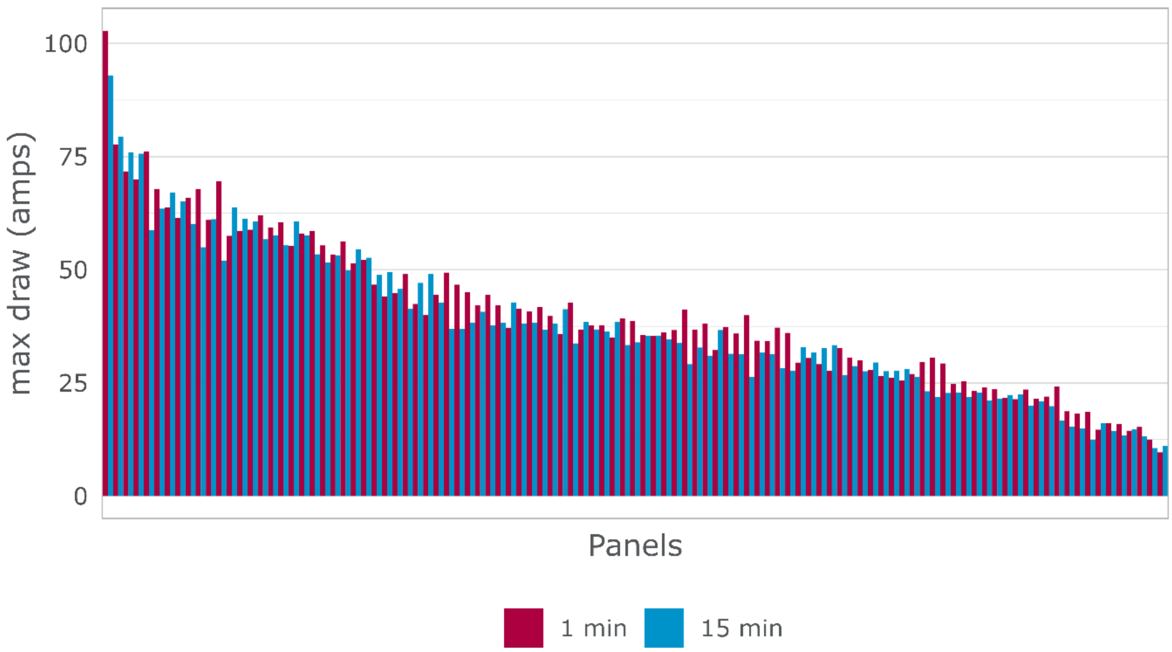

Figure 8. 1-minute peaks and 125% of the maximum 15-minute draw for homes with 100 A panels. *Source: Massachusetts RBUECS Study Phase 7.*

In Figure 9, the 1-minute peak load on homes with 200-amp panels are on average around 65 amps, with 5% of homes reaching or exceeding 100 amps. No panels had readings over 100 amps when using 125% of the 15-minute metered data and the average of the 15-minute maximum draws was 55 amps.

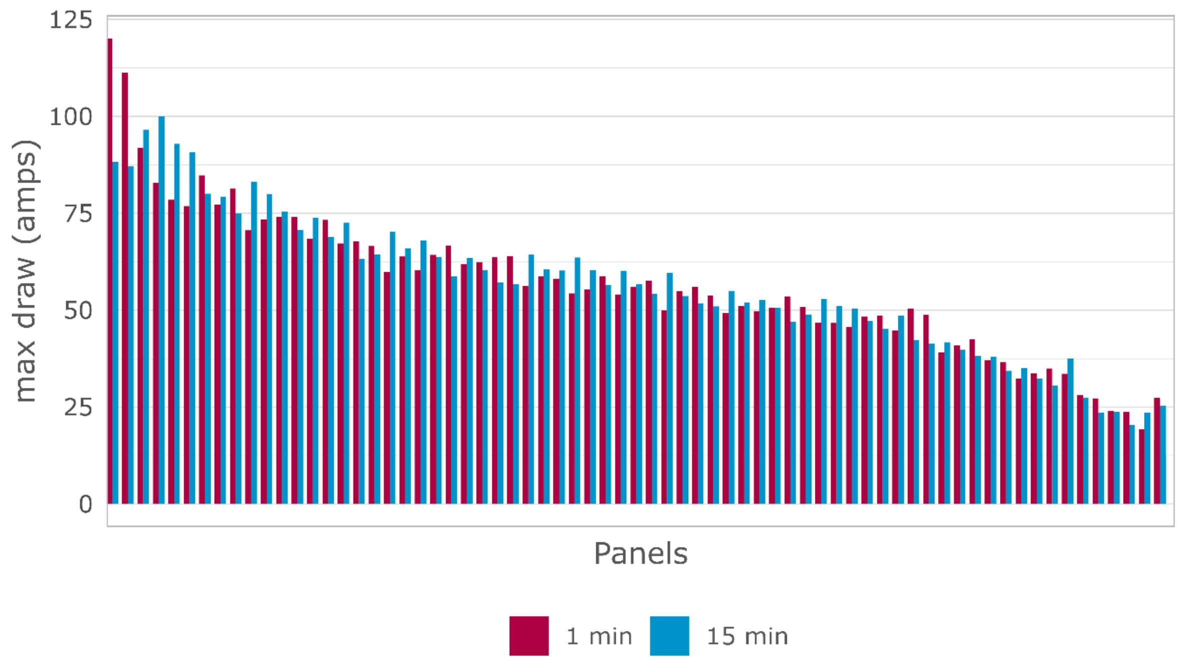

Figure 9. 1-minute peaks and 125% of the maximum 15-minute draw for homes with 200 A panels. *Source: Massachusetts RBUECS Study Phase 7.*

Electrical Panel Load Management

There are electrical panels now available that allow a user to dynamically limit the total electrical load by automatically shedding load according to user-defined or automated logic. For example, a user may select on-demand circuits such as on oven or dryer as a higher priority over a water heater, HVAC, or an EV charger that can be interrupted more often. When the on-demand devices are off, the lower-priority devices will use their "capacity." These smart panels also can be used to optimize loads for battery backup, or to take advantage of time-of-use rates. Smart panels can be added to existing panels or completely replace the original panel. Currently, there are several such panels available; one, the Luminsmart[7] is a supplement to an existing panel, and the other, the Span[8] is a panel replacement. There also are simpler devices coming to the market that simply only allow a car charger to operate when the load on the panel is low. In the 2023 edition of the National Electrical Code, there is a new section within Article 220 (service calculations) that addresses energy management systems (EMS) and load management. Section 220.70 states: "If an EMS is used to limit the current to a feeder or service in accordance with 750.30, a single value equal to the maximum ampere setpoint of the EMS shall be permitted to be used in load calculations for the feeder or service. The setpoint value of the EMS shall be

[7] https://www.luminsmart.com/platform/smart-electrical-panel
[8] https://www.span.io/panel

considered a continuous load for the purposes of load calculations."[9] There is also a reference to 750.30 in Section 625.42 for electric vehicle charging systems. For new EV chargers connected to existing panels that are near capacity, the systems with integrated energy management will be an inexpensive solution to address capacity constraints, while complying with the code. The NEC also contains recognition for non-coincident loads. Section 220.60 allows for the largest of two or more noncoincident loads to be considered when calculating loads. This approach can be referred to as "circuit-sharing" for managed loads.

In cases of electrification when the load slightly exceeds the panel capacity, a smart panel could replace an existing panel of the same size, avoiding the need for a larger panel. For example, to add an EV charger in a home with a 100-amp panel at capacity, the existing panel could be replaced by a smart panel that would optimize charging during non-peak times.

Conclusion

The electrification readiness analysis, completed as part of the Massachusetts residential baseline study, provides foundational information for energy efficiency measures related to electrical panel upgrades, informs policy makers on the actual cost of electrification, and supports electrification program enhancements and designs.

Half of electric panels in the Massachusetts baseline study have 100-amp service and the other half have 200-amp service. Of the homes with 100-amp panels, 60% had sufficient capacity to add a heat pump, but very few had additional capacity to add electric cooking or water heating equipment after adding a heat pump. All the homes with 200-amp panels had capacity to add a heat pump, cooking, and water heating equipment, and 85% had sufficient capacity to also add an EV charger.

Where the actual load (15-minute) is known, the NEC allows for potential additional capacity. For the 105 100-amp panels analyzed, the maximum actual load was 93 amps, and the average was 38 amps. For the 75 200-amp panels analyzed, the maximum load was 100 amps, and the average was 55 amps. Based on the results of the metering analysis the service load calculations are conservative and there is potential for electrification without a panel upgrade if sufficient metering is done. Without utility advanced metering infrastructure (AMI), end users can have electricians meter their electrical services in accordance with NEC Section 220.87. However, as utilities slowly progress to advanced metering, like nonresidential customers, AMI data may eventually be available on residential customer electric utility bills.

To install heat pumps, induction stoves and other electric devices, many homes will need to upgrade their electrical panel to a higher amperage, replace their panel with a smart panel, replace appliances with a low-power option, or install load controls (e.g., circuit pausers and circuit sharers). Homeowners with 100-amp panels will reach capacity in attempting to electrify and will either need to install load limiting devices or upgrade to 200 amps or even 400 amps. Homes that install one or more high-power EV chargers may find that they exceed the capacity of a 200-amp panel. The Electrical Panel Upgrade Federal Tax Credit[10], part of the federal Inflation Reduction Act, offers opportunities to reduce the cost to homeowners of upgrading their home's electrical capacity. However, other initiatives or incentives may be needed to relieve the bottleneck on electrification caused by insufficient electrical panels.

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9 https://nfpa.org/70

10 https://www.energy.gov/policy/articles/making-our-homes-more-efficient-clean-energy-tax-credits-consumers

References

Guidehouse. 2023. *Massachusetts Residential Building Use and Equipment Characterization Study Phase 7*. https://ma-eeac.org/wp-content/uploads/Residential-Building-Use-and-Equipment-Characterization-Study-Comprehensive-Report-2023-12-22.pdf.

National Electrical Code, Section 220, 2023. https://nfpa.org/70.