Electric Panels for the 21st Century

Benjamin Zank, Energy Solutions
Tim Minezaki, Energy Solutions
Eliot Stein, Energy Solutions

ABSTRACT

As the need to act on climate change becomes increasingly urgent, transforming the United States' existing housing stock will play a critical role in reaching our greenhouse gas emissions reduction goals. Converting homes across the country to all electric buildings outfitted with high efficiency technologies and electric vehicle infrastructure will be pivotal in helping shift our nation away from fossil fuels. Yet, the electrical panels that manage the flow of electricity into our homes are largely unprepared for the significant increase in demand that will come from fuel switching. To ensure safe and reliable home electrification we must upgrade the capacity of these panels. These upgrades should happen as early in the decarbonization process as possible so that they are a tool for accelerating decarbonization, rather than a hindrance.

In this paper, we investigate electric load increases that will result from decarbonizing our homes, which demonstrates the need for 200 amp (A) electric panels. Next, we take a look at current building codes across the country and provide insight into how they could better initiate the upgrades our calculations suggest are needed. Our paper suggests how incentives, as well as contractor and customer education, could successfully support policy compliance. We also recognize the challenge and infrastructure strain of upgrading nearly all electric panels nationwide and offer alternatives to these upgrades. In order to implement alternatives where possible, governments and program implementers will need to take a more active role in fully decarbonizing existing homes.

Introduction

With 95 million existing single-family homes in the United States, single-family residences account for nearly three-quarters of residential sector energy consumption (Griffith 2021). While policymakers have made strides with regulations to decarbonize new buildings (NRDC 2021), in order to meet state and national climate goals by 2030 (The White House 2021), we must focus on transforming the nearly 100 million existing homes to create more meaningful carbon reductions. The United States' existing housing stock must mirror what we envision for newly constructed homes.

Half of home energy consumption comes from natural gas and other fossil sources (EIA 2021). Converting traditionally fossil fuel-powered end uses – space and water heating, cooking ranges, and clothes dryers – to high efficiency electric alternatives is the fastest and most efficient way to decarbonize the residential sector. Single family homes will also play a critical role in transitioning the transportation sector to a cleaner future. Half of all transportation sector fuel use and carbon emissions come from light duty vehicle emissions (Griffith 2021). Making sure existing homes are outfitted with charging infrastructure will help speed up electric vehicle adoption.

While converting our existing housing stock to all-electric and EV-ready buildings is a key step towards reducing our reliance on fossil fuels, these changes will also vastly increase residential electricity demand. Currently, the electric panels in many of America's single-family homes are not prepared for significant electrical load growth. With most homes utilizing 60A or 100A electric panels, they will struggle to handle the additional electricity demand. Electric panels should not be a barrier to implementing these urgent home improvements. Consequently, we must upgrade residential electric panels to provide enough capacity to meet the load of a fully electrified home and support shifting to electric appliances.

We argue that existing single-family homes should either be outfitted with at least a 200A electric panel or load sharing alternatives to make switching from fossil gas appliances to electric ones an easy choice for consumers. Our paper provides an analysis of how electric load will grow when converting a mixed fuel home to all-electric, demonstrating the necessity of higher capacity panels. Next, we look at existing building codes at the federal and state level, providing suggestions for how regulation can provide guidelines for the transition. We note that building codes alone may not do enough to push existing residential building owners to switch to electric appliances, especially with additional costs such as panel upgrades. Upgrades come with a considerable time and cost burden, and we recommend thoughtfully designed incentive programs to spur the transition. Our paper also discusses the importance of consumer and contractor education around making homes all-electric ready and of adequate resource planning to manage upstream costs associated with improving grid infrastructure capacity. We also provide several options to reduce load growth that may limit the need for panel replacements in the e

xisting housing stock. Regardless of the route taken, we will need a wholistic and nuanced approach driven by diverse stakeholder engagement to effectively transition our nation's mixed fueled housing into the all-electric climate solution our planet demands.

1. Fuel Substitution and Load Growth

In this section we will investigate a mixed fuel home's electric demand and the additional load of electrifying each appliance that is likely to run on gas and determine the tipping point for needing additional electric panel capacity. Fully decarbonizing single-family homes, including electrifying space and water heating, cooking, and clothes drying, will add significant load to homes. Electric vehicle charging infrastructure will also impact the amount of electricity a home demands. By gaining a better understanding of the impact these fuel substitution measures will have on electric load, program implementors, contractors, and consumers will know as early as possible if and when they should upgrade their service panel

We used the calculation methodology provided by the National Electrical Code (NEC), some version of which has been adopted in 46 states. The service load for new homes is calculated using Article 220.82 of the NEC, and a slightly less conservative calculation is used for adding load to an existing home, Article 220.83 (220.83 uses 100 percent of the first 8,000 Volt Amperes (VA) rather than the first 10,000 before switching to 40 percent). See the tables below for a sample calculation of the electrical load for a 1,600 ft^2 home, which is the average size of an existing single family home (Pinsker 2019). Table 1 provides the load calculation for the home assuming it does not have AC and only has electric appliances for which there are typically not gas options.

This mixed-fuel home would only use 43A of electrical capacity and could even be served by a 60A panel. Table 2 shows how much additional capacity is needed with each electrified end use for the home. The Volt Amperes (VA) of appliances with specific brand names are from Redwood Energy's *Watt Diet Calculator* (Redwood Energy 2022). We can see that converting the space heating to a heat pump adds the most load to the panel because the NEC uses coincidence factor of 100% for space conditioning, with the second largest additional load coming from the induction cooking range.

Table 1: Load calculation for mixed fuel existing home without central AC

End Use	Volt Amperes (VA)
General Lighting and receptacles (ft2 X 3 VA/ft2)	4,800
Kitchen and living area small appliance outlets (2 minimum, 1500 VA each)	3,000
Laundry room outlet	1,500
Clothes Washer: Standard Samsung	1,800
Refrigerator: Frigidaire 27.6 ft^2	1,020
Garbage Disposal: GE	480
Dishwasher: Frigidaire	1,200
Kitchen Hood	168
Total VA with coincidence factor calculation 100% of first 8,000VA + 40% of the remainder	**10,387**

Table 2: Effect of each additional electrified end use on total load

Added Electrified End Use	Volt Amperes (VA)	After coincidence factor calculation	Total VA	Total Amps
Starting capacity from Table 1	13,968	10,387	10,387	43
Dryer	5,000	2,000	12,387	52
Range (cooktop + oven): Kitchen aid induction	12,504	5,002	17,389	72
Water heater: Rheem 30A	5,040	2,016	19,405	81
EV charger	7,200	2,880	22,285	93
HP space heating and cooling: Greater of 4kVA for 100% of heating/cooling and 6.5kVA for 65% of resistance backup	6,500	6,500	28,785	120

Assuming that the home has a 100A panel, several end uses could be electrified before having to make an upgrade. However, in order to fully decarbonize this home – even without EV charging – a larger panel is needed. While 125A and 150A panels exist, they are not a standard equipment size for builders at this moment while 200A panels are, so the default choice to fully electrify this home would likely be a 200A panel. Alternative to panel upgrades, such as installing load sharing devices, will be discussed in Section 4.

2. Electric Panel Requirements in Building Codes

In existing homes, panel upgrades can be complex, expensive, and take several months to complete depending on conditions. On the other hand, it is simple to install a larger capacity panel in new homes and much cheaper. Unfortunately, the 2021 version of the International Residential Code (IRC) – the model code upon which the residential code of 49 states is based on – still only requires the ampacity of ungrounded service conductors (i.e. the panel capacity) to be not less than 100 amperes for single-family dwellings and not less than 60 amperes for all dwelling types (Section E3602.1). The fact that only 60 amperes are required for each unit in a duplex and onward makes switching any appliance from gas to electric even more challenging. One study estimated that as many as 48 million households nationally may need to upgrade their panel in order to fully electrify (Pecan Street 2021), another putting the figure at 70 percent of all breaker boxes in homes (Higgins, et al. 2021). These numbers are increasing every year that higher capacity panels are not required in new construction.

On the other hand, the 2019 version of the California Energy Code has mandatory "solar ready" provisions that include 200A service for single family residences located in subdivisions of ten or more (Title 24, Part 6 Section 110.10(e)). California built on these requirements in the 2022 version of the Energy Code with new "electric ready" and "energy storage systems (ESS) ready" requirements. If any gas appliances are installed – specifically a water heater, space heater, cooktop, or clothes dryer – then a dedicated 240 volt branch circuit with the necessary amperage (30-50A depending on appliance) for an electric replacement must be installed next to that gas appliance. In the case of ESS readiness, either an independent critical load panel with ESS ready interconnection equipment must be installed or a dedicated raceway to a subpanel can be installed with the backed-up load circuits and supplied by the main panel that is at least 225A. See Sections 150.0(n) and 150.0(s)-(v) of the California Energy Code for more information.

These requirements in the California Energy Code are critical for making it simple and affordable to fully electrify homes down the line and they should be considered in the IRC. However, these requirements primarily affect new construction, and the vast majority of homes that need to be electrified have already been built. It may be possible to include provisions for existing buildings which would require gas appliances to be replaced with electric appliances at the end of the equipment life, but such provisions must also be supported through a variety of incentive programs, otherwise it is likely that many homes will not comply. It would be very difficult for building departments to enforce such a requirement, especially since most appliances do not require a permit to be replaced. And once a new gas appliance is installed it will be in operation for at least a decade or two. Furthermore, as discussed above, installing an electric appliance does not stop at replacing the equipment – once enough appliances have been replaced a panel upgrade will often be necessary to avoid overloading and that is a very significant additional cost on the order of $2,000 to $5,000 (Pecan Street 2021) and can takes weeks to months to complete. Mandating these additional upgrades without financial support is going to be a tough sell.

3. Incentive Programs

Incentive programs are an important mechanism to encourage consumers to choose high efficiency electric appliances when a building code might not be the best tool or motivator. Incentive programs that offer rebates and financing support help make it an easy choice for consumers to replace their aging (or not so old) fossil gas equipment by reducing the upfront cost. Incentive programs for fuel switching are a new strategy that states are rolling out and utilities are participating in, because previously incentives could only be provided for replacing equipment with higher efficiency equipment of the same fuel. The Massachusetts Clean Energy Center (MassCEC) started providing programs to support electrification in 2013. MassCEC conducted a whole-home air source heat pump pilot program from May 2019 through June 2021 that gave Massachusetts the confidence to start a full-fledged whole-home rebate program in January 2022 (MassCEC 2022). Mass Save is now providing both a significant rebate and a 0 percent interest loan of up to $25,000 so that consumers can replace their heating systems and only have a low monthly payment. On the other side of the country, TECH Clean California just launched its pilot implementation in December 2021 and is providing heat pump HVAC and heat pump hot water heater incentives across the state (TECH Clean California 2022). One particularly innovative piece of the TECH program is that in regions where there are existing incentives for heat pumps, the TECH incentives are layered on top and the installation is enrolled in both programs. This sort of incentive layering can create large rebates for consumers and make the installation costs of high efficiency heat pumps cost competitive with gas equipment. For TECH, additional incentives for panel upgrades may be provided if replacing the gas equipment with electric equipment requires the upgrade, but it is not a standalone incentive. The program has had very rapid uptake, to the point where it has already run out of its initial incentives in some utility service territories.

A distinct but related set of incentive programs exists for electric vehicles. Most new electric vehicles are eligible for a federal tax credit and there are state and local incentives as well. Rebates for charging equipment also exists but tend to be based only on equipment cost and not the installation cost. Because of the large load draw for Level 2 chargers, installing them is one of the most likely triggers for a panel upgrade. We recommend programs further support charging infrastructure by providing incentives towards the cost of installing charging equipment and any resulting panel upgrade.

As opposed to types of programs mentioned above, tax credits and rebates for installing solar panels tend to look at and provide support against the entire cost of the project without any caps. Tax credits can be applied to additional work that is needed for the installation such as a panel upgrade or roof replacement. Photovoltaic (PV) systems over 4.25kW usually require an upgrade to 200A amp service, which can support a system of up to 12kW (Pickmysolar 2022). Researchers estimated that panel upgrades are occurring in 20-30 percent of rooftop solar installations (Building Decarbonization Coalition 2022). Since a panel upgrade is a fairly regular part of installing solar panels, it is more explicitly emphasized in incentive programs. Homes that are planning to go all electric would benefit from larger solar systems, and so a panel upgrade would typically be needed both for the appliances and for the PV system. The timing of whole home electrification is then important to coordinate in the same year that the solar is installed, because system sizing and rebates tend to be tied to the electric load of the home. Homeowners will need education and support to properly time upgrades to take full advantage of all the incentives, rebates, and other financing opportunities available to them.

People also have access to low interest loans that may be leveraged for decarbonization and panel upgrades when selling or purchasing a home. When purchasing an existing home, buyers can expect that many appliances will be near the end of their serviceable life and will require replacing soon, as the previous homeowner does not have a strong incentive to upgrade these prior to the transaction (Mully n.d.). Ideally, a buyer would identify aging appliances during a prepurchase home inspection and receive a credit or loan to cover the costs of replacement. Local governments and program implementers should work with new homeowners to plan for and complete these upgrades so that the homes are fully decarbonized as quickly as possible.

One large, hard to reach market for these incentive programs is rental properties, which make up approximately 36 percent of households nationally (Desliver 2021). When landlords are looking to upgrade the appliances of their properties, they are likely thinking about what would give the best return on their investment and allow them to charge more rent. New appliances such as laundry machines, cooking ranges, dishwashers, refrigerators, etc. are going to factor more into how a tenant thinks of the value of their home rather than what is heating their water. So any incremental cost or time – e.g., for paperwork or permitting – to install an electric heat pump water heater compared to a gas water heater is going to be a tough sell for landlords. There are similar issues for space heating: even with generous incentive programs and 0 percent interest loans, the renovations may cause the unit to be unrentable during construction, highlighting the challenge for this market. It is critical for incentive programs to consider this large fraction of households when determining their program design. Some possible avenues for addressing rentals include supporting a market for window and portable heat pump units – as compared to window and portable AC units – that can be installed directly by landlords or tenants; designing turnkey incentive programs to upgrade the electric panel and complete full home decarbonization between tenants; developing new policies or programs that require an electrification feasibility study before a unit goes back onto the rental market.

4. Alternatives to Panel Upgrades

Electric panel upgrades are a vital component of decarbonization and in addition to often being costly to the individual homeowner, there are significant costs that are socialized among all ratepayers. It is therefore important to consider ways to mitigate electrical upgrades for the system as a whole. Upgrades will be needed upstream in the grid infrastructure in order account for the increased load. Low voltage distribution transformers often provide electricity for 5-7 homes depending on design standards and load. If several of those homes doubled their electrical capacity, larger (or additional) transformers would be required. The Sacramento Utility District (SMUD) estimates the cost of upgrading a service transformer between $4,800-$6,700 and it may cost an additional $8,000 per home if the service lines to the transformer needs to be upgraded (Building Decarbonization Coalition 2022). The utility and customer typically split these cost, with the utility costs covered by ratepayers broadly. There are then going to be costs even further upstream if panel upgrades are happening at scale, such as upgrades to transmission lines and substations. It is therefore in everyone’s best interest to see what alternatives there are to just increasing the capacity of nearly every panel.

Utilities are becoming aware of the large costs that would result from upsizing the electric panels in their service territories to meet state and national decarbonization goals. A recently published PG&E (Pacific Gas & Electric) and SDGE (San Diego Gas & Electric) study found that in cases where utility infrastructure needed to be upgraded to handle increased electrical load, some customers paid upwards of $30,000 between the utility service upgrade, electrical panel upgrade, new transformers, and trenching (Pena, et al. 2022). The report suggests providing nonfinancial and financial incentives to mitigate the need for electric panel upgrades and encourages utilities to continue to assess how to avoid the need for service upgrades when completing electrification retrofit projects.

The following subsections offer potential solutions to reducing new electric load and minimizing the need for panel upgrades. One note: it is unclear how familiar building departments are with any of the alternatives laid out below and how comfortable they will be with them. Targeted outreach and education for building departments is a critical component of actualizing these alternatives.

A. Existing Load Calculation

The NEC provides a few ways to determine existing loads and the capacity needed for additional loads. As an alternative to the calculation in Article 220.83 that was demonstrated above, Article 220.87 of the NEC permits the use of a year of data monitoring to determine existing loads. If data for a year is unavailable then data can be collected for 30-days instead. In the case of 30-day data, the maximum demand is determined by finding the highest average kilowatts reached and maintained for a 15-minute interval and seasonal loads such as space heating need to be accounted for by metering or calculation. Since the lighting and plug load assumptions in the NEC are based on square footage and an assumed occupancy per square foot, this alternative determination could reduce the assumed existing load in homes and reduce the need for a panel upgrade. This sort of monitoring requires planning and resources and so utilities and programs would need to be directly involved in order to take advantage of it.

B. EV Charger Rating

As noted in Section 1 and Section 3, Level 2 EV chargers can have a significant impact on a home's electrical load, and their wide range of maximum power draw adds complexity to panel sizing. Article 625.41 of the NEC requires overcurrent protection for chargers to be not less than 125 percent of the maximum load of the equipment, so even more capacity needs to be provided than the charger is able to normally draw. However, Article 625.42 states that when an automatic load management system is used, the maximum load is that which is allowed by the management system. Therefore, with the right control system, chargers can be installed in such a way as to not exceed the panel safety rating. A system that monitors how much electricity is being used at all times by the home and can automatically reduce the load of the charger when needed would allow for a charger to be added without having to calculate whether there is enough electrical capacity available (Brooks 2020).

C. Automatic Circuit Sharing

One step more generalizable from controlling the load of EV chargers is using a single breaker for two loads and switching between them as needed. Appliances that are used infrequently during the day or for a short amount of time (e.g. dryers and cooktops) and those that are on regular schedules that can be interrupted (e.g. water heaters and EV chargers) pair well together on the same breaker. Automatic circuit sharing devices already exist that allow two appliances to be on the same 240 Volt outlet and be toggled between depending on use. Examples include SimpleSwitch, NeoCharge, Dryer Buddy, and Splitvolt (John 2022). These devices typically allow the user to select a primary appliance that will always be able to draw power and a secondary appliance that can draw power when the primary is not on.

Looking at Table 2, if the cooking range and EV charger were on the same breaker it would reduce the calculated electrical capacity by 12A (from the charger) and if the water heater and dyer were on the same breaker it would reduce the calculated electrical capacity an additional 9A (same for both). This would bring down the needed electrical capacity to 99A and would fit in the 100A panel. These circuit sharing devices are an important alternative to consider and could work well in many cases to avoid a panel upgrade. While in some cases this circuit sharing devices can be used to add loads that do not require a permit, in other cases a building department may need to review and approve their use. Readers who want to learn more about these types of products and low voltage appliances may be interested in Redwood Energy's *A Pocket Guide to All-Electric Retrofits of Single-Family Homes* (Armstrong, et al. 2021).

D. Power Control Systems

While there may be ways around upgrading the panel to electrify the home, if we are looking to add significant amounts of rooftop solar and energy storage, we may be stuck having to upgrade the panel. However, many solar arrays are installed in homes with 100A of electrical capacity (we mentioned above that panel upgrades only occur 20-30 percent of the time when solar is installed). This can either be accomplished by installing a smaller system or by making the connection directly on the supply side of the panel rather than the load side. This feeds the solar power directly to the grid without going through your panel. The limiting factor here is that the homeowner and utility then have very limited control over that solar energy – it cannot be used to directly power the home or directly charge an energy storage system, which are both important for increased grid flexibility and backup power.

However, the 2020 version of the NEC now has Article 705.13, which states that power control systems can be installed to control the output of power production sources (renewable energy) and energy storage systems. The homeowner is then able to add as much solar and storage as needed on the load side of the panel without having to make upgrades (Brooks 2020). When a power control system is integrated with an automatic load management system, that can lead to even more options: if there are too many devices drawing power from the grid to allow the EV charger to operate, the power control system can directly feed power to the charger from the solar array or the energy storage system.

5. Advanced Planning and Market Education

As electrifying all end uses in a home will typically require a panel upgrade or an alternative like those discussed above, it is important to determine the best strategy to handle the additional electrical load before the equipment needs to be installed. Upgrading a panel not only will often cost several thousand dollars but can take weeks or even months to install (John 2022). If a gas furnace breaks in the middle of winter, the resident cannot wait months without heat in order to replace the unit with a heat pump. Incentive program administrators and contractors should help the homeowner consider the infrastructure needs to replace all the gas appliances in the property and encourage a planned replacement before the equipment fails. If the homeowner is applying for a rebate to switch their water heater from gas to electric, the program should validate the state of other gas appliances. Programs should determine whether additional electrical capacity will be needed and support adding dedicated circuits to enable those future electrification projects. Standalone incentives for panel upgrades will be a key component in case a particular appliance does not trigger the need for the panel upgrade on its own. If a contractor is getting regular service calls to repair a gas boiler, they should encourage the homeowner to consider replacing it with a heat pump rather than running it till it completely fails. Landlords in particular will need encouragement to pay the additional cost of replacing equipment rather than repairing it because they often do not directly benefit from the efficiency improvements and improved comfort that comes from new appliances.

This sort of cross selling and education may not be typical for incentive program providers and contractors but is a critical component to avoid emergency replacements with a new fossil gas appliance. Electricians may also not be used to providing additional electrical capacity and planning for end uses that will not be installed immediately. It is important for program administrators to work with contractors and ensure a shared understanding of how the program is helping people fully electrify their homes.

Conclusion

Fully electrifying a home requires a complex set of considerations beyond switching from gas to electric appliances. Consequently, landlords/homeowners will need extra support from incentive program administrators, contractors, and utilities in order to determine the best options for their entire home. Renters are also a critical stakeholder as they can be advocates for these upgrades and will be the ones actually using the appliances.

Many homes will need to increase their electrical capacity, others may be able to avoid it using some of the tools this paper discusses. There clearly needs to be advanced planning and engagement from programs and utilities in order to manage this transition as quickly and cost-effectively as possible. We also need contractors to be fully engaged in this process because they are making recommendations to homeowners about what products to install and what upgrades are needed.

If done correctly, this type of advanced planning of electrical capacity can be a driver of decarbonization rather than an inhibitor. Once the homeowner has either upgraded their panel or been shown how to mitigate such an upgrade, they will be on a path towards replacing all of their gas appliances with electric ones.

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