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The State of Demand Flexibility Programs and Rates

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The State of Demand Flexibility Programs and Rates

Prepared for the
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Acronyms and Abbreviations

C&I	Commercial and Industrial
CPP	Critical peak price
CPR	Critical peak rebate
kW	Kilowatt
kWh	Kilowatt hour
DLC	Direct load control
DOE	Department of Energy
HVAC	Heating, ventilation, and air conditioning
RTP	Real-time price
SGIP	Self Generation Incentive Program
TOU	Time-of-use
VPP	Variable peak price

Executive Summary

Demand flexibility can reduce carbon emissions and electricity costs by shedding load during peak periods or by shifting that load into off-peak hours. However, there is a lack of data on the characteristics and performance of programs and rates that promote demand flexibility. Such data can help policy makers and regulators establish demand flexibility goals and can inform the design of the programs and rates that achieve those goals.

This report provides foundational data on programs and rates that promote demand flexibility in residential and commercial buildings in the United States. We constructed a dataset of 148 programs and 93 rates through a review of utility websites, published electricity tariffs, and a database of demand-side programs. We categorize the programs by the technology that enables flexibility. Then, we describe the structure of demand flexibility events and the types and levels of incentives offered. For the two most common program types in our dataset—Wi-Fi thermostat and battery storage programs—we provide additional details on program designs. We also report data on program outcomes, including enrollment and participation, energy and demand savings, and costs. We categorize rates as either technology rates (which require one or more demand flexibility technologies for eligibility) or dynamic rates (which encourage demand flexibility by changing prices in response to grid conditions). We detail the structure of dynamic rate events, report prices for critical peak pricing and variable peak pricing rates, and describe features of technology rates.

Our dataset shows that demand flexibility programs are widespread, with the 148 programs coming from 38 states and Washington, DC. 84% of these programs are Wi-Fi thermostat or battery storage programs; the remaining 16% are a mix of programs that promote demand flexibility with thermal storage, building automation, heat pumps for space and water heating, and clothes dryers.

The programs, regardless of the enabling technology, generally target summer afternoon and evening peaks, though some do address winter peaks. Battery programs generally allow more events (median of 60) than Wi-Fi thermostat programs (median of 15) do, which likely reflects tradeoffs with occupant impacts that Wi-Fi thermostat programs face.

Demand flexibility programs offer multiple types of incentives: upfront incentives to promote adoption, retention incentives to encourage continued enrollment, and performance incentives to drive demand reductions. The mix of incentive types vary by demand flexibility technology. Wi-fi thermostat programs typically offer both upfront and retention incentives and few offer performance incentives, which suggests the programs are targeting high enrollment rather than high savings per participant. Wi-Fi thermostat upfront and retention incentive are generally less than $100 per enrolled device and $30 per year respectively. In contrast, battery programs offer fewer retention incentives and most offer upfront and/or performance incentives.

We found relatively little data on outcomes (enrollment, participation, energy and demand savings, and costs) of the demand flexibility programs in our dataset. Of the 15 Wi-Fi thermostat programs with reported costs and demand savings data, nine had first year costs of saved peak demand less than $100 per kW.

In our dataset of 93 demand flexibility rates, most rates (69) are dynamic rates, while 27 are technology rates; 3 rates had both technology requirements and dynamic features. Among dynamic rates, critical peak pricing (CPP) rates are more common than real time pricing (RTP), critical peak rebates (CPR), and variable peak pricing (VPP) rates. CPP and VPP rates generally have a maximum number of events that a utility calls in a year and maximum event length. CPP rates have a median maximum event count of 15 and maximum event length of 5 hours. Like demand flexibility programs, CPP and VPP events generally occur in summer afternoons. CPP and VPP event windows are largely fixed by time of day, but occasionally flexible. Relative to the standard volumetric rate during events, residential CPP rates are 1-10 times higher and commercial CPP rates can be more than 10 times higher. Demand flexibility rates with technology requirements always include at least one of the following features: a time-of-use rate; operating window requirements (e.g., only during off-peak hours); and/or some level of utility or third-party control. Many rates with technology requirements allow multiple technologies, but the majority apply to chemical or thermal energy storage.

We did not find reported enrollment, demand savings, or participant cost savings from electricity rates, and therefore do not report these outcome data.

Most of the programmatic and rate-based efforts to procure demand flexibility identified in our study focus on reducing demand during summer peaks driven by space conditioning consumption. Programs and rates will need to evolve over time to achieve a more fulsome vision of demand flexibility that involves the provision of a wider variety of grid services. In particular, program designs would need to change if the electrification of end uses shifts peak demand into winter mornings in cold regions.

Publicly available data on participant enrollment, participation, and energy reductions in demand flexibility programs and rates are largely insufficient to relate differences in outcomes to program and rate characteristics. Standardized and expanded reporting of these outcomes would provide data that enables analysis of program and rate performance drivers.

1. Introduction

The U.S. Department of Energy's National Roadmap for Grid-Interactive Efficient Buildings defines demand flexibility as follows (Satchwell et al. 2021):

"Demand flexibility, also sometimes referred to as load flexibility, is the capability provided by on-site DERs to reduce, shed, shift, modulate, or generate electricity. *Building* demand flexibility specifically represents the capability of controls and end-uses that can be used, typically in response to price changes or direct signals, to provide benefits to buildings' owners, occupants, and to the grid."

This report provides an in-depth review of current practices among programs and rates that promote demand flexibility in residential, commercial, and industrial buildings in the United States (U.S). Most of these programs and rates provide grid services by encouraging the shedding or shifting of building electricity loads. Demand response programs that procure reductions in end-use load in response to utility or grid operator signals exemplify the shed mode. Rate structures that charge higher prices during periods of peak electricity consumption also encourage shed. Shifting involves moving the timing of loads across the day, such as by pre-cooling a building in the afternoon to reduce evening peak demand.

Demand flexibility can lower carbon emissions and energy costs by shedding load during peak hours, or by shifting that load into off-peak hours. These reductions in peak demand reduce the need for carbon-intensive and expensive gas generators and can mitigate the impacts of building and transportation electrification (Goldenberg, Dyson, and Masters 2018; Hale, Stoll, and Mai 2016). Demand flexibility can also reduce the curtailment of renewable generation by shifting load into hours of solar and wind generation (Stoll, Buechler, and Hale 2017; Goldenberg, Dyson, and Masters 2018). Additionally, demand flexibility can reduce the costs of electric distribution systems by deferring or avoiding distribution system upgrades through non-wires alternatives.

In 2020, more than 11.6M electricity customers provided about 29.5 GW of demand flexibility capacity through retail demand response programs (FERC 2022). Commercial and industrial customers provided half of this capacity. Analysis from Brattle suggests that the entry of new technologies (e.g. thermal storage), the expansion of existing programs (e.g. smart thermostats) and dynamic electricity pricing can increase this potential significantly through 2030 (Hledik et al. 2019).

Data on the characteristics and performance of these demand flexibility programs and rates can inform their design and refine estimates of their potential. However, policy makers and utilities often lack these data. We address this gap by collecting and summarizing detailed data on demand flexibility programs and rates and describing their characteristics and outcomes. Where possible, we also relate program outcomes to these characteristics.

This report will help policy makers and regulators establish goals for demand flexibility and support utilities designing programs and rates to achieve those goals.

2. Data and methods

2.1 Demand flexibility programs

2.1.1 Scope of covered programs

There is no universal definition of demand flexibility, nor of programs that promote demand flexibility technologies and their dispatch in response to grid conditions. Moreover, in this report we seek to characterize emergent approaches to promoting demand flexibility in buildings. As such, we applied the following screening criteria to identify programs for detailed data collection:

- The program must provide event-based payments or other incentives to flex load. This criterion ensures that the programs can modify load in response to grid conditions, which is a key condition of demand *flexibility*. This criterion excludes energy efficiency programs that incentivize "passive" reductions in energy and demand in a way that is not directly responsive to specific grid conditions.
- The program must require the use of a demand flexibility technology to flex load. This ensures that the studied programs promote the adoption of demand flexibility technologies, as opposed to only the dispatch of technologies already in place. This criterion excludes behavior-based demand response programs in which customers manually adjust loads. We include programs that leverage technologies already in place, as well as those adopted as part of a program.
- The program must not be a longstanding demand response program type that has been well studied in the past. We excluded central air conditioning compressor, pool pump, electric resistance water heating and commercial and industrial (C&I) direct load control (DLC) programs that involve physical switches. However, we *do* include DLC programs that control heat pump loads. We made this exception because of increasing interest in heat pumps and the potential for demand flexibility to mitigate the peak demand impacts of building electrification. EV charging programs were not in scope for this analysis.

2.1.2 Program screening and collection

We identified electricity customer-funded demand flexibility programs for collection by applying the previously described screening criteria to programs found on websites and in regulatory reports from 147 electric utilities.[1] First, we screened programs from 97 utilities found in a database of demand-side programs regulatory reports (E Source).[2,3] To make sure that our screening covered all states in a consistent manner, we then identified the largest utilities, regardless of ownership structure, that

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[1] We collected website data in 2022. Data on current program websites, therefore, may differ from the data we collected. The regulatory reports we reviewed typically covered 2021 programs and were filed in 2022.

[2] For a description of E Source's data services and products, see www.esource.com

[3] We did not include any programs administered through grid operators in the scope of collection.

collectively covered 50% or more sales in each state and reviewed programs on their websites.[4] This decision criterion resulted in a list of exactly 100 utilities, 50 of which were also in E Source. In some states a single utility covered more than 50% of retail sales on its own (e.g. Public Service Elec & Gas Co in New Jersey). In other states, reaching 50% of retail sales required multiple utilities. For example, in Ohio we collected data on three utilities, AEP Ohio, First Energy Ohio Edison, and Duke Energy Ohio. These are the three largest utilities in Ohio by retail sales, and collectively accounted for more than 60% of the state's sales in 2020.[5,6] We also reviewed the websites of the 45 utilities that we identified in ESource but were not on the list of utilities that accounted for 50% or more of each state's sales. Appendix A lists the utilities by state that we reviewed.

For each of the programs at these utilities that met our screening criteria, we collected data on program characteristics and performance reported in regulatory filings and published on utility websites. In particular, where available we collected data on demand flexibility event structure, incentive types and amounts, enrollment and participation levels, program spending and energy and demand savings. The following sections summarize the results of the data collection.

2.1.3 Demand flexibility program dataset

148 programs at the studied utilities met our criteria. 82 of these programs (55%) incentivized Wi-Fi thermostats and 42 (28%) supported battery storage. The remaining 24 programs (16%) were a mix of programs that promoted thermal storage and building automation[7] as well as heat pump and heat pump water direct load control programs.[8] Additionally, there was one program that controlled electric dryers (among other loads). In Table 1, we describe how each of these technologies provides demand flexibility in the programs in our dataset. Due to their prevalence, we present more results on Wi-Fi thermostat and battery programs than other program types. Where possible, we present data on the other program types.

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[4] We included investor-owned, municipal, cooperative, state, federal, and public power district utilities in this selection process.

[5] 2020 was the most recent year of utility retail sales data available at the time of this utility selection process. Since the impacts of the COVID-19 pandemic on electricity sales were national, we do not believe they would change the utilities selected by our screening very much if at all.

[6] At the time of data collection, the most recent year of EIA-861 data was 2020.

[7] The small number of building automation system programs may be a result of our screening process. We looked for explicit references to building automation in descriptions of commercial demand response programs in regulatory reports and on utility websites. However, these descriptions often lacked detail about how participants reduced load, which led to us screening out many of the programs. It is possible that some of these participants used building automation systems.

[8] Shares of programs do not sum to one due to rounding.

Table 1. Demand flexibility approaches by program technology

Program technology	Demand flexibility approach
Wi-Fi thermostat[9]	Set-point change: Utility signal increases/decreases thermostat set-point to reduce HVAC cooling/heating demand during an event Cycling: Utility signal turns HVAC system on and off at a regular period (e.g. 15 minutes) during an event Optimization: Thermostat adjusts HVAC operation in response to time-varying electricity rate
Battery storage	Battery discharges stored electricity during an event, avoiding part (or all) of a building's demand
Thermal storage	Electricity cools or heats a material that stores thermal energy. That energy is released during an event to help meet space conditioning and/or water heating demand.
Building automation system	Upon receiving event signal, system automatically reduces various loads throughout building
Heat pump	Direct load control device receives signal to reduce heat pump load or cycle heat pump off
Heat pump water heater	Direct load control device receives signal or is scheduled to shift heat pump water heater load
Clothes dryer	Direct load control device receives signal to shut off dryer load

The programs in our dataset have wide national coverage and are weighted towards investor-owned utilities. The programs we identified came from 38 states and Washington D.C (Figure 1).[10] We found Wi-Fi thermostat programs operating nationwide, in 33 states. In contrast, we identified battery storage programs in only 13 states, all in the West and Northeast census regions. Investor-owned utilities operated 82% of the programs in our dataset, with the remaining 18% administered by a mix of municipal, co-operative, and state-run entities as well as third-party organizations and community choice aggregators. While investor-owned utilities only comprise 13% of utilities nationally, they do account for more than 70% of annual retail sales (EIA 2021). By selecting the largest utilities in each state such that they covered at least 50% of state sales, we ensured that our sample is relatively representative of national utilities by sales, and addresses programs at the utilities that serve the most load. However, our dataset is not necessarily reflective of all demand flexibility programs active in the United States, especially those run by smaller municipal utilities and cooperatives.

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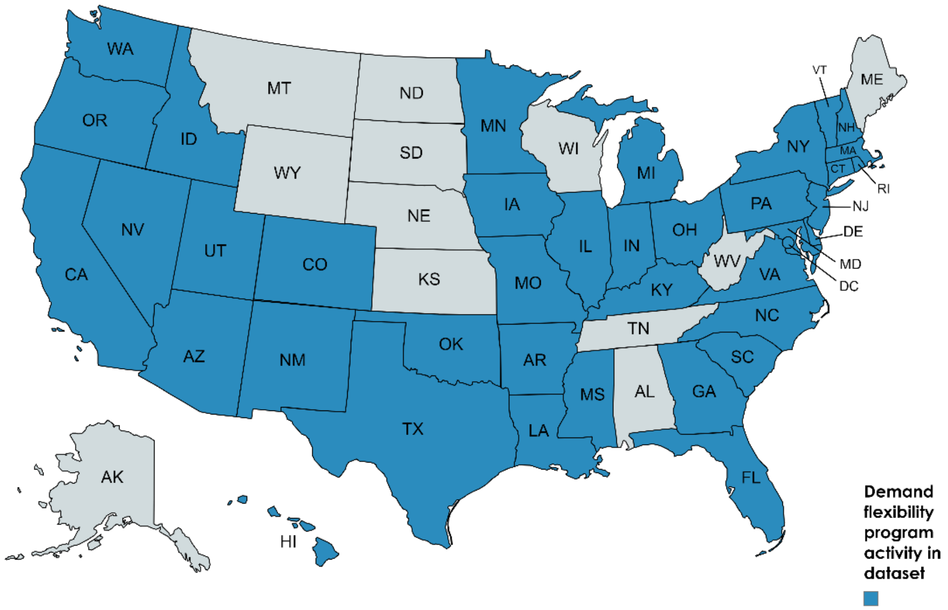
[9] We do not include energy efficiency programs that promote the adoption of Wi-Fi thermostats but not their use during events due to our first screening criterion, which requires that programs provide incentivizes to flex load.

[10] Demand flexibility programs may exist in the 12 states where we did not identify any programs, since we did not review all utilities in every state. These states may also have programs that we excluded from our collection such as central air conditioning compressor DLC programs.



Created with mapchart.net

Figure 1. States with a demand flexibility program in our sample.

Note that we did not review all utilities in each state.

The demand flexibility programs in our dataset differ in the electricity customer classes they serve. The Wi-Fi thermostat programs are largely residential (52 of 82, or 63%). In contrast, all seven building automation system programs and six of seven thermal storage programs serve commercial and industrial customers. Battery storage programs are more balanced, with 20 of 42 (48%) serving residential customers, 16 of 42 (38%) serving commercial and industrial customers, and the remaining six programs (14%) serving all customer classes.

2.2 Demand flexibility rates

2.2.1 Scope of rate collection

As with programs, there is no accepted universe of rates that promote demand flexibility technologies and their dispatch. Electricity rates that are within the scope of our data collection and analysis include at least one of the three following features:

- The rate *includes dynamic rate components* that are not defined in advance but depend on grid conditions in some way. In our analysis, we categorize dynamic rates into three sub-categories: *critical peak pricing*, *variable peak pricing*, and *real-time pricing*. All three dynamic rate categories include price components that are subject to change depending on grid conditions.
- The rate *lists one or more demand flexibility technologies as an eligibility condition*. We consider any technology that can provide some level of load shape flexibility to be a demand flexibility technology. We organize eligible rates into nine technology categories: air conditioning, energy

storage, smart thermostats, space heating: electric resistance, space heating: heat pumps, thermal storage, water heating: electric resistance, water heating: heat pumps, and other (this includes rates with open-ended language for technology eligibility).

- The rate *has a structural relationship to demand flexibility programs*. This would include rates that require participation in a demand flexibility program for eligibility, or rates whose enrollment is a requirement for a demand flexibility program. This condition is satisfied by only a small number of rates we reviewed, and all of those rates also include one of the other two features above, so we do not further consider these rates as their own category in the analysis that follows.

We do not include time-of-use rates without dynamic components, or rates with demand charges but no dynamic components. These rates impact load shapes, but they are not responsive to grid conditions on a specific day and in that sense do not promote demand flexibility.

We do not collect technology-specific rates that are commonplace, well studied, or not primarily intended to procure demand flexibility. For example, we do not include rates specific to space or water heating if they are primarily intended for direct load control.[11] We also do not include rates with baseline allowances or differentiated prices that are specific to heating fuel type.[12] The technology rates we collect generally include emerging technologies (i.e., energy storage) or a greater level of utility control, such as access to thermostat adjustments or whole home management.

2.2.2 Rate screening and collection

We collected rates from the same universe of 100 utilities defined in our program data collection (see Section 2.1.2), so that we consider rates available to over half of the customers in each of the 50 states.

To enable our analysis of rates, we collected rate data in a unified format, doing our best to enforce consistency. Several factors made consistency a challenge. Utilities issued rates using differing levels of aggregation and provided varying levels of detail in rate filings. For example, some states represented multiple variations of a rate (e.g., customer size or interconnection level) in a single rate sheet while other states used separate rate sheets for each variation in rate. Furthermore, we found differences in how utilities represented dynamic rates. When implementing a critical peak price across multiple rate classes, for example, some utilities created multiple separate rate sheets reflecting the addition of the critical peak price to the underlying rate structures.[13] Other utilities utilized riders for the dynamic

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[11] See, for example, Duke Energy Carolinas, North Carolina's RE rate for residential service with both electric water heating and space conditioning requirements: https://www.duke-energy.com/-/media/pdfs/for-your-home/rates/electric-nc/ncschedulere.pdf?rev=bd09ea126f564d8e89d5d20d610ed7cc

[12] See, for example, PG&E's E-1 residential rate, which has differing tiers depending on heating fuel: https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_E-1.pdf

[13] NV Energy, for example, uses separate rate schedules for each different combination of critical peak pricing with other rates; see https://www.nvenergy.com/about-nvenergy/rates-regulatory/electric-schedules-north

portion of the rate.[14] Dynamic features represented in the former fashion produced multiple rates, while dynamic features expressed as riders generally required only one rider per customer class.[15]

Where utilities implement dynamic elements through riders, we count these riders as rates. We include all eligible rates or riders for utilities even where the same dynamic rate is represented multiple times (e.g., separate critical peak pricing rate schedules for single family home and multi-family customers). As a result, the count of rates in the collection represents some utilities more than once and is not equivalent to the total count of utilities that offer a particular type of rate.

2.2.3 Overview of collected rates

As shown in Figure 2, 69 of the 93 rates we collected are dynamic rates, while 27 have technology requirements that include demand-flexible technologies. We collected three rates with both features:

- Commonwealth Edison's residential peak time rebate rate where the utility is authorized to control the customer's thermostat, if present;[16]
- Duke Energy Carolinas, North Carolina's residential time-of-use rate with critical peak pricing available only to customers with electric space and water heating;[17] and
- Southern California Edison's general service time-of-use rate with critical peak pricing available only to customers with energy storage and demand of 20 kW or less.[18]

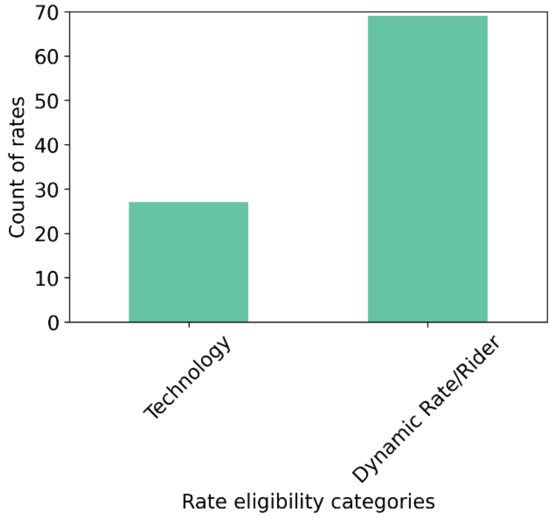

Figure 2. Count of rates by eligibility category

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[14] Green Mountain Power, for example, has one critical peak rider that applies to all commercial and industrial customers. For a description of the utility's rates, see: https://greenmountainpower.com/rates/

[15] A rider tariff represents a supplemental charge that is only applicable for combination with specific rate schedules. https://pubs.naruc.org/pub.cfm?id=53788304-2354-D714-5194-BCE9529A6212

[16] For details on Commonwealth Edison's rates, see: https://www.comed.com/SiteCollectionDocuments/MyAccount/MyBillUsage/CurrentRates/Ratebook.pdf

[17] For details on Duke Energy Carolinas North Carolina's rates, see: https://www.duke-energy.com/-/media/pdfs/for-your-home/rates/electric-nc/ncschedulere-tc.pdf?rev=6507453a4238449a80a7c81fcf8e9908

[18] See Southern Carolina Edison's general service time-of-use rate here: https://www.sce.com/sites/default/files/inline-files/TOU-GS-1%20Rate%20Fact%20Sheet_WCAG.pdf

Figure 3 shows rates by customer class. 32 of the rates are residential and 60 are commercial and/or industrial (C&I). Two rates, Avista Corp's Peak Time Rebate and Eversource Energy's Variable Peak Pricing, apply to all customer classes.[19] We include these rates serving all customers in both the residential and commercial counts in Figure 3. We consider general service rates as both commercial and industrial, unless customer class is explicitly defined. Only two rates, Alabama Power's Real Time Pricing and Consumers Energy's Energy Intensive Primary, are exclusively industrial rates.[20] We categorize commercial rates as small, medium, or large based on each utility's classification. If not available, we use Southern California Edison's classification where commercial customers under 20 kW are small, 20 kW-200 kW are medium, and 200 kW-500 kW are large. 36 of our 62 collected C&I rates are available to small and medium customers.

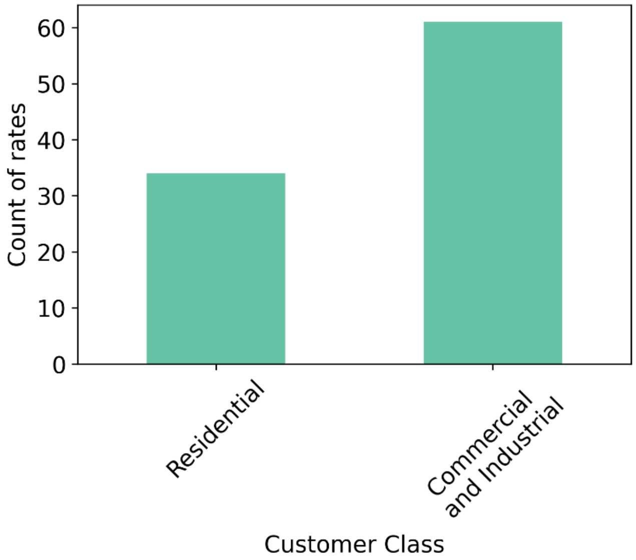

Figure 3. Count of rates by customer class

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[19] Avista Corp's Peak Time Rebate is available here: https://www.myavista.com/-/media/myavista/content-documents/our-rates-and-tariffs/wa/wa_084.pdf
Eversource Energy's Variable Peak Pricing Rider is available here: https://www.eversource.com/content/docs/default-source/rates-tariffs/vpp.pdf

[20] Alabama Power's Real Time Pricing rate is available here: https://www.alabamapower.com/content/dam/alabama-power/pdfs-docs/Rates/rtp.pdf. Consumer Energy's Energy Intensive Primary Rate EIP is available here: https://www.consumersenergy.com/-/media/CE/Documents/rates/electric-rate-book.pdf

Figure 4 shows the number of collected rates by state. We found at least one rate that met our criteria for collection in 26 states. 21 of our 93 rates are from California utilities. Pilot rates made up only 9 of the 93 collected rates. Again, we note that we did not collect rates from all utilities in every state; these counts refer to the rates we collected, not to all available rates in a state.

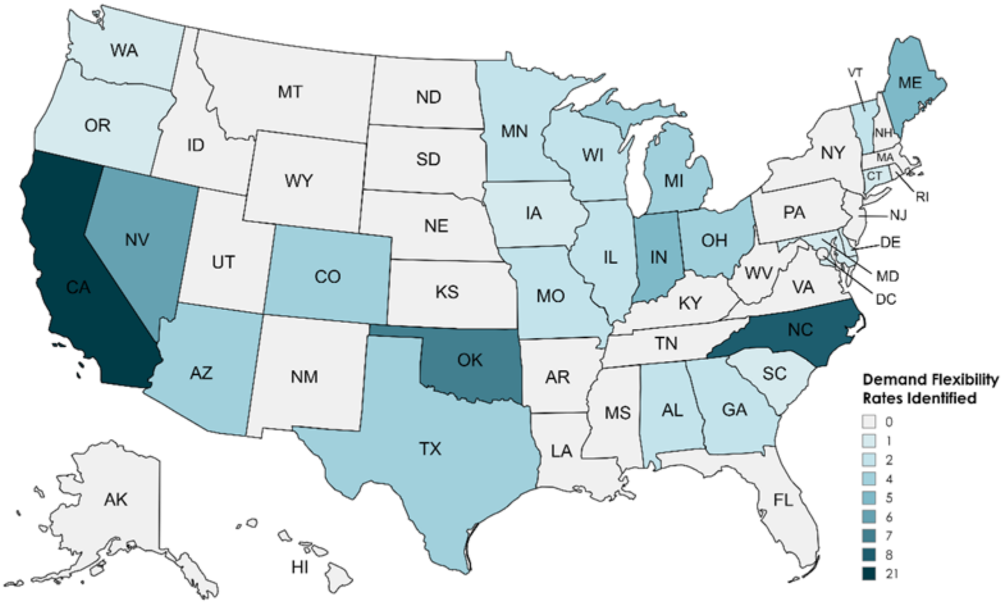

Figure 4. States by number of demand flexibility rates identified in our sample.

Note that we did not review all utilities in each state.

3. Demand flexibility program characteristics and performance

3.1 Demand flexibility grid services

The programs in our dataset all seek to shed building loads in certain hours. In some cases, the programs may accomplish this shed by shifting load to a different time of the day. Battery and thermal storage programs all shift load out of peak periods by storing energy at times of lower electricity prices, such as in the middle of the day when there is significant solar generation. Similarly, the heat pump water heater programs heat water outside of peak times and store it for later use. Some Wi-Fi thermostat programs also shift load by pre-cooling a building ahead of a summer peak demand event. 29 of the 82 Wi-fi thermostat programs in our dataset (35%) mentioned pre-cooling on program websites, but only 17 required it. In contrast, we did not find any building automation system programs that reported load shifting.[21] While dryer loads can be shifted, the one program we identified only shed dryer loads.

By shedding load, all of the demand flexibility programs in our dataset provide capacity value to the grid. During grid emergencies, when utilities face power reliability risks, this capacity value is even greater. Many demand flexibility programs reported that they provide capacity support during grid emergencies, including 39 of the 82 Wi-fi thermostats and three of the seven building automation system programs. We did not find any battery storage programs that explicitly indicated potential event calls during grid emergencies. We also note that some programs may provide capacity during grid emergencies but not report that information on the websites we reviewed.

3.2 Demand flexibility event structure

In this section of the report, we describe key characteristics of demand flexibility events and compare them across the different program technology types. These characteristics include the months and hours in which events take place, the maximum length and number of events as well as event notification windows. We address these characteristics because utilities often report information on them to prospective participants on program websites. Where possible, we relate these characteristics to program design and demand flexibility grid services.

3.2.1 Event timing

3.2.1.1 Time of year

Programs limit events to certain months and hours that align with grid needs. We show how many programs utilities report as active (i.e. could have and event) in each month by demand flexibility technology in Figure 5. The programs we identified mostly address summer months, when many utilities experience system peaks driven by space cooling. 56 of 64 Wi-Fi thermostat programs with

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[21] Note that any program that affects space conditioning usage may have small shifting effects even absent pre-cooling or pre-heating, as buildings may use additional electricity after an event to return to their set points. Here we do not consider these “snap-back” effects to represent load shifting.

reported data (88%) and 18 of 22 battery programs (88%) operate exclusively in the summer. The remaining eight Wi-Fi thermostat programs (12%) operate in both summer and winter, with event hours varying by season. Notably, five of these programs are in southern states (South Carolina, Texas, and Georgia) that have a relatively high share of electric space heating (EIA 2023). Six programs (three building automation system, two battery storage, and one thermal storage) operate continuously throughout the year.

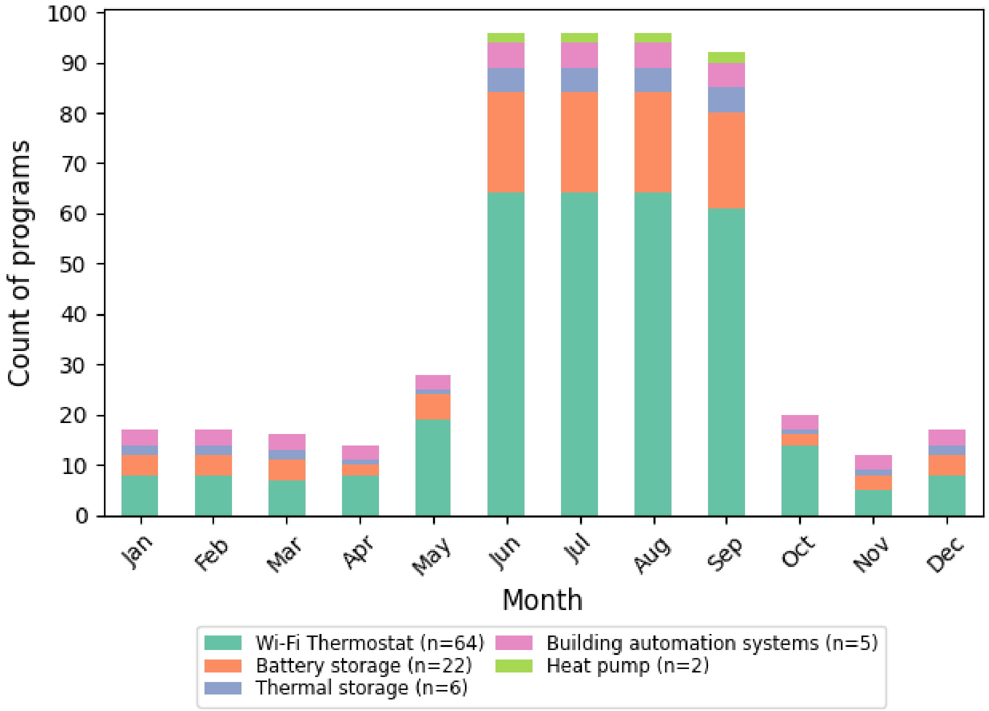

Figure 5. Program event windows by month and technology

3.2.1.2 Time of day

Figure 6 shows the number of programs that include each hour of the day in their summer event windows. Figure 7 shows the same for winter programs.[22] In both figures, we include the six programs that operated year-round.

Across technology types, summer event windows typically straddle afternoon and early evening hours, which aligns with peak demand driven by space cooling. In some Wi-Fi thermostat programs, summer event windows extend into the late evening, up to 11 PM[23]. In jurisdictions with increasing levels of rooftop solar that shift summer peak net demand later into the evening, this flexibility for late-evening events may be increasingly valuable. The median summer Wi-Fi thermostat program calls events within

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[22] We do not apply a single definition of summer and winter here. Instead, we accept utilities' season assignment.

[23] See Consolidated Edison's Wi-Fi thermostat website for program details: www.coned.com/en/save-money/rebates-incentives-tax-credits/rebates-incentives-tax-credits-for-residential-customers/bring-your-thermostat-and-get-$85

six-hour windows, slightly longer than the five-hour median for battery programs. As expected, these windows exceed the median maximum event lengths (four and three hours, respectively) for both program types.

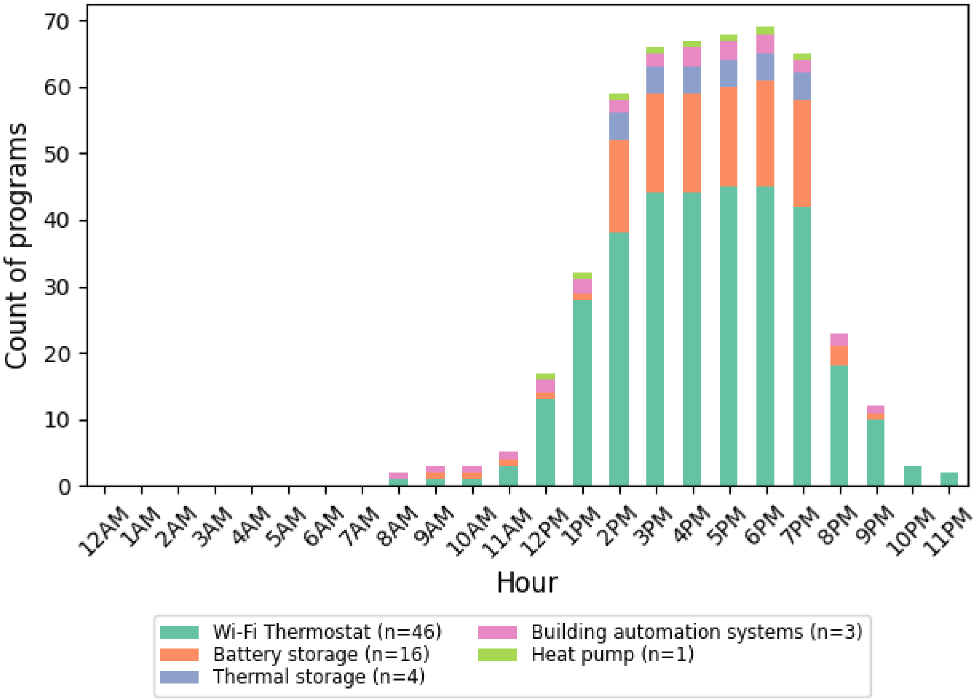

Figure 6. Summer program event windows by hour of the day and technology

Winter event periods vary by technology. Wi-Fi thermostat program winter events typically occur in the early morning, which coincides with electric space heating demand. In contrast, the event periods for the three battery storage programs with reported data start at 9AM, 2PM, and 6PM. Battery programs, however, could have also events in early winter mornings by charging or holding a charge overnight. The absence of battery program events occurring in these hours may result from the lack of reported data or battery programs not operating in jurisdictions where early morning winter demand reductions are valuable (e.g. southern states with high levels of electric space heating).

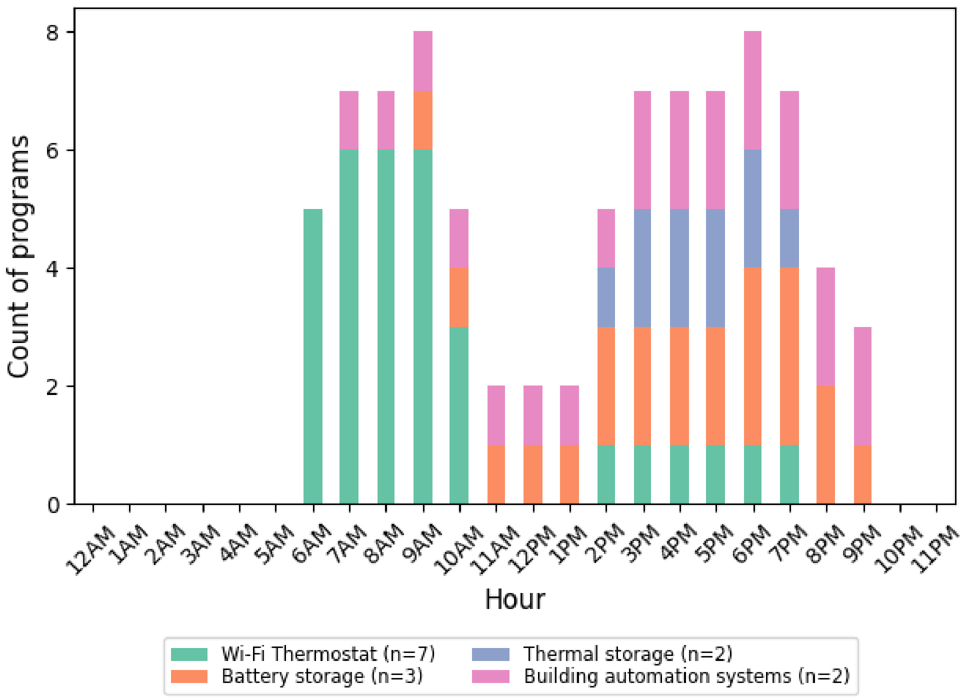

Figure 7. Winter program event windows by hour of the day and technology

3.2.2 Maximum number of events allowed

Programs often cap the number of demand flexibility events they may call in a year. We find that battery programs generally allow a greater number of potential battery events than Wi-Fi thermostat programs (Figure 8). In our dataset, the median Wi-Fi thermostat program allows a maximum of 15 events whereas the median battery program permits 60. This difference likely reflects the potential thermal comfort impact of Wi-fi thermostat events. In contrast, battery events do not affect any building energy services. Thermal comfort concerns likely affect the willingness of utility customers to participate, which results in a tradeoff between event frequency and program enrollment. This result is not universal as we do find Wi-Fi thermostat programs that allow many more events (maximum 35) and battery programs that allow far fewer (minimum 5). We also find state-level differences: six of the 11 programs that reported a maximum of 60 events were in Massachusetts and four others were in neighboring states and/or operated by Massachusetts utilities (National Grid and Eversource). However, the high maximum event count for battery programs in our dataset is not restricted to New England. Two programs, one operated by Arizona Public Service and the other by Xcel Energy Colorado[24], reported a maximum number of battery events of 100 (Arizona Public Service Company 2022).

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[24] For program details, see www.xcelenergy.com/staticfiles/xe-responsive/Environment/Renewable%20Energy/23-10-509_CO-RenewableBattery_is_P03.pdf

Differences in the objectives of battery programs may explain some of the variation in the reported maximum number of events. For example, Eversource's Targeted Dispatch program aims to reduce the annual hourly ISO-New England peak over at most eight events.[25] In contrast, Eversource's Daily Dispatch program seeks to reduce the 40 highest daily peaks over the course of at most 60 events.[26,27] For the increased number of potential events in the Daily Dispatch program, Eversource offers a higher incentive for the average event demand reduction ($200 per kW) than it does in the Targeted Dispatch Program ($100 per kW). Furthermore, Hawaii's Battery Bonus program has daily events (i.e. 365 per year), which aligns with the program's goal of integrating renewables and achieving the state's 100% clean energy goal.[28]

We found less data on the actual number of called program events. Among the 23 Wi-Fi thermostat programs for which data is available, the median program called five events, far less than the median maximum event count of 15. We only found actual event counts for two battery programs. In both cases, the number of events is about 30, or half of the median maximum event count. Programs may set high limits on maximum event counts to provide a buffer for an increased need for events.

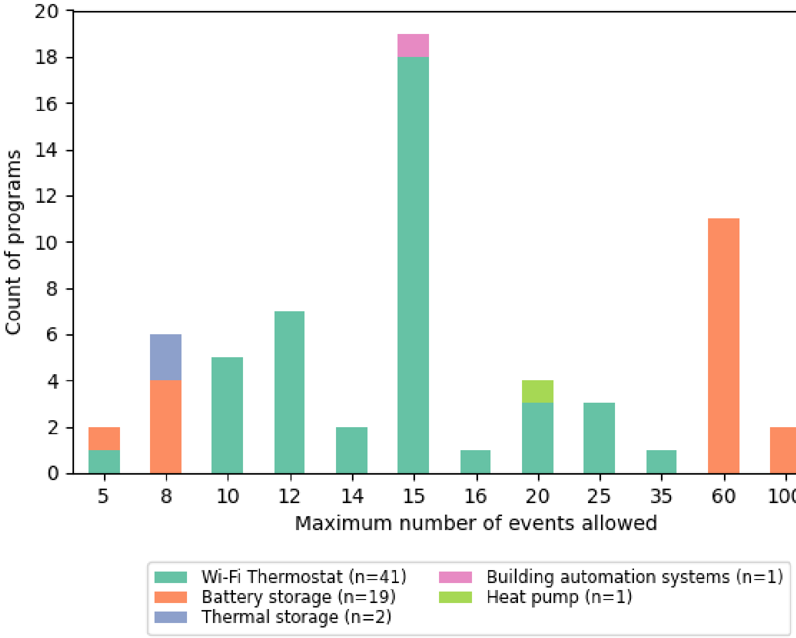

Figure 8. Maximum number of events allowed by demand flexibility technologies

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[25] For a description of the battery programs operated under MassSave, which included Eversource among other Massachusetts utilities, see www.nationalgridus.com/media/pdfs/bus-ways-to-save/connectedsolutions-ciprogrammaterials.pdf

[26] Ibid

[27] The maximum number of events (60) likely exceeds the number of daily peaks (40) in the Daily Dispatch program due to uncertainty in when the 40 highest daily peaks will occur. For example, a hot July day with a significant cooling-driven peak may not be one of the days with the 40 highest daily peaks if August has many hot days. An event on that July day, however, may be a good hedge against the possibility of August not having many hot days.

[28] For details on the Battery Bonus program, see www.hawaiianelectric.com/products-and-services/customer-renewable-programs/rooftop-solar/battery-bonus

3.2.3 Maximum event length

Figure 9 presents reported maximum event lengths by demand flexibility technology. Notably, seven of the ten programs that reported maximum Wi-Fi thermostat events of six hours cycle HVAC systems through thermostats as opposed to changing the thermostat set point. The cycling programs periodically (e.g. every 30 minutes) turn HVAC systems on and off, so a six-hour event would still include multiple hours with cooling at preferred levels, albeit spaced out. In contrast, the programs that change thermostat set points do not provide intermittent relief from the event, which may mean that participants prefer shorter events. Since Wi-Fi thermostat programs change the temperature in buildings, often during very hot days, participants are likely unwilling to accept extended periods without their preferred levels of space cooling.

Of the 18 battery storage programs with reported data, 15 have maximum event lengths of three hours. This window is slightly longer than the 2.6 hours that the median battery in California's Self Generation Incentive Program (SGIP) could discharge at full capacity (see Section 3.3.2.2) for details on calculation).[29] This alignment suggests that these programs set their event hours relative to the full capacity of potential battery discharge.

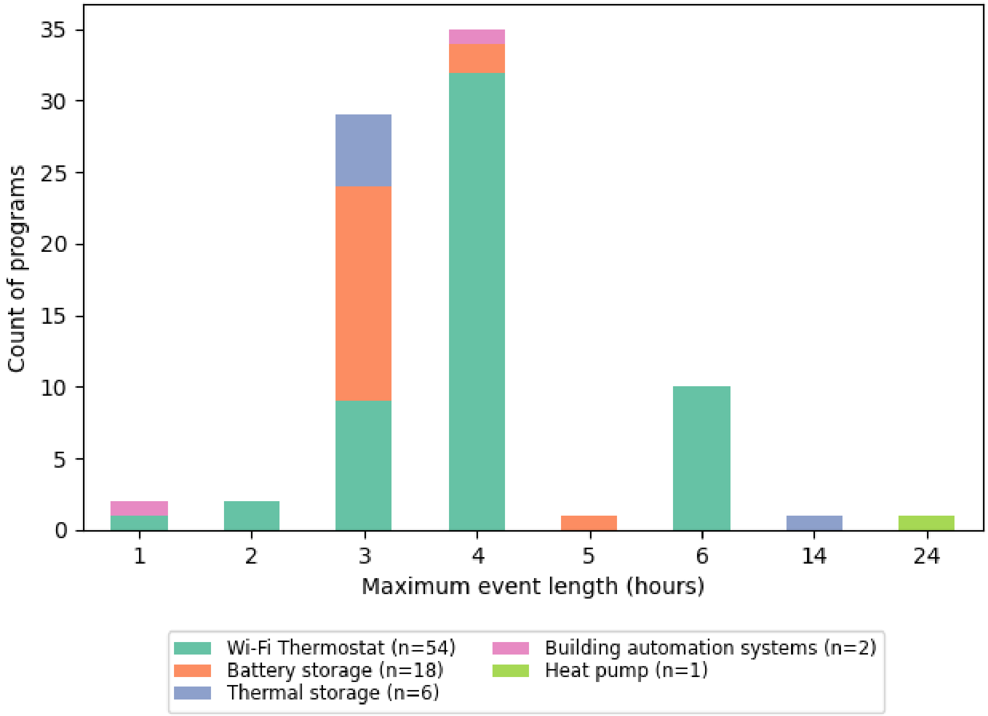

Figure 9. Maximum program event length in hours by demand flexibility technology

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[29] For an archive of SGIP project data, see www.selfgenca.com/report/weekly_statewide_archives/. We accessed data on August 7th, 2023

Two programs, both operated by Otter Tail Power Company, have maximum event hours well above those of the other program types. The utility's Deferred Load Rate offers a discounted rate for customers with thermal storage systems that it can control up to 14 hours per day. [30,31] Otter Tail's Dual Fuel Rate controls cold climate heat pumps that serve as primary heating system with gas backups 24 hours a day. Heating as the controlled load may explain the longer event hours. Since Otter Tail operates in a cold climate, electric heating loads are likely significant throughout the day. Moreover, both programs can attain load reductions without thermal comfort compromises, as the Deferred Load Rate controls storage and the gas backup heating can compensate for controlled heat pumps under the Dual Fuel Rate.

3.2.4 Length of event notification windows

About 80% of the programs of we reviewed did not report how far ahead of time that a participant receives a notification. For those that did, we find that Wi-Fi thermostat programs are more likely to provide day-of notifications than day-ahead notifications (see Figure 10). In contrast, two of the four building automation system programs and all of the battery and thermal storage programs only have day-ahead notifications. The selection of day-ahead notifications in the battery and thermal storage programs may reflect the time constraint posed by storing electrical and thermal energy. For example, if a battery optimizes for an event, it may change its rate of charge relative to a non-event day. In this case, a day-of notification could result in reduced discharge capacity. Similarly, for a thermal storage system that creates ice to reduce chiller loads during a summer peak, a day-of notification may not give sufficient time for ice production.

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[30] Ottertail describes its rate structures here: www.otpco.com/pricing/minnesota/residential-rate-summary-mn/

[31] We treat the Deferred Load Rate as a program due to its control of the thermal storage load. In contrast to the demand flexibility rates discussed in Section 4.1 that have increased prices during peak hours, the Deferred Load Rate offers volumetric rate ($/kWh) discounted relative to Ottertail's standard residential rate. The rate serves as the mechanism for compensating participants as opposed to being a signal for demand reduction itself.

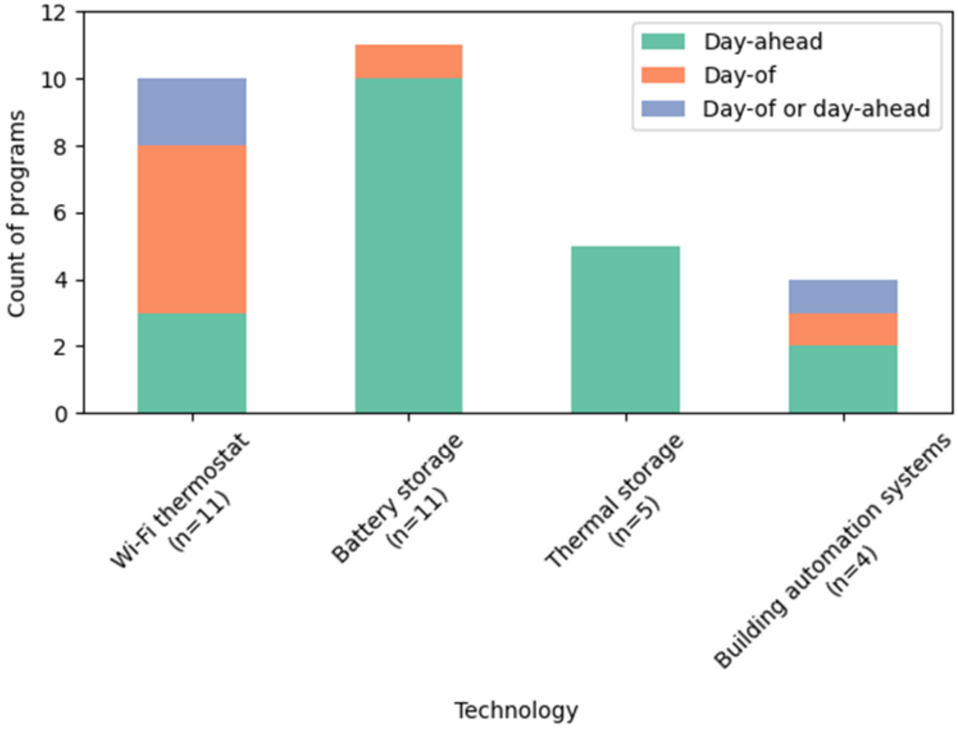

Figure 10. Event notification window by program type

3.3 Incentives

In this section, we review the incentives that demand flexibility programs in our dataset offer their participants. First, we describe how programs structure up-front, retention, and performance-based incentives. For battery and thermostat programs, we then relate incentive structure to program objectives and present distributions of incentive levels.

3.3.1 Incentive structure

Utilities offer up-front incentives to drive demand flexibility technology adoption and performance incentives to promote event participation. Up-front incentives may come in the form of a rebate or a bill credit that reduces the cost of adoption. Utilities tie these incentives to the purchase or installation of a technology (e.g., a Wi-Fi thermostat) or the rated size of the installed equipment (e.g. a payment per kW of battery capacity). In Wi-Fi thermostat programs that cycle HVAC systems on and off, this upfront incentive may scale with the level of reduction in HVAC operation that participants commit to upon sign-up. For example, Pepco offers three up-front incentive levels that correspond with the share of an event period that the HVAC system cycles off, ranging from $30 for a commitment to 50% cycling (shut-off half the time) to $60 for a commitment to 100% cycling (completely shut off).[32] Up-front battery incentives can reward enrollment ($/battery) or committed or installed battery power (expressed in $/kW) or energy ($/kWh).

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[32] For a details on Pepco's EnergyWise Rewards program, see: https://energywiserewards.pepco.com/dc/participation/

Retention incentives encourage continued enrollment in a program. Importantly, this approach does not incentivize participants to maximize demand reductions nor discourage event opt-outs. However, by rewarding retention, these incentives may decrease attrition, increasing enrollment overtime as well as the potential for demand reductions. Wi-Fi thermostat retention incentives can reward each month, season, or year that a participant remains enrolled. Battery storage retention incentives can provide payments per kW or kWh (installed or committed to events) per month, season, or year of enrollment.

Performance incentives connect participants' financial rewards to the outcomes they achieve. For battery programs, performance incentives are generally specified in dollars per kW or kWh provided by the battery. In 19 of the 21 battery programs in our dataset with performance incentives, participants earn incentives based on average kW reductions across multiple events. In the other two cases, participants earn incentives based on kWh discharges during events.[33,34] In Wi-fi thermostat programs, performance incentives may reward average demand reductions[35] across events, participation in individual events[36], or participation in a minimum share of event hours (e.g. 80% in a year).[37]

In Figure 11, we show how incentive types vary by demand flexibility technology for the programs in our dataset. A majority of Wi-Fi thermostat programs (48 of 67 with reported data, or 72%) provide a combination of up-front and retention incentives while only two offer performance incentives. This distribution of incentive approaches suggests that Wi-Fi thermostat programs are primarily targeting high enrollment numbers rather than attempting to increase per-participant demand reductions. The prevalence of retention incentives also reflects the short enrollment term required by some Wi-Fi thermostat programs, which may be only one year.[38] In contrast, fewer battery storage programs in our dataset offer retention incentives. Battery storage program terms may be longer (up to 10 years),[39] so retention may be less of an immediate concern. Most battery storage programs in our dataset offer up-front incentives, performance incentives, or both. This mix may reflect that both incentive types are important in battery program design. Upfront incentives offset the high costs of installing a battery and performance incentives encourage the demand reductions that motivate the program.

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[33] See Marin Clean Energy's energy storage program for an example of $/kWh incentive for battery event discharges: https://mcecleanenergy.org/facility-energystorage

[34] We also note that two programs, one operated by Green Mountain Power (www.greenmountainpower.com/rebates-programs/home-energy-storage/powerwall) and the by Liberty Utilities (www.new-hampshire.libertyutilities.com/bath/residential/smart-energy-use/electric/battery-storage.html) lease batteries to their customers. The incentive in these programs is a below market-rate lease.

[35] For details on Duke Energy Progress South Carolina's business Wi-Fi thermostat program, see www.duke-energy.com/business/products/energywise-business

[36] For details on Indiana Michigan Power's Wi-Fi thermostat program, see https://electricideas.com/at-home/energy-saving-programs/smart-thermostat/

[37] For details, see Orange and Rockland Utilities's Wi-Fi thermostat program website: https://www.thermostatrewards.com/oru/faq

[38] See program terms for Xcel Energy AC rewards: https://www.xcelenergy.com/staticfiles/xe-responsive/Business%20Programs%20&%20Rebates/Equipment%20Rebates/ST%20DR%20Program%20Terms%202020.pdf

[39] See description of Hawaiian Electric Battery Bonus program: https://www.hawaiianelectric.com/products-and-services/customer-renewable-programs/rooftop-solar/battery-bonus

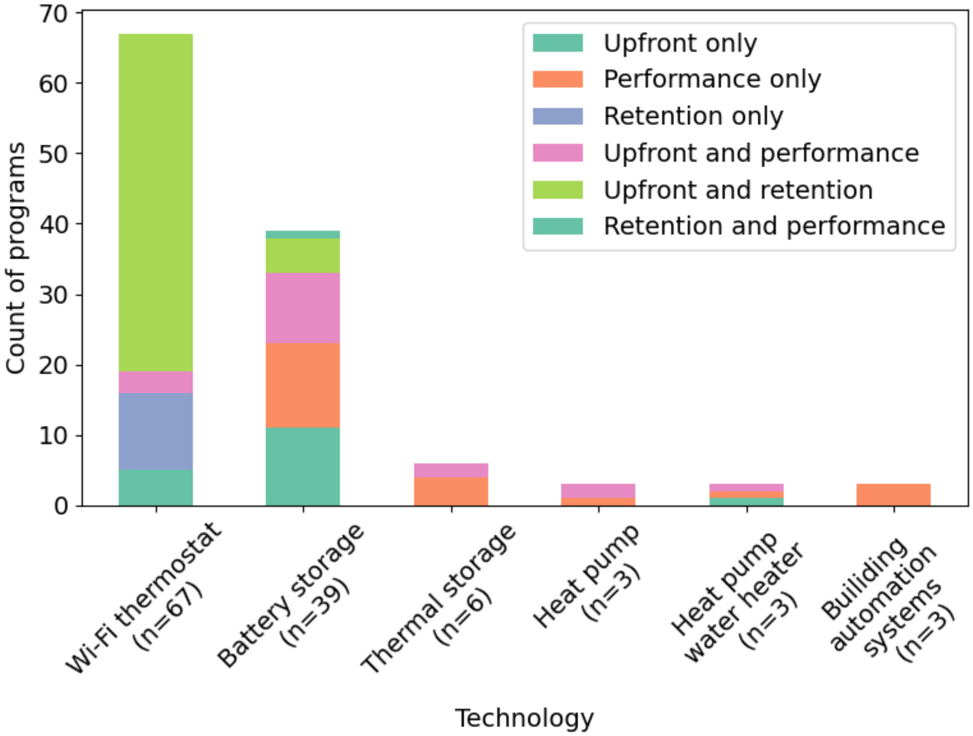

Figure 11. Incentive type by demand flexibility technology

3.3.2 Incentive levels

Due to the limited number of non-thermostat or battery programs in our dataset, we only report incentive results for thermostat and battery programs.

3.3.2.1 Thermostats

We find that upfront incentives for Wi-Fi thermostat programs are typically under $100 for all customer classes, as shown in Figure 12.[40] These incentives can offset the costs of some Wi-Fi thermostat models, which could promote adoption. However, the prevalence of Bring-Your-Own-Device programs that target participants that already have Wi-Fi thermostats suggests that up-front incentives are more important for enrollment than technology adoption. Notably, the only program we identified that offers an incentive beyond $150 serves commercial customers.[41] This higher incentive level ($300) may reflect the possibility of larger demand reductions with commercial customers. Retention incentives for Wi-Fi thermostat programs in our dataset are generally $30 or less per year and never exceed $60 per year.

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[40] Utilities also offer free thermostats with direct installation as the exclusive delivery channel (https://mn.my.xcelenergy.com/s/business/cost-savings/ac-rewards-smart-thermostat) or as an alternative to up-front incentives for a customer who already owns a thermostat (https://welcome.demandresponse.consumersenergy.com/?utm_campaign=smart-thermostat-program&utm_medium=vanity-url&utm_source=smartthermostat&utm_content=smartthermostat). We do not include the in-kind incentive value of these free thermostats in Figure 12.

[41] See details on Consumer Energy's business Wi-Fi thermostat program here: www.businessthermostatprogram.consumersenergy.com/start

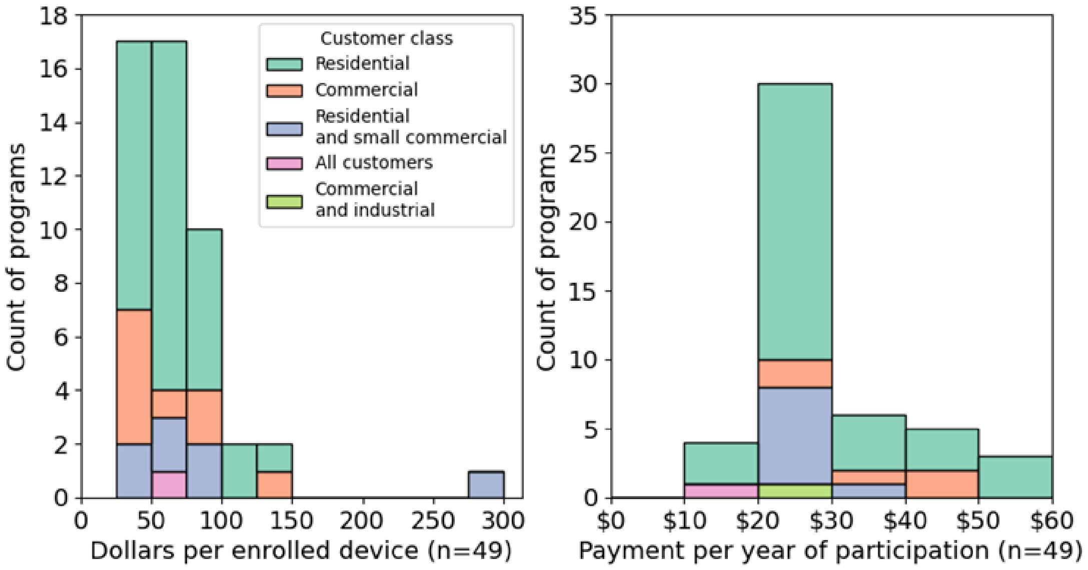

Figure 12. Wi-Fi thermostat program upfront and retention incentives

3.3.2.2 Batteries

As described in section 3.3.1, the battery programs in our dataset offer a mix of upfront, performance, and retention incentives. Due to the different units for these incentives (e.g. $/kW installed vs $/kW reduced) and variation in the periods over which the performance and retention incentives apply, we estimated the total value of the incentives with standardized battery sizes and performance assumptions. First, we identified median residential and commercial battery capacities (kW) and their associated energy (kWh) ratings from California's Self Generation Incentive Program (SGIP) for batteries installed since 2020.[42] Since SGIP did not separate industrial customers, we used the 90th percentile commercial battery capacity for industrial batteries. We summarize these ratings in Table 2.

Table 1. Typical SGIP battery system sizes

System size	Residential	Commercial	Industrial
kW	5	15	20
kWh	13.2	39.6	52.8

Next, we made the following assumptions about program performance and operations:

- Batteries discharge at rated power in each event
- Performance and retention incentives apply for the reported commitment period.
- If a program reports a range of incentives, we use the average

We show the distribution of estimated upfront, retention, and performance incentives by customer class in Figure 13. We also show the sum of these incentives for any program with multiple incentive types. Note that in Figure 13 we are counting incentives that apply to multiple customer classes

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[42] For an archive of GSIP project data, see www.selfgenca.com/report/weekly_statewide_archives/. We accessed data on August 7th, 2023

separately, so we count some programs more than once. The incentive estimates are illustrative of the potential incentives that a participant can earn over the life of a battery program and, importantly, are sensitive to the input assumptions.

Overall, we find that incentive levels vary between and within customer classes. Given that commercial and industrial batteries are larger than their residential counterparts, it is unsurprising that incentives offered by commercial and industrial programs are also higher. More notable is the variation of incentives within customer classes. For example, residential up-front incentives vary from $500 to $5,300 with a median of $2500. Battery ownership explains some of this variation. The smallest up-front residential incentive is from a program operated by Arizona Public Service in which the utility owns the customer-sited battery. The incentive, therefore, does not need to offset the cost of purchasing a battery. Additionally, under our assumptions residential performance incentives vary from $6900 to $10,000. This variation results in part from variation in the number of years that performance incentives apply (five vs. ten years). We also find variation in the commercial and industrial program upfront and performance incentives.

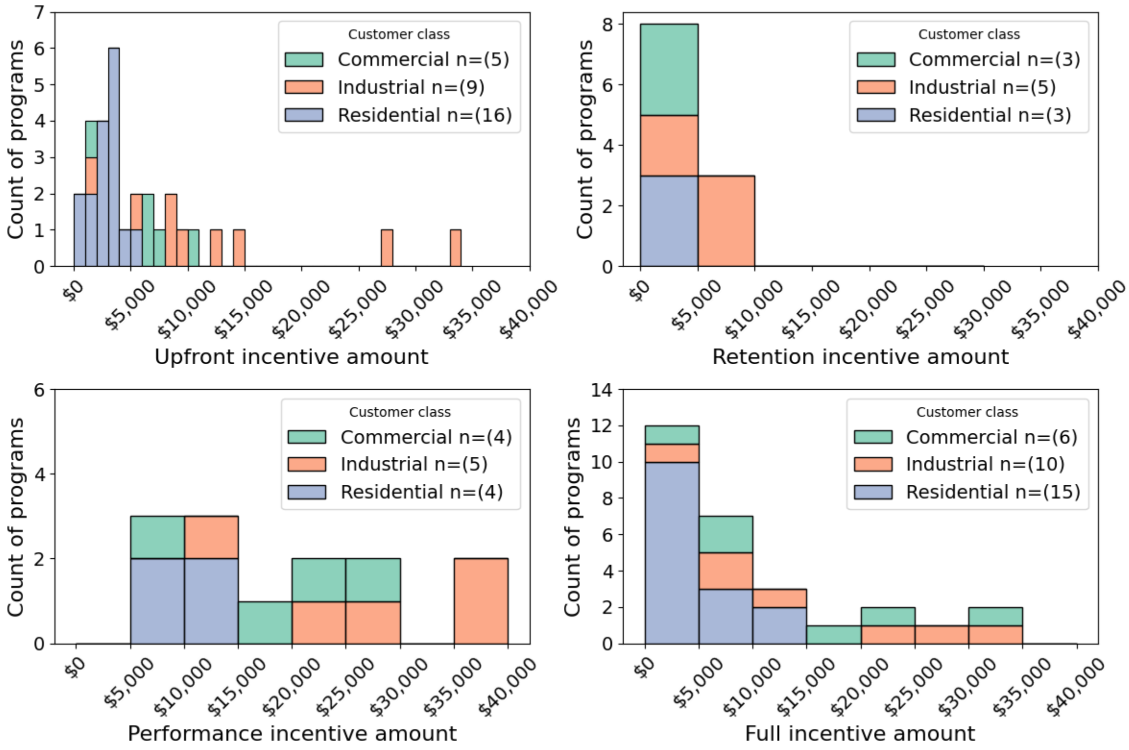

Figure 13. Estimated battery incentive levels for five years of program participation by customer class

3.4 Program details

This section summarizes data we collected on program design elements and operations specific to Wi-Fi thermostat and battery storage programs. For Wi-Fi thermostats, we describe the strategies programs use to control heating and cooling demand, including typical ranges for set-point temperature changes. For battery storage, we discuss different approaches to charging, dispatch, and reserving storage capacity for customer use. Small sample sizes preclude similar analyses of the other demand flexibility program types.

3.4.1 Thermostat Programs

3.4.1.1 Control Strategy

We categorized Wi-Fi thermostat programs according to the control strategy they employ to reduce demand. Of the 73 Wi-Fi thermostat programs that indicated their control strategy, 45 provided demand flexibility exclusively by changing thermostat set points, while 21 reduced demand exclusively through HVAC cycling (see Table 3). A small share of programs in our dataset uses algorithms to optimize HVAC operation based on time-of-use rates. Additionally, some programs use multiple control strategies. Xcel Energy's Minnesota, for example, either changes thermostat set points or cycles HVAC systems through thermostats in its Energy AC Rewards program.[43] Some programs included automated changes to HVAC operation based on occupancy behavior and or weather. However, we did not treat this approach as separate control strategy as it did not have event-based incentive to flex load, one of our selection criteria. Additionally, it was unclear whether it was a feature of a program or default capability of the thermostats.

Table 2. Breakdown of Wi-Fi thermostat control strategies

Wi-Fi thermostat control strategy	Share of programs
Set point only (n=45)	62%
Cycling only (n=21)	29%
Optimize only (n=1)	1%
Set point and cycling (n=4)	5%
Set point and optimize (n=2)	3%

3.4.1.2 Set point changes

Wi-Fi thermostat programs that control set points may stipulate the maximum upward or downward changes to HVAC set point temperatures to create expectations for participant thermal comfort. For both set point changes, we find little variation across programs. 22 of 24 summer-only programs with reported data (97%) have a maximum set point increase of four degrees for cooling reductions. Of the 16 summer-only programs that also reported a maximum set point *decrease* for pre-cooling, 12 (75%) have a maximum decrease of three degrees. This consistency in set-point changes indicates a high level of industry standardization in program design. We also note that the absence of maximum set point changes reported on program websites and regulatory reports may reflect a lack of reporting and may not indicate that programs do not limit set points.

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[43] For details, see https://www.xcelenergy.com/staticfiles/xe-responsive/Business%20Programs%20&%20Rebates/23-04-537_CO-MN-NM_AC-Rewards_TandC_FINAL.pdf

Relatively few programs that we reviewed require pre-cooling or pre-heating set point changes. Only 16 of the 82 Wi-Fi thermostat programs (20%) reported that pre-cooling is required for event participation. Similarly, three of the eight thermostat programs that operate in the winter reported pre-heating requirements. Again, more programs may have these rules but not include them on the websites and regulatory reports we reviewed.

3.4.2 Battery program details

39 of the 42 battery storage programs in our dataset (95%) require that participating customers own their batteries. In three residential programs operated by Arizona Public Service (Arizona Public Service Company 2022), Green Mountain Power,[44] and Liberty Utilities,[45] the utility owned customer-sited batteries. In this section we review program design details specific to battery storage programs, including dispatch methods, rules on reserved capacity, and charging approaches.

3.4.2.1 Dispatch methods

All but one of the battery programs in our dataset that reported data on dispatch mechanisms (34 of 35) involve battery dispatch in response to event-based signals from utilities or aggregators (e.g. the battery manufacturer). In one of these programs (offered by the Sacramento Municipal Utility District (SMUD)), the battery dispatches in response to the utility's time-of-use rate.[46] SMUD also offers two other tiers of participation that require customers sign up for the utility's critical peak pricing rate.[47] In these program tiers, event-based signals and price signals are effectively the same.

The absence of rate-based dispatch in our battery program collection does not mean that rates do not affect their operations outside of events. For example, customers may set their charge and discharge cycles based on time-of-use rate windows; many batteries include this as an operational mode. Additionally, we describe battery-specific rates in Section 4.3.

The one program in our dataset that does not involve direct dispatch was Hawaiian Electric's Battery Bonus program, in which participating customers commit to a utility-defined schedule for dispatching their batteries for self-consumption or grid discharge.[48] In this program, which involves daily customer dispatch, the battery does not react to a utility signal; customers schedule the battery to discharge for a two-hour period at a time provided by the utility when they sign up. Hawaiian Electric then verifies that battery performance adheres to the agreed schedule using metering data.

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[44] For details, see https://greenmountainpower.com/rebates-programs/home-energy-storage/powerwall/

[45] For details, see https://new-hampshire.libertyutilities.com/bath/residential/smart-energy-use/electric/battery-storage.html

[46] For details, see https://www.smud.org/en/Going-Green/Battery-storage/Homeowner

[47] For details on SMUD's critical peak price rate, see https://www.smud.org/en/Rate-Information/Residential-rates/Critical-Peak-Pricing

[48] See the Battery Bonus participant agreement for details: https://www.hawaiianelectric.com/documents/products_and_services/customer_renewable_programs/rule_31_appendix_A_SDP_agreement.pdf

3.4.2.2 Reserved capacity rules

Battery program designs balance grid needs with participant needs for back-up power. In 14 of the 42 battery programs in our dataset (33%) we found rules on the share of the battery capacity reserved for customer use and the share made available for grid services. The absence of rules identified for the remaining 28 programs may reflect a lack of reporting this information on program websites as opposed to a lack of the rules themselves. The rules we found include minimum (e.g. 51%[49]), maximum (e.g. 80%[50]), and customer-defined capacity levels for utility/aggregator control[51]. The minimum capacity level rules suggest that utilities may wish to ensure a certain level of potential load to control in order to reward program participation. For programs with maximum capacity commitments, reserve capacity rules balance customer and grid economic interests by enabling customer resiliency during outages. We also found that 10 of the 42 battery programs in our dataset (24%) reported that battery discharges would not occur ahead of forecasted major storms. Notably, all of these programs are in cold-climate states (Colorado, Massachusetts, Connecticut, New York, and Rhode Island). This commitment to reserve battery capacity for customer use during storms further illustrates how programs seek to balance participant resilience with providing grid services.

3.4.2.3 Charging approaches

We find that battery programs often allow stand-alone systems and grid charging. Of the 22 programs in our dataset for which found discussion on stand-alone systems, 19 allow it. We also find that 17 of 21 programs that mention grid charging allow it. However, all of these programs also allow customers to use solar to charge their batteries. From the data we collected, it remains unclear how common stand-alone systems and grid charging are relative to combined solar and battery systems and solar charging. Utility motivations for requiring that battery program participants have solar systems can include promoting renewable energy generation and customer resilience. For example, Hawaiian Electric's Battery Bonus program[52] couples storage with customer-sited solar to support the state's renewable energy goals. In particular, the program specifies that batteries should prioritize charging with mid-day solar. Marin Clean Energy's battery program[53] requires solar so that customers can power critical loads for long periods.

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[49] For details on SMUD's battery program, see https://www.smud.org/en/Going-Green/Battery-storage/Business

[50] See description of Portland General Electric's Smart Battery Pilot: https://portlandgeneral.com/pge-smart-battery-pilot-residential-rebate

[51] See details on Cape Light Compact's battery program here: https://www.capelightcompact.org/enrollmybattery/

[52] See details on Hawaiian Electric's Battery Bonus program here: Hawaiian Electric's Battery Bonus program couples storage with solar to support the state's renewable energy goals. See details here: https://www.hawaiianelectric.com/documents/products_and_services/customer_renewable_programs/battery_bonus_QA.pdf

[53] For details on Marin Clean Energy's program, see here: https://www.mcecleanenergy.org/facility-energystorage/

3.5 Enrollment and participation

In this section we characterize levels of enrollment and participation in demand flexibility programs.

3.5.1 Enrollment and participation levels

In this section we review the available data on program enrollment and participation. We use the term enrollment to refer to the number of customers who sign up for a program, and participation to refer to the number of customers who take part in specific events called by the programs (in other words, who do not opt out of program events).

In general, data on enrollment and participation were sparse for all technology types. Of the 148 programs in our dataset, we found reported enrollment data for 27 and reported participation data for 13. We found these data in annual utility demand-side management reports to regulators. Lag in reporting coupled with the recent launch of some of these programs, in particular for pilots, explains some of the lack of data. In other cases, reports simply lack information on enrollment and participation or report it aggregated with other programs. As with other data, we found more enrollment and participation data on Wi-Fi thermostat programs than for other program types.

Wi-Fi thermostat enrollment numbers vary significantly across the programs in our dataset. To account for differences in the number of customers served by utilities, we normalize reported enrollment counts by the number of customers in the customer class(es) that the program serves. We show the distribution of these enrollment levels by customer class in Figure 14. Enrollment levels vary by a factor of about 60, ranging from less than 0.1% in Xcel Energy New Mexico's Smart Thermostat program to 5.7% in Austin Energy's Power Partner program (Xcel Energy 2022; Austin Energy 2022).[54] Given that about 10% of households in the U.S. had smart thermostats in 2020, most of the Wi-Fi thermostat programs in our dataset have significant room for growth (Hronis and Beall 2020). For Bring-Your-Own-Device programs, increased program participation is dependent on increased market adoption of Wi-Fi Thermostats. Building codes that incentivize or require Wi-Fi thermostats in new construction or renovations can increase this adoption. California, for example, requires that some new non-residential buildings have HVAC controls capable of demand response and that certain non-residential retrofits of HVAC systems include Wi-Fi thermostats (California Energy Commission 2022). To reach levels of Wi-Fi thermostat program participation above the levels of market- and code-driven Wi-Fi thermostat penetration, programs that incentivize adoption will be necessary.

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[54] Enrollment in residential demand response programs overall can be higher than what we found reported for Wi-Fi thermostat programs. For example, Pepco reported that in 2021 294,650 customers, 55% of its residential customers, were enrolled in its Residential Demand Response Program, which includes both Wi-Fi thermostats and outdoor switches (Pepco 2022). In 2017, the most recent year in which Pepco program reported enrollment by technology, 72% of the 249,952 enrollees had outdoor switches and 28% had thermostats (Pepco 2018). In 2021, this level of Wi-Fi thermostat enrollment would have corresponded to 13% of customers. Since Pepco did not provide a similar breakdown in 2021, Figure 14 does not include data from Pepco's programs.

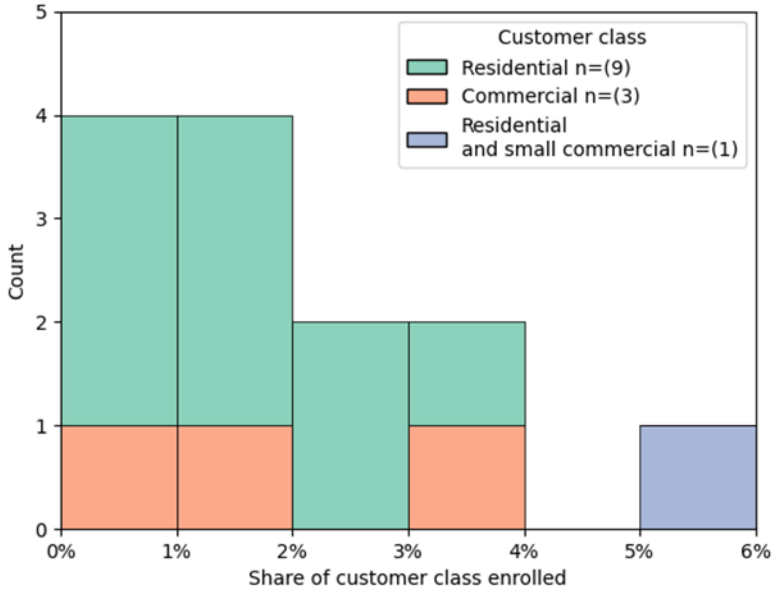

Figure 14. Wi-Fi Thermostat program participation as share of customers in eligible customer class(es)

For battery storage, we only found two programs with reported enrollment counts, 35 and 125, which both corresponded to less than .01% of customers in eligible customer classes. These low enrollment levels are not surprising given that battery programs are newer and less established than Wi-Fi thermostat programs. Notably, the one building automated system program in our dataset that reported participation data (Public Service Company of New Mexico's Peak Saver program) had 157 participants, or 81% of its industrial customers.

Due to limited data, we are not able to make any conclusions about the typical levels of event participation relative to customer enrollment. We also encountered varying definitions of participation that confounded the analysis. For example, it was ambiguous whether reported cumulative participants were counts of unique customers or whether customers who participated in multiple events were counted multiple times. We also found participants reported in units of utility customers and thermostats (which may not be the same, since programs may allow more than one thermostat per household) (Entergy Arkansas 2022; SMECO 2022). Finally, it was sometimes unclear whether utilities reported participant or enrollment counts.[55] Standardized reporting of program enrollment and participation would enable analysis that addresses how frequently enrollees participate.

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[55] See Consumer Energy's demand response program costs for details: https://mi-psc.my.site.com/sfc/servlet.shepherd/version/download/0688y000002qVlYAAU

3.5.2 Enrollment caps

As with any utility program, demand flexibility programs may have enrollment caps. These caps may set a maximum number of participants (for example, in Wi-Fi thermostat programs) or a maximum capacity of enrolled batteries. Across technology types, we find that 12 of the 148 programs in our dataset (8%) had enrollment caps and that the enrollment caps are somewhat more common in battery programs (6 of 42 programs, 14%) than in Wi-Fi thermostat programs (5 of 83 programs, 6.0%). The higher frequency of enrollment caps in battery programs may reflect their novelty or greater requirements for upfront effort from utilities, such as during the interconnection process, relative to Wi-Fi thermostat programs.

3.6 Energy and demand savings and costs

In this section we describe reported demand flexibility program costs and demand reductions.

Of the 148 programs in our dataset, we only found reported demand reductions for 31 and reported program spending for 21. This lack of program-level savings and spending data is not simply due to an absence of reporting. In many cases, the reported savings and spending combined the program of interest with related initiatives. For example, a utility may aggregate spending from multiple demand response programs, including those that are out of scope in this analysis.

To facilitate comparison between programs, we divided annual reported demand reductions by the reported number of events to estimate average demand reductions per event across all participants. Since many programs did not report event numbers, we could only estimate this average performance for 17 programs, which we show in Figure 15. While these data are limited, they do show a wide range of program impact. This range may result from differences in utility size, enrollment levels, event opt-outs, and per-household demand reductions.

Due to a lack of reported participation data, we were only able to calculate demand reductions per participant per event for five programs. The kW/participant/event in these programs ranged from 0.06 to 0.9.

Of the 21 programs with spending data, 19 also reported demand reductions. These data allowed us to calculate the first-year cost of saved peak demand, which we show in Figure 16.[56] Ten of the 19 programs have a cost of saved peak demand below $100 per kW.[57] Across the 15 Wi-Fi thermostat programs, we find a savings-weighted average first year cost of saved peak demand of $39 per kW. Comparing against other data on the cost of capacity, we find that Wi-Fi thermostat program costs are below the peak demand reduction cost of the least cost energy efficiency program, residential lighting (Frick et al. 2021).

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[56] Note that this figure does include pilots, which can have higher cost of peak demand. The Wi-Fi thermostat program in the rightmost bin with a cost of saved peak demand of $875 per kW is a pilot.

[57] Costs include program administration, marketing, evaluation, and customer incentives.

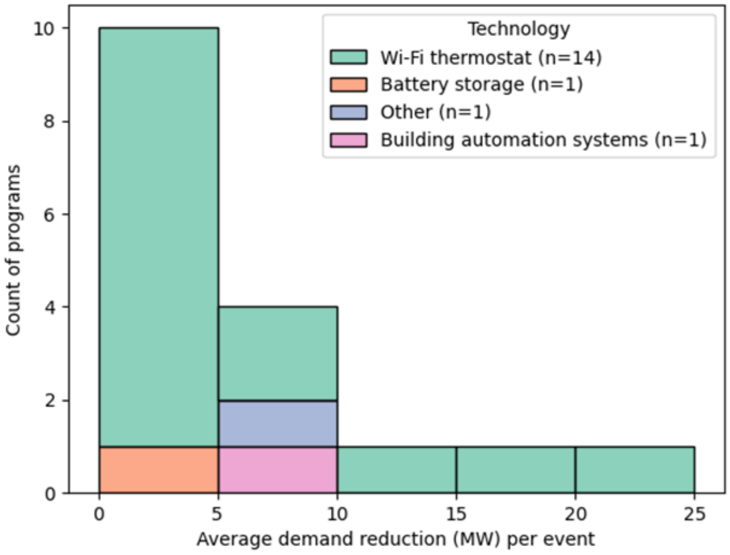

Figure 15. Average demand reductions per event across all participants by demand flexibility technology

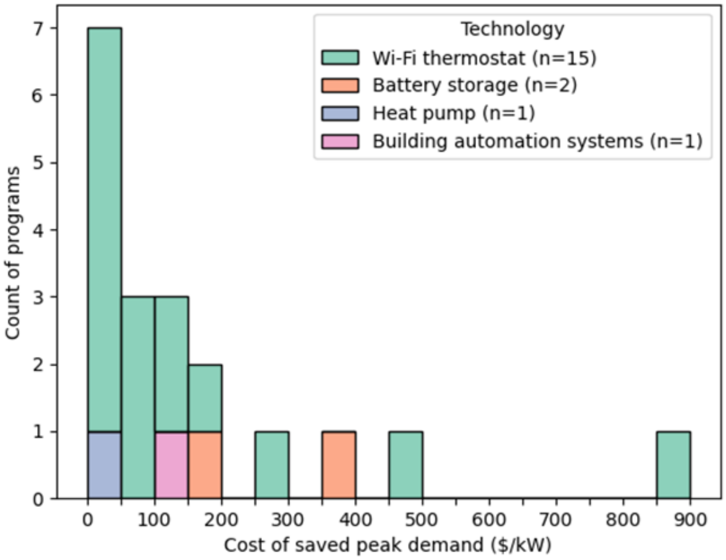

Figure 16. The first-year cost of saved peak demand by demand flexibility technology type

4. Demand flexibility rate characteristics

4.1 Dynamic Rates

We present dynamic rates by their rate components in Figure 17. We collect rates with a dynamic component for eligibility (i.e., critical peak price (CPP), critical peak rebate (CPR), variable peak price (VPP), and real-time price (RTP). We also track the presence of other components in those rates (i.e., flat vs. time-of-use rates, seasonality, and demand charges). 38 of our collected rates are CPP, four are CPR, six are VPP, and 21 are RTP. There is no overlap in dynamic rate components (i.e., no rates are in multiple dynamic categories).

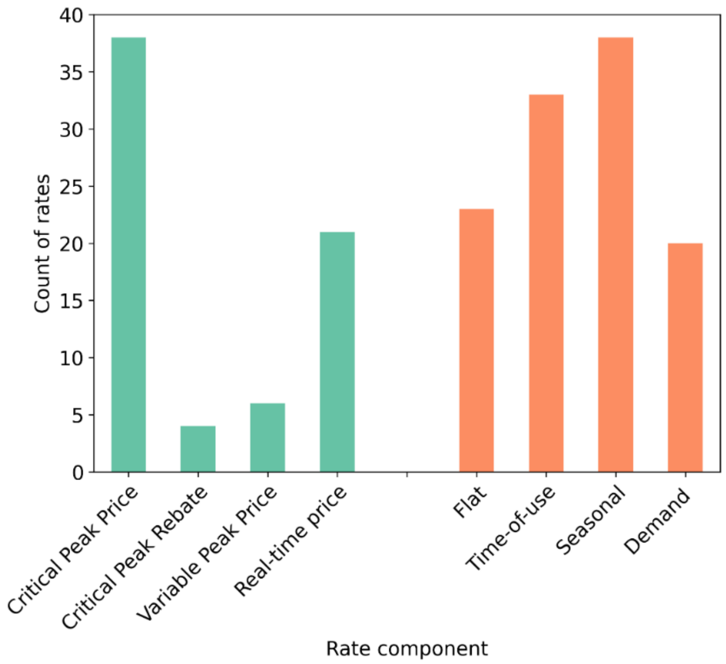

Figure 17. Dynamic rates by rate components

4.1.1 Dynamic rate events

In this section we provide details about events called under the CPP, VPP, and CPR rates that we collected.

The CPP and VPP rates generally set a maximum number of events that the utility can call in a year, whereas the VPP and CPR rates do not. We present the maximum event limits for the rates in our dataset in Figure 18. Every utility applies the same maximum number of events for all of its rates. The maximum number of allowed CPP events range from ten to 20 with a median of 15. Four out of fifteen utilities with CPP rates have 15 maximum events (Indiana Michigan Power Company (IN), Pacific Gas and Electric, Southern California Edison, and Xcel Energy (CO)), which represents the median maximum number of annual CPP events in our data. Two utilities have ten maximum events, the lowest maximum amount (Green Mountain Power and Ohio Edison Company); one utility has 20, the highest maximum amount (Duke Energy Carolinas, North Carolina).

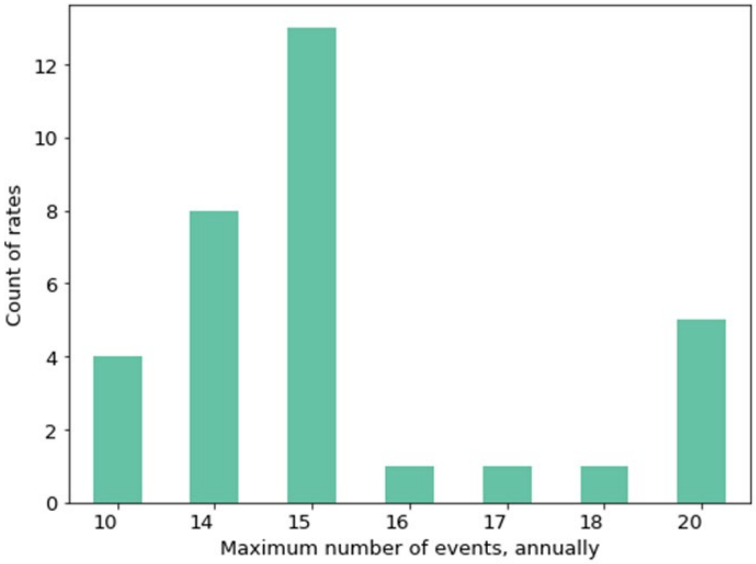

Figure 18. Maximum annual number of events for CPP rates

CPP rates also set a maximum number of event hours (see Figure 19). The event period often corresponds to the peak period for a utility's time-of-use rate. In most cases, the event length for critical peak events is fixed, meaning it is both the same length and during the same hours every time. The exceptions are Indiana Michigan Power Company and Alabama Power Company: these utilities specify the critical peak event length when notifying customers about an upcoming event. In our collection, maximum event lengths range from two to eight hours with a median of five hours.

In most cases, customers are alerted of a CPP event the day before. The exception is an Alabama Power rate whose customers are notified at least 15 minutes prior to the beginning of the event period.[58]

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[58] Alabama Power's Critical Peak Pricing rate can be found here: https://www.alabamapower.com/content/dam/alabama-power/pdfs-docs/Rates/XCPP.pdf

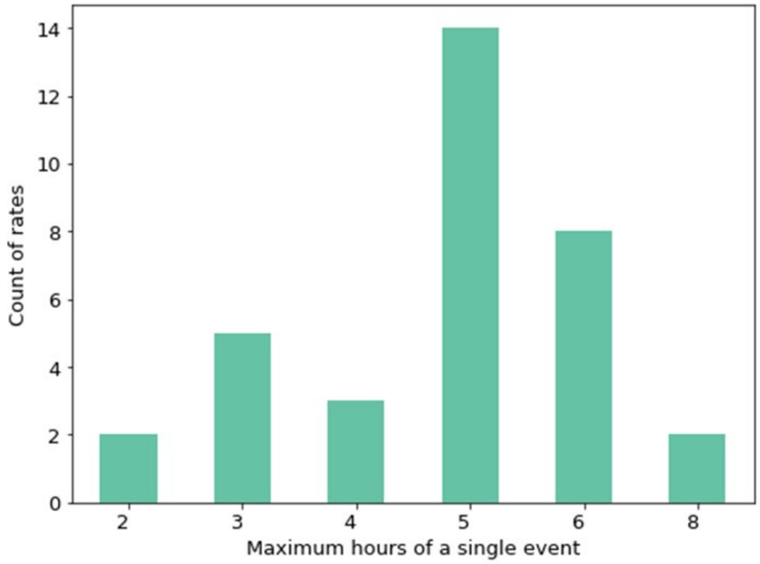

Figure 19. Maximum event length in hours for CPP rates

The six VPP rates we collected are collectively offered by two utilities: Oklahoma Gas and Electric and Eversource Energy (CT).[59] For these rates, the number of maximum annual events is not guaranteed; however, Oklahoma Gas and Electric states that the schedule is intended to only generate ten critical peak events per year. The maximum length of a single event for Oklahoma Gas and Electric is eight hours. Oklahoma Gas and Electric's Flex Price rate applies to all hours where customers can participate in the summer or winter season separately. The Eversource VPP rate is active during all months and effectively a two-period time-of-use rate where the on-peak rate is determined daily based on energy purchases; it does not have a maximum number of annual events or flexible event window. While the number of expected critical peak events is similar to CPP events, VPP rates can offer multiple "middle grounds" between the base rate and the highest peak price; customers may be able to tolerate more events and longer events when the lower tiers of VPP rates are called.

Generally, both CPP and VPP peak event windows occur in the afternoon (see Figure 20). Two rates from Indiana Michigan Power Company allow events to be called as early as 7 AM. Most CPP and VPP events only occur during the summer, from June through September, with a smaller number that also occur in May (See Figure 21). Only one CPP rate (Salt River Project) and one VPP rate (Eversource Energy) include events callable throughout the year, including in the winter months. It is notable that during winter months, the Salt River CPP rate's event window is in the early morning whereas the event window is in the afternoon during the summer.[60] In comparison to program events (see Figure 5), even fewer rates allow winter events to be called.

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[59] For details on Eversource's VPP rider, see: https://www.eversource.com/clp/vpp/downloads/VPP_Rider.pdf
For details on Oklahoma Gas and Electric's rates, see: https://www.oge.com/wps/wcm/connect/30784d6b-ee79-45cf-9e0c-33136f649918/6.50+-+GS-VPP+-+Stamped+Approved.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-30784d6b-ee79-45cf-9e0c-33136f649918-oet-GaA

[60] For details on Salt River Project's CPP rate, see: https://www.srpnet.com/assets/srpnet/pdf/price-plans/residential-electric/ratebook.pdf

The four CPR rates we collected are offered by Avista Corp, Commonwealth Edison Company, Consumers Energy Company, and Delmarva Power. All four of these rates do not guarantee a maximum number of events; maximums are presumably not necessary when offering a reward for action rather than increasing the price. The Avista Corp and Commonwealth Edison Company rates have a maximum event window of seven hours; the Consumers Energy Company rate has a maximum window of 6 hours; and the Delmarva Power CPR rate event window is always two hours. Three CPR rates have events that largely occur during summer afternoons, but the Consumers Energy Company rate has both a summer event window in the afternoon and a winter event window in the evening. [61]

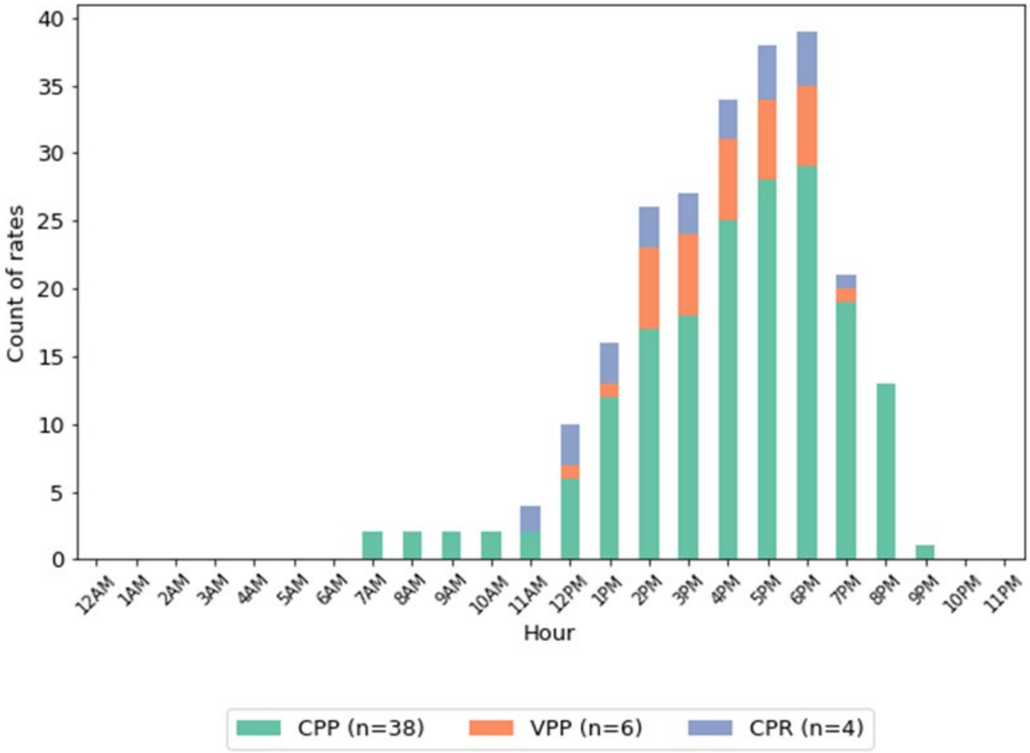

Figure 20. Count of event window occurrence by hour for CPP, VPP, and CPR rates

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[61] For details on Consumers Energy Company's CPR rate, see: https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/consumer/rate-books/electric/consumers/consumers-retired/consumers13cur.pdf?rev=3de85a1e663c4c088f875d78e0e0e402&hash=6D0E2D97838AC1BD1D85D64260E493D5

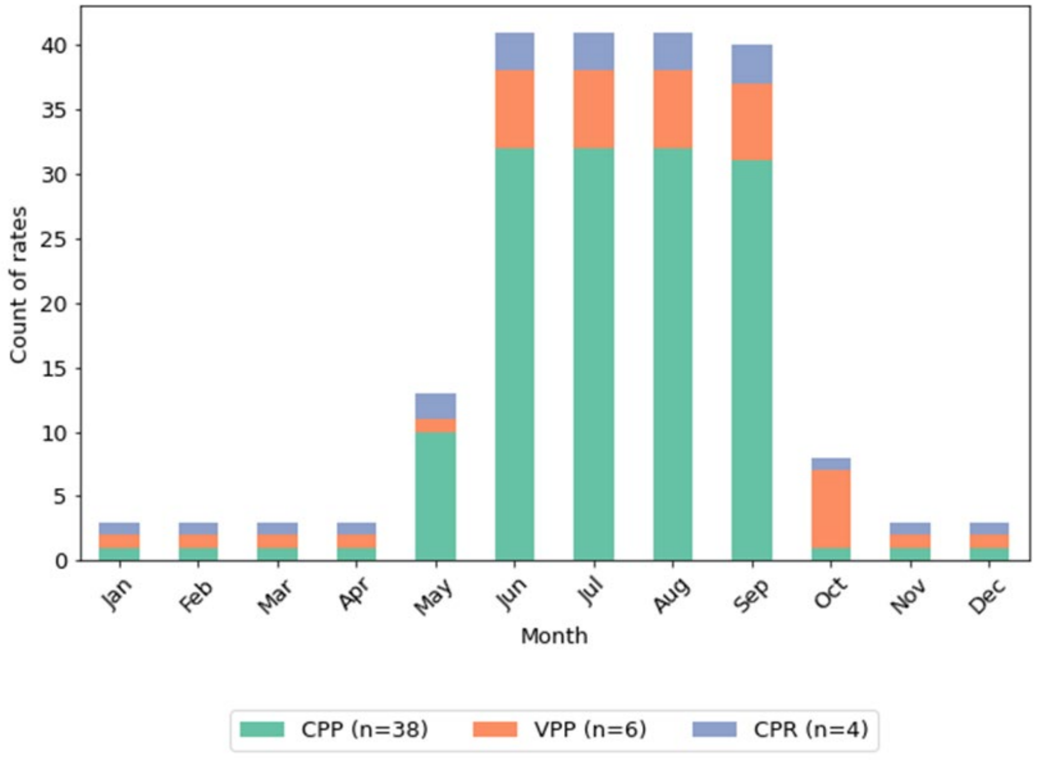

Figure 21. Count of event window occurrence by month for CPP, VPP, and CPR rates

We present CPP event prices in Figure 22. These prices range from $0.1/kWh (Duke Energy Ohio) to $1.44 (for Xcel Energy and Southwestern Public Service Company) and have median of $0.74/kWh (NV Energy).[62] As shown in Figure 22, most CPP rates with event prices above $1.00/kWh are C&I rates, and six CPP rates have event prices of $1.35/kWh or higher (for Xcel Energy and Southwestern Public Service Company, which are both Xcel Energy companies).

We calculated the CPP event ratio by dividing the event price by the volumetric rate during the same period (i.e., what the customer pays for electricity during a non-event) (see Figure 23). Most residential rates exhibit lower ratios while C&I rates exhibit a wider range. The five highest C&I rates have ratios around 180:1; again, these are the Xcel Energy and Southwestern Public Service Company rates. These rates not only have high CPP event prices, but they also include demand charges, and therefore have smaller volumetric charges. The two CPP rates for Consumer Energy Company exhibit the largest ratios for residential rates, above six, largely due to the highest event prices out of all residential rates ($0.95/kWh).

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[62] See Duke Energy Ohio's CPP rate here: https://www.duke-energy.com/-/media/pdfs/for-your-home/rates/electric-oh/sheet-no-32-rate-td-am-oh-e.pdf?rev=a037be54dc3c4615891c740896d4c5d2
See Xcel Energy's CPP rate here: https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Regulatory%20Filings/PSCo_Electric_Entire_Tariff.pdf

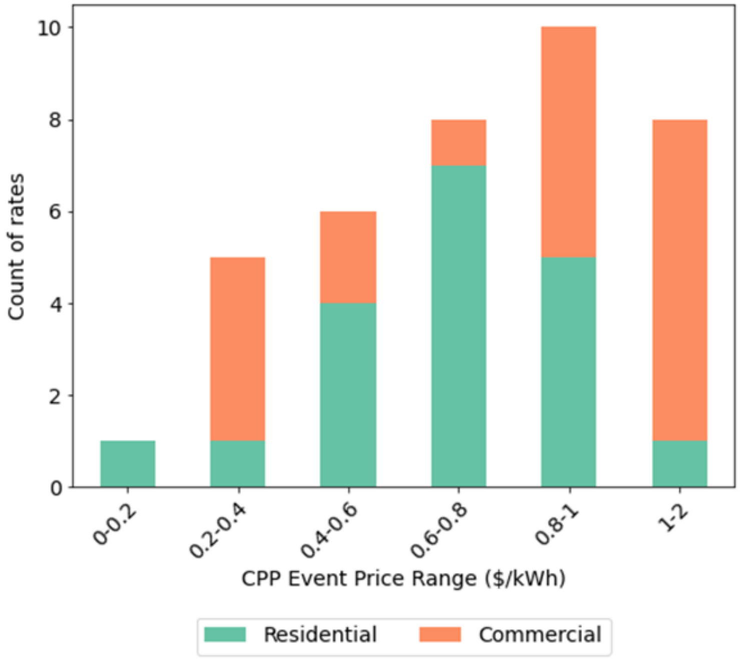

Figure 22. Distribution of event prices for collected CPP rates

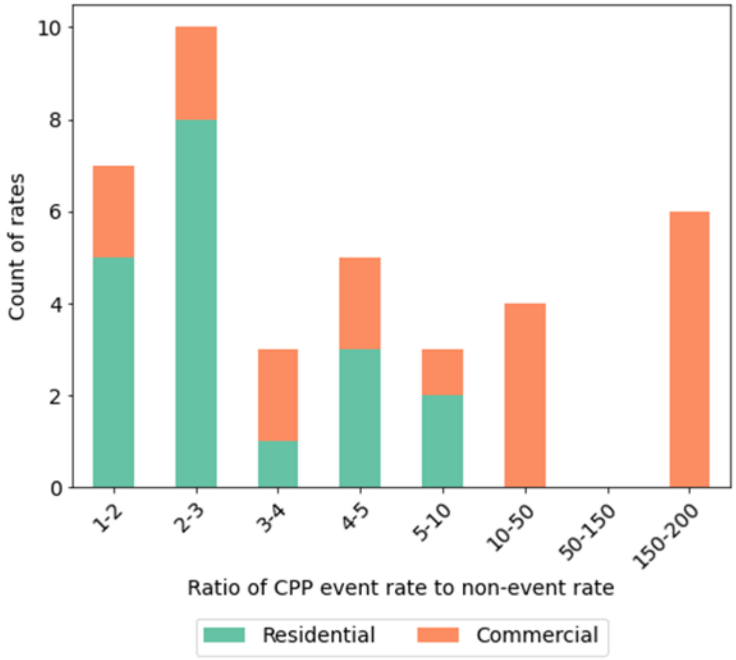

Figure 23. Ratio of CPP event price to price outside of events

For VPP rates, the peak period price is determined every day (during the applicable season) based on a market signal. Eversource Energy's peak rate is calculated every day, but the VPP rider does not detail its calculation.[63] Oklahoma Gas and Electric's peak rates are determined by assigning the peak period rate to one of four discrete tiers based on the day-ahead price excluding the energy portion of marginal supply costs.[64] We show the four tiers of OGE's residential and general service VPP rates (at time of publication) in Table 4. The "Low" rate shown in the table is equivalent to the off-peak price, where other tiers have rates that range from 2.4 to 14 times higher than the Low price.

Table 3. Variable peak prices for Oklahoma Gas and Electric's residential and general service VPP rates

	Residential VPP (¢/kWh)	General Service VPP (¢/kWh)
Low	3.60	3.21
Standard	8.50	9.00
High	19.70	23.00
Critical Peak	41.60	45.00

4.2 Real Time Pricing

We collected 21 rates that include real time pricing from the ten states shown in Figure 24. RTP rates are more difficult to summarize since the retail price of electricity in each interval is directly correlated to current wholesale prices and could take on any value. By contrast, variable peak pricing is often determined based on wholesale prices, but the retail price of electricity falls into discrete, pre-determined levels. Because RTP rates determine prices for every hour of the day, they do not include events in the sense that CPP and VPP rates do.

We find that most RTP rates are determined on an hourly interval where the real time pricing component is added to a flat rate. Generally, hourly prices are posted for each hour of the following day by times from 4 pm to midnight of the previous day. Five RTP rates offered by Southern California Edison have time-of-use charges incorporated into the real-time pricing rate.

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[63] For details on Eversource's VPP rider, see: https://www.eversource.com/clp/vpp/downloads/VPP_Rider.pdf

[64] For details on Oklahoma Gas and Electric's rates, see: https://www.oge.com/wps/wcm/connect/30784d6b-ee79-45cf-9e0c-33136f649918/6.50+-+GS-VPP+-+Stamped+Approved.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-30784d6b-ee79-45cf-9e0c-33136f649918-oet-GaA

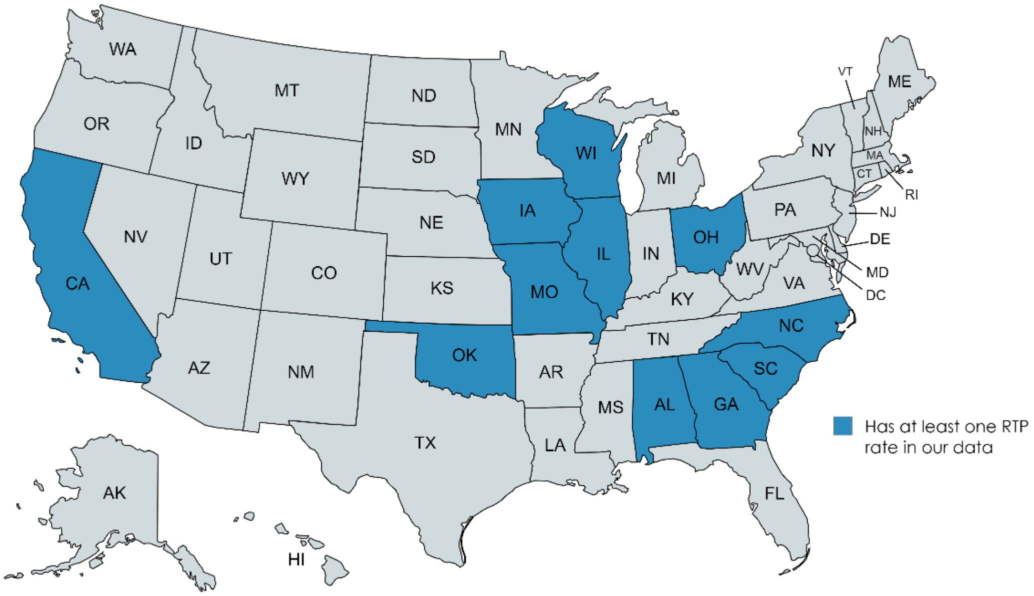

Figure 24. States where utilities in our sample have real time pricing rates.

Note that we did not review all utilities in each state; see Section 2.2.2.

4.3 Technology Rates

We categorize technology rates by their specific technology requirements in Figure 25. Categorization is not exclusive, and rates may have multiple eligible technologies (e.g., Pacific Gas and Electric's Electric Home rate is available to customers with electric vehicles, energy storage, or heat pumps for space conditioning or water heating).[65] Most rates with technology requirements include battery (n=16) or thermal storage (n=10). A smaller number list thermostats, space heating, and water heating technologies as conditions of eligibility where they are bundled together and provide greater level of utility control over multiple technologies within the home. The "other" category consists of Arizona Public Service's Technology Time-of-Use with Demand Charges rate and Consumers Energy's Residential

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[65] See Pacific Gas and Electric's Electric Home rate here: https://www.pge.com/en/account/rate-plans/find-your-best-rate-plan/electric-home.html

Summer On-Peak: Device Cycling Program rate, which include open-ended language for technologies with variable speed motors, cycling capabilities, or automated load control.[66]

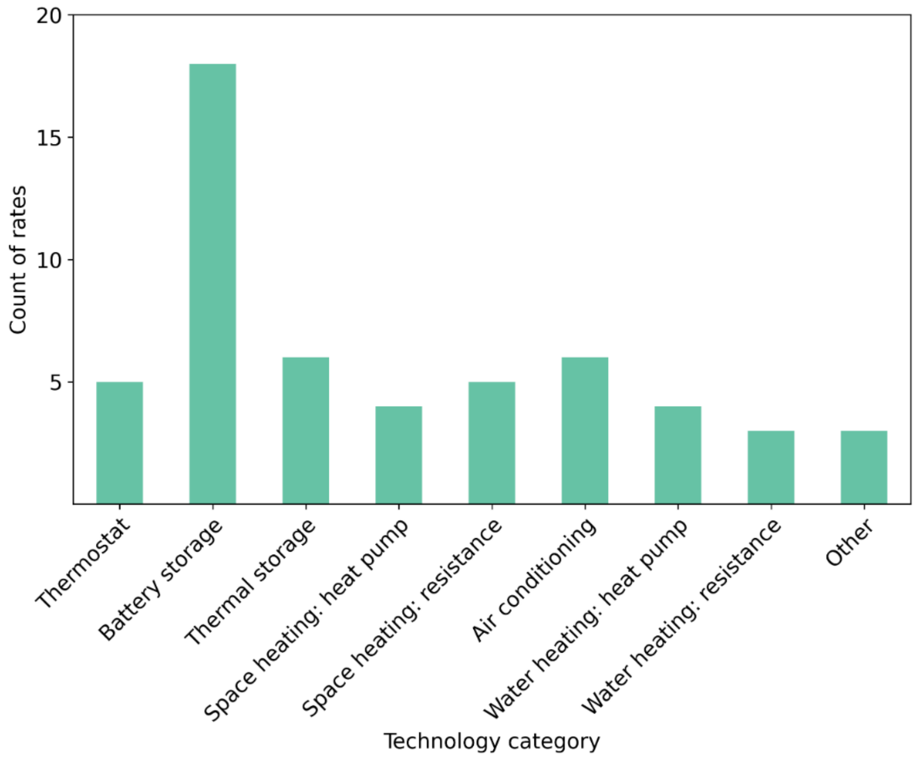

Figure 25. Count of technology rates by demand flexibility technology

For the 27 rates collected with technology requirements, we analyzed how they might enable demand flexibility. Broadly, we find that every rate includes a time-of-use component unless the rate applies more broadly to whole-building load management. Generally, the rates are defined by five broad categories:

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[66] See details on Arizona Public Service's TOU rate with demand charges here: https://www.aps.com/-/media/APS/APSCOM-PDFs/Utility/Regulatory-and-Legal/Regulatory-Plan-Details-Tariffs/Residential/Service-Plans/TechnologyTime-of-UsewithDemandCharge.ashx?la=en#:~:text=TECHNOLOGY%20TIME%2DOF%2DUSE%20WITH%20DEMAND%20CHARGE,-DESCRIPTION&text=The%20demand%20charge%20will%20also,Peak%20or%20Off%2DPeak).&text=The%20On%2DPeak%20time%20period,hours%20are%20Off%2DPeak%20hours.
For details on Consumers Energy's Residential Summer On-Peak: Device Cycling Program rate, see https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/consumer/rate-books/electric/consumers/Consumers_14_current.pdf?rev=3f02552bac794d6f90b278e11b8ac430&hash=C22AF93016E8E3BD643F1F4EA47EFCC0

- A time-of-use rate that is only available to buildings with technology in place, but no requirements around how technology is controlled or managed (e.g., Arizona Public Service rates)[67]
- A time-of-use rate where a technology has operating requirements but is not controlled by the utility (e.g., Indiana Michigan Power's Residential Off-Peak Energy Storage rate requires that thermal storage must only operate during off-peak hours; Minnesota Power requires that energy storage only operate between 10pm and 6 am for Off-Peak Service)[68]
- A time-of-use rate where energy storage technologies must provide some specific service, such as market participation or grid peak shaving (e.g., Central Maine Power's General Service Energy Storage rate requires energy storage to provide one or more service such as reactive power voltage support, operating reserves, regulation and frequency response, balancing energy supply and demand, or addressing a reliability concern)[69]
- A rate where the utility can control the customer's thermostat to change temperature settings (e.g., Commonwealth Edison's Peak Time Rebate rate)[70]
- A rate where the utility can cycle multiple devices connected to single load management system (e.g., Consumer Energy's Device Cycling Program within the Summer On-Peak Basic Rate)[71]

For the rates with a technology requirement, 13 apply to chemical energy storage (i.e., batteries) exclusively where six of them are C&I time-of-use rates only available to buildings with energy storage and do not impose additional operating requirements—the other seven rates require storage to be controlled by the utility or third-party (Central Maine Power, Evergy Kansas Central Co, and Portland General Electric). Four additional rates are available to either chemical or thermal energy storage (i.e., water heaters). Two of these rates are also time-of-use rates without additional requirements, while the other two rates include operational requirements where technologies can only operate during off-peak hours.

The other 10 rates are available to different technologies. Two rates apply to thermostats only, where the utility can control the setting. One rate applies to air conditioning devices only, where the

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[67] See details on Arizona Public Service's TOU rate here: https://www.aps.com/-/media/APS/APSCOM-PDFs/Utility/Regulatory-and-Legal/Regulatory-Plan-Details-Tariffs/Residential/Service-Plans/TechnologyTime-of-UsewithDemandCharge.pdf?sc_lang=en

[68] For details on Indian Michigan Power's storage rate, see: https://www.indianamichiganpower.com/lib/docs/ratesandtariffs/Indiana/IMINTB1902-29-2024.pdf
For details on Minnesota Power's storage rate, see: https://minnesotapower.blob.core.windows.net/content/Content/Documents/CustomerService/mp-ratebook.pdf

[69] For details on Central Main Power's storage rate, see https://www.cmpco.com/documents/40117/46387176/b-es_12.30.22.pdf/1eb01d6d-6480-31c2-44bd-ca125ec64d27?t=1673283671077

[70] For details on Commonwealth Edison's Peak Time Rebate rate, see https://www.comed.com/SiteCollectionDocuments/MyAccount/MyBillUsage/CurrentRates/Ratebook.pdf

[71] For details on Consumer Energy's rate, see https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/consumer/rate-books/electric/consumers/Consumers_14_current.pdf?rev=3f02552bac794d6f90b278e11b8ac430&hash=C22AF93016E8E3BD643F1F4EA47EFCC0

technology can only operate during off-peak hours.[72] Other rates apply to many different technologies, with the intention of enabling management of multiple building end uses and establishing some level of control over functionality.[73]

4.4 Enrollment and energy outcomes

Unlike demand-side management programs, utilities are not generally required to report on enrollment or energy outcomes for rate structures. Therefore, we were not able to gather sufficient data on these outcomes to conduct any analysis on these topics. In a few cases, utilities do report on rate-related outcomes in demand-side management evaluations, but this is infrequent. Arizona Public Service, for example reported enrollment levels and estimates of demand reductions from its residential rate its 2021 Demand Side Management Report (Arizona Public Service Company 2022)

The closest thing to a dataset of rate enrollment we are aware of is EIA's Form 861 dynamic pricing data. For each responding utility, these data indicate whether the utility offers each of the following rate options: critical peak pricing; critical peak rebate; real-time pricing; variable peak pricing; and time-of-use pricing.[74] The data also provide a count of customers enrolled in these rates. Unfortunately, this count indicates the total number of participating customers in all five rate types collectively. Time-of-use rates are by far the most common of the rate types EIA tracks, and are out of scope for this analysis. Therefore, the participant counts are not useful for estimating counts or shares of customers on rates that we classify as dynamic rates.[75] EIA might consider collecting enrollment counts by rate category, which could then allow analysis of whether certain rate designs are more or less successful at recruiting participants. Barbose, Goldman, and Neenan 2004 were able to access enrollment data for a number of RTP programs, though these data are now 20 years old and many of these rates are no longer offered.

In terms of energy outcomes, a substantial literature has demonstrated that CPP rates (Herter 2007; Herter, McAuliffe, and Rosenfeld 2007; Herter and Wayland 2010; Jang et al. 2015; Piette et al. 2006) critical peak rebates (Wolak 2007), and RTP rates (Allcott 2009) do reduce electricity consumption during events. Herter, McAuliffe, and Rosenfeld 2007 documented larger event reductions from customers with programmable communicating thermostats than from other customers, highlighting the importance of technology in facilitating demand flexibility. These studies generally review a single dynamic pricing implementation for which detailed data are available. More similar analyses of the

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[72] For details on Pacific Gas and Electric's E-RATE, see: https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_E-RSAC.pdf

[73] An example of this type of rate is Arizona Public Service's R-TECH rate, which can be found here: https://www.aps.com/-/media/APS/APSCOM-PDFs/Utility/Regulatory-and-Legal/Regulatory-Plan-Details-Tariffs/Residential/Service-Plans/TechnologyTime-of-UsewithDemandCharge.ashx?la=en

[74] We cross-checked our collected rates by utility against the 2022 EIA-861 data, which are self-reported by utility, and double-checked our collection where discrepancies emerged. In the significant majority of cases, our collected rate types by utility matched the EIA-861 data. In a number of cases, they did not, and we were not always able to determine why. Some utilities might have classified rates differently than we did; in other cases, the timing of our data collection might be responsible for the differences.

[75] Despite the title of the EIA dataset ("dynamic pricing"), we do not consider time of use rates to meet our definition of dynamic rates.

energy impacts of dynamic rates could facilitate cross-utility analysis of success factors for these rates; however, these analyses are not generally required of utilities and are expensive to conduct.

5. Discussion and conclusions

This section summarizes our most critical findings from the previous sections and identifies key conclusions for the design and evaluation of future demand flexibility rates and programs.

Among the demand flexibility programs we collected, Wi-Fi thermostat and battery storage programs are most common. Wi-Fi thermostat programs are mature and available from many utilities; battery storage programs are still emerging and less widely available. Thermal storage programs are less common. Some programs we collected allow multiple end-use technologies, and some allow participation by building automation systems that control multiple end uses.

Most rates that promote demand flexibility are dynamic rates that vary electricity pricing based on grid conditions. These dynamic rate elements may be built on top of either “flat” or time-varying base rate structures. Dynamic rates are fairly common, and often available in both residential and C&I sectors. Among dynamic rates, critical peak pricing rates are by far the most common. Real-time pricing rates, variable peak pricing rates, and critical peak rebates (which blur the line between rates and programs) are less common. Among critical peak pricing rates, peak prices and ratios of peak-to-non-peak prices vary significantly by utility; in general, the CPP rates with the most aggressive pricing are C&I rates. Rates that promote demand flexibility through technologies are somewhat split between being available exclusively for energy storage, with mixed level of operation restrictions or control, or offering whole-building availability where utilities have some level of control. Technology rates infrequently have dynamic pricing components, where the intention appears to largely be either controlling building loads or incentivizing specific technology adoption.

Notably, most programmatic and rate-based efforts to procure demand flexibility focus on reducing demand during summer peaks driven by space conditioning consumption (see Figures 5 and 21). Most parts of the country have summer-peaking electricity systems that drive a disproportionate share of costs, so addressing these peaks remains an appropriate focus. Nonetheless, a more fulsome vision for demand flexibility in buildings involves the provision of a wider variety of grid services (Satchwell et al. 2021), and programs and rates will need to evolve in order to support that vision. If building owners electrify space and water heating technologies, more utilities may become winter-peaking (Zhou and Mai 2021); renewables integration may motivate the need for specific dispatch patterns that are different from those to deal with peak load; voltage or frequency support may be needed at very different times. A subset of our collected programs does address other electricity system needs – some programs call events during the winter, while a few programs and rates can potentially call events year-round. Moreover, we did not collect every program and rate, and we expect that other novel and emerging approaches exist.

Data on enrollment, participation, and energy outcomes of demand flexibility programs and rates are largely insufficient to relate differences in outcomes to program and rate characteristics. This is particularly true for rates, whose impacts are not routinely evaluated. Evaluations of demand flexibility programs could deliver more value for cross-program analysis by consistently reporting enrollment, participation, and energy outcomes in a standardized fashion. Similarly, the Energy Information Administration (EIA) could modify how it collects and reports utility-level data on dynamic pricing and demand response. EIA Form 861 currently tracks demand response program enrollment, energy and demand savings, potential demand savings, and program costs at the utility-level (EIA 2021). Collection of data for individual program types (e.g. Wi-Fi thermostats) would give better visibility into the scale and impact of utility programs that promote demand flexibility. EIA currently tracks and reports the total number of customers on time-varying rates (including time-of-use rates) for each utility. Tracking enrollment for each type of dynamic rate (e.g. VPP vs CPP) would be more helpful.

On the program side, the data we were able to collect suggests that Wi-Fi thermostat programs are competitive with energy efficiency programs in terms of the cost required to procure reductions in peak demand. However, we find variable levels of enrollment in these programs (see Figure 14). These findings suggest that strategies that increase the participation of existing enrollees – such as opt-out rates or programs where such designs are reasonable – may deliver high value.

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APPENDIX A. Universe of utilities in program and rate screen

In Table A-1 we list the utilities and program administrators we reviewed for demand flexibility programs and rates.

Table A-1. Universe of utilities for program and rate collection

State	Utility/program administrator name	Utility/program administrator type	Screened for programs	Screened for rates
AK	Chugach Electric Association	Cooperative	Yes	Yes
AK	Golden Valley Elec Association	Cooperative	Yes	Yes
AK	Matanuska Electric Association	Cooperative	Yes	Yes
AL	Alabama Power Company	Investor-owned	Yes	Yes
AR	Entergy Arkansas	Investor-owned	Yes	Yes
AR	Southwestern Electric Power Company	Investor-owned	Yes	Yes
AZ	Arizona Public Service	Investor-owned	Yes	Yes
AZ	Salt River Project	State	Yes	Yes
AZ	Tucson Electric Power	Investor-owned	Yes	No
AZ	UniSource Energy Services	Investor-owned	Yes	No
CA	Bay Area Regional Energy Network	Third party	Yes	No
CA	Los Angeles Department of Water & Power	Municipal	Yes	No
CA	Marin Clean Energy	Community choice aggregator	Yes	No
CA	Pacific Gas & Electric	Investor-owned	Yes	Yes
CA	Pacific Power	Investor-owned	Yes	No
CA	Sacramento Municipal Utilities District	Municipal	Yes	No
CA	San Diego Gas & Electric	Investor-owned	Yes	No
CA	Southern California Edison	Investor-owned	Yes	Yes
CO	Xcel Energy	Investor-owned	Yes	Yes
CT	Eversource	Investor-owned	Yes	Yes
CT	United Illuminating Company	Investor-owned	Yes	No
DC	Potomac Electric	Investor-owned	Yes	Yes
DE	Delmarva Power	Investor-owned	Yes	Yes
FL	Florida Power & Light	Investor-owned	Yes	Yes
FL	Gulf Power Company (now part of Florida Power and Light)	Investor-owned	Yes	No
FL	Progress Energy Florida (Duke Energy)	Investor-owned	Yes	Yes
FL	Tampa Electric	Investor-owned	Yes	No
GA	Georgia Power Company	Investor-owned	Yes	Yes
HI	Hawaiian Electric Company	Investor-owned	Yes	Yes
IA	Alliant Energy	Investor-owned	Yes	No
IA	MidAmerican Energy	Investor-owned	Yes	Yes
ID	Avista	Investor-owned	Yes	No
ID	Idaho Power	Investor-owned	Yes	Yes

ID	Rocky Mountain Power	Investor-owned	Yes	No
IL	Ameren	Investor-owned	Yes	No
IL	Commonwealth Edison	Investor-owned	Yes	Yes
IL	MidAmerican Energy	Investor-owned	Yes	No
IN	AES Indiana	Investor-owned	Yes	No
IN	CenterPoint Energy	Investor-owned	Yes	No
IN	Duke Energy Indiana	Investor-owned	Yes	Yes
IN	Indiana Michigan Power	Investor-owned	Yes	Yes
IN	NIPSCO	Investor-owned	Yes	Yes
KS	Evergy Kansas Central	Investor-owned	Yes	Yes
KS	Evergy Kansas South	Investor-owned	Yes	Yes
KY	Kenergy Corp	Investor-owned	Yes	Yes
KY	Kentucky Utilities	Investor-owned	Yes	Yes
KY	Louisville Gas & Electric	Investor-owned	Yes	Yes
LA	Entergy Louisiana	Investor-owned	Yes	Yes
LA	Entergy New Orleans	Investor-owned	Yes	No
MA	Cape Light Compact	Community choice aggregator	Yes	No
MA	Eversource	Investor-owned	Yes	Yes
MA	National Grid	Investor-owned	Yes	Yes
MA	Unitil	Investor-owned	Yes	No
MD	Baltimore Gas & Electric Company	Investor-owned	Yes	Yes
MD	Delmarva Power	Investor-owned	Yes	No
MD	Potomac Electric Power Company	Investor-owned	Yes	Yes
MD	Southern Maryland Electric Cooperative	Cooperative	Yes	No
ME	Central Maine	Investor-owned	Yes	Yes
MI	Consumers Energy	Investor-owned	Yes	Yes
MI	Detroit Edison	Investor-owned	Yes	Yes
MN	Minnesota Power	Investor-owned	Yes	Yes
MN	Otter Tail Power Company	Investor-owned	Yes	No
MN	Xcel Energy	Investor-owned	Yes	Yes
MO	Ameren	Investor-owned	Yes	Yes
MO	Evergy Metro	Investor-owned	Yes	Yes
MS	Entergy Mississippi	Investor-owned	Yes	Yes
MS	Mississippi Power Company	Investor-owned	Yes	Yes
MS	Tennessee Valley Authority	Federal	Yes	Yes
MT	NorthWestern Energy	Investor-owned	Yes	Yes
NC	Duke Energy Carolinas	Investor-owned	Yes	Yes
NC	Duke Energy Progress	Investor-owned	Yes	Yes
ND	McKenzie Electric Cooperative	Cooperative	Yes	Yes
ND	Montana-Dakota Utilities Company	Investor-owned	Yes	Yes
ND	Mountrail-Williams Elec Cooperative	Cooperative	Yes	Yes
ND	Northern States Power Company	Investor-owned	Yes	Yes
NE	Nebraska Public Power District	Political subdivision	Yes	Yes

NE	Omaha Public Power District	Political subdivision	Yes	Yes
NH	Eversource	Investor-owned	Yes	Yes
NH	Liberty Utilities	Investor-owned	Yes	No
NH	New Hampshire Electric Cooperative	Cooperative	Yes	No
NH	Unitil	Investor-owned	Yes	No
NJ	New Jersey's Clean Energy Program	Third party	Yes	No
NJ	PSE&G	Investor-owned	Yes	Yes
NJ	Rockland Electric	Investor-owned	Yes	No
NM	El Paso Electric	Investor-owned	Yes	No
NM	Public Service Company of New Mexico	Investor-owned	Yes	Yes
NM	Xcel Energy	Investor-owned	Yes	Yes
NV	Nevada Energy	Investor-owned	Yes	No
NV	NV Energy - Nevada Power	Investor-owned	Yes	Yes
NY	Consolidated Edison	Investor-owned	Yes	Yes
NY	National Grid	Investor-owned	Yes	Yes
NY	NYSERDA	Investor-owned	Yes	No
NY	PSEG Long Island	Investor-owned	Yes	No
OH	AEP Ohio	Investor-owned	Yes	Yes
OH	AES Ohio	Investor-owned	Yes	No
OH	Duke Energy	Investor-owned	Yes	Yes
OH	FirstEnergy - Ohio Edison	Investor-owned	Yes	Yes
OH	FirstEnergy - The Illuminating Company	Investor-owned	Yes	No
OH	FirstEnergy - Toledo Edison	Investor-owned	Yes	No
OK	Oklahoma Gas & Electric	Investor-owned	Yes	Yes
OK	Public Service Company of Oklahoma	Investor-owned	Yes	Yes
OR	Idaho Power	Investor-owned	Yes	No
OR	PacifiCorp	Investor-owned	Yes	Yes
OR	Portland General Electric Company	Investor-owned	Yes	Yes
PA	Duquesne Light	Investor-owned	Yes	No
PA	FirstEnergy - Met-Ed	Investor-owned	Yes	No
PA	FirstEnergy - Penn Power	Investor-owned	Yes	No
PA	FirstEnergy - West Penn Power	Investor-owned	Yes	No
PA	PECO	Investor-owned	Yes	Yes
PA	PPL Electric Utilities	Investor-owned	Yes	Yes
RI	National Grid	Investor-owned	Yes	Yes
SC	Dominion Energy	Investor-owned	Yes	Yes
SC	Duke Energy	Investor-owned	Yes	Yes
SD	Black Hills Power	Investor-owned	Yes	Yes
SD	Northern States Power Company	Investor-owned	Yes	Yes
SD	NorthWestern Energy	Investor-owned	Yes	Yes
TN	City of Chattanooga	Municipal	Yes	Yes
TN	City of Memphis	Municipal	Yes	Yes
TN	Knoxville Utilities Board	Municipal	Yes	Yes
TN	Middle Tennessee E M C	Cooperative	Yes	Yes

TN	Nashville Electric Service	Municipal	Yes	Yes
TN	Tennessee Valley Authority	Federal	Yes	Yes
TX	Austin Energy	Municipal	Yes	Yes
TX	CenterPoint Energy	Investor-owned	Yes	No
TX	City of San Antonio	Investor-owned	Yes	Yes
TX	CPS Energy	Municipal	Yes	No
TX	El Paso Electric	Investor-owned	Yes	Yes
TX	Entergy Texas	Investor-owned	Yes	Yes
TX	Oncor	Investor-owned	Yes	No
TX	Pedernales Electric Cooperative	Cooperative	Yes	Yes
TX	Southwestern Electric Power Company	Investor-owned	Yes	Yes
TX	Southwestern Public Service Company	Investor-owned	Yes	Yes
TX	Texas-New Mexico Power Company	Investor-owned	Yes	No
TX	Xcel Energy	Investor-owned	Yes	No
UT	Rocky Mountain Power	Investor-owned	Yes	Yes
VA	Dominion Energy	Investor-owned	Yes	Yes
VT	Green Mountain Power	Investor-owned	Yes	Yes
WA	Avista	Investor-owned	Yes	Yes
WA	City of Seattle	Municipal	Yes	Yes
WA	Pacific Power	Investor-owned	Yes	No
WA	PUD 1 of Snohomish County	Political subdivision	Yes	Yes
WA	Puget Sound Energy	Investor-owned	Yes	Yes
WI	Wisconsin Electric Power Company	Investor-owned	Yes	Yes
WI	Wisconsin Power & Light Company	Investor-owned	Yes	Yes
WV	Appalachian Power Company	Investor-owned	Yes	Yes
WV	Monongahela Power Company	Investor-owned	Yes	Yes
WY	Rocky Mountain Power	Investor-owned	Yes	Yes