Title

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Abstract

Pecan Street's field-metered data offer an opportunity to track actual appliance usage patterns and energy consumption over multiple years, and can supplement data from the US Energy Information Administration's Residential Energy Consumption Survey (RECS). This report is based on dishwasher metering data collected from more than 500 households located in Texas, California, New York, and Colorado from 2012 to 2021. The historical dishwasher usage frequency, the COVID-19 period usage change, and the potential seasonal trend in usage were investigated. Dishwasher cycle features such as cycle duration, quick cycle usage frequency, and average per cycle dishwasher energy consumption were observed and characterized. Due to the sample size, the lack of demographic data, and the limited geographic locations of the participating households, the results are not nationally representative. However, when compared with the usage frequency reported by RECS, the field-obtained average annual cycle counts per household are 164 in 2015 and 197 in 2020 for selected households which are consistent with the RECS annual cycle counts of 181 and 191 respectively in 2015 and 2020 for the same geographic locations. Our findings support the use of RECS data to approximate field dishwasher usage. The field data usage frequency for households with infrequent dishwasher use could supplement the RECS information to better characterize the national usage distribution of different cycle selections.

1. Introduction

Residential dishwasher ownership in the United States (US) has grown steadily since the appliance's introduction in the 1950s. According to data from the US Energy Information Administration's (EIA's) 1980 Residential Energy Consumption Survey (RECS), less than 40 percent of US households owned a dishwasher in 1980 (US EIA, no date). In contrast, the 2020 RECS data indicate that approximately 73 percent of US households had a dishwasher in 2020, with RECS results from the intervening years showing steady growth in those 40 years (US EIA 2021A). The American Housing Survey (AHS) confirms the increasing trend seen in RECS: 45 percent ownership in 1987 and 74 percent ownership in 2019 (US Census Bureau, no date). (Figure 1-1)

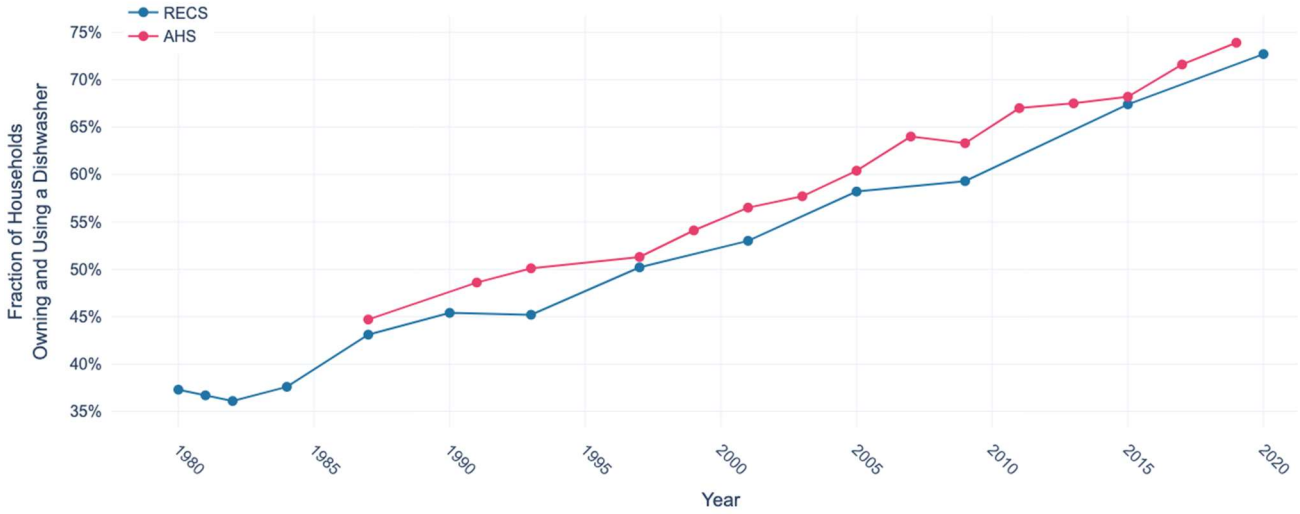


Figure 1-1. Fraction of US Households that Owned and Used a Dishwasher from 1987–2020

In 2003, minimally efficient dishwashers used 2.14 kilowatt-hours (kWh)/cycle (based on 1995 Association of Home Appliance Manufacturers [AHAM] data and Hoak et al. 2008) and less than 10 years later, minimally efficient dishwashers used 1.43 kWh/cycle (EERE 2016), a 34 percent reduction. The values include water heating energy but not standby power for the dishwasher electronic controls. However, separate from the appliance's direct energy draw, the efficiency and usage frequency of dishwashers also affects the volume of heated water used for its operations and the multiple fuels the water heater uses to heat that water.

Additionally, although the fraction of US households that own a dishwasher has grown over time, not all households actually use the dishwasher[1]. Beginning in 2001, RECS reported dishwasher usage within numerical bins describing a range of cycles per week, including "never" and "less than once per week." Since 2015, RECS has been reporting point estimates of average weekly dishwasher cycles, replacing the numerical bins. Both numerical bins and point estimates for cycles per week have a level of uncertainty when summed to cycle numbers per year.

[1] The fraction of household that have and do not use their dishwashers has remained largely constant over time despite the increase in dishwasher saturation.

A typical way to quantify dishwasher energy use, as evidenced by analyses conducted for the Department of Energy (DOE) appliance and equipment standards program, has relied on RECS data. (EERE, 2016) Additionally, energy usage varies depending on the types of cycles selected by the household: "pot wash," "normal," "quick," and "sanitize," to name a few. Field-metering data offers direct measurement of the number of annual cycles and energy variation represented by cycle types. It provides additional information such as energy use per cycle and energy usage per year. Nonetheless, most field-metering data cannot be considered as nationally representative due to the projects' sample sizes, geographic locations, project data collection durations, and other restrictions of the studies. Despite not having direct energy use measurements, national surveys such as RECS and AHS enable observations to be made on national use of appliances.

We begin this report by defining a standard-sized dishwasher and describing its operation. Next, we describe the data used in this report, including key attributes. The field-metered data provides direct measurement of household usage, and survey data presents respondent-provided information. We then explain our method for analyzing the data, and present key results from our analyses. Finally, we summarize the results and suggest next steps.

2. Dishwasher Definition and Operation

A *dishwasher* is defined under the Energy Policy and Conservation Act of 1975 as "a cabinet-like appliance which with the aid of water and detergent, washes, rinses, and dries (when a drying process is included) dishware, glassware, eating utensils, and most cooking utensils by chemical, mechanical and/or electrical means and discharges to the plumbing drainage system." (10 CFR 430.2, Definitions).

To function at its simplest level of operation, a dishwasher uses energy for four operations to power: (1) mechanical controls that include options for drying and cycle duration; (2) a pump to fill, circulate, and drain the cabinet; (3) one or more spray bars to spray water around the cabinet; and (4) a heating element to bring the water up to temperature for washing and to heat the air for drying. Additionally, energy is used by the water heater separate from the dishwasher to heat the water the dishwasher uses (Figure 2-1). The water heating energy consumption data associated with the dishwasher use was unavailable from Pecan Street; and, therefore, is out of the scope of this study.

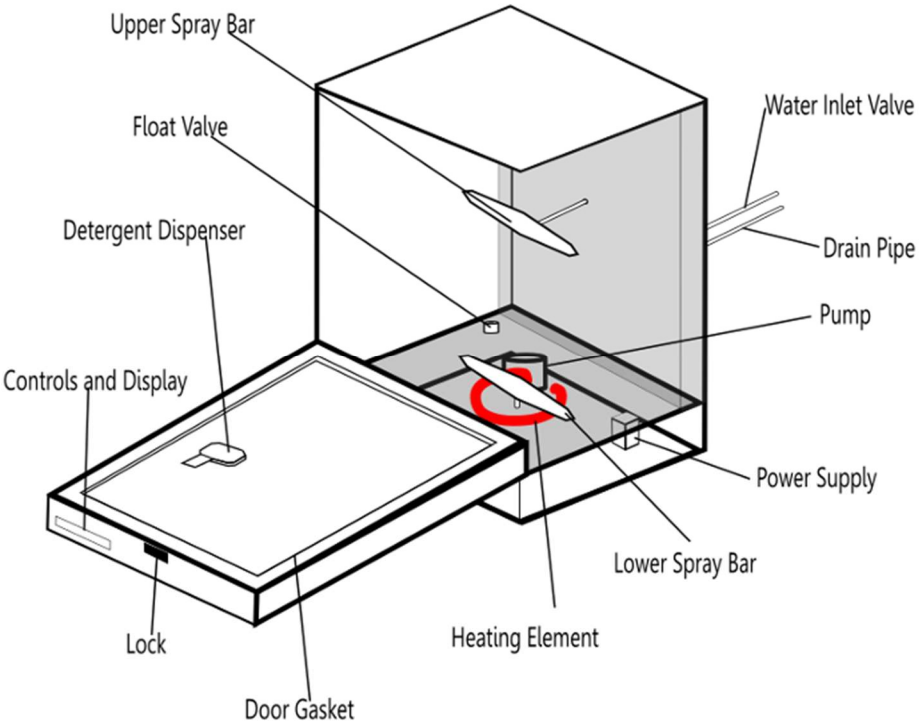
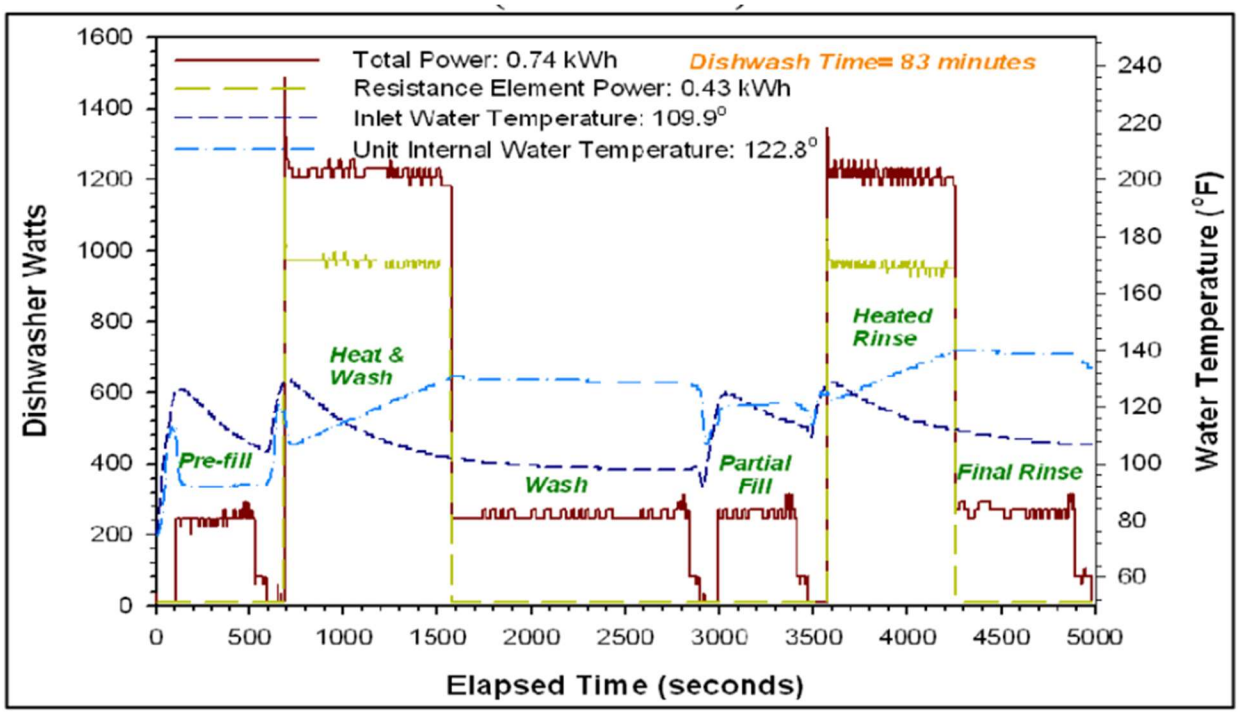


Figure 2-1. Schematic of a Typical Dishwasher[2]

Figure 2-2 presents an illustrative dishwasher cycle with the corresponding sequence of events. Note that the sequence of events, as well as the consumption level of the operations, vary substantially among dishwasher brands and models. Given the data resolution limit and the data noise level of the data we used, for this analysis we focused only on the wash, rinse, and, where applicable, drying cycles. See Section 3 for details about the Pecan Street data used for this study.

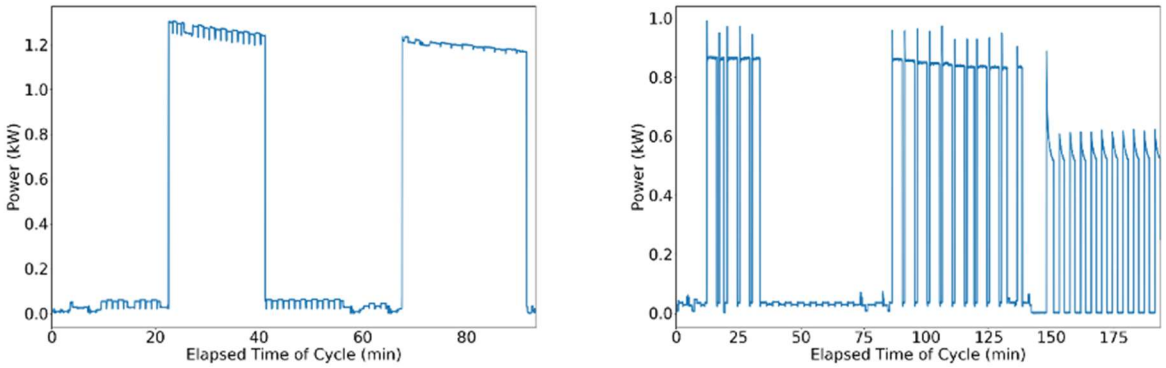
[2] Based on information found at https://home.howstuffworks.com/dishwasher.htm



Source: Hoak, Parker, and Hermelink 2008, Figure 3.

Figure 2-2. A Typical Dishwasher Cycle with Corresponding Sequence of Events

Figure 2-3 shows two dishwasher cycle power consumption examples that are of a typical dishwasher cycle length, duration, power level, and pattern observed in the Pecan Street data.[3] A typical dishwasher cycle consists of two (or three if the "heated dry" function is selected) high-power blocks interspersed with periods of lower power consumption.

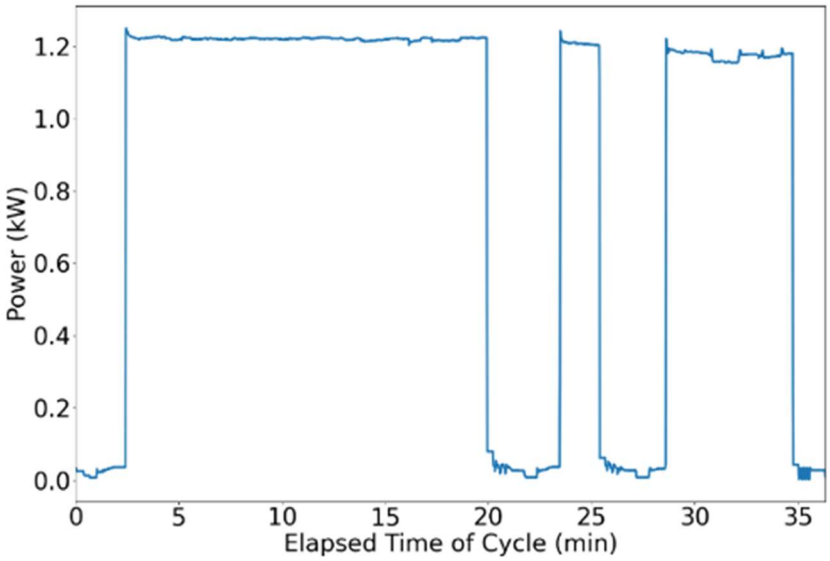


Source: Pecan Street (https://www.pecanstreet.org/)

[3] Pecan Street. https://www.pecanstreet.org/. Note that dishwasher cycles may differ significantly given different brands, models, functions, and/or features. Measurement environment and circuit noise can introduce measurement errors.

Figure 2-3. Typical Dishwasher Cycles

Usually, different dishwasher cycles can be selected (e.g., "normal" or "short"). For this analysis, we considered any cycles lasting less than or equal to one hour as "quick" cycles.[4] (EERE 2022, EERE 2020). We excluded cycles that lasted less than 16 minutes, some of which can be "rinse only" or "rinse and hold" operations lasting about 10–15 minutes.
Figure **2-4** shows the power consumption profile for a typical quick cycle.



Source: Pecan Street (https://www.pecanstreet.org/)
Figure 2-4. Typical Quick Cycle

3. Data Source

The Texas-based non-profit organization, Pecan Street,[5] has been compiling information on household energy consumption since 2009. Pecan Street gathers data for energy-consuming appliances and equipment from over 1,000 residential homes that have volunteered to have their energy usage data collected, often for multiple years. Power data are collected at 15-minute, 1-minute, or 1-second intervals using eGauge meters[6] at the electrical panel.[7] The power data collected at 1-second intervals are only available for a limited number of households in certain areas and/or over limited time periods. In order to analyze dishwasher usage frequencies and patterns for larger samples over relatively long periods, therefore, power data available at

[4] Note that as of the publication date of this report, DOE no longer defines a "quick cycle" or a "short cycle." The short cycle product class was withdrawn and the DOE test procedure no longer mentions a 1-hour or less representative cycle time. (Federal Register, 87FR2673, January 19, 2022; Federal Register, 88FR3234, January, 18, 2023)
[5] Pecan Street. https://www.pecanstreet.org/.
[6] eGauge is a meter that measures the power of individual circuits in an electric panel and combines an energy meter, data logger, and a web server, which allows measuring, storing and retrieving data directly from the device or from a remote location. https://www.egauge.net/home-energy-monitor/.
[7] The electrical panel usually can be found in the garage or basement of the residential property.

1-minute intervals were used. Note that, in most cases, dishwasher energy consumption is measured alone on a separate measurement channel; however, in some instances devices other than the dishwasher (e.g., garbage disposal) could be on the same circuit, making it difficult to distinguish between dishwasher energy consumption and consumption from other devices. In addition to power consumption, Pecan Street collects information on housing type and location, as well as limited household demographics but only for limited household samples.[8] Pecan Street does not collect appliance information such as brand and model number, so little is known about the metered dishwashers other than their power consumption.[9] This section provides a summary of the Pecan Street data used in this analysis.

As noted above, field-metered data are useful as a check on other data sources. However, some limitations are present in the Pecan Street data which are common to most field data:

- household sample location is limited to four states,
- households are not selected at random but volunteer to be a part of the Pecan Street data collection effort,
- household types are mainly single-family houses, and occupants may alter their behavior because of an awareness of meter presence and the need for energy efficiency.

Due to those constraints, our conclusion can be contextual and need to be interpreted with precautions.

3.1 Sample Selection

The full Pecan Street data sample includes over 1,000 households that joined the program between 2009 and 2021. The dishwasher data collection effort was started in 2012. For our analysis, we used data from households meeting the following criteria:

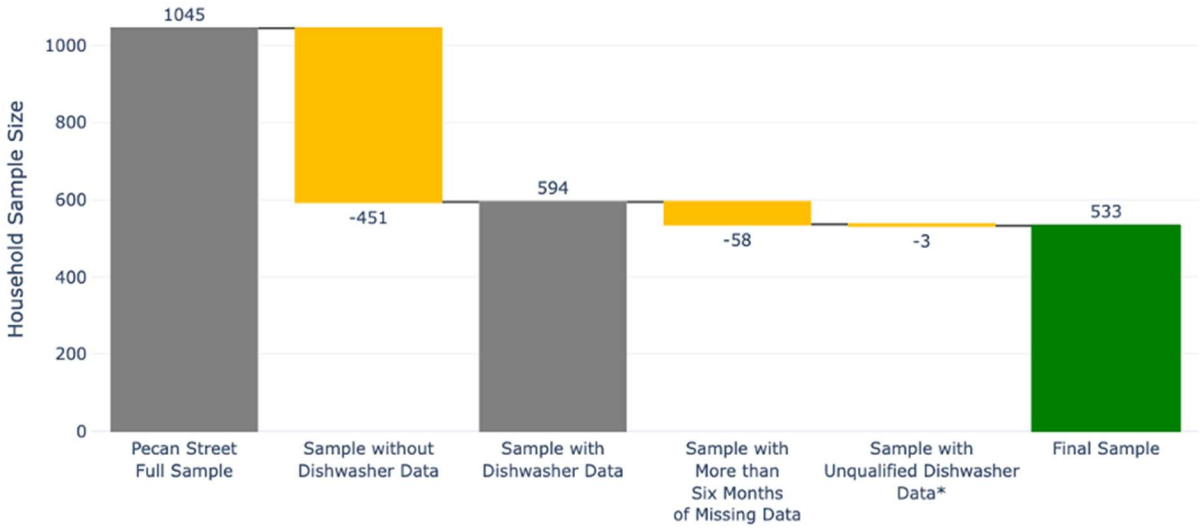
- Dishwasher data from electrical panel; are available for at least six months for a given calendar year during 2012 to 2021.[10]

Importantly, the Pecan Street data do not indicate changes in household occupants nor changes to the dishwasher appliance itself (e.g., repair or replacement). See Figure 3-1 for sample selection details.

[8] Household samples in limited location surveyed in 2012, 2013, 2014, 2017, and 2019.

[9] While the majority of households did not specify a dishwasher brand, eight different brands were noted by approximately 9 percent of households in a household appliance audit conducted in 2013 by Pecan Street. In another audit conducted by Pecan Street in 2017, 32 of the total 239 completed questionnaires mentioned they installed a new dishwasher. No brand or model specific information was collected at that time.

[10] Sensitivity analyses were conducted to evaluate the impact of setting the missing data threshold at six months, eight months and ten months. The results obtained from the current analysis still hold when setting the missing data threshold at eight and ten months, but it would reduce the current sample size by 9% and 20% respectively.



** Households with a significant fraction of power signals that are unlikely to be dishwasher usages.*

Figure 3-1. Pecan Street Household Sample Selection (2012–2021)

The households in our final sample participated in the program for an average of about five years, with a minimum of 1 year, and a maximum of 10 years (Figure 3-2). Note that the sample size and the households in the sample vary from year to year.

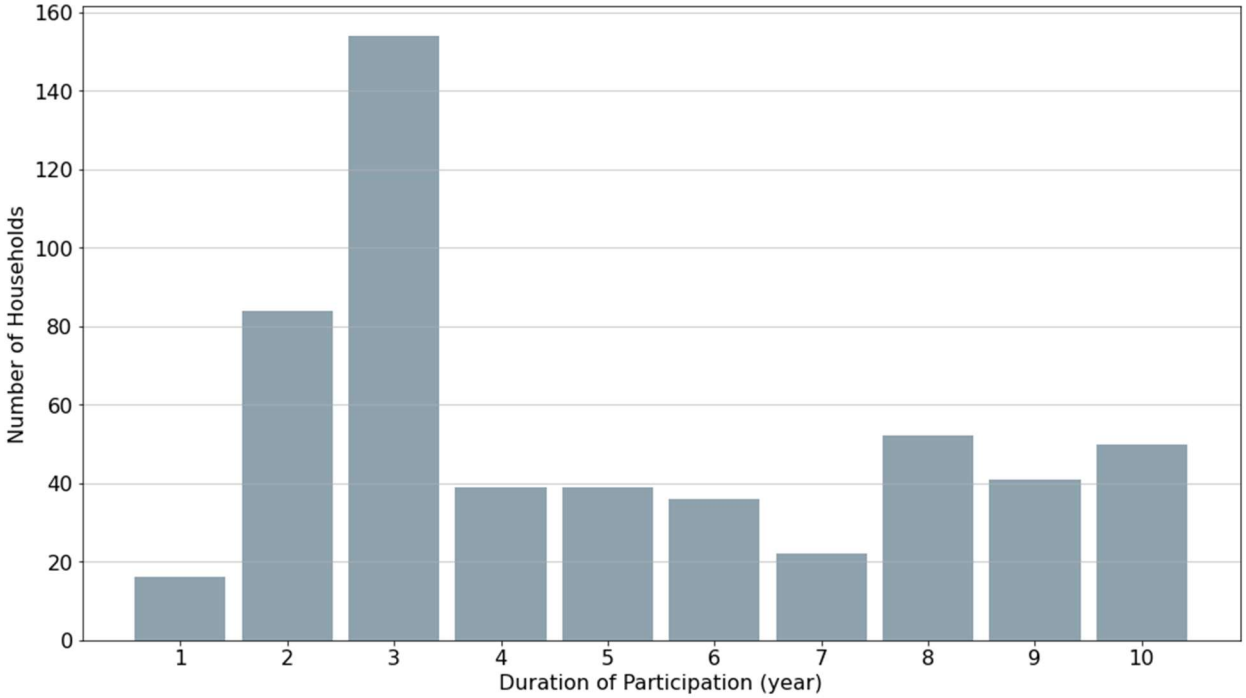


Figure 3-2. Number of Households by Length of Participation (years)
(Total sample size = 533)

3.2 Missing Date Rate

Pecan Street meters household electrical panel circuits using eGauge meters to gather real-time appliance power consumption data. Due to power outages and other electrical interruptions, the dataset may include periods of time when no data were collected.

The data are collected in 1-minute intervals, and the missing data rate is defined as the percentage of timestamps that are missing for a given year. Accordingly, each household has a different annual rate of missing data. The average rate of missing data across the final sample varies by year, as shown in Table 3-1. Both missing data rates by calendar year and rates by measurement period of each calendar year are shown, providing an idea of the actual amount of data collected versus extrapolated, and an evaluation of the data quality and continuity.

The Pecan Street project first started collecting dishwasher data in 2012. Because of the recruitment and the testing period, the annual missing data rate for 2012 is much higher than for the other years. The sum of the "Final Sample Size Per Year" column exceeds the final household sample size across all years (533) because many households were metered for multiple years.

Table 3-1. Pecan Street 2012–2021 Final Sample Missing Data Rate

Year	Average Missing Data Rate (%) of Calendar Year	Average Missing Data Rate (%) of Metered Period	Final Sample Size Per Year
2012	39.7	0.1	6
2013	13.9	1.1	106
2014	12.5	1.3	380
2015	6.8	0.4	333
2016	3.9	0.1	245
2017	7.4	0.3	200
2018	7.0	1.2	149
2019	12.7	1.2	194
2020	3.7	0.7	208
2021	4.9	0.6	189

3.3 Household Locations, Housing Types, and Years of Data Represented

Pecan Street began collecting data for dishwashers in Texas households in 2012 and expanded to include households in California and Colorado by 2014. New York households were included in 2019. Over 75 percent of the 533 households used in this study are in Texas (see Table 3-2).

The sample is comprised primarily of single-family homes (69.4 percent), with apartments representing one-quarter of the sample and townhomes making up the remaining 5.5 percent.

Table 3-2. Location and Housing Type for Dishwasher-Using Houses, Final Sample

State	Number of Households			Total
	Apartment	Single-Family Home	Townhome	
California	11	9	15	35 (6.6%)
Colorado		38		38 (7.1%)
New York		51		51 (9.6%)
Texas	123	272	14	409 (76.7%)
Total	134 (25.1%)	370 (69.4%)	29 (5.5%)	533 (100.0%)

4. Methodology

In this section, we describe how dishwasher energy usage is determined. In theory, dishwasher energy usage can be estimated by summing the measured energy usage of the dishwasher over an analysis period. However, because Pecan Street meters the dishwasher energy usage only at the electrical panel level, the metered energy consumption may include other plug-load devices (such as a garbage disposal) and electrical line noises (interference or measurement noise).

As a result, we identified dishwasher cycles in the metered data to estimate the energy usage of just the dishwasher. Cycle identification required setting minimum energy use levels and maximum time lapses between dishwasher operations.

4.1 Dishwasher Cycle Definition

In a complete dishwasher cycle, energy is used to perform the operations described in Section 2. We define the operation variables in the idealized dishwasher cycle (Figure 4-1) as follows:

- P_t is the power at certain timestamp t.
- P_s is the threshold of "active" mode power; data points with $P_t > P_s$ are assigned to "active" mode. The data points with $P_t \leq P_s$ are considered "non-active" mode.
- P_m is the maximum "active" mode power in a complete dishwashing cycle. Setting a dishwasher "active" mode power threshold enables distinguishing dishwasher cycles from interferences and noise, or measurement error and bias.
- T_g defines the maximum time gap between two consecutive "active" operation modes that typically occur in a dishwasher wash cycle. This variable allows us to link the "active" mode periods that may be separated by "non-active" mode periods in a dishwasher cycle when the "non-active" mode duration is shorter than T_g. Usually, more than two "active" mode periods can be found in a complete dishwasher cycle.
- T_c is the cycle duration, from start to completion of a dishwasher cycle. Defining the cycle time duration allows us to filter out interferences and noise, or measurement error and bias.

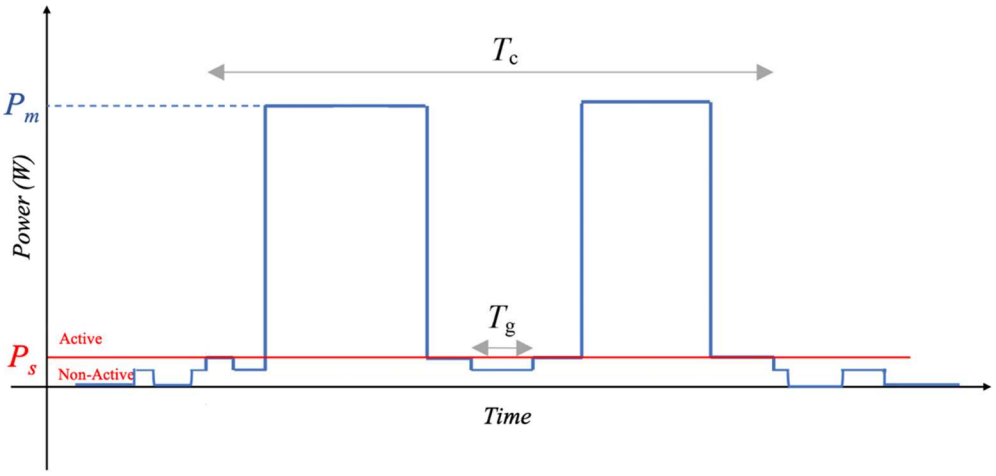


Figure 4-1. Power Consumption over Time for an Idealized Dishwasher Cycle that Includes Wash, Rinse, and Dry Operations

Householder behavior can be observed in energy use variation in the data when different cycles (e.g., "normal" or "quick") are selected. Data showing cycles from our sample sometimes may vary from the idealized view (Figure 4-1) due to differences in measurement environment (noise), cycle type selection, and non-dishwasher energy usage from the circuit. Although it is difficult to filter out the measurement noise from the data, efforts were made to filter out usage signals that do not correspond to a dishwasher wash cycle profile by characterizing dishwasher wash cycle features. We defined thresholds for P_s, P_m, T_g, and T_c to help eliminate non-dishwasher activity captured within the data.

4.2 Identification of Dishwasher Cycles

In this study, we used the following parameters to define dishwasher cycles in our dataset:

- $P_s = 10$ watts
  This value was set based on the general noise level found in the Pecan Street data and the typical "non-active" power level for dishwashers.
- $P_m \geq 500$ watts
  With P_m at or above 500 watts, we ensure that all the cycles identified are dishwasher cycles and not attributed to a different device in case multiple devices are connected on the same circuit. This value was estimated by the authors based on the prior knowledge and the exploration of the data.
- $T_g \leq 15$ minutes
  A threshold of T_g is set to a time period long enough to avoid characterizing multiple consecutive "active" mode periods as multiple independent cycles, but short enough to avoid combining two consecutive dishwasher cycles into one.
- $16 \text{ minutes} \leq T_c \leq 300$ minutes
  Given that most "rinse and hold" cycles last 10 to 15 minutes, and a dishwasher model with a 16-minute quick wash cycle was found on the market,[11] a 16-minute time period was chosen to filter out non-wash cycles (e.g., "rinse and hold" cycles), potential other device usage (e.g., garbage disposal), and electrical line loss. To rule out some potential effects of noise, we also omitted cycles longer than 300 minutes.

5. Results

Using the methodology described in the previous section, we estimated the average number of cycles per year, energy consumption per cycle, and fraction of cycles that are quick cycles. Additionally, in Section 5.5 we used a paired comparison (also known as a chained analysis) to find the common households in two specific years and eliminate potential differences from the year-to-year changes in the composition of households in the sample.

In this section, for each year we: (1) include only those households that have at least one cycle in that year, (2) extrapolate the annual number of cycles for each household by assuming the usage in the period of missing data is the same as the usage of measurement period, and (3) exclude data from the year 2012 due to the small sample size.[12]

The Pecan Street dataset is based on a limited sample of households in four states: Texas, California, New York, and Colorado. Therefore, the results presented in this section are not representative at the national level.

5.1 Average Annual Number of Dishwasher Cycles

[11] Other dishwashers, such as Smeg's model DWAUP364X provide an "Ultra Quick 16 minutes" program. The model widths are 60 centimeters (23.6 inches) wide. See https://www.canstarblue.com.au/appliances/brands/smeg-dishwashers/ and https://commercial.appliancesonline.com.au/public/manuals/Smeg-DWAUP364X-Under-Bench-Dishwasher-Datasheet.pdf.

[12] The six households that have data collected in 2012 also participated in other years. Therefore, excluding 2012 does not change the cumulative household sample size of 533.

Table 5-1 shows the estimated average number of dishwasher cycles per year across the households in our sample. This result illustrates the average field dishwasher wash cycle usage as well as the associated variability of frequency across the years, and could be used to infer annual consumption estimates when per cycle consumption estimates are available. Average annual cycle count ranges from 128 to 176 cycles per household.

Table 5-1. Estimated Annual Cycle Count for All Households with Dishwasher Having at Least One Cycle in Each Calendar Year

Year	Average Annual Cycles	Standard Deviation of Annual Cycles	Number of Households
2013	145	89	96
2014	128	102	330
2015	132	101	294
2016	142	100	225
2017	144	103	182
2018	141	98	136
2019	141	100	174
2020	176	117	189
2021	163	117	174

5.2 Quick cycle Usage Frequency

Currently, dishwasher models on the market may provide multiple cycle options, including (but not limited to) short or quick cycle, normal cycle and heavy duty cycle. The quick cycle may present a distinct usage profile both in terms of consumption and duration when compared to the other wash cycles. Unfortunately, there is no disaggregated data of the number of short and normal cycles run per year from the survey data including RECS. However, the field data allow a direct estimate of the percentage of quick cycles run among all cycles per year.

In this analysis, a quick cycle is defined as a dishwasher cycle that lasts between 16 minutes and 60 minutes. The 60 minutes threshold was chosen based on the 2022 final rule published by DOE to withdraw the short cycle product class for residential dishwasher. (EERE 2022)

Although some dishwasher models on the market may have quick cycle options that last longer than 60 minutes, the threshold of 60 minutes was selected in this study to distinguish quick cycles from normal cycles given that the lack of dishwasher model and cycle selection information for most household samples from the Pecan Street data. It is important to note that this choice may introduce bias to the average quick cycle consumption and duration estimates when compared to other studies.

Based on our definition and available samples, for the individual household-based portion of quick cycles run in a year among all dishwasher cycles, we found a median that varied between 0.3% and 0.9% from 2013 to 2021. Those quick cycles identified have an average length of 47 minutes and a median length of 51 minutes across all years for which data were collected. In terms of energy used per cycle (excluding the water heating energy), the quick cycles have an average of 0.49 kWh/cycle and a median of 0.46 kWh/cycle. The 2020 DOE test data show that

the quick cycle usually consumes more water and is therefore associated with more water heating energy consumption than normal cycles. (EERE 2020)

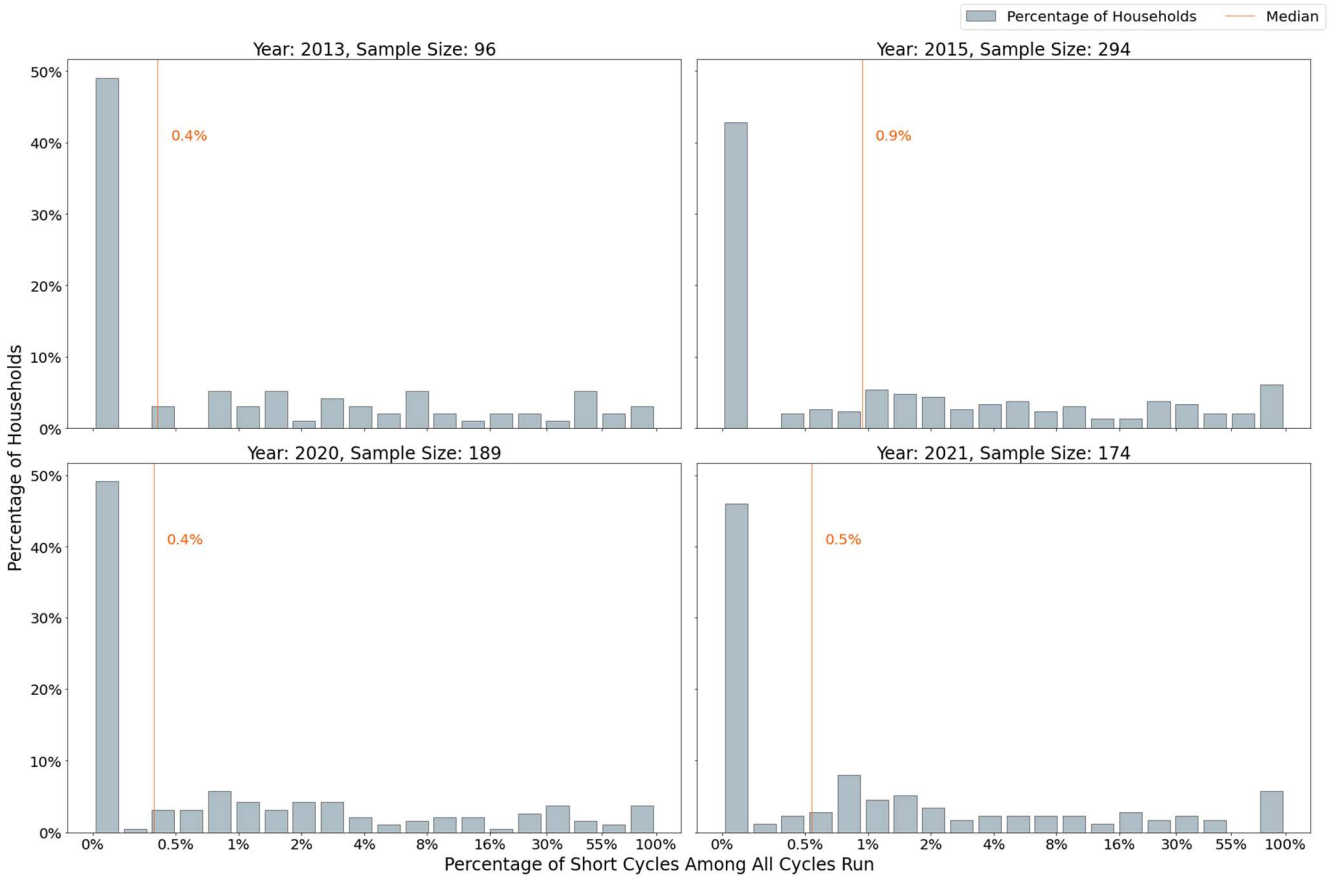
Figure 5-1 shows the household-based annual quick cycle percentage in relation to total cycles. For each subplot, we calculated the quick cycle percentage and derived the corresponding distribution from the household samples for each year. It appears that the median fraction of quick cycles run per year per household is generally constant across the years, and the household-based distribution is severely skewed. Note that the actual cycle options available to a given householder are unknown due to the lack of individual dishwasher make and model information which may bias the estimate of the fraction.

Table 5-2 shows the fraction of households using different percentage of quick- cycles out of all cycles. In general, more than 50 percent of households use quick cycles for less than 1 percent of the time, and the majority (about three quarters) of the households uses quick cycles for less than 5 percent of the time.

Table 5-2. Fraction of Households with Infrequent Quick Cycle Use

Year	Fraction of Household Samples (%)				Sample Size
	Never Use Quick Cycles*	Use Quick Cycle Less Than or Equal to			
		1% of Total Cycles [0, 1%]	5% of Total Cycles [0, 5%]	10% of Total Cycles [0, 10%]	
2013	49	58	76	83	96
2014	46	57	78	81	330
2015	43	52	72	79	294
2016	42	54	73	81	225
2017	41	53	77	83	182
2018	40	50	71	80	136
2019	49	60	79	85	174
2020	49	62	80	84	189
2021	46	62	79	85	174

*The fraction of households that never use dishwasher cycles shorter than 60 minutes due to the lack of a quick cycle option is unknown.



Note: The X (horizontal) axis of each subplot is on a logarithmic (base 2) scale.

Figure 5-1. Frequency Charts of Annual Percentage of Quick cycles Among All Cycles Run Based on Pecan Street2013, 2015, 2020 and 2021 Data

5.3 Energy Consumption per Cycle

Energy used during a dishwasher cycle includes energy for the operations described in Section 2. Table 5-3 shows the average and median value of energy consumed per cycle[13] from 2013 to 2021 for quick cycles, normal cycles, and all cycles. Within each cycle type, energy usage varies little between mean and median values, indicating moderate skewness in the distribution.

[13] No energy potentially used by the water heater that is connected to the dishwasher is included in this analysis because it is beyond the scope of the study.

Table 5-3. Estimated Per Cycle Consumption for Quick cycles, Normal Cycles and All Cycles Combined for Each Calendar Year

Year	Per Cycle Consumption for Quick Cycle (KWh/Cycle)		Number of Households with Quick Cycles	Per Cycle Consumption for Normal Cycles (KWh/Cycle)		Number of Households with Normal Cycles	Per Cycle Consumption for All Cycles (KWh/Cycle)		Number of Households with at Least One Cycle per Year
	Mean	Median		Mean	Median		Mean	Median	
2013	0.48	0.46	49	0.92	0.87	95	0.85	0.81	96
2014	0.42	0.40	177	0.92	0.88	324	0.85	0.83	330
2015	0.47	0.46	169	0.92	0.88	287	0.85	0.84	294
2016	0.48	0.46	130	0.92	0.89	223	0.86	0.85	225
2017	0.48	0.45	107	0.89	0.87	181	0.85	0.85	182
2018	0.48	0.47	81	0.91	0.91	135	0.87	0.87	136
2019	0.55	0.59	88	0.88	0.87	173	0.87	0.87	174
2020	0.54	0.53	96	0.90	0.89	187	0.88	0.87	189
2021	0.51	0.49	94	0.89	0.90	173	0.88	0.87	174

In addition to the "active" mode energy consumption, the characterization of dishwasher annual usage includes the "standby" mode energy consumption. The latter is usually calculated based on the annual standby mode operating hours, which are estimated by subtracting the annual "active" mode operating hours from the total hours in a year (8,766 hours) (EERE 2016). The "active" mode operating hours are calculated using the average per-cycle duration and the average annual cycle count. The Pecan Street data did not permit the calculation of standby mode energy consumption due to noise on the electrical circuit.

5.4 Cycle Duration

Table 5-4 shows the annual average and median cycle duration across households for quick cycles, normal cycles and all cycles combined. The average cycle length of quick cycles ranges from 45 minutes to 50 minutes, and the median ranges from 48 minutes to 54 minutes. In terms of normal cycles, the average cycle length ranges from 105 minutes to 119 minutes, and the median ranges from 101 minutes to 111 minutes. Note that the active mode duration in a cycle is shorter than the cycle duration in general due to the gap time (see Figure 4-1).

Table 5-4. Dishwasher Average Cycle Duration Quick cycles, Normal Cycles and All Cycles Combined for Each Calendar Year

Year	Cycle Duration for Quick cycles (Minutes)		Number of Households with Quick Cycles	Cycle Duration for Normal Cycles (Minutes)		Number of Households with Normal Cycles	Cycle Duration for All Cycles (Minutes)		Number of Households with at Least One Cycle per Year
	Mean	Median		Mean	Median		Mean	Median	
2013	48	50	49	105	101	95	100	97	96
2014	45	49	177	110	102	324	105	101	330
2015	48	52	169	110	102	287	103	100	294
2016	50	54	130	112	102	223	106	100	225
2017	47	49	107	112	106	181	107	102	182
2018	45	49	81	118	111	135	112	106	136
2019	45	48	88	118	107	173	113	103	174
2020	46	50	96	119	110	187	114	107	189
2021	46	51	94	119	110	173	113	107	174

5.5 Paired Comparison

This subsection presents a paired comparison that minimizes the sample bias due to different sample size and different households in the sample for each year of data.

5.5.1 Annual Cycle Count

We used a chained analysis to compare usage frequency across the measurement period (2013–2021). In a chained analysis, we analyze the year-to-year change for only the households that are represented in both years. This approach allows us to minimize the sample variation bias that occurs as a result of having different sample sizes (i.e., number of households) and different samples across years.

Due to the fluctuation in numbers of participating households, few households have data collected throughout the entire measurement period. To maximize the numbers of households included in our analysis in order to increase the validity of our findings, only consecutive years of data were compared. For example, for the years 2013 and 2014, only 91 households participated in both years of dishwasher data collection. We, therefore, compared the relative change for those 91 households instead of comparing the full sample pool for those two years of data.

Given that drastic relative change could be observed for some households due to infrequent usage,[14] which would have a significant impact on the average, we chose to calculate the relative change relying on the annual sample averages instead of calculating the average of household-based relative changes.

[14] For example, with a total cycle count of 1 in the first year and a total cycle count of 3 in the following year would result in a 200% relative change.

Table 5-5 shows the relative change in the usage frequency (i.e., the annual average number of dishwasher cycles) using the chained analysis approach. The percentage indicates the degree to which the usage changed as compared to the previous year. It is worth emphasizing that the percentage of change is calculated based on the average annual cycle count of households that have data for both years in the comparison shown in Table 5-5.[15]

Table 5-5. Change of Cycle Count Based on the Chained Analysis

Year	Average Cycle Count Change (%)*	95% Confidence Interval (%)	Number of Households*
2014 vs. 2013	+7.1	[1.1, 14.0]	91
2015 vs. 2014	-2.3	[-5.9, 1.4]	250
2016 vs. 2015	+2.4	[-0.6, 5.3]	212
2017 vs. 2016	-2.7	[-5.4, 0.1]	175
2018 vs. 2017	-0.8	[-5.9, 4.6]	126
2019 vs. 2018	-0.5	[-3.9, 3.3]	105
2020 vs. 2019	+24.3	[18.0, 30.5]	158
2021 vs. 2020	-5.8	[-9.6, -1.6]	166

***** *For each paired comparison, only households that participated in both years were included.*

The results shown in Table 5-5 suggest that dishwasher usage had been generally constant before 2020 except for a slight increase between 2013 and 2014, if we assume that the samples in each pair of comparison years across the analysis period are drawn from the same population (of 533 households) and the difference in sample pool for each pair of comparison do not entail important sample bias. A significant increase in usage (+24.3%) can be observed in 2020, despite the lack of COVID-related occupancy data and cooking frequency data collected, one could still assume that the increase could potentially be correlated with the shelter-in-place (SIP) requirements at the onset of the COVID-19 pandemic.

Usage decreased for the following year, 2021. However, usage of samples for the chained analysis (not necessarily representative of the four states) in 2020 is still higher than in the pre-COVID years. To better illustrate the year-to-year changes of the annual dishwasher cycles across the analysis period, Figure 5-2 shows the cumulative effect of the year-to-year average cycle count changes. It should be noted that the figure shows relative changes and not cycle counts. The confidence interval (CI) was estimated using a bootstrapping method. Specifically, the bootstrapping estimate was computed by 100,000 resamples with replacement of the observed sample and of equal size to the observed sample. The 95 percent confidence interval was then constructed by using 2.5 and 97.5 percentiles of the bootstrap distribution.

[15] Note that the changes could be attributable to a change in the household occupants or the dishwasher unit itself. That information is unavailable from the dataset.

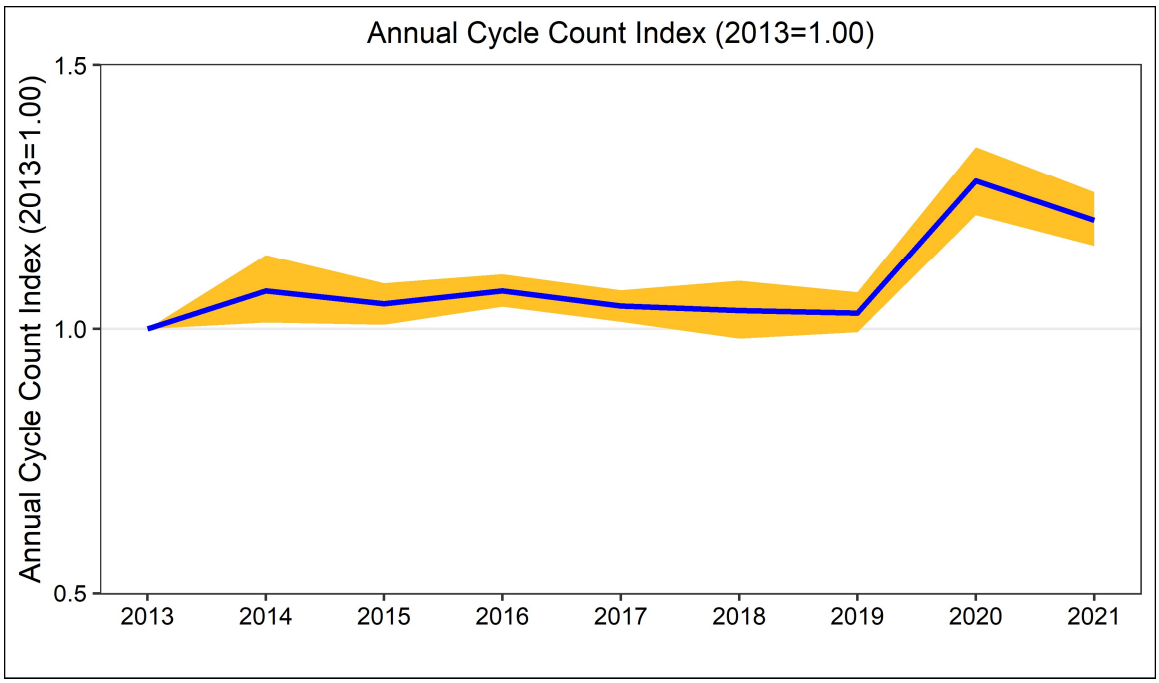


Figure 5-2. Annual Cycle Count Index (2013 = 1.00) Calculated Based on Relative Changes from the Paired Comparison

5.5.2 Quick cycle Usage Frequency

Using the chained analysis approach, Table 5-6 shows the comparison of portion of quick cycles (no longer than 60 minutes) to all dishwasher cycles across the years. The percentage indicates the frequency change in quick cycles compared to the previous year for households with data for both years. The 95% confidence intervals obtained by bootstrapping with 100,000 resampled datasets for each pair of comparisons suggest usage frequency of quick cycles had been generally constant.

Table 5-6. Change of Quick Cycle Usage Frequency Based on Chained Analysis

Year	Average Absolute Change of QuickCycle Usage Frequencies (%)*	95% Confidence Interval (%)	Number of Households
2014 vs. 2013	-0.02	[-1.6, 1.8]	91
2015 vs. 2014	-0.13	[-1.8, 1.5]	250
2016 vs. 2015	-1.01	[-2.8, 0.6]	212
2017 vs. 2016	-1.83	[-3.9, 0.0]	175
2018 vs. 2017	0.21	[-1.7, 2.0]	126
2019 vs. 2018	-1.45	[-3.9, 0.4]	105
2020 vs. 2019	1.33	[-0.1, 2.9]	158
2021 vs. 2020	0.36	[-1.1, 1.8]	166

* For each paired comparison, only households participated in both years were included. The values shown are averages of household-based absolute changes of quick-wash cycle usage frequency. The fraction of households that never use dishwasher cycles shorter than 60 minutes due to the lack of a quick-wash cycle option is unknown.

Table 5-7. Change of Quick Cycle Fraction Among Total Cycles Run Based on Chained Analysis

Year (2nd year vs. 1st year)	1st Year Quick Cycles as % of Total Cycles Run by All Samples (%)	2nd Year Quick Cycles as % of Total Cycles Run by All Samples (%)	Absolute Change in Average Quick Cycle Usage Frequencies (%)	Number of Total Cycles (1st year)	Number of Total Cycles (2nd year)	Number of Households*
2014 vs. 2013	9.4	8.9	-0.6	13,146	14,082	91
2015 vs. 2014	8.7	9.7	1.0	33,884	33,118	250
2016 vs. 2015	10.7	9.5	-1.2	29,845	30,546	212
2017 vs. 2016	9.0	7.9	-1.1	25,878	25,188	175
2018 vs. 2017	6.4	7.3	0.9	18,040	17,893	126
2019 vs. 2018	8.3	6.7	-1.6	14,968	14,900	105
2020 vs. 2019	7.0	7.9	0.9	22,501	27,963	158
2021 vs. 2020	7.5	8.0	0.5	29,784	28,049	166

* For each paired comparison, only households participated in both years were included. The fraction of households that never use dishwasher cycles shorter than 60 minutes due to the lack of a quick cycle option is unknown.

Table 5-7 shows the fraction of the total number of cycles run per year that were quick cycles across the paired household samples, indicating that the cycle-based usage frequency of quick cycles is generally constant for each pair of comparisons. This finding, in tandem with the results

shown in Table 5-2, suggests that there is no sufficient evidence of significant changes in quick cycle usage frequency over time among the households that run quick cycles.

5.6 COVID-19 Impact

This section investigates how dishwasher usage behaviors changed in 2020 in comparison to previous years. Our primary hypothesis for the change in usage patterns is COVID-19, which brought about SIP orders and other restrictions. Note that this is not a causal analysis, and therefore other confounding factors such as changes in occupancy and consumer dining-in-habits may also have contributed to the change of dishwasher usage. For the four states in our analysis, statewide SIP orders were instituted in 2020 at different dates: March 19 in California,[16] March 20 in New York,[17] March 20 in Texas,[18] and March 26 in Colorado.[19]

These restrictions may have led to more at-home food preparation and consumption, leading to increased dishwasher usage. In addition to higher instances of household food preparation, increased dishwasher usage could reflect changes in household occupancy.[20] Table 5-5 shows the distribution of annual usage change (expressed in number of annual cycles) observed for households that have measurements in both 2019 and 2020. On average, dishwasher usage in terms of main dishwasher cycles increased by 35 cycles for the 158 households represented in both 2019 and 2020.

Figure 5-3 shows the changes in the frequency that households operated their dishwashers. Few households (16 percent), used their dishwashers less frequently in 2020 than in 2019. Most homes (74 percent) increased their dishwasher usage by up to 100 cycles. A sizable proportion (10 percent) of households experienced an increase of over 100 dishwasher cycles.

[16] https://covid19.ca.gov/img/Executive-Order-N-33-20.pdf
[17] https://www.nyla.org/userfiles/To%20File%20(CR)/202.7.PDF
[18] https://gov.texas.gov/uploads/files/press/EO-GA_08_COVID-19_preparedness_and_mitigation_FINAL_03-19-2020_1.pdf
[19] https://drive.google.com/file/d/1O1EDCY6-A6QBKxzDImCSF8bBBdOOI3Km/view
[20] "There is also evidence that during-pandemic moves had big effects on places, from housing markets to school enrollment. Additionally, the timing of mobility spikes during coronavirus surges implies that the movers behind them may have been fleeing high-case areas, moving in with family, or even responding to housing insecurity." (Frost 2021).

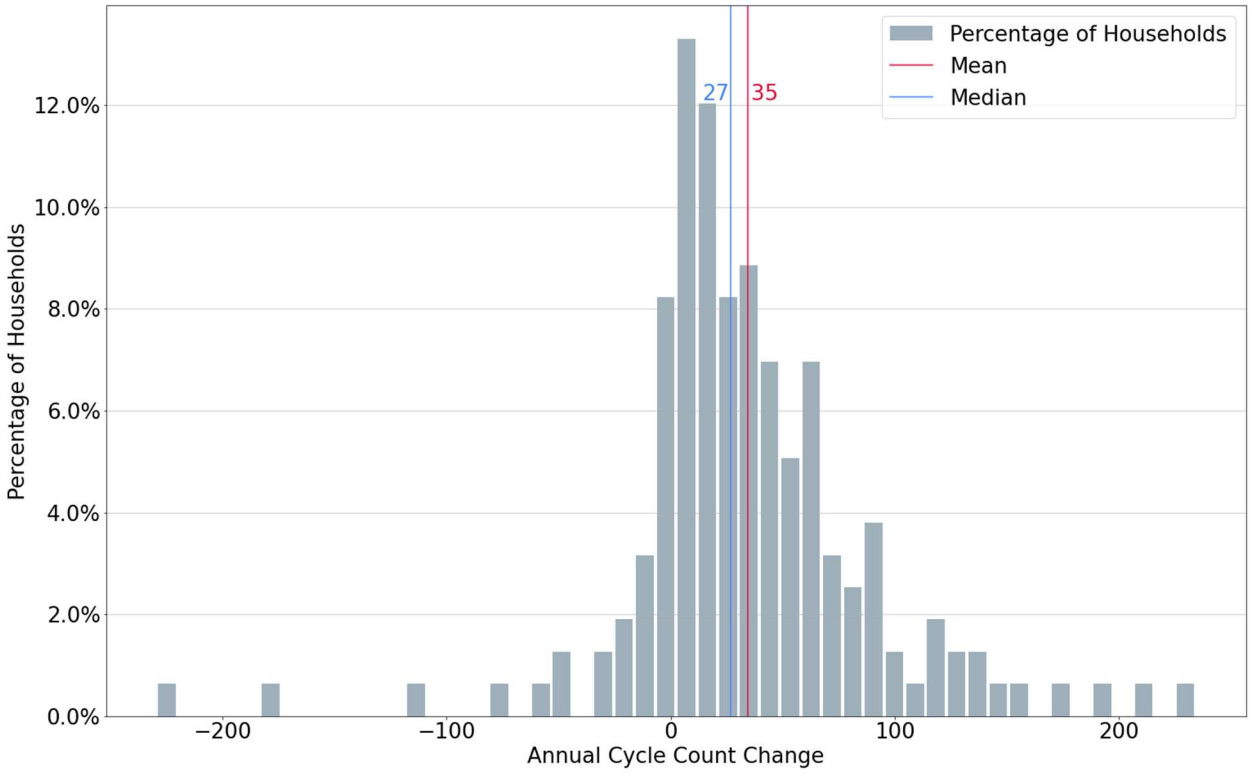


Figure 5-3. Dishwasher Cycle Change 2020 vs. 2019 (Sample Size = 158)

5.6.1 Weekly Usage from 2018 to 2021

Figure 5-4 shows the average number of cycles per week in each month for 2018, 2019, 2020, and 2021 of 81 households that had data collected for all four years. Generally, the observations suggest that the usage in winter months was slightly higher than in the summer months for the pre-COVID years (2018 and 2019). The observations also suggest the usage in March was likely lower than the usage in February for the pre-COVID years (2018 and 2019). A statistically significant increase in usage can be seen around March and April 2020 compared to the pre-COVID years (2018 and 2019),[21] which may correlate with the SIP orders to prevent the spread of the COVID-19 virus.

The usage frequency observed from the sample was lower from March 2021 to December 2021 when compared to March 2020 to December 2020, but it was still higher than in the pre-COVID years (2018 and 2019).

Note that, as of March 2021, Texas (the state with 66 percent of the households in the sample) allowed all businesses to reopen at full capacity (Office of the Texas Governor 2021). New York and California started to reopen in June 2021(California All, no date; Kerr 2021; New York State 2021).[22] These orders, together with changing COVID situations in 2021, could potentially have impacted dishwasher usage of the sample in 2021, and needs further investigation.

[21] One-tail paired *t*-tests suggest that the dishwasher usage in March and April 2020 is statistically higher (at 1% statistical significance level) than that in March and April 2018, and March and April 2019, respectively.
[22] Sixty-six percent of the samples are from Texas, and the remaining 34 percent are from New York, California, and Colorado.

Unfortunately, with this dataset, no occupancy or COVID impact-related information was collected to enable a causal analysis.

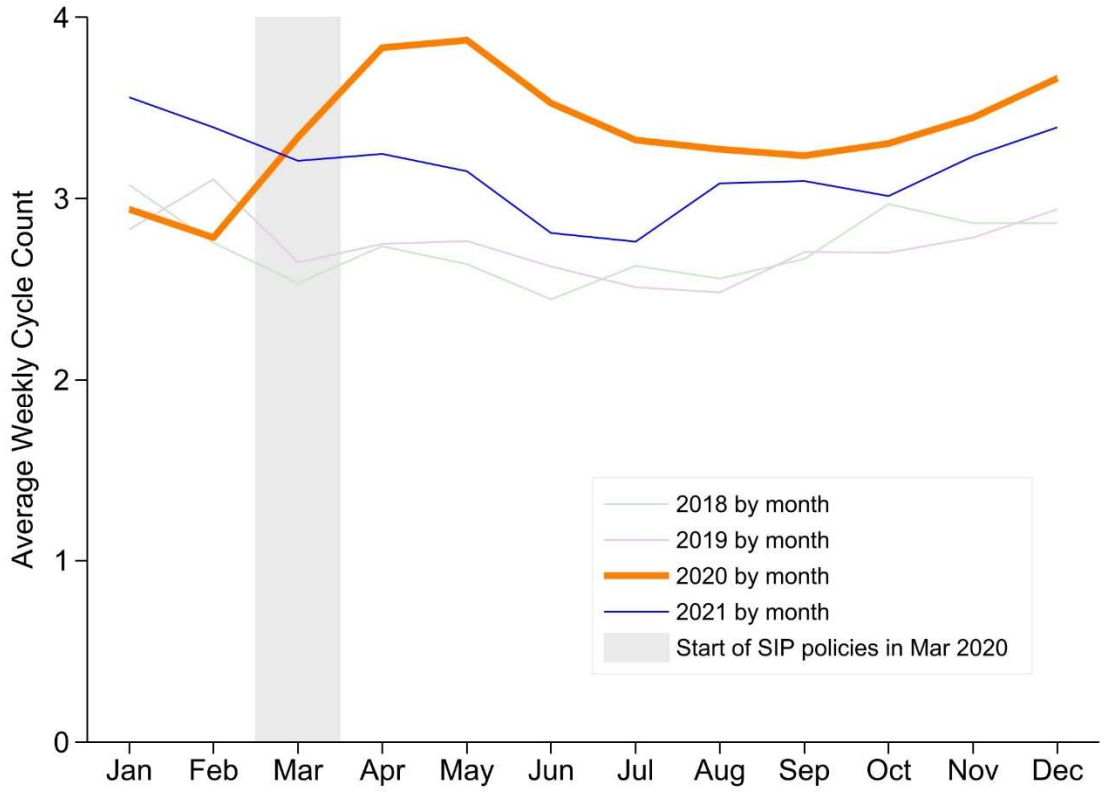


Figure 5-4. Average Dishwasher Cycle Counts per week from 2018 to 2021 (Sample Size = 81)

5.6.2 Continuously Metered Households

As noted above, the household sample changed each year. There are 50 households from which data have been collected since 2013 (see Figure 3-2); however, only 20 households meet the criteria for inclusion in this study from which data are still being collected as of 2021.

Figure 5-5 shows the historical usage of those 20 households starting from 2013. Assuming identical household occupants and dishwashers, an increase in usage is observed starting in 2020 (coinciding with the SIP period), implying a potential impact of the pandemic starting in 2020.[23] However, as stated, the increase may be due to other factors such as dishwasher replacement, change in household occupants, or changes in number of occupants.

[23] Household samples with no dishwasher cycles identified in a whole year during the analysis period are not shown in this chart.

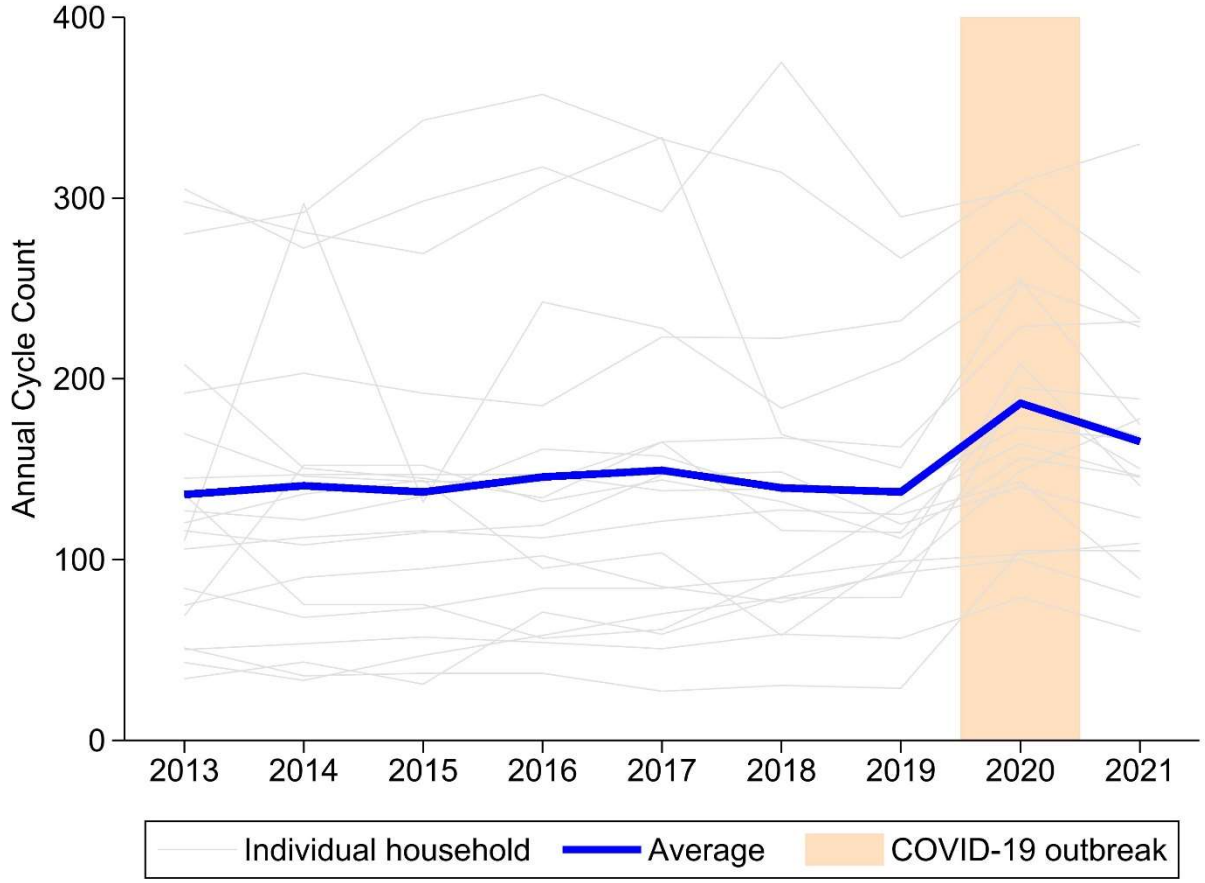


Figure 5-5. Annual Cycle Counts for 20 Households that Were Continuously Metered from 2013–2021

5.7 Usage Frequency of the Most-Used Cycle

In this section, we analyze data from 2021 to identify each household's most-used cycle type and its usage frequency. Due to the unavailability of cycle selection and model information, we clustered the cycles run in 2021 by their duration and energy intensity for each household, and reported the fraction of the most-used cycle (the number of the cycles found in the largest cluster divided by the total number of cycles run).

As shown in Table 5-8, the usage frequency of the most-used cycle had a mean of 77.4 percent and a median of 80.4 percent in 2021. Sixty-six households (of 174 households, or approximately 38 percent) used the same cycle for more than 90 percent of their dishwasher cycles run in 2021.

Table 5-8. Usage Frequency of the Most-Used Cycle in 2021

Sample Size	Median	Mean
174	80.4%	77.4%

Figure 5-6 shows the frequency of the most-used cycle durations per household. The average of most-used cycle duration is 119 minutes and the median is 114 minutes. Five households (of 174

households, or about 2.9%) had most-used cycle durations under 60 minutes. In RECS 2020, the respondents were also asked about their most frequently used dishwasher cycle (US EIA 2021c). On weighted average, 2.5% of all the respondents chose the quick cycle option, compared to 3.3% of the respondents located in CA, CO, TX and NY. Our finding seems therefore to be consistent with the RECS 2020 observation despite the sample bias.

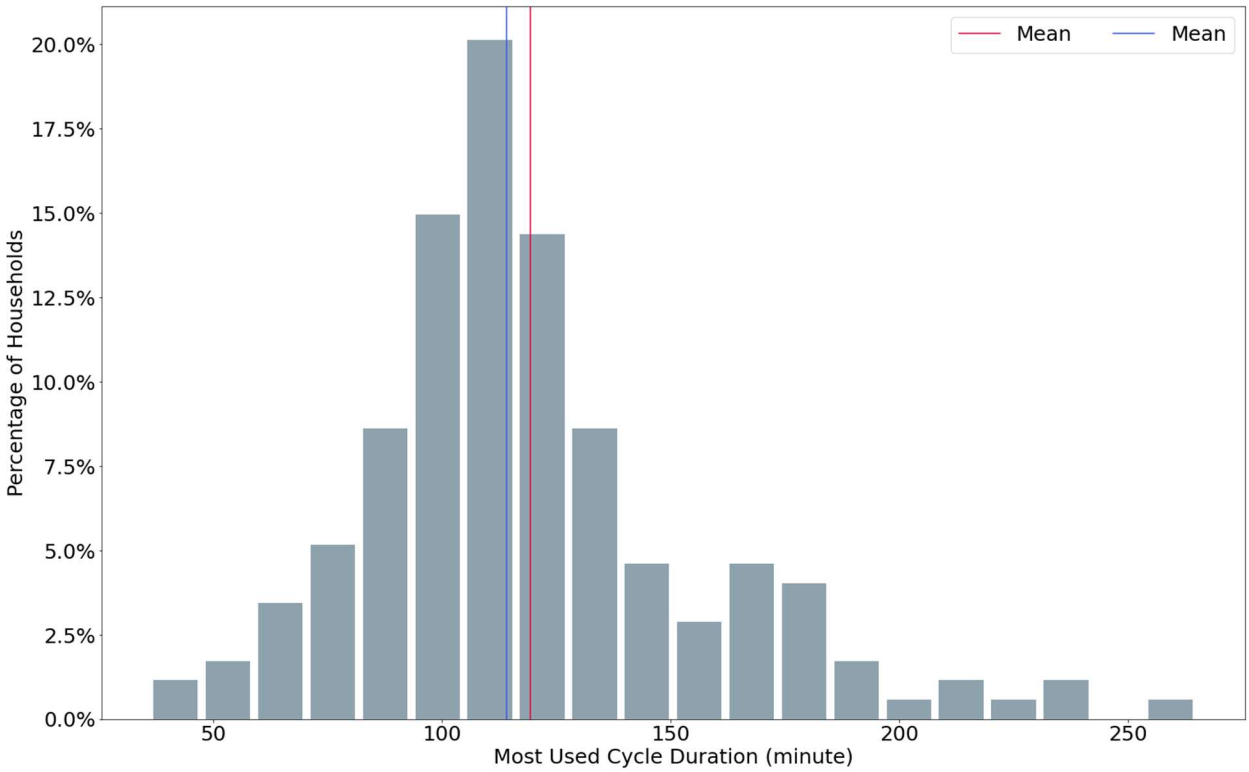


Figure 5-6. Frequency of Most-Used Cycle Duration (Minute)

6. Discussion

In this section we compare metered data with two sources of survey data, recognizing that field-metered data and survey data are inherently different. The survey data are from EIA's RECS and from a Lawrence Berkeley National Laboratory (LBNL) study (Stratton et al. 2021). Pecan Street data are not nationally representative; however, the data offer a detailed view into dishwasher energy usage for four states, over multiple years, and for hundreds of households. In contrast, both EIA's RECS and the LBNL survey are nationally representative, but without metered dishwasher usage frequency. RECS is conducted every 3–5 years, and the LBNL study conducted a national dishwasher online survey of users that purchased a dishwasher within a 24-month period over 2018–2019 (Stratton et al. 2021).

Given the multiple year representation of the Pecan Street data (2013–2021), the usage data obtained from RECS 2015 (US EIA 2015), RECS 2020 (US EIA 2021A), and the LBNL survey can be viewed with the Pecan Street data of the corresponding year. Differing estimates of

annual cycle count can serve as a cross validation step to minimize the bias from sample selection and data collection methods.

6.1 Survey Questions

In both RECS 2015 and RECS 2020, respondents were asked to report their weekly usage by indicating the number of dishwasher cycles run in a typical week (from 0 to 99). For the LBNL survey, respondents were asked to report their weekly usage by choosing one of the following bins:

- Less than once a week
- 1-3 times a week
- 4-6 times a week
- Once a day
- More than once a day

6.2 Weekly Usage

Comparing the three years of survey and field-metered data required different approaches for each comparison year because the datasets collected similar, but not identical, data. Also, even though RECS did not bin its usage frequency, we bin them here to compare them with the LBNL survey. Table 6-1 shows the household sample sizes for the four datasets.

Table 6-1. Household Sample Size Comparison

2015		2019		2020	
RECS 2015 (with dishwasher)	**Pecan Street**	**LBNL**	**Pecan Street**	**RECS 2020 (with dishwasher)**	**Pecan Street**
CA, CO, TX		**CA, CO, TX, NY**		**CA, CO, TX, NY**	
1,052	294	304	174	2,570	189

2015 Usage Comparison

For the 2015 usage comparison, we needed to approximate a state identification for the RECS 2015 households. Since RECS 2015 reports location at the census division level (not state level), we matched household data for cooling degree days (CDD) and heating degree days (HDD) to 2015 National Oceanic and Atmospheric Administration (NOAA) weather station data to identify the most likely state for each RECS 2015 household. The least squares method was used to minimize the difference between RECS sample's reported CDD/HDD and those weather stations situated in the same census division. The weather stations' annual CDD/HDD values were measured and published by NOAA (NOAA 2015).[24] We then compared the survey data with the field-metered data for California, Colorado, and Texas. Given that the majority of the housing types are single-family houses, no stratification was used to weight the usage frequency by state or by housing type to avoid the high risk of having a small outlier sample of multi-family households being assigned excess weight and biasing the overall average calculation.

[24] The weather station assignment used the following equation: $(HDD_{recs} - HDD_{noaa})^2 / \max(HDD_{noaa})^2 + (CDD_{recs} - CDD_{noaa})^2 / \max(CDD_{noaa})^2$.

Figure 6-1 illustrates a comparison of survey respondent-reported national usage from RECS 2015 and from Pecan Street metered data in 2015.

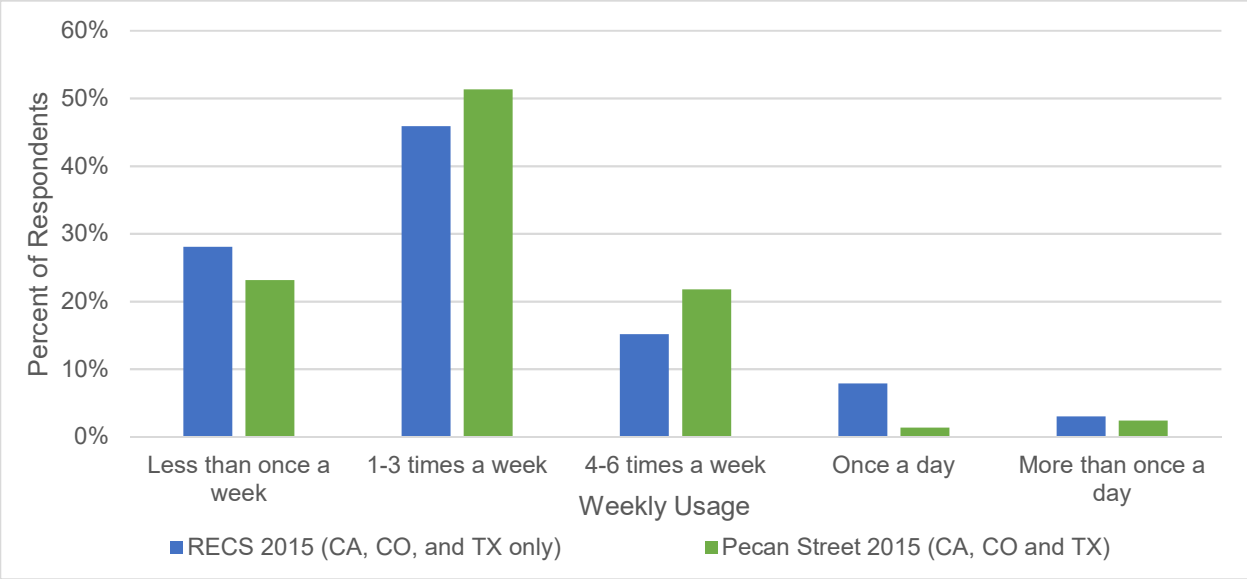


Figure 6-1. Dishwasher Weekly Usage Pattern Comparison between RECS 2015 and the Pecan Street 2015 Data

The usage patterns are similar between RECS 2015 and Pecan Street 2015 data. However, because RECS did not provide the respondent with the option of responding with fractions of a week, for households with low dishwasher usage (less than once a week) the exact average usage frequency cannot be compared directly. Note that in the Pecan Street data, all household samples with dishwasher measurements were accounted for, including those with zero cycles (to be consistent with RECS sample selection criteria).

2019 Usage Comparison

For 2019, we compared the LBNL survey data and the 2019 Pecan Street field data. Unlike RECS 2015, the LBNL survey does identify states. However, the LBNL survey reports usage within numerical bins (see Section 6.1 for the usage bin definition).

Figure 6-2 shows the comparison between survey data and field-metered data for 2019 for the four states of California, Colorado, Texas, and New York. Given the limited household sample of Pecan Street data for California and Colorado, their usage frequency is not representative of the state average usage, and a direct comparison cannot be made. Although the majority of the sample households are located in Texas, the Texas samples may also not be representative of the state, given the inherent bias with the program nature (such as volunteer-based sample selection and that most housing types are single-family houses) and sample bias.

The LBNL survey targeted consumers that had purchased a new dishwasher in the past 24 months. It is possible that consumers are more likely to use the newly purchased appliances; consequently, the portion of the survey respondents that use their dishwasher less than once a week is significantly less than what was observed in the Pecan Street data, which include dishwashers of all ages. This may also help to explain the discrepancy observed in the "Once a day" category.

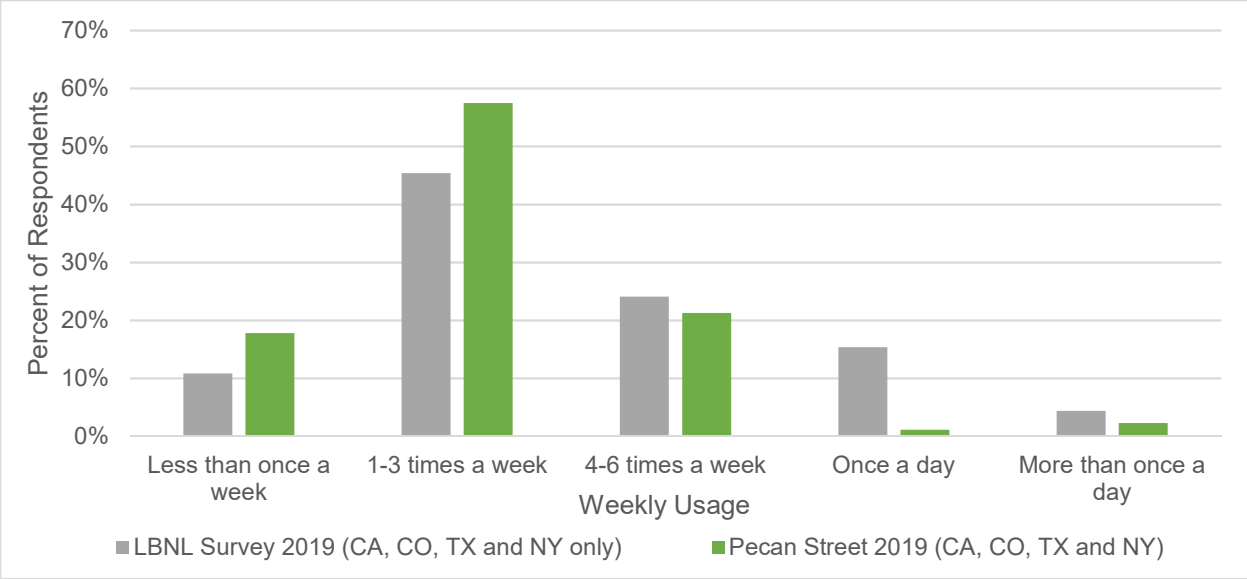


Figure 6-2. Dishwasher Weekly Usage Pattern Comparison between LBNL and Pecan Street 2019 Data

2020 Usage Comparison

Figure 6-3 illustrates the dishwasher usage comparison between the RECS 2020 survey data and the Pecan Street 2020 field-metered data. Unlike RECS 2015, RECS 2020 identifies individual states for each household in its sample; therefore, a direct state comparison can be made without using CDD/HDD matching. No other adjustments were made other than binning the usage to allow comparison across the datasets.

The usage pattern is similar to the comparison of RECS 2015 data with Pecan Street data; however, some differences do exist:

- The two categories with the largest discrepancies are "Less than once a week" and "4-6 times a week."
- The Pecan Street data showed a higher percentage of the consumers in the "1-3 times a week" and "4-6 times a week" categories, but a lower percentage of the consumers in the "Once a day" and "Less than once a day" categories.

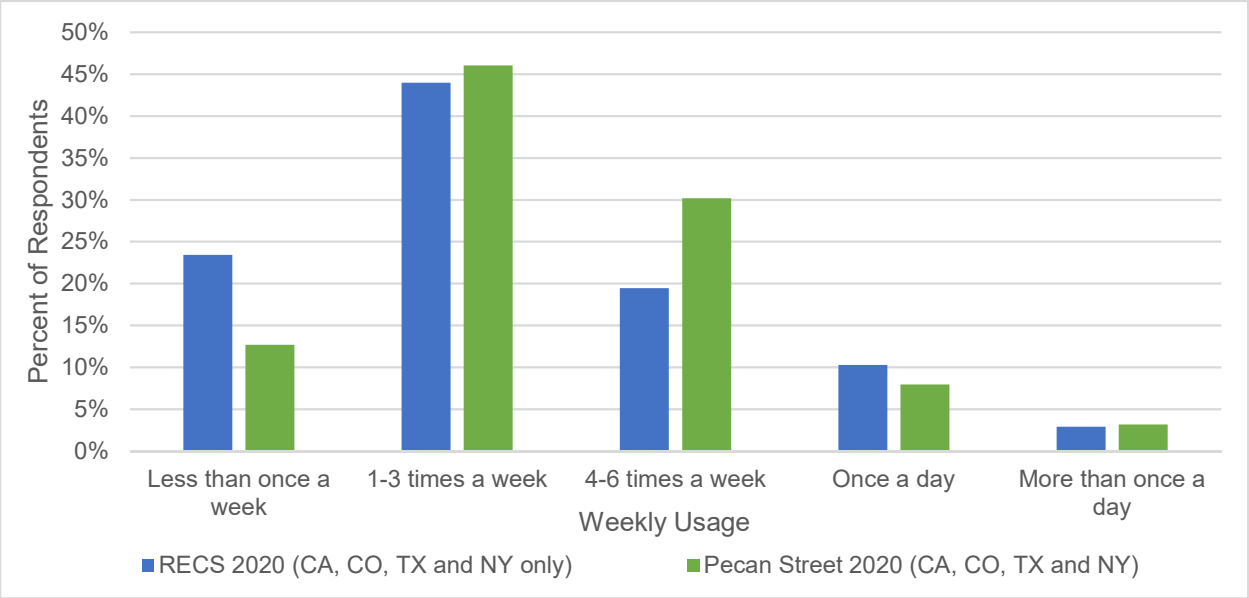


Figure 6-3. Dishwasher weekly usage pattern comparison between RECS 2020 and Pecan Street 2020 data

Comparison Observations

Based on the comparison of weekly usage from field metered data and survey data, some inconsistencies were observed. Multiple reasons can potentially result in those discrepancies. First of all, the usage frequency survey question refers to a typical week and may not include changes in usage that can occur during vacations, holidays, or festive events. Infrequent events such as these can impact the annual usage frequency. The field-metered data can potentially capture the impact of these atypical events, which may result in different usage patterns from those of typical weeks.

Another possible source of discrepancy can be related to the set-up of the usage bins. The usage bins present different degrees of variability due to the width of the interval defined (e.g., "once a day" versus "4-6 times a week"). In the LBNL survey, the cutoff of the category "once a day" and "more than once a day" presents more uncertainty for a respondent-reported survey.

Differences also arose from the limited household sample size for some states in the field-metered data. The Pecan Street data for California has only 19 households, which may not be interpreted as a representative sample of the whole state.

6.3 Usage Distribution of Infrequent Use

In the previous section, we noted that none of three respondent-reported surveys (two RECS surveys and one LBNL survey) took less than once per week use into account. For respondents reporting dishwasher usage at zero times per week, their usage is considered as zero in the national average annual cycle count calculation. However, some consumers may still use their dishwasher, even if the usage is less than once a week. The Pecan Street data provide the opportunity to quantify usage in the "less than once a week" bin. Figure 6-4. illustrates the annual cycle count distribution for Pecan Street sample households with dishwasher usage less

than once a week. This also includes those households with zero usage that were not included previously in the annual cycle count result (Table 5-1). The sample size is shown in the table on the x-axis for each year in Figure 6-4. On average, households that use their dishwasher infrequently (less than once per week) use it 15 cycles per year.

In each box and whisker plot, a box is drawn from the first quartile to the third quartile. The orange solid lines represent the medians, and the green dashed lines show the means. The whiskers indicate the range from first quartile to the first quartile-1.5*interquartile range (or IQR)[25] or from the third quartile to the third quartile+1.5*IQR.

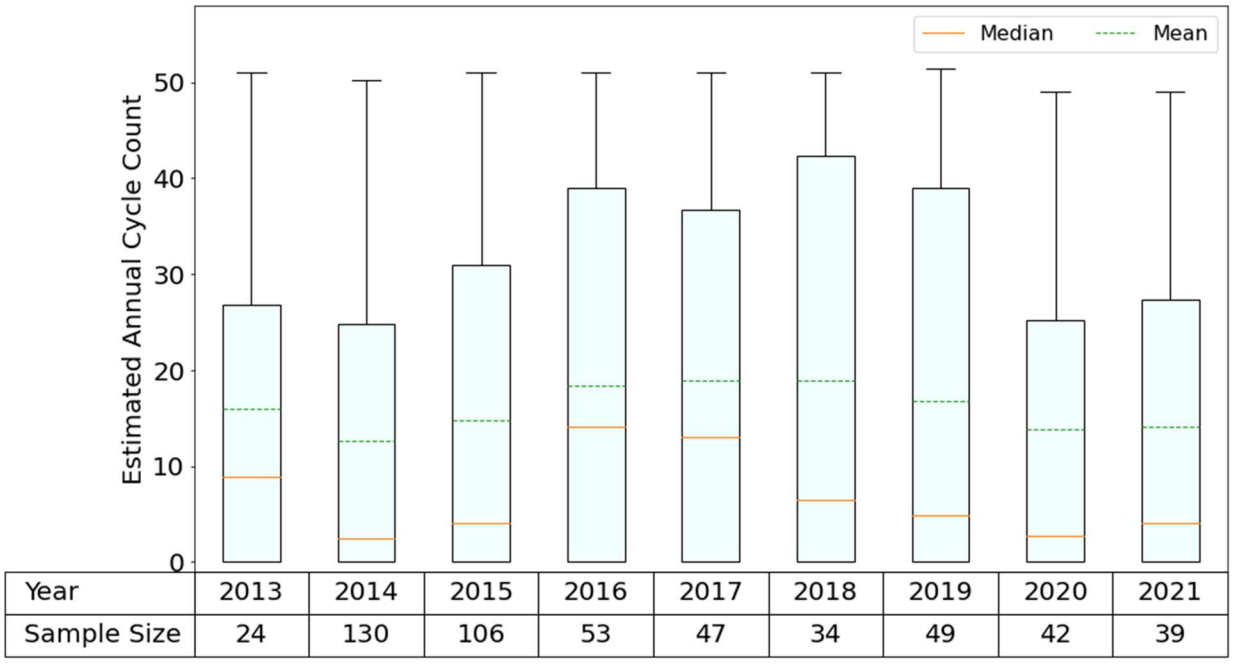


Figure 6-4. Dishwasher Annual Cycle Distribution for Households with Less Than 52 Cycles per Year, Pecan Street 2013–2021

6.4 Annual Cycle Comparison

To reasonably compare the field-metered data with the respondent-reported surveys, we limited weekly usage to only those households for which dishwashers were used at least once per week. Table 6-2 indicates the annual usage comparison between field-metered data and respondent-reported survey data. Households with fewer than 52 dishwasher cycles per year were excluded from the sample to avoid the need to distinguish between households with zero usage and households with usage of less than once per week. The percentage relative change is based on an average and does not take the sample size into account.

[25] The Interquartile Range, IQR, is the range between the first quartile and the third quartile.

Table 6-2. Annual Cycle Count Comparison with Selected Households Between Pecan Street 2015 and 2020 Data and RECS 2015 and 2020 Data by Applicable States for Households with at Least 52 Cycles per Year

	Pecan Street with Usage Equal to or Greater Than 52 Cycles/Year		RECS Survey Usage Equal to or Greater Than 52 Cycles/Year		% of Difference of Average Cycle Count (Relative to RECS)
Location	**Average Cycle Count**	**Household Sample Size**	**Average Cycle Count**	**Household Sample Size**	
2015 CA, CO, TX	164	227	181	671	-9
2020 CA, CO, TX, NY	197	166	191	2,038	3

Due to the limited sample size of California and Colorado, the Pecan Street state averages are not representative of the states' average usage. Therefore, the average annual cycles per year are shown for a filtered Pecan Street 2015 household sample that does not distinguish by the geographic location. A relatively small discrepancy (9 percent) is observed when compared with average cycle count values from RECS 2015 household samples from California, Colorado, and Texas based on the weather data matching.[26]

The same comparison was performed with the RECS 2020 data. The RECS 2020 sample size is significantly greater than the Pecan Street 2020 data. After applying the filter of equal to or greater than 52 cycles per year, the limited state subgroup annual cycle averages estimated from the two datasets are close (3 percent).

In summary, the above comparisons suggest that the dishwasher usage frequencies observed in the Pecan Street 2015 and 2020 field-metered data are generally consistent with the RECS 2015 and RECS 2020 respondent-reported usage frequencies, respectively.

6.5 Possible Sources of Differences

We have shown that the Pecan Street field-metered data are generally consistent with RECS respondent-reported usage frequencies from our comparisons based on limited geographic locations and a subsample of RECS. Considering the sample selection bias, the limited sample location and sample size of Pecan Street data, and the different data collection methods used for the two datasets, the consistency of usage frequency obtained is supportive of using RECS data as a nationally representative sample to estimate dishwasher annual usage frequency. In this section, we list several potential reasons for the small discrepancies.

[26] For context, 9 percent represents 16 cycles per year, which is approximately 23 kWh per year or 0.2 percent of a typical household's total electricity consumption, assuming 1.43 kWh/cycle (US EIA 2021b).

- Representative samples in field-metered data

Pecan Street relies on households volunteering for their energy metering program in four states. The sample is not nationally representative for various reasons:

1. Pecan Street only meters households in four states (Texas, California, Colorado, and New York).
2. Self-selection bias is inherent, due to the volunteer nature of the Pecan Street metering.
3. Most of the samples are single-family houses, and all the respondents were owners, not renters, which may imply a higher household combined income level compared to the national distribution.
4. Participating households may have heightened awareness of energy usage and curtail their energy consumption as a result of being metered. Under such circumstances, making nationally representative claims as a result of comparing RECS and Pecan Street data is not possible.

- Measurement period difference

The RECS 2020 household data were collected in two waves: September to November 2020 and January to April 2021 (US EIA 2020). Since March 2020 is the time when SIP orders were instituted for most parts of the country, and one year later (in March 2021) all business in Texas were allowed to reopen at full capacity, the surveyed usage in RECS 2020 appeared to be not fully reflecting the impact of the SIP orders. However, Pecan Street collected usage data of the whole year of 2020, including April through August, when the consumer behaviors may have been directly affected by SIP orders. However, without causal analysis, one could postulate that the observed increased usage during the pandemic could be related to the SIP.

- No state-level location information in RECS 2015

The discrepancy in the comparison of 2015 data may be attributable to the lack of state-level disaggregation in RECS 2015. For the RECS 2015 samples, the sample selection relied on matching reported CDD and HDD data to NOAA-based weather station data, which may introduce bias.

- Respondent-reported weekly usage

RECS asked the respondent to report the usage frequency in a typical week. Unreported are atypical weeks and fractional weekly usage due to household vacancy. In addition, holiday festivities can alter and bias the total cycle counts per year. For 2015 data, 23 percent of the Pecan Street field-metered households used their dishwashers fewer than 52 times a year and RECS respondent-reported data showed 27 percent of the households reported “zero usage” (i.e., less than one use per week). For 2020 data, 13 percent of the Pecan Street field-metered households showed usage fewer than 52 times a year, and the RECS respondent-reported households in California, Colorado, New York, and Texas showed 19 percent reported “zero usage” (i.e., less than one use per week).

- Cycle definition

This study was focused on complete dishwasher cycles and does not account for specific partial washes such as a “rinse and hold.” However, partial washes still consume water and energy, and may need to be considered for estimating the household’s dishwasher energy and water usage.

- Data collection challenges

The field-metered data may experience challenges that impact data quality:

  - inclusion of energy usage from additional devices on the same circuit
  - unstable connection at the electrical panel
  - data gaps due to electrical outages or device disconnection
  - electrical line noise due to equipment or field conditions

7. Conclusion and Perspective

This study estimates annual cycle counts for dishwashers and characterizes the length and frequency of dishwasher cycles using field-metered data in over 500 US households located in Texas, California, New York, and Colorado. Collected data from Pecan Street include dishwasher power measurements and housing characteristics.

Pecan Street's field-metered data across a 10-year period offer an opportunity to use actual appliance energy consumption to track household usage trends over time and to evaluate prior assumptions made in different usage and consumption analyses. We observed a variation in annual average dishwasher cycle counts ranging from 128 to 176 cycles per year during the analysis period (2013–2021). After matching geographic locations and removing households with fewer than one cycle per week, our analysis and results indicate that the RECS respondent-reported usages and the field-metered data are broadly consistent.

With the field-metered data, this study also explored the following dishwasher use aspects that had been unavailable in publicly available literature or data:

- most current average annual number of dishwasher cycles
- typical cycle profiles
- average cycle times
- possible impacts of the occupancy change after the shelter-in-place order due to COVID on the usage frequency
- historical quick cycle usage frequency
- frequency of most used cycle
- average and median of per-cycle energy consumption
- usage frequency distributions for households with infrequent use (less than once a week)

These findings provide helpful insight for future analyses and policy decisions. However, the lack of data, such as household demographics, dish soiled level, size of dishwasher loads, and the type of dishes and/or pots washed do not permit further investigation into the dishwasher cycle variation. Further insights may be gained in field-metering efforts by addressing the following issues:

- missing dishwasher model information
- limited household numbers
- lack of representative weighting
- narrow geographic coverage
- electrical line noise and/or usage from devices operating on the same electrical circuit as the dishwasher

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