CHAPTER 7. ENERGY AND WATER USE ANALYSIS

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CHAPTER 7. ENERGY AND WATER USE ANALYSIS

7.1 INTRODUCTION

To carry out the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8, DOE needed to determine the savings in operating costs that consumers would derive from more efficient products. DOE used consumer energy and water use data, along with energy and water prices, to develop the most significant component of consumer operating costs in the LCC and PBP analyses. (Maintenance and repair costs are the other contributors to operating cost.) This chapter describes how DOE determined the annual energy and water consumption of residential dishwashers.

7.2 PER-CYCLE ENERGY AND WATER CONSUMPTION BY EFFICIENCY LEVEL

Dishwasher per-cycle energy consumption has three components: energy used for heating water, operating the machine, and drying the dishes. The energy used to operate a machine powers the motor (to pump water and dispose of food) and booster water heater. The DOE test procedure provides the following equations to calculate the total per-cycle energy consumption of dishwashers:

$$DW_{CYCLE} = WH + M + D$$

$$DW_{CYCLE} = V \times T \times \frac{K}{e} + M + D$$

Where:

DW_{CYCLE} =	dishwasher per-cycle energy consumption,
V =	water consumption in gallons per cycle,
T =	nominal water temperature rise = 70 ºF (assuming a nominal inlet water temperature of 120 ºF),
K =	specific heat of water in kWh per gallon per degree Fahrenheit (0.0024), or Btus per gallon per degree Fahrenheit (8.2),
e =	efficiency of electric water heater (100 percent) or gas water heater (75 percent),
$WH = V \bullet T \bullet K/e$ =	water-heating per-cycle energy consumption,
M =	machine per-cycle energy consumption, and
D =	drying per-cycle energy consumption.

The largest component of dishwasher energy consumption is water-heating energy use. Water-heating energy use is directly dependent on water use.

To develop per-cycle energy use values, DOE used data developed by the engineering analysis. As discussed in chapter 5, DOE analyzed specific efficiency levels for standard-sized and compact dishwashers. Table 7.2.1 and Table 7.2.2 provide the annual energy use, per-cycle water use, and standby power for standard-sized and compact dishwashers, respectively. Also included in the tables is the standby power consumption corresponding to each efficiency level.

Table 7.2.1 Standard-Sized Dishwashers: Annual Energy Use, Per-Cycle Water Use, and Standby Power Use by Efficiency Level

Level	Annual Energy Use kWh/yr	Water Use gal/cyc	Standby Power W
Baseline	355	6.50	0
1	324	5.80	2.3
2	307	5.00	1.7
3	295	4.25	1.7
4	234	3.80	1.7
5	180	1.60	1.7

Table 7.2.2 Compact Dishwashers: Annual Energy Use, Per-Cycle Water Use, and Standby Power Use by Efficiency Level

Level	Annual Energy Use kWh/yr	Water Use gal/cyc	Standby Power W
Baseline	260	4.50	2.3
1	222	3.50	2.3
2	154	2.10	1.7

Based on the data in Table 7.2.1 and Table 7.2.2, DOE derived per-cycle energy use estimates using equations and assumption in the DOE test procedure.

DOE developed the per-cycle dishwasher energy use by first subtracting from the total annual dishwasher energy use the standby power energy use. The result is the annual dishwasher energy use, i.e., the energy dedicated to dishwashing only. The per-cycle dishwasher energy use is simply the annual dishwasher energy use divided by the average-use cycles per year.[1] Arthur D. Little (ADL) conducted a comprehensive analysis of dishwasher usage in 2001 that revealed that dishwashers are used, on average, 215 cycles per year.[2]

The following equation from the DOE test procedure demonstrates how the per-cycle dishwasher energy use is determined. Below is the equation for total annual energy use:

$$DW_{ANNUAL} = DW_{CYCLE} \times N + S_m \times \frac{H - (N \times L)}{1000}$$

Where:

DW_{ANNUAL} = total annual dishwasher energy consumption,
DW_{CYCLE} = per-cycle dishwasher energy consumption,
N = representative average dishwasher use of 215 cycles per year,
S_m = average standby power in Watts,
H = total number of hours per year = 8,766, and
L = average duration of dishwasher cycle.

Because both the total annual dishwasher energy use and standby power consumption are known, the per-cycle dishwasher energy consumption simply is:

$$DW_{CYCLE} = \frac{DW_{ANNUAL} - S_m \times \frac{H - (N \times L)}{1000}}{N}$$

Per-cycle dishwasher energy use is disaggregated into two general categories: (1) water heating; and (2) machine (e.g., motor energy for pumping) and dish drying from an electrical heating element. DOE determined the per-cycle water heating consumption by assuming the use of an electric water heater and multiplying the per-cycle water consumption by an assumed temperature rise of 70 ºF (21 ºC) and a specific heat of 0.0024 kWh/gal-ºF (4.186 joule/gram-°C). DOE determined the per-cycle machine and drying energy by subtracting the per-cycle water heating energy consumption from the per-cycle dishwasher energy consumption. Table 7.2.3 and Table 7.2.4 show energy use and components for standard-sized and compact dishwashers, respectively.

Table 7.2.3 Standard-Sized Dishwashers: Per-Cycle Energy Use by Efficiency Level

Level	Energy Use kWh/yr	Water Use gal/cyc	Standby Power W	Per-Cycle Energy Use Components		
				Total* gal/cyc	Water Heating** gal/cyc	Machine + Drying gal/cyc
Baseline	355	6.50	0	1.65	1.09	0.56
1	324	5.80	2.3	1.42	0.97	0.44
2	307	5.00	1.7	1.36	0.84	0.52
3	295	4.25	1.7	1.30	0.71	0.59
4	234	3.80	1.7	1.02	0.64	0.38
5	180	1.60	1.7	0.77	0.27	0.50

* Standby annual energy use based on an assumed dishwasher cycle of one hour and 215 cycles per year; Standby hours = 8,766 hours – 215 * 1 hour = 8,551 hours.

** Based on the use of an electric water heater at 100% efficiency.

Table 7.2.4 Compact Dishwashers: Per-Cycle Energy Use by Efficiency Level

Level	Energy Use kWh/yr	Water Use gal/cyc	Standby Power W	Per-Cycle Energy Use Components		
				Total* gal/cyc	Water Heating** gal/cyc	Machine + Drying gal/cyc
Baseline	260	4.50	0.0	1.12	0.76	0.36
1	222	3.50	2.3	0.94	0.59	0.35
2	154	2.10	1.7	0.65	0.35	0.30

* Standby annual energy use based on an assumed dishwasher cycle of one hour and 215 cycles per year; Standby hours = 8,766 hours – 215 * 1 hour = 8,551 hours.

** Based on the use of an electric water heater at 100% efficiency.

7.3 AVERAGE ANNUAL ENERGY AND WATER CONSUMPTION BY EFFICIENCY LEVEL

DOE determined the average annual energy and water consumption by multiplying the per-cycle energy and water consumption by the number of cycles per year.

In 2003, DOE revised its test procedure for dishwashers to more accurately establish their efficiency and energy and water use. The 2003 test procedure amendments included a reduction in the average-use cycles per year. As discussed above, ADL conducted a comprehensive analysis of dishwasher usage in 2001 in 26,000 households that revealed that dishwashers are used, on average, 215 cycles per year.[2] The 2005 RECS provides data indicating the annual usage of households with dishwashers. Of the almost 4400 households in RECS, 2480 have dishwashers. The average-use value for dishwashers in the 2005 RECS households is 174 cycles per year. But because the ADL survey is a much more comprehensive and larger survey than the survey performed for RECS, DOE chose an average usage of 215 cycles per year as the most representative value for average dishwasher use.

DOE calculated dishwasher annual energy consumption from the per-cycle values reported in Table 7.2.3 and Table 7.2.4 by multiplying them by the average-use cycles as shown below with the following equations:

$$DW_{WH-ANN} = WH \times N$$

$$DW_{MACH-ANN} = M \times N$$

$$DW_{DRY-ANN} = D \times N$$

Where:

$DW_{WH\text{-}ANN}$ = total annual dishwasher energy consumption,
$DW_{MACH\text{-}ANN}$ = total per-cycle dishwasher energy consumption, and
$DW_{DRY\text{-}ANN}$ = total per-cycle dishwasher energy consumption.

DOE calculated dishwasher annual water consumption with the following equation:

$$DW_{WATER-ANN} = DW_{WATER-CYC} \times N$$

Where:

$DW_{WATER\text{-}ANN}$ = total annual dishwasher water consumption, and
$DW_{WATER\text{-}CYC}$ = total per-cycle dishwasher water consumption.

The annual energy and water consumption shown in Table 7.3.1 for standard dishwashers and in Table 7.3.2 for compact dishwashers reflect an annual usage of 215 cycles per year. The annual water-heating energy consumption reflects the use of an electric, gas, or oil water heater.

Table 7.3.1 Standard-Sized Dishwashers: Annual Energy and Water Use by Efficiency Level

Efficiency Level	Annual Energy Use						Annual Water Use
	Total	Water Heating*			Machine + Drying +	Standby	
		Electric	Gas	Oil			
	kWh/yr	kWh/yr	MMBtu/yr	MMBtu/yr	kWh/yr	kWh/yr	gal/yr
Baseline	355.0	234.8	1.068	1.068	120.2	0.0	1,398
1	324.0	209.5	0.953	0.953	94.8	19.7	1,247
2	307.0	180.6	0.822	0.822	111.9	14.5	1,075
3	295.0	153.5	0.698	0.698	127.0	14.5	914
4	234.0	137.3	0.624	0.624	82.2	14.5	817
5	180.0	57.8	0.263	0.263	107.7	14.5	344

* Electric, gas, and oil water heating based on water heater efficiencies: 100% for electric, 75% for gas, 75% for oil.

Table 7.3.2 Compact Dishwashers: Annual Energy and Water Use by Efficiency Level

Efficiency Level	Annual Energy Use						Annual Water Use gal/yr
	Total kWh/yr	Water Heating*			Machine + Drying + kWh/yr	Standby kWh/yr	
		Electric kWh/yr	Gas MMBtu/yr	Oil MMBtu/yr			
Baseline	260.0	162.5	0.739	0.739	77.8	19.7	968
1	222.0	126.4	0.575	0.575	75.9	19.7	753
2	154.0	75.9	0.345	0.345	63.6	14.5	452

* Electric, gas, and oil water heating based on water heater efficiencies: 100% for electric, 75% for gas, 75% for oil.

7.4 VARIABILITY OF DISHWASHER USAGE

The 2005 RECS indicates that 2,480 of the 4,382 households in the survey use dishwashers. For each household using a dishwasher, RECS provides data on the number of dishwasher cycles in the following bins: (1) less than once per week, (2) once per week, (3) 2–3 times per week, (4) 4-6 times per week, (5) at least once per day. DOE converted the above to annual values and created a triangular or uniform distribution for each bin. Table 7.4.1 shows the share of households in each bin and the distribution used. DOE randomly assigned a specific numerical value from within the appropriate bin to each household in the dishwasher sample. The average number of cycles per year derived from the RECS 2005 data is 174.

Table 7.4.1 RECS 2005 Dishwasher Usage Data

Bin	Share of RECS Households		Distribution Used
	Percentage* %	Count	
Less than once per week	17	402	Triangular, 1 to 52
Once per week	14	325	Uniform, 26 to 78
2–3 times per week	34	834	Uniform, 78 to 182
4–6 times per week	18	464	Uniform, 182 to 338
At least once per day	17	455	Triangular, 300/400/500

*Percentages represent weighted values.

To determine the variability of dishwasher usage, DOE normalized the household usage values from RECS so that the average-use value equaled 215 cycles per year rather than the weighted-average value of 174 cycles per year as indicated by RECS. DOE determined the usage for each RECS household with a dishwasher based on the following equation:

$$N_{DW} = N_{DW\_HH} \times \frac{N_{DOE\_AVG}}{N_{RECS\_AVG}}$$

Where:

N_{DW} = modified dishwasher usage for specific RECS household,
N_{DW_HH} = dishwasher usage for specific RECS household as specified by RECS,
N_{DOE_AVG} = average dishwasher usage of 215 cycles per year as established in the DOE test procedure, and
N_{RECS_AVG} = average dishwasher usage of 174 cycles per year as established by RECS.

With the normalized dishwasher usage known for each RECS household, DOE determined the corresponding annual energy and water consumption. For all RECS households, dishwasher use frequency varies from 1 to over 600 cycles per year. Figure 7.4.2 shows the probability distribution of the modified dishwasher usage that DOE determined for each RECS household.

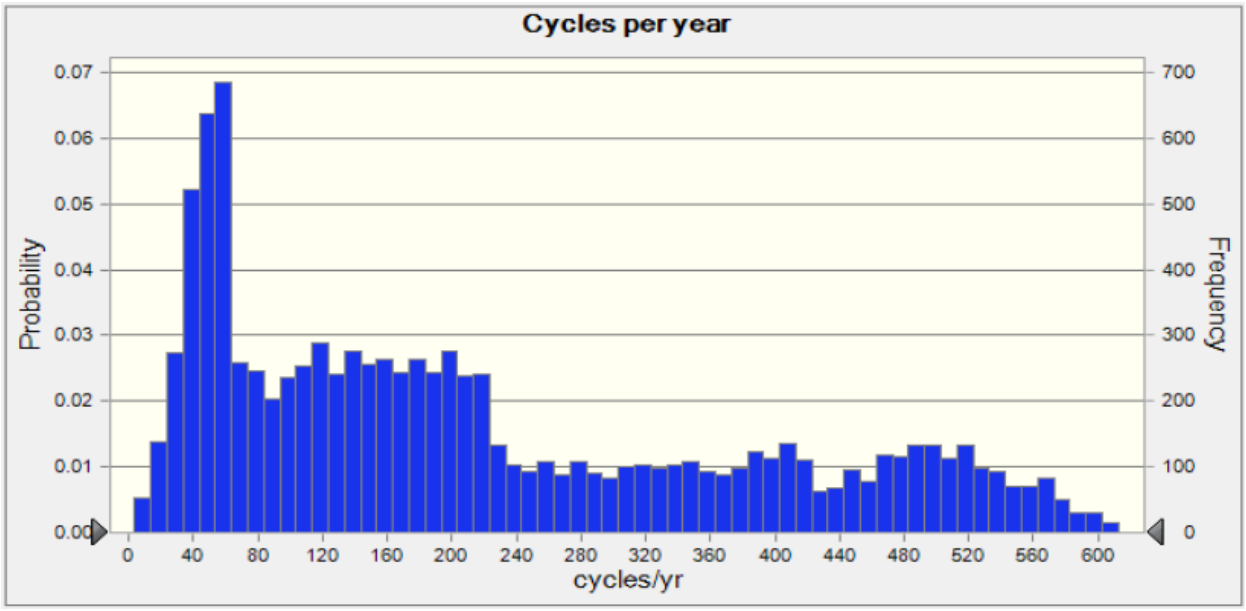

Figure 7.4.2 Distribution of Dishwasher Annual Usage (cycles per year) Based on 2005 RECS Usage Data

REFERENCES

1 U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products: Test Procedure for Dishwashers, Final Rule. *Federal Register*. August 29, 2003. Vol. 68, no. 168: pp. 51887–51903.

2 Arthur D. Little. *Review of Survey Data to Support Revisions to DOE's Dishwasher Test Procedure*, December 18, 2001. Prepared for the U.S. Department of Energy by Arthur D. Little: Cambridge, MA.