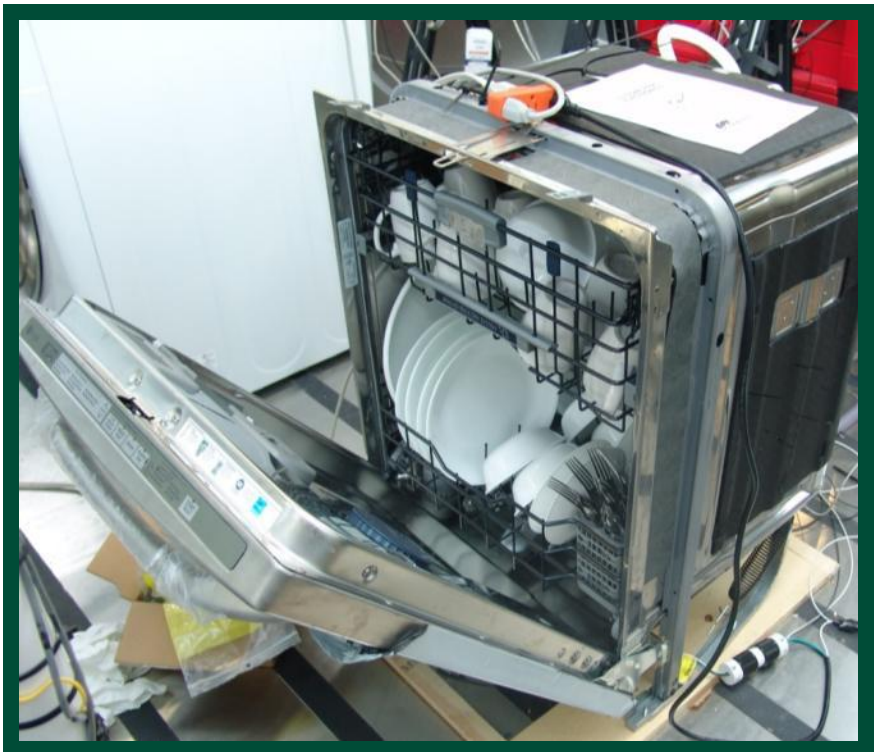
Design & Engineering Services

DEMAND RESPONSE POTENTIAL OF RESIDENTIAL APPLIANCES: DISHWASHER A

DR10SCE1.16.03 Report



Prepared by:

Design & Engineering Services
Customer Service Business Unit
Southern California Edison

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Acknowledgments

Southern California Edison's (SCE's) Design & Engineering Services (DES) group is responsible for this project in collaboration with the Tariff Program & Services (TPS) group. It was developed as part of SCE's Demand Response, Emerging Markets and Technology program under internal project number DR10SCE1.16.03. DES project manager Sean Gouw conducted this technology evaluation with overall guidance and management from Carlos Haiad and Devin Rauss of DES and Mauro Dresti of TPS. For more information on this project, contact sean.gouw@sce.com.

EXECUTIVE SUMMARY

OVERVIEW

To help consumers take advantage of the emerging smart grid, private industry is creating products that put more control of energy use into the hands of users. In particular, some products integrate advanced control features aimed at ensuring demand response (DR)—or the ability to react to adverse grid conditions or price signals.

To better understand the capabilities of smart appliances, Southern California Edison (SCE) has initiated a series of projects to test appliances from various manufacturers in a laboratory environment. In particular, this testing seeks to fill current information gaps by examining DR capabilities in appliances.

The current project, conducted under the larger SCE effort, focused on DR laboratory testing and evaluation of an ENERGY STAR–compliant dishwasher (produced by a manufacturer referred to as Manufacturer A) equipped with DR capabilities. Specifically, to achieve DR goals, dishwasher A could either delay its operating wash mode or eliminate an enhanced heated dry mode.

OBJECTIVES AND APPROACH

The objectives of the testing were to quantify the DR potential for dishwasher A and characterize its response to DR signals under varying operational scenarios. The project included two types of tests:

- Acquire the power profile data of dishwasher A under various operational settings
- Quantify the demand reduction potential for dishwasher A
- Characterize the response of dishwasher A to DR signals under varying operational scenarios

FINDINGS

The testing program led to the following findings:

- Dishwasher A consistently demonstrated compliance with its intended DR strategy. The report includes details on various operational nuances, including influences of DR event type, length, and time of occurrence in relationship to dishwasher operations.
- The dishwasher had the potential to eliminate or delay up to 1 kilowatt (kW) of demand.
- DR delay scenarios did not impact the energy consumption of the dishwasher.
- The heated dry enhancement increased the energy consumption of a normal wash mode by 40%, indicating the potential for significant energy use reductions by eliminating this enhancement.
- The dishwasher met manufacturer specifications.

ANALYSIS

Table 1 summarizes estimates of the energy consumption and demand reduction potential for several dishwashers. These savings potentials were based on assumptions about energy consumption, demand consumed, and data on dishwashers from a number of sources.[1,2,3,4,5]

It is important to note that the peak demand reduction potential (i.e., DR potential), is based on an unrealistic assumption that 100% of the load is coincidental with the peak and that 100% program participation would be achieved. However, this number provides a basis for determining DR potential using more realistic assumptions for coincidental load and program participation.

TABLE 1. SUMMARY PEAK DEMAND REDUCTION FROM DISHWASHER DEMAND RESPONSE CONTROLS*

	ANNUAL ENERGY CONSUMPTION (KWH)	PEAK DEMAND (KW)	DR PEAK DEMAND REDUCTION (KW)
Federal energy consumption regulations for standard-sized dishwashers manufactured on/after January 1, 2010 (**per dishwasher**)	355	-	-
Typical dishwasher peak demand (**per dishwasher**)	-	1.2 – 2.4	-
Dishwasher A energy profile (**per dishwasher**)	322	1.00	1.00
Estimates for California • Assumptions: - 8.7 million dishwashers - Per dishwasher: ○ 355 kWh/yr energy consumption ○ 2.4 kW peak demand ○ 1 kW demand reduction potential	3,088,500,000	20,880,000	8,700,000
SCE Territory • Assumptions: - 3 million dishwashers - Per dishwasher: ○ 355 kWh/yr energy consumption ○ 2.4 kW peak demand ○ 1 kW demand reduction potential	1,065,000,000	7,200,000	3,000,000

* This chart shows technical potential only to provide a baseline for analyzing DR potential using more realistic assumptions about coincident load and program participation.

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[1] California Energy Demand 2012-2022 Adopted Forecast (Volume 1: Table 1-3: "Electricity Noncoincident Peak Demand by Sector" and Figure 1-8: "Forecasts for Number of Households, Statewide;" Volume 2: Figure 2-7: "SCE Planning Area Residential Peak" and Figure 2-8: "SCE Planning Area Residential Household Projections"). http://www.energy.ca.gov/2012_energypolicy/documents/index.html#EnergyDemandForecast

[2] Estimating Appliance and Home Electronic Energy Use. http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040

[3] CEE Super-Efficient Home Appliances Initiative: Dishwashers. http://library.cee1.org/sites/default/files/library/9285/2012_SEHA_ID_3.pdf

[4] Banner Subset – RASS Total Results. http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004_RASS.PDF

[5] Banner Subset – SCE. http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-SCE.PDF

ABBREVIATIONS AND ACRONYMS

ACEEE	American Council for an Energy-Efficient Economy
AHAM	Association of Home Appliance Manufacturers
ATO	Advanced Technology Organization
BL	baseline testing
DBT	dry-bulb temperature
DES	Design and Engineering Services
DOE	Department of Energy
DR	demand response
DW	dishwasher
EMS	energy management system
FN	functional testing
HAN	home area network
kW	kilowatt
kWh	kilowatt-hour
MW	megawatt
NI	National Instruments
NIST	National Institute of Standards and Technology
psig	pounds per square inch, gage
TOU	time of use
TTC	Technology Test Centers
W	watt
Wh	watt-hour

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FIGURES

TABLES

INTRODUCTION

Major electrical grid failures over the past few decades, along with the emergence of widespread renewable generation and increased need for understanding energy consumption, have driven a growing push for an electric smart grid. Employing vast networks of communicating equipment on both the utility and customer sides of the meter, the smart grid is expected to improve the visibility and control over how and when energy is consumed.

Utilities have taken the lead on the smart grid components of the transmission and distribution system, as well as those of smart meters, which enable communication between the utility and the customer. However, to take full advantage of the smart grid, energy consumers need access to home area networks (HANs) with energy control software and smart appliances, which, together with the smart meter, enable communication of rates and grid conditions and offer integrated control capabilities to respond to the information received.

A key benefit to the utility of the fully enabled smart grid is the enablement of demand response (DR) capabilities, which can help stabilize energy costs and grid impacts by reducing energy consumption during peak periods. For this, the smart infrastructure allows the utility to send a signal to a customer's smart meter, which then communicates with the appliance (via a number of possible paths), directing it to take action to reduce load. Built-in algorithms allow smart appliances to determine whether they can respond to the signal while maintaining a minimal level of service to the consumer.

Private industry has advanced technologies to address smart grid needs. Several appliance manufacturers, for example, have begun integrating advanced control features into their products to enable products to reduce energy use and react to adverse grid conditions or price signals. In addition, the Association of Home Appliance Manufacturers (AHAM) and efficiency organizations coordinated by the American Council for an Energy-Efficient Economy (ACEEE) have recently come together in a formal agreement regarding appliances.[6] Outlining a number of smart appliance requirements, this agreement has been used by the U.S. Environmental Protection Agency's (EPA) ENERGY STAR program as a platform for building new programs. This agreement marks a key milestone in promoting the vision of an operating smart grid.

To better understand the capabilities of smart appliances and to inform the EPA's efforts, Southern California Edison (SCE) has initiated a series of projects to test a number of appliances from various manufacturers in a laboratory environment. In particular, this testing examines DR capabilities in appliances, as little yet is known about how appliance DR capabilities will be implemented.

This report focuses on DR laboratory testing and evaluation of a dishwasher (dishwasher A) produced by a manufacturer referred to here as Manufacturer A. Functional testing of dishwasher A was performed by Design and Engineering Services (DES) in SCE's Technology Test Centers (TTC), and communication testing was performed at SCE's HAN lab by the Advanced Technology Organization (ATO). This testing is intended give SCE a better understanding of how dishwasher A will react to certain DR signals.

[6] AHAM, et. al. 2011. "Joint Petition To ENERGY STAR To Adopt Joint Stakeholder Agreement As It Relates To Smart Appliances." http://www.energystar.gov/products/specs/system/files/Petition_to_ENERGY_STAR_from_Joint_Stakeholders.pdf

BACKGROUND

DISHWASHER DEMAND AND ENERGY USAGE AND MARKET DATA

Residential buildings contribute significantly to peak demand constraints within California and SCE's service area. The *California Energy Demand 2012–2022 Adopted Forecast* estimated that in 2011, the California residential sector consumed roughly 24,000 megawatts (MW) of peak demand. Approximately 10,000 MW of this total was consumed by the residential sector in SCE territory. Additionally, the report estimated residential households in 2011 to number roughly 13 million in California and 4.5 million in SCE's service area.[7]

Dishwashers, a common appliance in this market, can have fairly significant peak demand impacts: dishwasher power draw may range anywhere from 1.2 to 2.4 kilowatts (kW).[8] In California, where about 67% of households have a dishwasher[9] (for a total of about 8.7 million dishwashers), dishwashers account for approximately 2.5% of residential energy use.[10] Given that about 67% of SCE households have a dishwasher, nearly 3 million of California's dishwashers reside in SCE territory.

Dishwasher energy use has benefitted from federal regulations. Table 2 summarizes these regulations, which cover energy consumption (kilowatt-hours (kWh) and water consumption. The regulations shown apply to standard-sized dishwashers (capacity equal to or greater than eight place settings plus six serving pieces as specified in ANSI/AHAM DW-1).[11]

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[7] California Energy Demand 2012-2022 Adopted Forecast. (Volume 1: Table 1-3: "Electricity Noncoincident Peak Demand by Sector" and Figure 1-8: "Forecasts for Number of Households, Statewide;" Volume 2: Figure 2-7: "SCE Planning Area Residential Peak" and Figure 2-8: "SCE Planning Area Residential Household Projections). http://www.energy.ca.gov/2012_energypolicy/documents/index.html#EnergyDemandForecast

[8] Estimating Appliance and Home Electronic Energy Use. http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040

[9] Banner Subset - RASS Total Results. http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004_RASS.PDF

[10] CEE Super-Efficient Home Appliances Initiative: Dishwashers. http://library.cee1.org/sites/default/files/library/9285/2012_SEHA_ID_3.pdf

[11] Electronic Code of Federal Regulations. Energy and Water Conservation Standards.

http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=b6dda990498bdcd8ca997c8c88eeb604&rgn=div6&view=text&node=10:3.0.1.4.18.3&idno=10

TABLE 2. FEDERAL REGULATIONS REGARDING DISHWASHER ENERGY AND WATER USE

DISHWASHERS AFFECTED	MAXIMUM ANNUAL ENERGY CONSUMPTION (KWH)	MAXIMUM WATER CONSUMPTION PER CYCLE (GALLON)
Manufactured on/after January 1, 2010	355	6.5
Manufactured on or after May 30, 2013	307	5.0
Qualified as ENERGY STAR compliant (ENERGY STAR Version 4.1, effective August 11, 2009)	324	5.8
Qualified as ENERGY STAR compliant (ENERGY STAR Version 5.2, effective January 20, 2012)[12]	295	4.25

The next step in improving dishwasher energy use is the inclusion of smart components for greater control.

CURRENT DEFINITIONS FOR DEMAND RESPONSE AND SMART APPLIANCES

The California Public Utilities Commission defines DR as follows:

> Demand Response is a resource that allows end-use electric customers to reduce their electricity usage in a given time period, or shift that usage to another time period, in response to a price signal, a financial incentive, an environmental condition or a reliability signal. Demand response saves ratepayers money by lowering peak time energy usage, which are high-priced. This lowers the price of wholesale energy, and in turn, retail rates. Demand response may also prevent rolling blackouts by offsetting the need for more electricity generation and can mitigate generator market power.[13]

In 2010, joint petitioners (AHAM and energy-efficiency advocates coordinated by ACEEE) proposed a guideline to the U.S. Department of Energy (DOE) for defining smart appliances.[14] The guideline defines a smart appliance as follows:

> …a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and

[12] ENERGY STAR, Dishwashers Key Product Criteria. http://www.energystar.gov/index.cfm?fuseaction=products_for_partners.showDishwashers

[13] http://www.cpuc.ca.gov/PUC/energy/Demand+Response/

[14] AHAM, et. al. 2011. "Joint Petition To ENERGY STAR To Adopt Joint Stakeholder Agreement As It Relates To Smart Appliances" www.energystar.gov/products/specs/system/files/Petition_to_ENERGY_STAR_from_Joint_Stakeholders.pdf

> automatically adjust its operation depending on both the signal's contents and settings from the consumer. The product will be sold with this capability, which can be built-in or added through an external device that easily connects to the appliance. The costs of such devices shall be included in the product purchase price.
>
> These signals must include (but are not limited to) appliance delay load, time-based pricing and notifications for load-shedding to meet spinning reserve requirements. Any appliance operation settings or modes shall be easy for an average, non-technical consumer to activate or implement. Additionally, a Smart Appliance or added device may or may not have the capability to provide alerts and information to consumers via either visual or audible means. The appliance may not be shipped with pre-set time duration limits that are less than those listed below, but may allow consumer-set time duration limits on smart operating modes, and will also allow consumers to override any specific mode (e.g. override a delay to allow immediate operation, limit delays to no more than a certain number of hours, or maintain a set room temperature).
>
> **The term 'delay load capability'** refers to the capability of an appliance to respond to a signal that demands a response intended to meet peak load deferral requirements, but which also could be used to respond to a sudden maintenance issue at another time of day.
>
> **The term 'spinning reserve capability'** means the capability of an appliance to respond to a signal that demands a response intended to temporarily reduce load by a short-term, specified amount, usually 10 minutes."

The joint petitioners' proposed guidelines document goes on to propose product-specific definitions for various appliances. For dishwashers, the definitions are as follows:

> Dishwashers: a dishwasher must have the following minimum capabilities
>
> i) Delay load capability - upon receipt of a signal requesting a delay of load for a time duration not exceeding either 4 hours or such other period that the consumer may select, the product must automatically delay the start of the operating cycle beyond the delay period , and
>
> ii) Spinning reserve capability - upon receipt of a signal requesting the start of a reduced load period for a time duration not exceeding 10 minutes, the product must automatically reduce its average wattage during this period by at least 50 percent relative to average wattage during this period in the operating cycle under the DOE test conditions.

A particular appliance's ability to reduce load depends on the type of signal received, as well as the appliance's operational status when the signal is received. Currently, only durational, reliability-based DR signals are sent by the utility. However, utilities anticipate sending price signals, namely time-of-use (TOU) signals, in the future, thus allowing the smart appliance to optimize performance based on the total cost of operation.

As an overarching requirement, the DR-capable appliances must still be able to provide consumers the anticipated service, with no detriments to performance. For example, a DR-capable dishwasher should still provide clean dishes, even if the cycle is delayed by an event.

COMMUNICATIONS OVERVIEW AND TESTING

Communication with smart appliances can be achieved through multiple hardware configurations. It is important to note that the signals do not tell the device to turn off; rather, they alert the device to the existence of an event and allow the device's internal algorithms to determine whether or not a response is feasible.

The following sections describe three hardware models that enable communication with smart appliances. While all of these configurations can theoretically provide connectivity to the end unit, SCE and other utilities tend to support model 1. It avoids certain risks, especially related to customer information, present in some of the other models.

MODEL 1: SMART METER ⟺ GATEWAY ⟺ SMART APPLIANCE

In this model, the smart meter receives a signal and communicates to the gateway via Zigbee or similar protocols. The gateway then translates the signal to communicate with multiple appliances and devices via a variety of communication protocols. This configuration is depicted in Figure 1.

MODEL 2: SMART METER ⟺ SMART APPLIANCE

In this model, the meter receives a signal and communicates directly with the appliance using one of many protocols, such as Zigbee. This architecture eliminates the energy management system (EMS) shown in Figure 1. Most smart meters can pair with only a limited number of devices in this manner.

MODEL 3: UTILITY ⟺ SMART APPLIANCE

In this model, the utility communicates directly with the appliance using communication capabilities outside of the smart meter infrastructure. Examples include an air conditioning (AC) cycling program that uses pager technology or direct communication with the appliance via the cloud. This method does not make use of either the advanced meter or EMS shown in Figure 1.

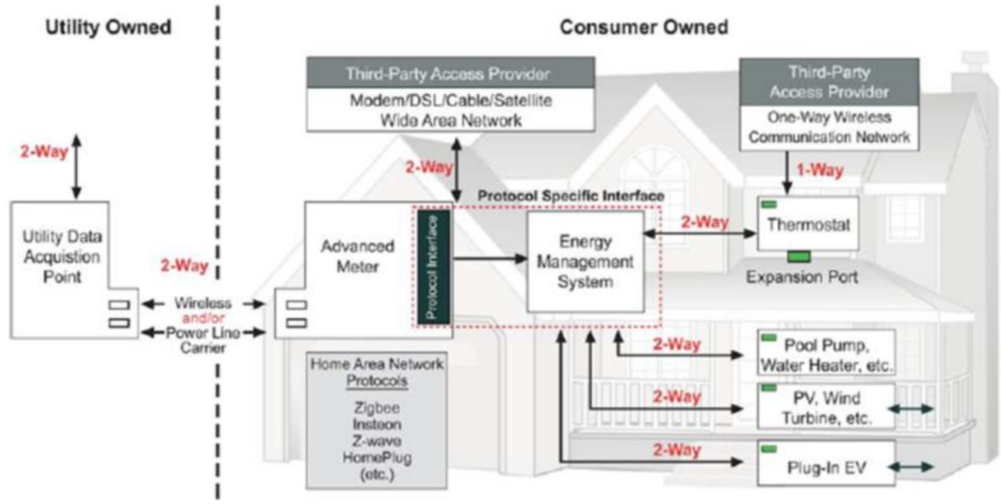

FIGURE 1. TYPICAL ARCHITECTURE TO ENABLE COMMUNICATION BETWEEN THE UTILITY AND THE CUSTOMER

ASSESSMENT OBJECTIVES

The main objectives for this project are to:

- Acquire the power profile data of dishwasher A under various operational settings
- Quantify the demand reduction potential for dishwasher A
- Characterize the response of dishwasher A to DR signals under varying operational scenarios

Note that as a prerequisite to this project, SCE's ATO had previously conducted testing to verify the communications capabilities of dishwasher A. These tests focused on the dishwasher's ability to receive and interpret DR event signals, including event cancellations, multiple events sent at once, or errant event data. They did not delve into the dishwasher's actual response to the event.

TECHNOLOGY/PRODUCT EVALUATION

GENERAL OPERATION OF A DISHWASHER

Figure 2 illustrates the components of a typical dishwasher with key components circled (in red). Generally, a dishwasher brings water into the tub/tank/sump, where it may be mixed with detergent/rinsing agent, and/or pre-heated with an electrical heating element. During the wash cycle, the wash pump forces water through the upper/lower spray arms, where it is sprayed onto dishware. Water pressure causes the arms to rotate, thereby enabling water to reach all of the dishes in the compartment. The soiled water collects back in the tub, where it can be expelled via the drain pump once the washing cycle is complete. Generally, the key components that influence electrical demand are the heating element, the wash pump, and the drain pump.

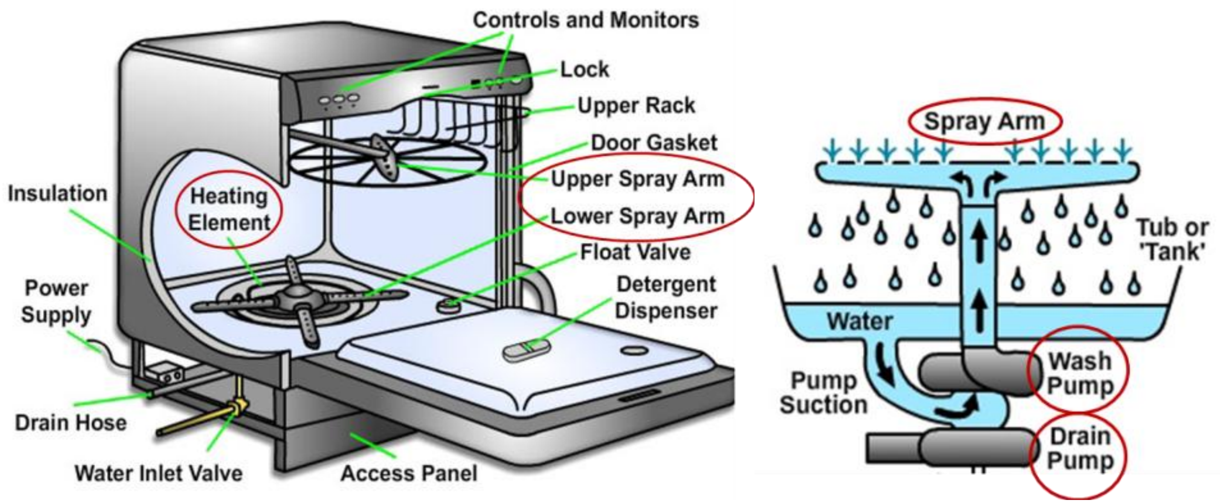

FIGURE 2. DISHWASHER DIAGRAMS[15]

THE DISHWASHER TEST UNIT

These laboratory tests were conducted on DR-capable dishwasher A. This appliance includes a module that allows for automatic adjusting of each cycle based on soil level, water temperature, and water hardness (manually set/calibrated). Dishwasher A was coupled with a communication module to enable the connectivity needed to utilize the smart appliance features. Dishwasher A is rated by its manufacturer to consume 322 kWh/year and is therefore compliant with the 324 kWh/year

[15] http://www.chemistryinyourcupboard.org/finish/2

requirement of ENERGY STAR Version 4.1[16]. The 1 kW peak demand of this dishwasher places it below the anticipated threshold (1.2 kW – 2.4 kW) of most typical dishwashers.

Dishwasher A has these characteristics:

- Intended for use with hot water inlet temperatures from 120°F to 150°F
- Built-in model, intended for under-counter installation
- Top-control model with air-dry or optional heated dry

The dishwasher has three modes of operation, as described below:[17]

- **Off Mode**: An energy-using product is connected to a main power source and is not providing any standby mode or active mode function.

- **Standby Mode:** The product is connected to a main power source and offers one or more of the following user-oriented or protective functions which may persist for an indefinite time:
  - Ability to facilitate the activation of other modes (including activation or deactivation of active mode) by remote switch (including remote control), internal sensor, or timer
  - Continuous functions, including information or status displays (including clocks) or sensor-based functions

  Standby mode is the lowest power consumption mode that cannot be switched off or influenced by the user and that may persist for an indefinite time when the dishwasher is connected to the main electricity supply and used in accordance with manufacturer's instructions.

- **Active Mode:** The dishwasher is performing the main function of washing, rinsing, or drying (when a drying process is included) dishware, glassware, eating utensils, and most cooking utensils by chemical, mechanical, and/or electrical means, or is involved in functions necessary for these main functions, such as admitting water into the dishwasher or pumping water out of the dishwasher.

  The dishwasher's general sequence of operation is Sensing -> Washing -> Drying, described as follows:

  - **Sensing**: A built-in sensor measures the amount of soil and the water temperature. In response, the dishwasher will adjust the selected cycle to achieve optimal performance. For most wash programs, the sensor will adjust to heavy, medium, and light dish soil levels.
  - **Washing**: This consists of prewash, main wash, and rinse periods.
  - **Drying**: Depending on user inputs, the dishwasher may air dry or heater dry the items washed.

According to the manufacturer's literature, dishwasher A contains 10 different wash programs and 4 different enhancements. Table 3 summarizes information provided by the manufacturer on the wash programs and Table 4 summarizes the enhancements.

[16] Energy Star, Dishwashers Key Product Criteria. http://www.energystar.gov/index.cfm?fuseaction=products_for_partners.showDishwashers

[17] http://www1.eere.energy.gov/buildings/appliance_standards/residential/dishwashers.html

TABLE 3. DISHWASHER A WASH PROGRAMS

#	CYCLE	DESCRIPTION	WATER USE/RUN TIMES BY SOIL LEVEL (APPROXIMATE)		
1	Anti-Bacteria	This cycle raises the water temperature in the final rinse to sanitize the dishware. The cycle length will vary depending on the temperature of the inlet water. **Note:** The Anti-Bacteria cycle is monitored for sanitization requirements. If the cycle is interrupted during or after the main wash or if the incoming water temperature is so low that adequate water heating cannot be achieved, the sanitizing conditions may not be met. In these cases, the sanitized light will not illuminate at the end of the cycle. **Note:** NSF-certified residential dishwashers are not intended for licensed food establishments.	**Heavy** 8.8 gal/ 105 min	**Medium** 7.5 gal/ 95 min	**Light** 6.3 gal/ 85 min
2	DeepClean™ (some models)	This cycle is meant for heavily soiled dishes or cookware with dried-on or baked-on soils. This cycle may not remove burned-on foods. Everyday dishes are safe to be used in this cycle. **Note:** On some models, the Steam Pre-Wash enhancement will be automatically selected when the Deep Clean cycle is chosen and cannot be de-selected.	**Heavy/Medium/Light** 9.6 gal/111 min		
3	Cookware/Pots & Pans (some models)	This cycle is meant for heavily soiled dishes or cookware with dried-on or baked-on soils. This cycle may not remove burned-on foods. Everyday dishes are safe to be used in this cycle.	**Heavy** 10.0 gal/ 80 min	**Medium** 8.8 gal/ 70 min	**Light** 7.5 gal/ 60 min
4	Normal Wash	This cycle is for medium/heavily soiled dishes and glassware.	**Heavy** 8.8 gal/ 70 min	**Medium** 7.5 gal/ 60 min	**Light** 5.0 gal/ 50 min
5	SpeedCycle™ (some models)	This cycle is for everyday dishes and glassware.	**Heavy/Medium/Light** 7.5 gal/35 min		
6	Hand/Gentle (Chine Crystal)	This cycle is for lightly soiled china and crystal.	**Heavy/Medium/Light** 7.5 gal/35 min		
7	Glasses (some models)	This cycle is specifically designed for glasses.	**Heavy/Medium/Light** 7.5 gal/30 min		
8	Plastics Cycle (some models)	The longer time for this cycle includes a built-in drying portion that is specifically designed to reduce the risk of melting plastic items and improve plastic drying.	**Heavy** 8.8 gal/ 120 min	**Medium** 7.5 gal/ 105 min	**Light** 5.0 gal/ 90 min
9	Top Rack Only (some models)	This cycle washes lightly soiled dishes on the upper rack only.	**Heavy** 8.2 gal/ 70 min	**Medium** 7.0 gal/ 60 min	**Light** 4.6 gal/ 50 min
10	Rinse and Hold (Rinse Only)	For rinsing partial loads that will be washed later. Do not use detergent with this cycle.	**Heavy/Medium/Light** 2.5 gal/10 min		

Table 4. Dishwasher A Program Enhancement Options

#	Option	Description
1	Delay Hours	The start of a wash cycle can be delayed for up to 24 hours (depending on model).
2	Temp Boost/Added Heat/Extra Hot Wash	When selected, the cycle will run longer with heating element on to improve both wash and dry performance. **Note:** Cannot be selected with the Rinse and Hold cycle.
3	Steam PreWash/PreWash (some models)	For use with heavily soiled and/or dried-on, baked-on soils. This option must be selected prior to starting the cycle. The Pre-Wash option adds 15 minutes and the Steam Pre-Wash option adds 24 minutes to the cycle time. **Note:** Cannot be selected with Rinse and Hold cycle.
4	Heated Dry Light	**Light Off:** Shuts off the drying heat option. Dishes will air dry naturally to save energy (manufacturer discussions indicated that a fan-dry option is no longer available). **Light On:** Turns the heater on for fast drying. This will extend the total cycle time by 45 minutes for the Normal cycle, 38 minutes for the Top Rack Only and Cookware cycles, 32 minutes for the Deep Clean cycle, 15 minutes for the Anti-Bacteria and Plastics cycles, and 30 minutes for all other cycles.

For purposes of this test, the Normal Wash program (no enhancements) is considered to be the "normal" mode of operation that would be seen in the field. This is based on general experience and discussions with the manufacturer.

Dishwasher Test Unit DR Capability

The Joint Petition defines minimum requirements for smart appliances; individual manufacturers are free to decide how to ultimately implement the DR schemes into the appliances. Upon request from SCE, the manufacturer provided the DR response information shown in Table 5.

Table 5. Dishwasher A DR Response Overview

Appliance	Other	Price Signal			
		Low	Normal	High	Critical
Dishwasher A	Power Reporting/ Customization	-	-	Delay Start	Turn Heated Dry Off

The DR strategy of GE dishwashers is as follows:

- ***High* price signal: Delay start of operation until event clears.**
  - DR delay start will not interrupt a wash cycle that has already started.
  - The dishwasher also contains its own "delay start" enhancement, independent of DR. The delay from a DR signal will override a manually-set delay start enhancement.
- ***Critical* price signal: Respond as for *High* price signal plus turn heated dry off.**

The DR responses for this appliance were designed prior to the development of the AHAM definitions, yet they appear to map into those requirements. However, GE terminology relies on High and Critical price signals, whereas the joint-petition agreement leverages the terms "spinning reserve" and "delay load," which are defined solely by the duration of the event itself.

TECHNICAL APPROACH/TEST METHODOLOGY

DR test procedures were developed with guidance from the following applicable standards:

- ANSI/AHAM DW-1-2010 – Household Electric Dishwashers[18]
- DOE Uniform Test Method for Measuring the Energy Consumption of Dishwashers[19]

TEST UNIT INSTALLATION

The dishwasher was installed as recommended by the manufacturer, ensuring that it was freestanding and level. All connections, such as for supply water, drain lines, and power, were completed with guidance from the installation instructions provided by the manufacturer. A water recirculation loop was employed to maintain water temperature and pressure at the inlet to the dishwasher, as illustrated in Figure 3.

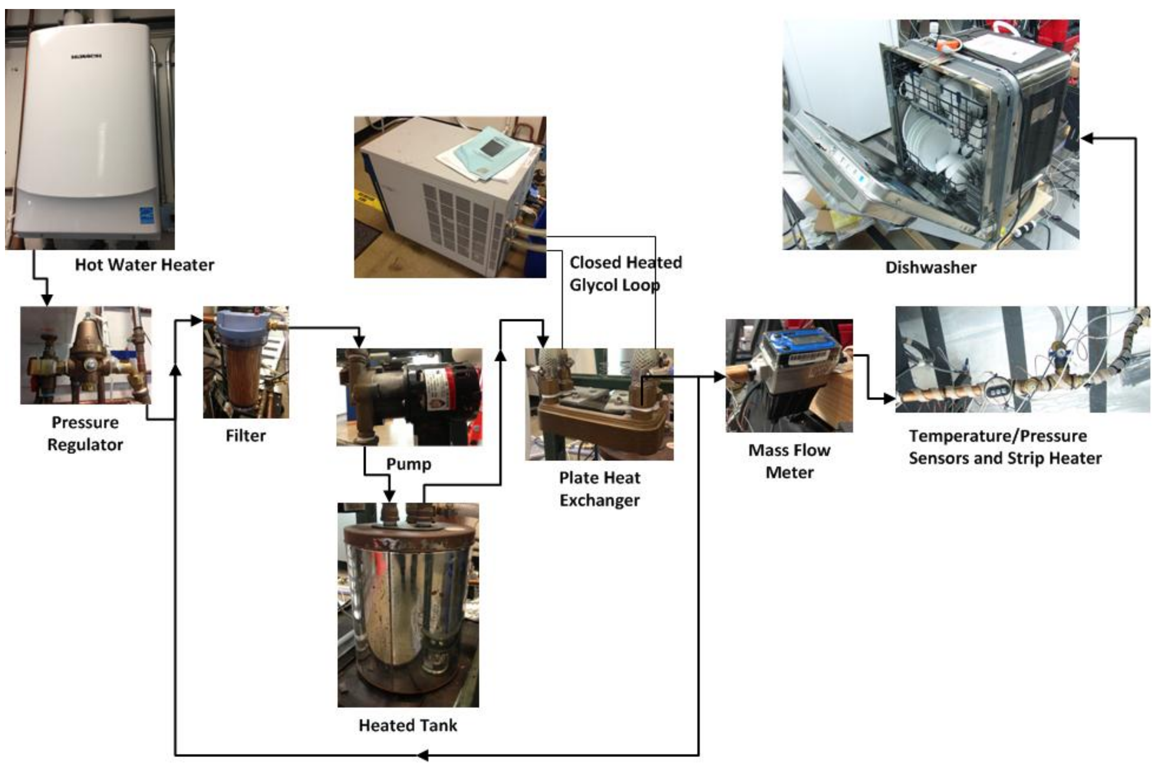

FIGURE 3. WATER RECIRCULATION LOOP

[18] Association of Home Appliance Manufacturers. http://www.aham.org/

[19] CFR, Title 10, Chapter II, Subchapter D, Appendix C to Subpart B of Part 430. http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&tpl=%2Findex.tpl

TEST CONTROL PARAMETERS AND INSTRUMENTATION

Guidance was obtained from the federal/AHAM test procedures for residential dishwashers. Various key parameters were continuously monitored and controlled: electrical frequency, voltage, surrounding dry-bulb temperature (DBT), and supply water pressure and temperature. Table 6 details the target nominal values and tolerances of key parameters controlled during testing.

TABLE 6. CONTROL PARAMETERS

CONTROL PARAMETER		NOMINAL	TOLERANCE ±
Electrical	Frequency	60 Hz	1%
	Voltage	120 V	2%
Ambient Conditions	DBT	75°F	5°F
Supply Water	Temperature	120°F	2°F
	Pressure	35 psi	2.5 psi

This unit only had a hot water input. The federal test method states that dishwashers be tested with cold or hot water, where cold water is 50°F and hot water can be 120°F or 140°F (±2°F in all cases). Both 120°F and 140°F fell within the range of appropriate temperatures deemed suitable by the manufacturer (120°F–150°F). Historically, 140°F was a typical setting for residential water heaters[20] and continues to be for colder climates.[21] However, the California Energy Commission recommends a water heater set-point of 120°F[22] for energy efficiency purposes; this setting has become standard practice for California residents. Thus, 120°F was chosen for testing, as it is representative of common hot water supply temperatures for SCE customers and falls within the manufacturer's recommended range. Table 7 details the target tolerances associated with laboratory instrumentation, adopted from the federal/AHAM test procedure.

TABLE 7. INSTRUMENTATION

SPECIFIED DEVICE	ACCURACY	NOTES
Temperature measurement	± 1°F	N/A
Water meter	±1.5 % of measured flow rate	≤ 0.1 gallon resolution
Water pressure gauge	≤ 5% of measured value	≤ 1 psi resolution
Watt-hour (Wh) meter	≤ 1% of measured value	≤ 1 Wh resolution

[20] Ehow website. http://www.ehow.com/list_7497272_temperatures-hot-water-heaters.html

[21] Office of Energy Efficiency and Renewable Energy website. http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/waterheater_lifecycle_1098.pdf, Figure 4.

[22] Consumer Energy Center, California Energy Commission. http://www.consumerenergycenter.org/residential/appliances/waterheaters.html

Data acquisition was accomplished through the use of LabVIEW software and National Instruments (NI) hardware as well as a Yokogawa power analyzer. Data was collected every 5 seconds on 22 channels. Table 8 lists all of the sensor types, monitoring points, and pertinent accuracy information. All sensors were calibrated to National Institute of Standards and Technology (NIST) traceable requirements prior to installation. Accuracies listed are from sensor manufacturer data and do not necessarily include accuracy of the data acquisition system or calibration.

TABLE 8. LIST OF INSTRUMENTATIONS

MAKE/MODEL	ACCURACY—NIST TRACEABLE	TARGET ACCURACY (FEDERAL/AHAM REQUIREMENTS)	CALIBRATION DATE (LOCATION)	KEY PARAMETER (UNITS)
Masy Systems, Ultra-premium probe (type-T thermocouples)	±0.18°C [at 0°C] (±0.32°F)	±1°F	Aug. 2011 (In-house)	Test room DBT (°F)
Wilcon Industries, Resistance temp. detector (RTD), platinum 100Ω	±0.10% of reading	±1°F	Aug. 2011 (In-house)	Water inlet temperature (°F)
Great Plains Industries, GM 1RSP-2	±0.35% of reading	±1.5% of measured flow rate	Jun. 2011 (Manufacturer)	Water inlet flow rate (gal/min)
Setra, C207 (0-100 psi)	±0.13% of full scale	≤5% of measured value	Oct. 2011 (In-house)	Water inlet pressure (psig)
Yokogawa, WT1800	±(0.1% of reading + 0.05% of measurement range)	≤1% of measured value	Jun. 2011 (Manufacturer)	Total power (watt (W)), voltage, frequency (Hz)

TEST LOAD

Several dishware items were selected for use, with guidance from the test load called out in the AHAM test procedure. Table 9 presents the list of items prescribed in the *AHAM DW-1- 2010 Household Electric Dishwashers* test procedure. However, the procedure also requires several makes and models of dishes that are high-priced and not readily available at common retailers. To implement more realistic test loads, speed up procurement, and reduce costs of the testing, readily available off-the-shelf items with similar descriptions were chosen. These items had dimensions similar to—but not exactly the same as—those specified by the AHAM standard. As such, a reasonable test load fit played a role in test load selection.

Furthermore, the AHAM test procedures call for test load soiling procedures with specific ingredients and separate procedures unique to each item in the test load. The dishwasher manufacturer indicated that the level of soil on the load only impacts energy consumption, not demand. The soil level affects only the duration of the wash cycle. Imposing soil levels on the test load results would increase testing time and costs and add variability to the test results that would reflect variations in the dishwasher soil sensing.

Energy consumption and dishwashing performance are not key goals of these efforts. As a result, the test load was not soiled for testing, and the dishwasher's soil sensor was defaulted to a medium level.

Table 9. Test Load

Description		Item
8 Place Settings	Dishware	8 cups: 0.21 L (7 oz)
		8 saucers: 14 cm (5.5 in)
		8 dinner plates: 10 in (26 cm)
		8 bread and butter plate: 17 cm (6.7 in)
		8 dessert bowls:13 cm (5 in)
	Glassware: clear, no pattern	8 ice tea glasses: 12.5 fl oz (355 ml)
	Flatware	8 knives: solid handle
		8 dinner forks
		8 salad forks
		16 teaspoons
6 Serving Pieces	Dishware	1 serving platter: 9½ in. oval (24 cm)
		2 serving bowls: 1 qt (1 L)
	Serving Flatware	1 serving cold meat fork
		2 serving spoons

TESTING AND RESULTS

The project team conducted 17 test scenarios that fall into 3 categories:

1. **Baseline (BL)Testing** - Represents operational modes anticipated to be most commonly selected in standard use; does not include the influence of DR signals
2. **Functional (FN) Testing** – Explores scenarios of additional wash programs and enhancements that may influence the peak demand of the dishwasher
3. **Demand Response Testing** – Comprehensively explores the responses of the dishwasher to DR signals under varying instances of operation

Each test type will be discussed in the sections below.

Table 10 lists all 17 test scenarios. All test scenarios were conducted three times for repeatability purposes. The project team conducted 53 test runs. That is, 17 scenarios were conducted three times and 2 additional scenarios were run as investigative iterations. Total power is measured at the appliance power cord. This section presents a representative test for each scenario (as denoted by an iteration number).

To supplement this testing, which examined the energy profile of the appliance as a whole, the project team also tested the energy of individual appliance components, as described in Appendix A. Also conducted were tests to determine the effects on demand profile of running two appliance concurrently, with results in Appendix B.

Appendix C contains the results for all 17 runs of the test scenarios.

TABLE 10. TEST SCENARIOS

TEST	MODE/ ENHANCEMENTS	WATER INLET TEMPERATURE	DR SIGNAL	NOTES
BL-1	Normal Wash	120°F	N/A	N/A
BL-2	Normal Wash + Heated Dry			
FN-1	Normal Wash + Added Heat + Steam + Heated Dry	120°F	N/A	N/A
FN-2	Anti-Bacteria	120°F		
FN-3	Normal Wash	90°F		
DR-1	Normal Wash	120°F	High price signal	DR occurs during standby DR event = 8 min
DR-2	Normal Wash + Delay Start			DR occurs during standby Manual delay = 1 hr DR event = 1 hr + 8 min
DR-3	Normal Wash + Delay Start			DR occurs during standby Manual delay = 1 hr DR event = 8 min
DR-4	Normal Wash			DR occurs during wash cycle DR event = 8 min
DR-5	Normal Wash			Run dishwasher twice DR occurs during 1st wash cycle DR event = 1 hr + 8 min
DR-6	Normal Wash + Heated Dry	120°F	Critical price signal	DR occurs during standby DR event = 8 min
DR-7	Normal Wash + Heated Dry			DR occurs during wash cycle DR event = 8 min
DR-8	Normal Wash + Heated Dry			DR occurs during wash cycle DR event = 1 hr + 30 min
DR-9	Normal Wash + Heated Dry			DR occurs during wash cycle DR event = 1 hr + 50 min
DR-10	Normal Wash + Heated Dry			DR occurs during heated dry cycle (heater cycled **off**) DR event = 8 min
DR-10a	Normal Wash + Heated Dry			DR occurs during heated dry cycle (heater cycled **on**) DR event = 8 min
DR-11	Normal Wash + Heated Dry			DR occurs during heated dry cycle (heater cycled **off**) DR event = 40 min
DR-11a	Normal Wash + Heated Dry			DR occurs during heated dry cycle (heater cycled **on**) DR event = 50 min
DR-12	Normal Wash + Heated Dry			Run dishwasher twice DR occurs in 1st heated dry cycle DR event = 50 min

Note: Soil-sensing mode is disabled for all test scenarios, soil sensor defaults to medium level.

BASELINE TESTING

This section provides details on the two baseline test scenarios:

- BL-1, which explores the normal wash mode of operation
- BL-2, which explores the normal wash mode, with the heated dry enhancement

BL-1 TESTING

Figure 4 illustrates the general sequence of operation for BL-1 (iteration #1). Within this sequence, illustrates the demand profile of BL-1 (iteration #1). Figure 5 illustrates the demand profile of BL-1 (#1). Total power and time details are summarized for the major cycles in Table 11.

To understand the power draw, it's important to note which key components are active during the different cycles. During pre-wash cycles, the wash pump is the only key component that runs. During main wash cycles, the wash pump and heating element are active. During the rinse cycles, active key components switch from wash pump only, to wash pump and heating element, and finally back to wash pump only. The dishwasher's drain pump activates in between pre-wash, and main wash cycles. Drain pump power was found to be minimal, when compared to wash pump and heating element power. Apendix A quantifies the power draw of individual components.

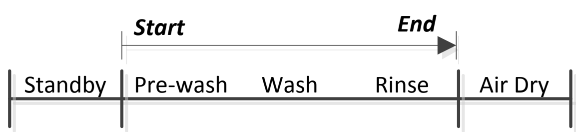

FIGURE 4. BL-1 (#1) NORMAL WASH – GENERAL SEQUENCE OF OPERATION

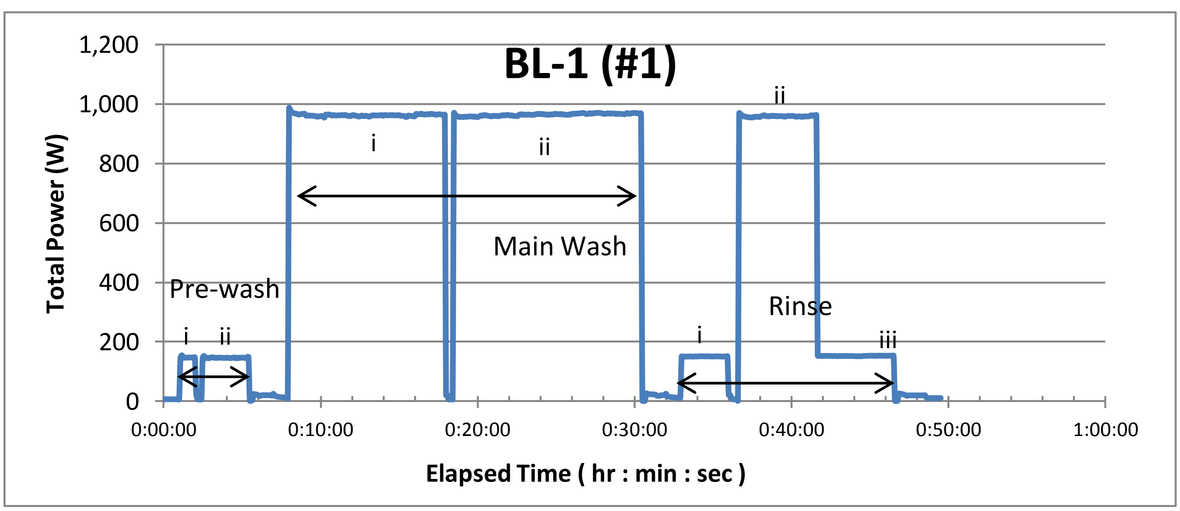

FIGURE 5. BL-1 (#1) NORMAL WASH – DEMAND PROFILE

TABLE 11. BL-1- NORMAL WASH (#1) – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash i	0:00:55	0:01:05	0:02:00	148	155	146	2.47
Pre-wash ii	0:02:55	0:02:30	0:05:25	147	153	145	7.34
Main Wash i	0:09:55	0:08:00	0:17:55	962	986	954	160
Main Wash ii	0:11:55	0:18:30	0:30:25	964	969	955	193
Rinse i	0:02:55	0:33:00	0:35:55	151	152	150	7.55
Rinse ii	0:04:55	0:36:40	0:41:35	958	969	954	79.8
Rinse iii	0:04:50	0:41:40	0:46:30	153	154	152	12.5
Operation Mode Total	0:49:30	0:00:00	0:49:30	563	986	2.27	465

BL-2 TESTING

Figure 6 illustrates the general sequence of operation for BL-2 (iteration #1) and Figure 7 illustrates the demand profile of BL-2 (iteration #1). BL-2 features a similar demand profile to that of BL-1, but adds heated dry cycle at the end. The heated dry cycle consists of 11 steps that involve an active heating element. Total power and time details are summarized for the major cycles in Table 12 . The total energy consumption of BL-2 (662 Wh) was about 42% greater than that of BL-1 (465 Wh) due to the added heated dry enhancement.

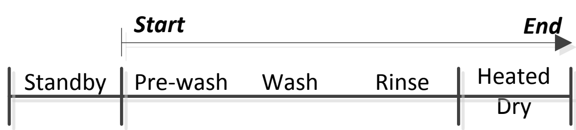

FIGURE 6. BL-2 (#1) NORMAL WASH + HEATED DRY – GENERAL SEQUENCE OF OPERATION

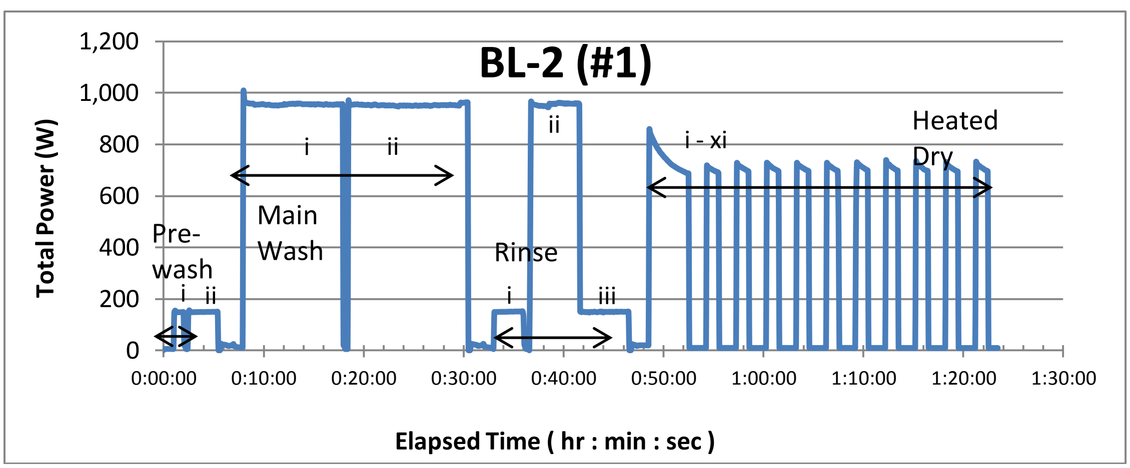

FIGURE 7. BL-2 (#1) NORMAL WASH + HEATED DRY – DEMAND PROFILE

TABLE 12. BL-2 (#1) NORMAL WASH + HEATED DRY – OPERATION CYCLES SUMMARY

Cycle	Time (hr : min : sec)			Total Power (W)			Energy (Wh)
	Duration	Start	End	Avg.	Max	Min	
Pre-wash i	0:00:55	0:01:05	0:02:00	150	156	149	2.51
Pre-wash ii	0:02:55	0:02:30	0:05:25	151	157	150	7.54
Main Wash i	0:09:55	0:08:00	0:17:55	957	1007	951	159
Main Wash ii	0:11:55	0:18:30	0:30:25	954	971	948	191
Rinse i	0:02:55	0:33:05	0:36:00	151	153	133	7.56
Rinse ii	0:04:50	0:36:45	0:41:35	957	967	945	78.4
Rinse iii	0:04:50	0:41:40	0:46:30	151	153	148	12.4
Heated Dry i	0:03:55	0:48:35	0:52:30	745	859	688	49.7
Heated Dry ii	0:01:10	0:54:20	0:55:30	703	719	690	14.6
Heated Dry iii	0:01:10	0:57:20	0:58:30	710	729	695	14.8
Heated Dry iv	0:01:10	1:00:20	1:01:30	712	730	696	14.8
Heated Dry v	0:01:10	1:03:20	1:04:30	711	729	697	14.8
Heated Dry vi	0:01:10	1:06:20	1:07:30	698	729	505	14.5
Heated Dry vii	0:01:10	1:09:15	1:10:25	703	731	554	14.6
Heated Dry viii	0:01:10	1:12:15	1:13:25	715	739	699	14.9
Heated Dry ix	0:01:10	1:15:15	1:16:25	712	736	698	14.8
Heated Dry x	0:01:10	1:18:15	1:19:25	710	732	696	14.8
Heated Dry xi	0:01:10	1:21:15	1:22:25	711	734	696	14.8
Operation Mode Total	1:23:25	0:00:00	1:23:25	476	1007	2.29	662

FUNCTIONAL TESTING

Three functional test scenarios were selected to explore the potential effect of various enhancements and operation modes on power draw. FN-1 explored the cumulative impacts of the added heat, steam (pre-wash), and heated dry enhancements on the normal wash mode of operation. FN-2 explored the anti-Bacteria mode. FN-3 explored whether using a dishwasher inlet temperature lower than that recommended by the manufacturer, (specifically, 90°F) would increase demand. Often, hot water lines will lose heat from the water heater to the appliance; this test was designed to understand the possible impact of this heat loss.

FN-1 TESTING

Figure 8 illustrates the general sequence of operation for FN-1 (iteration #1). Within this sequence, FN-1 consists of three pre-wash cycles, two steam pre-wash cycles, three main wash cycles, four rinse cycles, and five heated dry cycles. Figure 9 illustrates total power profile for FN-1 (iteration #1). Total power and time details are summarized for the major cycles in Table 13.

As expected, the added heat, steam, and heated dry enhancements alter dishwasher operation. However, the power draw of major cycles remains comparable to that of similar cycles witnessed during baseline operation. For example, the roughly 950 W power draw of the main wash cycle in FN-1 (which features an additional main wash cycle) is comprable to that of the main wash cycles in BL-1. Ultimately, this finding implies that these settings will impact only energy consumption, and will not yield additional demand savings potential.

The total energy consumption of FN-1 (1633) was about 250% greater than that of BL-1 (465 Wh) due to the addition of the steam (pre-wash), added heat, and heated dry mode enhancements.

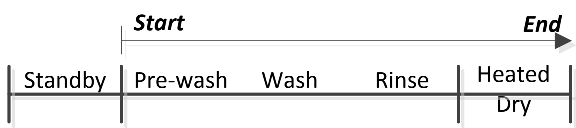

FIGURE 8. FN-1 (#1) NORMAL WASH + ADDED HEAT + STEAM + HEATED DRY – GENERAL SEQUENCE OF OPERATION

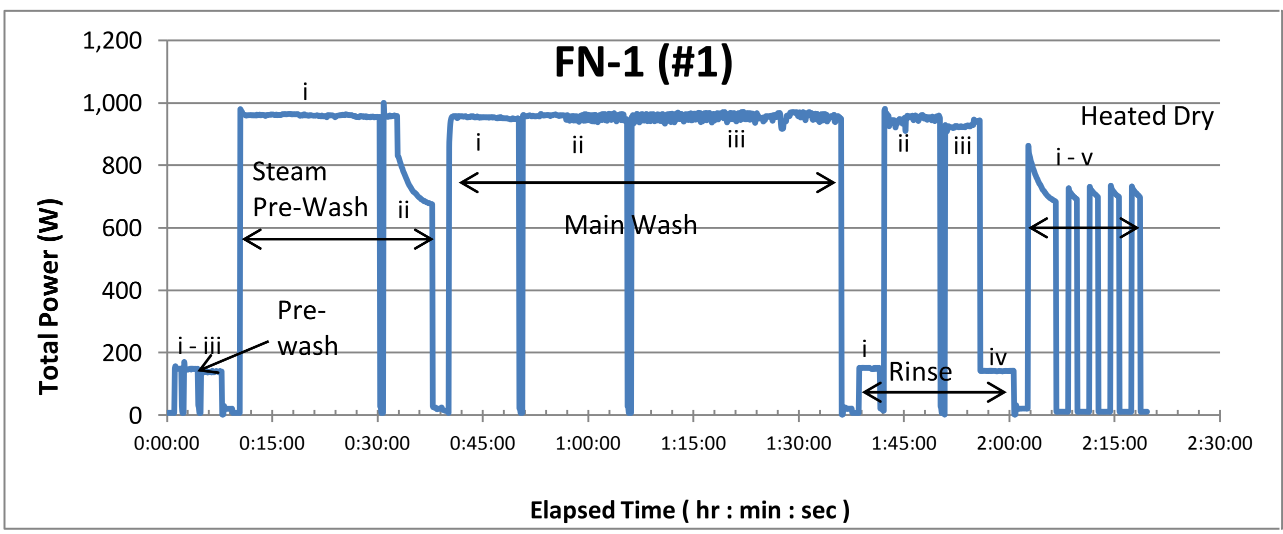

FIGURE 9. FN-1 (#1) NORMAL WASH + ADDED HEAT + STEAM + HEATED DRY – DEMAND PROFILE

TABLE 13. FN-1 (#1) NORMAL WASH + ADDED HEAT + STEAM + HEATED DRY – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash i	0:00:55	0:01:05	0:02:00	149	157	148	2.49
Pre-wash ii	0:01:55	0:02:25	0:04:20	149	169	146	4.95
Pre-wash iii	0:02:55	0:04:50	0:07:45	139	146	136	6.96
Steam Pre-wash i	0:19:50	0:10:25	0:30:15	960	979	953	319
Steam Pre-wash ii	0:06:55	0:30:50	0:37:45	792	996	675	92.5
Main Wash i	0:09:55	0:40:10	0:50:05	951	957	857	159
Main Wash ii	0:14:50	0:50:40	1:05:30	954	967	938	237
Main Wash iii	0:29:50	1:06:10	1:36:00	953	971	916	475
Rinse i	0:02:55	1:38:35	1:41:30	150	152	147	7.51
Rinse ii	0:07:55	1:42:10	1:50:05	949	981	909	127
Rinse iii	0:04:55	1:50:50	1:55:45	927	946	908	77.2
Rinse iv	0:04:45	1:55:50	2:00:35	141	143	140	11.4
Heated Dry i	0:03:55	2:02:40	2:06:35	739	861	683	49.3
Heated Dry ii	0:01:10	2:08:25	2:09:35	704	726	691	14.7
Heated Dry iii	0:01:10	2:11:25	2:12:35	712	731	698	14.8
Heated Dry iv	0:01:10	2:14:25	2:15:35	712	734	698	14.8
Heated Dry v	0:01:10	2:17:25	2:18:35	712	732	696	14.8
Operation Mode Total	2:19:35	0:00:00	2:19:35	701	996	2.35	1633

FN-2 TESTING

Figure 10 illustrates the general sequence of operation for FN-2 (anti-bacteria) (iteration #1). Within this sequence, FN-2 consists of one pre-wash cycle, one main wash cycle, and three rinse cycles. Figure 11 illustrates total power for FN-2 (iteration #1). Total power and time details are summarized for the major cycles in Table 14.

The anti-bacteria cycle alters dishwasher operation. However, the power draw of major cycles remains comparable to that of similar cycles witnessed during baseline operation. For example, although FN-2 features only one main wash cycle, the main wash cycles of BL-1 and FN2 have a similar average power draw of roughly 950 watts. Again, this indicates that these settings do not have any impact on the DR potential of this appliance.

The total energy consumption of FN-2 (1416 Wh) was about 200% greater than that of BL-1 (465 Wh) due to the longer run times and extensive heating element usage associated with the anti-bacteria operation mode.

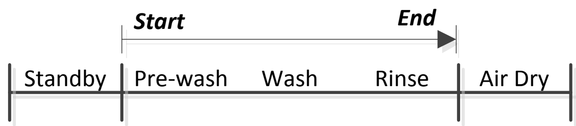

FIGURE 10. FN-2 (#1) ANTI-BACTERIA – GENERAL SEQUENCE OF OPERATION

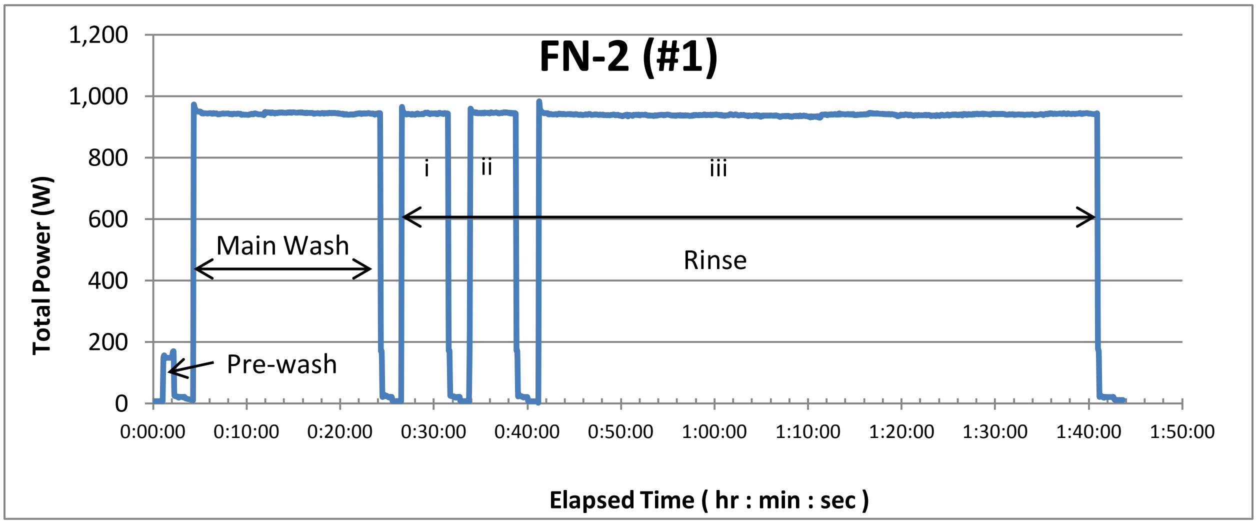

FIGURE 11. FN-2 (#1) ANTI-BACTERIA – DEMAND PROFILE

TABLE 14. FN-2 (#1) ANTI-BACTERIA – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash	0:01:05	0:01:05	0:02:10	152	170	148	2.95
Main Wash	0:20:05	0:04:20	0:24:25	938	973	171	315
Rinse i	0:05:05	0:26:35	0:31:40	919	965	172	2.60
Rinse ii	0:05:05	0:33:50	0:38:55	910	960	172	2.43
Rinse iii	0:59:50	0:41:15	1:41:05	938	982	171	2.25
Operation Mode Total	1:43:40	0:00:00	1:43:40	819	982	2.55	1416

FN-3 TESTING

Figure 12 illustrates the general sequence of operation for FN-3 (low inlet water temperature) (iteration #1). Within that sequence, FN-3 consists of two pre-wash cycles, two main wash cycles, and two rinse cycles. Figure 13 illustrates total power for FN-3 (iteration #1). Total power and time details are summarized for the major cycles in Table 15.

The lower inlet water temperature of 90°F caused longer wash and rinse cycles than those witnessed in BL-1, which had a 120°F inlet water temperature. For example, the FN-3 main wash ii cycle was about 17 minutes, while the BL-1 main wash cycle ii was about 12 minutes. Nonetheless, the main wash cycles in Tests BL-1 and FN-3 had a comparable average power draw of roughly 950 watts. These findings indicate that loss of heat in domestic hot water lines does not impact the DR potential of the appliance.

The total energy consumption of FN-3 (606 Wh) was 30% greater than that of BL-1 (465 Wh) due to the longer run times and extensive heating element usage associated with lower water inlet temperatures introduced to the normal wash operation mode.

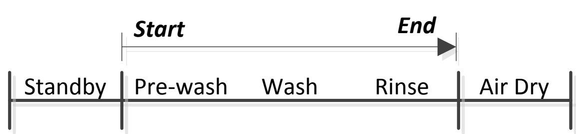

FIGURE 12. FN-3 (#1) NORMAL WASH (LOW INLET WATER TEMPERATURE) – GENERAL SEQUENCE OF OPERATION

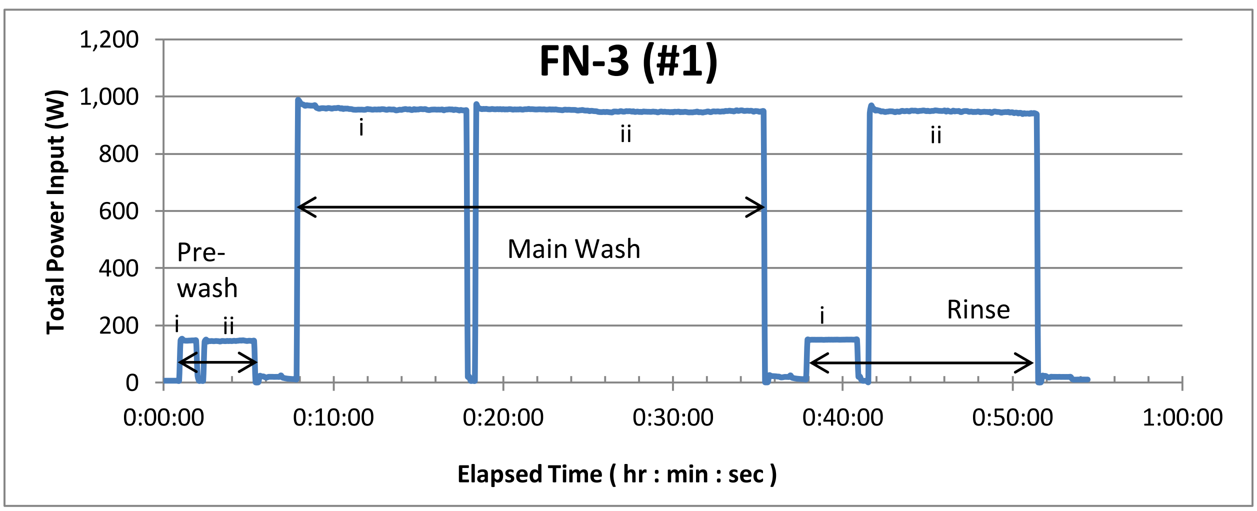

FIGURE 13. FN-3 (#1) NORMAL WASH (LOW INLET WATER TEMPERATURE) – DEMAND PROFILE

TABLE 15. FN-3 (#1) NORMAL WASH (LOW INLET WATER TEMPERATURE) – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash i	0:00:55	0:01:00	0:01:55	148	154	147	2.47
Pre-wash ii	0:02:55	0:02:25	0:05:20	146	151	143	7.32
Main Wash i	0:09:55	0:07:55	0:17:50	958	989	952	160
Main Wash ii	0:16:55	0:18:25	0:35:20	951	973	944	269
Rinse i	0:02:55	0:37:55	0:40:50	151	151	150	7.54
Rinse ii	0:09:50	0:41:35	0:51:25	948	969	938	157
Operation Mode Total	0:54:25	0:00:00	0:54:25	667	989	2.28	606

DR TESTING

A total of twelve DR test scenarios were run, with either the *High* or *Critical* DR signals imposed during different modes of operation.

HIGH DR PRICE SIGNAL

The dishwasher was anticipated to respond to the price signal of High in two ways:

- If the DR event was active when the start button was pushed, the wash cycle start would be delayed.
- If the wash cycle had already started when the DR event was initiated, dishwasher operation would continue unchanged.

HIGH DR PRICE SIGNAL: DR-1

Figure 14 illustrates the general sequence of operation for DR-1 (iteration #3), which tested dishwasher response to a DR event initiated during the standby mode. Figure 15 illustrates the demand profile for the DR-1 (iteration #3) test scenario. Table 16 summarizes the total power and time details.

The DR test was conducted as follows:

- **Step 1:** With the dishwasher in standby mode, an 8-minute DR event was initiated.
- **Step 2:** A normal wash mode was started 1 minute after the DR signal was initiated.
- **Step 3**: The dishwasher was allowed to run through its programmed operation.

The dishwasher responded to the DR event signal by delaying the start of operation until the end of the event. This delay confirmed that the dishwasher responds to the DR event as anticipated. Total energy consumption of DR-1 (461 Wh) was comparable to that of BL-1 (465 Wh).

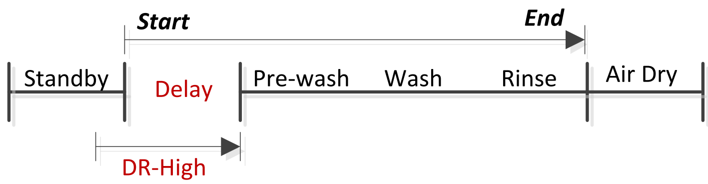

FIGURE 14. DR-1 (#3) NORMAL WASH, HIGH PRICE DR EVENT – GENERAL SEQUENCE OF OPERATION

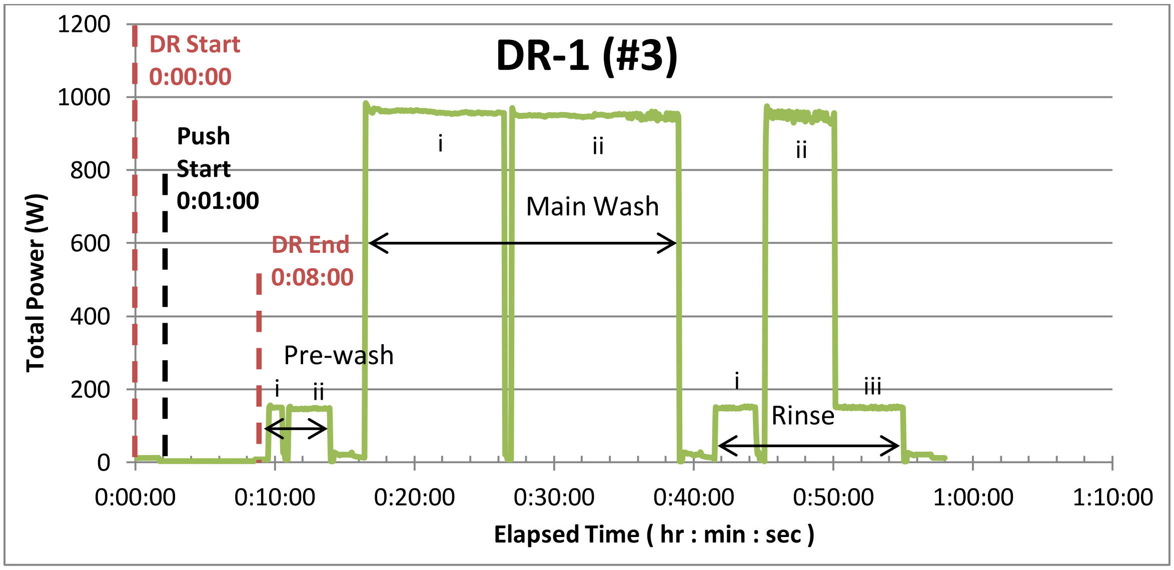

FIGURE 15. DR-1 (#3) NORMAL WASH, HIGH PRICE DR EVENT – DEMAND PROFILE

TABLE 16. DR-1 (#3) NORMAL WASH, HIGH PRICE DR EVENT – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash i	0:00:55	0:09:35	0:10:30	150	156	149	2.50
Pre-wash ii	0:02:55	0:11:00	0:13:55	147	153	145	7.33
Main Wash i	0:09:55	0:16:30	0:26:25	960	983	954	160
Main Wash ii	0:11:55	0:27:00	0:38:55	949	969	936	190
Rinse i	0:02:50	0:41:35	0:44:25	149	153	147	7.24
Rinse ii	0:04:55	0:45:10	0:50:05	945	973	853	78.8
Rinse iii	0:04:50	0:50:10	0:55:00	150	153	146	12.3
Operation Mode Total	0:57:00	0:01:00	0:58:00	477	983	2.64	461

HIGH DR PRICE SIGNAL: DR-2

Figure 16 illustrates the general sequence of operation for DR-2 (iteration #2), which tested dishwasher response to initiation of a DR event when the appliance in standby mode has been manually set to delay start. Figure 17 illustrates the demand profile for the DR-2 (iteration #2) test scenario. Table 17 summarizes the total power and time details.

The DR test was conducted as follows:

- **Step 1:** With the dishwasher in standby mode, a normal wash mode + 1 hour delay mode enhancement was initiated.
- **Step 2:** 1 minute into the cycle, a 1 hour + 8 minute DR event was started.
- **Step 3:** The dishwasher was allowed to run through its programmed operation.

The observed delay lasted for 1 hour + 8 minutes. This result indicates that the DR signal overrides the user-initiated 1-hour delay enhancement. This was the anticipated response. Total energy consumption of DR-2 (465 Wh) was the same as that of BL-1 (465 Wh).

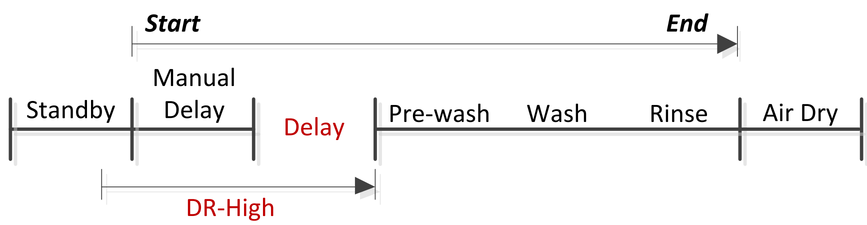

FIGURE 16. DR-2 (#2) NORMAL WASH + DELAY START, HIGH PRICE DR EVENT (DR OVERRIDE) – GENERAL SEQUENCE OF OPERATION

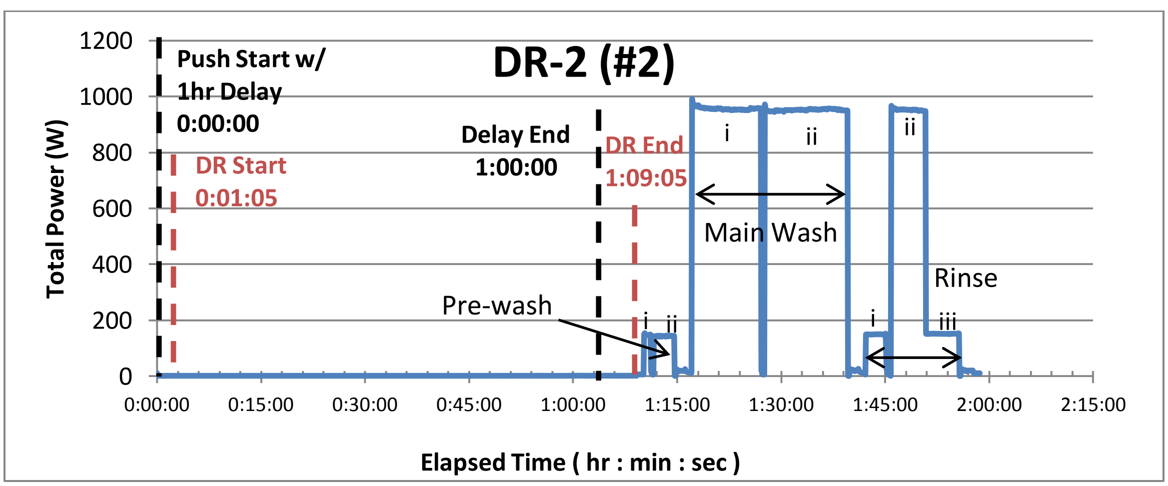

FIGURE 17. DR-2 (#2) NORMAL WASH + DELAY START, HIGH PRICE DR EVENT (DR OVERRIDE) – DEMAND PROFILE

TABLE 17. DR-2 (#2) NORMAL WASH + DELAY START, HIGH PRICE DR EVENT (DR OVERRIDE) – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash i	0:00:55	1:10:15	1:11:10	149	155	147	2.48
Pre-wash ii	0:02:55	1:11:40	1:14:35	144	146	140	7.22
Main Wash i	0:09:55	1:17:10	1:27:05	957	990	951	160
Main Wash ii	0:11:55	1:27:40	1:39:35	952	970	945	190
Rinse i	0:02:50	1:42:15	1:45:05	151	153	150	7.32
Rinse ii	0:04:55	1:45:55	1:50:50	953	966	947	79.4
Rinse iii	0:04:45	1:50:55	1:55:40	153	154	152	12.3
Operation Mode Total	1:58:40	0:00:00	1:58:40	235	990	2.50	465

HIGH DR PRICE SIGNAL: DR-3

Figure 18 illustrates the general sequence of operation for DR-3 (iteration #3), which tested dishwasher response if a delay wash is manually set after a DR event has been initiated. Figure 19 illustrates the demand profile for the DR-3 (iteration #3) test scenario. Table 18 summarizes the total power and time details.

The DR test was conducted as follows:

- **Step 1:** With the dishwasher in standby mode, an 8-minute DR event was initiated.
- **Step 2**: A normal wash mode + 1 hour delay mode enhancement was initiated 1 minute after initiation of the DR signal.
- **Step 3:** The dishwasher was allowed to run through the delay and its programmed operation.

The user-initiated delay enhancement was maintained, as seen below. This was the anticipated response. Total energy consumption of DR-3 (463 Wh) was comparable to that of BL-1 (465 Wh).

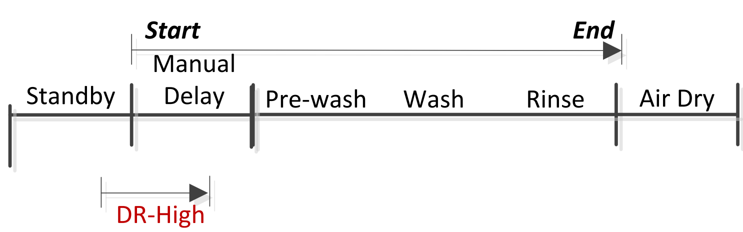

FIGURE 18. DR-3 (#3) NORMAL WASH + DELAY START, HIGH PRICE DR EVENT (NO DR OVERRIDE) – GENERAL SEQUENCE OF OPERATION

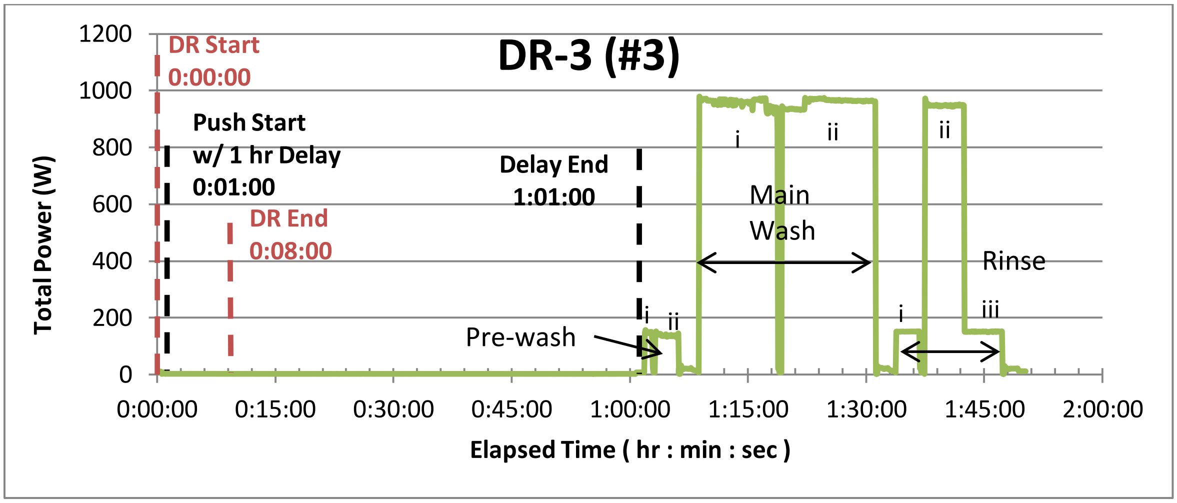

FIGURE 19. DR-3 (#3) NORMAL WASH + DELAY START, HIGH PRICE DR EVENT (NO DR OVERRIDE) – DEMAND PROFILE

TABLE 18. DR-3 (#3) NORMAL WASH + DELAY START, HIGH PRICE DR EVENT (NO DR OVERRIDE) – OPERATION CYCLES SUMMARY

Cycle	Time (hr : min : sec)			Total Power (W)			Energy (Wh)
	Duration	Start	End	Avg.	Max	Min	
Pre-wash i	0:00:55	1:01:55	1:02:50	146	157	122	2.43
Pre-wash ii	0:02:55	1:03:15	1:06:10	139	152	130	6.95
Main Wash i	0:09:55	1:08:50	1:18:45	957	978	850	160
Main Wash ii	0:11:50	1:19:20	1:31:10	958	974	931	190
Rinse i	0:02:55	1:33:50	1:36:45	151	152	151	7.57
Rinse ii	0:04:55	1:37:30	1:42:25	948	971	943	79.0
Rinse iii	0:04:45	1:42:30	1:47:15	151	153	149	12.2
Operation Mode Total	1:49:25	0:00:50	1:50:15	252	978	2.42	463

HIGH DR PRICE SIGNAL: DR-4

Figure 20 illustrates the general sequence of operation for DR-4 (iteration #1), which tested diswasher response to a DR signal initiated during a normal wash cycle. Figure 21 illustrates the demand profile for the DR-4 (iteration #1) test scenario. Table 19 summarizes the total power and time details. The DR test was conducted as follows:

- **Step 1:** A normal wash mode was initiated.
- **Step 2:** 1 minute into the active wash cycle, an 8-minute DR event was initiated.
- **Step 3:** The dishwasher was allowed to run through its programmed operation.

The dishwasher cycle was not interrupted by the DR signal. This was the anticipated response. Total energy consumption of DR-4 (461 Wh) was comparable to that of BL-1 (465 Wh).

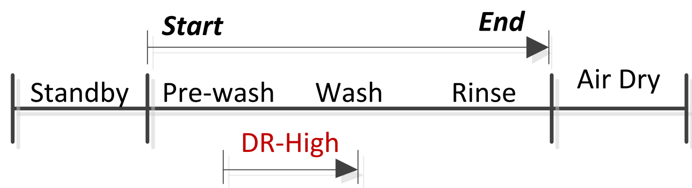

FIGURE 20. DR-4 (#1) NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE – GENERAL SEQUENCE OF OPERATION

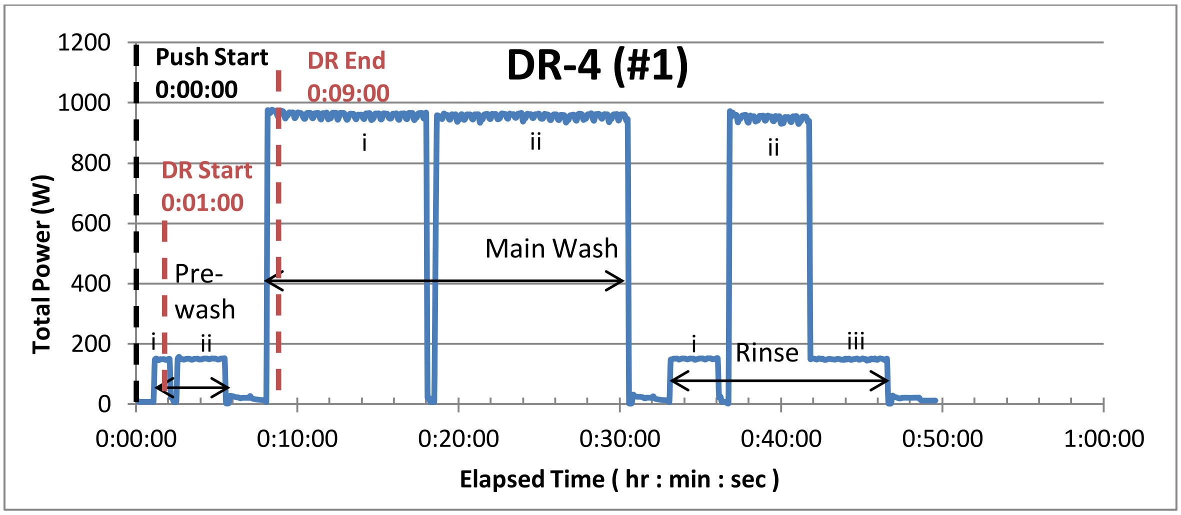

FIGURE 21. DR-4 (#1) NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE – DEMAND PROFILE

TABLE 19. DR-4 (#1) NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX	MIN	
Pre-wash i	0:00:55	0:01:10	0:02:05	149	151	146	2.48
Pre-wash ii	0:02:55	0:02:35	0:05:30	150	157	148	7.51
Main Wash i	0:09:50	0:08:10	0:18:00	960	977	943	159
Main Wash ii	0:11:55	0:18:35	0:30:30	953	967	532	191
Rinse i	0:02:55	0:33:10	0:36:05	150	152	147	7.52
Rinse ii	0:04:55	0:36:50	0:41:45	950	971	931	79.2
Rinse iii	0:04:45	0:41:50	0:46:35	149	152	144	12.0
Operation Mode Total	0:49:35	0:00:00	0:49:35	557	977	2.67	461

HIGH DR PRICE SIGNAL: DR-5

Figure 22 illustrates the general sequence of operation for DR-5 (iteration #1), which tested dishwasher response to a DR signal initiated during the first of two normal wash cycles. Figure 23 illustrates the demand profile for the DR-5 (iteration #1) test scenario.

Table 20 summarizes the total power and time details. The DR test was conducted as follows:

- **Step 1:** A normal wash mode was initiated.
- **Step 2:** 1 minute into the active wash cycle, a 1 hour + 8 minute DR event was initiated.
- **Step 3:** A second normal wash mode was initiated at 1:04:00, allowing extension of the DR event into the second mode of operation.
- **Step 4:** The dishwasher was allowed to run through its programmed operation.

The dishwasher's first wash cycle was not impacted by the DR event. The second wash cycle was delayed. This was the anticipated response. Because DR-5 involved two operations of the dishwasher, the total energy consumption of DR-5 (923 Wh) was compared to twice that of BL-1 (465 * 2 = 930 Wh)—which showed that consumption levels were nearly identical.

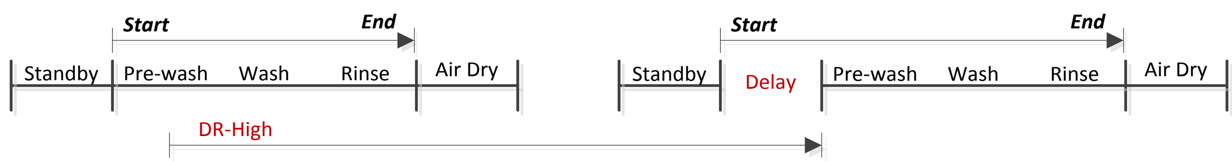

FIGURE 22. DR-5 (#1) TWO DISHWASHER OPERATIONS: NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE OF 2ND MODE – DEMAND PROFILE

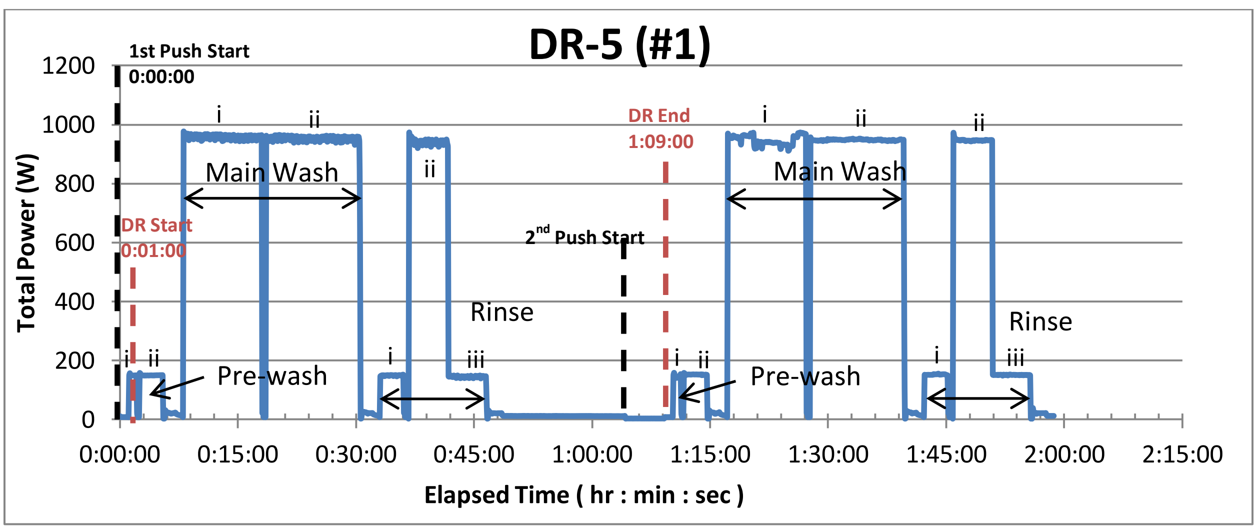

FIGURE 23. DR-5 (#1) TWO DISHWASHER OPERATIONS: NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE OF 2ND MODE – DEMAND PROFILE

Table 20. DR-5 (#1) Two Dishwasher Operations: Normal Wash, High Price DR Event During Wash Cycle of 2nd Mode – Operation Cycles Summary

Cycle		Time (hr : min : sec)			Total Power (W)			Energy (Wh)
		Duration	Start	End	Avg.	Max	Min	
1st Operation Mode	Pre-wash i	0:00:55	0:01:10	0:02:05	150	157	148	2.49
	Pre-wash ii	0:02:55	0:02:30	0:05:25	150	157	149	7.49
	Main Wash i	0:09:55	0:08:05	0:18:00	960	977	945	160
	Main Wash ii	0:11:55	0:18:35	0:30:30	953	966	650	191
	Rinse i	0:02:55	0:33:10	0:36:05	146	152	22	7.28
	Rinse ii	0:04:55	0:36:45	0:41:40	943	973	921	78.6
	Rinse iii	0:04:45	0:41:45	0:46:30	145	149	139	11.6
1st Operation Mode Total		0:49:30	0:00:00	0:49:30	558	977	2.81	461
2nd Operation Mode	Pre-wash i	0:00:55	1:10:20	1:11:15	146	158	141	2.44
	Pre-wash ii	0:02:55	1:11:40	1:14:35	152	158	150	7.61
	Main Wash i	0:09:55	1:17:15	1:27:10	949	974	912	158
	Main Wash ii	0:11:55	1:27:45	1:39:40	945	957	313	189
	Rinse i	0:02:55	1:42:15	1:45:10	152	155	149	7.60
	Rinse ii	0:04:55	1:45:55	1:50:50	948	973	944	79.0
	Rinse iii	0:04:45	1:50:55	1:55:40	151	152	148	12.2
2nd Operation Mode Total		0:54:40	1:04:00	1:58:40	503	974	2.69	459
Both Operation Modes		1:58:40	0:00:00	1:58:40	466	977	2.69	923

Critical DR Price Signal

The dishwasher was anticipated to respond to a price signal of Critical by:

- Delaying cycle start, as described above in the response to the High signal.
- Eliminating or delaying the heated dry portion of the wash cycle.

Critical DR Price Signal: DR-6

Figure 24 illustrates the general sequence of operation for DR-6 (iteration #3), which tested dishwasher response to a DR event initiated when the appliance is in standby mode and then manually set for a normal wash and heated dry enhancmenet . Figure 25 illustrates the demand profile for the DR-6 (iteration #3) test scenario. Table 21 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: With the dishwasher in standby mode, an 8-minute DR event was initiated.
- Step 2: A normal wash mode + heated dry mode enhancement was initiated 1 minute after the DR signal was started.
- Step 3: The dishwasher was allowed to run through the delay and its programmed operation.

The start of the dishwasher's wash cycle was delayed by the DR signal. Because the signal did not extend into the heated dry portion of its operation, heated dry was not disabled. This was the anticipated response. Total energy consumption of DR-6 (651 Wh) was comparable to that of BL-2 (662 Wh).

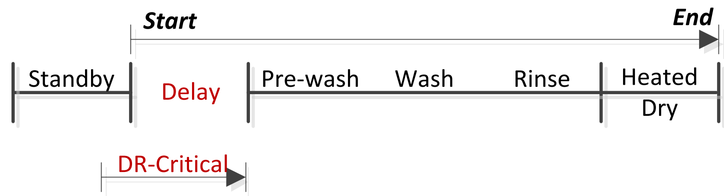

FIGURE 24. DR-6 (#3) NORMAL WASH + HEATED DRY, CRITICAL DR DELAY EVENT – GENERAL SEQUENCE OF OPERATION

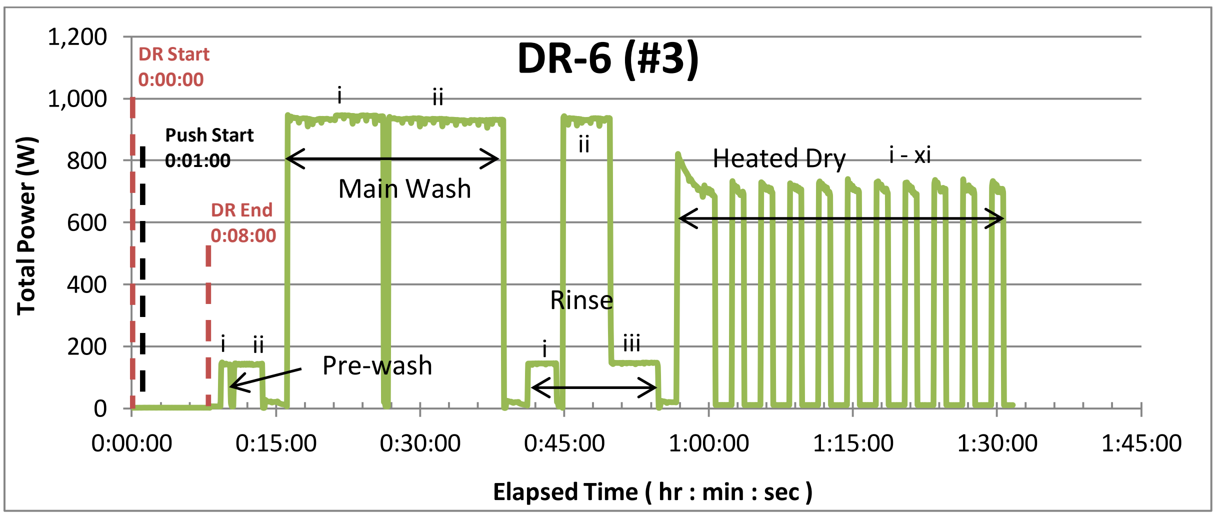

FIGURE 25. DR-6 (#3) NORMAL WASH + HEATED DRY, CRITICAL DR DELAY EVENT – DEMAND PROFILE

Table 21. DR-6 (#3) Normal Wash + Heated Dry, Critical DR Delay Event – Operation Cycles Summary

Cycle	Time (hr : min : sec) Duration	Start	End	Power (W) Avg.	Max.	Min.	Energy (Wh)
Pre-wash i	0:00:55	0:09:20	0:10:15	143	149	142	2.39
Pre-wash ii	0:02:55	0:10:40	0:13:35	142	146	120	7.11
Main Wash i	0:09:55	0:16:15	0:26:10	939	947	911	156
Main Wash ii	0:11:55	0:26:45	0:38:40	932	942	906	186
Rinse i	0:02:55	0:41:15	0:44:10	145	146	141	7.26
Rinse ii	0:04:55	0:44:55	0:49:50	923	944	326	76.9
Rinse iii	0:04:50	0:49:55	0:54:45	147	149	134	12.0
Heated Dry i	0:03:55	0:56:45	1:00:40	726	821	475	48.4
Heated Dry ii	0:01:10	1:02:30	1:03:40	705	733	689	14.7
Heated Dry iii	0:01:10	1:05:30	1:06:40	712	730	697	14.8
Heated Dry iv	0:01:10	1:08:30	1:09:40	712	727	698	14.8
Heated Dry v	0:01:10	1:11:30	1:12:40	711	733	685	14.8
Heated Dry vi	0:01:10	1:14:30	1:15:40	712	739	698	14.8
Heated Dry vii	0:01:10	1:17:30	1:18:40	713	733	693	14.9
Heated Dry viii	0:01:10	1:20:30	1:21:40	708	730	688	14.7
Heated Dry ix	0:01:10	1:23:30	1:24:40	714	738	699	14.9
Heated Dry x	0:01:10	1:26:30	1:27:40	710	738	690	14.8
Heated Dry xi	0:01:10	1:29:30	1:30:40	712	734	694	14.8
Operation Mode Total	1:30:40	0:01:00	1:31:40	426	947	2.53	651

Critical DR Price Signal: DR-7

Figure 26 illustrates the general sequence of operation for DR-7 (iteration #1), which tested dishwasher response to initiation of a DR event when the appliance in standby mode has been manually set to delay start. Figure 27 illustrates the demand profile for the DR-7 (iteration #1) test scenario. Table 22 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal wash mode + heated dry enhancement was initiated.
- Step 2: 1 minute into the active wash cycle, an 8-minute DR event was initiated.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The dishwasher's operation was not interrupted by the DR signal. The heated dry portion was maintained, since the DR signal did not extend into that period. This was the anticipated response. Total energy consumption of DR-7 (660 Wh) was comparable to that of BL-2 (662 Wh).

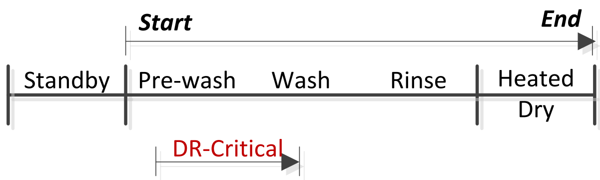

FIGURE 26. DR-7 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT DURING WASH – GENERAL SEQUENCE OF OPERATION

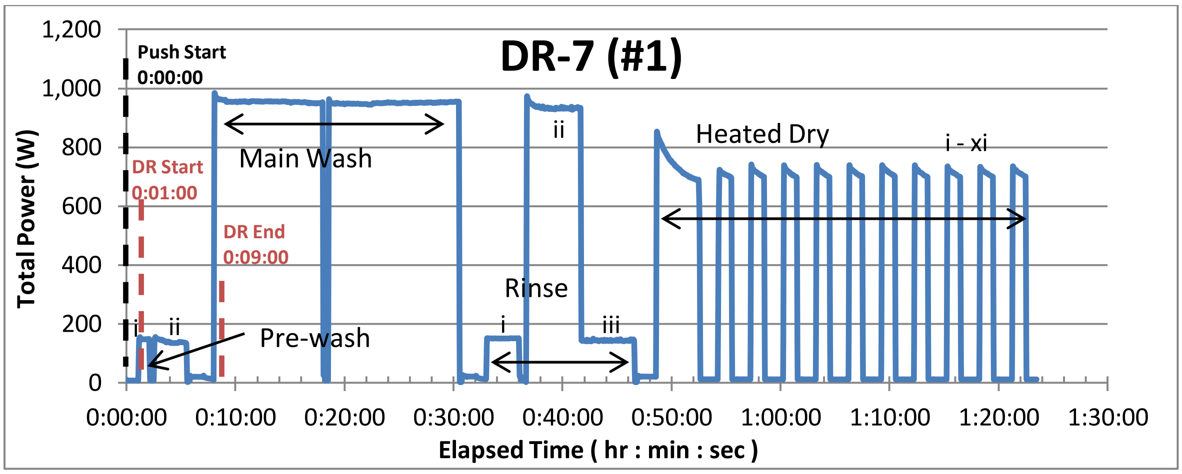

FIGURE 27. DR-7 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT DURING WASH – DEMAND PROFILE

TABLE 22. DR-7 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT DURING WASH – OPERATION CYCLES SUMMARY

Cycle	Time (hr : min : sec)			Power (W)			Energy (Wh)
	Duration	Start	End	Avg.	Max.	Min.	
Pre-wash i	0:00:55	0:01:10	0:02:05	148	155	147	2.47
Pre-wash ii	0:02:55	0:02:35	0:05:30	140	155	133	7.00
Main Wash i	0:09:55	0:08:05	0:18:00	955	984	949	159
Main Wash ii	0:11:55	0:18:35	0:30:30	950	963	944	190
Rinse i	0:02:55	0:33:05	0:36:00	151	151	150	7.53
Rinse ii	0:04:55	0:36:45	0:41:40	936	973	927	78.0
Rinse iii	0:04:50	0:41:45	0:46:35	144	150	141	11.8
Heated Dry i	0:03:55	0:48:40	0:52:35	738	852	548	49.2
Heated Dry ii	0:01:10	0:54:20	0:55:30	695	723	516	14.5
Heated Dry iii	0:01:10	0:57:20	0:58:30	714	740	699	14.9
Heated Dry iv	0:01:10	1:00:20	1:01:30	714	738	697	14.9
Heated Dry v	0:01:10	1:03:20	1:04:30	714	739	698	14.9
Heated Dry vi	0:01:10	1:06:20	1:07:30	715	739	701	14.9
Heated Dry vii	0:01:10	1:09:20	1:10:30	717	739	701	14.9
Heated Dry viii	0:01:10	1:12:20	1:13:30	714	738	698	14.9
Heated Dry ix	0:01:10	1:15:20	1:16:30	713	735	699	14.9
Heated Dry x	0:01:10	1:18:20	1:19:30	713	733	699	14.9
Heated Dry xi	0:01:10	1:21:20	1:22:30	714	735	700	14.9
Operation Mode Total	1:23:30	0:00:00	1:23:30	474	984	2.75	660

CRITICAL DR PRICE SIGNAL: DR-8

Figure 28 illustrates the general sequence of operation for DR-8 (iteration #3), which tested dishwasher response to initiation of a DR event during the active wash cycle. Figure 29 illustrates the demand profile for the DR-8 (iteration #3) test scenario. Table 23 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: The normal wash mode + heated dry enhancement was initiated.
- Step 2: 1 minute into the active wash cycle, a 1 hour + 30 minute DR event was initiated.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The dishwasher's operation was not delayed, but the heated dry cycle was interrupted (this would normally have started at ~48 minutes). The heated dry portion resumed operation after the DR event cleared. This was an interesting, and unexpected, finding from this test. This indicates that the heated dry is simply shifted, rather than eliminated. Total energy consumption of DR-8 (660 Wh) was comparable to that of BL-2 (662 Wh).

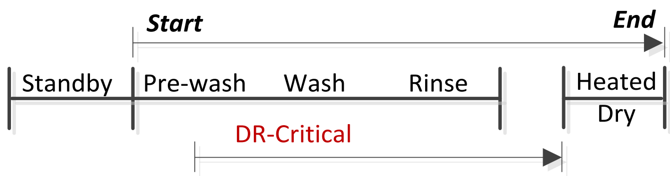

FIGURE 28. DR-8 (#3) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DELAY – GENERAL SEQUENCE OF OPERATION

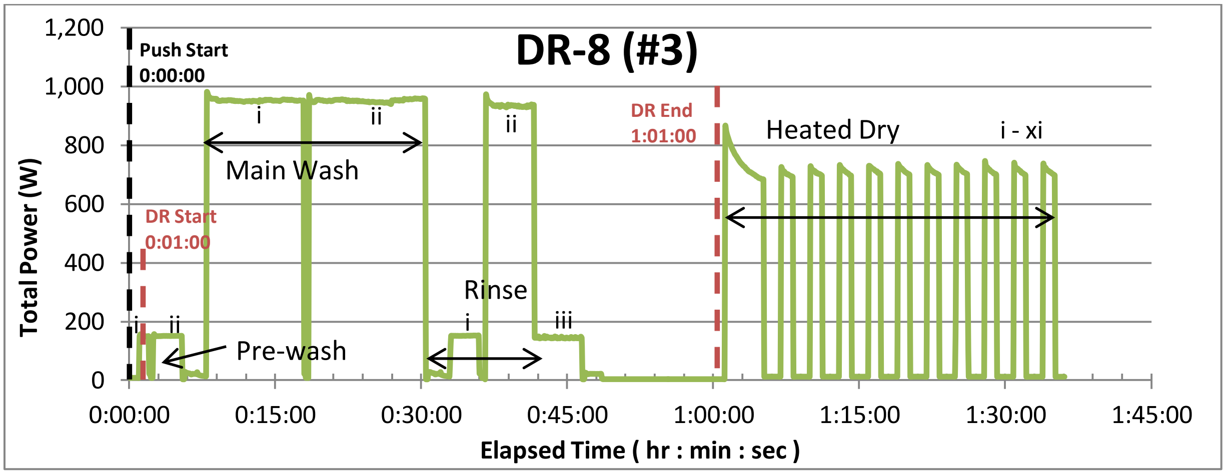

FIGURE 29. DR-8 (#3) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DELAY – DEMAND PROFILE

TABLE 23. DR-8 (#3) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DELAY – OPERATION CYCLES SUMMARY

Cycle	Time (hr : min : sec)			Power (W)			Energy (Wh)
	Duration	Start	End	Avg.	Max.	Min.	
Pre-wash i	0:00:55	0:01:05	0:02:00	150	156	149	2.50
Pre-wash ii	0:02:55	0:02:30	0:05:25	150	157	149	7.51
Main Wash i	0:09:55	0:08:00	0:17:55	953	981	947	159
Main Wash ii	0:11:55	0:18:30	0:30:25	951	969	940	190
Rinse i	0:02:55	0:33:00	0:35:55	149	152	88	7.46
Rinse ii	0:04:55	0:36:40	0:41:35	936	972	928	78.0
Rinse iii	0:04:50	0:41:40	0:46:30	144	150	142	11.8
Heated Dry i	0:03:55	1:01:15	1:05:10	740	865	683	49.3
Heated Dry ii	0:01:10	1:07:00	1:08:10	704	725	691	14.7
Heated Dry iii	0:01:10	1:10:00	1:11:10	709	728	696	14.8
Heated Dry iv	0:01:10	1:13:00	1:14:10	711	732	696	14.8
Heated Dry v	0:01:10	1:16:00	1:17:10	715	729	701	14.9
Heated Dry vi	0:01:10	1:19:00	1:20:10	714	736	699	14.9
Heated Dry vii	0:01:10	1:22:00	1:23:10	712	732	699	14.8
Heated Dry viii	0:01:15	1:24:55	1:26:10	655	733	227	14.6
Heated Dry ix	0:01:10	1:27:55	1:29:05	715	745	699	14.9
Heated Dry x	0:01:10	1:30:55	1:32:05	714	739	697	14.9
Heated Dry xi	0:01:10	1:33:55	1:35:05	712	736	697	14.8
Operation Mode Total	1:36:05	0:00:00	1:36:05	412	981	2.89	660

CRITICAL DR PRICE SIGNAL: DR-9

Figure 30 illustrates the general sequence of operation for DR-9 (iteration #1), which tested dishwasher response to a DR event initiated during the wash cycle that would extend past the normal period of the heated dry cycle. Figure 31 illustrates the demand profile for the DR-9 (iteration #1) test scenario.

Table 24 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal wash mode + heated dry enhancement was initiated.
- Step 2: 1 minute into the active wash cycle, a 1 hour + 50 minute DR event was initiated; the duration of the event would ensure that the DR signal would extend past the time allotted for heated dry.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The DR signal did not delay the wash cycle, but disabled the heated dry enhancement. Unlike the results of DR-8, the heated dry did not resume after the DR event ended. This indicates that there is a preset time period for the heated dry, and if the DR event delays the heated dry beyond that preset time, the heated dry cycle is eliminated, rather than shifted. This is a key finding for utility program design. Total energy consumption of DR-9 (464 Wh) was 30% lower than that of BL-2 (662 Wh) because the DR event eliminated the heated dry enhancement. Total energy consumption of DR-9 was comparable to that of BL-1 (465 Wh).

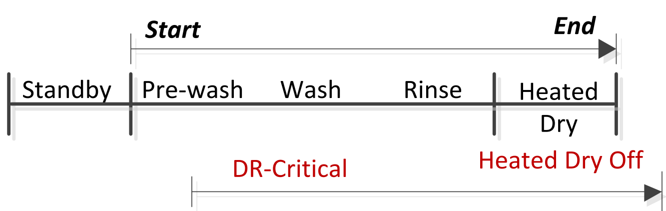

FIGURE 30. DR-9 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DISABLED – GENERAL SEQUENCE OF OPERATION

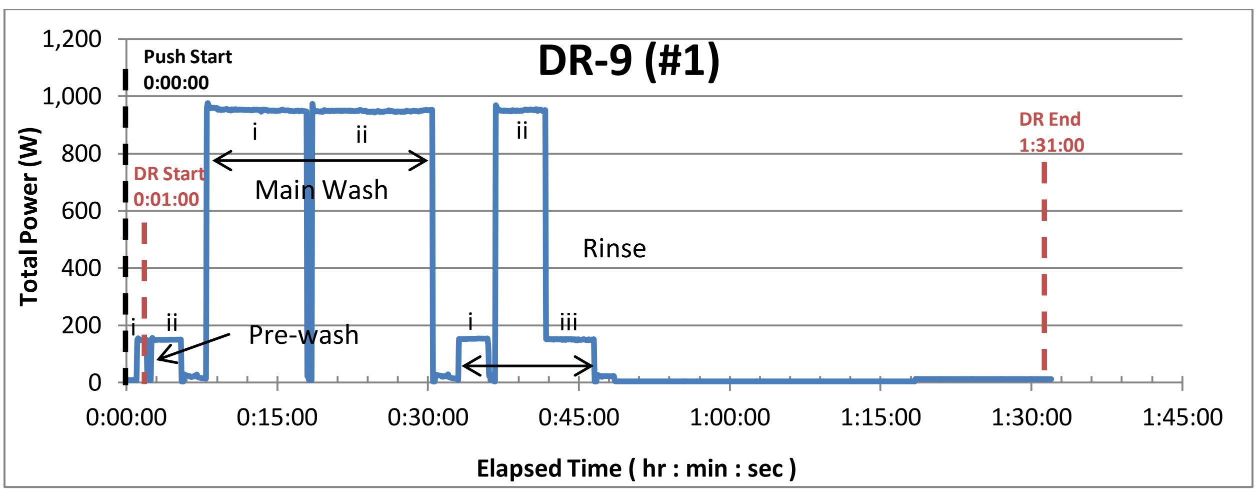

FIGURE 31. DR-9 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DISABLED – DEMAND PROFILE

TABLE 24. DR-9 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DISABLED – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX.	MIN.	
Pre-wash i	0:00:55	0:01:05	0:02:00	148	154	147	2.47
Pre-wash ii	0:02:55	0:02:30	0:05:25	149	155	148	7.44
Main Wash i	0:09:55	0:08:00	0:17:55	952	975	946	159
Main Wash ii	0:11:55	0:18:30	0:30:25	948	971	943	190
Rinse i	0:02:55	0:33:05	0:36:00	151	153	125	7.56
Rinse ii	0:04:55	0:36:45	0:41:40	951	968	947	79.2
Rinse iii	0:04:45	0:41:45	0:46:30	150	153	146	12.1
Operation Mode Total	1:32:00	0:00:00	1:32:00	302	975	2.89	464

CRITICAL DR PRICE SIGNAL: DR-10

Figure 32 illustrates the general sequence of operation for DR-10 (iteration #2), which tested dishwasher response to a DR event initiated near the beginning of the heated dry cycle. Figure 33 illustrates the demand profile for the DR-10 (iteration #2) test scenario. Table 25 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal wash mode + heated dry enhancement was initiated.
- Step 2: Approximately 5 minutes into the heated dry cycle, an 8-minute DR event was initiated.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The DR signal interrupted the heated dry cycle. The remaining heated dry cycles resumed at the end of the DR signal (11 in total). As with to DR-8, this interesting result needs to be considered for future program design. Total energy consumption of DR-10 (664 Wh) was comparable to that of BL-2 (662 Wh).

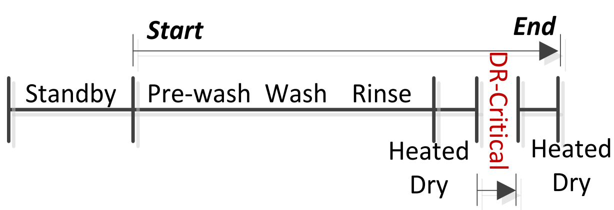

FIGURE 32. DR-10 (#2) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER OFF CYCLE) – GENERAL SEQUENCE OF OPERATION

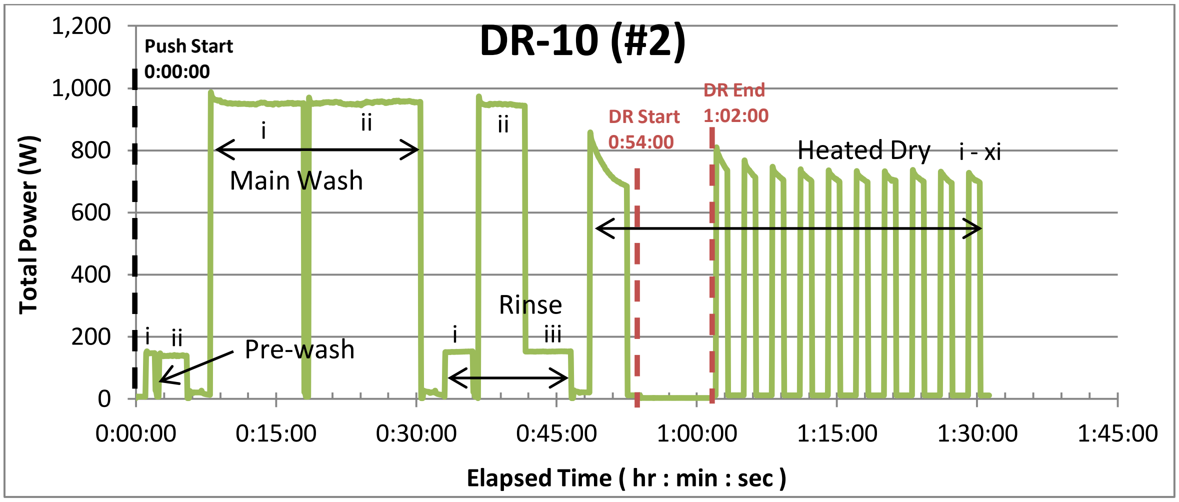

FIGURE 33. DR-10 (#2) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER OFF CYCLE) – DEMAND PROFILE

TABLE 25. DR-10 (#2) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER OFF CYCLE) – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			TOTAL POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX.	MIN.	
Pre-wash i	0:00:55	0:01:05	0:02:00	147	153	146	2.46
Pre-wash ii	0:02:55	0:02:30	0:05:25	139	147	137	6.95
Main Wash i	0:09:55	0:08:00	0:17:55	952	986	947	159
Main Wash ii	0:11:55	0:18:30	0:30:25	954	969	945	191
Rinse i	0:02:55	0:33:05	0:36:00	152	153	150	7.58
Rinse ii	0:04:55	0:36:40	0:41:35	948	972	943	79.0
Rinse iii	0:04:50	0:41:40	0:46:30	153	153	152	12.5
Heated Dry i	0:03:55	0:48:35	0:52:30	741	856	684	49.4
Heated Dry ii	0:01:10	1:02:05	1:03:15	766	809	735	16.0
Heated Dry iii	0:01:10	1:05:05	1:06:15	734	734	734	1.02
Heated Dry iv	0:01:10	1:08:05	1:09:15	721	721	721	1.00
Heated Dry v	0:01:10	1:11:05	1:12:15	716	716	716	0.99
Heated Dry vi	0:01:10	1:14:05	1:15:15	713	713	713	0.99
Heated Dry vii	0:01:10	1:17:05	1:18:15	711	711	711	0.99
Heated Dry viii	0:01:10	1:20:05	1:21:15	712	712	712	0.99
Heated Dry ix	0:01:10	1:23:05	1:24:15	713	713	713	0.99
Heated Dry x	0:01:10	1:26:05	1:27:15	710	710	710	0.99
Heated Dry xi	0:01:10	1:29:05	1:30:15	709	709	709	0.98
Operation Mode Total	1:31:15	0:00:00	1:31:15	436	986	2.61	664

CRITICAL DR PRICE SIGNAL: DR-10A

An additional iteration, referred to as DR-10a, was conducted to confirm results when the DR signal interrupts a heated dry cycle during an active heating element portion (the previous iterations showed a DR signal that coincidentally occurred during a heater off-cycle). Figure 34 illustrates the general sequence of operation for DR-10a (iteration #1). Figure 35 illustrates the demand profile for the DR-10a test scenario. Table 26 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal cycle + heated dry enhancement was initiated.
- Step 2: Approximately 2 minutes into the heated dry cycle, an 8-minute DR event was initiated.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The DR signal interrupted the heated dry cycle. Once the DR event cleared, the interrupted heater cycle resumed and the remaining heated dry cycles continued as normal. Based on the findings of the first set of DR-10 tests, this was the anticipated response. Total energy consumption of DR-10a (661 Wh) was comparable to that of BL-2 (662 Wh).

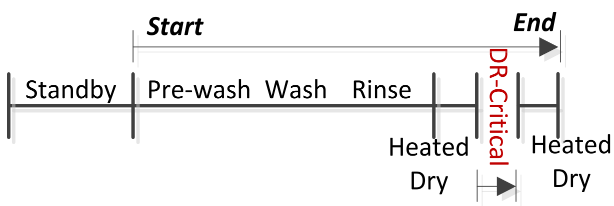

FIGURE 34. DR-10A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER ON CYCLE) – GENERAL SEQUENCE OF OPERATION

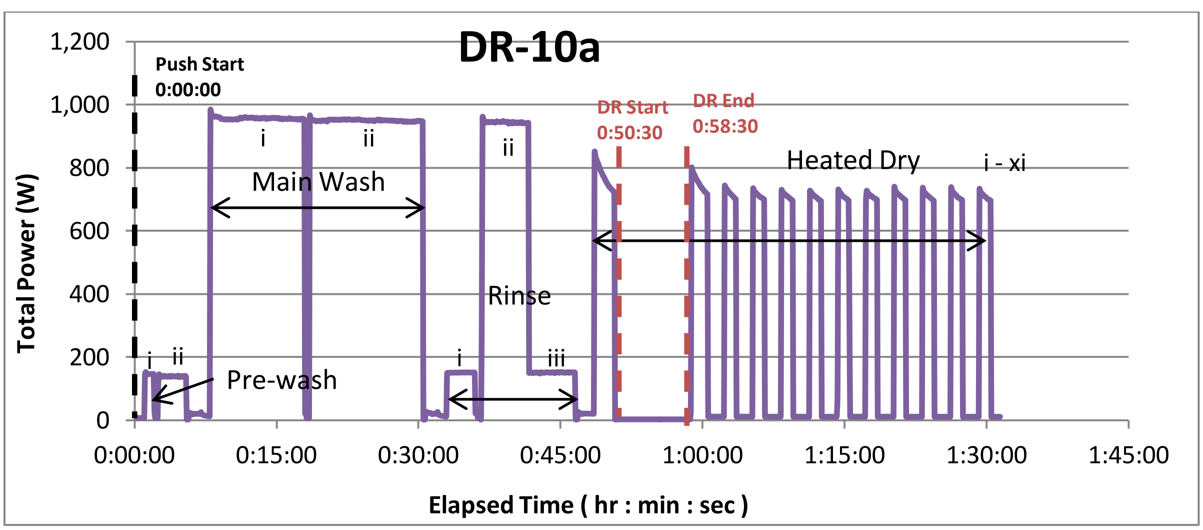

FIGURE 35. DR-10A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER ON CYCLE) – DEMAND PROFILE

TABLE 26. DR-10A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER ON CYCLE) – OPERATION CYCLES SUMMARY

Cycle	Time (hr : min : sec)			Power (W)			Energy (Wh)
	Duration	Start	End	Avg.	Max.	Min.	
Pre-wash i	0:00:55	0:01:05	0:02:00	147	153	146	2.45
Pre-wash ii	0:02:55	0:02:30	0:05:25	139	146	136	6.97
Main Wash i	0:09:55	0:08:00	0:17:55	956	983	952	159
Main Wash ii	0:11:55	0:18:30	0:30:25	950	965	945	190
Rinse i	0:02:55	0:33:00	0:35:55	151	152	149	7.56
Rinse ii	0:04:55	0:36:40	0:41:35	934	961	333	77.8
Rinse iii	0:04:50	0:41:40	0:46:30	151	153	148	12.4
Heated Dry i (interrupted)	0:02:05	0:48:35	0:50:40	772	850	722	27.9
Heated Dry i (resumed)	0:01:40	0:58:50	1:00:30	751	800	715	21.9
Heated Dry ii	0:01:10	1:02:20	1:03:30	719	743	700	15.0
Heated Dry iii	0:01:10	1:05:20	1:06:30	713	734	699	14.9
Heated Dry iv	0:01:10	1:08:20	1:09:30	711	730	695	14.8
Heated Dry v	0:01:10	1:11:20	1:12:30	709	727	694	14.8
Heated Dry vi	0:01:10	1:14:20	1:15:30	689	731	387	14.4
Heated Dry vii	0:01:10	1:17:15	1:18:25	708	727	689	14.8
Heated Dry viii	0:01:10	1:20:15	1:21:25	713	739	697	14.9
Heated Dry ix	0:01:10	1:23:15	1:24:25	711	736	696	14.8
Heated Dry x	0:01:10	1:26:15	1:27:25	712	738	697	14.8
Heated Dry xi	0:01:10	1:29:15	1:30:25	710	733	696	14.8
Operation Mode Total	1:31:25	0:00:00	1:31:25	434	983	2.74	661

CRITICAL DR PRICE SIGNAL: DR-11

Figure 36 illustrates the general sequence of operation for DR-11 (iteration #1), which tested dishwasher response to a DR event initiated during the heated dry cycle that extended through the entire cycle. Figure 37 illustrates the demand profile for the DR-11 (iteration #1) test scenario. Table 27 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal wash mode + heated dry enhancement was initiated.
- Step 2: 5 minutes into the heated dry cycle, a 45-minute DR event was initiated.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The DR signal interrupted and completely disabled the heated dry cycle. This was the anticipated response based on the prior DR event test results. Total energy consumption of DR-11 (511 Wh) was 23% lower than that of BL-2 (662 Wh) because a portion of the heated dry enhancement was eliminated.

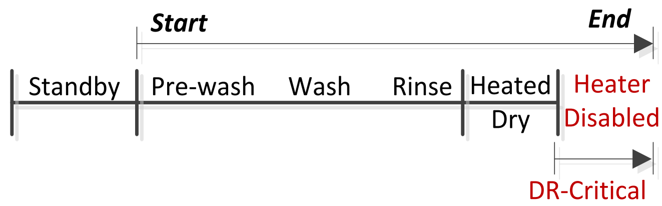

FIGURE 36. DR-11 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER OFF CYCLE) – DEMAND PROFILE

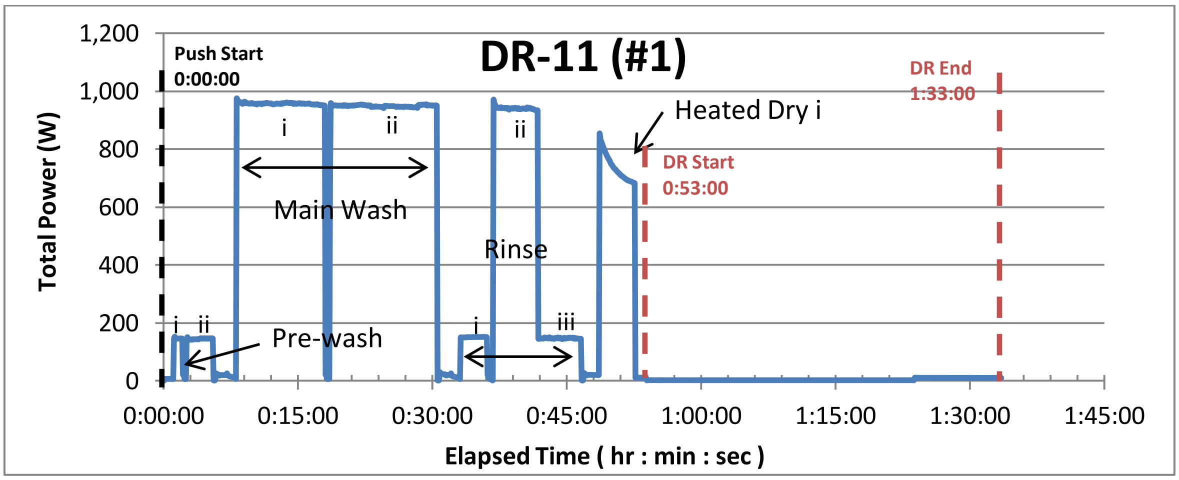

FIGURE 37. DR-11 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER OFF CYCLE) – DEMAND PROFILE

TABLE 27. DR-11 (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER OFF CYCLE) – OPERATION CYCLES SUMMARY

Cycle	Time (hr : min : sec)			Power (W)			Energy (Wh)
	Duration	Start	End	Avg.	Max.	Min.	
Pre-wash i	0:00:55	0:01:10	0:02:05	147	153	146	2.45
Pre-wash ii	0:02:55	0:02:35	0:05:30	146	152	142	7.29
Main Wash i	0:09:50	0:08:10	0:18:00	958	975	950	158
Main Wash ii	0:11:55	0:18:35	0:30:30	948	959	666	190
Rinse i	0:02:55	0:33:10	0:36:05	152	152	150	7.58
Rinse ii	0:04:55	0:36:50	0:41:45	942	970	934	78.5
Rinse iii	0:04:45	0:41:50	0:46:35	148	151	144	11.9
Heated Dry i	0:03:55	0:48:40	0:52:35	737	853	683	49.1
Operation Mode Total	1:33:30	0:00:00	1:33:30	327	975	2.15	511

CRITICAL DR PRICE SIGNAL: DR-11A

An additional iteration, referred to as DR-11a, was conducted to confirm results when the DR signal interrupts a heated dry cycle during an active heating element portion (the previous iterations showed a DR signal that occurred during a heater off-cycle). Figure 38 illustrates the general sequence of operation for DR-11a. Figure 39 illustrates the demand profile for the DR-11a test scenario. Table 28 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal wash mode + heated dry enhancement was initiated.
- Step 2: Approximately 2 minutes into the heated dry cycle, a 50-minute DR event was initiated.
- Step 3: The dishwasher was allowed to run through its programmed operation.

The DR signal interrupted the heated dry cycle. The heated dry cycle remained deactivated. This was the anticipated response based on the prior DR event test results. Total energy consumption of DR-11a (489 Wh) was 26% lower than that of BL-2 (662 Wh), because a portion of the heated dry enhancement was eliminated.

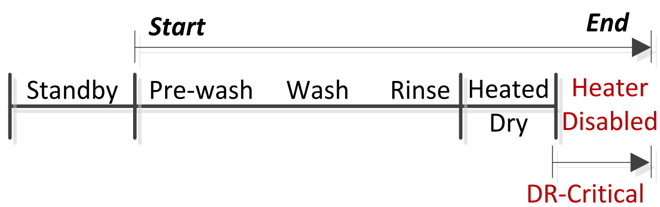

FIGURE 38. DR-11A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER ON CYCLE) – GENERAL SEQUENCE OF OPERATION

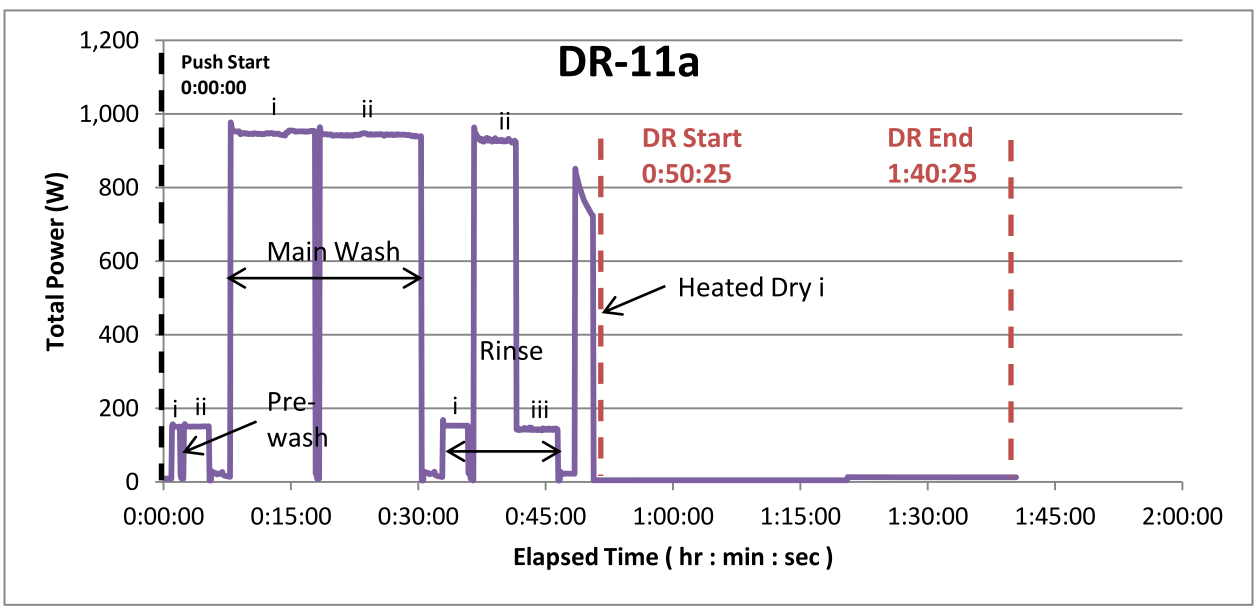

FIGURE 39. DR-11A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER ON CYCLE) – DEMAND PROFILE

TABLE 28. DR-11A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER ON CYCLE) – OPERATION CYCLES SUMMARY

CYCLE	TIME (HR : MIN : SEC)			POWER (W)			ENERGY (WH)
	DURATION	START	END	AVG.	MAX.	MIN.	
Pre-wash i	0:00:55	0:01:00	0:01:55	149	156	148	2.49
Pre-wash ii	0:02:55	0:02:25	0:05:20	149	156	149	7.47
Main Wash i	0:09:55	0:07:55	0:17:50	949	976	941	158
Main Wash ii	0:11:55	0:18:25	0:30:20	943	963	937	189
Rinse i	0:02:55	0:32:55	0:35:50	152	166	151	7.60
Rinse ii	0:04:55	0:36:35	0:41:30	930	962	922	77.5
Rinse iii	0:04:50	0:41:35	0:46:25	142	147	139	11.6
Heated Dry i	0:02:05	0:48:30	0:50:35	772	850	722	27.9
Operation Mode Total	1:40:25	0:00:00	1:40:25	292	976	2.78	489

CRITICAL DR PRICE SIGNAL: DR-12

Figure 40 illustrates the general sequence of operation for DR-12 (iteration #3), which tested dishwasher response to a DR event initiated during the heated dry cycle that extended into a second cycle of normal + heated dry enhancement. Figure 41 illustrates the demand profile for the DR-12 (iteration #3) test scenario. Table 29 summarizes the total power and time details. The DR test was conducted as follows:

- Step 1: A normal wash mode + heated dry enhancement was initiated.
- Step 2: 5 minutes into the heated dry cycle, a 50-minute DR event was initiated.
- Step 3: A second normal wash + heated dry enhancement cycle was initiated at 1:24:00, allowing the DR event to extend to delay the second wash cycle.
- Step 4: The dishwasher was allowed to run through its programmed operation.

The first heated dry portion was interrupted and disabled. In addition, the second normal wash mode was delayed by the DR signal. The second heated dry portion remained active. This was the anticipated response based on the prior DR event test results. Total energy consumption of DR-12 (1171 Wh) was 77% greater than that of BL-2 (662 Wh). The consumption for DR-12 reflects two operations of the dishwasher and the elimination of a portion of the heated dry enhancement during the first operation.

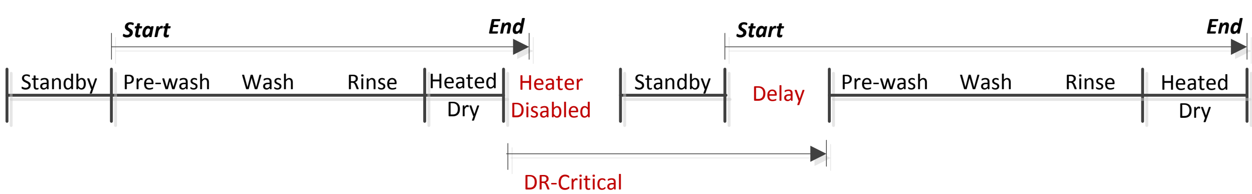

FIGURE 40. DR-12 (#3) TWO DISHWASHER OPERATIONS: NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT (DURING 1ST OPERATION, HEATED DRY OFF CYCLE), DELAYED 2ND OPERATION – GENERAL SEQUENCE OF OPERATION

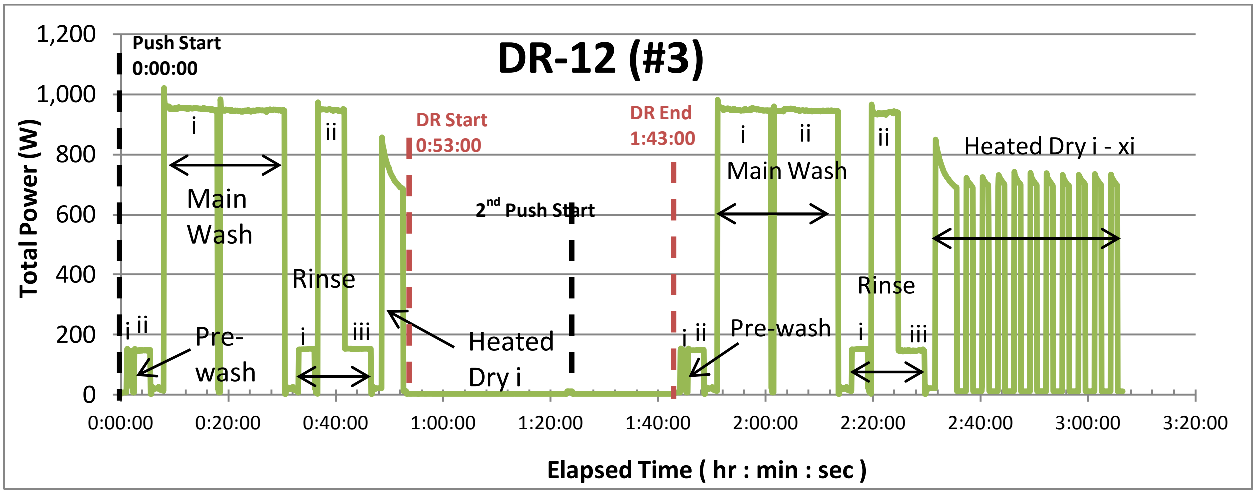

FIGURE 41. DR-12 (#3) TWO DISHWASHER OPERATIONS: NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT (DURING 1ST OPERATION, HEATED DRY OFF CYCLE), DELAYED 2ND OPERATION – DEMAND PROFILE

TABLE 29. DR-12 (#3) TWO DISHWASHER OPERATIONS: NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT (DURING 1ST OPERATION, HEATED DRY OFF CYCLE), DELAYED 2ND OPERATION – OPERATION CYCLES SUMMARY

Cycle		Time (hr : min : sec)			Power (W)			Energy (Wh)
		Duration	Start	End	Avg.	Max.	Min.	
1st Operation Mode	Pre-wash i	0:00:55	0:01:05	0:02:00	147	153	146	2.45
	Pre-wash ii	0:02:55	0:02:30	0:05:25	147	153	144	7.37
	Main Wash i	0:09:55	0:08:00	0:17:55	954	1018	946	159
	Main Wash ii	0:11:55	0:18:30	0:30:25	947	984	942	189
	Rinse i	0:02:55	0:33:05	0:36:00	152	153	150	7.60
	Rinse ii	0:04:55	0:36:40	0:41:35	950	973	943	79.1
	Rinse iii	0:04:50	0:41:40	0:46:30	153	154	152	12.5
	Heated Dry i	0:03:55	0:48:35	0:52:30	739	856	686	49.3
1st Operation Mode Total		0:53:30	0:00:00	0:53:30	571	1018	2.63	510
2nd Operation Mode	Pre-wash i	0:00:55	1:44:10	1:45:05	148	154	147	2.47
	Pre-wash ii	0:02:55	1:45:35	1:48:30	149	154	147	7.44
	Main Wash i	0:09:55	1:51:05	2:01:00	950	983	946	158
	Main Wash ii	0:11:55	2:01:35	2:13:30	947	961	943	189
	Rinse i	0:02:55	2:16:05	2:19:00	152	153	151	7.60
	Rinse ii	0:04:55	2:19:45	2:24:40	939	966	932	78.3
	Rinse iii	0:04:50	2:24:45	2:29:35	147	151	144	12.0
	Heated Dry i	0:03:55	2:31:40	2:35:35	742	850	691	49.5
	Heated Dry ii	0:01:10	2:37:25	2:38:35	704	722	690	14.7
	Heated Dry iii	0:01:10	2:40:25	2:41:35	688	725	403	14.3
	Heated Dry iv	0:01:10	2:43:20	2:44:30	713	731	694	14.9
	Heated Dry v	0:01:10	2:46:20	2:47:30	716	743	700	14.9
	Heated Dry vi	0:01:10	2:49:20	2:50:30	713	739	698	14.9
	Heated Dry vii	0:01:10	2:52:20	2:53:30	712	738	696	14.8
	Heated Dry viii	0:01:10	2:55:20	2:56:30	709	732	695	14.8
	Heated Dry ix	0:01:10	2:58:20	2:59:30	714	732	700	14.9
	Heated Dry x	0:01:10	3:01:20	3:02:30	714	735	698	14.9
	Heated Dry xi	0:01:10	3:04:20	3:05:30	712	733	697	14.8
2nd Operation Mode Total		1:42:30	1:24:00	3:06:30	386	983	2.76	660
Both Operation Modes		3:06:30	0:00:00	3:06:30	377	1018	2.63	1171

Discussion and Conclusions

Generally, dishwasher A consistently performed in a manner compliant with its originally intended strategy and has the potential to avoid its peak demand of roughly 1 kW. Overall, the DR benefits from this dishwasher that could be realized by an electric utility are dependent upon the price signal, the duration of the DR event, and the timing of the DR event relative to the dishwasher's operating stage.

Discussed below are a few areas of key importance:

- **High Event:** The dishwasher responds to a high price signal by delaying the start of a new wash mode during the DR event; the dishwasher does not change a wash mode already in progress. When the duration of the DR event was longer than a user-input delay start mode enhancement, the DR event took priority. When the duration of the DR event was shorter than a user-input delay start mode enhancement, the delay start mode enhancement was not impacted.
- **Critical Event:** In response to a critical event, the dishwasher responds as with the high event, but also has the capacity to reduce average wattage during its heated dry cycle. Specifically, it can reduce wattage by well over 50% by deactivating the electric heating elements, but only during the heated dry cycle. However, if the duration of a critical DR event is shorter than the original allotment of time for the heated dry cycle, the heated dry cycle will re-activate in its entirety once the critical DR event ceases.

  Moreover, the dishwasher cannot reduce wattage during any operating point other than the heated dry cycle, even thought other cycles use the heating elements. Depending on the dishwashing modes and enhancements selected by the user, various cycles, such as steam pre-wash, main wash, or rinsing, may also use the heating element. Thus, DR event would have little to no effect on the demand under many scenarios. Further, the benefits that can be derived are not likely to be immediate, as they require the dishwasher to enter the drying cycle.

Table 30 summarizes the peak demand and energy consumption during the total operations of all test scenarios discussed in the results section. As shown, for high price DR events (DR-1 through DR-5), the average demand was reduced anywhere from 1% to 58% (6 to 328 W). Energy consumption and peak demand witnessed in these scenarios were not significantly impacted. For critical price DR events (DR-6 through DR-12), the average demand was reduced anywhere from 1% to 39% (2 to 184 W). Peak demand was minimally impacted, up to 6% reduction (11 W), and energy consumption was reduced up to 30% (228 Wh), depending on how much of the heated dry cycle was eliminated.

TABLE 30. SUMMARY OF PEAK DEMAND AND ENERGY CONSUMPTION DURING THE TOTAL OPERATION OF ALL TEST SCENARIOS

Test	Iteration #	DR Signal	Average Demand (W)	Peak Demand (W)	Energy Consumption (Wh)	Baseline	Average Demand % Difference from Baseline	Peak Demand % Difference from Baseline	Energy Consumption % Difference from Baseline
BL-1	1	-	563	986	465	BL-1	-	-	-
BL-2	1	-	476	1007	662	BL-1	-15%	2%	42%
FN-1	1	-	701	996	1633	BL-1	25%	1%	251%
FN-2	1	-	819	982	1416	BL-1	45%	0%	204%
FN-3	1	-	667	989	606	BL-1	18%	0%	30%
DR-1	3	High	477	983	461	BL-1	-15%	0%	-1%
DR-2	2		235	990	465	BL-1	-58%	0%	0%
DR-3	3		252	978	463	BL-1	-55%	-1%	0%
DR-4	1		557	977	461	BL-1	-1%	-1%	-1%
DR-5*	1		466	977	923	BL-1	-17%	-1%	98%
DR-6	3	Critical	426	947	651	BL-2	-11%	-6%	-2%
DR-7	1		474	984	660	BL-2	-1%	-2%	0%
DR-8	3		412	981	660	BL-2	-13%	-3%	0%
DR-9	1		302	975	464	BL-2	-37%	-3%	-30%
DR-10	2		436	986	664	BL-2	-8%	-2%	0%
DR-10a	-		434	983	661	BL-2	-9%	-2%	0%
DR-11	1		327	975	511	BL-2	-31%	-3%	-23%
DR-11a	-		292	976	489	BL-2	-39%	-3%	-26%
DR-12*	3		377	1018	1171	BL-2	-21%	1%	77%

*Note: Scenarios DR-5 and DR-12 involve two operations of the dishwasher.

APPENDIX A: A SNAPSHOT OF COMPONENT-LEVEL POWER MEASUREMENTS

For BL-2, a fourth iteration of testing was conducted to shed light on the breakdown of dishwasher power consumption by individual components. Total power is logged by the laboratory's instrumentation, while separate portable instrumentation is connected to three key components (heating element, wash pump, and drain pump) for spot measurements. Figure 42 illustrates the demand profile and spot measurements for BL-2 (#4). Table 31 summarizes manufacturer's rated power, and lab-measured power ranges for key dishwasher components.

The sum of spot measurements of the three components came within close agreement of the total power measurements logged. As anticipated, the heating element comprises the overwhelming majority of total power consumption. Additionally, the sequential nature of the dishwasher's operation allows for distinction between components in the total power profile, without separate component monitoring.

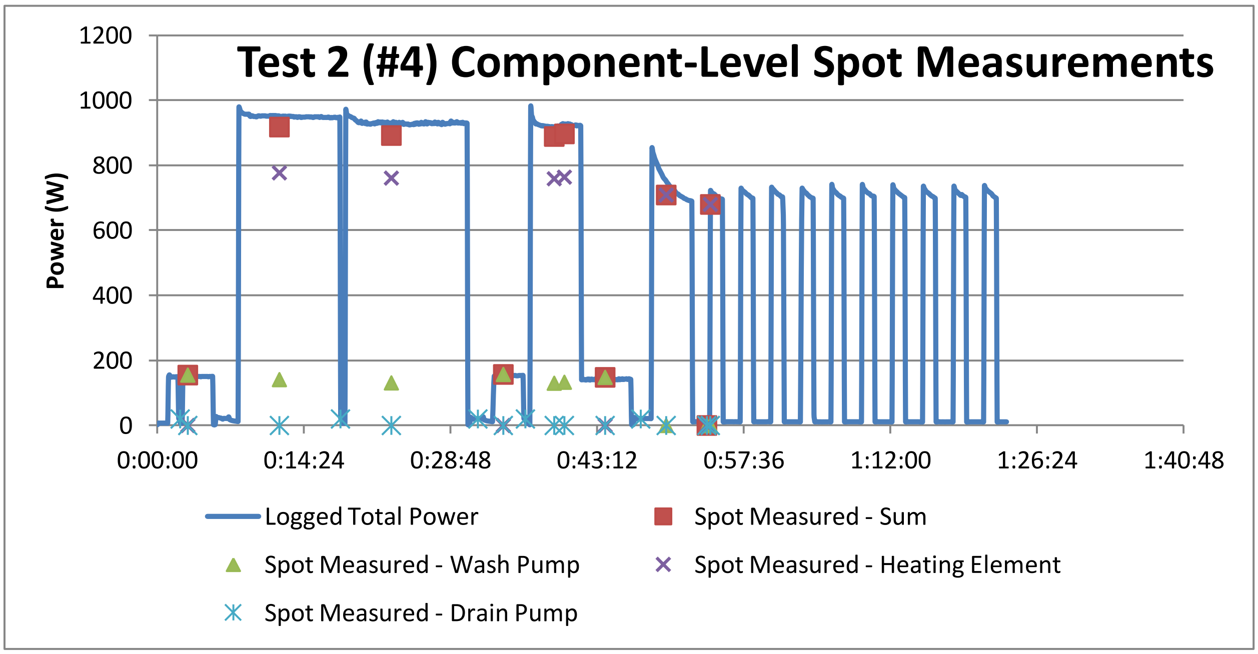

FIGURE 42. BL-2 COMPONENT-LEVEL DEMAND PROFILE

TABLE 31. BL-2 DISHWASHER COMPONENT-LEVEL POWER SUMMARY

COMPONENT	MANUFACTURER'S RATED WATTAGE	TTC MEASURED RANGE
Wash pump	60–100 W	130 –157 W
Heating element	600–800 W	680–777 W
Drain pump	40–50 W	17–22 W
Water valve	5–10 W	N/A

APPENDIX B: POWER PROFILE NOISE CAUSED BY CONCURRENT APPLIANCE TESTING

Fluctuations in measured power were observed for several cases of dishwasher tests that are not attributable to the dishwasher's inherent operation. Here, the fluctuations were "noise" due to concurrent DR testing of a separate appliance. Lab setup involved use of a voltage regulator shared between two appliances: the dishwasher and a clothes washer. Figure 43 illustrates the voltage and total power for both the dishwasher and clothes washer tested during a given period: the clothes washer is not active. Figure 44 illustrates the voltage and total power for both the dishwasher and clothes washer tested during a given period: the clothes washer is active, and showcases a peaky demand profile that causes noise in the dishwasher's demand profile.

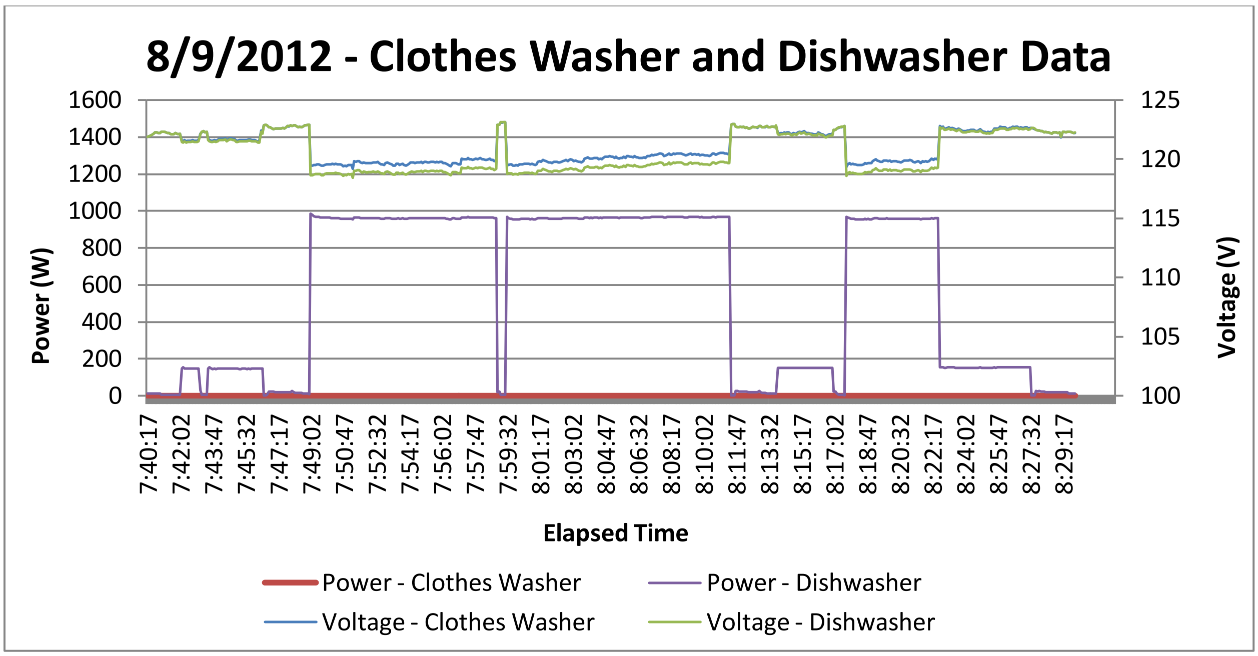

FIGURE 43. EXPLORING THE EFFECTS OF CONCURRENT DR APPLIANCE TESTING – CLOTHES WASHER OFF

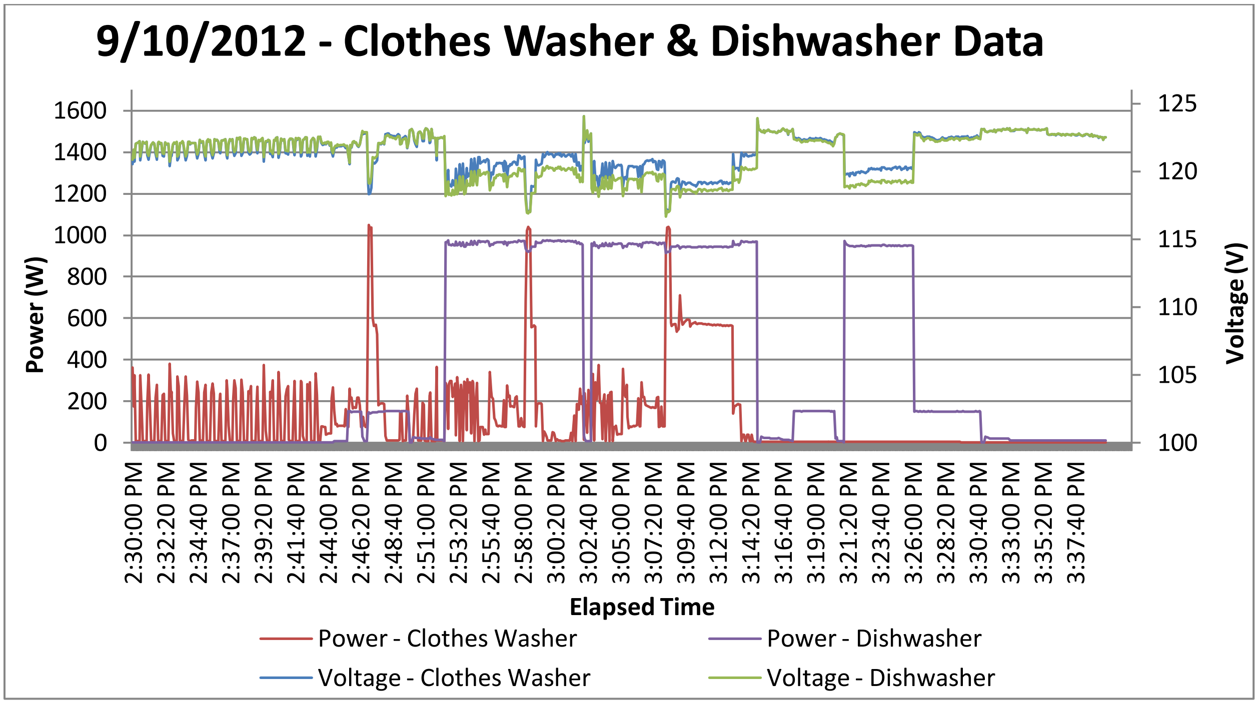

FIGURE 44. EXPLORING THE EFFECTS OF CONCURRENT DR APPLIANCE TESTING – CLOTHES WASHER ON

APPENDIX C: TEST ITERATIONS

Demand profiles for all iterations are illustrated in Figure 45 through Figure 61. Generally, for any given test scenario, good agreement is witnessed across the three iterations. Minor anomalies are observed in some cases:

- In BL-2 iteration #2, the second rinse event lasts slightly longer than in the other iterations.
- In DR-7 iteration #3, the second rinse event ramps down, rather than maintaining a fairly constant level as seen in the other iterations.
- Various cases of more "noise" resulted from concurrent clothes washer testing.

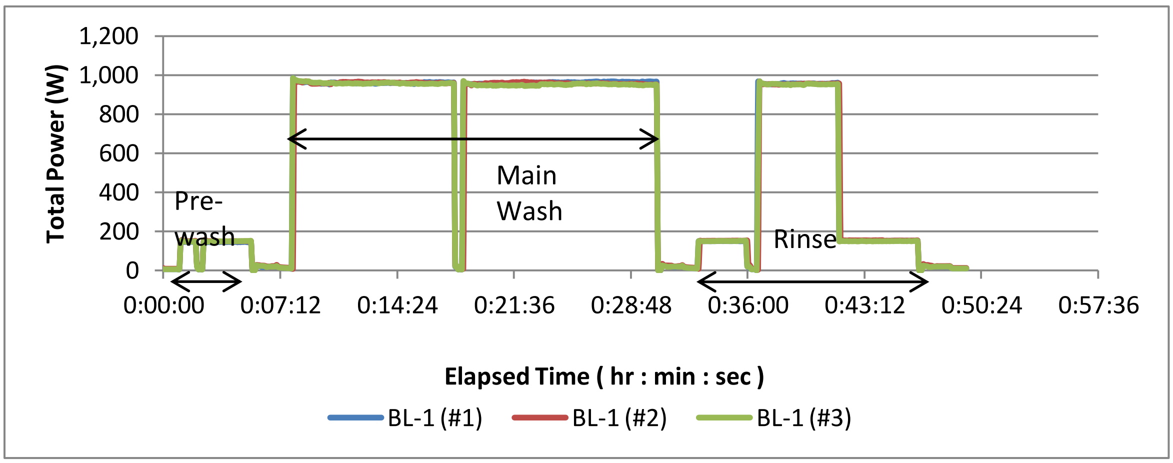

FIGURE 45. BL-1 NORMAL WASH – DEMAND PROFILES FOR ALL ITERATIONS

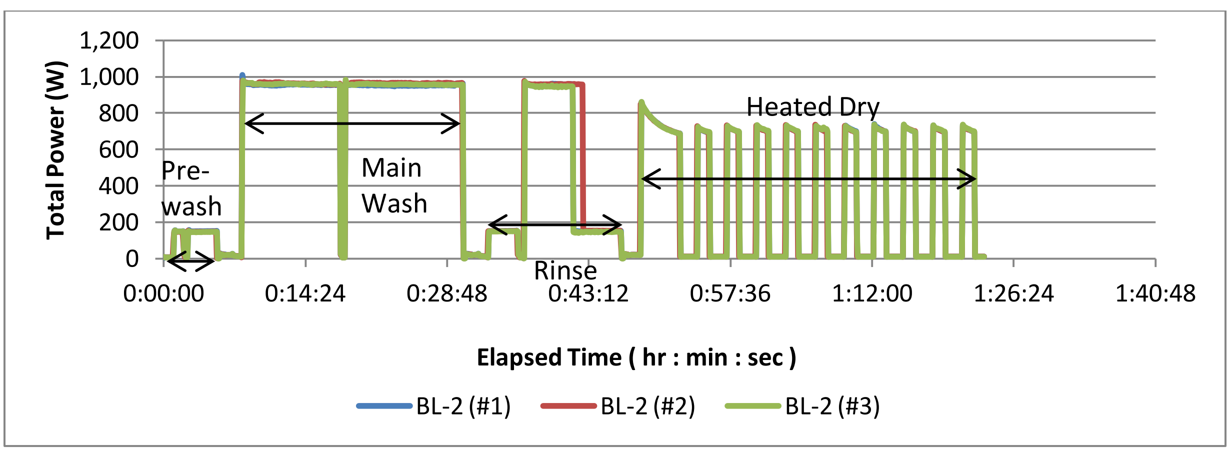

FIGURE 46. BL-2 NORMAL WASH + HEATED DRY – DEMAND PROFILES FOR ALL ITERATIONS

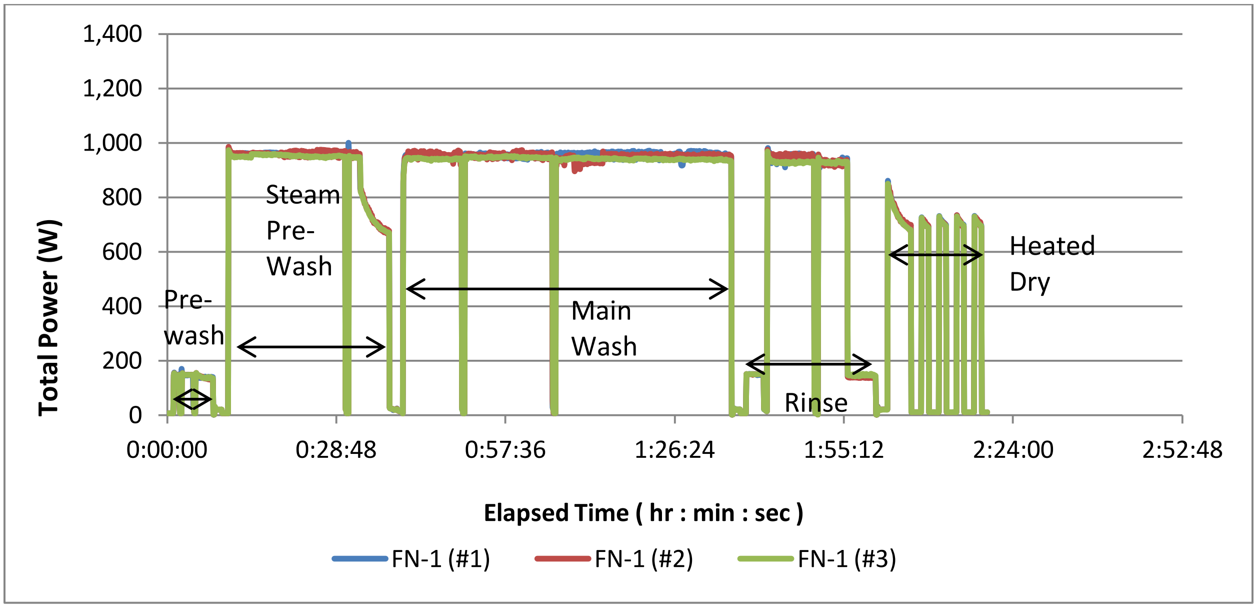

FIGURE 47. FN-1 NORMAL WASH + ADDED HEAT + STEAM + HEATED DRY – DEMAND PROFILES FOR ALL ITERATIONS

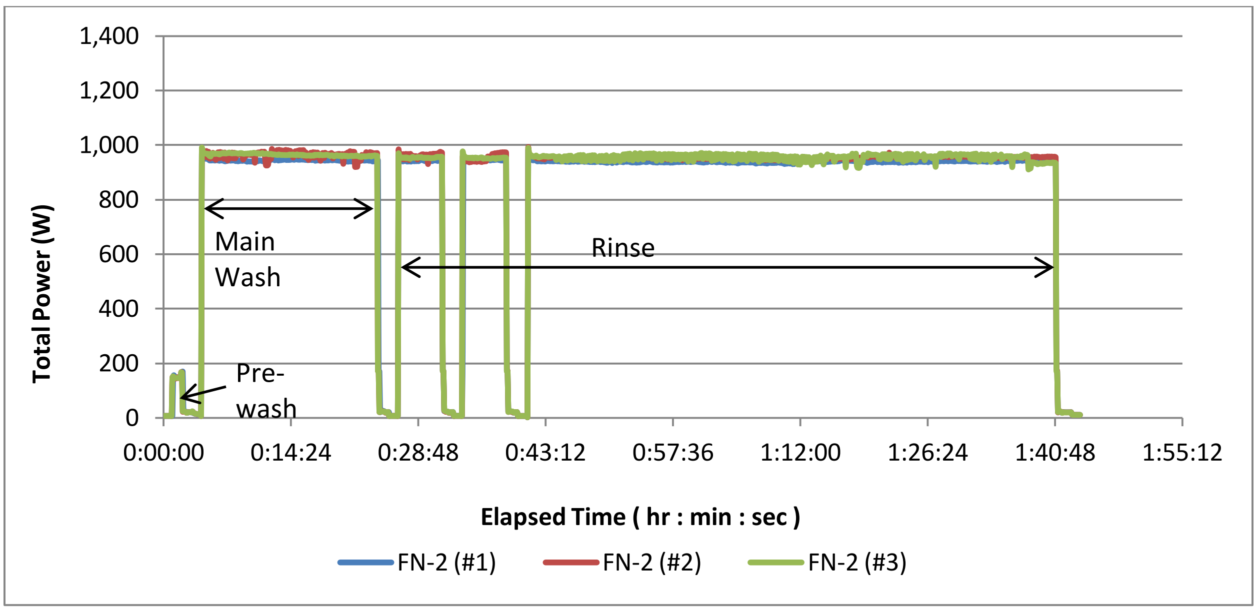

FIGURE 48. FN-2 ANTI-BACTERIA – DEMAND PROFILES FOR ALL ITERATIONS

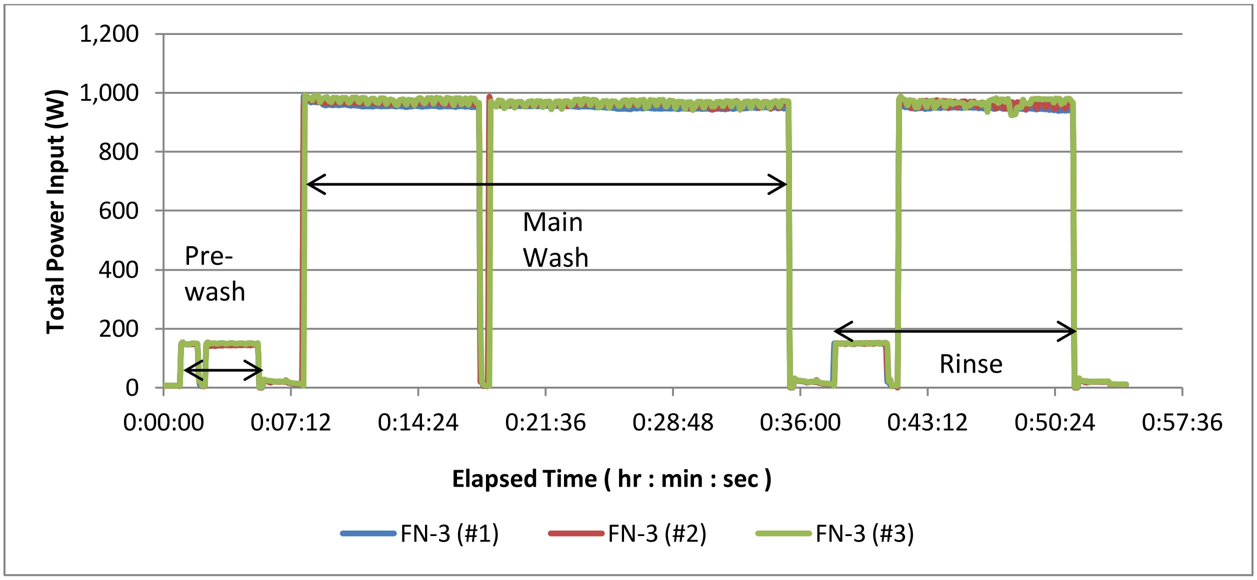

FIGURE 49. FN-3 NORMAL WASH (LOW INLET WATER TEMPERATURE) – DEMAND PROFILES FOR ALL ITERATIONS

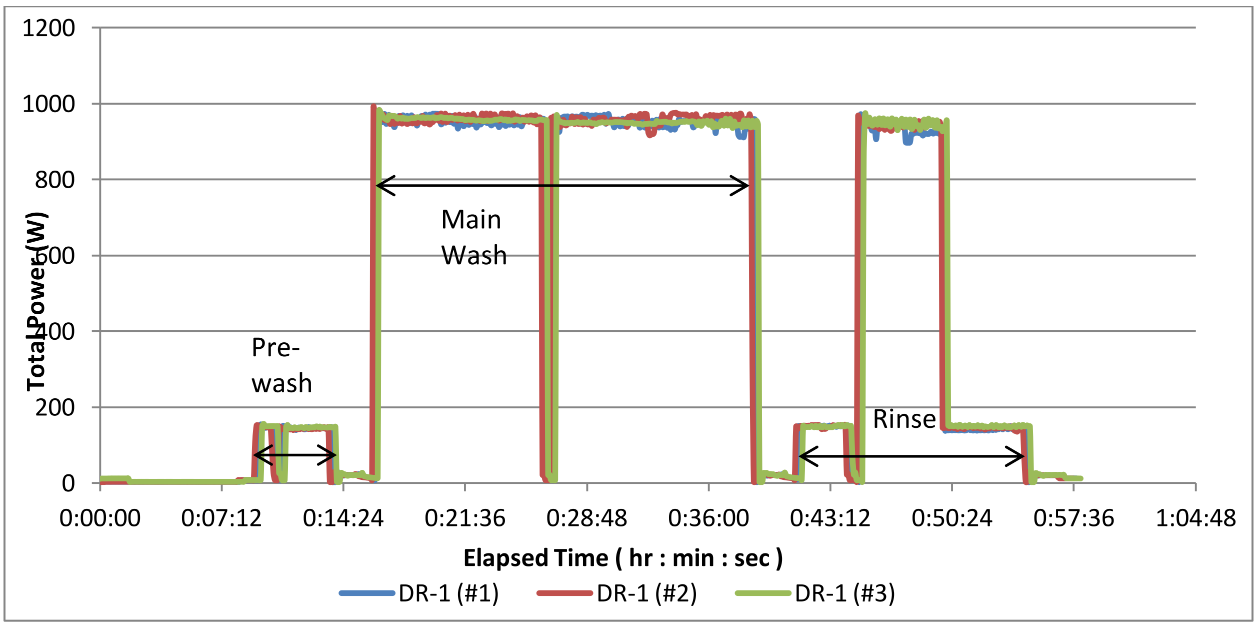

FIGURE 50. DR-1 NORMAL WASH, HIGH PRICE DR EVENT – DEMAND PROFILES FOR ALL ITERATIONS

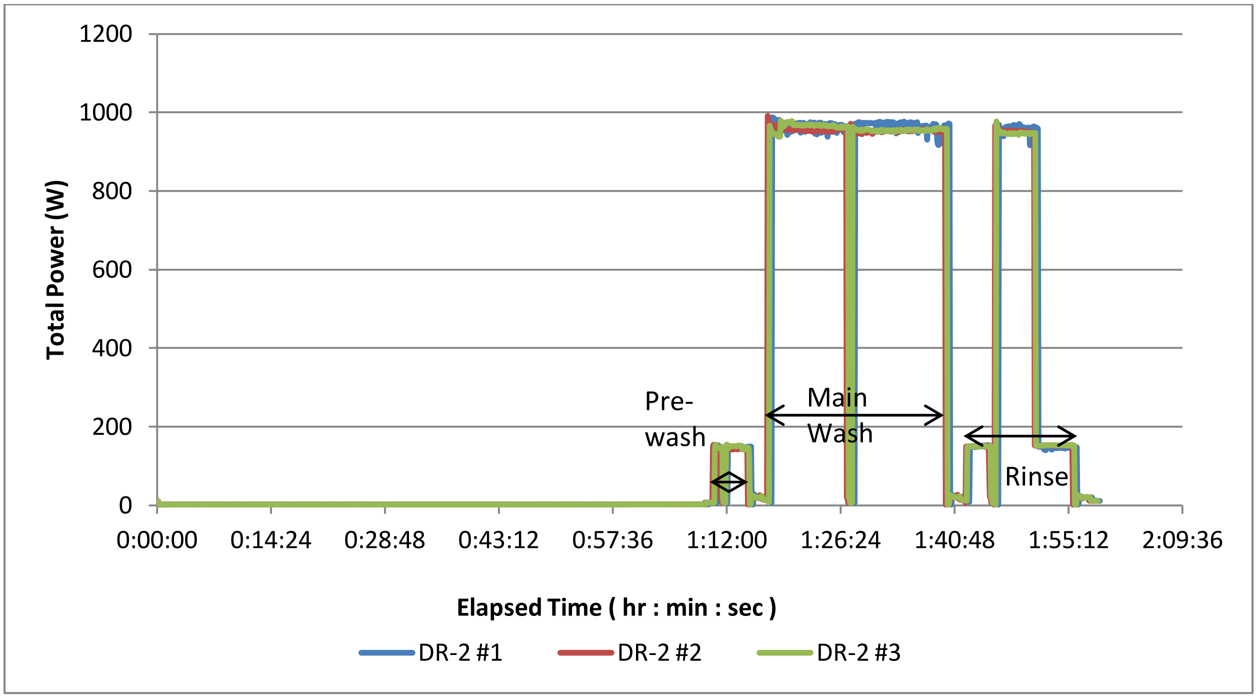

Figure 51. DR-2 Normal Wash + Delay Start, High Price DR Event (DR Override) – Demand Profiles for all Iterations

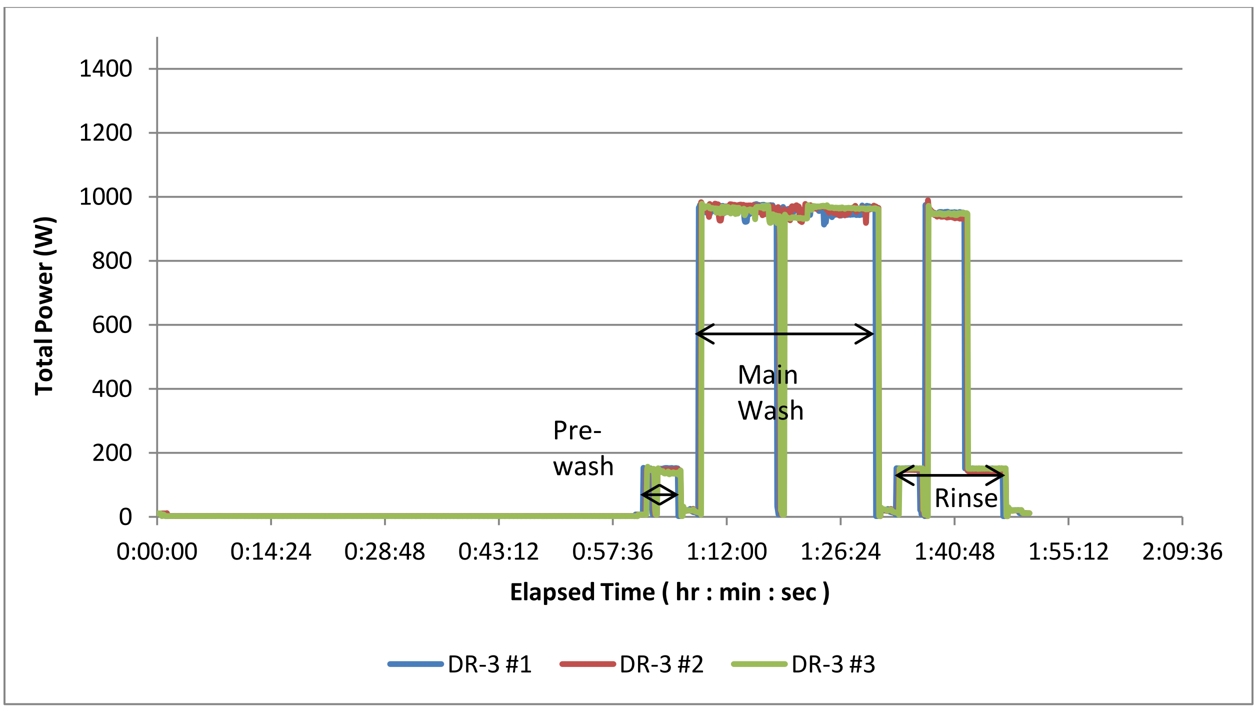

Figure 52. DR-3 Normal Wash + Delay Start, High Price DR Event (No DR Override) – Demand Profiles for all Iterations

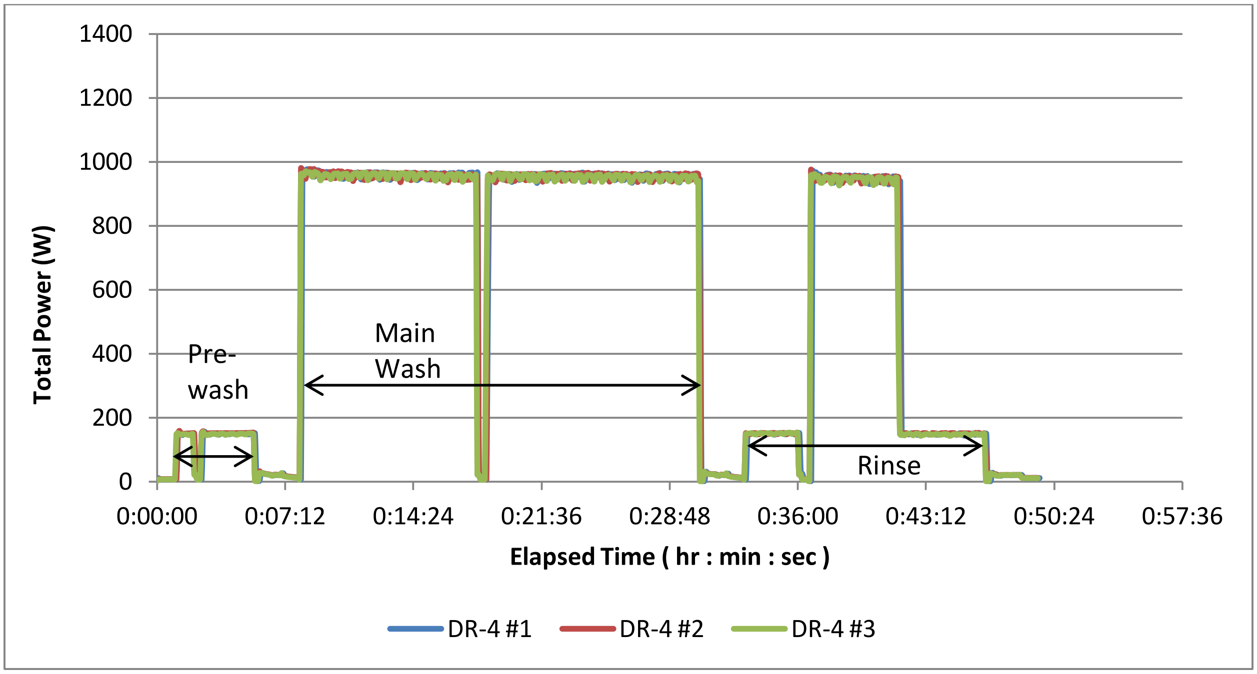

FIGURE 53. DR-4 NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE – DEMAND PROFILES FOR ALL ITERATIONS

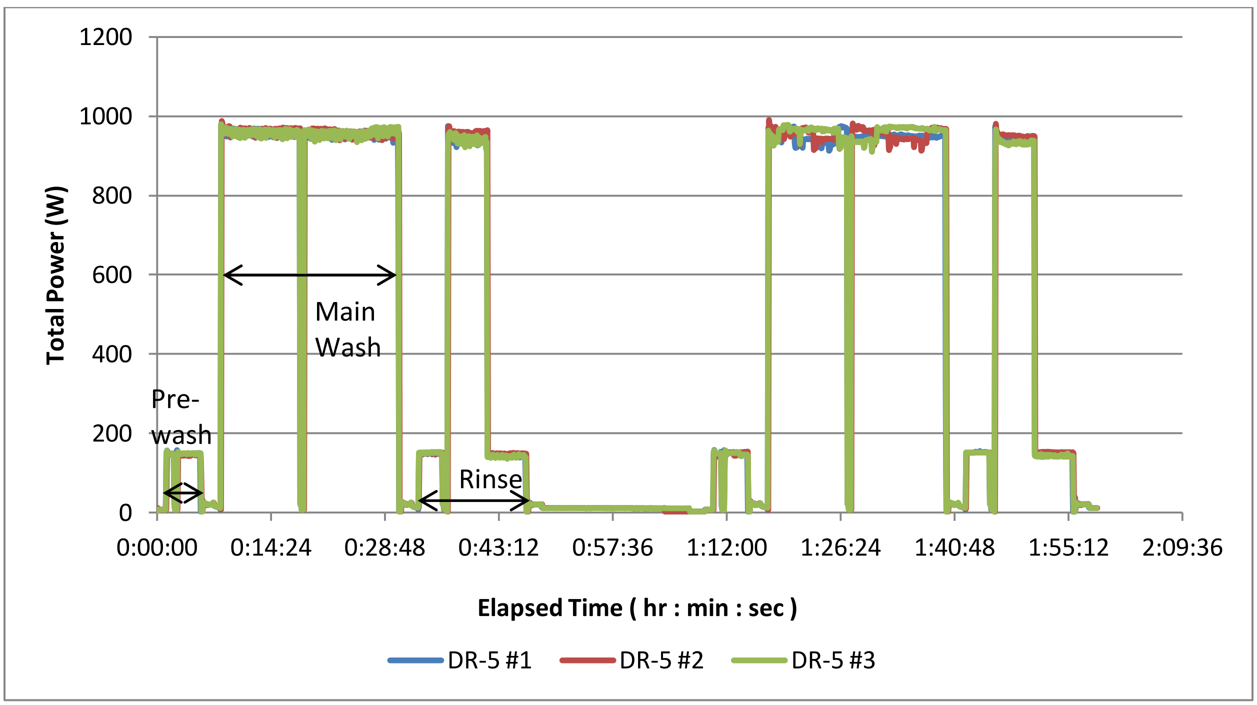

FIGURE 54. . DR-5 TWO DISHWASHER OPERATIONS: NORMAL WASH, HIGH PRICE DR EVENT DURING WASH CYCLE OF 2ND MODE – DEMAND PROFILES FOR ALL ITERATIONS

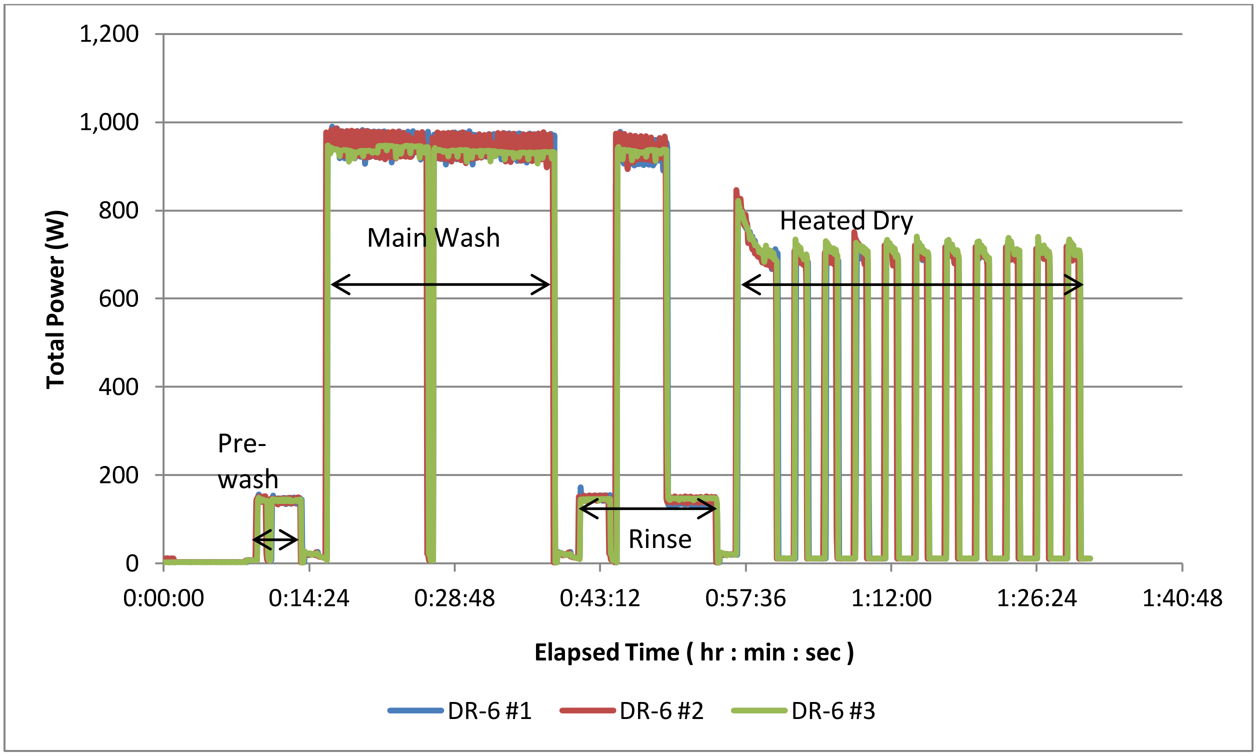

FIGURE 55. DR-6 NORMAL WASH + HEATED DRY, CRITICAL DR DELAY EVENT – DEMAND PROFILES FOR ALL ITERATIONS

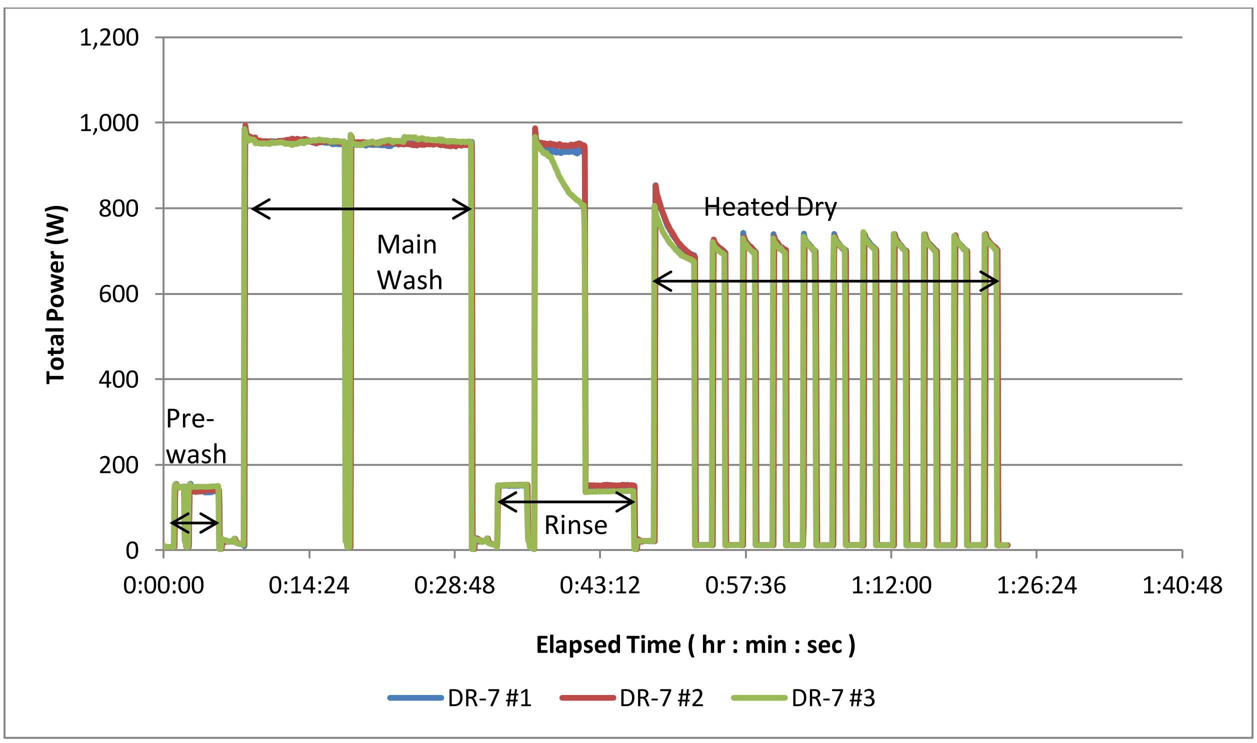

FIGURE 56. DR-7 NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT DURING WASH – DEMAND PROFILES FOR ALL ITERATIONS

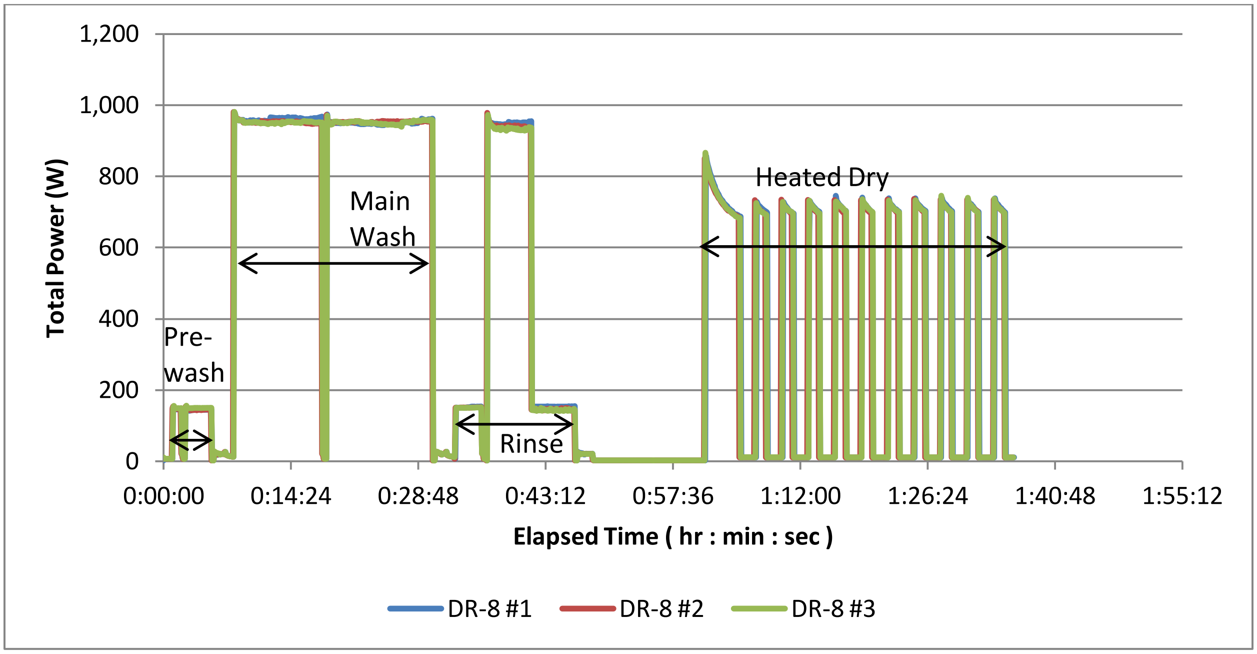

FIGURE 57. DR-8 NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DELAY – DEMAND PROFILES FOR ALL ITERATIONS

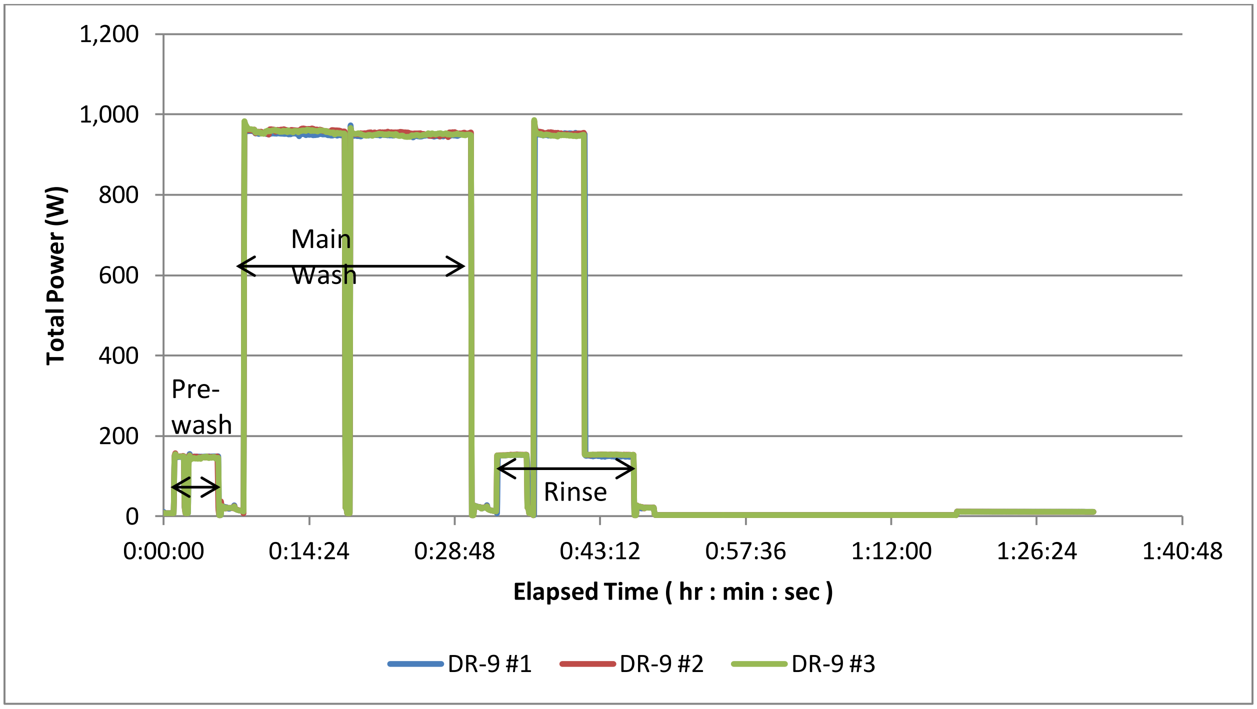

FIGURE 58. DR-9 NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY DISABLED – DEMAND PROFILES FOR ALL ITERATIONS

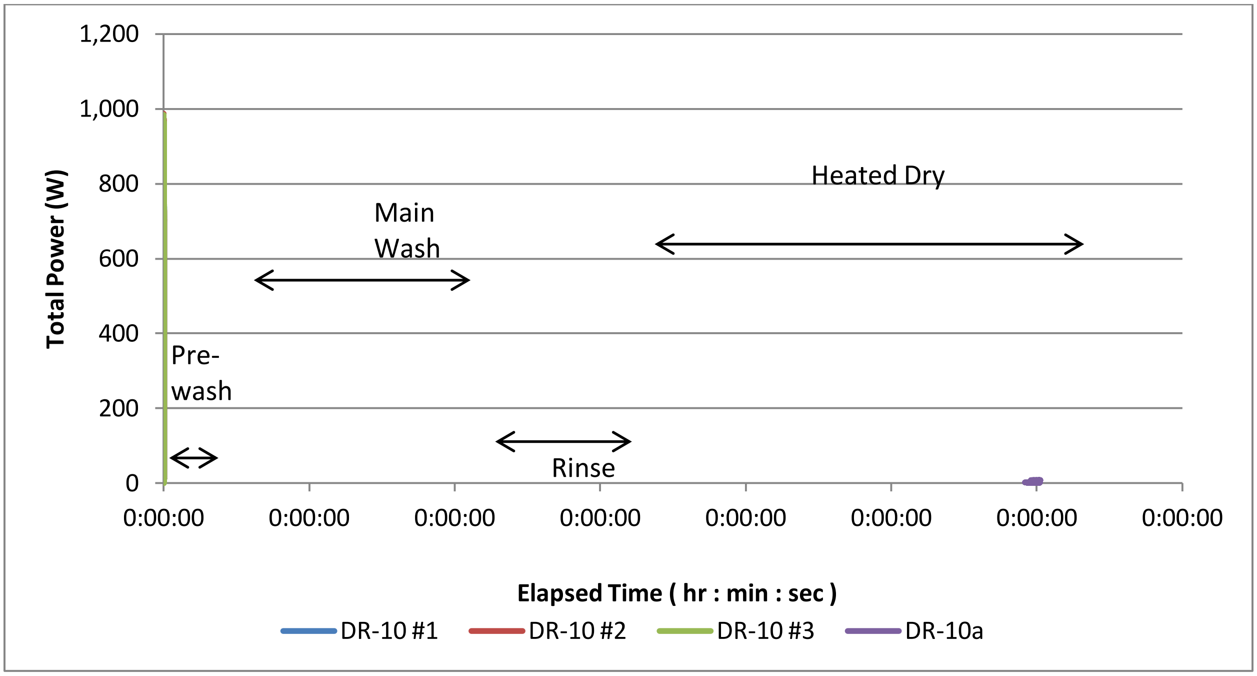

FIGURE 59. DR-10 NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER OFF CYCLE) AND DR-10A NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DELAY (DURING HEATER ON CYCLE) – DEMAND PROFILES FOR ALL ITERATIONS

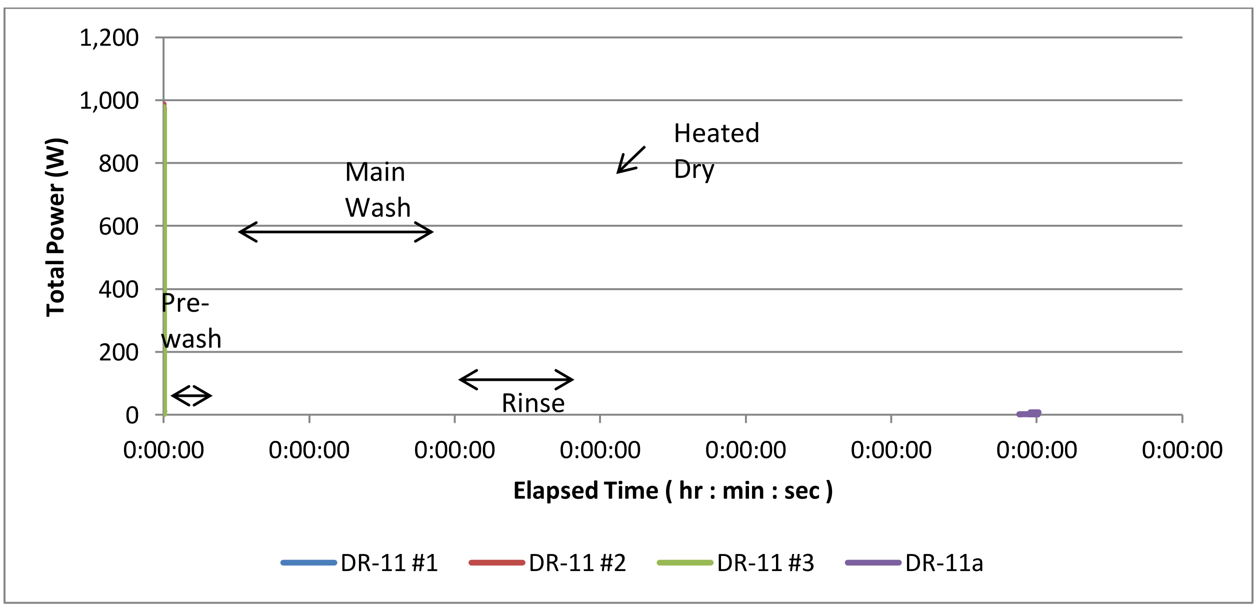

FIGURE 60. DR-11 NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER OFF CYCLE) AND DR-11A (#1) NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT, HEATED DRY INTERRUPT/DISABLED (DURING HEATER ON CYCLE) – DEMAND PROFILES FOR ALL ITERATIONS

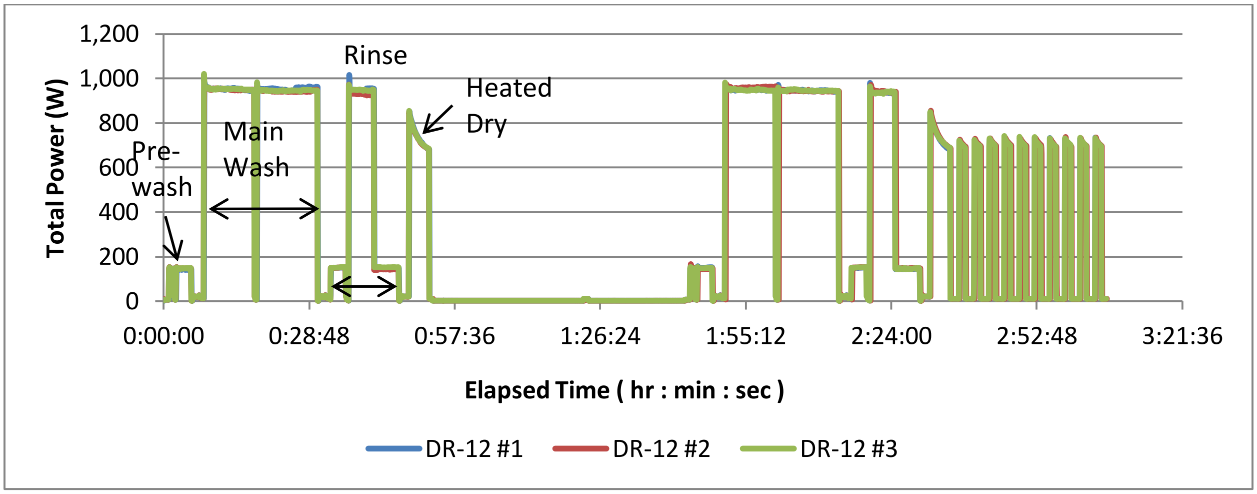

FIGURE 61. DR-12 TWO DISHWASHER OPERATIONS: NORMAL WASH + HEATED DRY, CRITICAL PRICE DR EVENT (DURING 1ST OPERATION, HEATED DRY OFF CYCLE), DELAYED 2ND OPERATION – DEMAND PROFILES FOR ALL ITERATIONS