Design & Engineering Services

Demand Response Potential of Residential Appliances –Clothes Washer (LG)

DR11SCE1.03.02

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SOUTHERN CALIFORNIA EDISON

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Southern California Edison's (SCE's) Design & Engineering Services (DES) group is responsible for this project in collaboration with the Tariff Program & Services (TP&S) group. It was developed as part of SCE's Demand Response, Emerging Markets and Technology program under internal project number DR11SCE1.03.02. DES project manager Scott Mitchell conducted this project with overall guidance and management from Carlos Haiad of DES and Carl Besaw of TP&S. For more information on this project, contact: scott.mitchell@sce.com.

ABBREVIATIONS AND ACRONYMS

AHAM	Association of Home Appliance Manufacturers
CWS	Cold water supply
DAQ	Data acquisition
DOE	US Department of Energy
DR	Demand Response
HAN	Home area network
HWS	Hot water supply
LCD	Liquid crystal display
NI	National Instruments
NIST	National Institute of Standards and Technology
SCE	Southern California Edison
TTC	Technology Test Centers
UUT	Unit under test
W	Watt
Wh	Watt-hour

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EXECUTIVE SUMMARY

This project was created to evaluate performance of a Demand Response (DR) capable clothes washer under various DR event and operational scenarios. Where possible, quantify the DR potential for each test scenario.

This project sought to evaluate DR capabilities of various residential appliances in a laboratory environment. Several manufacturers have recently developed DR-capable appliances, but little is known about how DR capabilities will be implemented. This testing will give Southern California Edison (SCE) a better understanding of how specific appliances will react to certain DR signals before they are installed at customer sites.

The overarching DR Appliance project is aimed at three types of residential appliances: refrigerators, dish washers, and clothes washers. This report is focused on clothes washers manufactured by LG Electronics.

Overall, the clothes washer performed as intended for each of the test scenarios. For Spinning Reserve events (<10 minute duration) it immediately ceased operation until the event cleared, then resumed normal operation (with the exception of the delay in Test G) to complete the cycle. For Delay Load events (>10 minute, <4 hour duration) it allowed any in-progress wash cycles to complete, then delayed any new wash cycles until the event cleared. These operations satisfy the requirements established in the Association of Home Appliance Manufacturers (AHAM) guidelines and were flawlessly executed under test.

Despite the fact that this particular clothes washer performed as expected, there appears to be a disconnect between utility needs during DR events and the AHAM definitions of Spinning Reserve and Delay Load, and what a clothes washer is required to do in response to each type of signal. Further investigation with other appliances and manufacturers, as well as increased engagement with AHAM and standards setting agencies is needed to steer the Smart Appliance requirements in a more utility-friendly direction.

INTRODUCTION

In response to major electrical grid failures over the past few decades, coupled with the emergence of widespread renewable generation and increased awareness of energy efficiency, there has been a growing push for an electric "Smart Grid". The Smart Grid is envisioned to employ vast networks of communicating equipment that will enable much improved visibility and control over how and when we consume energy. While utilities have taken the lead on the smart meter and upstream components of the transmission and distribution system, progress has been slower on the customer side of the meter. In order to fully take advantage of the Smart Grid, energy consumers need access to equipment and appliances that enable communication of rates and grid conditions, and offer some sort of integrated control capabilities to respond to the information received.

In the residential space, a combination of Smart Meters, Home Area Networks with energy supervisory software, and Smart Appliances will be needed to achieve a true Smart Grid. Several appliance manufacturers have begun implementing advanced control features into their products that are specifically focused on energy reduction and the ability to react to adverse grid conditions. Demand Response (DR) is one of the capabilities included in these "Smart Appliances".

Conceptually, DR allows the utility to send a signal to a customer's Smart Meter in response to a critical adverse grid condition requiring a quick reduction in connected load to prevent widespread grid failure. The DR signal is then re-broadcast from the Smart Meter to the HAN or Smart Appliances, which react by reducing load as much as possible. Smart Appliances have algorithms built into them that allow them to determine whether they can respond to the signal while maintaining a minimal level of service to the consumer.

This project seeks to evaluate DR capabilities of various residential appliances in a laboratory environment. Several manufacturers have recently developed DR-capable appliances, but little is known about how DR capabilities will be implemented. This testing will give Southern California Edison (SCE) a better understanding of how specific appliances will react to certain DR signals before they are installed at customer sites.

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BACKGROUND

In 2010, joint petitioners to the US Department of Energy (DOE) (including the Association of Home Appliance Manufacturers (AHAM)) proposed a guideline (AHAM, 2011) for defining "Smart Appliances", which included implementation of DR strategies.

The guideline defines a "Smart Appliance" as:

> *"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 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)."* (AHAM, 2011)

DR EVENT DEFINITIONS

The document breaks DR into 2 specific types of capabilities: Spinning Reserve and Delay Load. They are differentiated by the event duration characteristic that accompanies the DR signal. DR events with duration of 10 minutes or less are categorized as Spinning Reserve while those lasting 10 minutes to 4 hours are categorized as Delay Load. A particular appliance's ability to reduce load depends on the type of signal received as well as its operational status when the signal is received.

As an overarching requirement, the DR capable appliances must still be able to provide consumers the anticipated value of their operation without detrimentally affecting performance. For example, a DR capable clothes washer should still be able to clean the clothes and not damage them by enacting a DR event. Similarly, a refrigerator must maintain safe temperatures even though it is responding to a DR event. In most cases, short interruptions of appliance operation would not affect performance.

CLOTHES WASHER DEFINITIONS

The document further defines minimum requirements for each type of appliance. For clothes washers, it requires:

- *“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*
- *“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 time period by at least 50 percent relative to average wattage during this period in the operating cycle under DOE test conditions.”*

COMMUNICATIONS TESTING

Concurrent with this project, SCE’s Advanced Technologies group conducted testing on the communications capabilities of the LG clothes washer. These tests focused on its 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 washer’s actual response to the event. More information can be found in their project report.

ASSESSMENT OBJECTIVES

The goal of this project is to observe the clothes washer's response to DR signals and quantify the demand reduction that can be expected during different portions of the wash cycle.

The four main objectives for this project are:

- Observe and quantify response when Spinning Reserve DR signal is received during each of the stages of the wash cycle
- Observe and quantify response when Spinning Reserve DR signal is received for various water temperature settings
- Observe and quantify response when Spinning Reserve DR signal is received for various clothing loads
- Observe and quantify response when Delay Load DR signal is received during the wash cycle and in between wash cycles

PRODUCT EVALUATION

LG Electronics supplied a prototype DR-capable clothes washer for testing. The product is based on the commercially available model WT5101HV, with the addition of an LCD user interface, Zigbee® communication hardware, and an integrated smart control system.

At a high level, the DR algorithms programmed into the clothes washer aimed at performing the following tasks:

- For Spinning Reserve events, all washer operations would immediately cease until the event cleared (thus reducing energy by greater than 50% during the DR period, as required by the AHAM guideline).
- For Delay Load events, it would allow any wash cycle in-progress to finish, then delay any subsequent wash cycle until the event had cleared.

The scope of tests would both verify the functionality of these algorithms and provide quantification of the DR potential during various phases of operation. Testing was conducted in a laboratory environment in SCE's Technology Test Centers. This was mainly due to the fact that it enables repeated testing of the appliance using identical loads in controlled environment conditions. Thus, the influence of uncontrolled variables is minimized. Furthermore, existing data acquisition equipment could be utilized with little infrastructure investment.

TECHNICAL APPROACH

Following a series of discussions between LG and SCE, a comprehensive document was compiled to document the control algorithms implemented to meet the Smart Appliance requirements for clothes washers. Subsequently, a test plan was developed to monitor the washer's performance under various baseline operating conditions as well as in response to DR events. The DR test scenarios were geared toward validating the intended operation algorithms rather than being a comprehensive demonstration of ALL potential DR event situations.

TEST PLAN

The test plan was loosely modeled after Appendix J1 of 10 CFR 430 Subpart B, the DOE Uniform Test Method for Measuring the Energy Consumption of Automatic and Semi-Automatic Clothes Washers. However, because the goal here was determining DR potential rather than quantifying energy performance, compliance was limited to instrumentation and general appliance installation and testing practices.

The Unit Under Test (UUT) was installed in TTC's controlled environment room 1. Hot and cold water were supplied and a standpipe configuration was established in a neighboring floor drain.

A set of baseline tests were envisioned to capture data on normal wash cycle based on different clothing fill levels and wash water temperatures (**Error! Reference source not found.**). Test F was designed to activate the UUT's 1,000 W internal heater by creating a need for hot water, but only supplying cold water.

TABLE 1. BASELINE TEST SCENARIOS

SCENARIO	DESCRIPTION	CLOTHING FILL LEVEL	WASH WATER TEMP	RINSE WATER TEMP
A	Baseline A	Full	Cold	Cold
B	Baseline B	Full	Warm	Cold
C	Baseline C	Full	Hot	Cold
D	Baseline D	2/3	Cold	Cold
E	Baseline E	1/3	Cold	Cold
F	Baseline F (no HWS, only CWS)	Full	Hot	Cold

Clothing was replicated using uniform white cotton cloths as shown in **Error! Reference source not found.**. A full load was determined to be 10.6 lbs by completely filling the UUT washtub volume with dry unpacked cloth. The 2/3 and 1/3 loads were 7.1 lbs and 3.5 lbs, respectively. The cloth was dried between tests.

FIGURE 1. UNIFORM TEST CLOTH

The test plan called for water temperature to be maintained at 135±5°F (Hot), 90±5°F (Warm), and 60±5°F (Cold) with water pressure at 35±2.5 psig. The wash settings used were: Material – Cotton/Normal, Soil Level – Normal, Spin – High. While many more settings were available, testing every permutation would have vastly increased the time and effort needed to complete this project. The selected settings are believed to represent the most commonly used settings in normal operation, thus the most probable condition during a real DR event.

A second set of tests was designed to capture the clothes washer's reaction to Spinning Reserve and Delay Load events initiated during various portions of the wash cycle and with various wash conditions (**Error! Reference source not found.**). The corresponding baseline for each DR test is indicated in the table. The Spinning Reserve signal contained a duration code for 8 minutes, while the Delay Load signal duration was 60 minutes. The test period was considered to be the length of the entire wash cycle, except for the Delay Load tests which were focused on verifying functionality of the algorithms. (Delay Load scenarios merely shift the entire wash cycle until the time the DR event clears, thus the actual wash performance is identical to what is seen in baseline Test A.)

TABLE 2. DR TEST SCENARIOS

DESIGNATION	BASELINE	SCENARIO	CLOTHING FILL LEVEL*	WASH WATER TEMP	RINSE WATER TEMP
Spinning Reserve Event (duration = 8 min)					
G	A	DR initiated during fill	Full	Cold	Cold
H	A	DR initiated during wash cycle	Full	Cold	Cold
I	A	DR initiated during drain	Full	Cold	Cold
J	A	DR initiated during rinse	Full	Cold	Cold
K	A	DR initiated during spin	Full	Cold	Cold
L	D	DR initiated during spin	2/3	Cold	Cold
M	E	DR initiated during spin	1/3	Cold	Cold
N	C	DR initiated during fill	Full	Hot	Cold
O	C	DR initiated during rinse	Full	Hot	Cold
S	C	DR initiated during spin	Full	Hot	Cold
R	F	DR initiated during heater on	Full	Hot	Cold
U	A	DR memory test – turn off smart grid function, start wash cycle, initiate DR event, turn on smart grid function	Full	Cold	Cold
Delay Load Event (duration = 60 min)					
P	A	Delay Load event initiated between wash loads	Full	Cold	Cold
Q	A	Delay Load event initiated during wash load	Full	Cold	Cold
T	A	Delay Load event initiated during wash load, attempt to start new load afterward	Full	Cold	Cold

INSTRUMENTATION PLAN

The backbone of the data acquisition system for the test room consisted of LabVIEW software and National Instruments (NI) hardware. The system currently configured has capacity for 288 sensor inputs: 128 thermocouple channels, 64 RTD channels, 64 current channels, and 32 voltage channels.

For this project instrumentation was designed to follow the requirements of the DOE test method, with additional sensors added to enable more focused analysis of the DR-related performance of the UUT. Data was collected every 10 seconds on 26 channels. **Error! Reference source not found.** lists all of the sensor types, monitoring points, and pertinent accuracy information. All sensors were calibrated to NIST-traceable standards prior to installation. Accuracies listed are from sensor manufacturer data and do not necessarily include accuracy of the DAQ system or calibration.

TABLE 3. INSTRUMENTATION

SENSOR TYPE	MAKE/MODEL	ACCURACY (NIST TRACEABLE)	CALIBRATION DATE (LOCATION)	CORRESPONDING KEY MONITORING POINTS
Temperature (type-T special limits grade thermocouples)	Masy Systems, Ultra-Premium Probe	± 0.54 °F	6/2011 (In-house)	• Ambient Temp
Temperature (RTD)	Hy-Cal Engineering Model RTS-37-A-100 Platinum 100Ω	± 0.10% of reading	6/2011 (In-house)	• Cold Water Inlet Temp • Hot Water Inlet Temp
Water Flow Rate Meter	Great Plains Industries, Inc. Model GM 1RSP-2	0.35% of reading	6/2011 (Macnaught Pty, Ltd.)	• Cold Water Flow • Hot Water Flow
Water Pressure	Setra, Inc. Model C207 (0-100 psi)	± 0.13% of full scale	6/2011 (In-house)	• Cold Water Pressure • Hot Water Pressure
Power	HIOKI, Inc. Model 3169-21	± 0.2% of reading	6/2011 (In-house)	• Total Power
Power	HIOKI, Inc. Model 3169-21	± 0.2% of reading	6/2011 (In-house)	• Motor + Pump + Heater Power
Power	Yokogawa/Juxta Model 248951-540-AFR-0-0	± 0.1% of reading ± 0.05% of full scale	6/2011 (In-house)	• Pump Power • Heater Power
Scale*	Sartorius Model CISL1N-U	± 0.1 gram (± 0.0035 ounces)	6/2011 (In-house)	• Clothing Weight

**One-time readings, not connected to data acquisition system.*

Figure 2 shows the complete test rig and monitoring equipment used to conduct this project. The computer in the foreground interfaced with the laboratory smart meter test device to send DR signals. The DR signal was received by a wireless antennae built into the clothes washer. Power monitoring equipment is visible to the left of the meter and ambient conditions were monitored by sensors on the white pole in the center of the picture. Power measurements for the motor could not be measured independently due to physical constraints. In this case, it was measured together with the pump and heater components and separate measurements were subtracted from the combined readings.

FIGURE 2. DR EQUIPMENT AND INSTRUMENTATION

The water supply connections and measurement equipment are detailed in Figure 3. The drainage valve in the hot water line was opened prior to testing to ensure that water temperature was maintained in the proper range.

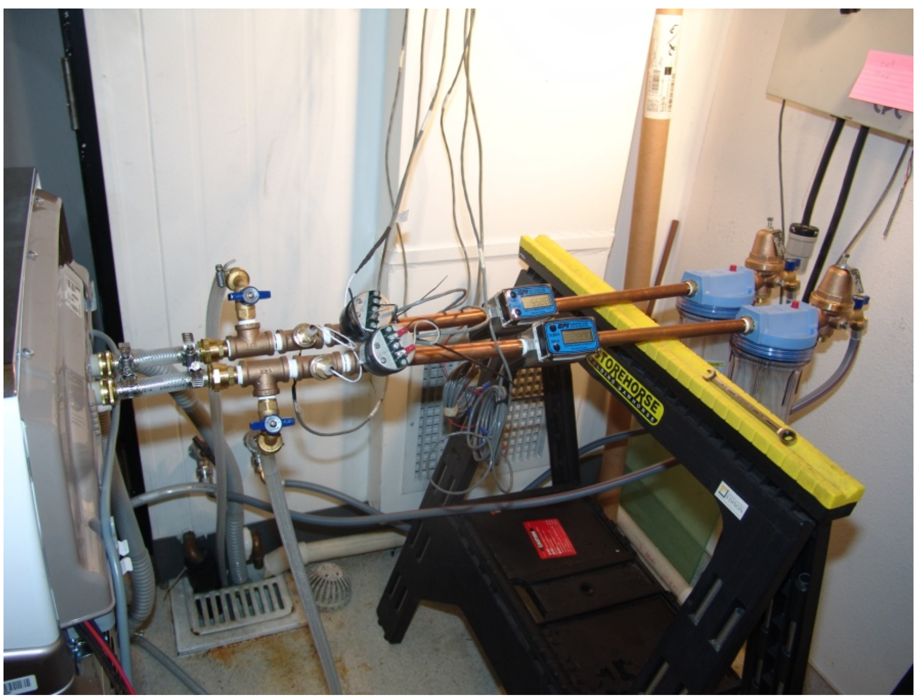

FIGURE 3. WATER SUPPLY AND INSTRUMENTATION

DATA ANALYSIS

The 10-second raw data collected in each test scenario was reduced into 1-minute average values. Data analysis and graphical representations are based on the 1-minute data. Calculations necessary to proceed from raw data to final results are presented in the following sections.

POWER

$$P_{Motor} = P_{Motor+Pump+Heater} - P_{Pump} - P_{Heater} \quad (1)$$

where,

P_{Motor} = motor power, W
$P_{Motor+Pump+Heater}$ = measured combined motor, pump, and heater power, W
P_{Pump} = measured pump power, W
P_{Heater} = measured heater power, W

$$P_{Misc} = P_{Total} - P_{Pump} - P_{Heater} - P_{Motor} \quad (2)$$

where,

P_{Misc} = miscellaneous power, W
P_{Total} = measured total power, W

ENERGY

$$E = \sum_{t=0}^{120} P(t)\left(\frac{1\,hr}{60\,min}\right) \quad (3)$$

where,

E = energy consumed, Wh
P(t) = instantaneous power demand, W
t = time, min

DR POTENTIAL

$$DR = \sum_{t=i}^{i+d} P(t) \quad (4)$$

where,

DR = DR potential, W
P(t) = instantaneous total power demand, W
t = time, min
i = time of DR initiation from start of wash cycle, min
d = duration of DR signal, min
(The DR potential is essentially a moving average calculated at each minute of the wash cycle. See Results section for further discussion.)

RESULTS

BASELINE TESTS

Component-level power consumption profiles for each of the baseline tests are shown in Figures 4 through 9. The colored bars on the top of each Figure give a general relation between power consumption and stages of the wash cycle. The same basic power profile is repeated in all of the test scenarios, with the exception of Test F (Figure 9) where the heater was operating.

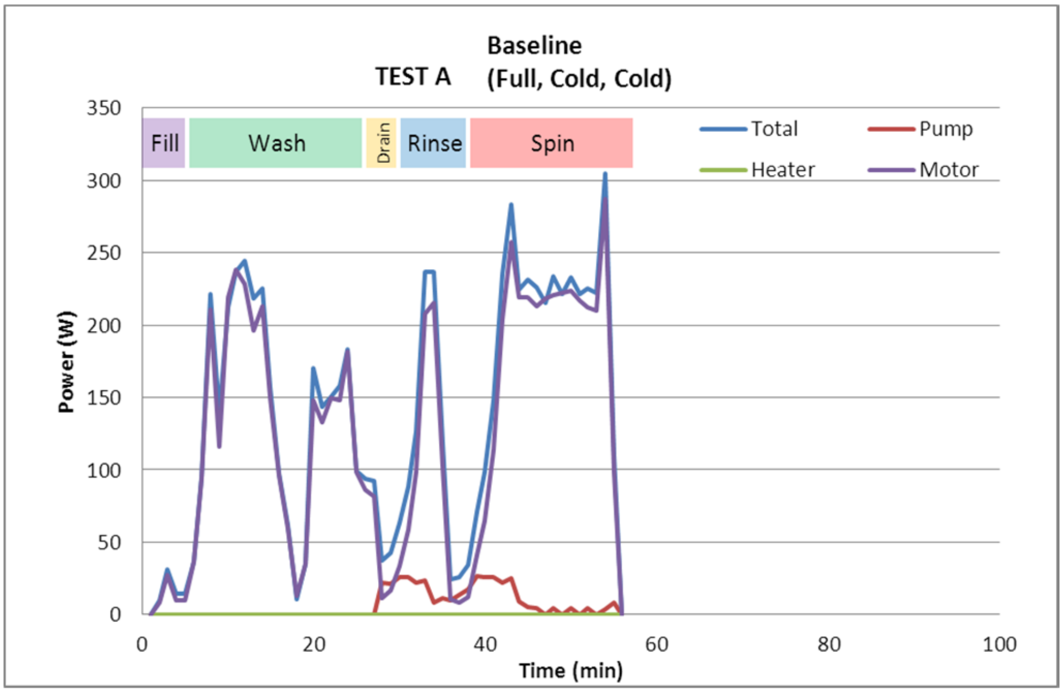

FIGURE 4. BASELINE TEST A POWER PROFILE

Changing the water temperature to warm had minimal impact on the power profile (Test B, Figure 5).

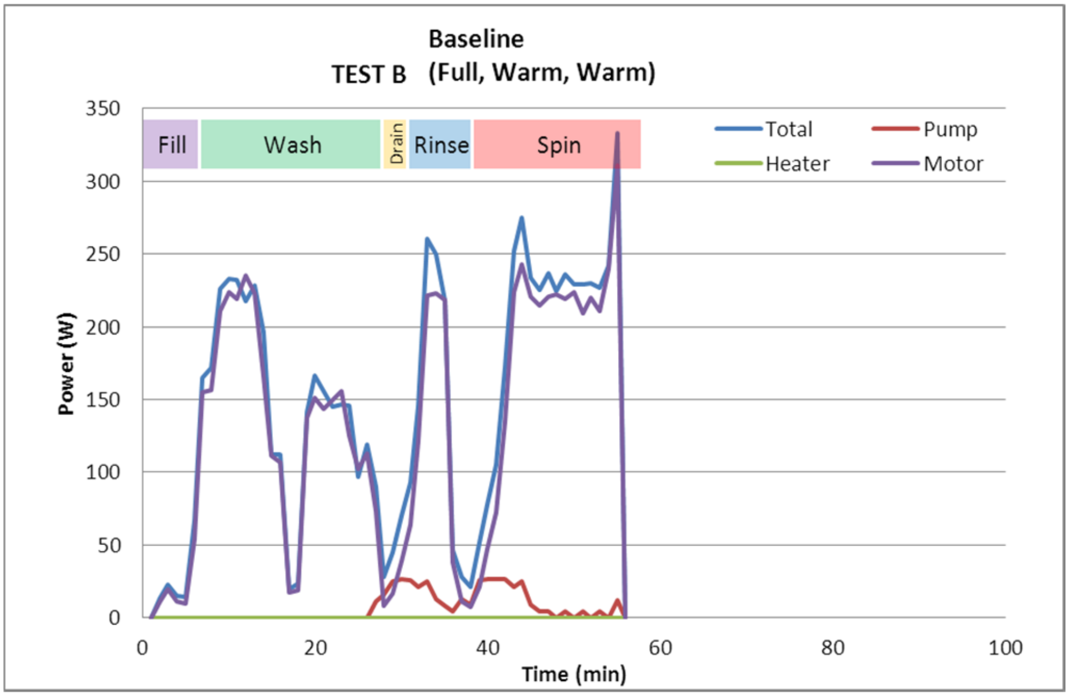

FIGURE 5. BASELINE TEST B POWER PROFILE

However, increasing to hot water (Test C, Figure 6) reduced the first peak by approximately 75 W.

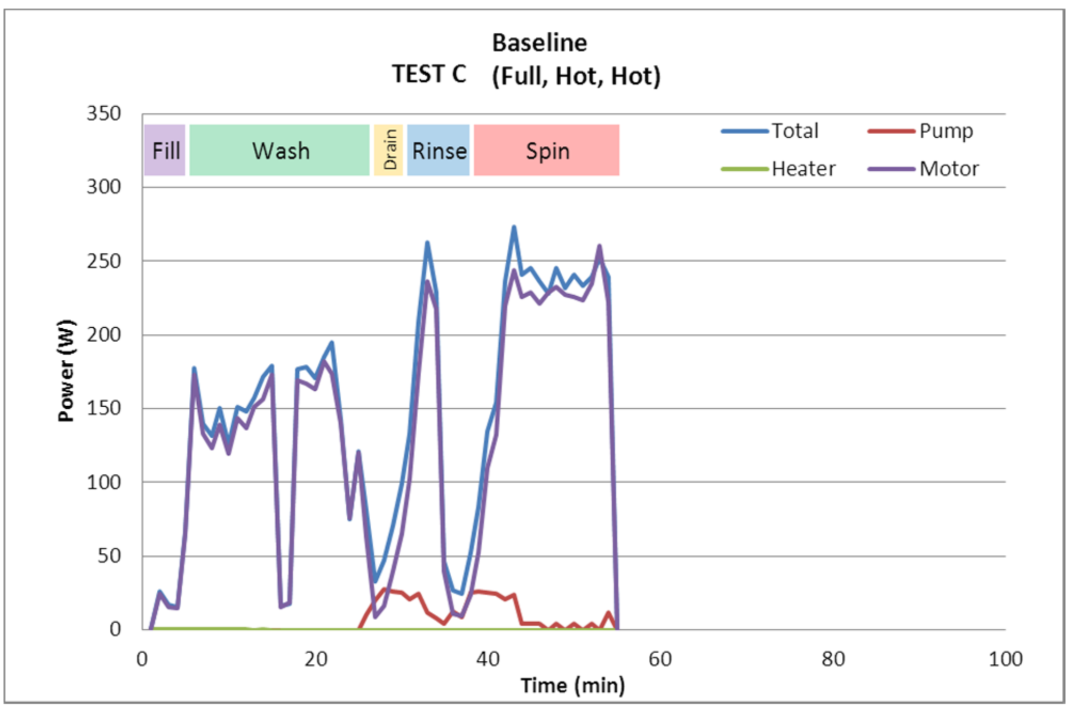

FIGURE 6. BASELINE TEST C POWER PROFILE

Reducing the amount of clothing in the wash bin by one-third resulted in a noticeable decrease in motor power during the fill and wash cycles (Test D, Figure 7)

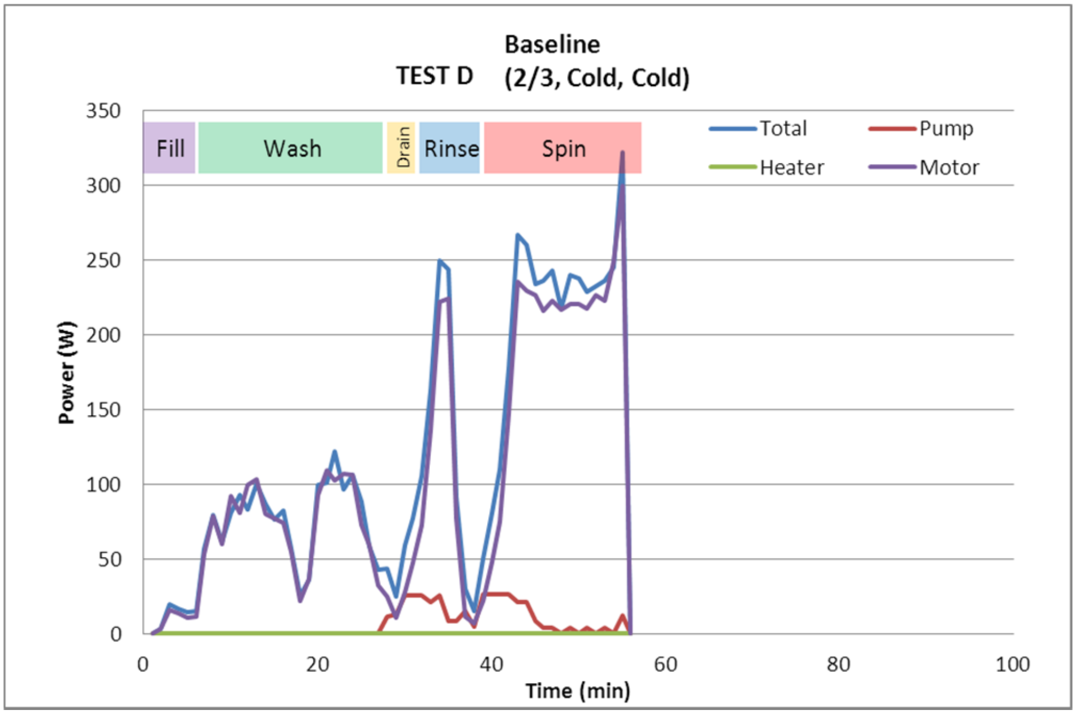

FIGURE 7. BASELINE TEST D POWER PROFILE

Reducing the clothing in the wash bin by an additional one-third resulted in a decrease in motor power during the wash cycle (Test E, Figure 8), but much smaller than was seen in Test D.

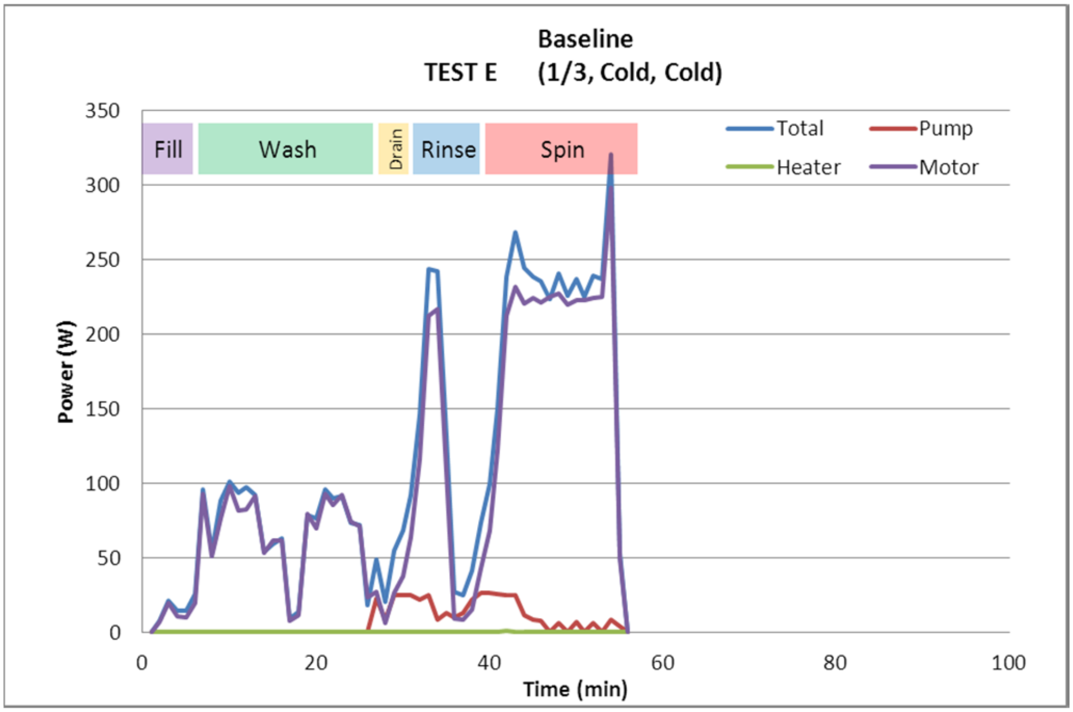

FIGURE 8. BASELINE TEST E POWER PROFILE

During Test F a hot water wash was selected, but only cold water was supplied to the washer. Thus, the internal 1000 W heater activated to bring the water to temperature before the wash cycle started. Figure 9 depicts the power profile for this test, including the three ~10 minute heater cycles at the beginning. This process extended the total wash time to approximately 82 minutes and changed the profile of the remainder of the wash cycle from what is typically seen in Test A.

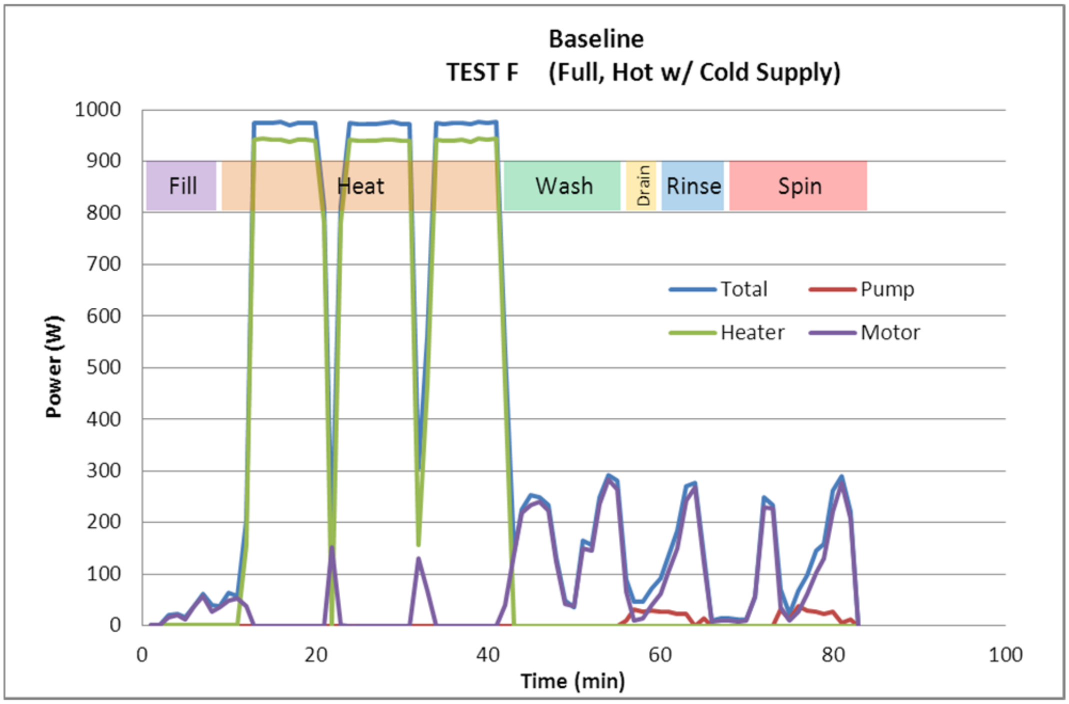

FIGURE 9. BASELINE TEST F POWER PROFILE

While energy consumption of the washer was not a primary focus of this project, it can be useful in understanding how various parameters affect the washer's overall performance. Figure 10 shows the energy consumption for each of the baseline tests. Note the slight energy reduction when clothing material was removed from the washtub (Tests D & E) and the dramatic increase with the heater operating (Test F).

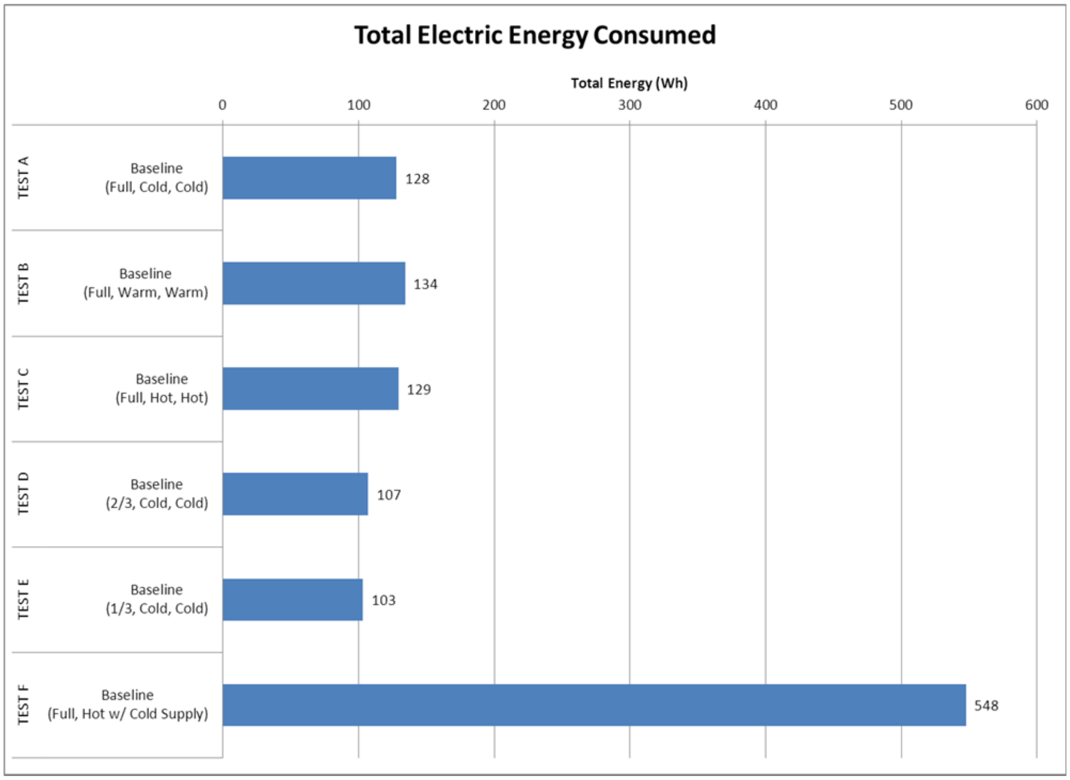

FIGURE 10. BASELINE ENERGY CONSUMPTION

SPINNING RESERVE TESTS

This section gives an estimation of the maximum DR potential for each Baseline scenario then compares each Spinning Reserve test to its corresponding Baseline test. Summary results for each set of tests are contained in the Appendix.

BASELINE A – COLD WASH, FULL LOAD

Figure 11 gives a graphical representation of the DR potential values for Baseline A test scenario. The blue line is the measured total power value from the test period. The DR potential can be calculated in multiple ways, with appropriateness depending on how the data will be used:

The red and green lines are 5 and 10 minute moving averages, respectively, that give the average DR potential for an event of 5 or 10 minute duration which is initiated at that moment during the wash cycle. For example, the point plotted at 20 minutes along the X-axis represents the average power over the length of a DR event initiated at the 20 minute mark and continuing thru the 25th minute or 30th minute depending on which duration is used. This assumes that all power consuming components shut off during the event, as indicated by the manufacturer.

The purple line represents the maximum DR potential (i.e. peak) observed during the following 10 minutes. For example, the point plotted at 20 minutes along the X-axis represents the maximum power observed during a DR event initiated at the 20 minute mark and continuing thru the 30th minute. This also assumes that all power consuming components shut off during the event.

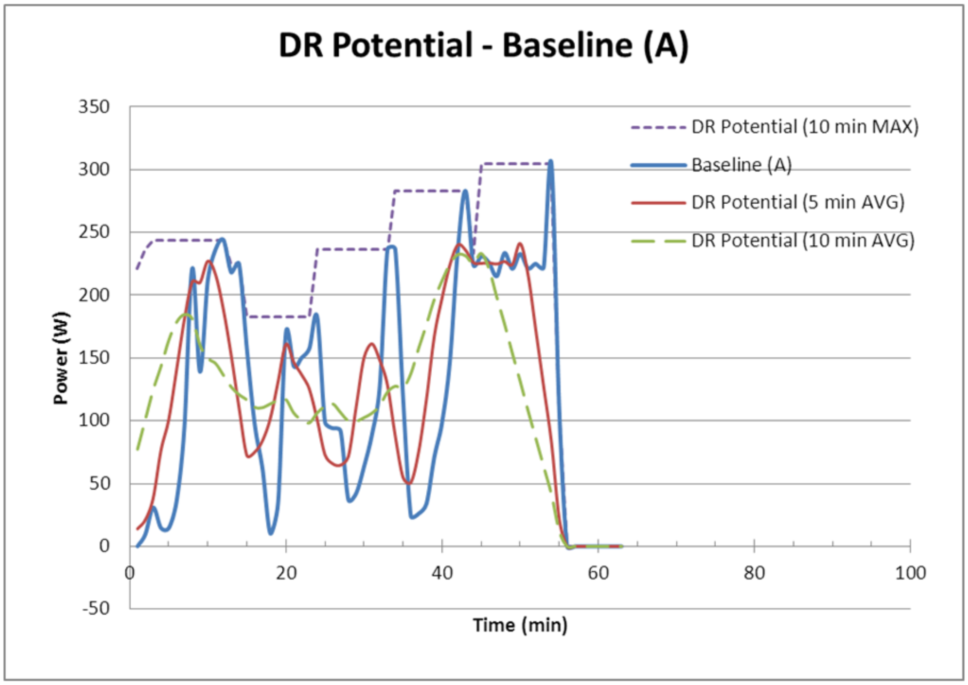

FIGURE 11. DR POTENTIAL – BASELINE A

Figure 12 shows the performance of Test G with the DR event initiated during the fill cycle. The upper pair of lines on the graph is a comparison of power profiles while the lower pair compares cold water flow. Total energy consumption and water use are presented on the right side of the graphs. The "DR" block represents the 8-minute duration DR Spinning Reserve event.

Curiously, for this test an 8-minute DR event caused a 25 minute increase in the overall length of the wash cycle. The washer also used 19 Wh more energy and 6.3 gallons more water over the test period with the DR event. Test G was repeated to ensure this was not an abnormal result, and the same operation was observed.

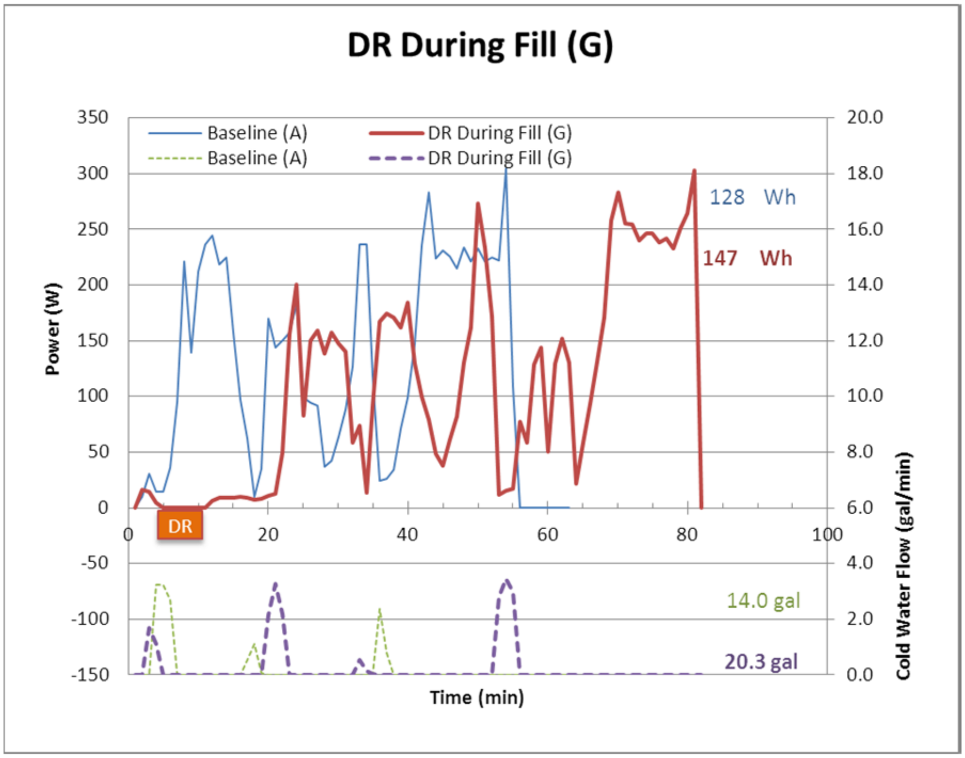

FIGURE 12. POWER AND WATER CONSUMPTION COMPARISON – BASELINE A & TEST G

For the remaining tests, an 8 minute DR event resulted in an approximately 8 minute longer cycle (as expected). Figure 13 shows that initiating an event during the wash phase increased total energy by 9 Wh and water consumption by 0.4 gallons.

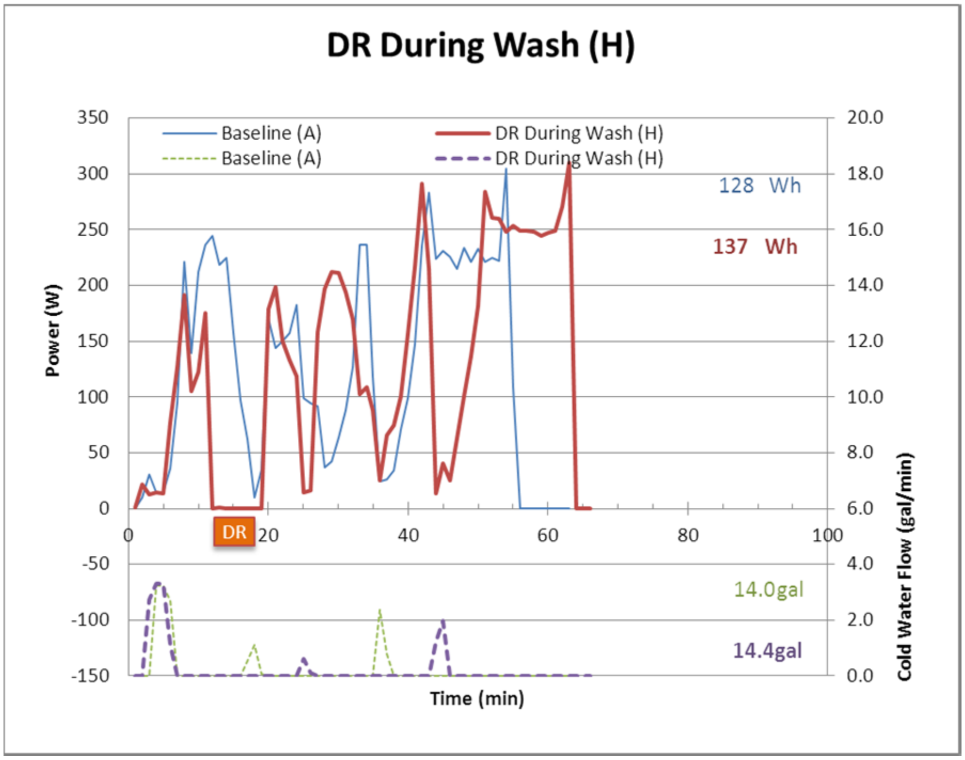

FIGURE 13. POWER AND WATER CONSUMPTION COMPARISON – BASELINE A & TEST H

Initiating a DR event during the drain phase resulted in a 5 Wh energy increase and 0.7 gallon water increase (Figure 14).

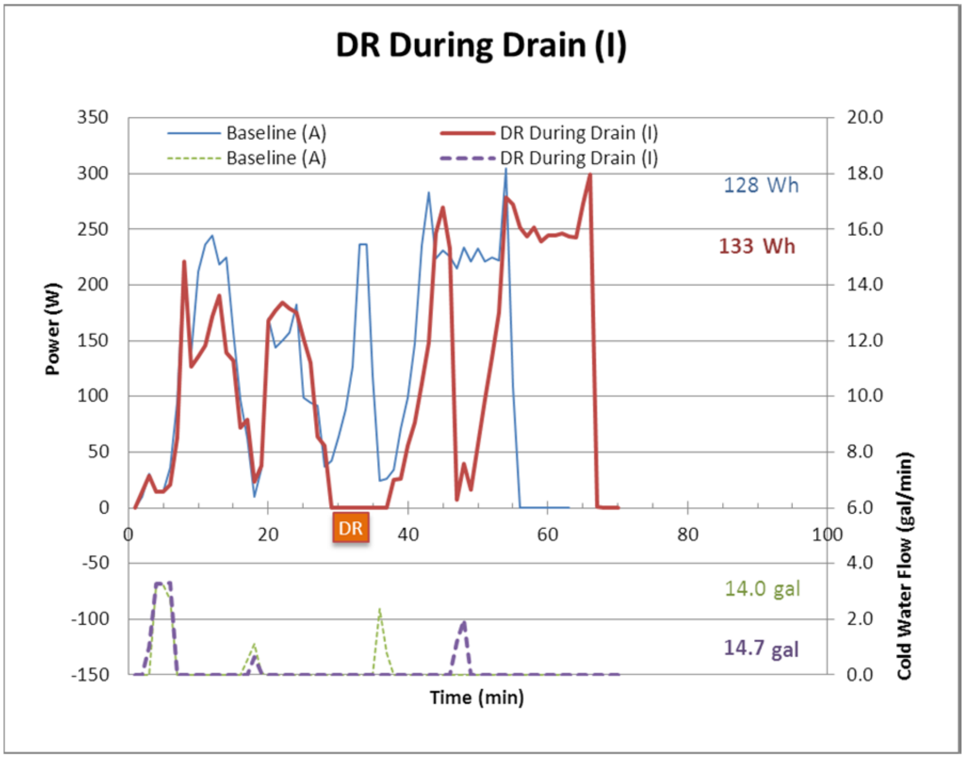

FIGURE 14. POWER AND WATER CONSUMPTION COMPARISON – BASELINE A & TEST I

Initiating the DR event during the rinse phase increased energy by 7 Wh and water by 1.2 gallons (Figure 15).

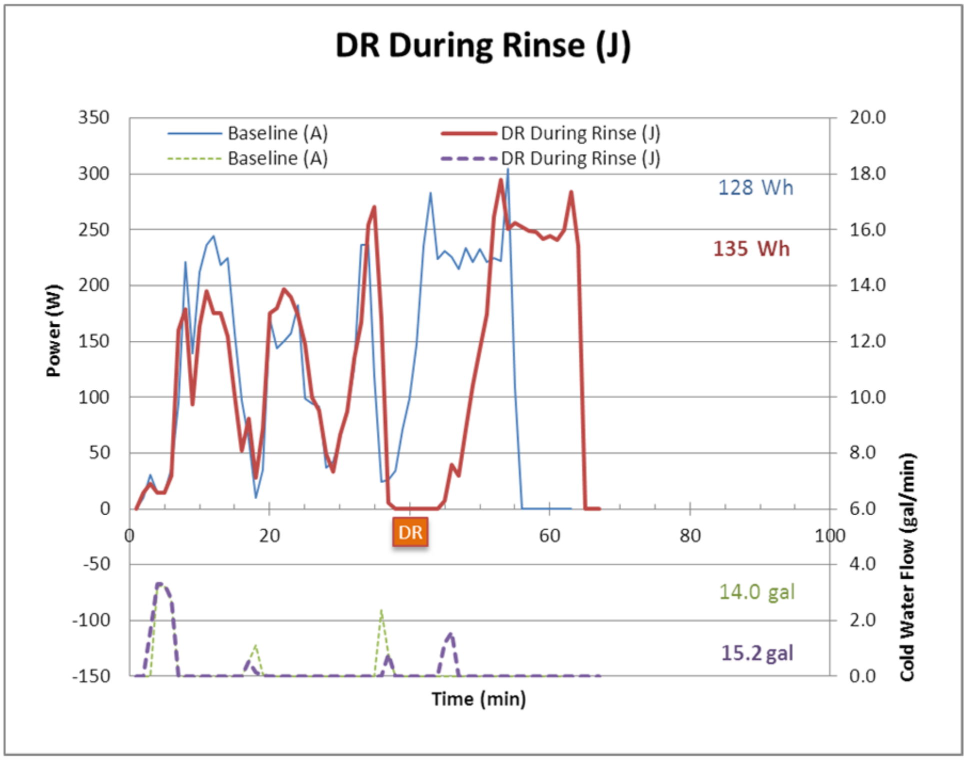

FIGURE 15. POWER AND WATER CONSUMPTION COMPARISON – BASELINE A & TEST J

Similar increases of 5 Wh and 0.9 gallons were observed when the DR event was initiated during the spin phase (Figure 16).

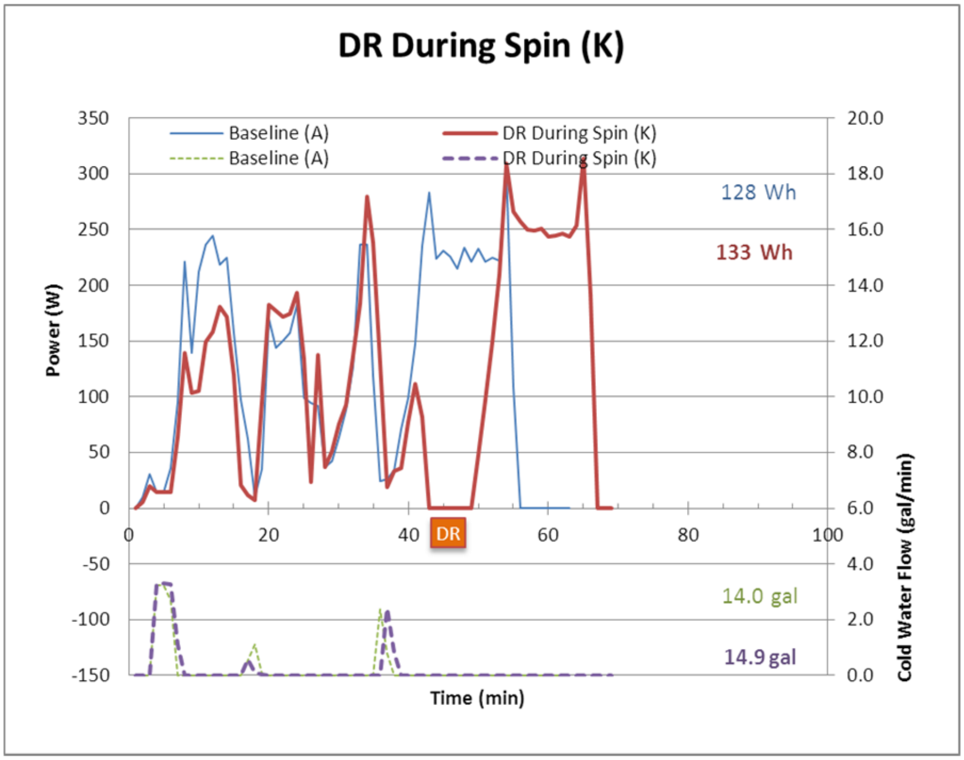

FIGURE 16. POWER AND WATER CONSUMPTION COMPARISON – BASELINE A & TEST K

BASELINE B & C – WARM AND HOT WASH, FULL LOAD

Figure 17 and Figure 18 depict the maximum DR potential of Test B (warm wash) and Test C (hot wash), respectively.

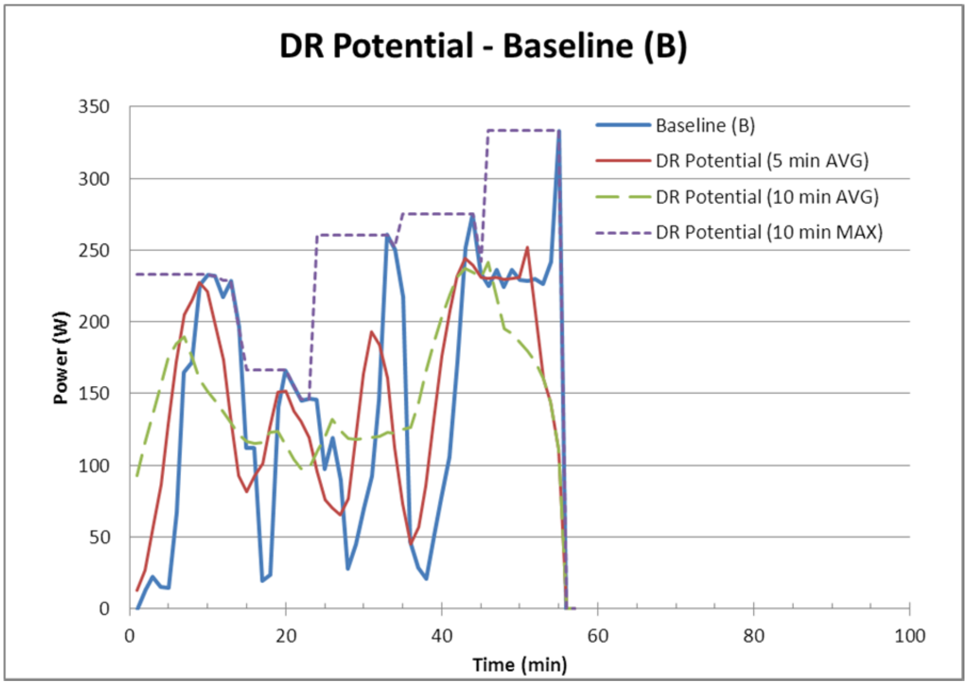

FIGURE 17. DR POTENTIAL – BASELINE B

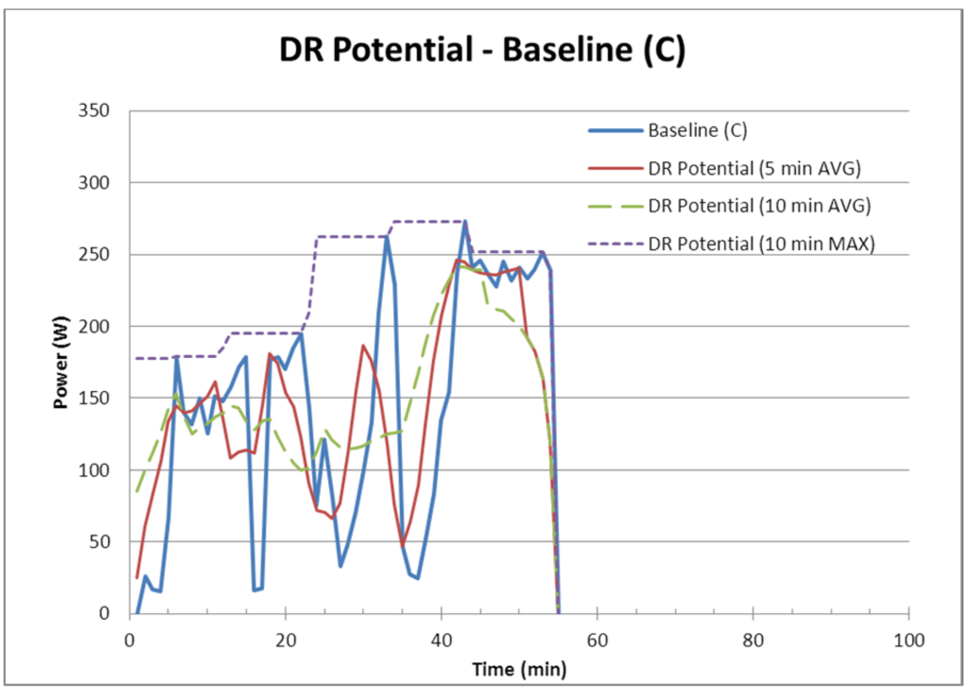

FIGURE 18. DR POTENTIAL – BASELINE C

Figure 19 compares performance during the hot wash cycle Baseline C with the DR during fill Test N. A second pair of lines has been added to represent hot water consumption. The light blue line is represents the Baseline while the orange line represents the DR event. Note that the extended delay observed in Test G was not repeated here. Increases of 5 Wh, 3.9 gallons of cold water, and 1.5 gallons of hot water were measured in the DR scenario.

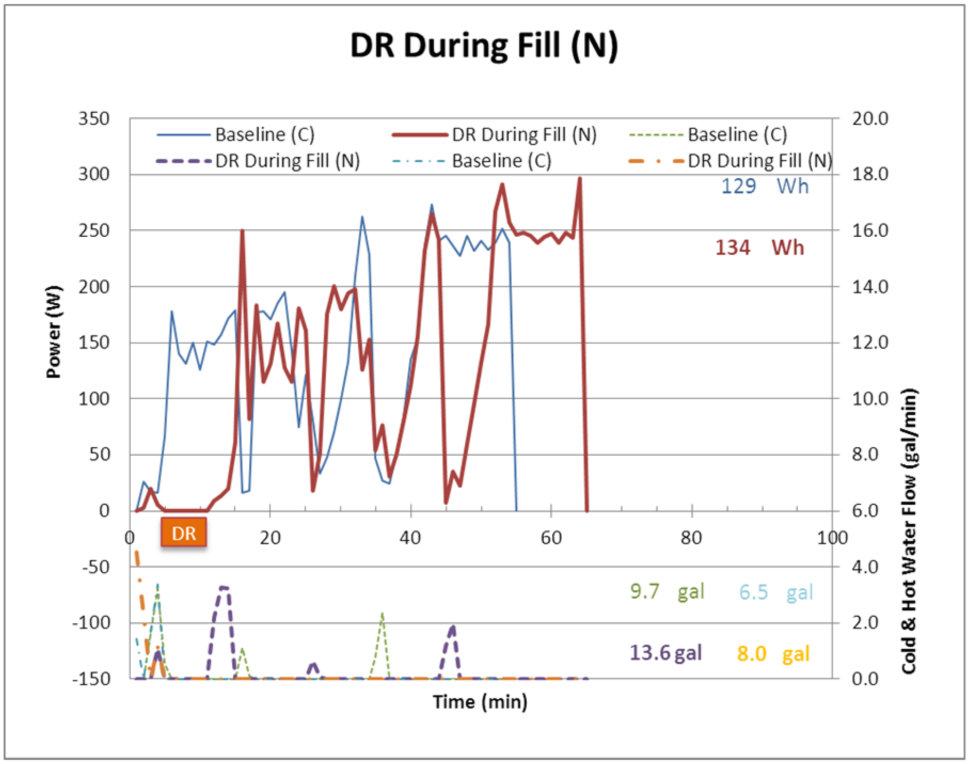

FIGURE 19. POWER AND WATER CONSUMPTION COMPARISON – BASELINE C & TEST N

For a DR event initiated during the rinse phase, increases of 6 Wh, 0.4 gallons of cold water, and 5.3 gallons of hot water were observed (Figure 20).

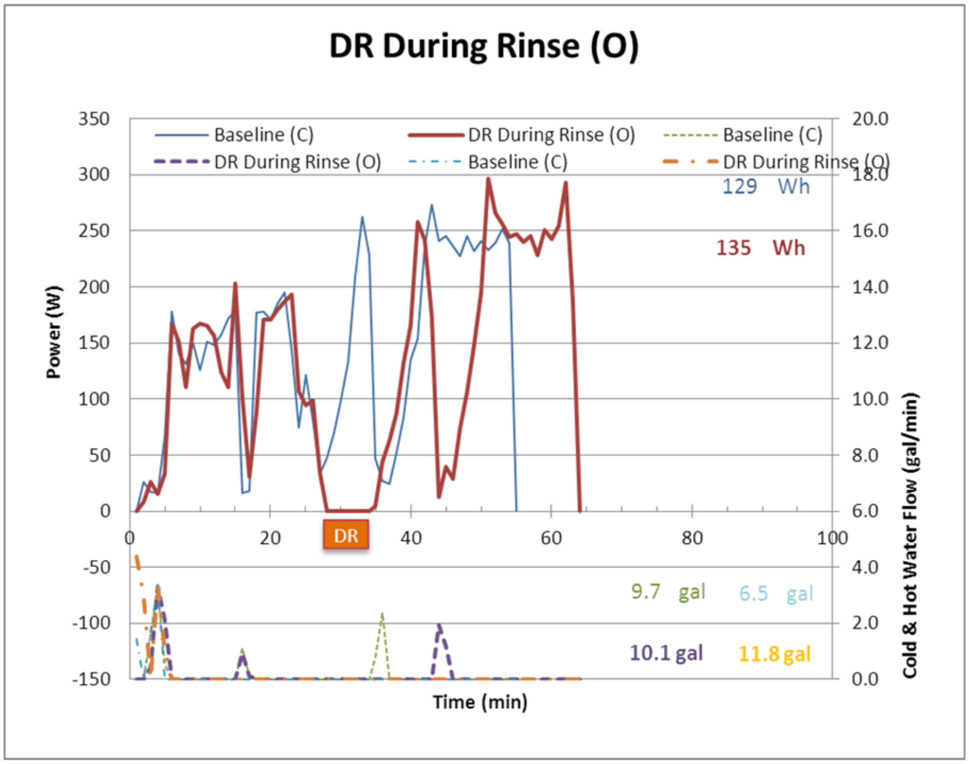

FIGURE 20. POWER AND WATER CONSUMPTION COMPARISON – BASELINE C & TEST O

When the DR event was initated during the spin phase, a reduction of 3 Wh and 0.2 gallons cold water accompanied a 4.9 gallon increase in hot water consumption. As shown in Figure 21.

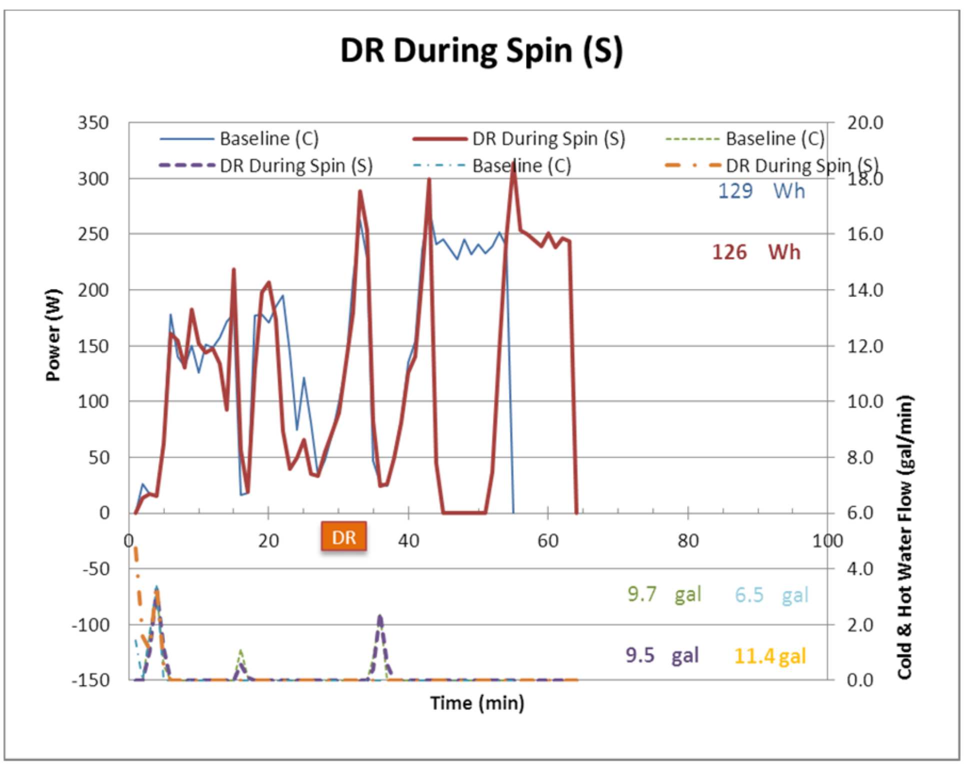

FIGURE 21. POWER AND WATER CONSUMPTION COMPARISON – BASELINE C & TEST S

BASELINE D & E – COLD WASH, 2/3 AND 1/3 FULL LOAD

Figure 22 and Figure 23 depict the maximum DR potential of Test D (2/3 load) and Test E (1/3 load), respectively.

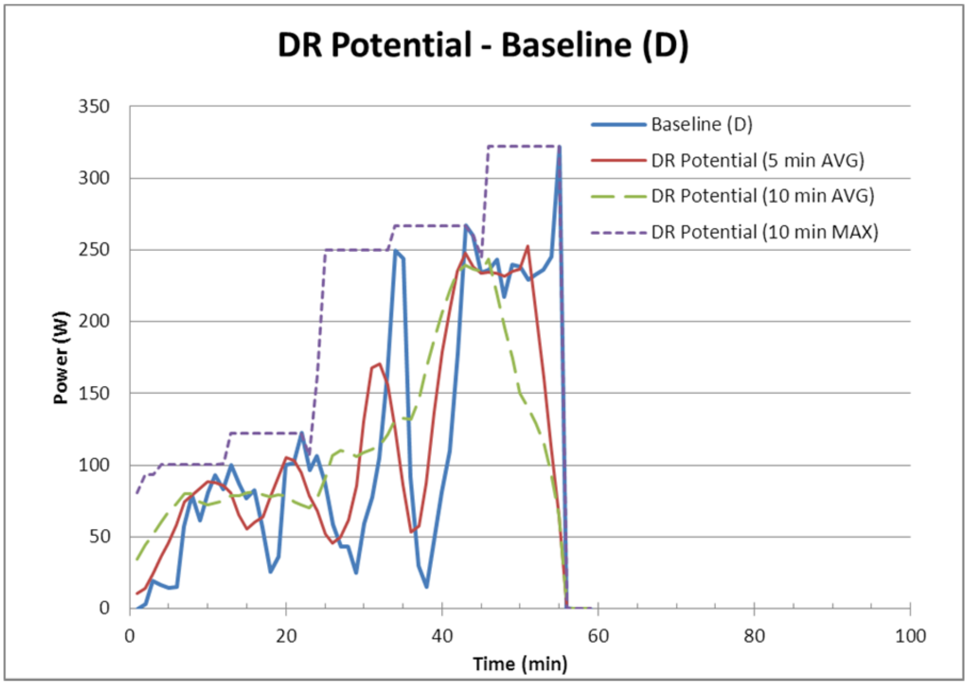

FIGURE 22. DR POTENTIAL – BASELINE D

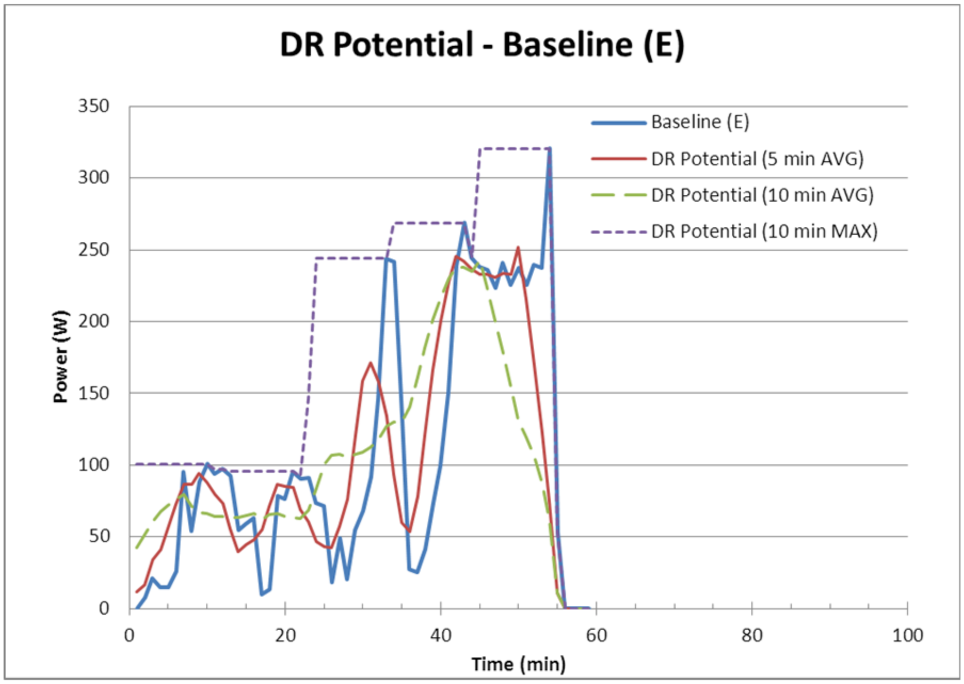

FIGURE 23. DR POTENTIAL – BASELINE E

Figure 24 compares performance during the 2/3 load cycle Baseline D with the DR during spin Test L. An increase of 7 Wh, with no increase in cold water were measured in the DR scenario.

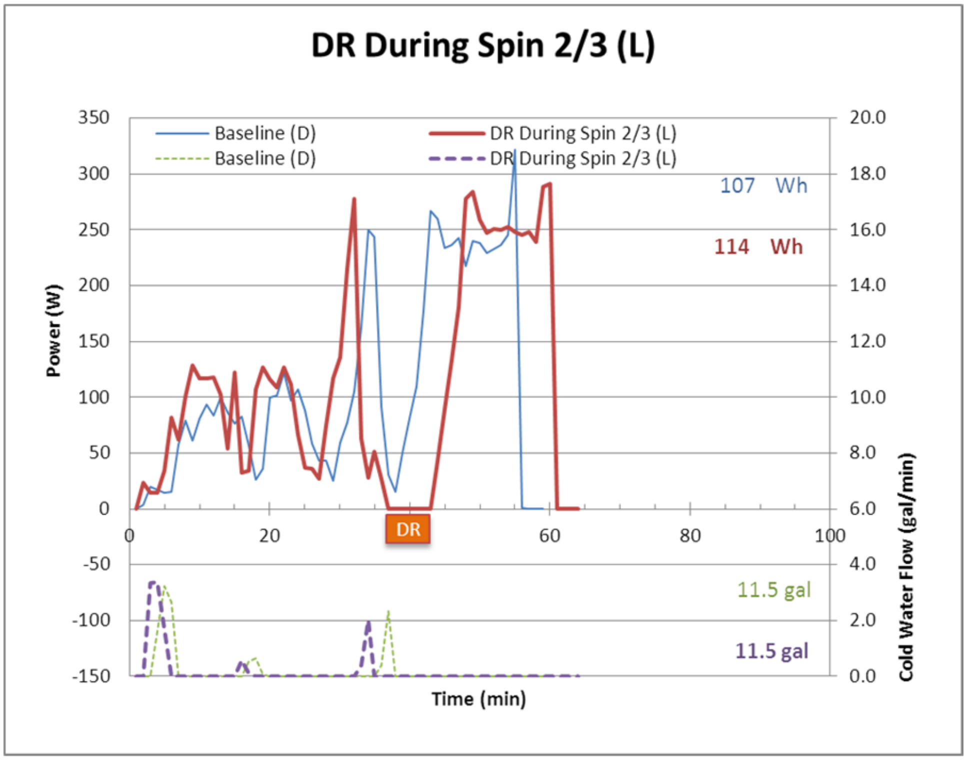

FIGURE 24. POWER AND WATER CONSUMPTION COMPARISON – BASELINE D & TEST L

Figure 25compares performance during the 1/3 load cycle Baseline E with the DR during spin Test M. Increases of 5 Wh and 0.2 gallons of cold water were measured in the DR scenario.

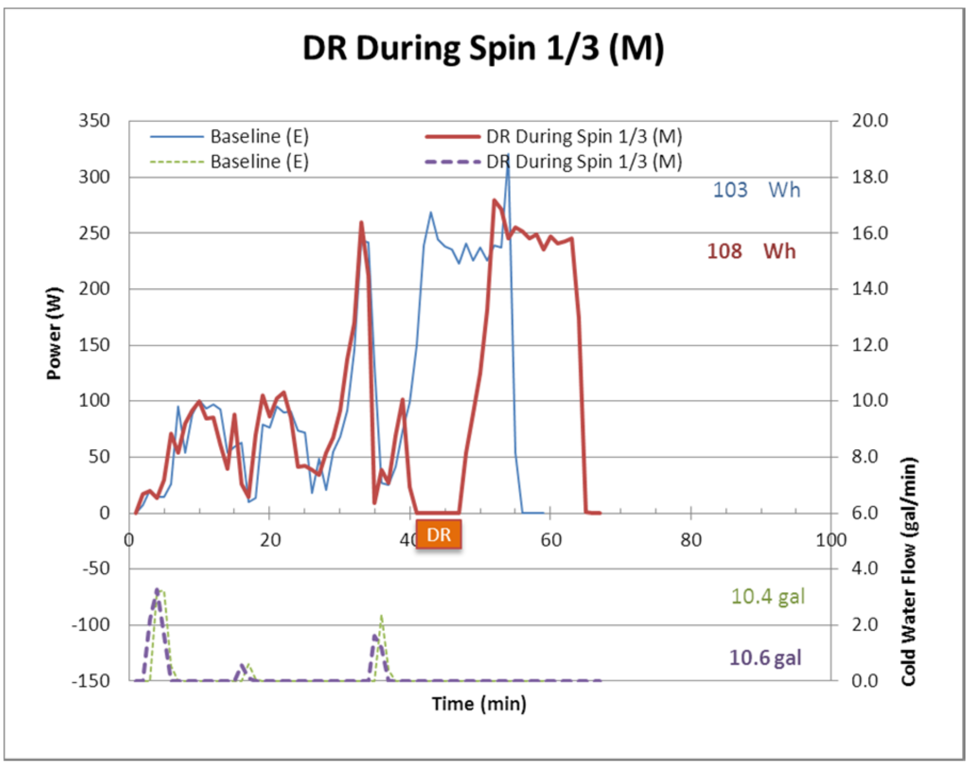

FIGURE 25. POWER AND WATER CONSUMPTION COMPARISON – BASELINE E & TEST M

BASELINE F – INTERNAL WATER HEATER

Figure 26 depicts the maximum DR potential of Test F where a hot wash was called for, but only cold water was supplied to the clothes washer. This was achieved by deactivating the remote water heater. The 1000 W internal heater cycled on for three 10-minute intervals before beginning the wash functions.

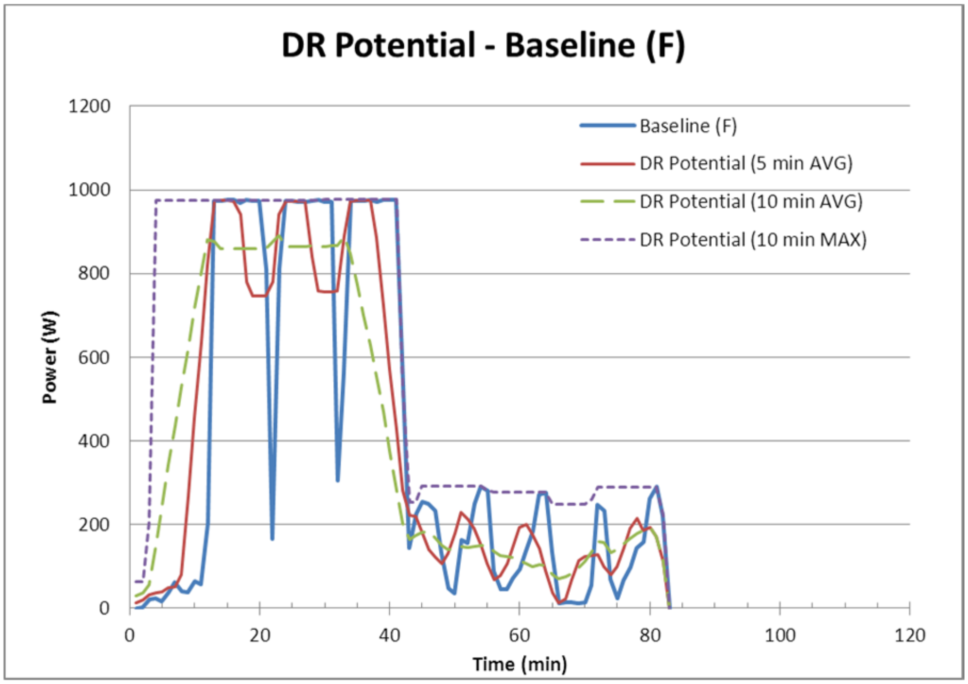

FIGURE 26. DR POTENTIAL – BASELINE F

Figure 27 compares performance during the Baseline F with the DR during heater mode (Test R). Note that the washer drew water through both the hot and cold water supplies even though the remote water heater was deactivated, thus providing cold water. Increases of 5 Wh and 0.2 gallons of cold water were measured in the DR scenario.

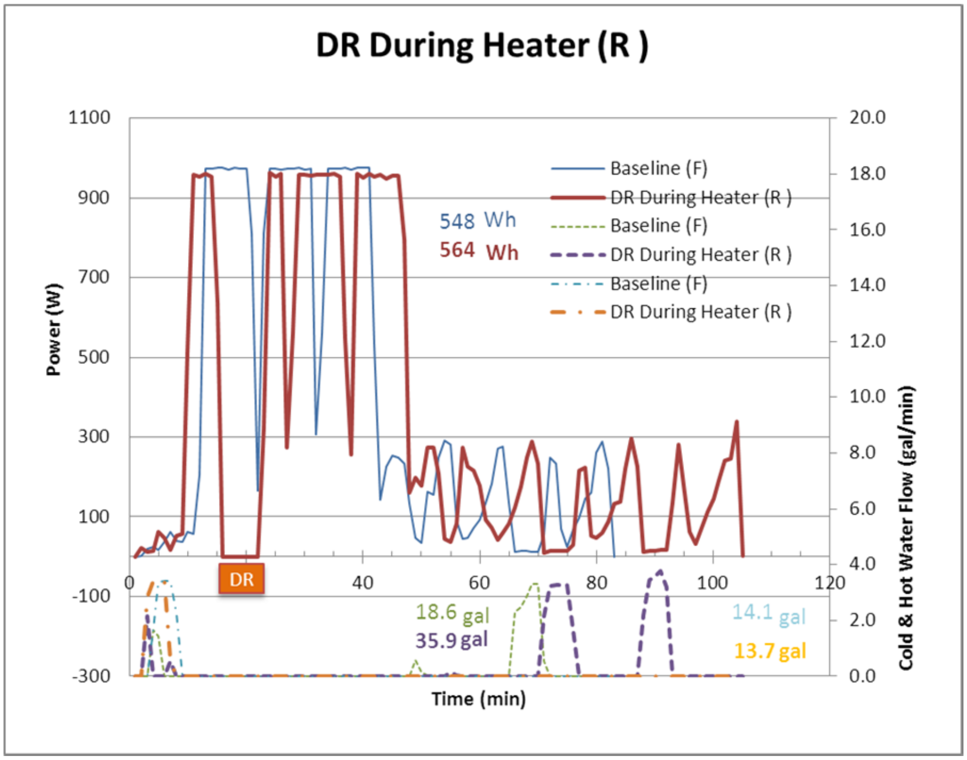

FIGURE 27. POWER AND WATER CONSUMPTION COMPARISON – BASELINE F & TEST R

DELAY LOAD TESTS

The series of Delay Load tests examines the clothes washer's response to DR events lasting longer than 10 minutes. It is envisioned that the majority of DR events called would fall into this category. A signal for a 60-minute duration event was sent at various stages of the wash cycle to observe its response. These tests used a cold wash cycle with full load of clothing (Baseline A).

DELAY LOAD EVENT WHILE IDLE

Test P addressed an event initiated when the clothes washer was already in an off state. **Error! Reference source not found.** gives the time sequence of events used to conduct the test, while the power profile in Figure 28 shows the wash cycle starting after the DR event had cleared. As soon as the event was initiated, a message appeared on the user interface: "*Power consumption in your area is high. The utility has shifted the operation of your selected cycle to a period of lower energy consumption. Estimated time remaining 1:51*." (This is the combined DR event and wash cycle time.)

TABLE 4. TIME SEQUENCE FOR TEST U

MINUTE	ACTION
0	Machine off
1	Initiated a 60 minute duration DR event, message displayed on user interface
2-5	Multiple attempts made to start wash cycle, to no avail
62	Wash cycle started after event cleared

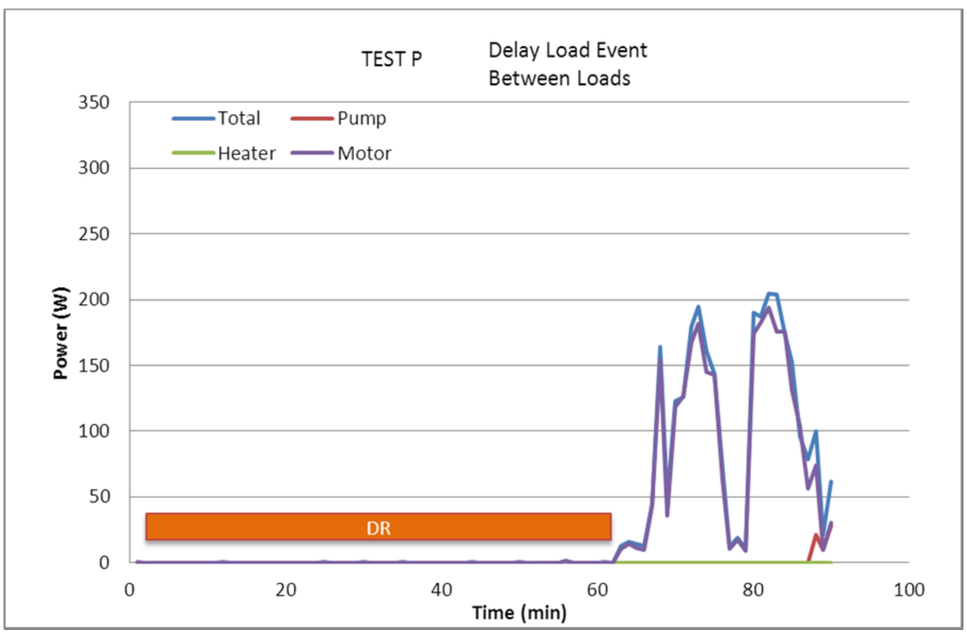

FIGURE 28. TEST P POWER PROFILE

DELAY LOAD EVENT DURING WASH

Test Q addressed an event initiated when the clothes washer was in the middle of a wash cycle. **Error! Reference source not found.** gives the time sequence of events used to conduct the test, while the power profile in Figure 29 shows no effect on the on-going wash cycle when the DR event was initiated. The machine hesitated for a few seconds, but continued normal operation through the end of its cycle. No message was displayed on the user interface.

TABLE 5. TIME SEQUENCE FOR TEST Q

MINUTE	ACTION
1	Wash cycle started
26	Initiated a 60 minute duration DR event, machine hesitated for about 20 seconds, then continued normal operation
58	Wash ycle ended

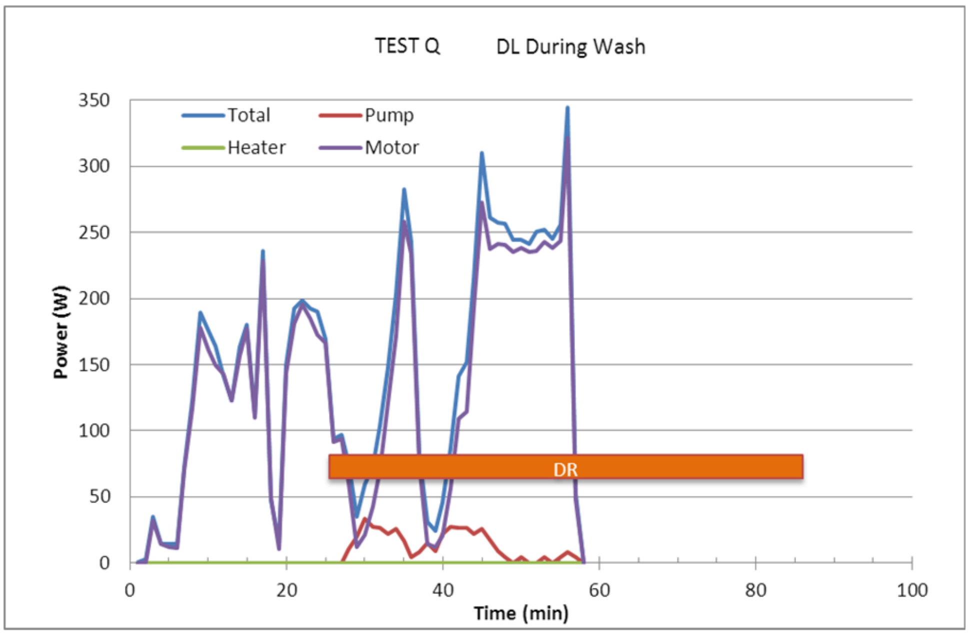

FIGURE 29. TEST Q POWER PROFILE

DELAY LOAD EVENT DURING MULTIPLE WASH LOADS

Similar to Test Q, Test T addressed an event initiated when the clothes washer was in the middle of a wash cycle, with the addition of a second wash cycle attempting to start immediately after the first was complete. **Error! Reference source not found.** gives the time sequence of events used to conduct the test, while the power profile in Figure 30 shows no effect on the on-going wash cycle, but delay of the second cycle until after the DR event had cleared. The machine hesitated for a few seconds when the event was first received, but continued the wash cycle. A message was displayed on the user interface once an attempt to start the second cycle was made.

TABLE 6. TIME SEQUENCE FOR TEST T

MINUTE	ACTION
-26	First wash cycle started (not depicted in Figure 30
1	Initiated a 60 minute duration DR event, machine hesitated for about 20 seconds, then continued normal operation
30	First wash cycle ended
31	Attempted to start second wash cycle, to no avail. Message appeared on user interface.
60	Second wash cycle started

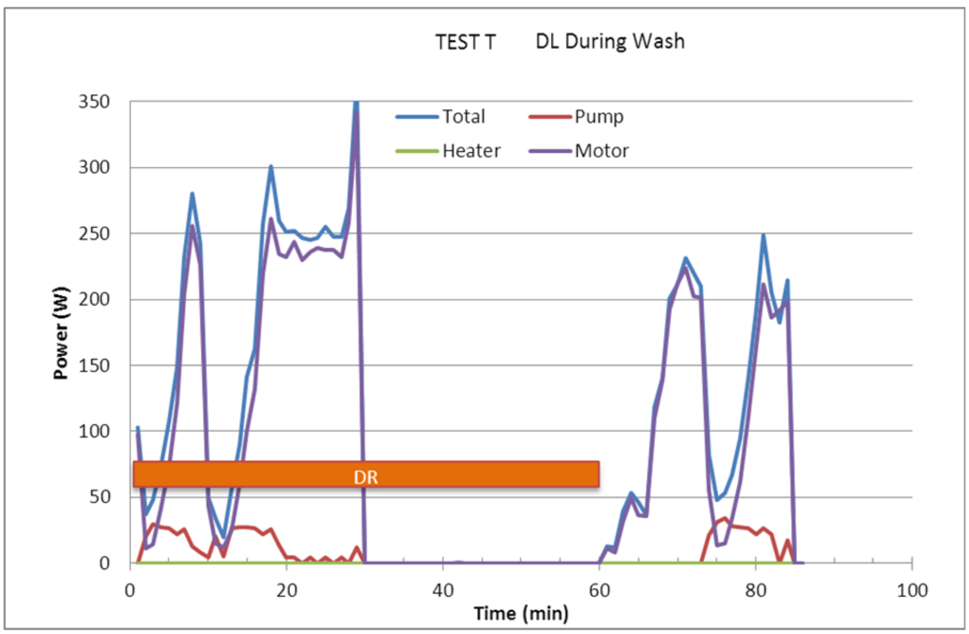

FIGURE 30. TEST T POWER PROFILE

DELAY LOAD EVENT DR POTENTIAL

Quantification of the DR potential for Delay Load events is complicated. It is a function of several variables: state of the machine when the signal is received, time remaining in the on-going wash cycle, duration of the DR event, and the user's desire to start a new load during the event. Because the event does not interrupt wash cycles already in progress, the operation will follow the power profiles observed in Baseline A (or B thru F, depending on the circumstances of the particular load in progress). And the DR potential will only be realized if the user actually tries to start another load during the DR event. Thus, additional modeling using actual usage profiles will be necessary to estimate the a reasonable anticipated demand reduction.

DR MEMORY FUNCTIONALITY TEST

Test U was intended to investigate the ability of the clothes washer to maintain DR events in memory, then later respond to those events when the DR functionality was enabled. Table 7 details the sequence of events.

TABLE 7. TIME SEQUENCE FOR TEST U

MINUTE	ACTION
0	DR functionality turned off through touch screen user interface
4	Wash load initiated
14	Initiated an 8 minute duration DR event
15	DR functionality activated – machine instantly turned off due to DR event in progress
22	Operation resumed

Figure 31 shows the power profile for Test U, including approximately 20 minutes of unusual operation immediately following the DR event. This resulted in a significant increase in the length of the overall wash cycle

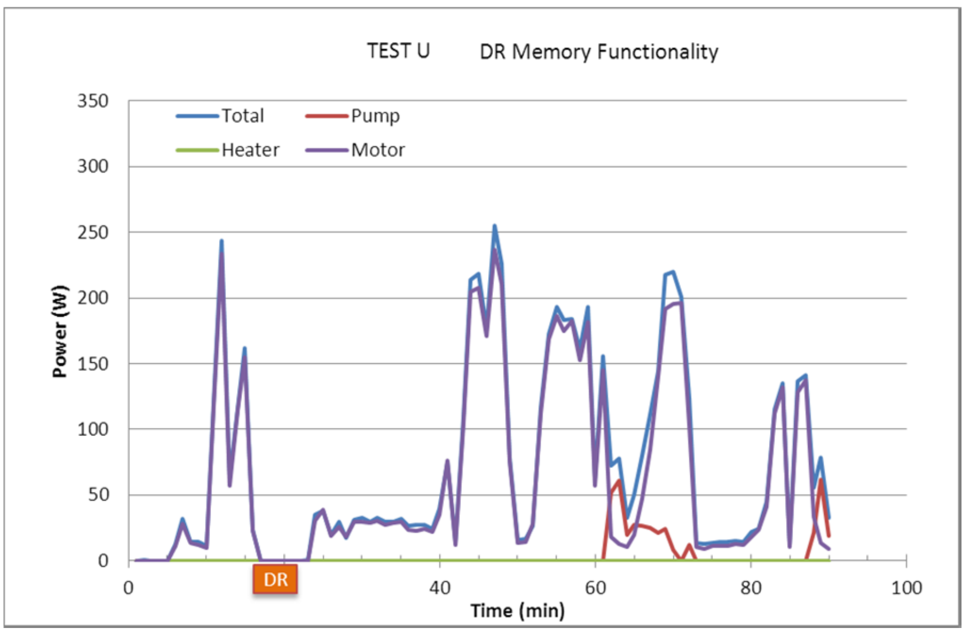

FIGURE 31. TEST U POWER PROFILE

RECOMMENDATIONS

Overall, the clothes washer performed as intended for each of the test scenarios. For Spinning Reserve events it immediately ceased operation until the event cleared, then resumed normal operation (with the exception of the delay in Test G) to complete the cycle. For Delay Load events it allowed any in-progress wash cycles to complete, then delayed any new wash cycles until the event cleared. These operations satisfy the requirements established in the AHAM guidelines and were flawlessly executed under test. However, there appears to be a disconnect between utility needs during DR events and the AHAM definitions of Spinning Reserve and Delay Load, and what a clothes washer is required to do in response to each type of signal.

DR events are typically initiated in response to some sort of isolated catastrophic event on the grid. Whether it is the loss of a high voltage transmission corridor due to excessive wind or an automobile accident taking out a more localized distribution pole, the need for demand reduction on the affected circuits is immediate and the duration may be unknown. In order to get the most beneficial demand reduction, the DR scheme adopted by AHAM forces the utility to choose to either:

1) send a signal for a short Spinning Reserve that will immediately provide reduction for all clothes washers currently operating and hope that the problem is solved before they all come back on in 10 minutes, or

2) send a signal for a longer Delay Load event that will give no immediate reduction but will prevent additional clothes washer load from coming on-line.

Each of these options has advantages and disadvantages, but there will not be time for the grid operator to properly weigh these before sending out the DR signal. It may be several minutes before the cause of an event is known and any estimate of its duration can be made.

It is unclear how this problem may be further impacted by other types of DR capable appliances. Subsequent testing and future increased interaction with AHAM and standards-setting agencies will attempt to address these issues.

APPENDIX

TABLE 8. SUMMARY FOR BASELINE A TESTS

Data Category	TEST A	TEST G	TEST H	TEST I	TEST J	TEST K
	Baseline (Full, Cold, Cold)	DR During Fill (A Baseline)	DR During Wash (A Baseline)	DR During Drain (A Baseline)	DR During Rinse (A Baseline)	DR During Spin (A Baseline)
Test						
Date	7/14/11	12/8/11	10/19/11	12/2/11	10/19/11	10/20/11
Start Time	10:56:06	15:29:07	11:30:09	13:29:09	15:27:09	10:30:08
Power						
Pump Average Power (W)	6.5	4.6	6.4	5.9	6.8	6.9
Pump Max Power (W)	26.2	26.1	33.0	26.0	27.5	33.7
Heater Average Power (W)	0.0	0.0	0.0	0.0	0.0	0.0
Heater Max Power (W)	0.0	0.0	0.0	0.0	0.0	0.0
Motor Average Power (W)	125.0	98.7	114.4	107.1	112.7	106.8
Motor Max Power (W)	287.0	273.4	272.0	277.8	269.5	299.6
Total Average Power (W)	137.2	107.5	128.0	117.2	124.6	119.3
Total Max Power (W)	304.6	302.8	310.4	299.1	294.6	314.1
Total Min Power (W)	0.0	0.0	0.0	0.0	0.0	0.0
Energy						
Pump Energy (Wh)	6	6	7	7	7	8
Heater Energy (Wh)	0	0	0	0	0	0
Motor Energy (Wh)	117	135	122	121	122	119
Total Energy (Wh)	128	147	137	133	135	133
Room						
Average Room Temp (°F)	75.2	75.4	74.9	73.8	74.8	74.8
Water Properties						
Avg Cold Water Temperature (°F)	71.7	70.7	72.4	70.8	72.6	72.3
Avg Cold Water Pressure (psig)	34.6	36.4	34.3	32.9	33.7	33.5
Total Cold Water Flow (gal)	14.0	20.3	14.4	14.7	15.2	14.9
Avg Hot Water Temperature (°F)	75.2	75.0	74.9	74.6	75.0	74.5
Avg Hot Water Pressure (psig)	36.6	38.5	48.3	33.1	46.1	43.2
Total Hot Water Flow (gal)	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 9. SUMMARY FOR BASELINE B & C TESTS

Data Category	TEST B	TEST C	TEST N	TEST O	TEST S
	Baseline (Full, Warm, Warm)	Baseline (Full, Hot, Hot)	DR During Fill (C Baseline)	DR During Rinse (C Baseline)	DR During Spin (C Baseline)
Test					
Date	7/14/11	12/2/11	10/21/11	10/24/11	10/21/11
Start Time	14:22:05	10:29:09	12:53:05	13:33:09	13:59:05
Power					
Pump Average Power (W)	7.0	6.9	6.4	6.4	7.7
Pump Max Power (W)	26.8	27.7	27.7	27.5	28.3
Heater Average Power (W)	0.0	0.0	0.0	0.0	0.0
Heater Max Power (W)	0.0	0.0	0.0	0.0	0.0
Motor Average Power (W)	130.8	128.9	112.9	115.7	103.9
Motor Max Power (W)	311.1	260.6	275.9	282.0	277.9
Total Average Power (W)	143.9	141.1	124.1	126.3	116.5
Total Max Power (W)	333.2	273.0	296.5	296.8	313.4
Total Min Power (W)	0.0	0.0	0.0	0.0	0.0
Energy					
Pump Energy (Wh)	7	6	7	7	8
Heater Energy (Wh)	0	0	0	0	0
Motor Energy (Wh)	122	118	122	123	113
Total Energy (Wh)	134	129	134	135	126
Room					
Average Room Temp (°F)	75.3	73.1	74.8	74.8	74.8
Water Properties					
Avg Cold Water Temperature (°F)	72.6	69.4	73.6	73.3	74.6
Avg Cold Water Pressure (psig)	34.5	33.7	33.9	34.3	34.0
Total Cold Water Flow (gal)	11.9	9.7	13.6	10.1	9.5
Avg Hot Water Temperature (°F)	78.3	106.6	102.1	103.4	102.2
Avg Hot Water Pressure (psig)	50.6	33.6	33.7	32.8	33.3
Total Hot Water Flow (gal)	2.3	6.5	8.0	11.8	11.4

TABLE 10. SUMMARY FOR BASELINE D & E TESTS

Data Category	TEST D	TEST E	TEST L	TEST M
	Baseline (2/3, Cold, Cold)	Baseline (1/3, Cold, Cold)	DR During Spin (D Baseline)	DR During Spin (E Baseline)
Test				
Date	7/14/11	7/13/11	10/20/11	10/20/11
Start Time	8:45:05	13:53:07	14:13:08	15:17:08
Power				
Pump Average Power (W)	6.7	7.2	6.1	7.3
Pump Max Power (W)	26.7	26.4	27.3	35.3
Heater Average Power (W)	0.0	0.0	0.0	0.0
Heater Max Power (W)	0.0	0.7	0.0	0.0
Motor Average Power (W)	103.7	98.7	98.3	87.0
Motor Max Power (W)	299.9	298.4	274.7	243.9
Total Average Power (W)	114.9	110.6	110.2	98.2
Total Max Power (W)	321.9	320.5	291.4	279.5
Total Min Power (W)	0.1	0.0	0.0	0.0
Energy				
Pump Energy (Wh)	6	7	6	8
Heater Energy (Wh)	0	0	0	0
Motor Energy (Wh)	97	92	102	96
Total Energy (Wh)	107	103	114	108
Room				
Average Room Temp (°F)	75.3	75.2	74.9	74.9
Water Properties				
Avg Cold Water Temperature (°F)	71.8	75.2	73.3	74.8
Avg Cold Water Pressure (psig)	34.4	34.3	33.2	31.9
Total Cold Water Flow (gal)	11.5	10.4	11.5	10.6
Avg Hot Water Temperature (°F)	75.0	76.6	76.5	75.2
Avg Hot Water Pressure (psig)	38.1	33.3	44.6	43.1
Total Hot Water Flow (gal)	0.0	0.0	0.0	0.0

TABLE 11. SUMMARY FOR BASELINE F TESTS

Data Category	TEST F Baseline (Full, Hot w/ Cold Supply)	TEST R DR During Heater On (F Baseline)
Test		
Date	10/17/11	10/24/11
Start Time	8:50:03	9:59:09
Power		
Pump Average Power (W)	5.0	6.2
Pump Max Power (W)	36.8	51.2
Heater Average Power (W)	306.1	234.1
Heater Max Power (W)	943.9	928.5
Motor Average Power (W)	69.7	70.0
Motor Max Power (W)	282.3	318.3
Total Average Power (W)	395.9	322.3
Total Max Power (W)	976.7	964.3
Total Min Power (W)	0.0	0.0
Energy		
Pump Energy (Wh)	7	11
Heater Energy (Wh)	423	410
Motor Energy (Wh)	96	123
Total Energy (Wh)	548	564
Room		
Average Room Temp (°F)	75.0	75.0
Water Properties		
Avg Cold Water Temperature (°F)	72.6	72.2
Avg Cold Water Pressure (psig)	36.1	35.2
Total Cold Water Flow (gal)	18.6	35.9
Avg Hot Water Temperature (°F)	73.6	72.9
Avg Hot Water Pressure (psig)	52.2	55.5
Total Hot Water Flow (gal)	14.1	13.7