December 21, 2020

REPORT #20-317

Coming Clean: Revealing Real-World Efficiency of Clothes Washers

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Glossary of Terms and Acronyms

Term/Acronym	Meaning
AHAM	Association of Home Appliance Manufacturers
AHAM Cotton	Association of Home Appliance Manufacturers (AHAM) 100% cotton load of sheets, pillowcases and towels as specified by AHAM HLW-1-2013 and IEC 60456 (2010), Annex C
CCW/CCWs	commercial clothes washer/commercial clothes washers
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CFR	Code of Federal Regulations
CLA	Coin Laundry Association
consumer clothes washer	A consumer product designed to clean clothes, utilizing a water solution of soap and/or detergent and mechanical agitation or other movement. Primarily used in the residential setting and for light commercial purposes.
cu ft	cubic foot or cubic feet
DEF	dryer energy factor
DOE	U.S. Department of Energy
DUF	dryer usage factor
EPA	U.S. Environmental Protection Agency
ESME 2017	ENERGY STAR® Most Efficient qualified residential clothes washers 2017
ESME	ENERGY STAR Most Efficient qualified residential clothes washers 2018 - present
ESRPP	ENERGY STAR Retail Products Platform
ESV8	ENERGY STAR version 8 qualified clothes washer
ESV8 FL	ENERGY STAR version 8 qualified front-load clothes washer
ESV8 TL	ENERGY STAR version 8 qualified top-load clothes washer
FL	front-load clothes washer
IMEF	Integrated Modified Energy Factor
IWF	Integrated Water Factor
J2	U.S. DOE's Appendix J2 for amended test procedure for consumer clothes washers, specified in 10 CFR Part 430, Subpart B
J2 Plus	The supplemental test protocol developed under this research project.
lb	pound or pounds
LUFs	load use factors
MAEDbs	Modernized Appliance Efficiency Database System (for CEC)
MEF-J2	Modified Energy Factor, as measured by the DOE J2 test procedure
NEEA	Northwest Energy Efficiency Alliance
NOPR	Notice of Proposed Rulemaking
NPCC	Northwest Power and Conservation Council
NQ	Consumer clothes washer machines not qualified to ESME or ESV8
OPL	on-premise laundry
RBSA	Residential Building Stock Assessment
RCW/RCWs	residential clothes washer/residential clothes washers
RECS	U.S. Residential Energy Consumption Survey
RFI/RFIs	Request for Information/Requests for Information
RMC	remaining moisture content

Term/Acronym	Meaning
RTF	Regional Technical Forum (Advisory Committee of the NPCC)
RPM	revolutions per minute
TL	top-load clothes washer
TSD	U.S. DOE Technical Support Document
TUFs	temperature use factors
UEC	unit energy consumption
UES	unit energy savings
UUT/UUTs	unit under test/units under test

Acknowledgements

Kannah Consulting thanks NEEA and its stakeholders for the opportunity to conduct this research project in pursuit of better understanding of real-world energy use of clothes washers. In particular, we appreciate guidance and input from:

- Beth Littlehales, Senior Program Manager
- Nick Leritz, Market Transformation Manager, Consumer Products
- Eric Olson, Senior Product Manager
- Louis Starr, P.E., Senior Engineer, Energy Codes and Standards
- Christina Steinhoff, Principal Analyst DPA
- Shilpa Surana, Engineer, Energy Codes and Standards

We also thank the following individuals for providing their technical and industry expertise to the project team:

- Jennifer Light, NPCC's RTF
- Ryan Firestone, RTF contract analyst, SamDiego Consulting LLC
- Greg Brown, CFA, RTF contract analyst, Brolte, LLC
- Lloyd Harrington, Energy Efficient Strategies Pty. Ltd.

Executive Summary

Coming Clean: Revealing Real-World Efficiency of Clothes Washers documents the research effort by the Northwest Energy Efficiency Alliance (NEEA) to improve understanding of the real-world energy efficiency of consumer clothes washers. The project had two key objectives: 1) enable updates to regional unit energy consumption (UEC) and unit energy savings (UES) to reflect real-world conditions better, and 2) develop a supplemental washer test procedure that is more representative than DOE's Appendix J2 test procedure (J2). The research focused on washers' contribution to energy use in the clothes dryer (drying energy), representing the majority of energy included in DOE's Integrated Modified Energy Factor (IMEF) washer metric. The project team tested 12 residential clothes washers (RCWs) and two commercial clothes washers (CCWs) in the lab and conducted other technical research and analysis. Lab testing evaluated how drying energy changed with common conditions found in NEEA's laundry equipment field studies. A literature review and team analysis of NEEA's market data and other publicly available data informed the methodology and conclusions. This effort also informed NEEA's concurrent comments to DOE on RCW and CCW test procedures and standards. Key findings of this research include:

- Drying energy is approximately 1.1 to 1.7 times higher in the real world than the drying energy predicted by J2.
- The increase in drying energy varies significantly by the washer, given differences in water extraction algorithms among machines. This has two effects:
    - Significant rank order changes among machines when alternate drying energy (evaluated with real-world variables) is considered in IMEF in place of the currently prescribed J2 drying energy.
    - Significant uncertainty in UEC calculations when translating J2 drying energy measurements to real-world drying energy estimates.
- Key changes in the test procedure could improve the estimate of real-world drying energy and lower test procedure burden for manufacturers by 8 to 15%. Other test procedure changes recommended herein further improve representativeness and reduce burden by 25 to 45%. These test procedure changes could yield substantial savings for washers, even in the absence of a standards update.
- CCWs present previously untapped savings opportunities in the region given this group has historically been overlooked and readily available technologies can improve CCW efficiency.

Several topics emerge as opportunities for further research. First, more lab testing of both RCWs and CCWs could focus on many areas: 1) increase statistical certainty for UEC estimates, 2) better characterize the untapped savings opportunity for CCW, 3) quantify impacts of different settings on hot water energy use, 4) inform test procedure changes for largest capacity RCWs, and 5) characterize efficiency improvements of specific water extraction technologies that impact drying energy. Second, field studies to update the average use parameters of RCWs and investigate those same parameters in CCWs would enable better UEC estimates and inform future test procedure recommendations. Finally, further study of the CCW category could enable more rigorous quantification of energy use and savings.

1. Introduction

In 2019, the Northwest Energy Efficiency Alliance (NEEA) launched a research project to improve understanding of real-world energy efficiency of consumer clothes washers. This effort directly supports the Northwest Power and Conservation Council's (NPCC) Regional Technical Forum (RTF) Research Strategy for Efficient Clothes Washers (2017).

As defined in the Code of Federal Regulations (CFR), a clothes washer is a consumer product designed to clean clothes, utilizing a water solution of soap and/or detergent and mechanical agitation or other movement, and must be one of the following classes: automatic clothes washers, semi-automatic clothes washers, and other clothes washers. Under Title 10 Chapter II Subchapter D Part 430 Subpart A §430.2 in the CFR, manufacturers have been required to comply with the U.S. Department of Energy (DOE) energy conservation standards for clothes washers since 1988 (2019).

NEEA aimed to quantify just how sensitive DOE's lab testing results are to certain assumptions embedded in its clothes washer test procedure, namely fabric type, load sizes and washer settings. Although the primary focus of this investigation was residential clothes washers (RCWs), NEEA also took the opportunity to include two commercial clothes washers (CCWs) in the test sample to assess performance and also possibly refine RTF energy and savings estimates for this product category.

NEEA contracted Kannah Consulting to conduct a research project with two primary components. The first is a lab test program to isolate and measure the most important variables that affect washer efficiency. Key project outcomes are updates to RCW and CCW unit energy consumption (UEC) estimates. These updates will be used by RTF to develop unit energy savings (UES) formulas for the region, which will enable NEEA and other stakeholders to assess and refine programmatic efforts. The second project component is for technical analysis to develop an alternative clothes washer test protocol that best represents real-world energy use. This protocol is intended to serve and inform incentive program approaches for the region, as well as support NEEA's longer-term efforts on the national level. Already, this research project served to provide timely lab, market and consumer end-use data for comments to DOE in response to current test procedure and standards regulatory activity.

This report documents research efforts and is divided into the following sections:

- **Rationale and Relevant Background** describes the project need and provides an overview of existing research important for context;
- **Methodology** details the project testing and analysis approaches;
- **Results and Key Findings** provides outcomes from the full sample testing runs, UEC estimate calculations, and recommendations for the DOE test procedure to achieve more real-world measurements; and
- **Conclusions** assesses the overall project and identifies additional areas for research.

2. Rationale and Relevant Background

2.1. Project Need

On March 7, 2012, DOE published an amended test procedure for consumer clothes washers, specified in 10 CFR Part 430, Subpart B, Appendix J2 (U.S. DOE 2019), which required manufacturers to use the test procedure starting March 7, 2015. NEEA research suggests this test procedure and related energy savings values most likely do not reflect real-world consumer clothes washer use (NPCC RTF 2017; NEEA et al. 2016; Hannas and Gilman 2014). This concerns stakeholders as DOE lab testing results are widely used in setting standards and energy efficiency program levels, including federal energy conservation standards (CFR 2014 and 2012), U.S. Environmental Protection Agency (EPA) ENERGY STAR® specification levels (U.S. EPA 2020, 2018, 2017a, 2017b), and utility energy efficiency measure qualification criteria, such as Consortium for Energy Efficiency (CEE). Additionally, beginning August 2, 2019, and continuing through to the time of this writing, DOE issued a number of Requests for Information (RFIs) related to both residential and commercial laundry equipment and already one Notice of Proposed Rulemaking (NOPR) for the RCW category. While always intended to support input to DOE for standards and test procedure development, this research project proved very timely for NEEA's efforts within this realm, supporting the Energy Codes and Standards Team in developing comments to DOE with recent, relevant data and analysis (NEEA 2020a, 2020b, 2020c, 2019a and 2019b).

As it relates directly to NEEA and regional stakeholders, RTF UEC and UES values for both RCWs and CCWs are principally derived from lab testing results using the test procedure detailed in DOE's Appendix J2 (J2). Based on this dependency, new research is critical to better understand the energy efficiency of clothes washers in a typical setting. RTF (2017) identified that RCWs represent the greatest cost-effective opportunity for clothes washer energy savings in the region and that is the product category of primary focus for this effort. However, the project team had sufficient reason to believe that RTF values may be low for CCWs (discussed further below in the Literature Review Summary) and testing of even just a few models could provide important data to NEEA, RTF, and other stakeholders.

With the goal to improve the connection between real-world performance and lab tests, the project team first analyzed existing literature on consumer clothes washer efficiency. A summary of the most important considerations related to this project follows.

2.2. Literature Review Summary

2.2.1. Washer Test Procedure Overview

There are several test procedures worldwide used to measure the efficiency of RCWs and CCWs. The most relevant procedures – J2, AHAM HLW-1-2013 (2013) and International Electrotechnical Commission (IEC) 60456 (2010) – focus on testing RCWs but can also be applied to consumer-sized CCW used in multifamily apartment buildings and laundromats. Note, in particular, that there are three different types of load materials employed and various approaches to determining settings, load sizes, and test series. Also, J2 is the only test procedure that does not measure cleaning efficacy; it only measures energy use. Key test procedure attributes are summarized in Table 1 below.

Table 1. Various national and international test procedures for consumer clothes washers.

TEST:	U.S. DOE J2 (2015)[a]	AHAM HLW-1-2013[b]	IEC 60456 (2010)[b]
Purpose	Energy and water use (mandatory in U.S.)	Cleaning efficacy and energy use (voluntary)	Cleaning efficacy and Efficiency (mandatory for some regions outside the U.S.)
Test series	Generally 11 to 26 test runs, but depends on available washer settings	Selectable by user; examples: soil removal, tangle free action test and water retention test	Five test runs per series; various series allowed to test different performance/ efficiency attributes
Load Material	DOE momie or granite weave cloth (50% cotton, 50% polyester)	100% cotton sheets, pillowcases and towels (AHAM Cotton) [c]	100% cotton sheets, pillowcases and towels (AHAM Cotton)[c] or synthetic men's shirts and pillowcases
Textile allowed age	Not more than 60 test runs	Average aged load between 29 and 51 cycles	Average aged load between 30 and 50 cycles for cotton load; Average age of 20 and 60 for synthetic load
Settings	Normal Program	Not specified, selectable	Not specified, selectable
Load Size(s):	Three loads: (1) Minimum (3 lb), (2) Maximum: depends on basket size, usually 10 to 20 lb, and (3) the average of Minimum and Maximum	Determined by manufacturer; various load sizes may be used	Determined by the manufacturer for the program and settings employed; can be sized at rated capacity or part load
Example of entities using protocol	U.S. Government	U.S. Manufacturers	European and Asia-Pacific Countries
Low-power mode measured?	Yes, for RCW only	No	Yes

Notes: [a] The test procedure employed in Canada, CAN/CSA-C360-13 (R2018), is very similar to J2 requirements.
[b] Committees have convened to determine future revisions to these test procedures (AHAM technical committee and IEC TC 59D); revisions expected within the next few years.
[c] The AHAM HLW-1-2013 and IEC 60456 (2010) 100% cotton load material is essentially identical.
General: In addition to the protocols shown, there are also bi-national sustainability standards for clothes washers: AHAM 7003-2016 and CSA R7003-16. Safety requirements and other specifications for industrial washing machines and washer-extractors can be found in ISO 10472-2:1997 and ISO 9398-4:2003. A summary of these standards is not included in this report given the project focus.

2.2.2. The Importance of Drying Energy

DOE establishes RCW efficiency using the Integrated Modified Energy Factor (IMEF), a measure that considers:

- Machine energy – the energy used by the washer during the cycle and while on standby,
- Hot water energy – the energy used to heat the water used during the wash cycle, and

- Drying energy – the energy used to remove the water remaining in the load once in the clothes dryer.

In short, the higher the IMEF, the more energy efficient the clothes washer. For example, the most efficient standard-sized RCWs have an IMEF of approximately 2.1 to 3.1. The least efficient fall between 1.6 and 2.0. Front-load (horizontal axis) washers are generally more efficient than top-load (vertical axis) washers. CCWs utilize a similar metric, Modified Energy Factor (MEF-J2), which is highly similar to IMEF, but does not consider standby energy. The most efficient front-load CCWs have an MEF-J2 of 2.98, and the least efficient (top-load) are 1.35 (U.S. DOE 2020).

Drying energy is a dominant variable in the IMEF equation (NEEA 2019; Richter 2005). U.S. DOE's Technical Support Document (TSD) (2012) confirms that drying energy is the majority of energy use included in IMEF. For the most efficient top loaders (Level 8, TSD Table 7.2.1), drying energy is approximately 65% of total energy calculated in the IMEF. For the most efficient front-loaders (Level 8, TSD Table 7.2.2), the drying energy is 88% of total energy calculated in the IMEF. U.S. DOE Tables are provided in Appendix A for reference. Drying energy dominates CCW MEF also (NEEA 2020c).

KEY FINDING: <u>The research team's calculations and other literature clearly indicate that for the most efficient washers, clothes dryer energy use dominates the efficiency metric and has the biggest impact on efficiency rankings.</u>

Therefore, the primary attribute under study is drying energy and how that energy use is affected by fabric type, settings, and load size. This discovery also expanded the scope for this research project to incorporate limited testing for CCWs, as the project team identified additional data suggesting RTF estimates of CCW energy use may be conservative and represent a greater opportunity for savings than previously thought:

- CCWs likely have shorter cycle times than RCWs, which may lead to higher drying energy.
- Commercial clothes dryer energy use per pound (lb) of textiles may be higher than residential clothes dryer energy use.[1]
- DOE standards and ENERGY STAR specifications differ for CCWs; efficiency levels for CCW are sometimes higher and sometimes lower than RCW (CFR 2014 and 2012; U.S. EPA 2017b).

[1] The research team compared commercial gas dryer efficiency data published by the California Energy Commission (CEC) (Foster Porter and Denkenberger 2016, p.42) to NEEA's residential gas dryer efficiency data (C. Riegler, personal communication, September 5, 2019). The average efficiency of three laundromat-sized commercial dryers (six, four, and 31) revealed an efficiency of 1.9 lb per kWh. The average efficiency of the residential dryers under NEEA's test procedure (Dymond 2017) was 2.2 lb per kWh. Furthermore, the average commercial load size was generally larger (2 lb per cu ft of drum) than the load size of residential (1.6 lb per cu ft of drum). Larger loads produce higher efficiency results. The research team expects that if the machines were tested in the exact same way, the difference in their efficiency (in lb per kWh) is likely to be even larger.

2.2.3. Typical Residential Clothes Washer Field Use

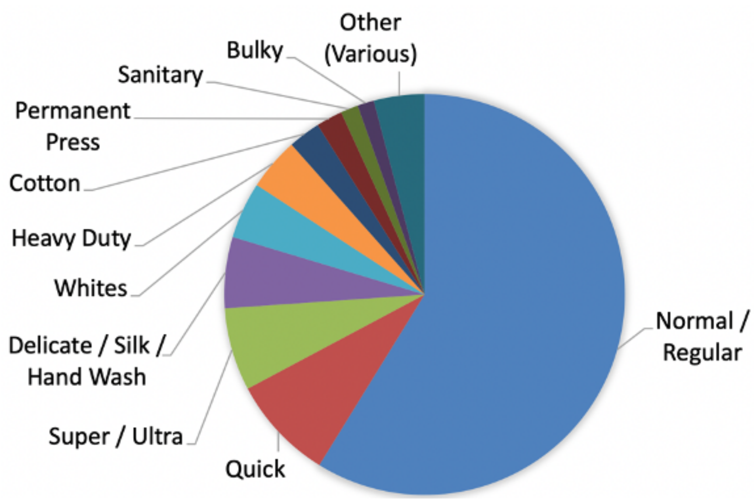
In 2012, NEEA performed a Residential Building Stock Assessment (RBSA) Laundry study and collected detailed laundry usage data from 46 single-family households in the Northwest (Hannas and Gilman 2014). Energy use metering of washers and dryers was combined with detailed participant logs of laundry equipment settings, load weights, and other characteristics. The sample design covered variation in household occupancy and only included households with newer laundry equipment to capture the most recent settings and features available. Given the importance of the field study to this research, key results from that published report are summarized in Table 2 along with relevant values for these parameters currently employed in J2. Note that J2 does not have different textile types, and so Table 2 only reports the RBSA Laundry Study for this parameter.

Table 2. Washer field parameters from RBSA Laundry Study and J2.

Field Parameter	Field Use (percent of all washer cycles)	Source
Wash Temperature	57% Warm 34% Cold 9% Hot	Hannas and Gilman 2014, Table 24, All Loads, p. 78
	49% Warm 37% Cold 14% Hot/Extra hot	J2, Section 4.1.1, Table 4.1.1, Clothes washers with cold rinse only
Load Size	Field average: 7.6 lb 52% Medium (6 to 12 lb) 36% Small (less than 6 lb) 11% Large (12 lb and up)	Hannas and Gilman 2014: Table 1, All Loads; p. 15; Table 22, All Loads, p. 78 *Note:* Load size findings in Dymond 2018 generally agree with those listed here.
	74% Average 14% Minimum (3 lb) 12% Maximum	J2, Section 4.1.3, Table 4.1.3, Automatic water fill control system
Textile Type	60% medium weight 24% light weight 16% heavy weight	Hannas and Gilman 2014, Table 23, All Loads, p. 78

Notes: J2 specifies three load sizes for testing: *Minimum* (3 lb), *Maximum* (scales with the capacity of the washer; current market sizes are up to 24.40 lb), and a middle-sized load called *Average* (the average of the Minimum and Maximum load sizes).

Furthermore, this team aggregated previously unanalyzed raw data from this study to understand the prevalence of RCW program settings. A total of 1456 washer cycles were recorded. Approximately 13% of those cycles had no program recorded by the study participant and are excluded. Analysis of the remainder of the program cycles is shown in Figure 1. Table values are rounded to the nearest whole percent. Programs that represented less than one percent of total cycles in the study were collapsed into "Other." Note that the most prevalent cycle is Normal/Regular, which is the washer program evaluated in J2. Other programs with use more than 3% of the time include Quick, Super/Ultra, Delicate/Silk/Hand Wash, Whites, and Heavy Duty.



Program	Percent of total cycles
Normal/Regular	59%
Quick	8%
Super/Ultra	7%
Delicate/Silk/Hand Wash	6%
Whites	5%
Heavy Duty	4%
Cotton	3%
Permanent Press	2%
Sanitary	1%
Bulky	1%
Other (Various)	4%

Figure 1. Washer program selection as a percent of total wash cycles.

KEY FINDINGS: Normal program, warm wash temperatures, and relatively small loads are the most common conditions of real-world use in the residential setting.

2.2.4. Representation of Typical Load Size of Residential Clothes Washers in J2

J2 specifies three load sizes for testing: *Minimum* (3 lb), *Maximum* (scales with the capacity of the washer; current market sizes are up to 24.40 lb), and a middle-sized load called *Average* (the average of the Minimum and Maximum load sizes). The project team reviewed J2, the RBSA Laundry study data, NEEA's ENERGY STAR Retail Product Portfolio (ESRPP) program data[2] and other international research. From this literature review and data analysis, we concluded that middle-sized loads are most frequently used in RCW in the field; however, DOE's current definition for establishing the J2 *Average* is outdated because it is no longer representative of typical consumer use:

- The range of basket sizes of RCW has dramatically increased in the last decade, skewing the J2 *Average* load calculation adversely. Specifically, in 2010 the market-weighted average basket size was 3.5 cu ft (Mauer et al. 2013) and the corresponding J2-defined *Average* test load calculation was 8.5 lb. At the time this test load was very similar to the NEEA RBSA Laundry Study field average load size of 7.6 lb and considered fairly representative of real-world energy and water use. However, the market-weighted average basket size has increased 25% and is now 4.4 cu ft[3] with a J2-defined *Average* load of 10.4 lb, which is 40% higher than the NEEA-region field average.

[2] ESRPP works to transform consumer product markets with a midstream, retailer-focused strategy. Through it, NEEA has tracked clothes washer market trends in the Northwest since 2015. Information gathered includes product efficiency levels, technological advancements, and region-specific sales data. See https://neea.org/our-work/programs/rpp for more information on ESRPP.

[3] Based on market-weighted average basket size in NEEA's ESRPP program data.

- Remaining Moisture Content (RMC) is measured only with the *Maximum* load size in J2, a relatively uncommon load size in actual consumer RCW use according to RBSA Laundry Study field data.
- NEEA field data suggest that there is not a clear correlation between load size and capacity for RCWs (NEEA et al. 2016). Other international clothes washer field research conducted by clothes washer manufacturers (Electrolux and Fisher & Paykel) and other consumer group research (conducted by Choice[4]) agree that average load size is relatively small (approximately 6.6 lb) and independent of capacity (Australian Department of Climate Change and Energy 2011; Energy Efficient Strategies 2011).

Increased basket size impacts on the *Average* load definition in J2 are discussed further in NEEA's comments to DOE (2020b, 2020c, 2019b) and have also been cited by other stakeholders (ASAP et al. 2020, NEEA et al. 2016).

KEY FINDING: <u>The project team concludes from this literature review that the J2 *Average* load size is no longer representative of typical field load size for RCW.</u>

3. Methodology

3.1. Objectives

To reach the project goal of better understanding real-world energy use of RCWs and CCWs, NEEA and Kannah established four key objectives:

- Objective #1: Identify and isolate important variables observed in NEEA's field studies that have the biggest impact on consumer clothes washer drying energy and are also not currently part of DOE's J2 protocol. The findings from the first objective support the remaining three objectives.
- Objective #2: Provide current technical information to enable updates to regional UEC estimates for RCW and CCW, including the number of commercial cycles per day.
- Objective #3: Develop a supplemental test protocol that more accurately reflects real-world drying energy use of clothes washers, including consideration of fabric types, program settings and load sizes for potential use in future NEEA clothes washer incentive programs and efforts related to U.S. DOE standards and ENERGY STAR specifications.
- Objective #4: Utilize lab, market and consumer end-use data for regulatory and programmatic efforts.

To accomplish the first objective, the research team divided lab testing into three phases: 1) washer sampling plan development, 2) pilot testing, and 3) full sample testing. The project team enlisted an independent ISO 17025 certified laundry equipment test laboratory and together,

[4] Choice is an Australian consumer information organization similar to U.S.-based Consumer Reports. See https://www.choice.com.au.

they developed the following approach to measure differences in consumer clothes washer efficiency under various conditions.

3.2. Washer Sampling Plans

The objective for the RCW sampling plan was to obtain a market-relevant snapshot of top-selling washing machines in NEEA's region (≥ 1000 unit sales in 12 months) that also: a) have not been discontinued and are still readily available in the marketplace, b) represent four categories of efficiency, and c) demonstrate technological diversity.

To that end, the research team analyzed NEEA's ESRPP program data from May 2018 to April 2019 and identified 44 total models that fell into the four key efficiency groups found in the market: ENERGY STAR Most Efficient (ESME), ENERGY STAR version 8 front-load (ESV8 FL), ENERGY STAR version 8 top-load (ESV8 TL) and non-qualifying (NQ). These units represented 51% of sales in that timeframe. Table 3 summarizes the market data collected.

Table 3. RCW ESRPP sample data summary.

Efficiency Level	Load Style	Number of Top-selling Models	Relevant U.S. Environmental Protection Agency (EPA) ENERGY STAR Specification
ESME	Front	n = 9	U.S. EPA 2018[5]
ESV8 FL	Front	n = 5	U.S. EPA 2017b
ESV8 TL	Top	n = 11	U.S. EPA 2017b
NQ	Top	n = 19	U.S. EPA 2017b

Next, the team collected the following information from CEC's Modernized Appliance Efficiency Database System (MAEDbS) (CEC 2019): manufacturer, brand, Integrated Modified Energy Factor (IMEF), Integrated Water Factor (IWF), and RMC. Any units that were the same basic model per the CEC (e.g., color finish was only differentiator) were collapsed under one model. Finally, to increase technological diversity, the team selected top-selling units from each manufacturer within each of the four efficiency groups while giving some prioritization to diversification of reported RMC values, which determine a washer's drying energy (lower RMC is less drying energy). The project team's final selection included a dozen models (n = 12). Table 4 provides a complete summary of each unit under test (UUT) procured for this project, omitting only the manufacturer name and model number. UUTs 01 through 12 are RCWs and UUTs 13 and 14 are CCWs.

[5] ENERGY STAR annually releases ESME criteria; however, no changes related to the efficiency metric have occurred since 2018 but a cleaning metric was added in 2019.

Table 4. Units under test summary.

UUT #[a]	% Market	Efficiency Level	Design	IMEF	RMC	Basket (ft³)	# Program Cycles	Max spin (RPM)	Price (US$)
01	*2.1*	*ESME*	*Front*	*2.92*	*29.4*	*4.4*	*9*	*1300*	*983*
02	1.0	ESME	Front	2.92	27.9	5.2	14	1300	1098
03	0.4	ESME	Front	2.92	28.9	4.5	10	1300	899
04	2.6	ESV8 FL	Front	2.76	28.8	4.5	10	1300	698
05	2.5	ESV8 FL	Front	2.80	30.8	4.2	8	1300	628
06	0.5	ESV8 FL	Front	2.76	29.8	4.3	5	1100	597
07	2.5	ESV8 TL	Impeller	2.06	36.5	5.3	11	850	999
08	*1.8*	*ESV8 TL*	*Impeller*	*2.06*	*40.0*	*5.2*	*10*	*800*	*699*
09	1.1	ESV8 TL	Impeller	2.38	29.9	5.2	14	950	1124
10	*5.3*	*NQ*	*Agitator*	*1.57*	*44.4*	*3.5*	*8*	*700*	*398*
11	2.8	NQ	Agitator	1.57	34.9	5.2	5	850	899
12	0.6	NQ	Impeller	1.57	38.1	4.5	8	700	629
13	NA	NQ	Agitator	1.35	48%	3.19	3	710	1139
14	NA	ESV8[b]	Front	2.2	36%	3.1	3	NA	1954

Notes: *Italicized* UUTs in shaded rows are models used for the pilot testing phase.
[a]UUTs 1 – 12 are RCWs, 13 and 14 are CCWs.
[b]Qualified to ENERGY STAR (version 8) commercial washer specification (U.S. EPA 2017b)
RMC = Remaining moisture content as reported in the CEC MAEDbS
RPM= Revolutions per minute

In total, the 12 selected RCW models represented 21% of 12-month sales and included six front loaders and six top loaders from five manufacturers: Samsung, LG, Electrolux, GE, and Whirlpool. There are a range of basket volumes (3.5 to 5.3 cu ft), as well as setting options relevant to drying energy: variable spin speed, spray/deep rinse, and various program cycle options. Prices started at $400 and topped at $1100. This sampling plan has both advantages and disadvantages.

The most significant benefit is that the three units in each group maximize confidence in UEC estimates for RTF. Furthermore, this selection represents a significant portion of market sales, covers a range of prices and includes diversity of manufacturers and washer technologies. The primary limitation is that it does not allow the project team to fully examine the impact of basket size on efficiency (the sample does not include the smallest or the largest baskets available in the "standard" category), which could be an important issue to the test procedure and standards. Nevertheless, it maximizes the range of energy efficiency in the top-selling market to reveal as much as possible about the array of efficiency levels and technologies.

The CCW sample plan followed a slightly different methodology primarily because the same type of ESRPP sales data are not collected for this product category and the sample size is much smaller (n = 2). The selected CCWs are generally considered residential-sized commercial machines. We identified two units—one NQ top-loader and one ENERGY STAR qualified front-loader—to provide some information about two different levels of efficiency in the commercial market. Additional details on the CCW sample plan can be found in Appendix B.

Next the project team focused on isolating the primary variables affecting RMC in the J2 protocol through a pilot test on three of the 14 units.

3.3. Pilot Washer Testing

3.3.1. Pilot Test Plan

The purpose of running a pilot test is two-fold: First, the project team needed to test and isolate key variables that may impact drying energy so that they can be ranked in order of importance for the full sample testing phase. Essentially, this means performing a large number of test runs on just a few machines and—after identifying the most important variables—performing only those relevant test runs on the full sample. The second reason to perform a pilot test is that it provides the project team an opportunity to troubleshoot and/or make modifications to keep the full sample testing process efficient and ensure confidence in the results.

To enable the most visibility into how all top-selling RCW might perform when under test, diverse RCWs were selected from the full sample for the pilot testing. UUTs 01, 08, and 10 were chosen as they represent a range of technologies in the market—front-loading, top-loading impeller, and top-loading agitator—and are from three different manufacturers.

Given the importance of drying energy use in the overall IMEF metric, we focused the pilot phase to compare the standard drying energy tests used in the J2 test procedure and other alternative test runs. This allowed the project team to observe drying energy changes as variables were isolated. Drying energy is determined from the RMC measured in J2, which is defined as the ratio of the total weight of water (at the end of the washer cycle) to the textile load's total bone-dry weight. For most washers, DOE prescribes one or two test runs to evaluate the washer's RMC. These test runs are with Maximum load size, Cold Wash/Cold Rinse cycles and the Normal/Regular program.[6] If spin speed is selectable, then the test is run two times, with Minimum and Maximum spin speed. If spin speed is not selectable, then the test is run only once. All other settings remain in default for the RMC J2 test.

For the pilot test phase, the project team focused on the following variables:

- two alternative textiles in addition to DOE's J2-defined cloth textile (NEEA's Dryer Test Procedure Load and AHAM Cotton Load),
- three load sizes (Minimum, Maximum and Fixed),
- two additional program settings (Delicate and Heavy Duty).
- two wash temperatures (Cold and Warm), and
- two spin speeds (Maximum and Minimum).

A discussion of each variable follows.

[6] A washer's program settings are capitalized in this report to minimize confusion when discussing specific washer settings vs. temperatures and spin cycles generally. We also abbreviate Wash/Rinse cycle settings hereafter (e.g., Cold/Cold).

Alternative Textiles. The project team included alternate wash load textiles in the pilot to understand how RMC varied with the textile type. Alternate loads were intentionally selected to be more similar to textile loads found in NEEA's field and lab study (Dymond 2018). In particular, higher cotton content textiles were included because they are more hydrophilic than synthetic fibers (such as rayon and polyester), making water extraction more difficult. Article size, shape, and thickness are other variables the project team considered. The two alternate loads included:

- AHAM Cotton – 100% cotton textile load of sheets, small towels and pillowcases specified in AHAM HLW-1-2013 (AHAM 2013); identical to IEC 60456 100% cotton load (IEC 2010), and
- NEEA Dryer – Nearly 100% cotton load of clothing, and bath towels specified in NEEA's clothes dryer test procedure (Dymond 2017).

Table 5 summarizes the textile load specifications, as well as the respective advantages and shortcomings of each.

Table 5. Clothes washer textile load protocols advantages and limitations.

Load Type	Advantages	Limitations
DOE J2-defined • Momie or granite weave • 50% cotton and 50% polyester fibers • Uniform size, each piece is approximately 2' by 3'	• Highly repeatable and reproducible • Well established for energy testing of laundry equipment in the U.S. • RMC corrections by lot enable historical comparisons of performance	• Shape, size, and thickness of articles not as representative of typical consumer textile loads
AHAM Cotton • 100% cotton sheet, towel and pillowcase • Tightly specified in AHAM 2013 and IEC 60456 • Some variety of thickness and size	• Established for use for clothes washer efficiency and performance testing by AHAM and IEC • Provides additional information about residential RMC in field, given some field loads are 100% cotton and/or more difficult to spin dry because of article size differences	• 100% cotton not representative of all consumer textile loads, which on average contain synthetic content
NEEA Dryer • Cotton blends of various weaves and types specified in NEEA's dryer test procedure • Contains real-world clothing and towels with a wide variety of thicknesses, shapes and sizes purchased from Land's End	• Variety of size and thickness likely more similar to residential loads that have mix of synthetic and cotton, and a variety of sizes, thicknesses and shapes • Historical comparison with NEEA dryers test procedure possible	• Reproducibility over time is problematic as styles and fabrics change from supplier • Variety of pieces means a more complex load building approach (number of pieces) for different loads

Load size. Given the goal of identifying RMC tests that better reflect real-world use, the pilot included a middle-sized fixed load of 8.45 lb, equal to the load size used in the DOE test procedure for clothes dryers (2012). This load is also similar to the field average of 7.6 lb documented in the RBSA Laundry Study.

Delicate and Heavy Duty Program Cycles. These wash programs were among those documented in the field and were selected for testing because they were common across all washers in the project sample.

Wash temperatures. The standard J2 test for RMC is to run the cycle with the Cold/Cold setting. However, NEEA's RBSA Laundry Study and DOE's weighting in the test procedure confirm a warm temperature for the wash cycle is more common. Therefore, the wash setting labeled Warm was included in the pilot for most of the tests to understand how this may impact real-world RMC.

Spin speeds. Spin speed and duration both affect the RMC of a textile load. Although, in general, these specific characteristics are not directly selectable on the user interface of washers, "spin" level (Low, Med, High, etc.) is often selectable. Several pilot tests included Maximum and Minimum spin selections better to understand the range of spin available on the machines.

Table 6 provides a complete overview of the test runs and the associated condition focus area(s) under study. Several important notes about the test runs include:

- The Maximum load size was based upon Table 5.1 of J2.
- The Normal cycle was selected according to J2 Section 1.25, except for spin speed.
- To confirm AHAM Cotton Load's repeatability, certain runs with exactly the same variables were completed two times (runs 8 and 9; 12 and 13).
- UUT-10 does not have selectable spin speeds, so runs 2, 5, and 10 were omitted for that machine.

Table 6. Pilot test run plan.

Condition focus area(s)	Run #	1 - Settings (wash temperature)	2 - Settings (wash temperature, spin speed)	3 - Load size	4 - Load size	5 - Load size, spin speed setting	6 - Settings (program & likely spin speed)	7 - Settings (program and likely spin speed)	8 & 9 - Textile type	10 - Textile type, settings (spin speed)	11 - Textile type & load size	12 & 13 - Textile type & load size	14 - Baseline	15 - Baseline
Textile Type	DOE J2-defined Load	✓	✓	✓	✓	✓	✓	✓					✓	✓
	AHAM Cotton Load								✓	✓	✓			
	NEEA Dryer Load											✓		
Load Size	Maximum	✓	✓				✓	✓	✓	✓			✓	✓
	Fixed (8.45 lb)			✓							✓	✓		
	Minimum (3.0 lb)				✓	✓								
Program Cycle	Normal	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
	Delicate						✓							
	Heavy Duty							✓						
Wash/ Rinse Temp	Cold/Cold												✓	✓
	Warm/Cold	✓	✓	✓	✓	✓			✓	✓	✓	✓		
	Program Default						✓	✓						
Spin Speed	Maximum	✓		✓	✓			✓	✓		✓	✓	✓	
	Minimum		✓			✓	✓			✓				✓
Compare data to:		**14**	**15**	**1, 4, 11, 12 & 13**	**1 & 3**	**Run 2**	**1 & 2**	**1 & 2**	**1**	**2**	**3, 12 & 13**	**3 and 11**	**1**	**2**

3.3.2. Pilot Test Results

An independent ISO 17025 certified laundry equipment test laboratory completed lab testing on UUTs 01, 08, and 10 in the fall of 2019 using the test runs identified in Table 6 above. The project team conducted data processing and analysis using the following approach:

- RMC was corrected for the lot of textiles used.
- RMC was compared to RMC values in CEC MAEDbs and to each other.
- Key variables were compared (washer settings, load size, textile type) to baseline runs.

The J2 baseline test results were consistent with RMCs in the CEC MAEDbs database, confirming these models perform to manufacturer expectations for RMC results. Repeatability (95% confidence interval) was ±2.1% for the AHAM load and ±1.0% for the NEEA Dryer load.

Test results showed that changing any variable increases RMC. Those with the most significant impact are, in relevant order: textile type, program selection, wash temperature, load size, and spin speed selection in Normal program. Table 7 summarizes the average increase in RMC by changes in each variable. These pilot findings agreed with the research team's initial expectations for some tests, but not for others. For example, in the Delicate program, textiles are treated more gently, so we expected a lower spin speed, shorter spin duration, and higher RMC compared to the Normal program (which is what testing revealed). In contrast, we were surprised to see that a change in wash temperature on the machine resulted in an increase in RMC that was more significant than increasing the spin speed level selected. The RMC results did not match our expectations <u>because washing machines adjust their spin algorithm with</u>

changes to settings and inputs from load sensing at the beginning of a cycle, altering spin duration and sometimes spin speed. For example, the spin duration for the J2-specified RMC tests with Cold wash setting (Runs 14 and 15; 19 minutes) was an average of 60% longer than the same exact settings and load size with Warm wash (Runs 1 and 2; 12 Minutes). Spin algorithm findings are discussed in more detail in the full sample results (Section 4).

Given the purpose of this study is to examine real-world drying energy impacts of consumer setting choices, we did not attempt to fully isolate impacts of physical parameters separate from washing machine spin algorithms. Instead, the team focused on observing the outcome of testing using real-world settings, textiles types, and load sizes. In this way, the testing is a proxy for what is likely to happen during real consumer use, predicting energy use in the real-world.

Table 7. Pilot test data summary.

Variable	Baseline Test Run	Test Run with Variable Change Used for Comparison	Average RMC increase (% points)	Average RMC increase
Textile Type	**Run 3:** J2-specified cloth, Normal program, Warm wash, 8.45 lb load, Max spin	**Run 11:** AHAM Cotton	30 percentage points	70%
		Runs 12 and 13: NEEA Dryer Load	27 percentage points	63%
	Runs 1 and 2: J2-specified cloth, Normal program, Warm wash, Max load, Max and Min spin	**Runs 8, 9 and 10:** AHAM Cotton	32 percentage points	78%
Program: Delicate and Heavy Duty	**Run 14:** J2-specified cloth, Normal program, Cold wash, Max load, Max spin	**Run 6:** Delicate w/ Min spin	23 percentage points	63%
		Run 7: Heavy Duty w/ Max spin	8 percentage points	23%
Settings: Wash Temperature	**Average Runs 14 and 15[a]:** J2-specified cloth, Normal program, Max load, Cold wash	**Runs 1 and 2:** Warm wash	6 percentage points	18%
Load Size: Smaller	**Run 1:** J2-specified cloth, Normal program, Max load, Warm wash, Max spin	**Run 4:** 3 lb load	7 percentage points	18%
		Run 3: 8.45 lb load	2.5 percentage points	6%
Spin Speed Selection in Normal Program UUTs 01 & 08 only	**Run 14:** J2-specified cloth, Normal program, Cold wash, Max load, Max spin	**Run 15:** Min spin	0.4 percentage points	1%
	Run 1: J2-specified cloth, Normal program, Warm wash, Max load, Max spin	**Run 2:** Min spin	3 percentage points	9%
	Run 4: J2-specified cloth, Normal program, Warm wash, 3 lb. load, Max spin	**Run 5:** Min spin	4 percentage points	9%

Notes: [a]UUT 10 did not have two spin speeds.

Before selecting the final sample, however, the project team and stakeholders first needed to analyze the methodology options for updating UEC estimates. The chosen approach would affect the priority of selected variables for the full sample testing phase.

Selecting the methodology approach for updating UEC estimates.

We identified two possible methodologies for updating RMC calculations and corresponding RTF values for UEC estimates: weighted average and Bayesian inference. A description of both, along with advantages and disadvantages, is provided in Table 8 below.

Table 8. Methodology options for calculating RMC and UEC estimates.

	Weighted Average Method	Bayesian Inference Method
Description	Develop a weighted average of runs to represent field RMC. The research team would develop test runs representing common conditions found in the NEEA field study, such as load size and settings, and then create a weighted average of test runs to represent the new "field RMC" variable for the RTF. This new RMC can be used to calculate an updated IMEF and UEC for the region.	Bayesian inference is a statistical inference method in which Bayes' theorem is used to update the probability for a hypothesis as more evidence or information becomes available. It is used in many fields where not all data are available. Essentially, it starts with a currently assumed value and then adjusts that value with available data. Under this approach, the project team updates the J2 RMC (current value) with wash temperature, load size, program, and textile type information from field data and test runs to calculate the new "field RMC" used to update the IMEF and UEC estimates for the region.
Advantages	• More familiar to regional stakeholders, as it is similar to the methodology for NEEA's dryer test procedure. • Can combine variables that may interact together in one run (e.g., load size and program selection). • More confidence in overall representativeness of the region.	• Enables the isolation of variables that impact RMC. • Enables specific corrections based on field data. • RMC can be updated over time as new field information becomes available. • Enables RTF to apply adjustments to other machines in the market. • More effective for advocacy, as opportunities for test procedure improvements can be discussed independently.
Disadvantages	• Not as useful for national standards purposes, as DOE is less likely to adopt test runs that represent a single region of the U.S.	• Estimates may not be as region-specific.

The methodology needed to be defined before we could select the runs for the full sample test plan. Simply put, NEEA and the RTF had to decide where to prioritize: Should the project focus on more confidence in the region-specific UEC estimates, or should it prioritize efforts that would support improving the representativeness of federal specifications and standards?

Ultimately the group reached a consensus to utilize the Bayesian inference method, prioritizing RMC measurement improvements and a more straightforward path for standards and specification development. This approach is still highly useful to develop confident UEC estimates for the region. With that decision in place, the project team homed in on seven runs to include in the full sample testing process, detailed in Table 9 of Section 3.4. Before discussing the entire sample test plan, however, we first provide the rationale for the test load selected and explain introducing a new subset test run.

Opting to utilize AHAM HLW-1-2013 vs. the NEEA Real-World Test Load

The project team initially expected to see statistically significant differences in the increase in RMC between the AHAM Cotton load and the NEEA Dryer textile load. Pilot test results, however, revealed that they perform very similarly: The AHAM Cotton load had only a slightly higher RMC (74%) than NEEA's specified dryer load (71%). After thoughtful discussion among key stakeholders, we concluded that utilizing an industry-established and widely accepted load would have more value in immediate and future standards and specification efforts. Therefore, the alternative textile load specified for the full sample testing phase is the AHAM Cotton.

Including a subset run on three UUTs to assess the impact of larger basket size.

As discussed in section 2.2.3 of the literature review, basket sizes have increased substantially in recent years, causing concern that the *Average*-specified load size in J2 may no longer represent the real-world average-size load of 7.6 lb found in the field (Hannas and Gilman, 2014). Although we can reasonably assume that many people run smaller loads in bigger basket sizes and thus increase energy consumption, more data are needed to provide constructive input to this question. Therefore, to better understand the impact of basket size on hot water use, machine energy use, and RMC, NEEA opted to conduct additional testing on this *Average*-specified load. The project team selected three units from the full sample with a basket volume of 5.2 cu ft (UUTs 02, 08, and 11) for an additional test run with J2-specified *Average* load size (12.25 lb) to obtain preliminary data. Although a small sample size, this effort still offers a valuable glimpse into the differences between a modern-day J2 *Average*-specified load and the typical average consumer load.

3.4. Full Sample Test Plan

As noted previously, the purpose of the pilot testing phase was to isolate variables that have the most significant impact on RMC and troubleshoot and make modifications to keep the full sample testing process efficient and ensure confidence in the results. With those objectives in mind (and methodology decisions described above), the project team identified seven runs for the full sample testing phase: three were retained as performed initially, three were slightly modified, and one entirely new run was created. Also included is the subset J2-defined *Average* load size runs on UUTs 02, 08, and 11. Table 9 details our full sample test plan approach, including the corresponding pilot run number for reference when applicable.

Table 9. Full sample testing plan.

Run & Condition focus area(s)		Run A - J2 Baseline	Run B - Settings	Run C - Settings and load size	Run D - Program	Run E - Program	Run F - Textile type	Run G - Textile, settings & load size	Run H - Settings & load size
Correlates to Pilot Run #		**14**	**1 Modified**	**3 Modified**	**6**	**7**	**8 Modified**	**New**	**New**
Textile Type	J2-defined Load	✓	✓	✓	✓	✓			✓
	AHAM Cotton Load						✓	✓	
Load Size	Maximum	✓	✓		✓	✓	✓		
	J2-defined Average								✓
	Fixed (8.45 lb)			✓				✓	
Program Cycle	Normal	✓	✓	✓			✓	✓	✓
	Delicate				✓				
	Heavy Duty					✓			
Wash/ Rinse Temp	Cold/Cold	✓					✓		
	Warm/Cold		✓	✓				✓	✓
	Program Default				✓	✓			
Spin Speed	Maximum	✓				✓	✓		
	Minimum				✓				
	Program Default		✓	✓				✓	✓
Compare data to:		**CEC RMC**	**A**	**B & G**	**A & B**	**A & B**	**A**	**Adjustment Verification & C**	**C**

Notes: Runs were generally modified from the pilot to utilize default spin speeds instead of manually adjusting the spin speed to a Maximum or Minimum setting.

4. Results, Key Findings and Recommendations

4.1. Summary

An independent ISO 17025 certified laundry equipment test laboratory conducted lab testing on the 14 clothes washers listed in Table 4 in early 2020 using the test run plan discussed above (Table 9). The project team completed data processing and analysis using the same approach as in the pilot phase (see section 3.3.2). The J2 baseline test run results remained consistent with RMCs in the CEC MAEDbs database, confirming these models perform to manufacturer expectations for RMC results. A summary of variable impacts on RMC is provided in Table 10, and complete test results are provided in Appendix C.

Table 10. Summary of full sample test results for RCWs and CCWs.

Variable	Baseline Test Run	Test Run with Variable Change Used for Comparison	Residential (n=12) Average RMC increase (by % points)	Residential (n = 12) Average RMC increase	Commercial (n = 2) Average RMC increase (by % points)	Commercial (n = 2) Average RMC increase
Textile Type	**Run A:** J2-specified cloth, Normal program Max load, Cold wash, Max spin	**Run F:** AHAM Cotton cloth	30 percentage points	92%	35 percentage points	79%
	Run C: J2-specified cloth, Normal program, 8.45 lb. load, Warm wash, default spin	**Run G:** AHAM Cotton cloth	30 percentage points	72%	33 percentage points	70%
Program: Delicate and Heavy Duty	**Run A:** J2-specified cloth, Normal program, Max load, Cold wash, Max spin	**Run D:** Delicate w/ Min spin	27 percentage points	84%	14 percentage points	32%
		Run E: Heavy Duty w/ Max spin	5 percentage points	16%	3 percentage points	6%
Load size: 8.45 lb	**Run B:** J2-specified cloth, Normal program, Max load, Warm wash, default spin	**Run C:** 8.45 lb	5 percentage points	14%	4 percentage points	9%
Settings: Wash temp	**Run A:** J2-specified cloth, Normal program, Max load, Cold wash, Max spin	**Run B:** Default spin	4 percentage points	12%	-1 percentage points	-1%

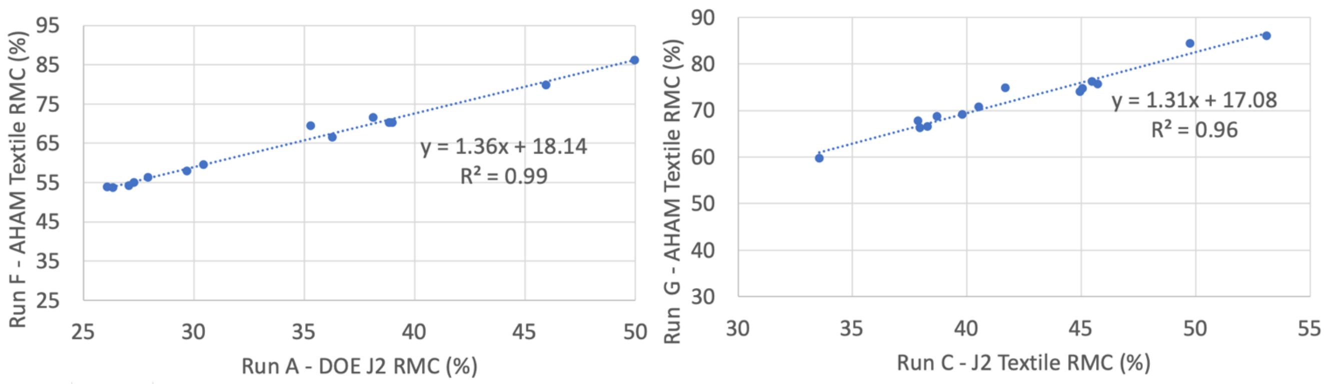
KEY FINDINGS: The primary takeaway from the test results is that nearly all deviations from J2 increase the RMC result. Furthermore, despite being a relatively repeatable and reproducible test, J2 does not effectively predict real-world RMC or the efficiency rank order of RCWs.

Detailed results and the corresponding discussion are provided in the following sections, starting with the textile type.

4.2. Textile Type

Although DOE's J2-defined test cloths may not effectively measure cleaning efficacy, they quite reliably predict RMC of AHAM Cotton textiles for these load sizes and wash/rinse settings: Maximum load with Cold/Cold (R^2 = 0.99) and 8.45 lb load with Warm/Cold (R^2 = 0.96); see

Figures 2 and 3. Figure 2 (left) compares Run A (DOE J2 RMC) baseline to the same test conditions except a change in textile type from J2-defined test load to AHAM Cotton. Similarly, Figure 2 (right) compares two test runs (C and G) with a single textile type change. Using these data, the project team established a mathematical relationship for RMC comparing the J2-defined textiles and the AHAM Cotton textiles (Figure 2).



Notes: LEFT: RCW and CCW Cold Wash/Cold Rinse Maximum load RMC: DOE J2 RMC (Run A) and AHAM Cotton textile (Run F). RIGHT: RCW and CCW Warm Wash/Cold Rinse 8.45 lb load RMC: DOE Test Load (Run C) and AHAM Cotton textile (Run G).

Figure 2. Relationship between textile type and RMC.

Analysis, illustrated in Figure 3, shows no significant rank changes among the 14 clothes washers tested. The DOE J2 RMC rank order of washers (lower RMC is better) is shown in the left-hand column (Run A). The right-hand column shows the RMC of the same test conditions except the substitution of the AHAM Cotton textile (Run F). The best (i.e., lowest RMC) washers are ESME models shown in blue circles. The ESV8 FL models in green circles are second best followed by ESV8 TL models shown as yellow/brown triangles. Finally, the NQ models shown in gray triangles have the highest RMC. (The legend on the far left is in the same order as the Run A data.) CCWs tested are square markers, are denoted with a "C" in the legend and have higher RMCs than their RCW counterparts. Note that generally, all the lines are of similar slope and almost entirely parallel moving left to right, indicating that the washers' rank order changes very little when the textile is changed. These data offer a clear conclusion.

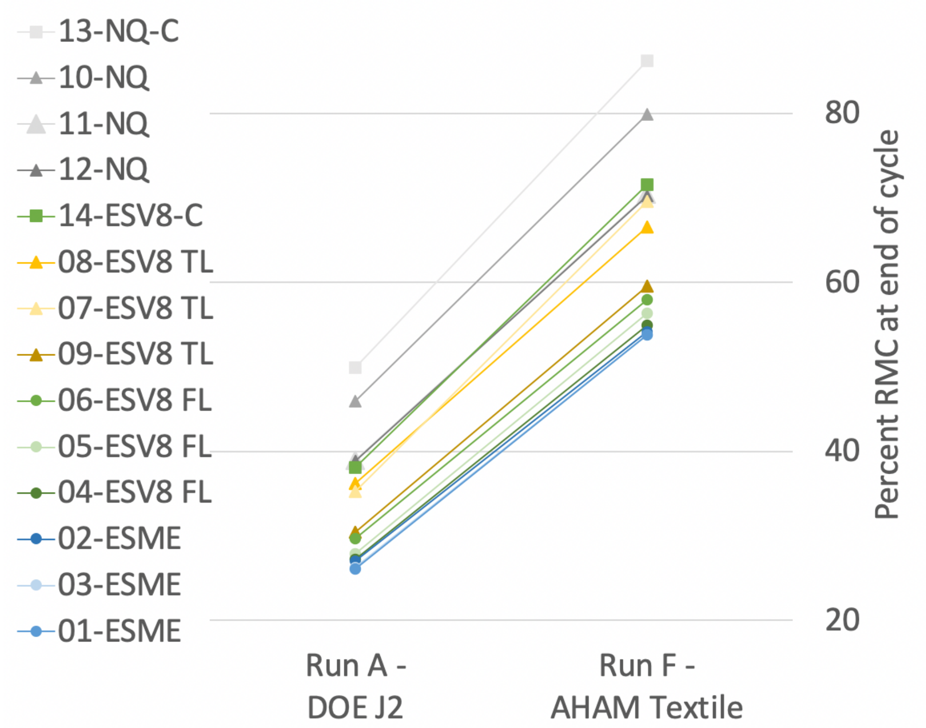


Figure 3. RCW and CCW RMC Rank order for DOE J2 RMC and AHAM Cotton textile loads.

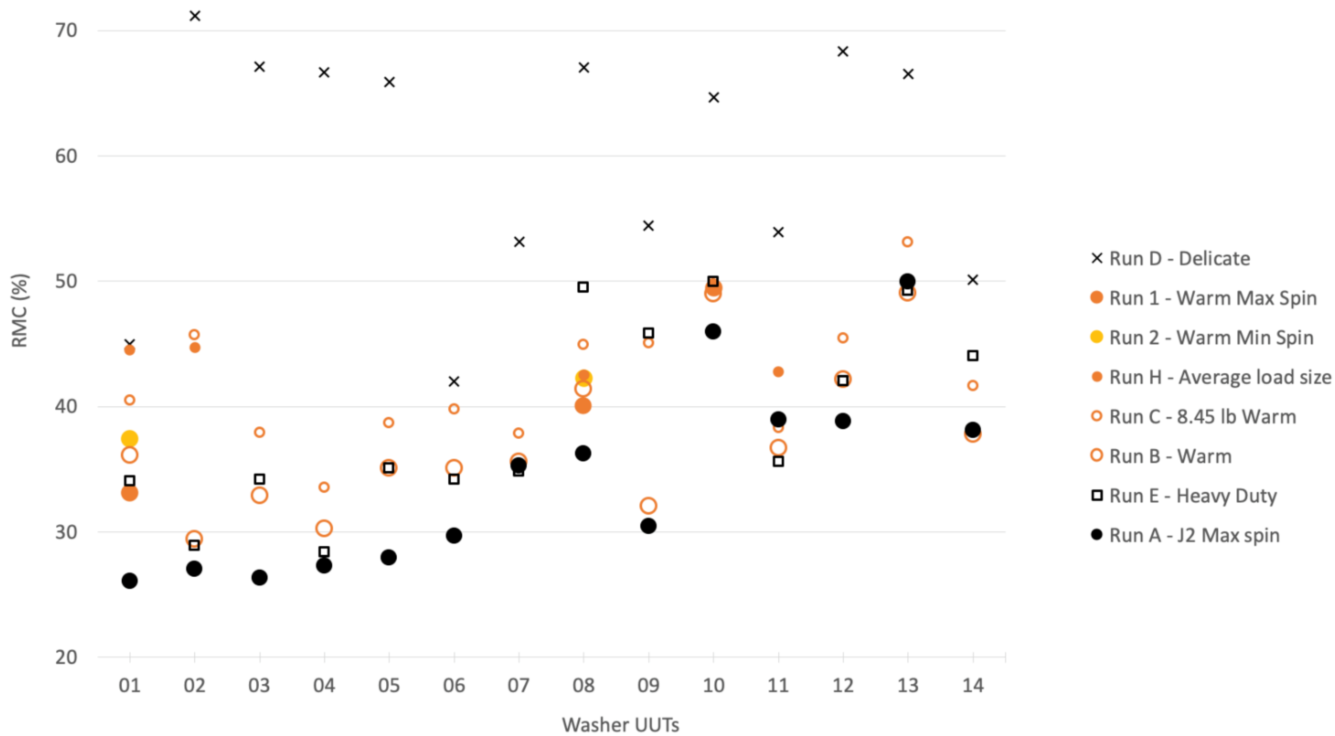
KEY FINDING: We can quickly establish a simple mathematical adjustment to calculate the RMC of AHAM Cotton textile and its associated drying energy use using the J2-defined test load results.

Results related to the textile type provided a clear and fairly straightforward interpretation and response. However, results related to wash temperatures, load sizes, and program settings presented more complex considerations. These variables are discussed together in the following section.

4.3. Temperature, Load Size and Program Settings

For ten of the 12 RCWs, every other test run performed increased the RMC relative to the J2 RMC test value (i.e., the textiles were wetter), resulting in more drying energy use. *For these ten washers, test runs with alternate wash temperatures, load sizes, and programs all resulted in a higher RMC.* A summary of these findings is illustrated in Figure 4 below. A number along the horizontal axis identifies each UUT, and percent RMC is shown on the vertical axis (lower is better). The dark black solid dot is this project's J2 RMC Maximum spin test results, generally the lowest RMC (best) result.[7] These findings agree with the CEC MAEDbs reported values. Other markers are the remainder of the test runs performed with J2-specified test loads (Test Runs B, C, D, E, H, 1 & 2).

[7] The Maximum spin value was used to represent the J2 RMC value in the full testing phase given results from the pilot phase of the study showing the J2 RMC tests for Minimum and Maximum spin settings were nearly identical (See test data in Appendix C). This issue is also discussed in NEEA 2020b, comment A.1.2, p. 5.



Notes: 1) UUT 01, 02 and 03 are ESME qualified, UUT 04, 05 and 06 are ESV8 FL qualified, UUT 07, 08 and 09 are ESV8 TL qualified, and UUTs 10 through 12 are NQ. For the commercial washers, UUT 13 is ESV8 qualified and UUT 14 is NQ.

2) Runs 1 & 2 were performed in the pilot phase of the study and therefore only apply to UUTs 01, 08 and 10. Run H was performed on a subset of washers as well: UUTs 02, 08 and 11. Although not originally in the full sample test plan, Run H data for UUT 01 are also available.

3) Test runs with letter designations were performed on all washers (full testing phase in Table 10).

4) Circles demark the runs performed with the Normal program. Orange and yellow markers are test runs with Warm wash. The size of the marker provides an indication of the test run load size (smaller markers are test runs with load sizes less than J2-defined Maximum).

Figure 4. RMC for RCW and CCW test runs with J2-defined test cloth.

Generally, front loaders were more efficient than top loaders. The highest RMCs measured were using the Delicate program while the lowest (other than the J2 RMC) were using the Heavy-Duty program. The only two exceptions to this general trend are UUTs 07 and 11. For UUT 07, the Heavy-Duty cycle and Warm Wash temperature cycle achieved a similar RMC to J2 RMC. For UUT 11, we observed repeatability issues with Run A. The CCWs (UUT 13 and 14) J2 RMC results for other test runs were also higher (worse) or very close to the J2 RMC measurement.

When considering these lab results in the context of those washer load sizes and settings most commonly found in the field—Normal program, Warm/Cold, and a 7.6 lb average load size—the project team observes that RMC increases significantly with smaller load sizes and warmer wash temperatures. This increase in RMC increases drying energy in the field relative to the drying energy estimated by the J2 RMC test.

KEY FINDING: Comparing these lab data to common field settings and load sizes, we can conclude that the current J2 RMC test does not represent the RMC of a typical wash cycle.

We provide a discussion of RMC results in the context of spin speed and spin duration next.

4.3.1. Spin Speed and Spin Duration

The washer's final spin algorithm is the set of rules the washer follows when extracting water from the load at the end of a wash cycle. Two key characteristics of the spin algorithm that impact RMC are maximum spin speed and spin duration. Testing revealed these two elements vary with settings selected on the washer and impact the RMC at the end of the cycle. Figures 5, 6, and 7 plot the relationships between spin speed, spin duration, and RMC for all RCW and CCW test runs using J2-specified test cloth. The color and shape scheme designating washers in the figures mimic Figure 3 (above). In addition, those markers with the thick black border are the J2 RMC tests (Run A), and, in Figure 7, CCWs have patterned bubbles (instead of squares). We made the following general observations about these test run data:

- Front-load models generally have higher spin speeds than top-load models.
- Top spin speed in Normal program varies from 700 RPM to 1350 RPM across the 14 washers.
- Delicate always has a lower spin speed than Normal (note that Delicate program on 11 of 12 RCWs are particularly distinctive and called out as a group in the figures).
- Spin duration is generally shorter for CCWs than for comparable RCW.

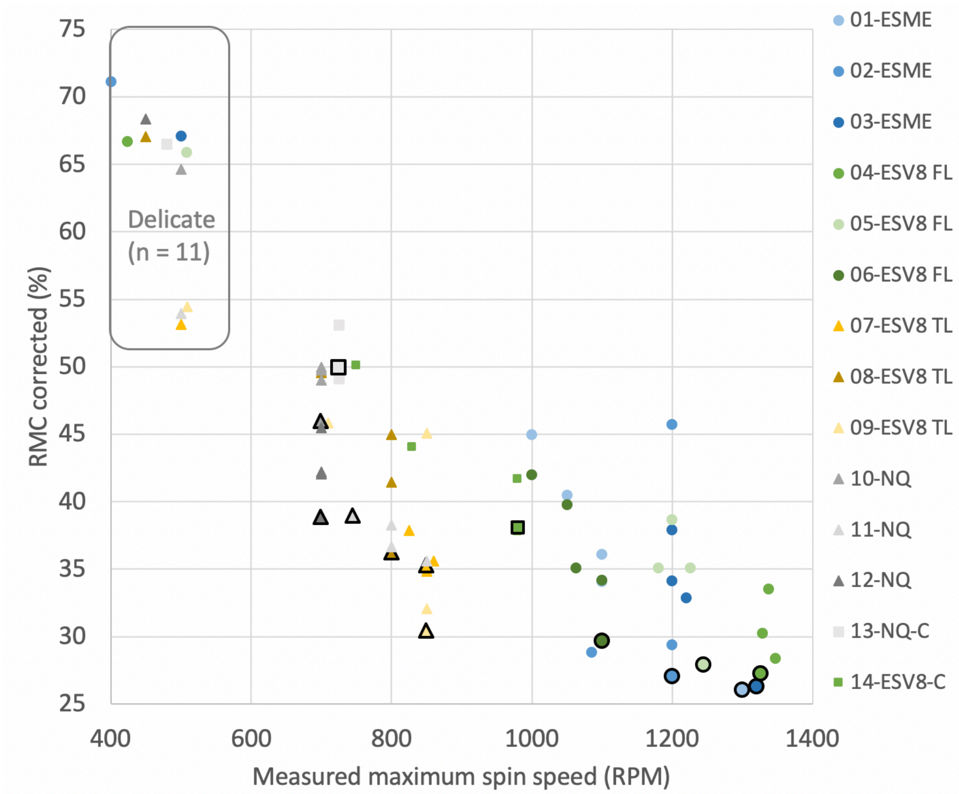


Figure 5. RCW and CCW spin speed and RMC.

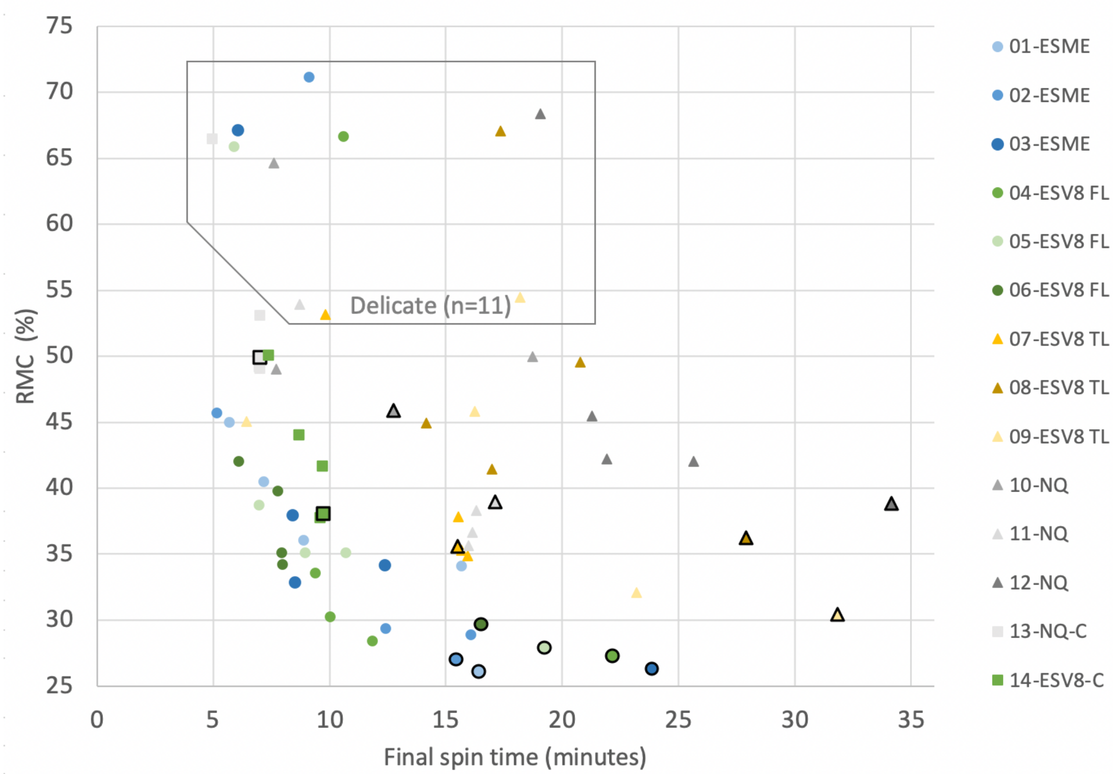
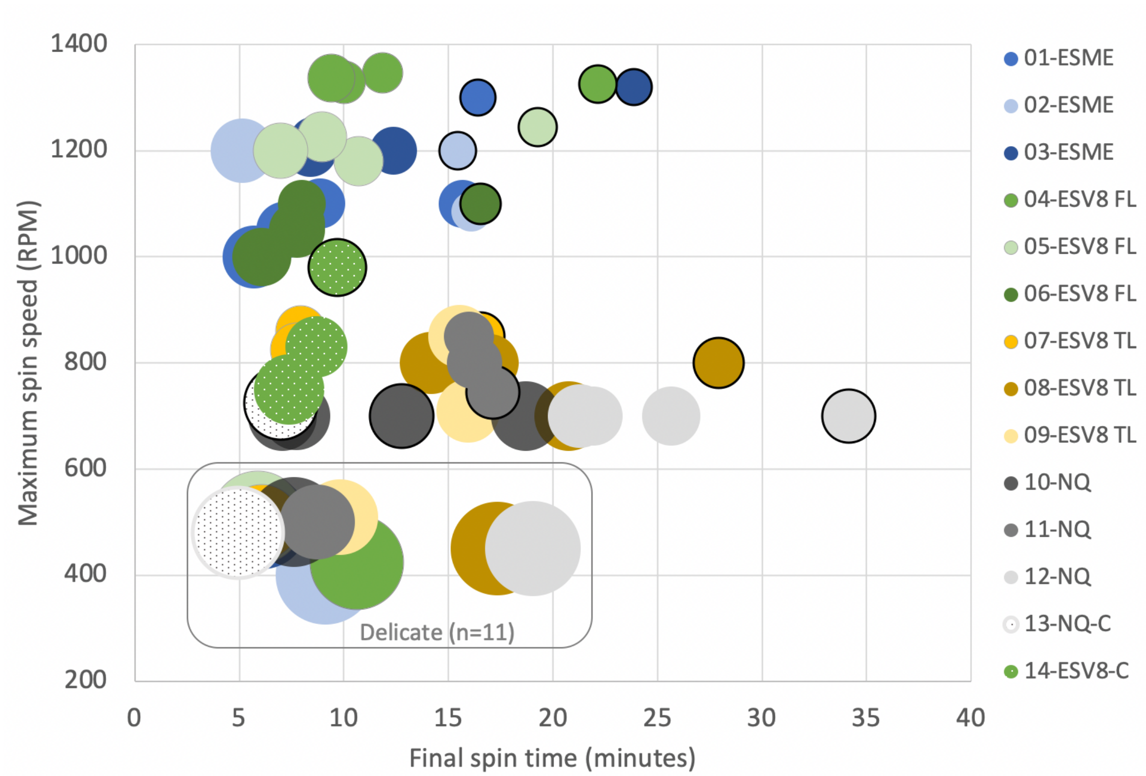


Figure 6. RCW and CCW spin duration and RMC.



Notes: The size of the bubble shown is indicative of the RMC value at the end of the cycle (higher RMC, larger bubble size).

Figure 7. RCW and CCW spin speed, spin duration and RMC.

KEY FINDING: General trends observed in testing reflect well-understood differences between top and front load washer technology and expected differences between RCW and CCW, giving confidence in test data results.

We made several additional observations about spin speed, spin duration, and RMC that we did not anticipate at the start of this project:

- For RCWs, top-load models generally spin longer than front-load models.
- The J2 RMC values for 11 of the 12 RCWs are among those test runs with the longest spin durations (longer than 15 minutes).
- Spin duration varies quite widely (5 minutes to 34 minutes) across all test runs.
- Spin speeds are slower and RMC is higher for a CCW than for comparable RCW.

Next, these observations about RMC are discussed in more detail in the context of program settings and their associated spin algorithms.

4.3.2. Spin Algorithm

Our project team considered these RMC, spin speed, and spin duration data and concluded that the increase in RMC for different wash temperatures, programs, and load sizes is primarily due to spin algorithm differences. Testing revealed that machines have different spin speeds and spin times when load size, wash temperature, and program settings are changed from the J2 baseline. The spin algorithm changes with changes to settings (such as Program selection or wash temperature) and may be adjusted further with load sensing at the beginning of the cycle (used to measure load size). While the physical properties of textiles may have some impact, spin algorithm differences drive the differences in RMC for the various test runs in NEEA's data set.

For example, UUT 08-ESV8 TL (impeller) spun the load 10 minutes longer in Cold/Cold (wash/rinse) setting (Run A) than for the same test run that used Warm/Cold (Run 1), shown in Figure 8 below. Note that the spin profiles overlap precisely, but the warm wash test run ends ten minutes before the cold wash test run. The Cold/Cold test on UUT 01-ESME had seven more minutes of spin than the Warm/Cold setting. UUT 10-NQ added five minutes of spin time for Cold/Cold. These examples are exact comparisons with the spin speed set to Maximum in both cases with wash temperature as the only variable change between the two test runs. Furthermore, these top-selling models represent three different manufacturers and technology types (front load, impeller top load, and agitator top load).

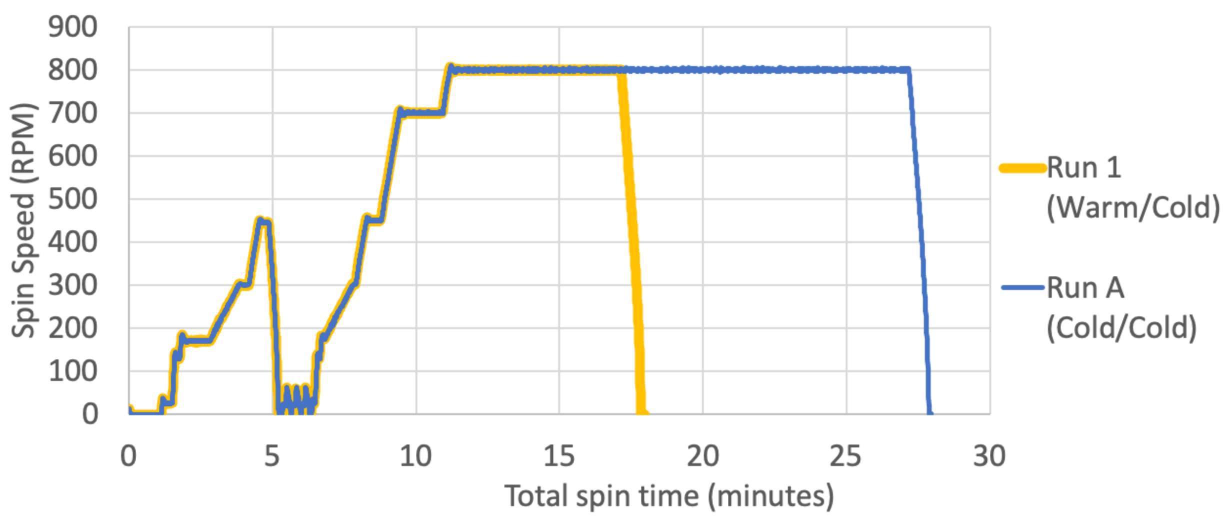


Figure 8. UUT 08-ESV8 TL wash/rinse spin algorithm comparison for Cold/Cold and Warm/Cold.

Test data also reveal that RMC increases an average of 10% when the wash temperature is changed from Cold/Cold Maximum spin to Warm/Cold default spin (an average of Run B compared to an average of Run A). This is primarily a result of longer spin times for the Cold/Cold cycle, which extend an average of seven minutes compared to the Warm/Cold. A change in the load size from the Maximum to a fixed 8.45 lb on Warm/Cold resulted in an average of 14% increase in RMC and an average two-minute reduction of spin time (the average of Run C compared to the average of Run B). The reduced spin time for the smaller 8.45 lb load may be due to adjustments to the spin algorithm during load sensing at the beginning of the cycle and/or other sensing technology later in the cycle. These average reductions in RMC and spin time are shown in Table 11 below. Furthermore, the reduction in spin time and RMC is inconsistent from machine to machine—even within a given efficiency level—because manufacturers take different approaches in spin programming changes for various wash temperatures and load sizes.

Table 11. Average RMC and spin time changes for wash temperature and load size.

		Wash temperature change from Cold to Warm Wash (Run A to Run B)[a]	Load size change from Maximum to 8.45 lb load (Run B to Run C)[b]
Residential (n=12)	**Average RMC percentage point increase[c]**	4 percentage points	5 percentage points[d]
	Average RMC increase (%)	12%	14%
	Spin time average decrease (minutes)	8 Range: 0 to 15	3 Range: 0 to 17
	Spin time average decrease (%)	38%	21%
Residential and Commercial (n=14)	**Average RMC percentage point increase[c]**	3 percentage points	5 percentage points
	Average RMC increase (%)	7%	10%
	Spin time average decrease (minutes)	7 Range: 0 to 15	2 Range: 0 to 17
	Spin time average decrease (%)	35%	19%

Notes: [a] Load size for Runs A and B is Maximum (Table 9).
[b] Both Run B and Run C are tested with Warm Wash (Table 9).
[c] Given RMC is expressed as a percent, the average difference between two test runs can be characterized as a difference in percentage points of the RMC results of each test.
[d] 2017 NEEA testing of 13 washers with NEEA's dryer load agreed with this finding, showing increasing RMC with decreasing load size. Specifically, load sizes of 4.2 lb, 8.4 lb and 12.6 lb, had RMCs of 63%, 56% and 55%, respectively (NPCC RTF 2018b).
General: Commercial units are not shown separately in this table as there are only two in that group, so the average is less indicative of the full market.

KEY FINDING: We conclude that changes to washer spin algorithms drive the differences in RMC for the various test runs, particularly for alternate programs and wash temperatures. Furthermore, analysis of these wide differences in RMC revealed that the impacts to rank order changes are substantial.

The latter assertion is detailed in the next section.

4.4. Rank Order Changes

We compared the J2 RMC test run values of the 12 RCW to one another and found the rank order of the RMC values mimics the general efficiency level expected for the four washer groups. On the left side of Figure 9, J2 RMC results (Run A) of ESME machines are the most efficient by the IMEF metric and have the lowest RMC. ESV8 FL machines have an RMC slightly higher than the ESME machines. Next, ESV8 TL machines have RMC higher than all the front loaders, and the washers with the highest DOE J2 measured RMC values are NQ models.[8]

However, when testing the RMC of RCWs using the Warm/Cold setting (Run B)—notably a test run that DOE already uses to measure other energy use parameters of the machine (machine energy use, water use and hot water energy use)—the rank order changes dramatically for some washers (see Figure 9). Of particular note: UUT 01-ESME moves from rank 1 (lowest RMC) to rank 8. UUT 09-ESV8 TL shifts in the alternate direction, from rank 7 to rank 3. Other substantial rank changes are visible as well.

When both wash temperature and load size are changed (Run C) relative to the J2 RMC test (Run A), UUT 02-ESME FL moves from a top performer (rank 3) to nearly last in the group (rank 11) along with a higher RMC than two of the three NQ models. Strikingly, UUT 11-NQ goes from the second-worst performer (rank 11) to one of the best (rank 4).

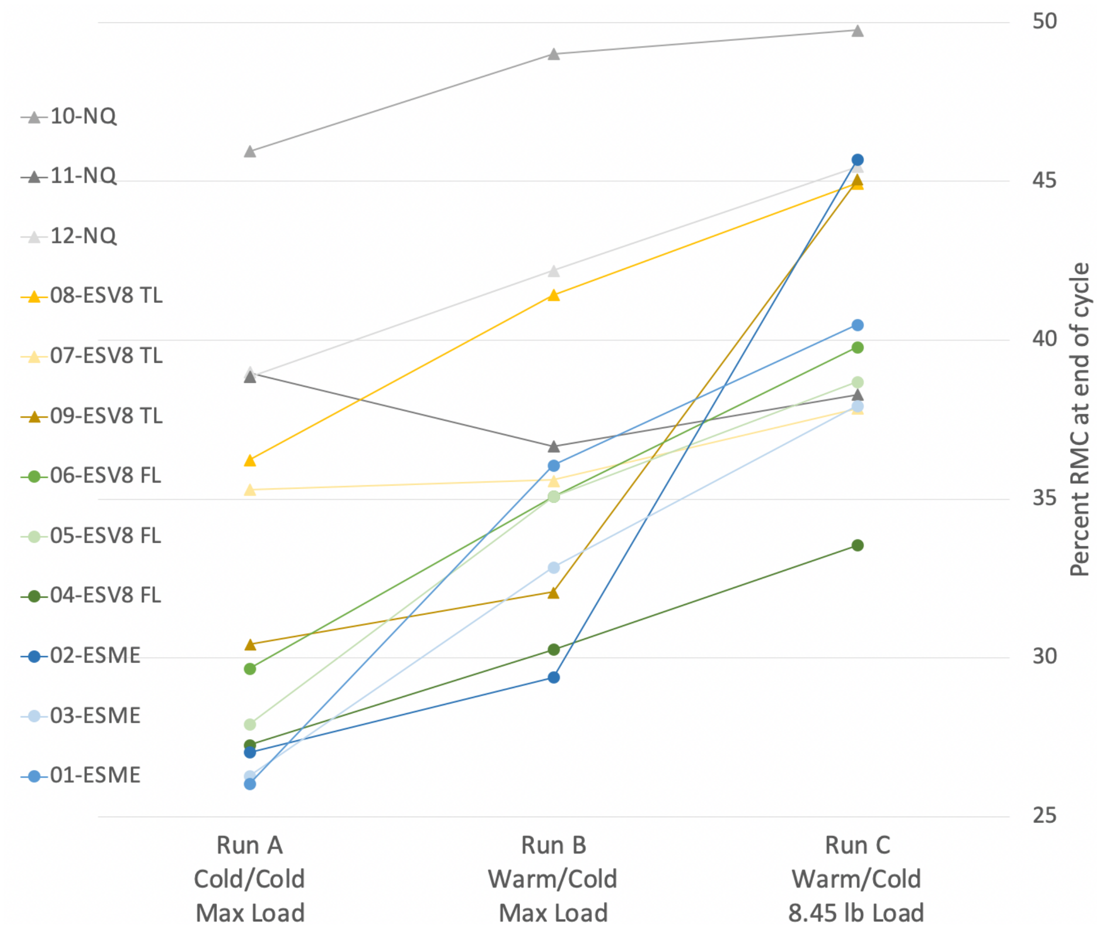


Figure 9. RCW RMC changes with Warm Wash/Cold Rinse and 8.45 lb load.

[8]CCWs were not included in this analysis given they are sold into a different market and therefore comparing the rank change of CCW to RCW is inappropriate. Furthermore, the sample size (*n*=2) of CCW is not large enough to consider rank order changes of CCW separately from RCW.

Moreover, because drying energy has such a substantial impact on IMEF calculations—especially for the most efficient washers—these changes in RMC also impact the rank of washers under IMEF. Figure 10 compares the rated IMEF for each washer to an alternative IMEF (A-IMEF) calculated with the drying energy from Run B and then from Run C. These A-IMEF values shown are what the IMEF would be if using Run B or Run C to represent the drying energy rather than using the current J2 RMC test. Using the rated IMEF and measured J2 RMC, we calculated the drying energy expected in the rated IMEF. Then, for Run B and Run C, we replaced that drying energy in the rated IMEF with the drying energy that would be expected given the RMC results in Run B or Run C. A-IMEF is the rated IMEF value with this alternative drying energy value in place of the drying energy calculated with the J2 RMC test runs. All other calculation parameters within J2 were used; only the Run B and Run C lot-corrected RMC values were utilized for A-IMEF.

Five of the 12 RCW UUTs—01-ESME, 02-ESME, 04-ESV8 FL, 07-ESV8 TL, and 09-ESV8 TL—substantially change rank under the A-IMEF Run C metric that includes changes to both load size and wash temperature. In particular, differences can be observed in Figure 11, which shows the relative IMEF/A-IMEF of each model tested compared to the average for the group. For this figure, the project team prepared three averages of the 12 washers: IMEF, A-IMEF (Run B), and A-IMEF (Run C), and then calculated the percent difference for each washer from the respective average value. The 0% line represents the average of all the washers (no change from average). As expected for rated IMEF (far left), the ESME washers are higher than the average and NQ are lower. Of note, UUT 02-ESME drops below all other front loaders when the RMC is evaluated with a warm water wash temperature and a smaller load (Run C). UUT 09-ESV8 TL hovers around the average value for rated IMEF and A-IMEF of Run B but becomes more than 10% lower than average when tested with Run C (Warm/Cold with 8.45 lb load).

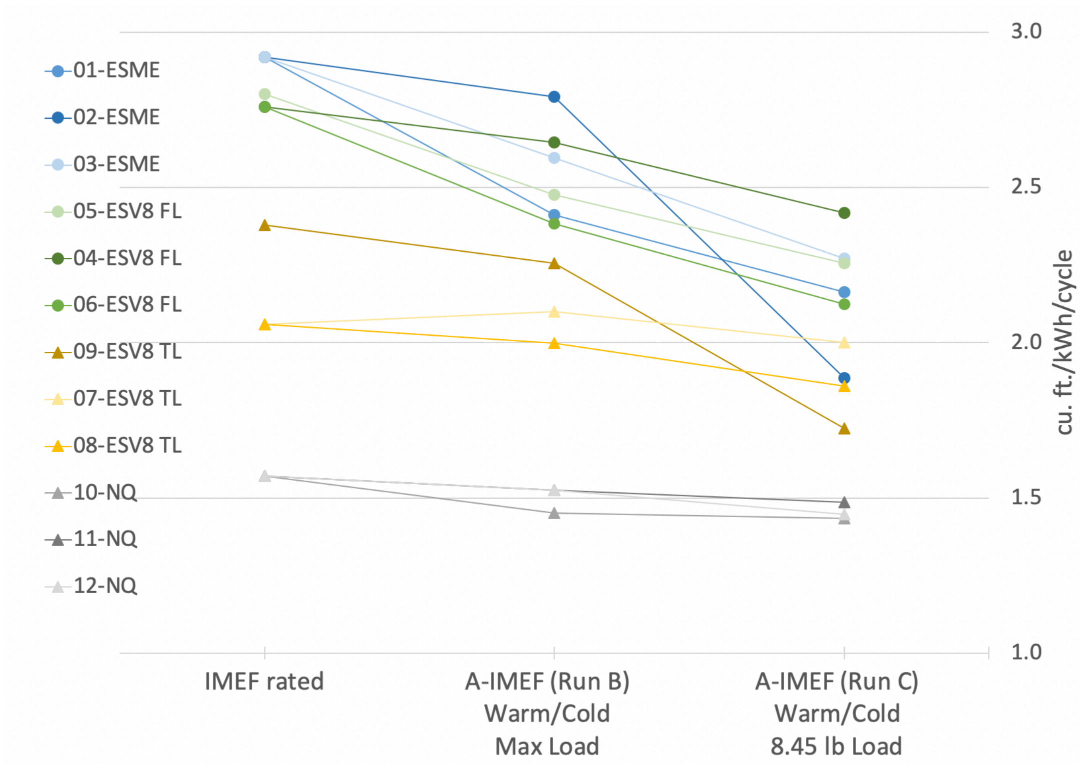


Figure 10. RCW IMEF changes with Warm Wash/Cold Rinse and 8.45 lb load.

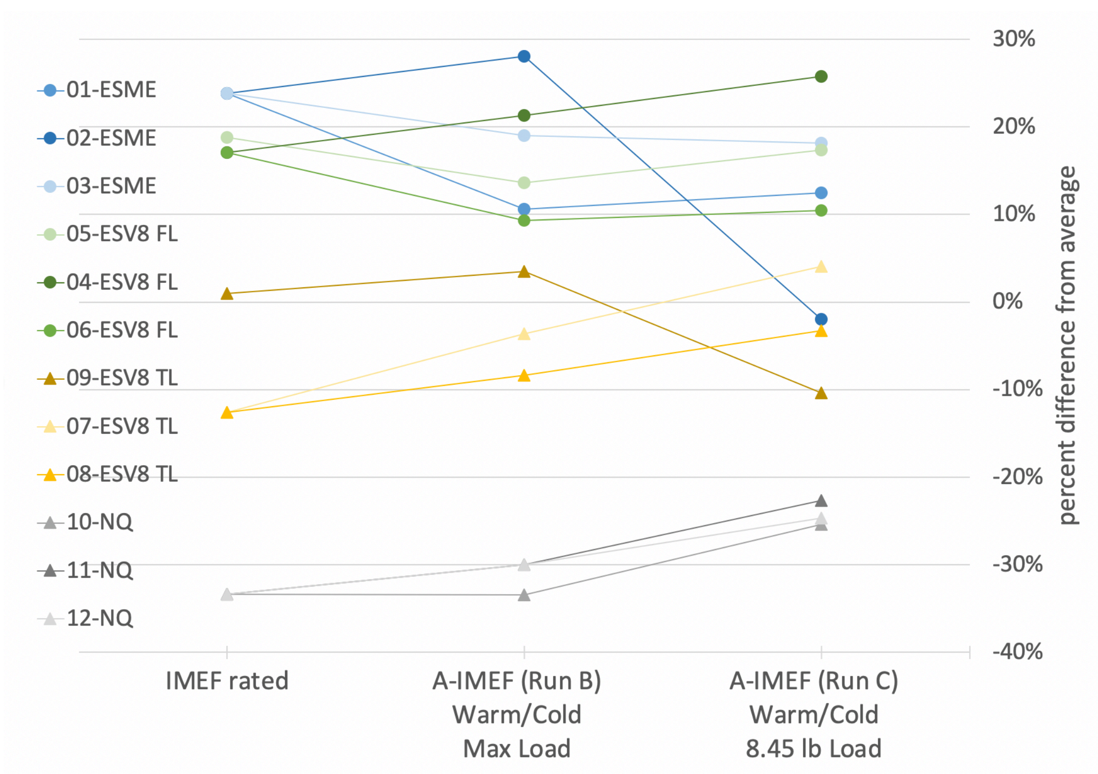


Figure 11. IMEF percent different from average for Warm Wash/Cold Rinse and 8.45 lb load.

KEY FINDINGS: RCW IMEF rank order changes with alternative RMC measurements confirm that a simple mathematical adjustment for warm wash or load size will not effectively represent a broader range of real-world conditions for a single RCW. These results indicate that measuring RMC at wash temperatures and load sizes already used in J2 and then averaging them using J2's temperature use factors (TUFs) and load use factors (LUFs) to represent a typical wash cycle would be a better metric for real-world energy use estimates.

The latter point is detailed in Section 4.7, while a discussion of how these findings impact UEC estimates follows next.

4.5. Real-World RMC

4.5.1. Real-World RMC Calculation Methodology

This section details the methodology used to calculate updates to the real-world RMC and UEC estimates for key market categories of washers. We employed a four-step process and utilized the following data sources:

- **Market data** from NEEA's ESRPP program for RCW market share by model,
- **Manufacturer-reported data** from CEC's MAEDbs compliance database for values such as IMEF, IWF, and RMC,
- **Field data** from NEEA's studies for consumer-usage estimates, and
- **Lab test data** from this project for real-world RMC estimates.

Step 1: Determine current average DOE Appendix J2 RMC, IMEF, IWF and basket size for a given washer group

For RCWs, we updated our market data using the same process described in section 3.2. This update only included 2019 for a calendar-year snapshot of the market. These data enabled us to characterize the sales-weighted manufacturer-reported values of IMEF, IWF, RMC, and basket size for a given washer group. The market-weighted percentages incorporated into our methodology are based on data collected on 367 RCW models representing all 2019 ESRPP sales in the Northwest. For CCW, we developed an average of the CEC's MAEDbs compliance database models, as CCW ESRPP data are not available. The market-weighted percentages incorporated for CCW are based on manufacturer data collected on 259 CCW models.

Step 2: Develop adjustment based on lab testing and field data to compute real-world RMC

Figure 12 below illustrates the RMC adjustment factor formula used to update RMC with real-world estimates for each RCW and CCW. The $Weighting_{field}$ is from RBSA Laundry Study data (see Table 12) and is the same for each washer. The RMC_{lab} variable is unique for each washer based on individual test results shown in Table 10.[9] Next, we multiplied the RMC Adjustment Factor by the DOE RMC to obtain the real-world RMC for each UUT. We confirmed that the individual variables could be isolated in this way with a methodology check (details in Appendix D).

[9] For the textile type adjustment, the calculation uses the difference between Run F and Run A shown in Table 10.

$$RMC\ Adjustment\ Factor = \frac{Lab\ RMC_{J2} + (\sum \Delta\ RMC_{lab} * Weighting_{field})}{Lab\ RMC_{J2}}$$

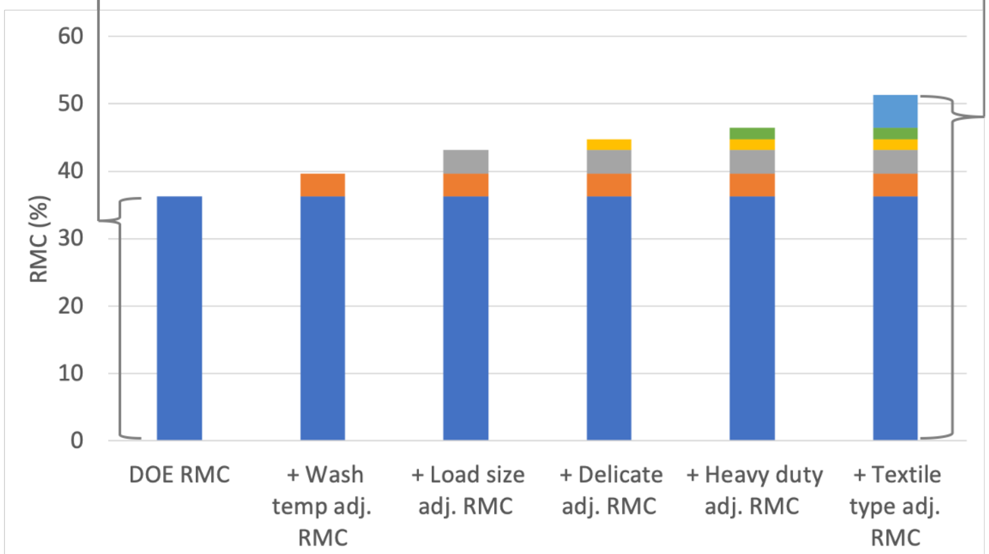


Figure 12. Real-world RMC estimate methodology on UUT 08.

Table 12. Weighting of variables in RMC adjustment factor methodology.

Field parameter	***Weighting*** $_{field}$	DOE J2 Value for RMC Measurement	Adjusting to?	Relevant Field Data (percent of total runs)	Source(s)
Wash Temp	66%	Cold	Not Cold (Warm + Hot)	Sum of 57% warm and 9% hot	Hannas and Gilman 2014, Table 24, All Loads, p. 78
Load Size	100%	Maximum load	Field Average (8.45 lb)	Field average is 7.6 lb, similar to 8.45 lb used in full sample test phase	Hannas and Gilman 2014: Table 1, All Loads, p. 15
Program	13%	Normal program	Heavy Duty	Sum of 7% Super/Ultra, 4% Heavy Duty, 1% Bulky[a]	Figure 1, Section 2.2.3 herein.
	6%		Delicate	Delicate/Silk/Hand Wash 6%	
Textile Type	16%	50% cotton / 50% synthetic	AHAM Cotton	16% heavy weight like AHAM Cotton load	Hannas and Gilman 2014, Table 23, All Loads, p. 78

Notes: [a]Note that the sum of these values is 13% given partial percentages not shown here.

Step 3: Develop equation with real-world RMC as a function of DOE J2 (Run A) RMC

Drying energy is nearly directly proportional to the RMC from the washer, [10] so using a statistically supported real-world RMC estimate is critical to developing valid UEC estimates. In this step we applied the RMC Adjustment Factors (step 2) for each unique UUT to its DOE J2 RMC (Run A). We then plotted that value (called "calculated real-world RMC") as a function of DOE J2 RMC (Run A) to establish an equation that will allow stakeholders to find real-world RMC as a function of the manufacturer-reported DOE J2 RMC values. However, our testing revealed uncertainties in real-world RMC that significantly impact confidence levels in calculated real-world RMC and resulting UEC estimates.

Calculated real-world RMC values showed wide variations for a given J2 RMC (Run A). These variations, foreshadowed by the rank order differences discussed in section 4.4, create a relatively high degree of uncertainty when trying to predict the relationship between J2's measurement of RMC and a real-world RMC for a group of washers ($R^2 = 0.33$ for RCW in Figure 13 and $R^2=0.53$ for CCW and RCW in Figure 14). For example, in Figure 13, similar RMC values measured under DOE J2 test (Run A) can significantly differ in the real-world RMC of RCWs. Around 27% RMC on the horizontal axis (DOE J2 RMC) results in 39 to 51% real-world RMC shown on the vertical axis. There are other examples of this type of wide variation as well. There is less variation when RCW and CCW data are combined (Figure 14), given that the two CCW tested have less spin program variation than the 12 RCWs (Table 11).

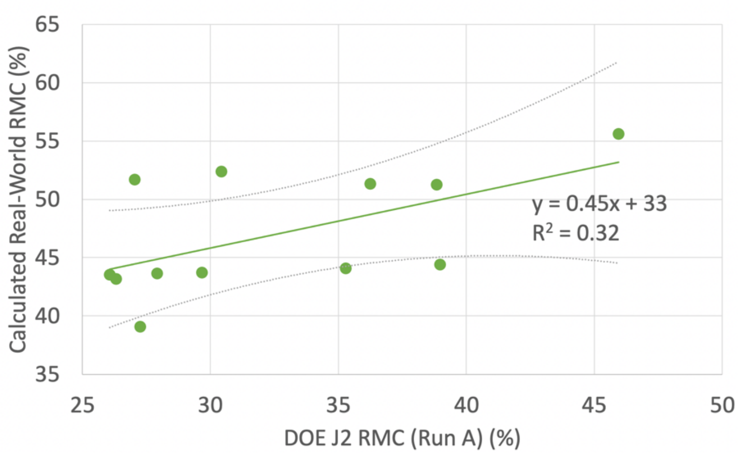


Figure 13. RCW calculated real-world RMC as a function of DOE J2 RMC (Run A).

[10] Given that J2 assumes some moisture is left in the textiles at the end of the drying cycle, the drying energy is not exactly directly proportional to the RMC of the washer.

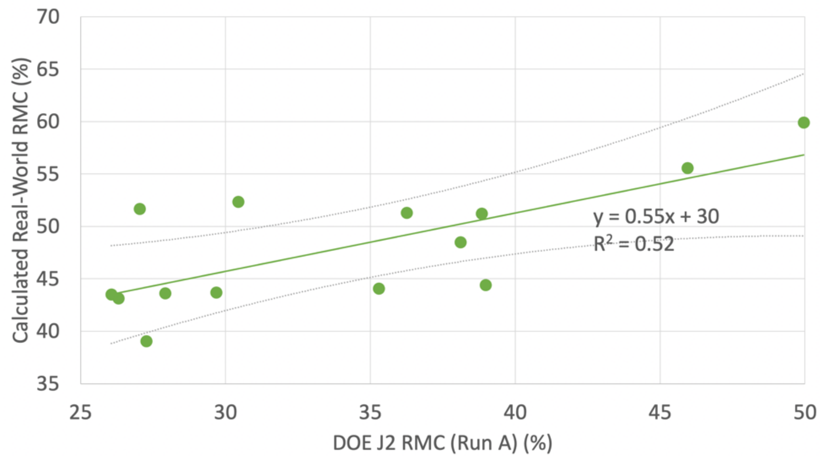


Figure 14. CCW and RCW calculated real-world RMC as a function of DOE J2 RMC (Run A).

Figure 15 also helps to demonstrate the issue. UUT 11 (top) showed very little difference in RMC across different real-world variables, while UUT 02 (bottom) showed dramatic increases in RMC when using different load sizes and program settings. These disparities mean adjustments vary by machine, which in turn leads to uncertainty when trying to estimate real-world RMC for a given group of washers.

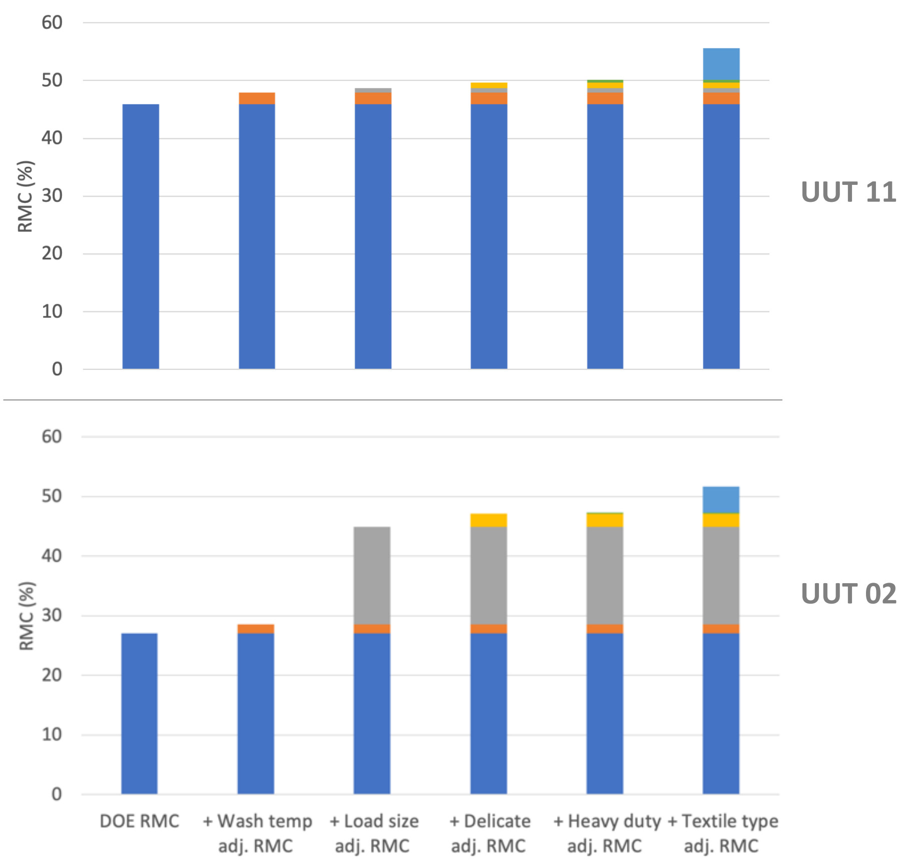
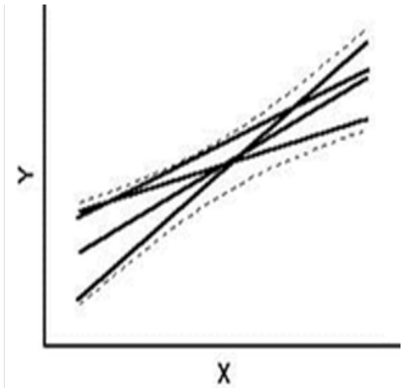


Figure 15. Real-world RMC calculation comparison: UUT 11 (top) and UUT 02 (bottom).

From a statistical perspective, this variation for very similar units means that there is uncertainty in the slope of lines shown in Figures 13 and 14 above[11] (slope line options are illustrated at the right; Zaiontz 2020). Despite this uncertainty, this team's calculations confirm a greater than 90% confidence that the slope of line predicting the calculated real-world RMC is positive. It is worth noting that the project team carefully considered other approaches for developing the adjustment factor that focused primarily on segmenting groups differently. In short, they required various arbitrary decisions that could make significant differences in outcomes.



Putting all the data together as a linear function removes the arbitrary grouping choice and enables the data alone to drive the correction. In Figure 16, the slope of the green line (adjusted RMC, Figure 16) shows the lower RMC values (ESME and ESV8 FL) have a greater adjustment factor than the NQ models when compared to a theoretical scenario of "no adjustment" shown as the yellow line (DOE J2 RMC=real-world RMC). This demonstrates that this approach of grouping the washers capture the overall trend in the data that washers with lower DOE J2 RMC have a larger adjustment to real-world RMC than NQ models with higher DOE J2 RMC. Additionally, RTF took a similar approach with its 2018 analysis of clothes washer savings (NWPCC RTF 2018b).

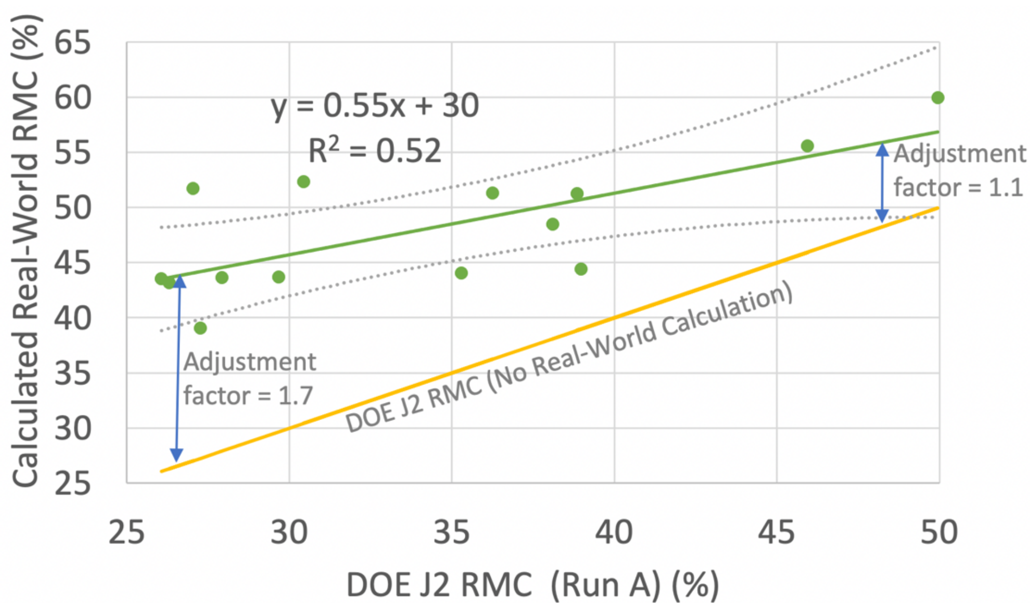


Figure 16. CCW and RCW calculated real-world RMC with average correction factors.

[11] For Figures 13 and 14, we followed the instructions in Liengme 2020 for how to calculate the 95% confidence region of the curve fit in Excel.

KEY FINDING: We conclude that the linear function reflects differences in RMC adjustment factors among the four washer groups under study. Despite some uncertainty, it is still the most technically sound and best method for calculating real-world RMC for a given washer group.

Step 4: Apply Step 3 equation to Step 1 average RMC to calculate real-world RMC

We entered the Average DOE J2 RMC for a given washer group (from Step 1) (shown in Table 13 below) into equations shown in Figure 13 (for RCW) and Figure 14 (for CCW) from Step 3. The output of those equations is the calculated real-world RMC. The error shown on the calculated real-world RMC represents the 95% confidence interval of the curve fit shown in Figure 13 (for RCWs) and Figure 14 (for CCWs). Given this, the error in the calculated real-world RMC differs slightly depending on the confidence in the linear fit for the relevant portion of the lines shown in Figures 13 and 14. The uncertainties shown in Table 13 are appropriate for comparing groups of washers only.[12] For reference, the average RMC adjustment factor for a given washer group is also included.

Table 13. Calculated real-world RMC and other associated values.

Market Segment	Washer group	Loading Style	IMEF[a]	IWF[a]	Average DOE J2 RMC[a]	Calculated Real-World RMC	RMC Adjustment Factor
RCW	ESME[b]	Front	2.91	3.11	29.4	45.9±4.0	1.56
	ESME 2017[c]	Front	2.77	3.11	28.9	45.6±4.1	1.58
	ESV8	Front	2.12	4.03	31.2	46.7±3.6	1.50
	NQ	Front	1.84	4.42	27.5	45.0±4.6	1.64
	ESME 2017[c]	Top	2.76	3.20	31.0	46.6±3.6	1.50
	ESV8	Top	2.09	4.18	36.2	48.9±4.1	1.35
	NQ	Top	1.57	6.63	42.3	51.7±6.7	1.22
CCW	ESV8	Front	2.55	3.88	34.7	48.6±3.2	1.40
	NQ	Front	2.00	4.09	36.4	49.5±3.3	1.36
	NQ	Top	1.53	8.08	50.2	57.1±7.6	1.14

Notes: [a] As measured by DOE J2 and reported by manufacturer to compliance database (described in Step 1).
[b] This refers to ESME 2018 specification. ENERGY STAR annually releases ESME criteria; however, no changes have occurred to the energy metric since last updated in 2018 (U.S. EPA 2018).
[c] This refers to ESME 2017 specification (U.S. EPA 2017a).

As expected, all machines' RMC adjustment factor is larger than 1.0, indicating that all machines spin more water out of the textiles in the J2 RMC tests than they do in real-world conditions. The adjustment factor for front-load machines tends to be higher than top-loading

[12] If one wants to calculate the error of the Calculated Real-World RMC for an individual washer, a different uncertainty methodology is appropriate. First, take the difference of the 14 individual washer adjusted values from the correlation line. Then, sum the squares of those differences and divide by 13 (the number of samples minus one, because the group is a sample rather than a population). Finally, take the square root of this quantity to find the standard deviation from the curve fit. This yields 4.0 percentage points, so a 95% confidence interval is +/-8.0 percentage points.

machines within a given market (residential or commercial). This indicates that on average, front-loaders have a more considerable difference in RMC performance between the lab and the real-world than top-loaders do. This is also observed in Figure 16.

We compared these results to other past Northwest research and confirmed that they generally agree with former RMC findings (Table 14 below). Using ESRPP data from 2019 and Table 13 above, we calculated the full market-weighted average of RCW's RMC adjustment factors in 2019 (Table 14). We then compared these market-weighted values to past market-weighted and field average RMC values available in literature for DOE J2 RMC, average field RMC, and RMC of 100% (or nearly 100%) cotton textiles. We then computed similar RMC adjustment factors for alternate years (where data are available) and compared them to this work. The market average DOE J2 RMC has improved (reduced) over time as washer extraction technology has continued to improve. In 2008, the DOE J2 RMC average was 47%, but with 2019 vintage machines, it improved by more than ten percentage points to 36%. Our findings document that these technology improvements affect real-world RMC as well, as the RMC in the field calculated with this work is lower than the field RMC measured in 2018 (now 49% on average compared to 63% measured in 2008). However, the adjustment factor in 2008 (1.34) and 2019 (1.36) is highly similar, given that our methodology assumes there have not been significant changes in how people do laundry over this time period. We conclude from these comparisons that this work logically fits with other regional work.

Table 14. Comparison of average RMC adjustment factors to past adjustment factors.

Market average	Machine Vintage		
	2008	**2016**	**2019**
DOE J2 RMC	47%[a]	37%[b]	36%
RMC in field	63%[c]	NA	49%
RMC of 100% cotton textile	NA	62%[b]	65%
RMC Adjustment Factor[d]	**1.34**	NA	**1.36**
Ratio of DOE J2 RMC to 100% cotton textile[e]	NA	1.68	1.80

Notes: [a] (U.S. DOE 2011)
[b] Calculated by NWPCC RTF (2018b; NEEA Washer Lab Tests Tab) based on NEEA 2016 ESRPP market data and NEEA lab measurements of washer RMC with the NEEA dryer load (Dymond 2017).
[c] Measured washer RMC in the Northwest, as reported by Hannas and Gilman (2014, p. 15).
[d] As defined by Figure 15 for 2019 data (this work). For 2008 data, we calculated the RMC adjustment factor by taking RMC in field divided by the DOE J2 RMC.
[e] Used in this study only for comparison to past studies and is defined as the RMC of the 100% cotton textiles used in the 2016 and 2019 testing divided by the DOE J2 RMC.

Understanding how these real-world RMCs may impact unit energy consumption (UEC) is discussed in the next section.

4.5.2. Real-World RMC Discussion and Implications

While RMC is nearly directly proportional to drying energy and has a significant impact on IMEF, IMEF considers other aspects of washer energy use. Specifically, washer UEC is the sum of drying energy, hot water energy, machine cycle energy, and (for RCW only) standby energy. To better understand the implications of the real-world RMCs shown in Table 13 above, we selected key categories of RCWs—ESME, ESV8 FL, ESV8 TL, and NQ—and calculated their UEC. *For this calculation, we only adjust RMC and corresponding drying energy*. Figure 17 compares the following UEC values:

- UEC predicted by DOE J2 (with DOE J2 values),
- UEC calculated by RTF in 2017,
- UEC currently used by NEEA in its washer program (based on 2019 market data), and
- UEC as calculated in this project.

Note that this project used regional adaptations of key calculation constants similar to RTF 2017 regional adaptations. For this work, the "+" symbols mark the 95% confidence interval of these estimates. Because of variability in RMC observed in testing and the uncertainty of linear fit discussed in step 3 of section 4.5.1, we see a relatively wide confidence interval in the UEC estimates of this work (2020 NEEA in Figure 17 below).

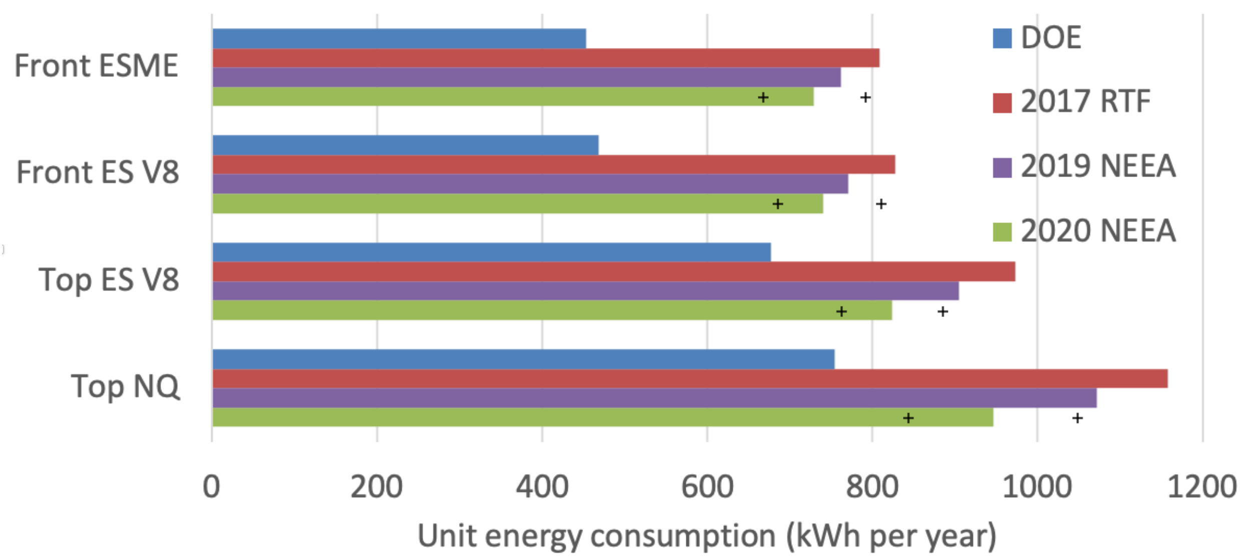


Figure 17. Efficiency level UEC (kWh per year) by RCW category.

From these calculations, we expect regional estimates of washer UEC to be lower than past RTF estimates but still much higher than DOE-derived estimates. (Some of this reduction from RTF values may be due to washer RMC improvements as spin technology gets better over time.) The estimates are limited because J2 does not effectively predict RMC; consequently, the uncertainty of the savings numbers is relatively high. (Recommended improvements to J2 are discussed in 4.7.) Despite the challenges noted, this research offers NEEA and other stakeholders a more sophisticated adjustment approach for washer UEC estimates, which will functionally support RTF in developing its upcoming revisions to regional UEC and UES estimates.

4.5.3. CCW Cycles Per Day and Other Values Used for CCW UEC Calculation

As part of this project, the team reviewed literature to identify the number of CCW cycles per day for RTF updates of CCW UEC and UES estimates. We identified one other data source for commercial dryer energy factor (DEF) that may be useful to RTF. Values and references are listed below:

- Multifamily CCW: 3.0 cycles per day (U.S. DOE 2014) and 2.5 cycles per day (Manthei 2013).
- Laundromat CCW: 4.1 cycles per day (U.S. DOE 2014) and 4 cycles per day (Manthei 2013).
- On-premise laundry (OPL) CCW: range 1 to 31 cycles per day, depending on facility type (TRC 2015, Table 4, p.11). Our calculations indicate including this higher OPL duty cycle in the CCW weighted average duty cycle increases the average from 3.16 cycles per day (multifamily and laundromat only) to 3.26 (average of multifamily, laundromat, and OPL).[13]
- Commercial clothes dryer energy intensity (dryer energy factor or DEF): J2 uses 0.5 kWh/lb water removed, but RTF uses 0.66 kWh/lb water removed based on field and laboratory studies showing that dryer efficiency is lower than measured by the DOE dryer test procedure (NPCC 2018a). Commercial dryers are unregulated, and there is evidence they are significantly less efficient than residential dryers (Foster Porter and Denkenberger 2016.) Therefore, DEF for CCW is likely to be even higher than 0.66 kWh/lb water removed used for CCW DEF in RTF's prior analysis.

Additional CCW findings are detailed in section 4.8.

4.6. Subset Test Runs with J2-defined Average Load

Given potential issues with the representation of typical load sizes in J2 (section 2.2.4), we selected a subset of RCW (UUT 02, 08, 11) with a larger basket size of 5.2 cu ft to examine energy use differences between two middle-sized loads (section 3.3.2): 1) J2-defined *Average* load of 12.25 lb (Run H, Table 9), and 2) Typical middle-sized load of 8.45 lb (Run C, Table 9).

We compared hot water energy, machine energy, and drying energy of these two load conditions. We found that average hot water energy did not change with load size. However, machine energy and drying energy did scale with load size. Specifically, moving from a 12.25 lb to an 8.45 lb load is a 31% reduction in load size; average drying energy was 31% lower with the smaller load; machine energy was 9% lower with this smaller load. Overall-water use declined by 11% as well. We conclude from these findings that selecting an appropriate middle-sized load is important to effectively characterize typical drying energy, machine energy, total machine energy, and total water use.

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[13] In this calculation, we assumed that the stock of less than 30 lb dryers in TRC 2015 corresponded to the stock of the current scope CCW in installed in OPL facilities. We scaled the 2400 units in California by population to 20,000 units in the US. This increased the total national stock of CCW by 0.9%. Then, we assumed the 14 cycles per day of the clothes dryers in this study equals cycles per day for CCW. This increases the CCW national weighted average of 3.16 cycles per day (multifamily and laundromat only) to 3.26 (average of multifamily, laundromat, and OPL).

With lab testing and analysis complete, the project team developed a supplemental protocol to more accurately measure real-world energy use.

4.7. Recommendations for J2 Plus Test Procedure

In collaboration with NEEA's Consumer Products team and the Energy Codes and Standards team, we identified nearly a dozen opportunities to improve the J2 test protocol for RCW and CCW so that it more realistically measures energy use as the machines typically perform. Some of the identified improvements were a direct result of project data. Other changes are based on a literature review or analysis of other available data. During this project, NEEA responded to DOE's test procedure RFI for clothes washers. Many of these recommendations are also detailed in the comment letter to DOE on that topic (NEEA 2020b).

We recommend five of these test procedure improvement opportunities as immediate changes to the test procedure for two reasons. First, they are simple to implement and unlikely to require additional lab tests above and beyond those currently specified in J2. Second, <u>these test procedure changes could yield substantial savings for washers, even in the absence of changes to the standards level (NEEA 2020b).</u>[14] These savings represent the vast majority of energy savings (~80%) that can be achieved with test procedure changes. They are listed in order of importance:

1. Measure RMC at default spin setting for each wash temperature and load size and average those RMCs using temperature use factors (TUFs) and load use factors (LUFs).
2. Eliminate multiple warm wash test runs and with a single test run on the wash temperature setting labeled Warm.
3. Calculate additional metrics, including pound per kWh and kWh per cycle.
4. Enable region-specific energy calculations.
5. Make a mathematical adjustment to a more realistic cloth composition.

Supplemental instructions enabling these five changes are detailed in a separate document called *<u>J2 Plus</u>* (provided for reference in Appendix E), and a discussion of each change follows. The full list of test procedure changes the project team identified can be found in Appendix F.

4.7.1. Weighted Average RMC Measurement

Data collected under this project supports removing the specific RMC test runs (section 3.8 of J2) and, instead, measuring RMC at the default spin setting for each temperature selection and load size. Then, average those RMCs using TUFs and LUFs in the same way the test procedure calculates other energy use parameters. This benefits multiple stakeholders by reducing test

[14] Pages 3 and 17 of NEEA 2020b provide information on the methodology used to calculate an estimated 35% savings in drying energy associated with test procedure changes (13% p. 3 and 23% p. 17). Because drying energy is a substantial portion of the energy use counted for washers (Section 2.2.2), this reduction in drying energy use yields significant energy savings for overall washer energy use as well.

burden by 8 to 15% (due to removing one or two test runs typically performed exclusively for RMC measurement) and increasing representativeness (by capturing RMC for all load sizes and water temperatures). Further specifics regarding this recommendation can be found in comment A.1 in NEEA 2020b.

4.7.2. Single Test Run on Warm Wash Temperature

Market data collected by NEEA's Energy Codes and Standards team supports eliminating the requirement for multiple test runs to represent the Warm/Cold condition, and instead, characterize the Warm/Cold temperature selection by a single test run on the wash temperature setting labeled Warm. Dropping the requirement offers the significant benefit of reducing the test burden on manufacturers. We estimate that this recommended change will eliminate six test runs from the test procedure (three load sizes at two wash/rinse temperatures), reducing the test burden by approximately 25 to 45%, depending on the model and the number of Warm wash selections offered on a particular machine. This benefit is expected for a sizeable percentage of the market given that more than 75% of washers sold in the Northwest have three or more discrete Warm/Cold temperature selections. NEEA's market data analysis supporting this recommendation can be found in comment B.1 in NEEA 2020b.

4.7.3. Alternative Energy Efficiency Metrics

Analysis of project data and other research supports developing an alternative energy efficiency metric, such as lb of textile per kWh or kWh per cycle, based on the LUF-weighted load size of the machine and the LUF- weighted and TUF-weighted energy use per cycle measured in the test procedure. These metrics are alternatives to IMEF. The lb per kWh metric enables calculation of UEC based on pounds of textiles washed per year rather than the number of cycles and is similar to DOE's test procedure for dryers. Either of these metrics enable washers of different basket volumes to be compared to one another more effectively. Further detail on this recommendation can be found in comments A.1 and C.5 in NEEA 2020b.

4.7.4. Region-Specific Changes

NEEA field data and other literature support the development of alternative test procedure calculations using region-specific constants:

1. Increase the dryer energy factor (DEF) to 0.66 kWh per lb of water.
2. Change LUF and TUF to match the RBSA Laundry Study and increase the number of load cycles to match field data (313 cycles per year).
3. Increase dryer usage factor (DUF) to match field data (0.935 of cycles).

J2 Plus has instructions that enable these region-specific calculations but maintains parallel calculations using DOE's constants for those stakeholders that prefer the national constants instead. Further detail on these recommendations can be found in comments D.1, C.4, and C.6 in NEEA 2020b.

4.7.5. Cloth Composition Mathematical Adjustment

Given that washing efficacy is not currently included in J2, as it is in AHAM HLW-1-2013 and IEC 60456 (2010), retaining the J2-specified 50% cotton 50% synthetic test cloth for near term testing is justifiable. As discussed in section 4.2, test results showed that a fairly simple mathematical adjustment for textile type can be made for the AHAM Cotton load. Specifically, we recommend the RMC used to calculate drying energy for a given washer, including a 16% weighted adjustment to AHAM Cotton to reflect those heavyweight and 100% cotton loads found in the field (16% from Table 12). We recommend that the AHAM Cotton mathematical adjustment be a simple average of the two mathematical relationships shown in Figure 2. We consider this adjustment a near-term step toward better real-world representation in J2.

In the future, adopting the AHAM Cotton load in J2 presents some opportunities not specifically explored in this research. First, a more realistic cloth like AHAM Cotton would enable cleaning efficacy testing to accompany efficiency testing (as is currently done in IEC 60456). Second, research has documented that J2-specified cloths do not adequately predict clothes dryer performance, and a load with greater diversity of thicknesses and shape (like AHAM Cotton) could be more effective in predicting energy use (Dymond et al. 2012 and Denkenberger et al. 2012). Moving to AHAM Cotton for both dryers and washers would enable a consistent textile for assessing their combined energy use.

KEY FINDING: <u>Test procedure changes to improve the estimate of real-world drying energy also lower test burden for manufacturers by 8 to 15%. Other test procedure changes recommended herein further improve representativeness and reduce burden by 25 to 45%. These test procedure changes could yield substantial energy savings for washers use even without changes to the standard level.</u>

4.8. Commercial Clothes Washers

As part of this project, the project team considered CCW lab results and reviewed literature to identify new information RTF can leverage in its next CCW UEC/UES update and future CCW energy savings opportunities for the region. Overall, we concluded that there are many reasons for the Northwest to give the efficiency of CCW more attention in the future. Opportunities to save energy in CCW are abundant, both because our testing revealed CCW have a greater opportunity to improve water extraction than their RCW counterparts and because not all energy use and savings of CCW are currently quantified. Furthermore, a stronger focus on CCW efficiency may help address equity issues in Northwest energy efficiency appliance efforts. Specifically, we identified the following four CCW observations and recommendations:

1. Lab testing revealed opportunities for improvements to CCW water extraction and, therefore, reductions in drying energy.
2. OPL facilities could be included in future RTF energy estimates.
3. Larger CCWs could be included in future RTF energy estimates.
4. A focus on CCW efficiency may help address equity issues in energy efficiency.

Similar points are detailed in NEEA's CCW letter to DOE (NEEA 2020c) and are summarized below.

Lab testing revealed opportunities for improvements to CCW water extraction and therefore reductions to drying energy.

Lab testing revealed that CCW spin speeds are lower and RMCs are higher than comparable RCWs. Figure 18 shows maximum spin speed and RMC of washers measured with the RMC test specified in Appendix J2 (Run A). The top-load CCW is among the slowest spinning top-load RCWs tested (Figure 18, left), and the RMC is the highest of the top loaders (Figure 18, right). The spin speed of the front-load CCW was 22% lower than the average front-load RCW. Furthermore, the front-load CCW RMC was 39% higher than the average of front-load RCWs tested. While not all of the RMC difference between RCWs and CCWs is attributable to a difference in spin speed, the significant difference in RMC between the markets is still notable.

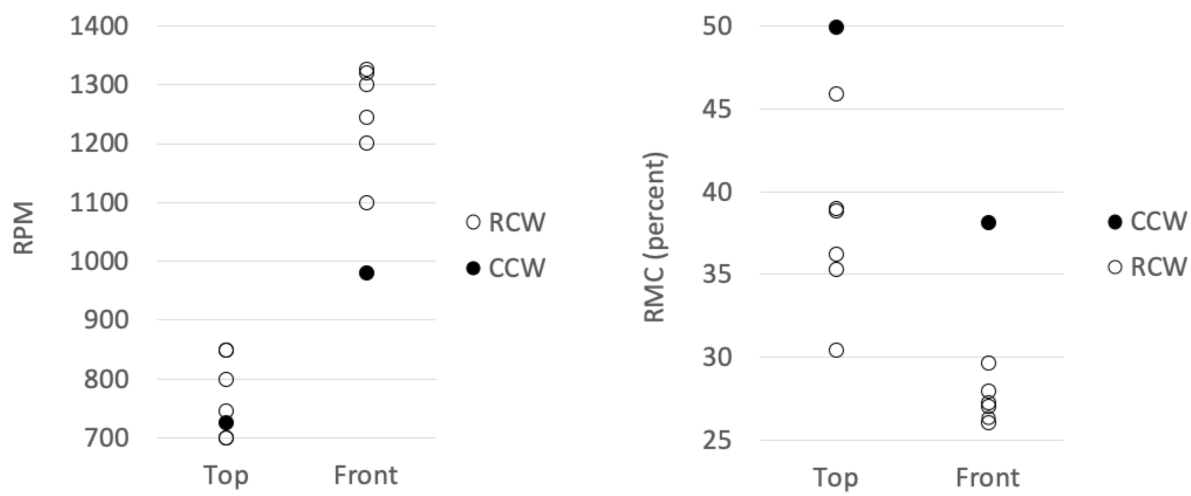

Figure 18. Comparison of CCW and RCW spin speed (left) and RMC (right) as measured under J2 (Run A).

Increasing spin time to reduce RMC may not be an effective approach for the commercial setting given the importance of shorter cycle times for consumer convenience (multifamily and laundromat) and critical business functions (OPL). Increasing spin speed to extract more water, however, seems appropriate for CCW. Additional technologies available to improve the efficiency of CCW are discussed in comment 2 of NEEA 2020c.

Consider including OPL facilities in RTF energy estimates.

Currently, RTF analyses only consider CCW installed in multifamily buildings and laundromats. Some CCWs covered by DOE's current definition are installed in facilities such as spas, hair salons, assisted living centers, and fire stations. These OPL CCWs with non-vended control panels enable employees to launder various textiles needed for standard operations (e.g., towels, sheets, and uniforms). In the last final rule of CCWs, DOE did not evaluate the energy use and savings of equipment installed in OPLs, citing a lack of data (U.S. DOE 2014). Since 2014, the CEC has published such data on the installed stock and duty cycle of OPL equipment (TRC 2015). While this study focuses on clothes dryers, the number of dryer cycles and stock can reasonably be assumed to be similar to washers in the same facility. While we expect the total number of OPL CCWs installed to be smaller than the total CCWs in multifamily laundries and laundromats, the same CEC research revealed the number of cycles per day in an OPL is much higher than CCWs used in multifamily laundries or laundromats (detailed in section 4.5.3). Therefore, NEEA encourages RTF to quantify the energy use and savings of the OPL CCW category in its analysis using the CEC-published studies and other available data.

Larger CCW could be included in future RTF energy estimates.

RTF's CCW scope does not address larger washers' energy and water use up to 8.0 cu ft (approximately 60 lb rating). This may be because CCW's definition in federal code is limited to machines with basket sizes no greater than 3.5 cu ft for front loaders and no greater than 4.0 cu ft for top loaders (United States Code 2010). Consumers often employ larger capacity clothes washers (both soft-mount and hard-mount) in laundromats and laundry centers found in multi-family buildings. According to CLA, approximately 47% of laundromats' washers have baskets larger than DOE-defined CCW (CLA 2019). These washers enable consumers to wash larger loads and bulky items that do not fit into smaller machines. There are several reasons to expand the scope of CCW to include these larger capacity machines (up to 8.0 cu ft):

- *Significant energy can be saved in the region*. Estimates in NEEA's CCW letter to DOE indicate that expanding the scope to commercial machines up to 8.0 cu ft capacity could save 0.3 quads site energy nationally over a thirty-year timeframe (NEEA 2020c). Scaling by population to the Northwest could mean energy savings of 200 GWh of electricity and 100 million therms of natural gas over thirty years for the region. These numbers are calculated with DOE's assumptions. As noted in section 4.5.3, the dryer energy factor should be at least 1.3 times as much as DOE assumes, significantly increasing the region's energy savings potential.
- *The test procedure can quickly address larger capacity commercial machines*. DOE's test procedure and test procedure waivers granted to Whirlpool and Samsung define guidance for load sizes up to 8.0 cu ft (U.S. DOE 2016).
- *EPA includes larger commercial clothes washers in its ENERGY STAR Program*. There are a number of front-loading larger capacity models in ENERGY STAR's qualified product list (U.S. EPA 2020).
- *More efficient washers help small businesses reduce utility costs*. Creating opportunities to address efficiency for all washers used in a laundromat would help cost-effectively lower utility costs for laundromat owners.

A focus on CCW efficiency may help address equity issues in energy efficiency.
According to the U.S. Residential Energy Consumption Survey (RECS), nearly one-fifth of U.S. households use a centralized laundry facility of some type to clean their family's clothes, bedding, and towels (U.S. EIA 2018). These households are more likely to be low-income than those that maintain a RCW within their dwelling. Saving money on utility bills at these centralized laundries will help mitigate increases in utility costs, making laundry services more affordable for low-income households. Focusing on efficiency for CCWs is likely to benefit many small business laundromat owners too. The 2019 Coin Laundry Association (CLA) survey reports that 60% of laundromat owners cite "high cost of utilities" as one of the biggest problems they face in their business (CLA 2019, p.6) and 58% indicate that utilities are 20% or more of their gross revenue (CLA 2019, p.21). These high utility costs impact rates charged to users of laundromats and multifamily laundries, leading to higher per cycle cost to wash a load.

The points above indicate that expanding CCW focus to larger capacity machines may be warranted. Next, we summarize the regulatory response efforts supported by this project.

4.9. Regulatory Activity for Laundry Equipment

This research proved timely, as crucial findings were used to support NEEA's Codes and Standards team in developing comments to DOE on the following responses to three RFIs and one NOPR for RCW and CCW:

- Docket Number EERE-2020-BT-STD-0001: NOPR for Energy Conservation Standards for Clothes Washers and Clothes Dryers Notice of Proposed Rulemaking (underway at the time of this writing and due October 13) (NEEA 2020a)
- Docket Number EERE-2016-BT-TP-0011: RFI for Test Procedures for Residential and Commercial Clothes Washers (NEEA 2020b)
- Docket Number EERE-2019-BT-STD-0044: RFI for Energy Conservation Standards for Commercial Clothes Washers (NEEA 2020c)
- Docket Number EERE-2014-BT-TP- 0034: RFI for Standards for Residential Clothes Washers (NEEA 2019a)

5. Conclusions

To conclude this project, we demonstrate through an assessment of project objectives that this research effort succeeded in achieving the overarching goal of developing a better understanding of the real-world efficiency of RCWs and CCWs. We also provide suggested areas for additional research.

5.1. Analysis of Objectives

Objective #1 – Identify and isolate important variables observed in NEEA's field studies that have the most significant impact on consumer clothes washer drying energy and are not currently part of DOE's J2 protocol. We found that DOE's momie cloth textile reliably predicts the increased RMC of the AHAM Cotton load. With rare exceptions, all other variable changes in the testing process also consistently increased to RMC from the J2 baseline. We concluded that washer programming drives the differences in RMC for the various test runs, particularly for program differences (e.g., Normal versus Delicate) and changes in wash temperature. These spin algorithms vary widely, even within one group of washers with a similar efficiency level. This variation among machines leads to significant rank order changes when RMC is measured differently (such as alternate load size and Warm/Cold temperature setting). *Altogether, we find that DOE's J2 test protocol does not represent real-world energy use, nor does it reliably measure energy consumption differences among machines.*

Objective #2 – Providing current technical information to enable updates to regional UEC estimates, including the number of commercial cycles per day. The project focused on adjusting UEC to better reflect a washer's contribution to real-world drying energy. Spin algorithm differences within individual models and across different machines created uncertainty in the mathematical adjustments to real-world RMC that account for field-observed program settings, temperature settings, and load size. Because drying energy is nearly directly proportional to the RMC from the washer, these uncertainties create uncertainties in the real-world washer UEC. We also found that the UEC is lower than past RTF estimates but still much higher than DOE-derived estimates. This is largely because past drying energy adjustments for the region were made assuming a nearly 100% cotton NEEA Dryer test load and because RMCs for washers have improved over the last decade. Despite the challenges noted, this research offers a more sophisticated adjustment approach for UEC estimates, which will functionally support RTF in updating the region's UES values. The team also identified values and sources for the number of CCW cycles per day for multifamily, laundromats, and OPL installations.

Objective #3 – Developing a supplemental test protocol that more accurately reflects the typical real-world drying energy use of clothes washers, including consideration of fabric types, program settings, and load sizes for potential use in future NEEA clothes washer incentive programs and national standards/specifications. Considering all research findings, we developed supplemental test instructions—*J2 Plus*—to enable high-priority improvement opportunities to J2 in the near term. It focuses on:

- Using TUFs and LUFs to capture RMC for all load sizes and water temperatures.
- Eliminating multiple test runs to represent the Warm Wash/Cold Rinse condition, and instead perform a single test run on the wash temperature setting labeled Warm Wash.
- Developing an alternative metric such as a pound of textile per kWh or kWh per cycle to replace IMEF.
- Enabling region-specific energy calculations in addition to J2 calculations with alternate values for DEF, DUF, LUF, and TUF that are based on NEEA's field research data.
- Incorporating a cloth composition mathematical adjustment to provide a real-world value for textile load type.

Other recommendations for future test procedure changes were identified as well and can be found in Appendix F.

Objective #4 – Utilizing lab, market, and consumer end-use data for regulatory and programmatic efforts. This research project proved to be timely, as the data and findings were used to support comments to DOE in response to multiple RFIs and a NOPR. Stakeholders are poised to assess programmatic efforts now that RTF can revise UES estimates.

5.2. Suggested Areas for Additional Research

Several topics emerge as opportunities for further research. First, more lab testing of both RCWs and CCWs could focus on a number of areas: 1) increase statistical certainty for UEC estimates, 2) better characterize the untapped savings opportunity for CCW, 3) quantify impacts of settings on hot water energy use, 4) inform test procedure changes for largest capacity RCW, and/or 5) characterize efficiency improvements of specific water extraction technologies that impact drying energy. Second, field studies to update RCW's average use parameters and investigate those same parameters in CCWs would enable better UEC estimates and inform future test procedure recommendations. Finally, further CCW research could enable more rigorous quantification of energy use and savings.

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Appendix A: U.S. DOE 2012 Technical Support Document Tables 7.2.1 and 7.2.2

Table 7.2.1 Top-loading Standard-Capacity Residential Clothes Washers: Per-Cycle Energy and Water Use by Efficiency Level

Level	Vol (ft^3)	Watts	MEF*	IMEF*	IWF (gal/cu ft)	RMC (%)	Energy Use (kWh/cycle)			
							Machine	Dryer	Water Heat+	Hot Water gal/cycle
Baseline	3.09	0.00	1.26	0.84	9.92	51.9%	0.279	2.16	1.24	6.90
1	3.38	0.00	1.40	0.98	9.92	53.6%	0.281	2.43	0.74	4.13
2	3.38	0.00	1.72	1.29	8.44	48.8%	0.228	1.69	0.69	3.85
3	3.76	2.30	1.80	1.34	7.95	37.9%	0.082	1.41	1.26	7.02
4	3.76	1.70	1.80	1.34	7.95	37.9%	0.082	1.41	1.26	7.02
5	3.76	0.08	1.80	1.37	7.95	37.9%	0.082	1.41	0125	4.92
6	3.86	0.08	2.00	1.57	6.47	36.6%	0.082	1.38	0.99	5.50
7	3.96	0.08	2.26	1.83	4.96	36.6%	0.077	1.41	0.67	3.74
8	4.34	0.08	2.47	2.04	4.10	34.8%	0.082	1.39	0.66	3.67

* cubic feet/kWh/cycle + based on use of electric water heater

Table 7.2.2 Front-loading Standard-Capacity Residential Clothes Washers: Per-Cycle Energy and Water Use by Efficiency Level

Level	Vol (ft^3)	Watts	MEF*	IMEF*	IWF (gal/cu ft)	RMC (%)	Energy Use (kWh/cycle)			
							Machine	Dryer	Water Heat§	Hot Water gal/cycle
Baseline	3.00	2.30	1.72	1.37	8.31	41.4%	0.113	1.31	0.69	3.86
1	3.00	1.70	1.72	1.39	8.31	41.4%	0.113	1.31	0.69	3.82
2	3.00	0.08	1.72	1.41	8.31	41.4%	0.113	1.31	0.70	3.88
3	3.00	0.08	1.80	1.49	7.80	41.4%	0.113	1.31	0.60	3.31
4	3.30	0.08	2.00	1.66	6.26	41.6%	0.163	1.42	0.40	2.22
5	3.41	0.08	2.20	1.84	4.73	38.6%	0.154	1.34	0.36	1.99
6	3.60	0.08	2.40	2.02	4.42	38.7%	0.164	1.41	0.20	1.13
7	3.83	0.08	2.60	2.20	4.01	36.2%	0.167	1.37	0.21	1.14
8	3.90	0.08	2.89	2.46	3.39	35.9%	0.155	1.38	0.04	0.25

Appendix B: Commercial Clothes Washer Sampling Plan Detail

For the two CCW units (UUT 13 and 14), the project team had to consider and weigh multiple variables in the selection process. Washers categorized as commercial can come in various forms:

- Soft mount (not secured) and hard mount (typically bolted to the floor)
- Residential size (3.5 cu ft) up to 30 cu ft (200 lb loads)
- On-Premises Laundry (OPL) used by a business to wash laundry on-site (e.g., businesses that depend on a consistent supply of fresh linens, such as salons and gyms)
- Vended laundry used in multifamily buildings and laundromats (owners may have an incentive for machines with higher RMC; i.e., more money is needed by the customer to dry the clothes)

Given the wide range of products and project scope that enabled the selection of only two commercial washers, the team narrowed their focus to machines within the DOE purview, are soft mounted, and have a smaller basket size (3.5 cu ft front-load). These units would generally be considered residential-sized (residential platform) commercial machines. Three efficiency levels exist for commercial washers within the chosen scope (vs. four in residential): ENERGY STAR front-loading, non-qualifying front-loading, and non-qualifying top-loading.

RPP sales data do not exist for this product category, so the project team used the number of models in the DOE database as a proxy for market share to identify market-dominant manufacturers. It listed a total of 165 models, which were filtered in the same manner as RCWs. The resulting sample units selected include an ENERGY STAR qualified front-loading model and a non-qualifying top-loading agitator model. Both are commonly used in laundromats and multi-family installations.

This approach's advantage is that it tends to reflect systematic differences between ENERGY STAR and non-ENERGY STAR markets. It also is consistent with guidelines and language for RCWs, avoids speculating on consumer psychology, and is easy to implement. This approach's disadvantage is that the models selected are probably not comparable purchase alternatives to a buyer. Another is that there is a greater influence of untended confounding variables (i.e., the two models may have random differences that have little to do with real differences between the two markets). Nonetheless, it achieves measuring the range of efficiencies within identified parameters to support RTF efforts to update savings estimates.

Appendix C: Test Data

Appendix D. Adjustment Methodology Check

We investigated to determine whether various variables could be isolated and considered separately to adjust RMC. We compared two scenarios to test for interactive effects:

- *Measured RMC.* We conducted a lab test with several variables combined into one test run (Run G: Normal Program, Warm wash, AHAM Cotton cloth, and 8.45 lb load size).
- *Calculated RMC*. We calculated the RMC starting with Run A (DOE J2 RMC) and then made three adjustments (wash temperature, load size, and textile type).

An alternate program (such as Delicate) was not included in the investigation, given the Normal program is the most common, so its interactive effects were the most important to consider.

On average, for the 12 RCW, the calculated RMC was only 0.2% wetter than the measured RMC; therefore, we did not make any adjustment for interactive effects in our RMC Adjustment Factor equation. The percentage change RMC (not percentage point change) for the four groups of washers in the project are shown below. A positive value means the calculated RMC is wetter:

- ESME FL: -2.9%
- ESV8 FL: -0.5%
- ESV8 TL: 2.4%
- NQ TL: 1.5%

Note that these values are independently rounded, and when averaged, they will produce a slightly lower result than 0.2%.

Appendix E. J2 Plus Test Protocol

At the time of this writing, the J2 Plus supplemental test procedure was still being finalized, so the document is not included in this initial report publication. An updated report will be issued upon its completion, and J2 Plus will be included as Appendix E.

Any questions about J2 Plus can be directed to Eric Olson, Senior Product Manager, at NEEA.

Appendix F. Additional Opportunities to Improve the J2 Test Procedure

In addition to the five test procedure changes recommended for immediate adoption in the *J2 Plus* test instructions (section 4.7), we recommend six other test procedure changes based on lab testing, research, and analysis. These changes were developed in collaboration with NEEA's Consumer Products team and the Energy Codes and Standards team. Opportunities for future improvements are listed below. The rationale for the first five changes can be found in the specified section of NEEA's test procedure letter to DOE (NEEA 2020b). The rationale for the sixth recommendation follows the list below. The six changes include:

1. Add standby tests for commercial washers and incorporate them into metric calculations (letter section A.5).
2. Change "Average" middle-sized load in test procedure to a fixed 7.6 lb load size (letter section C.3; also section 4.6 of this report).
3. Update the textile bone drying procedures to enable better repeatability and reproducibility of RMC measurements (letter section D.4).
4. Incorporate additional tests for alternate water fill systems and settings (letter section B.3).
5. Include standby energy use of connected functionality (letter section B.2).
6. Add programs such as Delicate and Heavy Duty to test procedure (rationale below).

Add Programs such as Delicate and Heavy Duty to Test Procedure

As discussed in section 3.3.1, Delicate and Heavy Duty were among the washer programs documented in the field (section 2.2) and were selected for testing because they were shared across all washers in NEEA's sample. We compared results from Run A to Run D and Run E and found significant increases in drying energy use, water heating energy use, and water use overall. Table 10 shows RMC increased significantly for both Delicate (85%) and Heavy Duty (17%) programs, increasing drying energy use substantially. Although not the focus of this project, we also found that RCW hot water energy use increased by 1.2 gallons for Delicate and 10.1 gallons for Heavy Duty. Average RCW water use increased by 48% for Delicate and 39% Heavy Duty. On average, RCW machine energy—which is the smallest share of energy use in the IMEF metric—decreased 66% for Delicate and 58% for Heavy Duty.

Given that machine energy is the smallest share of energy use, and all other aspects of washer energy use increased with both Delicate and Heavy Duty in this comparison, test data indicate that Delicate and Heavy Duty programs may use more energy than the Normal program. We recognize that Run A is not the specific energy use that would be reported out of the test procedure for a given washer. Still, these differences on a single test run comparison suggest that programs other than Normal are likely to use differing and possibly higher amounts of energy, and likely impact the typical average efficiency and energy use of a washer. Future research could consider alternate programs more extensively than possible under this project and considered for inclusion in future test procedure revisions.