Northwest Energy Efficiency Alliance (NEEA) Retail Products Portfolio (RPP) Methodology Documentation for Residential Clothes Washers

Table 1: Report Summary

Product	Clothes Washers
Last Updated:	October 01, 2018
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1. Introduction

This automatically-generated document reports the methodologies and assumptions used to calculate the sales-weighted unit energy consumption (UEC) of **residential clothes washers** (by product class) for the Northwest Energy Efficiency Alliance (NEEA) Retail Products Portfolio (RPP, also used interchangeably with 'Retail Products Platform') Program[1]. Since NEEA uses these calculated values to track and estimate long-term energy savings, it is important that the methodologies and assumptions are well-documented, transparent, and reproducible. This document is generated using `R Markdown`. The values reported in this document are retrieved from the same R source code used to calculate energy savings and thus reflect the actual values used as of the report generation date. Manual revisions to this document shall be tracked in Appendix Section A.1

2. Methodology

To calculate the sales-weighted UEC of each clothes washer product category, NEEA performs the following steps:

1. Acquire RPP sales data from RPP data provider (web portal)
2. Identify model attributes (product configuration and energy efficiency metric)
3. Modify/adjust the efficiency metric for NEEA-specific regional characteristics
4. Calculate UEC for each model
5. Weight model UECs by sales

The following sub-sections will discuss steps 1 through 4.

2.1 Sales Data

Sales data for the RPP program is managed on http://www.retailproductsplatform.com. NEEA and other program sponsors have access to only the masked and aggregated data. For the purposes of energy savings calculations, NEEA uses the `sales by model` dataset, which contains the brand and model number of each product sold through participating retailers, and the quantity of units sold for that model in a given month (aggregated by month).

2.2 Model Attributes

In order to determine the energy usage characteristics for each clothes washer model, each model number (for a given brand) was mapped to models in the ENERGY STAR® Qualified Products List[2], U.S. Department of Energy Compliance Certification Management System[3], and California Energy Commission Modernized Appliance Efficiency Database[4]. The table below shows which attributes were used for determining model UEC:

Table 2: Table of Attributes

Attribute	Equation Variable	Source(s)
Integrated Modified Energy Factor	$IMEF$	[2][3][4]
Volumetric Capacity (cu. ft.)	$Volume$	[2][3][4]
Remaining Moisture Content (%)	RMC	[2][4]
DOE Product Class (Configuration)	-	[2][3][4]

2.3 Calculations

Unit Energy Consumption (UEC) in kWh per year (kWh/yr) for each clothes washer model was calculated using equations derived from the U.S. Department of Energy (DOE) Test Procedure for Residential Clothes Washers[4]. For clothes washers, the UEC is calculated as the summation of four components:

$$UEC = E_{machine} + E_{dryer} + E_{stdby} + E_{HW}$$

$E_{machine}$, Energy used per year by the mechanical functions of the clothes washer
E_{dryer}, Energy used per year by a representative dryer (based on RMC of washer)
E_{stdby}, Energy used per year in standby mode by the washer
E_{HW}, Energy used per year to heat the water used by the washer (based on water usage of washer)

The four components are all interrelated; they are each components of the clothes washer efficiency metric, the integrated modified energy factor (IMEF). Each component is discussed in the subsequent section (a-d).

a. Machine Energy Use:

The machine energy use is the active-mode usage of the clothes washer machine. It is related to the energy used to agitate clothes and drain the drum. The metric is not linearly correlated with the IMEF because of a tradeoff between $E_{machine}$ and E_{dryer}. That is, the more energy used to drain the drum (i.e., through centrifugal force), the less energy is required to dry the clothes, and vice versa. Manufacturers may optimize $E_{machine}$ and E_{dryer} to maximize the IMEF. The machine energy use per year is calculated by the following equation:

$$E_{machine,RTF} = e_{machine} \times cycles_{RTF}$$

$e_{machine}$ is the machine energy use per cycle, as used by the RTF (R. Firestone)[6]. It is not a readily available metric. In order to determine this value, DOE conducted product testing, the results of which can be found in U.S. DOE Technical Support Documents[4]. The values used by the RTF (Appendix Table) are based on DOE's tests, which vary by configuration (i.e., top- or front-loading) and IMEF bin.

$cycles_{RTF}$ is the number of wash cycles per year specific to NEEA's region. A constant value of 311 was identified in NEEA's Clothes Washers Study[7] and is used for all clothes washer models.

b. Dryer Energy Use:

The dryer energy use is included in the UEC for this product because of the tradeoff between $E_{machine}$ and E_{dryer}. To put in other words, by including this term, NEEA includes in clothes washer UEC the additional energy that would be required from drying due to an inefficient washer. Manufacturers may optimize $E_{machine}$ and E_{dryer} to maximize the IMEF. The dryer energy used per year is calculated by the following equation:

$$E_{dryer,RTF} = (RMC_{adjusted,RTF} - RMC_{Final,RTF}) \times weight_{dry,RTF} \times DEF_{RTF} \times f_{dryer,e}$$

$RMC_{adjusted,RTF}$ is the model remaining moisture content, as acquired from Section 2.3 through database mapping, that is adjusted to real-world values based on a method submitted to the RTF[6]. The adjustment is linear: $\mathbf{A} \times RMC + \mathbf{B}$, where coefficients $\mathbf{A}$ and $\mathbf{B}$ are 1.247041 and 0.144436 (the slope and intercept), respectively.

$RMC_{Final,RTF}$ is the final RMC of the model after drying. The RTF has advised NEEA to use the value of 0.04, consistent with a method submitted to the RTF[6].

$weight_{dry,RTF}$ is the total weight (in lbs) of clothes dried per year. The RTF determined this value to be 2342 based on NEEA's Clothes Washers Study[7].

DEF_{RTF} is the dryer efficiency factor (kWh/lb). The RTF determined this value to be 0.66 based on a method submitted to the RTF[6].

$f_{dryer,e}$ is the fraction of electric to gas dryers in NEEA's region. This factor is to remove the energy consumption used by gas dryers since NEEA does not count gas savings. When this factor < 1, the UEC should be considered a "net UEC". The RTF determined this value to be 0.95, which is based on NEEA's Clothes Washer Study[7].

c. Standby Energy Use:

This standby energy use measures the non-active-mode energy consumption of the washer. Standby power usually depends on the features of the washer. For RPP, it is calculated bottom-up by the following equation:

$$E_{stdby} = \frac{P_{stdby} \times hours_{stdby}}{1000}$$

P_{stdby} is the standby power of the washer model, as used by the RTF (R. Firestone)[6]. It is not a readily available metric. In order to determine this value, DOE conducted product testing, the results of which can be found in U.S. DOE Technical Support Documents[4]. The values used by the RTF (Appendix Table) are based on DOE's tests, which vary by configuration (i.e., top- or front-loading) and IMEF bin.

$hours_{stdby}$ is the total annual hours in standby mode, 8465, as determined by U.S. DOE[4].

d. Hot Water Energy Use:

The hot water energy measures the energy required to heat water for clothes washing. The clothes washer itself does not typically heat the water; this is left to the home water heater. However, this value is included in the UEC because clothes washers determine how much hot water is used. To put in other words, by including this term, NEEA includes in clothes washer UEC the additional energy that would be required to heat additional water due to an water-inefficient washer. Manufacturers reduce water consumption of washers to maximize the IMEF.

This component of the UEC is calculated differently than the above components (a-c); it uses a top-down approach. That is, it takes the total UEC that **would** be calculated from DOE values and removes the DOE components E_{stby}, $E_{dryer,DOE}$, and $E_{machine,DOE}$. What is left is the how water energy use, as would be calculated from DOE values, E_{HW}, which is then adjusted to NEEA values. The hot water energy used per year, as described above, is calculated by the following equation:

$$E_{HW} = [(\frac{Volume}{IMEF} \times cycles_{DOE}) - E_{stby} - E_{dryer,DOE} - E_{machine,DOE}] \times \frac{weight_{wash,RTF}}{weight_{wash,DOE}} \times f_{heater,e}$$

$Volume$ is the volumetric capacity, as acquired from Section 2.3 through database mapping, measured in cubic feet. The value is used to calculated total energy use from the IMEF.

$IMEF$ is the model IMEF, as acquired from Section 2.3 through database mapping.

$cycles_{DOE}$ is the number of wash cycles per year assumbed by U.S. DOE[4]. This value is used to determine the washer UEC as would be calculated by DOE in order to subtract E_{stby}, $E_{dryer,DOE}$, and $E_{machine,DOE}$, thereby calculating hot water energy use.

$E_{dryer,DOE}$ is the dryer energy use (sub-section b), calculated with DOE assumptions[4] instead of RTF assumptions. For example, the DEF, DUF and $weight_{dry,DOE}$ are used to calculate this value. $weight_{dry,DOE}$ is determined by a table in the DOE Test Procedure, which is included for reference in the Appendix of this document.

$E_{machine,DOE}$ is the machine energy use (sub-section a), calculated with the DOE assumption of 295 for $cycles_{DOE}$. The per-cycle machine energy use, $e_{machine}$ is the same for both $E_{machine,RTF}$ and $E_{machine,DOE}$

$weight_{wash,RTF}$ is the total weight (in lbs) of clothes washed per year. This value is different than $weight_{dry,RTF}$ because NEEA's Clothes Washers Study[7] found that there are fewer clothes dried than washed (some clothes are hang-dried). The RTF determined this value to be 2505 based on NEEA's Clothes Washers Study[7].

$weight_{wash,DOE}$ is the total weight (in lbs) of clothes dried per year, as assumed by U.S. DOE. This is the same as $weight_{was,DOE}$ and is determined by a table in the DOE Test Procedure, which is included for reference in the Appendix of this document.

$f_{heater,e}$ is the fraction of electric to gas water hears in NEEA's region. This factor is to remove the energy consumption used by gas water heaters since NEEA does not count gas savings. When this factor < 1, the UEC should be considered a "net UEC". The RTF determined this value to be 0.59, which is based on RTF feedback (needs reference).

```
## Warning: package 'bindrcpp' was built under R version 3.4.4
```

Table 3: Table of Assumptions

	Value	Source
DOE Wash Cycles Per Year	295	[5]
RTF Wash Cycles Per Year	311	[6]
DOE Dryer Efficiency Factor (DEF)	0.5	[5]
RTF Dryer Efficiency Factor (DEF)	0.66	[6]
DOE Dryer Usage Factor (DUF)	0.91	[5]
RTF Dry Load Weight (lbs)	2342	[6]
RTF Wash Load Weight (lbs)	2505	[7]
DOE Final Remaining Moisture (RMC)	0.04	[5]
RTF Final Remaining Moisture (RMC)	0.04	[6]
RTF RMC Adjustment Curve Slope	1.247041	[6]
RTF RMC Adjustment Curve Intercept	0.144436	[6]
Standby Hours	8465	[5]
Fraction Electric Heater	0.59	[6]
Fraction Electric Dryer	0.95	[6]

3. Sources

[1] Retail Products Platform Sales Data. http://www.retailproductsplatform.com

[2] ENERGY STAR® Qualified Products List. https://www.energystar.gov/productfinder/

[3] U.S. Department of Energy Compliance Certification Management System. https://www.regulations.doe.gov/certification-data

[4] California Energy Commission Modernized Appliance Efficiency Database. https://cacertappliances.energy.ca.gov

[5] U.S. Department of Energy Technical Support Document for Clothes Washers (2012). https://www.regulations.gov/document?D=EERE-2008-BT-STD-0019-0047

[6] R. Firestone Clothes Washer Calculations for Regional Technical Forum (2017).

[7] NEEA Clothes Washers Study.

Appendix

A.1. List of Revisions

Date	Description	Author
October 1, 2018	Original Publication	P. Nguyen, Energy Solutions

A.2. R Functions

UEC Calculation Function

```
CalculateRTFUEC <- function(IMEF = numeric(), Volume = numeric(),
    RMC = numeric(), Configuration = character(), Adjust_electric = TRUE,
    drycloth_table = rtf_drycloth_table, constants = washer_constants) {

    # constants
    DOE_cycles_pyear <- constants["DOE Wash Cycles Per Year"]
    RTF_cycles_pyear <- constants["RTF Wash Cycles Per Year"]
    DOE_DEF <- constants["DOE Dryer Efficiency Factor (DEF)"]
    RTF_DEF <- constants["RTF Dryer Efficiency Factor (DEF)"]
    DOE_DUF <- constants["DOE Dryer Usage Factor (DUF)"]
    RTF_dry_pounds <- constants["RTF Dry Load Weight (lbs)"]
    RTF_wash_pounds <- constants["RTF Wash Load Weight (lbs)"]
    DOE_RMC_remain <- constants["DOE Final Remaining Moisture (RMC)"]
    RTF_RMC_remain <- constants["RTF Final Remaining Moisture (RMC)"]
    RTF_RMC_adjust_slope <- constants["RTF RMC Adjustment Curve Slope"]
    RTF_RMC_adjust_int <- constants["RTF RMC Adjustment Curve Intercept"]
    stby_hours <- constants["Standby Hours"]
    frac_elec_heater <- constants["Fraction Electric Heater"]
    frac_elec_dryer <- constants["Fraction Electric Dryer"]

    # RTF Calculated
    if (is.na(Configuration) | is.na(IMEF) | is.na(RMC) | is.na(Volume)) {
        standby_power <- NA
        machine_pcycle <- NA
    } else if ((Configuration == "Standard Top-loading") | (Configuration ==
        "Compact Top-loading")) {
        if (IMEF < 1.3) {
            standby_power <- 0
            machine_pcycle <- 0.26266667
        } else if (IMEF < 1.35) {
            standby_power <- 2.3
            machine_pcycle <- 0.08116667
        } else if (IMEF < 1.37) {
            standby_power <- 1.7
            machine_pcycle <- 0.08116667
        } else if (IMEF >= 1.37) {
            standby_power <- 0.08
            machine_pcycle <- 0.08116667
```

```
        }
    } else if ((Configuration == "Standard Front-loading") | (Configuration ==
        "Compact Front-loading")) {
        if (IMEF < 1.38) {
            standby_power <- 2.3
            machine_pcycle <- 0.113
        } else if (IMEF < 1.41) {
            standby_power <- 1.7
            machine_pcycle <- 0.113
        } else if (IMEF < 1.5) {
            standby_power <- 0.08
            machine_pcycle <- 0.113
        } else if (IMEF >= 1.5) {
            standby_power <- 0.08
            machine_pcycle <- 0.1606
        }
    } else {
        standby_power <- NA
        machine_pcycle <- NA
    }

    # calculations
    V <- rtf_drycloth_table["Volume"]
    LBS <- rtf_drycloth_table["lbs_per_year"]
    DOE_dry_pounds <- tail(LBS[Volume >= V], n = 1)
    # tail function just takes the correct value from the table
    RMC_adjust <- (RMC * RTF_RMC_adjust_slope) + RTF_RMC_adjust_int
    Dryer_pyear <- (RMC - DOE_RMC_remain) * DOE_DEF * DOE_DUF *
        DOE_dry_pounds
    E_standby <- standby_power * stby_hours/1000
    E_machine <- machine_pcycle * RTF_cycles_pyear
    if (Adjust_electric) {
        E_dryer <- (RMC_adjust - RTF_RMC_remain) * RTF_dry_pounds *
            RTF_DEF * frac_elec_dryer
        E_HW <- (((Volume/IMEF) * DOE_cycles_pyear) - E_standby -
            (machine_pcycle * DOE_cycles_pyear) - Dryer_pyear) *
            (RTF_wash_pounds/DOE_dry_pounds) * frac_elec_heater
    } else {
        E_dryer <- (RMC_adjust - RTF_RMC_remain) * RTF_dry_pounds *
            RTF_DEF
        E_HW <- (((Volume/IMEF) * DOE_cycles_pyear) - E_standby -
            (machine_pcycle * DOE_cycles_pyear) - Dryer_pyear) *
            (RTF_wash_pounds/DOE_dry_pounds)
    }

    RTF_UEC <- E_standby + E_machine + E_dryer + E_HW
    return(unname(RTF_UEC))
}
```

A.3. Reference Tables

Table 5: RTF Assumption for Dryer Clothes Weight (lbs)

Volume	lbs_per_year	Volume	lbs_per_year	Volume	lbs_per_year	Volume	lbs_per_year
0.0	885.000	1.5	1376.470	3.0	2258.225	4.5	3154.435
0.1	885.000	1.6	1434.290	3.1	2316.045	4.6	3212.255
0.2	885.000	1.7	1492.110	3.2	2373.865	4.7	3270.075
0.3	885.000	1.8	1549.930	3.3	2431.685	4.8	3327.895
0.4	885.000	1.9	1607.750	3.4	2489.505	4.9	3385.715
0.5	885.000	2.0	1665.570	3.5	2561.780	5.0	3443.535
0.6	885.000	2.1	1723.390	3.6	2619.600	5.1	3501.355
0.7	885.000	2.2	1781.210	3.7	2677.420	5.2	3559.175
0.8	957.275	2.3	1839.030	3.8	2735.240	5.3	3616.995
0.9	1015.095	2.4	1896.850	3.9	2793.060	5.4	3674.815
1.0	1072.915	2.5	1969.125	4.0	2850.880	5.5	3747.090
1.1	1130.735	2.6	2026.945	4.1	2908.700	5.6	3804.910
1.2	1188.555	2.7	2084.765	4.2	2966.520	5.7	3862.730
1.3	1246.375	2.8	2142.585	4.3	3024.340	5.8	3920.550
1.4	1304.195	2.9	2200.405	4.4	3082.160	5.9	3978.370

Table 6: RTF Assumptions for Machine Energy Use

Top-Loaders			Front-Loaders		
IMEF	**Machine Energy Use (kWh/cycle)**	**Standby Power (W)**	**IMEF**	**Machine Energy Use (kWh/cycle)**	**Standby Power (W)**
< 1.30	0.2626667	0.00	< 1.38	0.1130	2.30
1.30 <= x < 1.35	0.0811667	2.30	1.38 <= x < 1.41	0.1130	1.70
1.35 <= x < 1.37	0.0811667	1.70	1.41 <= x < 1.50	0.1130	0.08
>= 1.37	0.0811667	0.08	>= 1.50	0.1606	0.08