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DRYER FIELD STUDY

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Executive Summary

A documentation of the drivers and patterns of new clothes dryer energy use in homes is lacking. To expand the understanding of laundry systems in the region, NEEA commissioned a detailed review of clothes dryer use in a sample of residential sites.

Appliance energy use plays a large role in the overall electric energy requirements of a home (Larson, et al., 2014). A major component of this energy use is laundry equipment. While national ratings provide some guidance on the efficiency of washers and dryers, they do not advise utilities on the amount of energy associated with home laundry equipment or the pattern of use typical of Pacific Northwest homes. The design of the study is to see how users operate recent-model, high-efficiency washers and dryers in their homes. It evaluates what cycles they use, how many cycles they use per year, how much laundry they clean per cycle, and how much energy it takes to wash and dry those cycles. Dryer energy efficiency is the focus of the field study, but the amount of water in the clothes is tied to the washing machine parameters. This study is an extension of the Residential Building Stock Assessment (RBSA). RBSA included an assessment of the washer and dryer in each audited home and participants for this field study were recruited based on the results of the RBSA audit (Baylon, Storm, Geraghty, & Davis, 2012).

Clothes washer energy use has dropped 70 percent since 1990, but clothes dryers have not seen the same efficiency gains (EERE, 2014). However, with recent advancements in dryer technology, ENERGY STAR has recognized advanced clothes dryers with the Emerging Technology Award (ENERGY STAR, 2012). With the possibility of improved dryer technology, it has become critical to know laundry energy consumption and user habits to ensure the results of test procedures are reasonably reflective of typical use in the field.

This report covers a field metering and analysis project designed to assess these drivers of clothes dryer energy use. There are several important goals of this study:

1. Answer a wide range of questions about dryer energy use, laundry habits, and performance characteristics using a random sample of residences with newer laundry equipment.
2. Inform the Department of Energy (DOE) rulemaking on clothes dryer test procedures and characterize the way people do laundry and the ways that affects dryer energy use.
3. Provide insight to aid the Super-Efficient Dryer Initiative, SEDI (CLASP, 2014). NEEA, in collaboration with other stakeholders around the country, provides data to aid in increased efficiency for clothes dryer appliances and to bring dryers that are more efficient to the U.S. market.

To address these questions this study developed a combination of electric load metering and detailed participant logs that allowed the occupants to record details of the washer and dryer

loads and to assess the overlap between the energy use and the laundry habits of the participants. The goal of the metering is to ascertain how much energy the dryer uses for different cycles and how much moisture remains at the end of each washer and dryer cycle. Currently, the DOE test procedure makes certain approximations of incoming and final moisture content (e-CFR, 2014). Participants filled out detailed logs as part of their laundry routine, which involved logging information about the laundry cycle, laundry weight, and other pertinent characteristics. The logging of washer and dryer settings gives insight into the kinds and sizes of loads used and what are the most commonly used washer and dryer cycles. The metering and log information were combined together to create the analysis data set. Data from the wash cycles informs the input characteristics for the dry cycles.

Laundry loads vary drastically both in their composition and in the choices of settings to clean the loads. Loads can be small, large, dry, damp, heavy cloth, light cloth, delicate, heavy duty, etc., and users can choose to wash and dry, wash only, dry only, remove when damp, over-dry, fluff, de-wrinkle, etc. This makes it difficult to determine an efficiency level for comparison, so part of the analysis focuses just on the most typical loads rather than all of the loads. These “simple” loads have the following characteristics:

- Wash and dry
- Initial Remaining Moisture Content (RMC) between 33% and 100%
- Bone-dry weight between 3 lbs and 15 lbs
- No items removed between the wash and dry cycle
- No multi-run dryer cycles

The simple load criteria above helped divide the loads in the study into loads that relate to the DOE test procedure and loads that do not relate to the procedure. The simple loads allowed comparisons between loads and cycles with less variation in the data. Simple loads accounted for about half the loads using these parameters. **This means only about half of typical household laundry loads begin to resemble the federal test procedure.**

Both kWh and a combined energy factor (CEF) are the main metrics used in the dryer analysis for comparing metered results to the test procedure. CEF is a newer concept, so the dryers in this study did not have a CEF rating, but a potential baseline for future studies are the calculated field CEF values in this study.

The following are the main findings of comparing of the field data to the test procedures:

- Clothing types are much more varied than the 50/50 cotton/poly test cloth used in the DOE test procedure, and heavy fabric types appear to have an impact on dryer efficiency (lb/kWh) compared to light and medium fabric types. The effect is a 13% average decrease in dryer efficiency for heavy fabric type compared to light and medium fabric types.

- The test procedure distribution of wash temperatures is mostly in line with our findings (although there are fewer extra hot loads[1] in the field), but the percent of loads using warm rinse temperature is much lower in the field compared to the test procedure assumption.
- The percent of washer loads dried in the field (93.5%) is in line with the assumption in the new version of the test procedure (91%).
- The average test load weight and amount of water removed is consistent between the field data and the test procedure assumptions, though the variation in both bone-dry weight and water removed weight in the field data is large. Bone-dry weights in the field were as low as a couple pounds and as high as 20 pounds or more.
- The 70% ± 3.5% initial RMC used in the Appendix D test procedure is within the sampling error of the 71.0% ± 1.6% found across all loads in the study, but the 57.5% ± 3.5% of the new procedure in Appendix D1 (e-CFR, 2014) is outside of the sampling error bounds across all loads. For *simple loads,* the initial RMC value found in the field is 62.9% ± 0.6%, which is higher than the new Appendix D1 test procedure assumption and lower than the Appendix D assumption.
- There is an even split in the logbooks between medium and high temperature setting for most loads, but the test procedure only uses the high temperature setting. Interestingly, measured dryer max and median exhaust temperatures show no difference between medium and high temperature settings, and no difference by cycle length for medium and high temperature settings.
- Estimates based on the metering data suggest the dryer is off for 8453 ± 32 hours/year; the test procedure assumes 8620 hours/year. Alternatively, the data show an average dryer runs 307 ± 32 hours/year; the test procedure assumes 140 hours/year.
- The number of loads per year in the field was 311 ± 42. The test procedure assumption of 283 is within the sampling error of the study, though on the lower end of the error band.

[1] “Extra hot” and “sanitary” denote the same concept

- Dryers in the field have an average standby use of 5.5 Wh/load, 0.17 W, or 1.5 kWh/year. Future machines, with always-on communications connections, will likely have more standby use.
- EF and CEF are about 2.7 lb/kWh for all loads and 2.6 lb/kWh for simple loads. EF and CEF appear the same because of the very low standby for the machines in this study.
- Initial RMC, for clothes coming out of the washer, is 13.6% higher on average for vertical axis washers compared to horizontal axis washers.
- Auto-termination appears to perform better than manual termination only for low initial moisture contents, but for normal laundry there is no apparent difference in energy use.

Table 1 summarizes the field study results and provides a comparison to the test procedures.

Table 1. Summary of Field Study Results Compared to Test Procedures

Dryer Metric	DOE			Field Study – Simple Loads		Field Study – All Loads	
	Amended D Procedure	D1 Test Procedure	D2 Test Procedure	Mean	EB	Mean	EB
Load Composition	DOE Test Cloths			Homeowner Clothes			
Dryer Setting	Normal Duty, High Heat			Homeowner Settings			
Initial RMC of Dryer Load (%)	66.5%-73.5%	54.0%-61.0%	57.5% ± 0.33%	62.9%	1.0%	71.0%	2.7%
Final RMC of Dryer Load (%)	2.5%-5.0%	2.5%-5.0%	Auto: <2.0%	3.3%	0.5%	7.2%	3.2%
Water Removed/Load (lb)	4.62	4.52	4.69	4.73	0.14	4.81	0.13
Bone-Dry Load Weight (lb)	7.00	8.45	8.45	7.87	0.19	7.64	0.17
Duct restriction or exhaust cfm	2 7/8"	2 7/8"	2 7/8"	90.2 cfm ± 11.1 cfm			
Average Drying Time (min)	23 [a]	N/A	N/A	57.0	1.4	56.0	1.1
Raw Energy Use/Load (kWh)	2.24 [a]	2.84 [a,b]	2.84 [a,b]	3.17	0.07	2.96	0.06
Field Use Factor – Auto Cycle	1.04	1.04	1.00	N/A	N/A	N/A	N/A
Adj. Energy Use/Cycle (kWh)	2.33 [a]	2.95 [a]	2.84 [a]	3.17	0.07	2.96	0.06
Dryer Use Factor (J/J1/J2)	84%	84%	91%	100%	0.0%	93.5%	0.0%
Loads per Year	416	283	283	N/A	N/A	311	42
Average EF (lbs/kWh)	3.01 [a]	2.86 [a]	2.98 [a]	2.66	0.12	2.62	0.28
Lbs Dried per Year (lbs/yr)	2,912	2,391	2,391	N/A	N/A	2342	428
Energy Use per Year (kWh/yr)	967 [a]	835 [a]	804 [a]	N/A	N/A	915	132
Washer Vintage 2005-2009	N/A	N/A	N/A	77% [d]			
Washer Vintage 2009+	N/A	N/A	N/A	23% [d]			
Vertical Axis Washer	N/A	N/A	N/A	28% [d]			
Average Household Size	N/A	N/A	N/A	3.0 ± 0.3			
Fraction of Clothing Removed	N/A	N/A	N/A	0.0%	0.0%	Unk	Unk
Fraction of High Heat	100%	100% if avail.	100% if avail.	37.5%	0.1%	43.0%	0.1%
Dryness Setting [c]	N/A	N/A	Normal	61.0% [c]	0.2%	64.8% [c]	0.1%
Simple Loads (see definition)	100%	100%	100%	44.6%			

[a] Based on NEEA laboratory testing
[b] Though automatic termination in the field saves energy relative to timed dry, here we are comparing to technician termination in the test
[c] Test procedures D/D1 do not stipulate a dryness setting (cycle is stopped manually when the clothing reaches the final RMC range). D2 uses Normal dryness as long as final RMC <2.0%. Percents reported for field study are percent of loads using Normal dryness setting.
[d] Based on number of sites

1. Introduction

NEEA commissioned a detailed review of laundry use in the field in a sample of residential customers to relate the field data to federal test procedure data and to expand the regional understanding of dryer energy use and load characteristics. The study monitored laundry use with using a specially designed logbook in which participants documented their laundry loads and settings and with continuous metering of the energy use of the washer and dryer.

Appliance energy use plays a large role in the overall electric energy requirements of a home (Larson, et al., 2014). A major component of this energy use is laundry equipment and use patterns. While national ratings provide some guidance on the efficiency of washers and dryers they do not advise utilities on the amount of energy associated with home laundry equipment or the pattern of use typical of Pacific Northwest homes. The goal of the study design is to see how homeowners use recent-model, high-efficiency washers and dryers in their homes. It evaluates what cycles they use, how many cycles they use per year, how much laundry they clean per cycle, and how much energy it takes to wash and dry those cycles. This study is an extension of the Residential Building Stock Assessment (RBSA). RBSA included an assessment of the washer and dryer in each audited home and participants for this field study were recruited based on the results of the RBSA audit (Baylon, Storm, Geraghty, & Davis, 2012).

Clothes washer energy use has dropped 70 percent since 1990, but clothes dryers have not seen the same efficiency gains (EERE, 2014). However, with recent advancements in dryer technology, ENERGY STAR has recognized advanced clothes dryers with the Emerging Technology Award (ENERGY STAR, 2012). With the possibility of improved dryer technology it has become critical to know laundry energy consumption and user habits to ensure the results of test procedures are reasonably reflective of typical use in the field.

1.1. Study Goals

This report covers a field metering and analysis project designed to assess these drivers of clothes dryer energy use. There are several important goals of this study:

1. Answer a wide range of questions about dryer energy use, laundry habits, and performance characteristics using a random sample of residences with newer laundry equipment.
2. Inform the Department of Energy (DOE) rulemaking on clothes dryer test procedures, and characterize the way people do laundry and the ways that affect dryer energy use.
3. Provide insight to aid the Super-Efficient Clothes Dryer Initiative (SEDI). NEEA, in collaboration with other stakeholders around the country, provides data to aid in increased efficiency for clothes dryer appliances and to bring dryers that are more efficient to the U.S. market.

1.2. Background

The 2011 white goods agreement on new federal standards included a commitment to advocate for the upgrade of the clothes dryer test procedure (EERE, 2011). The current procedure terminates the test when the clothes load reaches a remaining moisture content (RMC) value of between 2.5% and 5%. Laboratory test data show clothes dryers can continue to use energy (sometimes a significant amount of energy) after reaching 5% RMC (Denkenberger, Mau, & Calwell, 2011) (Ecova, 2013). In addition, the test procedure measures energy use per cycle but is valid only for a particular type and size of clothes load – the load that is assumed to come out of the clothes washer and its test procedure. The average composition of a laundry load in the field almost certainly differs from the testing assumptions, so the current test load and procedures may not be consistent with either current laundry practice or laundry equipment operation.

The current test procedure makes an assumption about the remaining moisture content (RMC) of clothes as the clothes washer finishes. The DOE Appendix D test procedure assumes that this is 70% ± 3.5% (updated to 57.5% ± 3.5% starting in 2015), but some front-loading models can spin down to RMC values as low as 35%. With modern clothes washers and dryers, these testing assumptions may be much different from what currently available laundry equipment can deliver. All of these values, however, are applicable only to the DOE test load, which consists of single-ply sheets of 50/50 cotton/synthetic fabric. This study included in-situ field monitoring to measure these types of variables. The results of this research can inform a more accurate and empirically based way to specify a test procedure for calculating annual energy use in dryers.

There is also the need to establish a baseline of laundry use patterns and dryer energy consumption in order to enable a large-scale residential clothes dryer initiative. The amount of energy used by typical households is crucial to prioritizing dryer efficiency initiatives. Notwithstanding the highly variable capabilities of automatic cycle termination, it is reasonable to assume that the amount of dryer energy used is proportional to the amount of moisture removed. More advanced heat pump dryers may offer an avenue for dryer energy savings, and while some countries have developed effective programs to introduce heat pump dryer technologies (Nipkow & Bush, 2009) (Bush, Damino, & Josephy, 2013), at this time there are no commercial models available in the U.S. The many implications associated with the design and use of heat pump clothes dryers are beyond the scope of this study.

1.3. Study Design

To address these questions, the study developed a combination of electric load metering and detailed participant logs that allowed the occupants to record details of the washer and dryer loads. Together, the logs and metered data allow an assessment of the correlation of energy use and the laundry habits of the participants.

The data collection included a continuous metering of the washer and dryer energy use during the study period. The goal of the metering was to ascertain how much energy the washer and dryer use for different cycles and how much moisture remains at the end of each cycle. Currently, the DOE test procedure makes assumptions about incoming and final moisture content.

A major component of this project is the use of a participant laundry logging tool (see Appendix 2). The participant filled out a paper log as part of their laundry routine, which involved logging information about the laundry cycle, laundry weight, and other pertinent characteristics. The logging of washer and dryer settings gives insight into the kinds and sizes of loads used and the most commonly used washer and dryer cycles.

Metering data and logbook data included both washer and dryer loads, but the focus of the study is the dryer energy use and characteristics. Knowing the washer data helps establish the pre-conditions for dryer loads. A side analysis of washer data is included in the appendices.

2. Methodology

2.1. Study Design

The primary sample design sought to cover the variation in household occupancy to create a representative sample. A screening of RBSA audit sample for newer clothes washers and dryers (sold after 2001) helps ensure, but not guarantee, they have newer cycle options and features. All equipment for the study is from 2005 and later. Further characteristics, such as nameplate, verified the cycle options and features. The target sample size was 45 homes, though the study initially included 50 homes. At the end of the study period, there were a few sites that had partially or fully unusable data. Geography was not a factor, so the stratified sample did not use that basis and a majority of the sites were along the Interstate 5 corridor in western Oregon and Washington.

The site selection process used sample weights from RBSA to ensure a representative sample of recent vintage laundry equipment. Each home recruited was offered an incentive to track their laundry use with detailed logs and allow for the presence of energy monitoring in the home. Data and metering collection from each site occurred for four to six weeks in early 2012.

2.2. Metering

The metering protocol was designed to gather data at a sufficiently detailed level to characterize washer and dryer cycles, as well as to track a fairly exhaustive amount of information about individual laundry loads.

The protocol was fairly demanding; in addition to metering washer and dryer energy use and cycle information, Ecotope asked participants to characterize and weigh laundry before putting it into the washer and dryer and upon removing it from the dryer. Ecotope also asked participants to record washer and dryer cycle types. The study initially metered fifty sites with laundry equipment from 2005 or newer, but only 46 sites provided fully usable data. The metering equipment partially or fully failed at three sites. No connection could be made between the logbook entries and metered data at another site because the participants did a poor a job filling in their logbook.

The datalogger used was the Onset U30. A Continental Control Systems WattNode collected energy pulse information. Collection of energy use data occurred in a custom enclosure located between the washer and dryer plugs and the wall receptacles. One-minute interval data logging allowed for fine-resolution characterization of washer and dryer cycles. Temperature and relative humidity sensors at the dryer exhaust used the same sampling interval. Information collected at the time of the initial visit characterized the dryer venting – the length and number of bends in the duct run, the degree of obstruction by lint, and the dryer exhaust air flow rate.

Appendix 1 contains the complete metering protocol. Sample logbook entries are in Appendix 2.

2.3. Data Sets

There are two types of data sets from the study. The first is the raw metering data, which for each site consists of minute-by-minute recordings of washer watt-hours, dryer watt-hours, dryer exhaust relative humidity, and dryer exhaust temperature. The other data set includes all the characteristic data for the site, characteristics for the washer and dryer specifications, and logbook entries for each washer and dryer load. The characteristics/logbook data set also merged in the household demographics and other general information from the main RBSA audit.

Analysts entered logbook information into a database, double-checked the entries for accuracy, and merged in the metered data. This process developed a unique record of linking laundry behavior, laundry equipment efficiency, and the determinants of consumption of both clothes washers and clothes dryers.

The number of dryer loads used two methods to determine a count. The first used the minute-by-minute energy use to determine when a dryer was running and when it was not; each of the on-cycles had a sequential ID number applied. The second method reviewed the logbook entries to find the time of adding and removing a dryer load. Combining these two data sets provided a link between the logbook entries and the meter readings, but also highlighted a fairly common tendency to run a load through the dryer multiple times, either because the load was not dry yet or for other preferences, such as removing wrinkles because the load had been sitting in the drum too long.

The metered data also helped to find loads with missing logbook entries. Lulls in the metering data provided the definition of a load. The meters log data every minute, including during standby times, so gaps indicate breaks between loads. The combination of metering and logbook data can then indicate whether metering loads are part of the same logbook load, and these are flagged with a multi-run label for those loads. Example: a dryer load finishes, the occupant checks the load an hour later and notices the clothes are still damp and turns the dryer on again to finish the load.

2.4. Metrics

There are a number of common metrics used for washer and dryer testing. Some, like bone-dry weight and remaining moisture content (RMC), are common calculations for both washers and dryers, and some other metrics are equipment-specific.

The test procedure for determining bone-dry weight is to dry the clothes at maximum temperature for at least 10 minutes beyond the point of being dry, weigh the load, and then repeat further 10 minute drying time cycles on high temperature until the weight difference of the load from subsequent measurements is one percent or less. This process is obviously not the typical drying process in the field, so conversions from dry weight to bone-dry weight provide estimates of bone-dry weight for this study. Dry weight is the weight before the load goes into the washer. A check of the incoming weight (only for loads with no clothes removed) is the dry weight after the load leaves the dryer. An assumption of bone-dry weight prior to the wash cycle is 95% of the ambient dry weight. Immediately following the completion of the dryer cycle, the assumption is the ambient dry weight is equal to the bone-dry weight and the post-dryer weight is used as bone-dry weight if it appears the clothes going into the wash cycle have more than 5% moisture content (i.e., wet going into the washer). The 5% estimate is obtained from field studies showing similar values (Myers, Franco, Lekov, Thompson, & Sturges, 2010) (Ecova, 2013) (Durfee & Tomlinson, 2001) and is the upper limit for the DOE dryer testing procedure.

RMC is the weight difference of the load compared to bone-dry weight, divided by the bone-dry weight. Therefore, RMC is the weight of water divided by bone-dry weight.

$$RMC = \frac{Total\ Weight - Bone\ Dry\ Weight}{Bone\ Dry\ Weight}$$

In the test procedure, the specification of RMC occurs at two points in time, once after leaving the washing machine and again after leaving the dryer. In this report, the calculation of RMC also included going into the washing machine, since in the field not all clothing is dry going into the washing machine. In fact, if clothes are sitting at ambient condition in a room with typical humidity levels, the clothing will have about 5 percent RMC compared to its bone-dry weight as mentioned above.

The next two sections discuss machine-specific metrics used in the test procedures and this report.

2.4.1. Clothes Washer Metrics

The focus of this report is on dryer use and only includes washer analysis for items pertaining to the inputs for dryer use, such as factors affecting initial moisture content, removal of clothes, etc. However, the detail of data in the logbooks and metering allow additional analysis of washer loads, which are included in Appendix 4.

2.4.2. Clothes Dryer Metrics

All of the dryers in this study were rated under the test procedure 10 CFR 430 Appendix D to Subpart B (e-CFR, 2014), which was first implemented in 1998 and not updated until very recently. Implementation of an amended test procedure, 10 CFR 430 Appendix D1 to Subpart B (e-CFR, 2014), begins in 2015. Below is a presentation of both test procedures for context. The main items in the Appendix D procedure that are relevant to this report are:

- Test weight of 7.00 lbs
- Initial RMC of 66.5% – 73.5%

- Final RMC of 2.5% – 5.0%
- Test performed at highest temperature setting for the maximum amount of time and is stopped when the desired final RMC is achieved
- Calculation of Energy Consumption per Cycle, E_{ce}:

$$E_{ce} = \frac{66\%}{W_w - W_d} \times E_t \times FU$$

which is simply a formula to adjust the recorded energy use to a set of standard conditions. W_w is initial RMC, W_d is final RMC, E_t is the recorded energy use (kWh) during the dryer test cycle, and FU is a field use factor. The first term (66% / [Ww – Wd]) is an adjustment that is needed because of the range of initial RMC and final RMC values in the test procedure, which could produce a change in RMC of anywhere between 61.5% and 71.0%. The first term makes an adjustment from the test RMC difference to a standard 66%. The field use factor is a constant to adjust the energy use to the expected use in the field, and is 1.04 for automatic control systems (sensor dry, for instance) and 1.18 if there is no automatic control system.[2] Manufacturer test data for dryers were not available, so results below just show the energy consumption, E_{ce}, calculated from the field data without a comparison to rated values.

Initial RMC is the remaining moisture content going into the dryer (after the wash cycle) and final RMC is the remaining moisture content at the end of the dryer cycle.

The update in Appendix D1 makes a number of changes to parameters, as well as adds new metrics. Some of the key changes are:

- Test load weight increased to 8.45 lbs
- Initial RMC reduced to 54.0% – 61.0%
- Final RMC remains the same at 2.5% – 5.0%
- Test itself performed the same as before (max temp and run until final RMC achieved)
- Calculation of Energy Consumption per Cycle uses 53.5% instead of 66%, but the field use factors remain the same

[2] The manual field use factor was determined from a 1971 field study and the automatic field use factor was determined from a 1977 study. The factors are based on the observation that clothes were being overdried in the field (DOE, 2013).

- New standby energy use calculation with assumed 8620 off hours per year and 283 loads per year (standby energy use is referred to as E_{TSO} in the test procedure)
- New per-cycle energy calculation based on sum of E_{ce} and E_{TSO}
- New Energy Factor calculation,

$$EF = \frac{W_{bonedry}}{E_{ce}}$$

- New Combined Energy Factor,

$$CEF = \frac{W_{bonedry}}{E_{ce} + E_{TSO}}$$

where $W_{bonedry}$ is the bone-dry weight of the load. With the increase in test load weight and decrease in initial RMC, the E_{ce} value should be roughly the same in this new protocol. The more important metrics, however, are the new calculations used in energy efficiency standards. The units for EF and CEF are lb/kWh, where lb is weight of bone-dry clothing. As a note, there is no connection between washing and drying machine protocols, so the D term of washer MEF (the energy required by the dryer to remove the moisture) is simply a constant of 0.5 kWh/lb, or an EF of 2.0 lb/kWh.

The latest protocol is Appendix D2 (e-CFR, 2014), though the protocol is new enough that an implementation date has not been set. In the D2 protocol, the RMC normalization is only used for manual termination dryers; auto-termination dryers use the unaltered energy use. The D1 equations rather than D2 are used for the findings in this report since it is assumed most manufacturers will use D1 over D2 until the D2 implementation date draws near.

The key protocol differences between D1 and D2 are:

- A new spray bottle treatment for stricter control of the initial RMC to 57.5% ± 0.33%
- Auto-termination dryers terminate based on dryer controls rather than a fixed RMC value, and manual dryers termination between 1.0% and 2.5% RMC
- Manual dryers use an Energy Consumption per Cycle of 55.5%, but no normalization for automatic dryers
- No field use factor for auto-termination dryers
- Bone-dry weight, standby assumptions, loads/year assumption, and test procedure details not noted above all remain the same as D1

In the summaries later in the report, another calculation of efficiency is theoretical energy use divided by the metered energy use (or percent efficiency). The vaporization energy of water for the observed temperatures within the drum for this study is about 0.30 kWh/lb_{water}, so for a load that has 4.52 lbs of water removed, the theoretical energy required to remove this moisture is 1.36 kWh. If the dryer meter showed 2.72 kWh used, the percent efficiency would be 50%. In terms of EF, the theoretical limit of electric resistance dryers at 54% initial moisture content is 6.2 lb/kWh (most dryers in this study are about half or less compared to this value, though the theoretical efficiency of EF is based on initial moisture content, where the vaporization efficiency proposed here is only based on water weight).

2.5. Simple Loads

Actual laundry loads vary drastically both in their composition and in the choices of settings to clean the loads. Loads can be small, large, dry, damp, heavy cloth, light cloth, delicate, heavy duty, etc., and users can choose to wash and dry, wash only, dry only, remove when damp, over-dry, fluff, de-wrinkle, etc. This makes it difficult to determine an efficiency level for comparison, so part of the analysis below focuses just on the most typical loads rather than all of the loads. These "simple" loads have the following characteristics:

- Wash and dry
- Initial RMC between 33% and 100% coming out of the washer/into the dryer
- Bone-dry weight between 3 lbs and 15 lbs
- No items removed between the wash and dry cycle
- No multi-run dryer cycles

Identifying simple loads is a way to segment all of the loads into just loads that could approximate the DOE test procedure in order to make comparisons between groups with less variation in the data. Using these parameters, simple loads make up about half of the loads. The washer and dryer summaries below use simple loads. Summaries across all loads (rather than just simple loads) are given throughout the report as a representation of reality measured by this study.

2.6. Analysis

In the analysis below, EB refers to a 90/10 error bound of the mean. The terms "load" and "cycle" are interchangeable throughout the report. The units for usage are kWh, and units for dryer efficiency are lb/kWh. "Temperature setting" is the occupant-recorded washer or dryer setting. There were 46 sites with good data in the study, each metered for four to six weeks. A total of 1353 cycles were recorded, which are a combination of wash/dry cycles, wash-only cycles, and dry-only cycles gathered and merged from both the logs and metered data. Any “per year” analysis shown below is simply an extrapolation from the metering period to the entire year. Therefore, if a machine had 20 cycles over a 30-day period, we would calculate 243 loads per year.

The “n” values in the tables reflect summaries being generated using either load data or site data. Most tables denote in the header the type of n, but for mixed tables the type of n value is noted in-line. The labels for n value type are “L” for loads and “S” for sites. Summaries performed by site use the average or sum value within a site as the point estimate for that site.

3. Findings

3.1. Site Selection

As discussed in Section 2.1, study homes selected for this field study were from the main RBSA audit sample and screened for occupancy count and newer clothes washers and dryers manufactured after 2001 so that they have newer cycle options and features, though all the machines in this study are 2005 or newer. The sites did not have a geographical stratification, so the majority of the sites were along the I-5 corridor. Table 2 shows the distribution of sites based on occupancy, Table 3 shows the distribution of sites by state, and Table 4 shows the distribution of washers and dryers by machine vintage. In the distribution of sites by occupant bin, the table shows the final distribution of occupants during the metering period. At the time of recruitment, there was one more site in the 5+ bin and one less in the 3–4 bin.

Table 2. Distribution of Sites by Occupant Bin

Number of Occupants	Site Distribution	
	%	n (S)
1–2	48%	22
3–4	39%	18
5+	13%	6
Total	100%	46

Table 3. Distribution of Sites by State

State	Site Distribution	
	%	n (S)
Idaho	2%	1
Oregon	28%	13
Washington	70%	32
Total	100%	46

Table 4. Distribution of Sites by Washer and Dryer Vintage

Machine Vintage	Washers		Dryers	
	Mean	n (S)	Mean	n (S)
2005	13%	6	17%	8
2006	7%	3	7%	3
2007	15%	7	15%	7
2008	17%	8	20%	9
2009	22%	10	20%	9
2010	24%	11	20%	9
2011	2%	1	2%	1
Total	100%	46	100%	46

3.2. Simple Loads

Using a subset of loads helps reduce variability and provide better trends in the data parameters. The "simple" load properties are similar to the test procedure load parameters and comprise about half of the data in the study. Many of the summaries below and in the appendices show a side-by-side comparison of the analysis across all loads and just for the simple loads.

Table 5 shows the percent of all loads meeting each criterion of the simple load definition. Overall, there were 1270 dryer loads, but some categories had data missing due to incomplete logbooks, data only from metering for a load, or bad data. Listed in the right column is the number of loads satisfying each criterion. To find the total number of non-missing loads analyzed for each criterion, divide the given n by the percent.

Most categories only have two options – either the load meets the criteria or it does not. For two of the categories (RMC and dry weight), the load could be below or above the criteria. In the case of RMC, 9.2% are below 33% RMC and 12.2% are above 100% RMC. For weight, 8.2% are below 3 lbs and 2.6% are above 15 lbs. **For non-continuous loads, 19.5% of the loads had clothing removed and multiple dryer runs accounted for 17.8% of the loads.**

Table 5. Categorizing Simple Loads

Criteria	% of Loads	Loads Satisfying Criterion
Loads Washed and Dried	93.8%	1191
RMC Between 33% and 100%	78.7%	951
Dry weight Between 3 lbs and 15 lbs	89.2%	1085
No Items Removed Between Washer/Dryer	80.5%	980
No Multi-Run Dryer Loads	82.2%	1044
Simple Loads	44.6%	567

3.3. Clothes Washer Factors

As mentioned previously, Appendix 4 includes an extensive analysis of washing machine data. In this section, the focus is just on washer factors that affect clothes going into the dryer.

3.3.1. Water Temperature Settings

Hot water energy consumption is a parameter in the MEF formula found in Appendix J1, but also may affect dryer energy use. If clothes are warmer going into the dryer, the warm-up time of the dryer may be shorter. Table 6 shows a comparison of the wash and rinse temperature assumptions in the washer test procedure compared to the ratios found in the logbooks. **The wash temperature settings observed are very close to the test procedure, with the biggest deviations being fewer extra hot cycles[3] and more warm wash cycles in the metered data. For the rinse temperature, the test procedure assumes a much higher percent of warm rinse use than seen in the field.**

Table 6. Comparison of Test Procedure and Logbook Temperature Load Ratios

Temperature Setting	Test Procedure	Logbook
Extra Hot Wash	5%	1%
Hot Wash	9%	8%
Warm Wash	49%	56%
Cold Wash	37%	34%
Warm Rinse	27%	9%

3.3.2. Percent of Wash Loads Mechanically Dried

The J1 test procedure includes an assumption that 84% of the washer loads are dried, but the field data show 93.5% of washer loads dried. There is certainly a discrepancy here, but the new J2 procedure increases the value to 91%, which is closer to the field findings.

The values above refer to the number of loads dried and not quantity of clothing dried. A load with both a wash cycle and a dry cycle had both load types in the analysis even if the cycle had some items removed between the wash and dry cycle. For a load to have a wash cycle and no dry cycle, all clothing is removed and presumably air-dried.

3.4. Dryer CEF

The dryers in this study were rated using the Appendix D protocol and not the D1 protocol, so CEF was not a metric at the time of their production. However, the design of the data collection in the field allowed a field CEF calculation for these dryers. The following subsections discuss the parameters in the two test protocols compared to the field data, and then computations of field EF and CEF based on the D1 protocol. Appendix D2 includes more changes to the protocol and are listed in the following sections, where applicable.

[3] "Extra hot" and "sanitary" denote the same concept

3.4.1. Test Cloth

The DOE test procedures use a test cloth that is a 50/50 cotton-poly blend. Participants in this study would consider this a medium weight fabric when compared to silk (light) or jeans (heavy). Medium fabric accounted for about 59% of loads in the study (across all loads and for simple loads), as shown in Table 7. A list of examples for each fabric weight is in Appendix 2.

Table 7. Distribution of Loads by Fabric Weight

Fabric Weight	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Light	24.5%	0.1%	290	25.8%	0.1%	145
Medium	59.2%	0.1%	700	58.6%	0.1%	330
Heavy	16.2%	0.1%	192	15.6%	0.1%	88
Total	100.0%	0.0%	1182	100.0%	0.0%	563

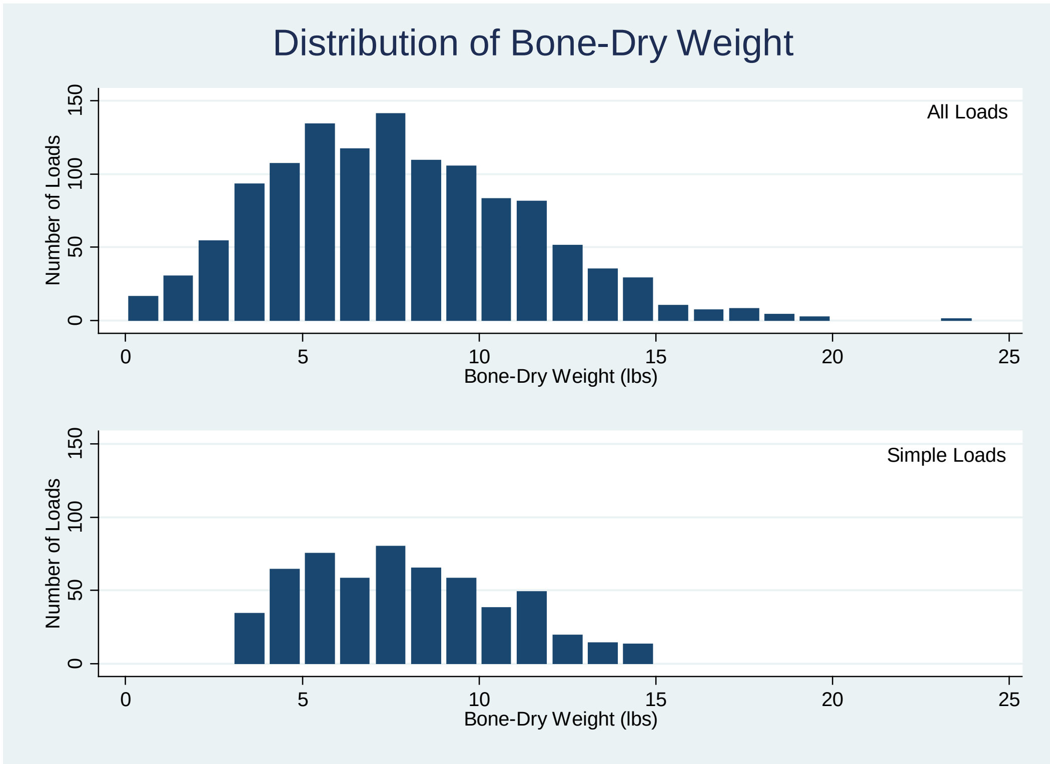
3.4.2. Load Weight

Appendix D specifies a dryer test load with a bone-dry weight of 7.00 lbs and both D1 and D2 specify 8.45 lbs. The average bone-dry weight found in the field was 7.64 lbs for simple loads and 7.87 lbs for all loads. Table 8 shows the percent of loads by bin in the field data and Figure 1 shows the distribution of bone-dry weight for dryer loads.

Table 8. Distribution of Dryer Loads by Bone-Dry Weight

Load Weight (lbs)	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–2	8.1%	0.0%	103	—	—	—
3–5	27.0%	0.1%	341	30.0%	0.1%	188
6–8	30.1%	0.1%	381	35.1%	0.1%	220
9–11	22.4%	0.1%	283	26.2%	0.1%	164
12–14	9.8%	0.0%	124	8.8%	0.1%	55
15+	2.6%	0.0%	33	—	—	—
Total	100.0%	0.0%	1265	100.0%	0.0%	627

Figure 1. Distribution of Bone-Dry Weight for Dryer Loads



The difference between the amount of water removed between the D, D1, and D2 protocols is minimal. The D and D1 protocols finish at the same final RMC (2.5% – 5.0%), and while D starts at a higher initial RMC (70% ± 3.5%), the test load is smaller (7.00 lbs). The EF formula normalizes the change in initial-to-final moisture content to 66% in Appendix D and 53.5% in Appendix D1. A 66% RMC change for a 7.00 lb test load is 4.62 lbs of water removed, while a 53.5% RMC change for an 8.45 lb test load is 4.52 lbs of water removed. The average amount of water removed in the field was 4.81 lbs for all loads and 4.73 lbs for simple loads.

The updated D2 protocol specifies a final RMC of 1.0% – 2.5% for manual termination dryers, but allows auto-termination dryers to run to completion using the normal dryness setting as long as the final RMC is under 2.0%. If 2.0% final RMC is not achieved using the Normal dryness setting, the dryness setting is increased and the test is repeated. The initial-to-final moisture content difference is 55.5%, which equates to 4.69 lbs of water removed.

3.4.3. Initial RMC

Initial RMC of the dryer loads in the test protocols was 70.0% ± 3.5% for the D protocol, 57.5% ± 3.5% for D1, and 57.5% ± 0.33% for D2 (D2 uses a final mass adjustment for more precision).

In the field, initial RMC was 71.0% ± 1.6% across all loads, and 62.9% ± 0.6% for simple loads. A distribution of the initial RMC values in the field is in Table 9.

Table 9. Distribution of Loads by Initial RMC

Initial RMC	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–32%	8.5%	0.0%	102	—	—	—
33–65%	48.1%	0.1%	579	61.4%	0.1%	348
66–99%	30.4%	0.1%	366	38.6%	0.1%	219
100%+	13.0%	0.0%	156	—	—	—
Total	100.0%	0.0%	1203	100.0%	0.0%	567

The initial RMC values shown in the table above are after the clothes leave the washing machine. The machines in this study are all from 2005 and later, but within that period there were some changes in the clothes washer standard around 2010. The following tables summarize the initial RMC by vintage. Table 10 summarized the initial RMC by washer vintage for both simple loads and all loads. Table 11 and Table 12 replicated the distribution shown above, but by vintage.

Table 10. Average Initial RMC by Vintage

Washer Vintage	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
2005–2009	69.4%	2.9%	951	63.9%	1.2%	442
Post 2009	76.9%	6.7%	258	59.3%	2.0%	125
Total	71.0%	2.7%	1209	62.9%	1.0%	567

Table 11. Distribution of Loads by Initial RMC for 2005–2009 Washers

Initial RMC	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–32%	9.2%	0.1%	87	—	—	—
33–65%	46.9%	0.1%	444	59.0%	0.2%	261
66–99%	31.8%	0.1%	301	41.0%	0.2%	181
100%+	12.1%	0.1%	114	—	—	—
Total	100.0%	0.0%	946	100.0%	0.0%	442

Table 12. Distribution of Loads by Initial RMC for Post 2009 Washers

Initial RMC	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–32%	5.8%	0.2%	15	—	—	—
33–65%	52.5%	0.3%	135	69.6%	0.6%	87
66–99%	25.3%	0.3%	65	30.4%	0.6%	38
100%+	16.3%	0.2%	42	—	—	—
Total	100.0%	0.0%	257	100.0%	0.0%	125

The initial RMC in newer equipment is higher across all loads compared to older equipment, but lower for simple loads. The error bounds for all loads are large but do not overlap. This could be due to certain behaviors of occupants skewing the data, since the simple loads are much closer together, or could be from other factors. Another possible factor is the type of washing machine – horizontal axis versus vertical axis. The horizontal axis machines are much more prevalent in the Post 2009 period compared to vertical axis machines. Table 15 summarizes the average initial RMC by vintage and washer type. The site count is for all loads – there were two horizontal axis machines with no simple loads, one from 2009 and one from 2010. One of these sites did not have any initial RMC data.

Table 13. Average Initial RMC by Vintage and Washer Type

Washer Vintage	All Loads		Simple Loads		Site Count	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
2005–2009	59.1%	98.4%	61.4%	74.3%	22	12
Post 2009	77.2%	74.9%	58.0%	73.5%	10	1
Total	63.6%	95.8%	60.6%	74.2%	32	13

In the table above, all of the vertical axis machines were above 72% for the All Loads column, with five of them averaging around 100% or above initial RMC across all loads. Two of these cases were still around 85% for simple loads, and across all sites for simple loads the vertical axis machines were between 62% and 87%. The horizontal axis machines were between 38% and 102% across all loads and between 46% and 86% for simple loads. Three of the ten sites for the horizontal axis machines Post 2009 were close to or above 100%, while the rest of that cohort were below 70%. The vertical axis machines did not have a similar jump in the data. All three of the high cases in the horizontal Post 2009 all loads group are very close to the average in the simple loads analysis.

The data above seem to point toward two trends:

- Washer vintage does not seem to be affecting the initial RMC of the dryer. It is homeowner behavior that is skewing the vintage trends. The simple loads show no noticeable difference between vintages. Further, there is no difference in vintage in the all loads column after dropping the three horizontal outliers and five vertical outliers.
- Washer axis type does seem to have an effect on initial RMC. The simple loads summary indicates about a 13.6% difference in initial RMC, as shown in Table 14.

Table 14. Average Initial RMC by Washer Type for Simple Loads

Washer Type	Simple Loads		
	Mean	EB	n (L)
Horizontal	60.6%	1.1%	472
Vertical	74.2%	2.4%	95
Total	62.9%	1.0%	567

3.4.4. Final RMC

The bone-dry estimate of final RMC values have more error in their calculation compared to initial RMC because of the calculated (rather than measured) bone-dry weight (see section 2.4). Since there is very little water remaining at the end of the dryer cycle, the final weight is very close to the estimated bone-dry weight, so any error in the bone-dry weight becomes very visible. This is different from the initial RMC where the wet clothes weight is much higher than the bone-dry weight.

3.4.5. Temperature Settings

The test procedures use the highest temperature setting to obtain the energy use per cycle. While this provides consistency across a multitude of temperature setting names and control strategies, Table 15 shows users tend to use the medium temperature setting most often, and use the low setting on occasion.

Table 15. Dryer Temperature Setting

Temperature Setting	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Low	11.4%	0.0%	142	11.2%	0.1%	67
Medium	46.1%	0.1%	577	51.7%	0.1%	310
High	42.5%	0.1%	532	37.2%	0.1%	223
Total	100.0%	0.0%	1251	100.0%	0.0%	600

While it appears the test may not be covering most load settings, the temperature within the dryer may tell a different story. Figure 2 shows the measured exhaust temperature for low, medium, and high temperature settings across all sites for simple loads. The data on the left of the graph are median load exhaust temperatures and the data on the right are max load exhaust temperatures. There is complete overlap of medium temperature setting with high temperature setting, and even some overlap in the median temperatures of the low setting with the high setting. An explanation from one manufacturer confirms this similarity in temperature[4].

However, this could be other factors confounding this finding. Two of the possible issues are manufacturer-specific control strategies and user-specific control strategies. Some manufacturers may have the strategy of using the same temperature for medium and high and might have other controls in place to differentiate between medium and high. One speculation is having high temperature run for longer than medium setting, and another speculation is the high temperature might not drift as low during the middle of the cycle compared to medium temperature setting

[4] GE reference to 125°F for Low and 135°F for both Medium and High (GE, 2014)

(see Appendix 11 for examples of the cyclic nature in temperature for dryer loads). The other possible issue is user-specific control strategies. Not every homeowner used all the settings on their dryer and Figure 2 is a combination across all simple loads at all houses. Sites may be over- or under-represented in each of the categories.

Figure 2. Comparison of Dryer Temperature Setting and Measured Temperature

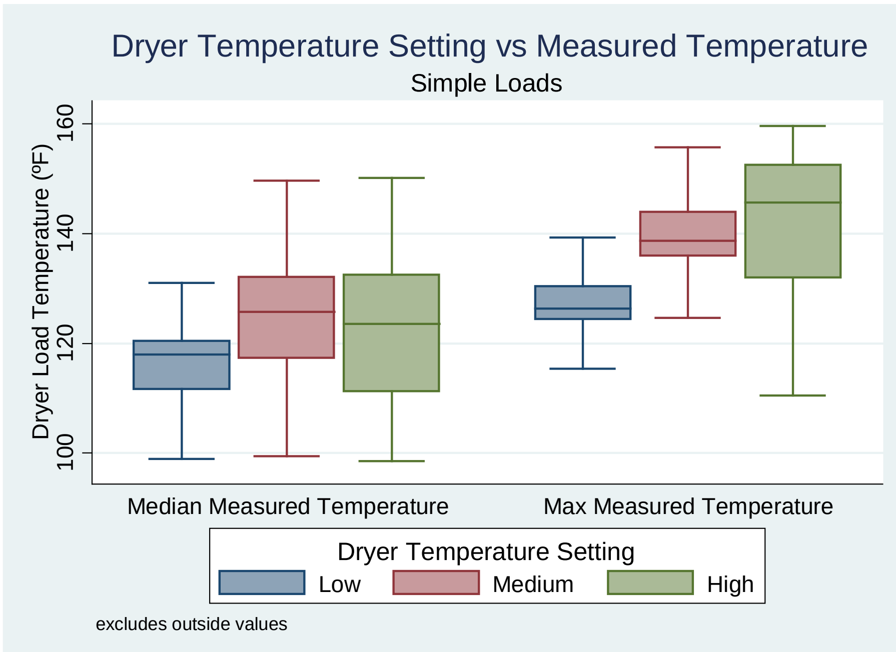


Figure 3 splits the data out by site to counteract the issues of manufacturer and occupant bias. The graph includes all sites that had at least three loads at both medium and high dryer setting. This allows a quick survey of max exhaust temperature for both medium and high temperature setting by home. There are three scenarios:

- Average temperature for medium setting is lower than for high setting: 2 sites
- Average temperature for medium setting is about equal to high setting: 6 sites
- Average temperature for medium setting is higher than for high setting: 2 sites

For the 10 sites shown below it does seem plausible that many dryers do not have a significant temperature difference between medium and high temperature settings.

Figure 3. Max Dryer Temperature by Dryer Setting and Site

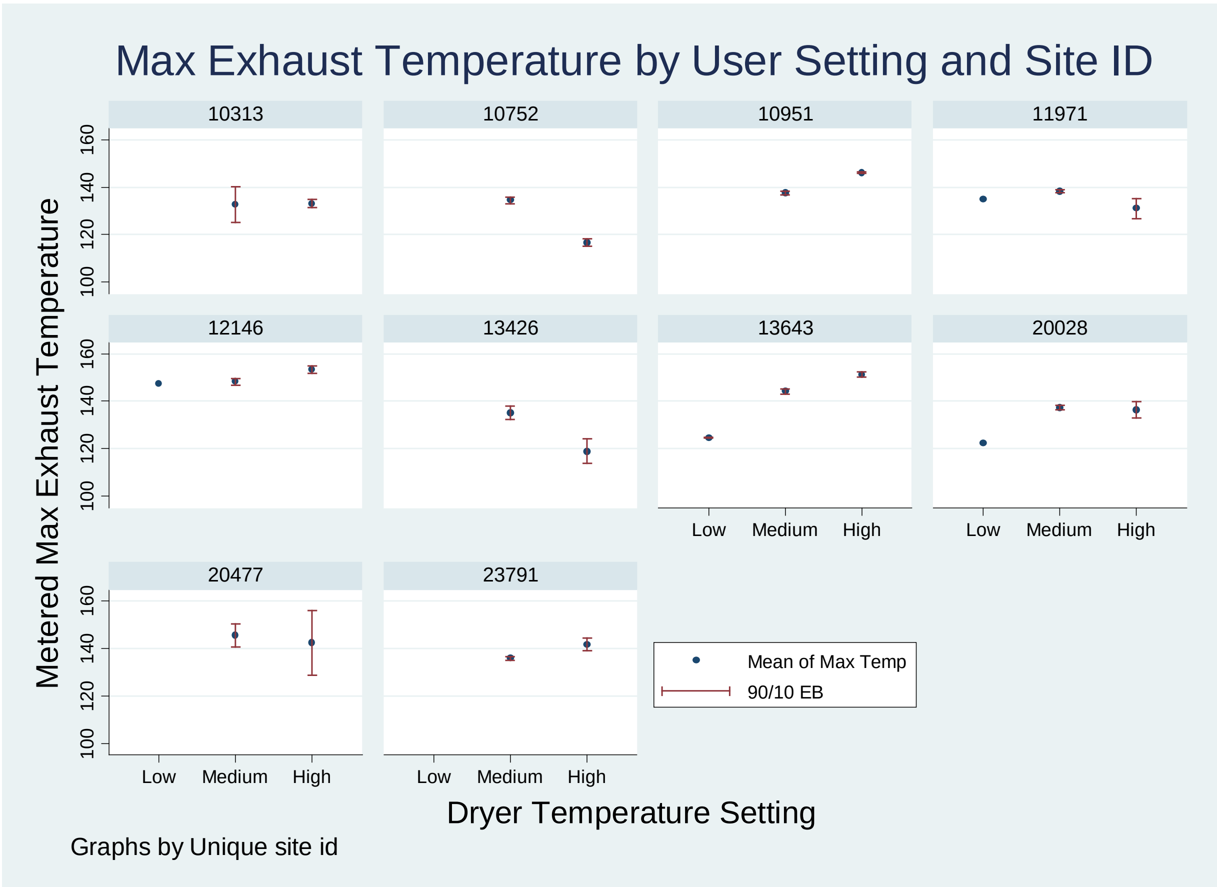
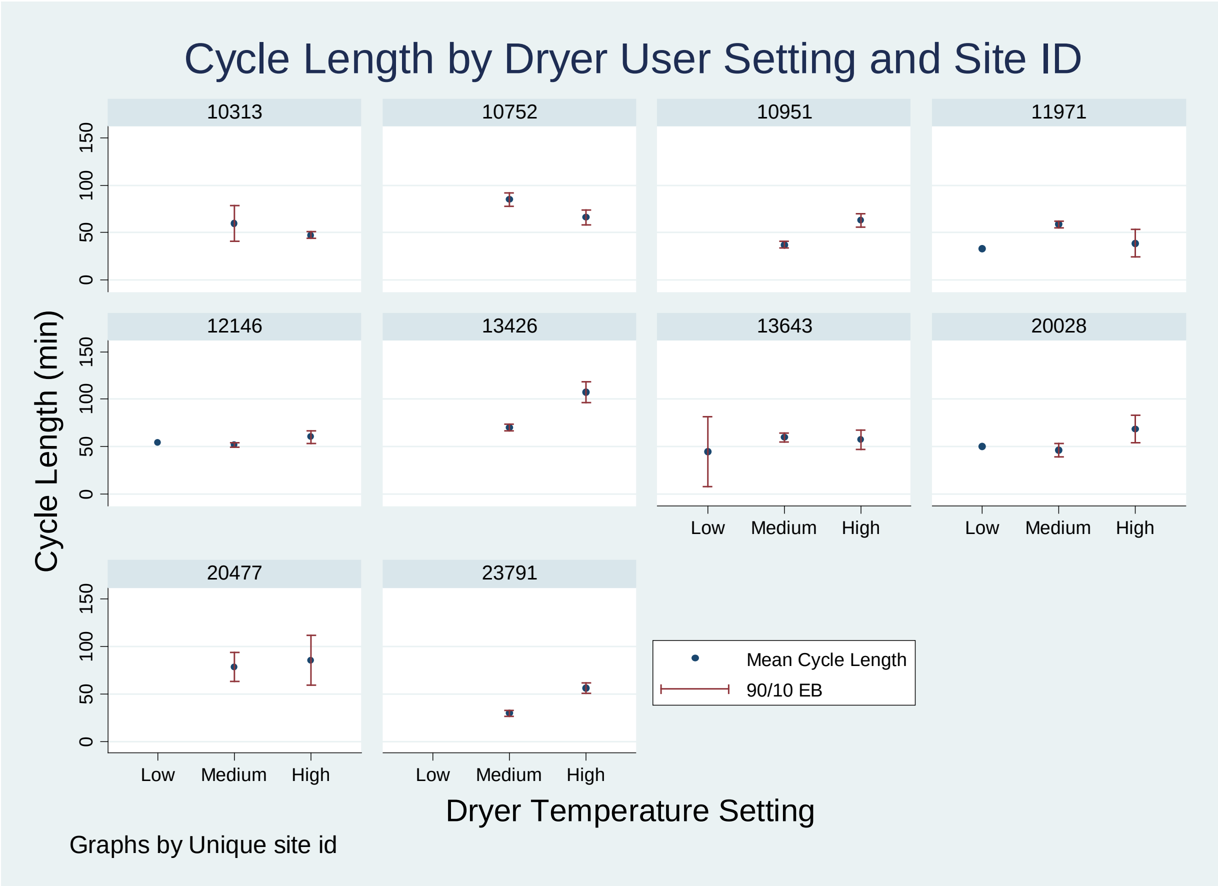


Figure 4 is the same analysis to look at cycle length by dryer temperature setting. The trend is very similar – not many sites are different between medium and high temperature settings. Therefore, cycle length is not likely the key difference.

Figure 4. Cycle Length by Dryer Setting and Site



3.4.6. Energy Consumption per Cycle

Both the D and D1 protocols use an RMC normalization to translate the energy use of the test result into an estimate of energy use for a standard RMC value. This normalization is necessary because of the range of acceptable initial and final RMC values in the test protocol. The translation assumes energy consumption is linear in relation to RMC within the acceptable RMC values.

In the D2 protocol, the RMC normalization is only used for manual termination dryers. Auto-termination dryers use the unaltered energy use. The equations in this section are from the D1 protocol since it is assumed most manufacturers will use D1 over D2 until the D2 implementation date draws near.

The D1 formula from section 2.4.2 is

$$E_{ce} = \frac{53.5\%}{W_w - W_d} \times E_t$$

where W_w is initial RMC, W_d is final RMC, and E_t is the recorded energy use (kWh) during the dryer test cycle. The field use factor has been set to one and dropped out of the formula since the field data from this study is directly used.

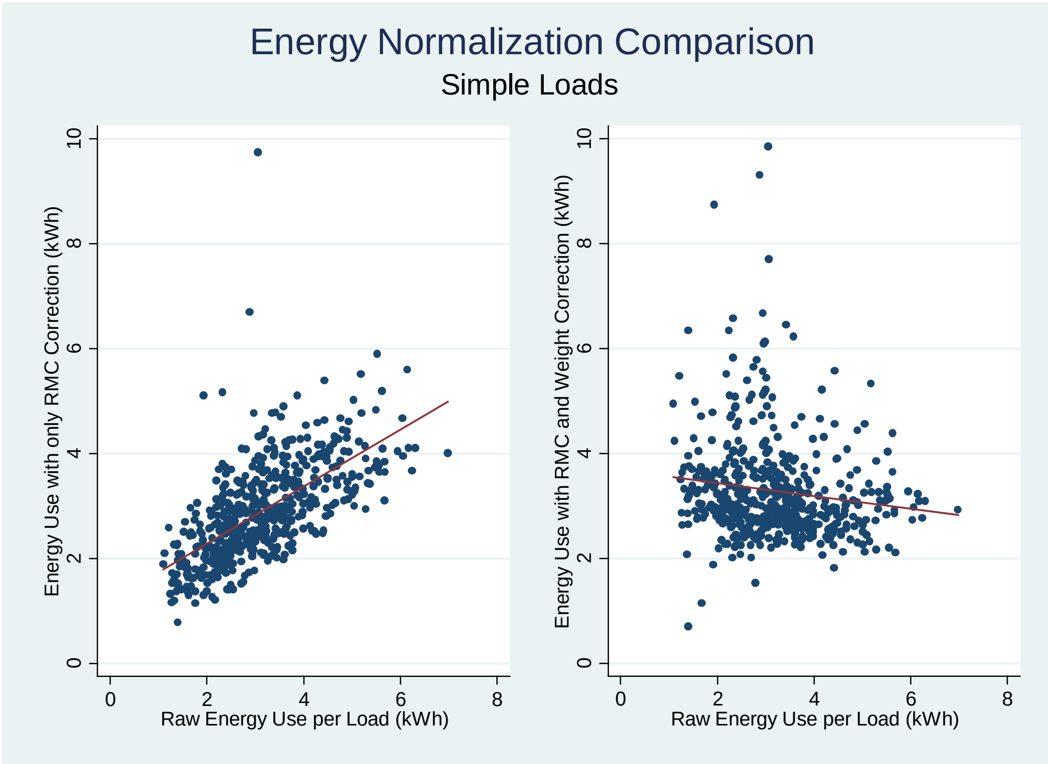
The formula above normalizes the difference in initial RMC and final RMC to a fixed value of 53.5%. However, the formula above also assumes a fixed input weight for the test procedure, which is not true for the field data. In order to estimate the field EF, a bone-dry weight linear normalization is used.

$$E_{ce} = \frac{53.5\%}{W_w - W_d} \times E_t \times \frac{8.45}{L_f}$$

where L_f is the bone-dry weight of the load. E_{ce} uses the field-recorded Ww, W_d, E_t, and L_f for each load, and the average load per site is then calculated. A standard weight of 8.45 lbs and RMC difference of 53.5% are used since this E_{ce} value will be used to calculate EF and CEF based on the D1 protocol.

Figure 5 shows the normalized E_{ce} per load on the vertical axis and raw energy use per load on the horizontal axis. The graph on the left is only normalized by RMC and the graph on the right is normalized by both RMC and load weight. Using both corrections provides a more constant value as shown by the more horizontal regression line in the right graph. The RMC and weight normalization formula go into the calculation of field EF and CEF.

Figure 5. Energy Consumption per Load Normalizations



3.4.7. Hours per Year

Of the 8760 hours in a year, the D1 and D2 protocols assume the dryer is in off/standby mode for 8620 of those hours, or about 98.4% of the time. **The minute-by-minute field data shows a 96.6% ± 0.5% idle time, or about 8463 hours.** This could be due to a difference in number of loads per year (see next section) or to an increase in cycle time compared to the protocol assumption. Since the standby use is so low compared to the cycle use (as discussed below), the difference in the number of off hours does not influence CEF.

3.4.8. Loads per Year

The D1 and D2 protocols also use a number of loads per year assumption in the calculation of EF and CEF. **The assumption is 283 loads per year, which is at the lower end of the error bound of 311 ± 42 loads found in the field.** Table 56 in the appendix has a distribution of the number of loads per year.

3.4.9. Standby Energy Use

Standby energy use on a per load basis goes into the CEF formula, so it is the average energy consumed between two cycles. All dryers (and washers) in this study used at least some standby energy, but most were very low. **On average dryer standby energy use in the field is 5.8 Wh ± 2.8 Wh per load (0.17 W on average, and 1.50 kWh ± 0.69 kWh on average per year).** As an aside, washers were much higher on average with 31.5 ± 9.3 Wh (0.87 W on average). A full discussion of standby energy use is in subsection A6.3 of Appendix 6.

3.4.10. Dryer EF

The EF value per site, which is an average across all loads at a site, uses the adjusted E_{ce} formula from section 2.4.2, which normalizes each load by the standard RMC and bone-dry weight values. The average EF for the field study is 2.63 lb/kWh ± 0.29 lb/kWh across 45 sites. For simple loads only, the average EF is 2.66 lb/kWh ± 0.12 lb/kWh across 44 sites.

3.4.11. Dryer CEF

If we now add the standby energy use into the dryer cycle data, we can produce the CEF value. For the field study, standby is a sum of all the energy during the non-energy time divided by the number of cycles. CEF uses the same analysis structure as EF, where we have excluded the one outlier. The standby energy use per load is about 5 Wh, whereas the dryer cycle energy use per load is about 2500 Wh. Thus, the addition of standby use to the cycle use for traditional dryers is not visible in the results. However, some of the latest dryer models are now equipped with an active Wi-Fi connection (none of these types of dryers were in this study). Assuming the connection adds 5 W of standby, this would increase the standby energy use per load to about 150 Wh per load, or about 6%. At this level, the standby energy use is more relevant in the CEF calculation.

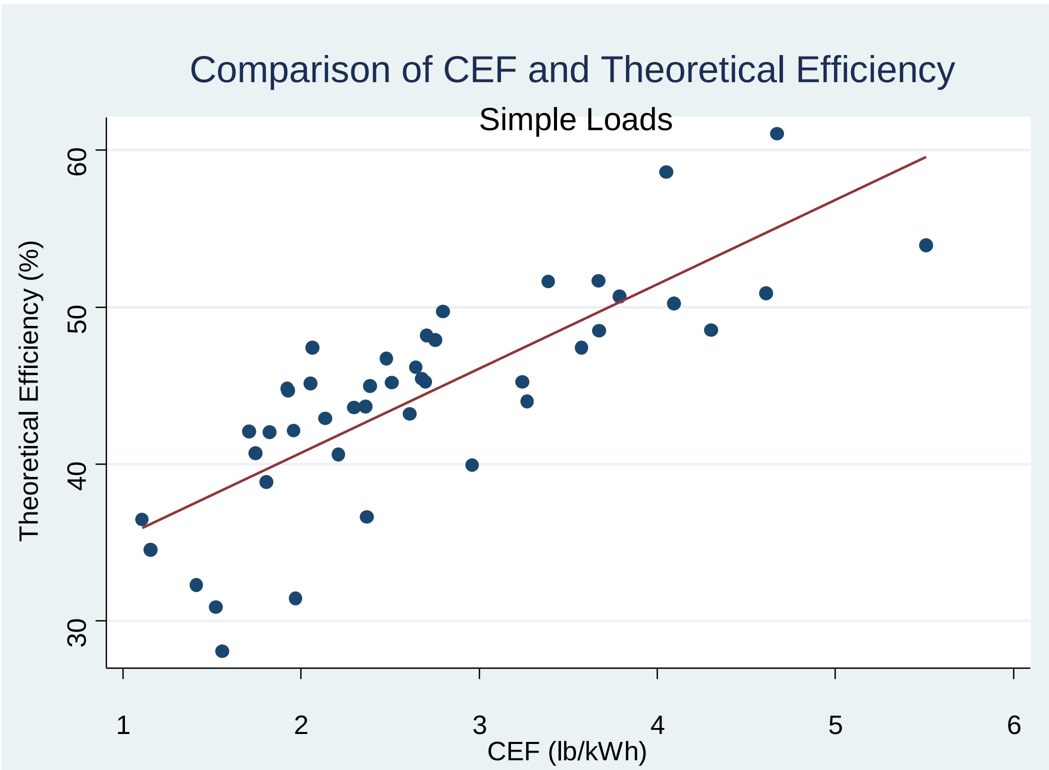
Since standby was so low for the dryers in this field study, the average CEF is the same as the EF, or 2.62 lb/kWh ± 0.28 lb/kWh across all loads at 45 sites, or 2.66 lb/kWh ± 0.12 lb/kWh for simple loads across 44 sites.

Note that the assumption for the washing machine MEF calculation is a dryer EF of 2.0 lb/kWh (see Appendix 4). The dryers in this study are more efficient on average compared to this assumption. Figure 6 in the next section shows CEF values by site.

3.4.12. Dryer Theoretical Efficiency

Section 2.4.2 describes a second type of metric, theoretical efficiency. The theoretical energy use is the vaporization energy required to evaporate and remove the observed amount of water from the load. The calculation uses the vaporization energy to set the minimum energy required to remove moisture from the load and divides by the actual energy use of the load. The average theoretical efficiency across sites is 45.0% ± 2.1% for all loads and 44.4% ± 1.7% for simple loads. Efficiency per site ranges from about 25% up to 70%. Note this is not part of the test protocol. The average theoretical efficiency for a site lines up well with the CEF for a site, as can be seen in Figure 6 below.

Figure 6. Comparison of Dryer CEF and Theoretical Efficiency



3.5. Additional Dryer Analysis

The CEF section above focuses on the parameters and calculations for the current and upcoming dryer standards. There are additional parameters possibly incorporated in the future, so the subsections below discuss results for some of these possible new parameters.

3.5.1. Dryer Energy Use Compared to RBSA Metering

A recently published RBSA Metering Report included energy monitoring of washers and dryers for a full year, but no logbook of load parameters (Larson, et al., 2014). The current field study metered for only four to six weeks and extrapolated to find the yearly number of loads and use, so the RBSA Metering study provides a comparison data set to see if the extrapolation was reasonable. A full discussion of the laundry vs. RBSA Metering report is in Appendix 12, but the results in Table 16 show the RBSA Metering report is within the error bound of the laundry field study, though on the low end of the error bound. The load shapes from the metering report also indicate some seasonal dependence of laundry use, though investigating the reasons behind this was beyond the scope of the RBSA Metering report.

Table 16. Comparison of Yearly Dryer Energy Use to Metering Report

Dryer Vintage	RBSA Metering Report			Laundry Report		
	Mean	EB	n (S)	Mean	EB	n (S)
2005–2009	833	87	30	978	160	36
Post 2009	636	215	5	688	147	10
Overall*	805	—	35	915	132	46

* For purposes of this comparison, only two vintages from the metering report went into calculating the average, and the report did not include EB for the overall case. Across all vintages in the metering report the average annual dryer use is 762 kWh ± 58 kWh (n = 64).

3.5.2. Dryer Auto-Termination

Dryer auto-termination is a prominent feature of many new dryers, but its effectiveness in the field is unknown. The following graphs explore the behavior of auto-termination loads in terms of both moisture and energy by comparing the dryer efficiency per load for auto-termination and timed dry (manual termination) loads.

In section 2.4.2 the normalized energy use provided consistency across different initial RMC values and different bone-dry weights when calculating the energy use per load, EF, and CEF values. The following graphs reference both the normalized EF and the non-normalized EF when looking at how the dryer properties change for auto and manual termination dryers.

Figure 7 shows the per-load normalized dryer efficiency versus water removed. The data indicate no noticeable difference between auto-termination and manual-termination load efficiencies. Both dryer types increase EF going from low amounts of water removed to high amounts.

Figure 8 shows the non-normalized EF by initial RMC. The load efficiency (EF) of automatic dryers is more consistent across initial RMC values compared to manual termination dryers, and the automatic dryers are more efficient at low levels of RMC. At high RMC values there appears to be no difference in dryer efficiency by termination type.

Figure 7. Dryer EF by Dryer Termination and Water Removed for Simple Loads

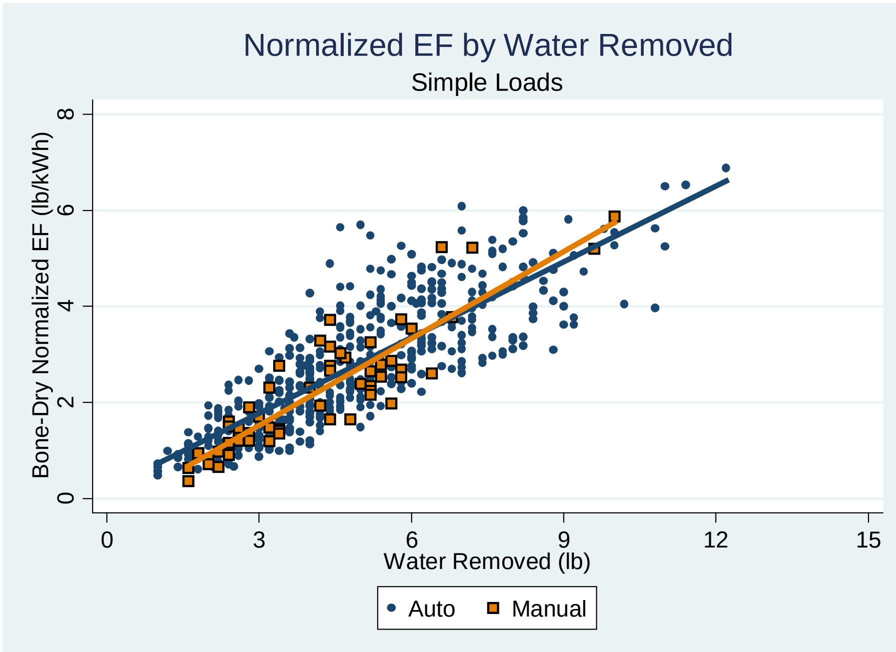
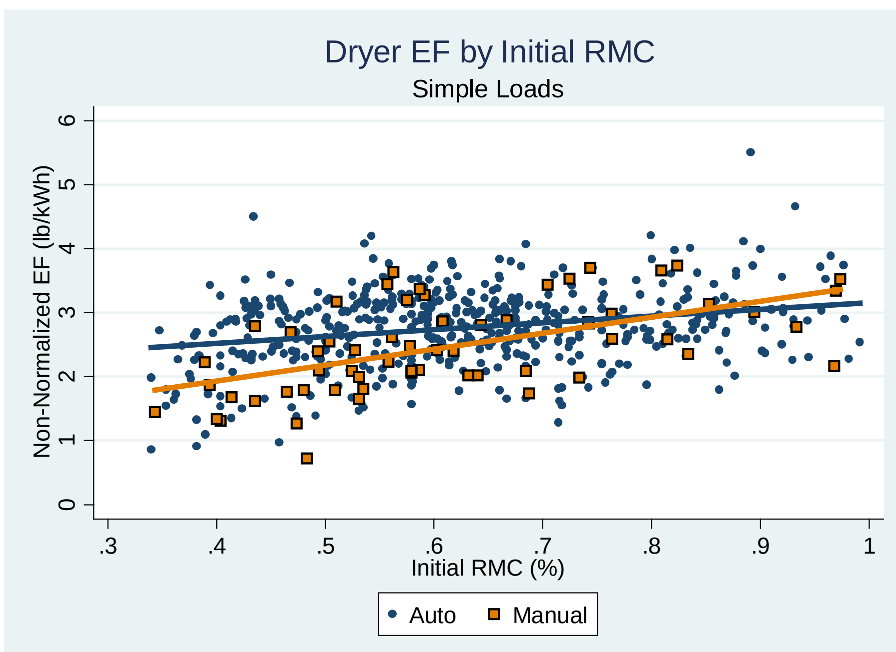
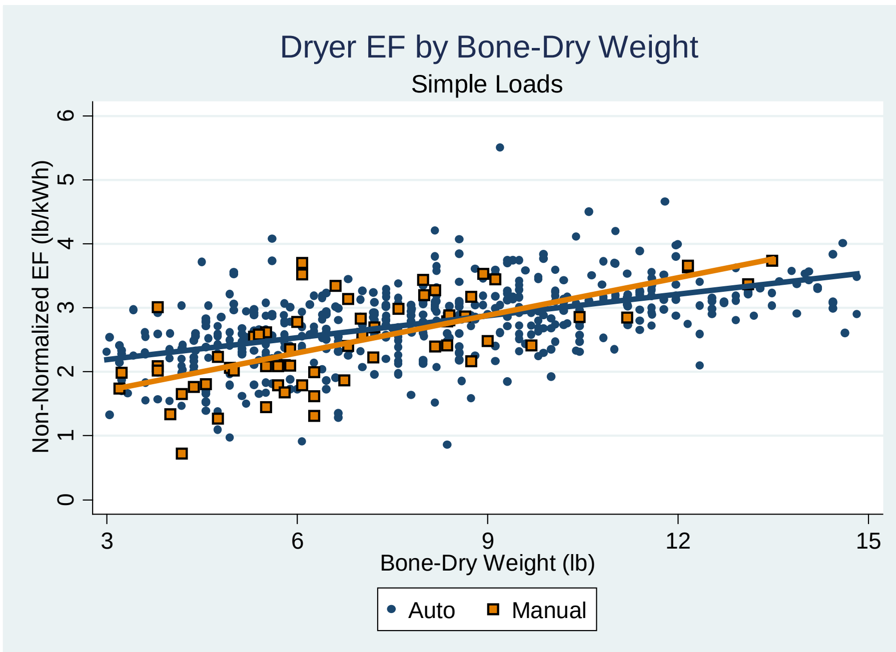


Figure 8. Dryer EF by Dryer Termination and Initial RMC for Simple Loads



The two graphs above are similar in nature, using moisture as the independent variable. The first is absolute moisture removed (water removed, in lb) by EF normalized by weight, and the second is moisture removed normalized by weight (initial RMC) by non-normalized EF. Figure 9 looks at weight as the independent variable, showing for both auto-termination and manual loads the heavier loads are more efficient than the lighter loads. This trend is slightly steeper in the manual loads.

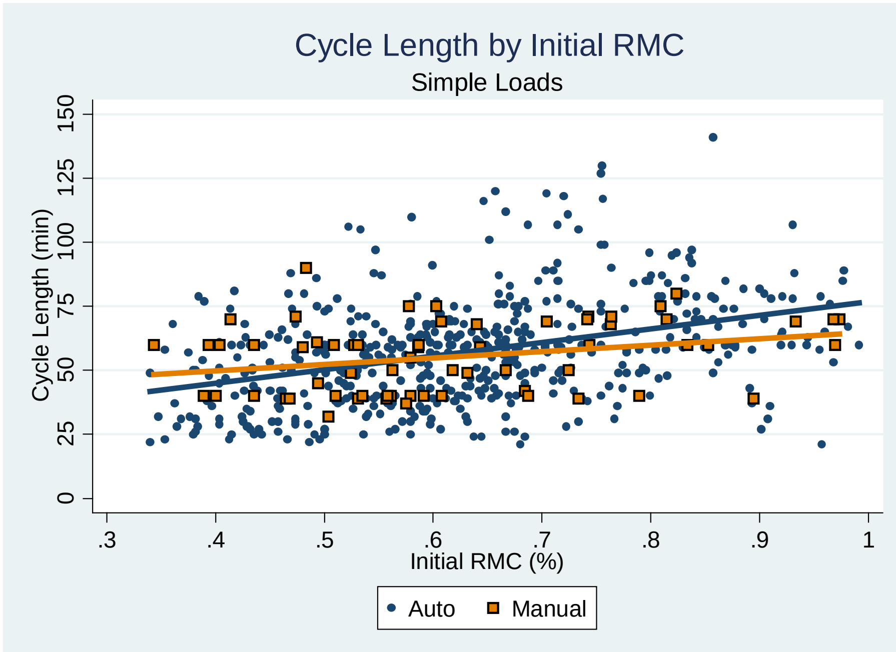
Figure 9. Dryer EF by Dryer Termination and Bone-Dry Weight for Simple Loads



Combining the three graphs above, there seems to be a pattern where the auto-termination feature works better than manual termination for small loads. For very large loads, the trends appear to show either manual termination efficiency might be higher than automatic termination or manual termination loads may have come out of the dryer a bit more damp. An analysis of final RMC by termination type would help indicate which of these scenarios is more likely, but as mentioned in section 3.4.4, the final RMC values are not reliable for this level of detailed analysis. Loads that are roughly “average” (about 9 lbs and 80% initial RMC, for instance) seem to have no difference between auto-termination and manual controls.

Figure 10 looks at the cycle time response across initial RMC. The auto-termination loads show an increase in cycle length with increased initial RMC, whereas manual load cycle times are much more consistent across initial RMC. For manual dryers there are distinct levels at 40 minutes, 50 minutes, 60 minutes, and 70 minutes.

Figure 10. Cycle Length by Initial RMC and Termination Mode for Simple Loads



A simple t-test of efficiency by termination type shows a significant difference between the groups (p = 0.0005) where the average EF of manual dryers is 2.47 lb/kWh and the average EF of automatic dryers is 2.76 lb/kWh. The same simple t-test analysis across other variables by termination type shows a significant difference in water removed (auto: 4.8 lb, manual: 4.0 lb) and bone-dry weight (auto: 8.0 lb, manual: 6.9 lb). There is no noticeable difference by termination type of initial RMC or cycle length. Overall, the t-tests suggest that auto-termination is slightly more efficient than manual termination, but this holds true only for small loads and loads with low initial RMC. For average loads, those more closely resembling the test procedure, there is no difference in field efficiency.

3.5.3. Dryer Temperature and Relative Humidity vs Final RMC

Final RMC is the standard testing method for determining the end of the load, but there is a desire to find a convenient proxy to indicate the approximate end of a cycle for field tests. For this study, the temperature and relative humidity in the dryer exhaust are available to compare to the final RMC. The final RMC for this study, as mentioned previously, is a rough estimate in itself because of the estimation technique for converting pre-washer dry weight and post-dryer dry weight into bone-dry weight. The following graphs are then just an exploration into apparent trends of temperature, relative humidity, and final RMC.

Temperature and relative humidity have one-minute recording frequency through the dry cycle, but RMC measurements only occur before and after the cycle. Because of this, we cannot follow the changes in these variables through the cycle, but we can review the single-point estimates for each load. The point estimates used below are the maximum temperature and minimum relative humidity observed during a cycle as a way to approximate the driest condition within the dryer and correlate it to the final RMC. The graphs below show what happens near the ideal final RMC of 2.5% to 5%.

Figure 11 and Figure 12 show no clear trends for final RMC by using minimum cycle relative humidity or maximum cycle temperature. Part of this is due to the innate nature of final RMC in this field study of having large errors, as can be seen by the obvious bimodal distribution centered on 0% and 5% final RMC. This is an artifact of the estimation technique for bone-dry weight. It is likely that the scatter below 5% RMC is due to the inaccuracies of this analysis although it is also likely that all of these cases are much dryer than 5% RMC. Figure 13 just shows there is a better correlation of the maximum temperature to minimum relative humidity.

Figure 11. Final RMC by Minimum Relative Humidity

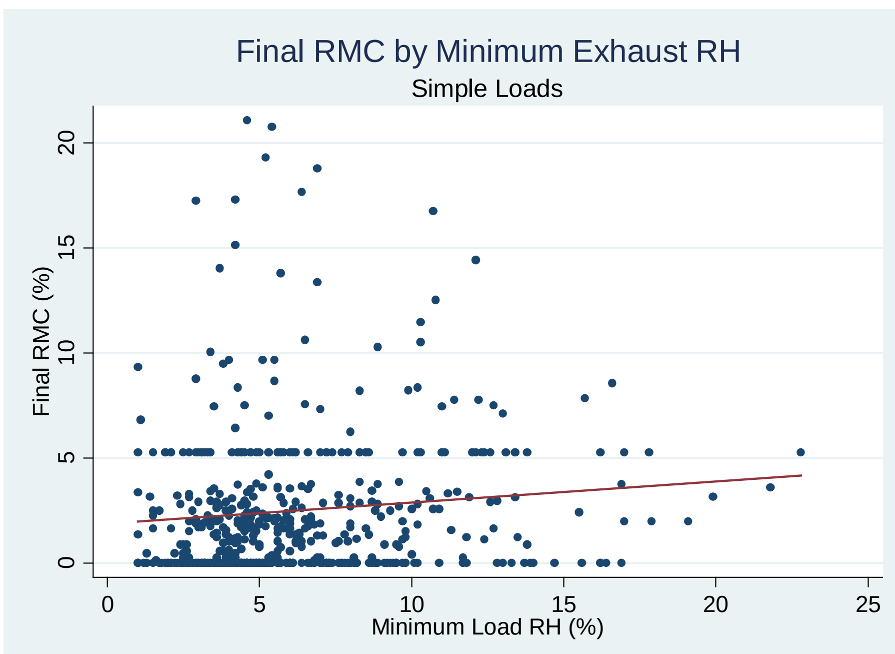


Figure 12. Final RMC by Maximum Temperature

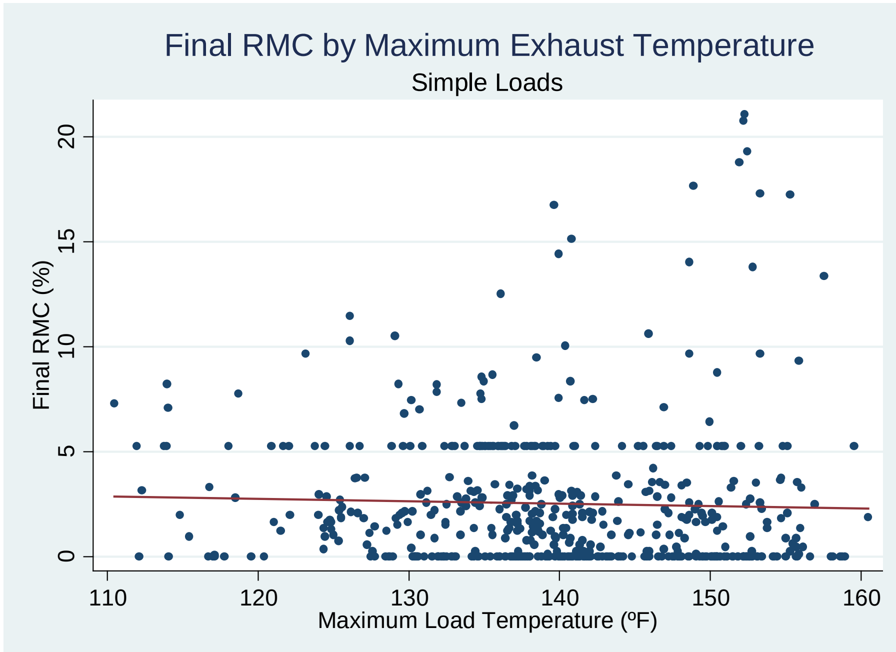
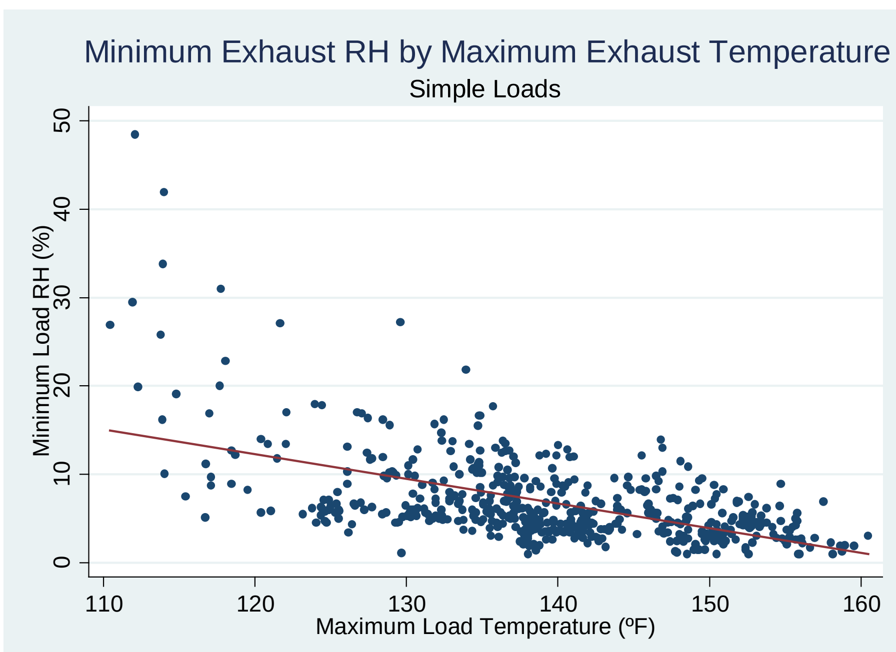


Figure 13. Minimum Relative Humidity by Maximum Temperature



3.5.4. Energy Use Below 5% RH

If relative humidity *could* be a proxy for determining whether a load is dry, then knowing how much time and energy the dryer used after the clothes were dry would be a good way to estimate the energy wasted in over-drying clothes.

Figure 14 shows an example of one version of this analysis, where 80% of loads do not use any (or very little) energy at low exhaust relative humidity. Because of the high first bar the rest of the bars are hard to compare, so Figure 15 excludes the 100 Wh category. In this second chart, we see both the auto-termination cycle graphs have a decreasing trend, while the manual cycle loads have fixed peaks further out in the graph. This is another indicator of the auto-termination loads responding to moisture content of the load.

In the figures below, the auto/simple case has 539 loads (41%), auto/not simple has 518 loads (39%), manual/simple has 88 loads (7%), and manual/not simple has 173 loads (13%).

Figure 14. Comparison of Energy Used Below 5% RH by Load Type

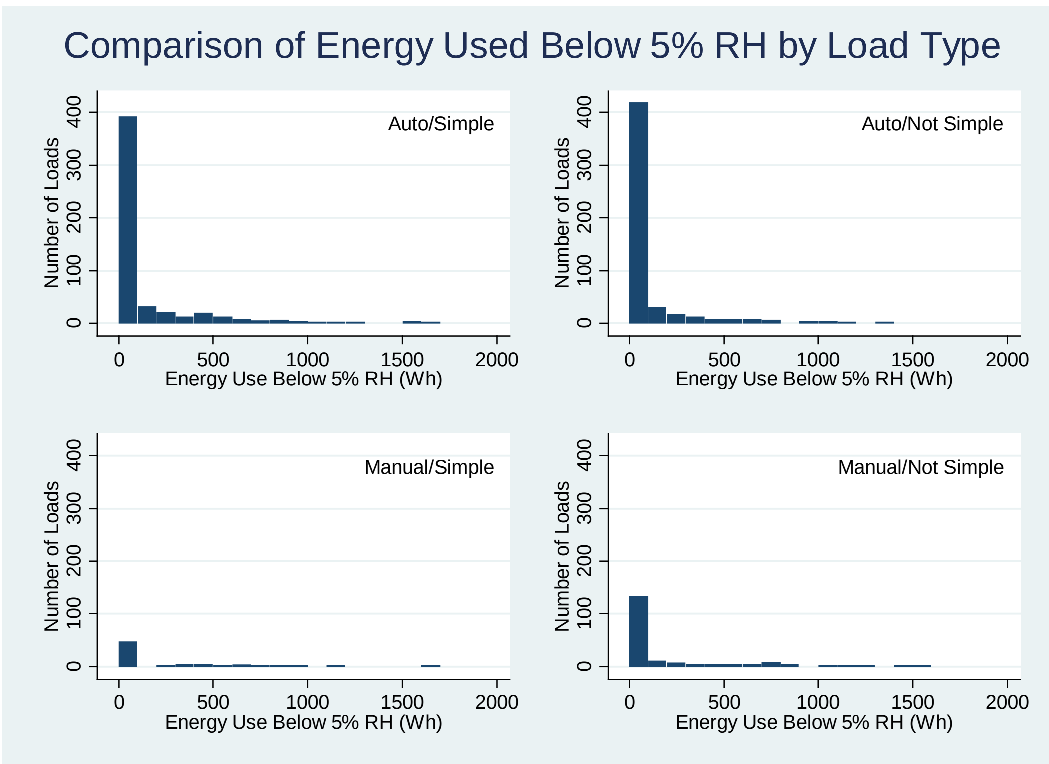
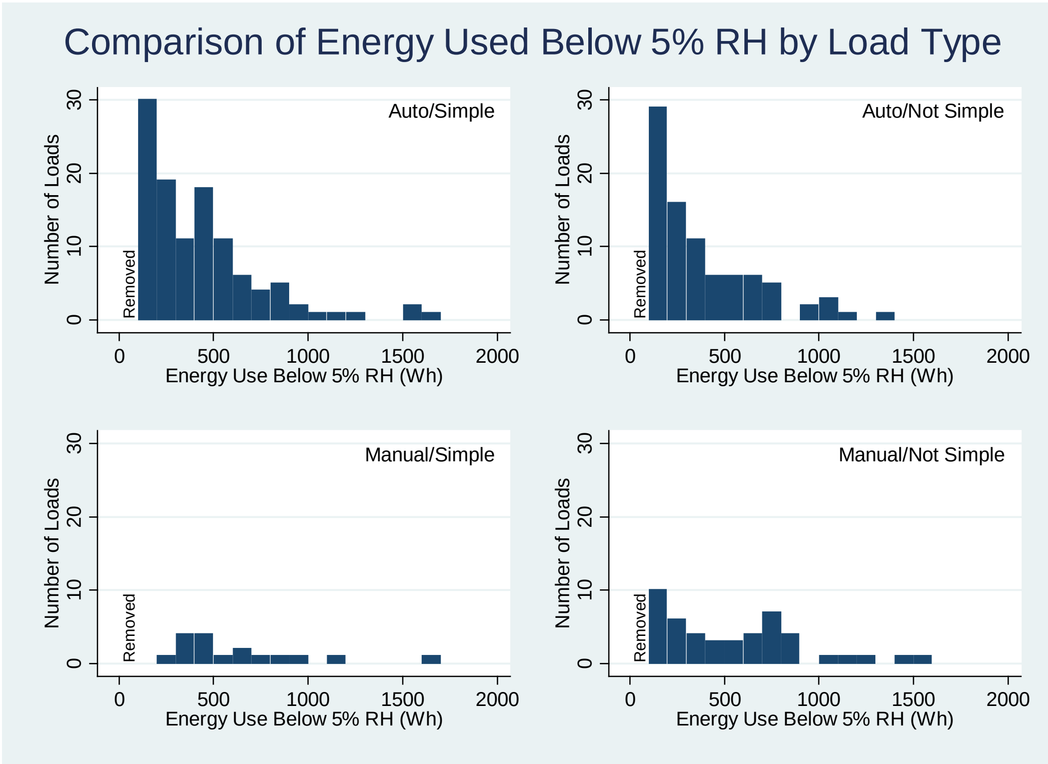


Figure 15. Comparison of Energy Used Below 5% RH by Load Type for Non-Zero Energy



3.5.5. Dryer Efficiency by Fabric Weight

Section 3.4.1 above mentions the test procedure uses a 50/50 cotton-poly blend fabric, or a medium fabric weight for this field study. However, **Table 17 and Figure 16 show there is no statistical efficiency difference between Light and Medium clothing types, and Heavy is about 13% lower efficiency than Light and Medium.** Figure 17 is a scatter plot of the dryer efficiency by bone-dry weight separated by fabric type category. Light and Medium are shown very close to each other, and Heavy has a similar efficiency to Light/Medium for very small loads, but Heavy does not have the same increase in dryer efficiency moving towards larger loads as Light and Medium loads.

Table 17. Dryer Efficiency (lb/kWh) per Load by Fabric Category

Fabric Category	Simple Loads		
	Mean	EB	n (L)
Light	2.74	0.11	142
Medium	2.70	0.07	322
Heavy	2.36	0.13	88

Figure 16. Dryer Efficiency (lb/kWh) by Fabric Category

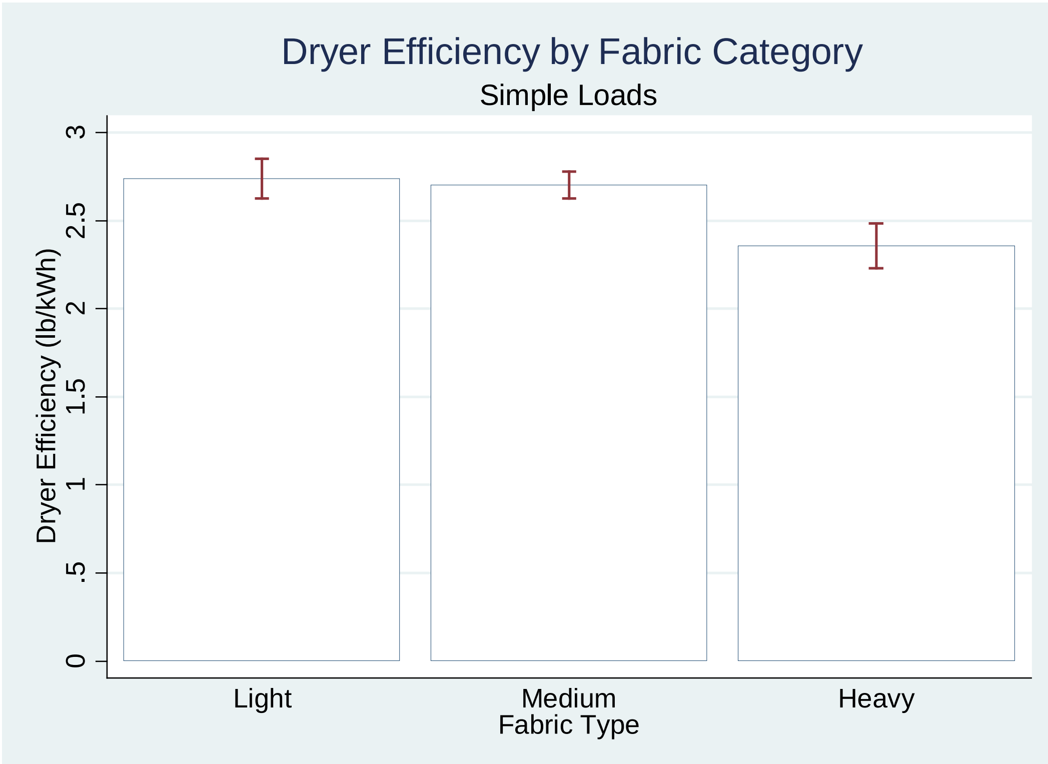
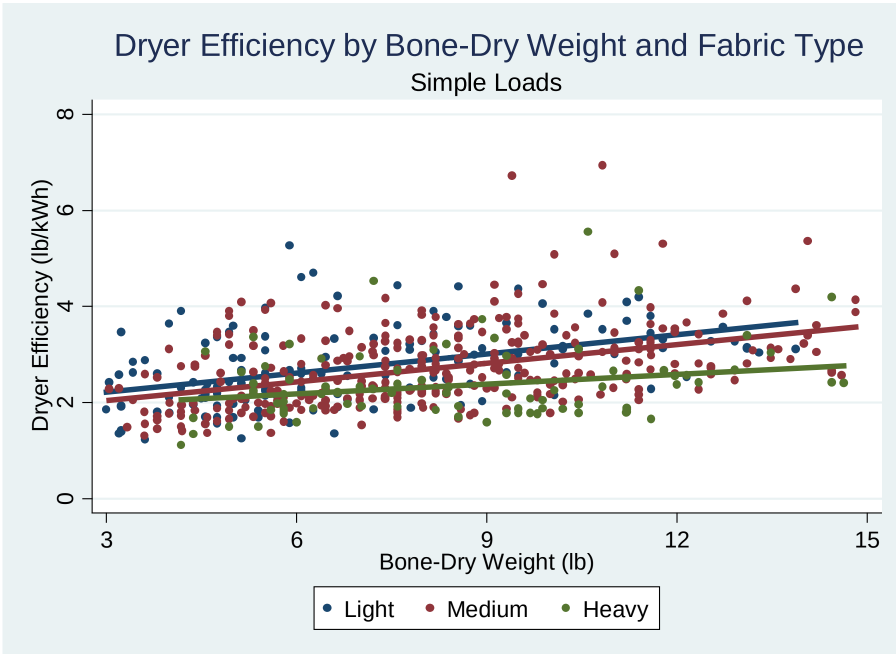


Figure 17. Dryer Efficiency (lb/kWh) by Bone-Dry Weight and Fabric Type



3.6. Description of Appendices

There are numerous appendices included with this report, many of which provide a more detailed analysis of particular characteristics. For instance, Appendix 5 through Appendix 10 gives a more complete breakdown of loads by categories and energy use by those categories.

The following are descriptions of each appendix.

Appendix 1 – The metering protocol used in the field, provided here for reference. In the second part of this appendix, there is a discussion about protocol improvements for future field studies.

Appendix 2 – A sample of washer and dryer logbook entries.

Appendix 3 – The original analysis questions for this data set, including links for finding each item in the report.

Appendix 4 – Analysis of washer loads beyond what is necessary for the dryer analysis.

Appendix 5 – A general breakdown of washer and dryer characteristics across loads. Data are generally in table format as distributions of loads for both simple loads and all loads.

Appendix 6 – The tables in this appendix use the same format as the previous appendix, but instead of distributions of loads by category, the tables show average energy use by category. Scatter plots show any trends in the data.

Appendix 7 – Scatter plots based on initial RMC and final RMC use the same categories as the previous appendix to see if there are any categorical trends for RMC.

Appendix 8 – There were some analyses that did not fit into the main discussion of the report, but were included in the original memo, so those are in this appendix.

Appendix 9 – This appendix contains a series of correlation graphs intended to facilitate more discussions about data trends across different categorical variables using a few metrics.

Appendix 10 – Appendix 5 showed a breakdown of distributions by category, and now in this appendix some of those categories are presented in two-way tables to show common variable combinations used.

Appendix 11 – Includes an expansion of the dryer load profiles shown in Appendix 6. This appendix shows a typical energy profile for each dryer that used an auto-termination.

Appendix 12 – This appendix discusses the washer and dryer results of the recently published RBSA Metering report compared to the field study.

4. Conclusions and Discussion of Results

The detailed review of laundry use in the field conducted by this study revealed characteristics of the typical load. In general, the typical load consists of 3 – 12 lb bone-dry laundry of medium weight and either mixed color/white fabric or colored fabric. The typical load uses warm or cold water for the wash cycle, cold water for the rinse cycle, and a high or medium spin speed. The entire load is transferred to the dryer eighty percent of the time, and the dryer runs for 30 – 75 minutes at medium or high heat with the normal or more-dry setting. The remaining moisture content of the load going into the dryer is between 33 – 100%. The dryer stops automatically eighty percent of the time.

To better understand how the field activity relates to the federal test procedure, the report introduced the concept of “simple loads.” Laundry loads in homes varied drastically both in their composition and in the choices of settings to clean the loads. Consequently, to compare efficiency across sites and to the test procedure, we examined simple loads which have the following characteristics: wash and dry; initial RMC between 33% and 100%; bone-dry weight between 3 lbs and 15 lbs; no items removed between the wash and dry cycle; and no multi-run dryer cycles. Overall, approximately half of all loads were “simple loads.”

In analyzing dryers, an analysis of both kWh and a combined energy factor (CEF, which is equal to EF in this field study) compare metered results to those from the test procedure. CEF is the Appendix D1 metric, but dryers in this study were too old to fall under this new protocol. Because of this, calculations of field CEF from this study provide a baseline for future studies. The following are comparison of field data to those found in the test procedure:

- Clothing types are much more varied than the 50/50 cotton/poly test cloth used in the DOE test procedure, and heavy fabric types appear to have an impact on dryer efficiency (lb/kWh) compared to light and medium fabric types. The effect is a 13% average decrease in dryer efficiency for heavy fabric type compared to light and medium fabric types.
- The test procedure distribution of wash temperatures is mostly in line with our findings (although there are fewer extra hot loads in the field), but the percent of loads using warm rinse temperature is much lower in the field compared to the test procedure assumption.
- The percent of washer loads dried in the field (93.5%) is in line with the assumption in the new version of the test procedure (91%).
- The average test load weight and amount of water removed is consistent between the field data and the test procedure assumptions, though the variation in both bone-dry weight and water removed weight in the field data is large. Bone-dry weights in the field were as low as a couple pounds and as high as 20 pounds or more.

- The 70% ± 3.5% initial RMC used in the Appendix D test procedure is within the sampling error of the 71.0% ± 1.6% found across all loads in the study, but the 57.5% ± 3.5% of the new procedure in Appendix D1 (e-CFR, 2014) is outside of the sampling error bounds across all loads. For *simple loads*, the initial RMC value found in the field is 62.9% ± 0.6%, which is higher than the new Appendix D1 test procedure assumption and lower than the Appendix D assumption.
- There is an even split in the logbooks between medium and high temperature setting for most loads, but the test procedure only uses the high temperature setting. Interestingly, measured dryer max and median exhaust temperatures show no difference between medium and high temperature settings, and no difference by cycle length for medium and high temperature settings.
- Estimates based on the metering data suggest the dryer is off for 8453 ± 32 hours/year; the test procedure assumes 8620 hours/year. Alternatively, the data show an average dryer runs 307 ± 32 hours/year; the test procedure assumes 140 hours/year.
- The number of loads per year in the field was 311 ± 42. The test procedure assumption of 283 is within the sampling error of the study, though on the lower end of the error band.
- Dryers in the field have an average standby use of 5.5 Wh/load, 0.17 W, or 1.5 kWh/year. Future machines, with always-on communications connections, will likely have more standby use.
- EF and CEF are about 2.7 lb/kWh for all loads and 2.6 lb/kWh for simple loads. EF and CEF appear the same because of the very low standby for the machines in this study.
- Initial RMC, for clothes coming out of the washer, is 13.6% higher on average for vertical axis washers compared to horizontal axis washers.
- Auto-termination appears to perform better than manual termination only for low initial moisture contents, but for normal laundry there is no apparent difference in energy use.

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Appendix 1. Metering Protocol

A1.1. Protocol Used for this Study

This appendix covers the equipment used in the metering study, the protocol for installing the equipment, and the data collected.

Equipment

Participant-based

- Digital scale with movable display, capacity 150 lb, 0.2 lb resolution
- 60-liter sturdy polyethylene container for weighing laundry
- Participant instruction book and logging sheets
- Reminder magnet

Electricity and related measurements

- **Custom-built NEMA enclosure** which includes a Continental Controls WNB-208-3Y Option P3 WattNode and Magnelab or Dent Engineering 0-333 mVAC split core current transformers. The site washer and dryer cords are plugged into approved electrical receptacles on the outside of the enclosure. The CTs are installed onto pigtails coming off of the receptacles and wired back to the WattNode (which also receives 120VAC from one of the receptacles). Short SO-type cords with approved plugs are then plugged back into the house receptacles to enable normal laundry equipment operation.
- This approach was chosen over custom field-wiring since we believe it is safer and saves time in the field.
- Output from the WattNode is via Onset Computing optically-isolated pulse counters. One is installed for the washer and one for the dryer. The WattNode measures true (RMS) power. A pigtail of signal wires starts at the pulse output channels of the WattNode and exits the enclosure via a strain-relief fitting. The installing technician crimps the appropriate signal wire to the pulse counter wires.
- Pulse counters are connected to an **Onset Computing U30 datalogger**. The U30 has 3G communication capability but that is not used in this project. The datalogger is set up to sample every 5 seconds and record (log) every minute.
- The dryer exhaust relative humidity and temperature are also measured on the same interval with an Onset Computer S-THB-M008 relative humidity (RH) sensor installed in the dryer exhaust vent.

The NEMA enclosure measures about 16x12x8 inches and the U30 about 8x8x6 inches. It can either can be mounted on a wall or hidden behind the laundry equipment, resting on the floor. The RH sensor and pulse counters each have an 8-meter cable to connect the sensor to the U30.

Dryer airflow

A custom volumetric capture hood is used to measure dryer airflow before and after any dryer maintenance. Measurements are to be taken at the dryer vent system terminus so that all system effects are included.

Metering Protocol

- Assess/sketch dryer venting system for functionality; decide if any preliminary repairs are needed
- Measure dryer venting system CFM pre- and post-lint screen cleaning
- Position/mount NEMA box and U30; plug in U30 & record serial number on form
- Crimp pulse counters to signal wire leads
- Label pulse counters and temp/RH sensor in HOBOware
- Set U30 to log 5 sec readings every minute (5 sec sampling, 1 minute logging)

Confirm pulse counters respond

- Confirm temp/RH sensor responds; measure dryer CFM in fan-only mode & record temp/RH
- Confirm washer and dryer each work after logging equipment installed
- Educate participant on laundry logging procedure
- Leave logbook at site
- Give participant incentive
- Take pictures/make notes

Data collected

Site level

- Dryer CFM, pre- and post-cleaning
- Make and model of equipment

Per load of laundry

- Weight of load coming into and going out of washer and dryer
- Time of transfer
- Color and type of fabric
- Washer and dryer cycle used
- Other washer and dryer settings
- Whether laundry was removed from the load between wash and dry cycles
- Whether dryer sheets were used
- Whether damp signal was used
- Whether there was a delay taking the laundry out of the dryer

A1.2. Protocol Improvements

After analyzing the data, a few improvements to the field protocol may improve future analysis. A review of each question on the form can help to see if the question has a better phrasing, but one in particular yielded almost no data. On the question referring to wrinkle guard use, only 9 loads answered in the affirmative, 1101 in the negative, and 208 loads did not have an answer. Either this feature is never used or the question was confusing to the participants. For newer dryers, wrinkle guard may be an automatically selected feature for some cycles, which is confounding the issue more.

With regard to instances of multiple dryer loads from a single washer load or multiple dryer cycles from a single washer cycle (often separated by long time intervals), the protocol could be clarified to better instruct the participants how to log this use. Some participants used new pages and some just wrote notes on the current page. It would be useful to also have a multiple choice question that asks why the dryer was run again with the same load – was the load still wet, or did it need de-wrinkling? And for loads that do not have a washer or dryer load associated with them, a multiple choice question asking why only one machine was used would be helpful – is it a dryer fluff cycle or were clothes wet from rain, and did the clothes get line dried instead of using dryer? In general, more multiple choice questions rather than free response would help speed up the initial data processing.

If there is a desire for a laboratory study, it should focus on parameters assumed to improve dryer efficiency. A sensitivity analysis of vent CFM, load density (how packed should the washer and dryer be with different fabric weights? Do they differ between wash and dry?), RMC, cycle time vs auto-termination, and any other relevant parameter would help inform the field study.

Appendix 2. Logbook

A2.1. Logbook Instructions

LAUNDRY LOG INSTRUCTIONS

Thank you for taking part in this study. The information that you are logging will help us to better understand your laundry habits, including when you do your laundry, the cycles you regularly use and the water retention of certain fabrics that you wash. We have created this handy journal to help you keep track of your logging. Please create one entry each time you wash and dry a load of laundry. To keep it simple, the Laundry Log Instructions are divided into what you record for the washer cycle and what you record for the dryer cycle.

*As a note, please make sure to accurately log your cycles, even if they don't follow the typical logging of one washer cycle and then one dryer cycle. For example, if you "fluff" your laundry load for an extra 20 minutes after the complete dryer cycle is finished, simply fill out an additional dryer cycle log to reflect that extra dryer cycle.

Also, if you do anything out of the ordinary or something that you think would be noteworthy in your laundry habits, put this information in the Participant Notes section of either the Washer Log or the Dryer Log.

Part One: Before the Washer Cycle

1. **Date/Time**: Record date (MM/DD/YY) and time (HH:MM) that you start the washer in the top section of the Washer Log. Remember to indicate if the time is AM or PM.

2. **Weigh Laundry Load**: Place entire laundry load in the study-provided basket, placing basket squarely on the study-provided scale. Do not use the lid.

3. **Record Weight in Log**: Record weight of clothes in the section labeled "Weight of Dry Clothes." Provide the exact weight (example 3.5 lbs.); please do not round the weight. Do not subtract the weight of the basket.

4. **Describe Color Characteristics**: Check box next to the color description that characterizes **the majority of the items** in that particular laundry load.

5. **Describe Fabric Characteristics**: Check box next to the fabric description that best characterizes **the majority of the items** in that particular laundry load.

   Use the fabric descriptions below as a guide:

FABRIC WEIGHT	EXAMPLES	
Light	• Permanent press • Light, casual shirts • Underwear	• Light socks • Pillow cases • Light weight / smaller sheets
Medium	• Heavy shirts • Casual pants • Heavy socks	• Medium weight / larger sheets • Light weight sweat pants and shirts • Pullovers
Heavy	• Towels • Flannel sheets • Jeans	• Heavy work clothing • Heavy sweat pants and shirts

6. **Set Machine**: Set washer cycle and all other options that you will be using for the wash cycle.

7. **Cycle Used**: Check the cycle number (1-3) used for this load in the field labeled “Cycle Used” (To remind yourself of your top 3 washer cycles, refer to the list at the front of your log that you completed with the installation technician). If you did not use one of your top 3 washer cycles, check the “Other” box and write in the name of the cycle that you used.

8. **Record Details of Wash Cycle**: Check the appropriate wash and rinse temperature (or write in other). Record the Spin Speed and Soil Level that the machine is using for this laundry load (Please note: Spin Speed and Soil Level are settings on the machine). Write in this information regardless of whether or not this was a default setting on the cycle or you personally selected the options.

9. **Other Options**: In “All Other Options,” list all additional options (if any) that you have used for this washer cycle (e.g. steam cycle or self-clean cycle).

10. **Delay Start**: Check “yes” or “no” to specify whether or not you are using the “delay start” option for this wash cycle.
    - If you check “yes”:
        - Record the number of minutes you programmed for the “delay start.”
        - Please also describe why you used the “delay start” option (e.g. you wanted to give your clothes more time to soak, etc.).

11. **Participant Notes**: Make any notes in the Participant Notes section that you think are important. Things to include could be why you used a particular cycle, why you used the “extra rinse” option, etc.

Part Two: Before the Dryer Cycle

1. **Date/Time**: Record date (MM/DD/YY) and time (MM: HH) that you start the dryer in the top section of the Dryer Log. Remember to indicate if the time is AM or PM.

2. **Separate Out Non-Dryer Items**: Remove clothes from the washing machine and only place those items that are going into the dryer into the laundry basket for weighing. You do not need to weigh the wet items that will be hung or line-dried.

3. **Weigh Laundry Load**: Place wet laundry load in the laundry basket and place basket squarely on the scale. Do not use the basket lid.

4. **Record Weight in Log**: Write weight of clothes in field labeled “Weight of Wet Clothes.” Provide the exact weight (example 3.5 lbs.); please do not round the weight. Do not subtract the weight of the basket.

5. **Note if Items Hung/Line Dried**: Check “yes” or “no” in the laundry log as to whether items were removed from the washer that are not going in the dryer.

6. **Set Machine**: Set dryer cycle and all other options that you will be using for the dryer cycle.

7. **Cycle Used**: Check the cycle number (1 or 2) used for this load in the field labeled “Cycle Used” (To remind yourself of your top 2 dryer cycles, refer to the list at the front of your log that you completed with the installation technician). If you did not use one of your top 2 dryer cycles, check the “Other” box and write in the name of the cycle that you used.

8. **For Manual or Timed Dry Cycles**: Check “yes” or “no” to indicate whether you are using a manual or timed dry cycle (these are cycles where you set the time the cycle will initially run). If “yes”, record the time that you set the cycle for (in minutes).

9. **For Automatic Cycles**: If you are using an **automatic** cycle for the dryer load, check “yes” or “no” as to whether or not you have manually added or removed time from the default drying time that is set for that cycle. Write in the space provided how much time (in minutes) that you added or removed (if applicable).

10. **Record Details of Dryer Cycle**: Fill in the Drying Temperature and Dryness Level that the machine is using for this laundry load (Please note: Drying Temperature and Dryness Level are settings on the machine). Write in this information regardless of whether or not this was a default setting on the cycle or you selected the options.

11. **Other Options**: In “All Other Options” list all additional options (if any) that you have used for this dryer cycle.

12. **Damp Signal:** Check “yes” or “no” to indicate whether you turned on the damp signal for this cycle. The damp signal is a setting on the machine that provides an alert when your clothes are approximately 80% dry.

13. **Weigh Laundry Load**: After the dryer cycle is complete, place entire dryer load in study-provided laundry basket, placing basket squarely on the study-provided scale. Do not weigh the lid.

14. **Record Weight in Log**: Write weight of clothes in field labeled "Weight of Dry Clothes." Provide the exact weight (example 3.5 lbs.); please do not round the weight. Do not subtract the weight of the basket.

15. **Record Time of Final Weighing:** Indicate the time (HH:MM) that you removed the dry clothes from the dryer and weighed them. Record whether this time is AM or PM.

16. **Dryer Sheets:** Check "yes" or "no" to indicate whether dryer sheets were used.

17. **Participant Notes:** Make any notes in the Participant Notes section that you think are important. Things to include could by why you used a particular cycle, why you used the "steam" option, etc.

Thank you again for participating in this study! If you have any questions as you are filling out your log, please give us a call at **1-877-506-2521** or email us at **laundrystudy@neea.org** (Hotline hours of operation are Monday – Friday, 9am-5pm).

A2.2. Sample Logbook

WASHER LOG

Date: 10 / Feb / Time: 6 : 01 ☐ AM ☐ PM Weight of Dry Clothes (before wash cycle): 8 . 6 lbs.

Color: *(check one)* ☐ White ☒ Mixed ☐ Colors

Fabric: *(check one – see instructions for fabric examples)*

☐ Light ☒ Medium ☐ Heavy

☐ Mixed Light / Medium ☐ Mixed Medium / Heavy ☐ Mixed Light / Medium / Heavy

Cycle Used: *(check one – refer to list of your top washer cycles for a reminder)*

☒ 1 ☐ 2 ☐ 3 ☐ Other ________

Wash Temp: ☐ Cold ☒ Warm ☐ Hot ☐ Other: ________ Rinse Temp: ☒ Cold ☐ Warm ☐ Hot ☐ Other: ________

Spin Speed: HIGH Soil Level: LIGHT All Other Options: ________

Use Delay Start: ☐ Yes ☒ No Reason for using delay start: ________

If **Yes**, for How Long? ________ mins.

PARTICIPANT NOTES: ________

DRYER LOG

Date: 2/10 / 12 Time: 7 : 36 ☐ AM ☒ PM Weight of **Wet** Clothes (before dry cycle): 9 . 4 lbs.

Were items removed from the washer that are not going in the dryer? *(i.e., line dry)* ☐ Yes ☒ No

Cycle Used: *(check one- refer to list of your top dryer cycles for a reminder)* ☒ 1 ☐ 2 ☐ Other ________

Did you use a manual cycle? ☒ Yes ☐ No If **yes**, how long did you set the cycle for? 30 mins.

Answer the following only if you used an **automatic** cycle:

Did you add time to the cycle? ☐ Yes ☒ No If **yes**, how much time did you add? ________ mins.

Did you remove time from the cycle? ☐ Yes ☒ No If **yes**, how much time did you remove? ________ mins.

Drying Temperature: MED Dryness Level: DRY

All Other Options: ________

Did you turn the damp signal on? ☐ Yes ☒ No Weight of **Dry** Clothes (after dry cycle): 8 . 4 lbs. Time of Weighing: 10 : 07 ☐ AM ☒ PM

Were dryer sheets used? ☐ Yes ☒ No

PARTICIPANT NOTES: ________

Appendix 3. Original Memo Questions

The evolution of this project included an original list of questions, which evolved into this report. The items below are the original memo questions with links to where the information is located in the report.

First priority analyses:

1) Number of annual cycles, average and range, and any obvious correlations (e.g. demographics)

Cycles per year are in Appendix 5 under the washer and dryer subsections, and correlations by demographics for loads per year are in the combined characteristics section of that appendix.

2) Annual dryer energy use, average and range, and any detectable correlations (e.g. load type and size, dryer cycle choice, air flow, RMC and choice of clothes washer cycle)

Annual dryer energy use is in Appendix 5 under the dryer subsection, and correlations for dryer energy use are in Appendix 6.

3) RMC (remaining moisture content) – There is a significant question about the relationship between humidity and exhaust temperature and RMC. What connection can be drawn?

No connections found between these parameters and final RMC, as discussed in section 3.5.3.

4) RMC of clothes entering and leaving the dryer. This will be evaluated by load type and size, clothes washer cycle type, top- vs. front-loading washers, automatic vs. timed-dry cycles and other salient metrics.

Graphs of initial and final RMC across various parameters are in Appendix 7.

5) Is there a correlation between clothes washer load size, load type, cycle time or cycle chosen and RMC? Mr. Stephens hypothesizes that a long spin cycle may indicate an unbalanced load and lead to a high RMC. It is possible that this could be driven by the load size or type.

Appendix 7 has a number of scatter plots to explore various load properties on initial and final RMC.

6) Are there other drivers of a high RMC coming out of the washer?

Appendix 7 has a number of scatter plots to explore various load properties on initial and final RMC.

7) Energy use after clothes reach 5% relative humidity, on average, and by make and model. Per Mr. Stephens many models are essentially the same but differ in model number; he will

assist us in grouping models. We will call out any models that do a particularly good or bad job of this. We note that dryer built-in sensors also do not measure RMC directly.

The results of energy use after 5% RH are in section 3.5.4, though the lack of correlation between temperature and relative humidity with final RMC in section 3.5.3 limits the usefulness of these results.

8) Energy use and cycle times – Is there a linear relationship?

Appendix 6 discusses the linear relationship of energy use and cycle times for both washers and dryers.

9) User cycle choices – list and categorize. We will analyze the manufacturers' manuals for the description of what conditions equate to what cycle name. This will allow us to come up with a standard typography of cycles, including the different manufacturers' names for each of those cycles. The goal is to create 3-4 major categories for the most common cycles (excluding outliers like "wool" or "steam dry").

Load weights and temperature settings are in sections 3.2 and 3.4, and a more complete picture of individual parameters is in Appendix 5 and in Appendix 10.

10) Clothes load types and sizes – characterization and range of variation. We will develop a matrix of load types/colors and see what patterns emerge. What is the distribution of load sizes in these bins? Which bins are most commonly used? Are there other salient factors?

These results are also in Appendix 5 and Appendix 10.

11) Is there a correlation between load size and/or type and choice of dryer cycle?

Cross-tabulations of load weights and cycle choices are in Appendix 10.

Second priority analyses:

12) Accuracy or reliability of clothes remaining moisture sensing or other end-of-cycle sensing technologies.

An analysis of termination type based on moisture content and time are in section 3.5.2.

13) How often are clothes held out of the dryer (from the clothes washer), and how much of the load is removed when this happens? Can this number be reliably derived from the initial and final measured weights of the laundry?

There was only a single measurement of the weight of clothes between the wash and dry cycles and this occurred just before going into the dryer. Therefore, there is no indication of the weight of clothes removed, but the logbooks did ask a yes/no question about clothing removed. Table 5 shows an estimate of 19.5% of loads both washed and dried had some clothing removed. In addition, Table 21 shows 6.1% of washer loads not dried at all, and Table 33 shows 6.2% of dryer loads not washed at all. Combining the first two concepts together, about 25.6% of washer loads had either part of all of the clothing not dried in the dryer.

14) Is there some way to rate dryer efficiency? We will consider various possible metrics, such as energy used per pound of moisture removed.

Energy consumption per cycle (E_{ce}) is discussed in section 3.4.6, energy factor (EF) in section 3.4.10, combined energy factor (CEF) in section 3.4.11, and theoretical efficiency (%) in section 3.4.12.

15) Energy use performance by clothes washer MEF.

Section A4.7 discusses washer energy use by MEF.

16) We will attempt to evaluate dryer airflow rates, both across the study and by model. We will also attempt to evaluate the impact of ducting on dryer airflow rates. We will attempt to parse out the impact of ducting on energy use. We may not have enough data to derive many conclusions on this topic given the variety in dryer models and ducting conditions. We will characterize ducting as unrestricted/average/highly restricted. Mr. Stephens notes that higher airflow may not be better where dryer energy efficiency is concerned.

Dryer CFM rates are in A5.2 of Appendix 5, and Table 70 and Figure 55 show the energy use by dryer CFM.

17) Fabric softener sheets and balls. We will evaluate the frequency of use and also look at whether frequent use may shellac moisture sensors and stop them from working. There are a couple of moisture sensor technologies: humidity sensors and current sensors. The effect may be different on the different technologies.

Appendix 5 includes the distribution of dryer sheet use per load and Appendix 6 includes the average energy use for loads with and without dryer sheets.

18) We will look at the metered data to characterize washer cycle components and graph a “typical” washer cycle.

Figure 38 through Figure 41 show examples of washer energy profiles for four different load types.

19) We will look at the metered data to characterize dryer cycle components. For each of the standardized dryer cycle types, what do the energy use and power signature look like? We will also look at cycle components such as wrinkle guard and delayed start.

Figure 57 through Figure 60 show a demo of four different dryer load types. Appendix 11 shows a demo of normal dryer cycle for each site.

20) All other things being equal, are there any clothes washers or dryers that consistently do a good job? What does a good job mean?

The variation of washer and dryer models in addition to the large variation of occupant behavior with laundry types and setting selections prevents a side-by-side comparison with any confidence.

21) Any shortcomings in the study or the data.

Subsection A1.2 of 5 discusses protocol improvements.

22) Any questions raised by the analysis that cannot be answered with the existing dataset.

Subsection A1.2 of 5 discusses protocol improvements.

Appendix 4. Washer Analysis

The main report focuses on dryer use and only includes washer analysis for items pertaining to the inputs for dryer use, such as factors affecting initial moisture content, removal of clothes, etc. However, the detail of data in the logbooks and metering allow additional detailed analysis of washer loads, which are included in this appendix.

A4.1. Clothes Washer MEF Protocol

An extensive analysis of washer efficiency would involve metering of water temperatures, water quantity, ratio of hot-to-cold water, verifying clothes container size, a more detailed characterization of the fabric types compared to the test cloth, and other factors. Some of these measurements would be a substantial deviation from the laundry process for the participants and a considerable increase in the complexity of the laundry metering system.

For this study, the occupants do their laundry as they always have, except for weighing the clothes and writing a log of how they are doing their laundry. A calculated field modified energy factor (field MEF) uses the data and assumptions gathered from this process, where the machine energy use, temperature settings, and RMC after the washing load combined with manufacturer-reported average water use per load and volume produces a field MEF. The modified energy factor (MEF) uses the following formula:

$$MEF = \frac{C}{M + E + D}$$

where:

- C is the clothes container size, in cu. ft. The field MEF uses manufacturer data for this parameter.
- M is the machine electrical energy and is one of the primary metering components of this study.
- E is the hot water energy consumption calculated from measurements of hot water per cycle across varying washer temperature settings. The Appendix J1 Test Procedure (e-CFR, 2014) assumes the wash and rinse ratios shown in Table 6 later in the report for advanced washers. The field MEF value uses the actual field temperature ratios (where hot is assumed all hot water, warm is 50% hot water, and cold is no hot water). Both Appendix J1 and the Appendix J2 Test Procedure (e-CFR, 2014) stipulate a 75 °F temperature rise assumption, which is in line with other regional field studies (RTF, 2014). The original Appendix J (CFR, 2012) test procedure assumed 90 °F temperature rise, which is much higher than found in the regional field studies. The current standard is J1 and all of the washers in this study used the J1 procedure.

- D is the energy required for removal of the remaining moisture in the wash load, calculated from the measured initial RMC. Another parameter that goes into the D calculation is the number of washer loads that are dried. Appendix J1 assumes 84% and the new Appendix J2 assumes 91%. A comparison of these assumptions to the field measurements are in the analysis below.

The field MEF results comparison to the rated MEF from the manufacturer is in the analysis below. Other analyses use the rated MEF as a categorical variable for comparing the MEF levels.

Summaries are presented below of the M parameter (washer mechanical energy), but due to the machines having varying capacities, the energy use comparison is normalized by dry load weight. For convenience, this normalization follows the dryer normalization formula shown in the next section and is reported in units of lb/kWh. The analyses use this efficiency parameter and label the value as Machine Efficiency (lb/kWh).

There are a number of parameters in this washer test procedure that inform the test protocol or the calculations in the procedure and a comparison of these values to the field results is below. The following sections walk through the parameters and compare the current protocol to the field results. These comparisons can solidify the test assumptions or add to the future updates to the protocol. All of these parameters in the washing machine test protocol lead up to the final MEF calculation, and so the discussion below will culminate in a comparison of reported MEF to field-calculated MEF.

A4.2. Test Cloth

The test cloth for washer loads is also the 50/50 cotton/poly blend used for dryer tests. Since most loads in the study were both washed and dried, the fabric weight distribution for washers in Table 18 is similar to dryers, as seen in Table 7 across all loads and simple loads, where 60% of loads fall into the medium fabric weight category.

Table 18. Distribution of Loads by Fabric Weight

Fabric Category	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Light	24.3%	0.1%	307	25.8%	0.1%	145
Medium	60.0%	0.1%	759	58.6%	0.1%	330
Heavy	15.7%	0.0%	198	15.6%	0.1%	88
Total	100.0%	0.0%	1264	100.0%	0.0%	563

A4.3. Load Weight

The test weight for the washer testing protocol is more complex than for dryers. For newer adaptive-fill washers, the test protocol stipulates tests performed at the minimum, average, and maximum fill level of the machine using a minimum, average, and maximum test load weight based on the volume of the machine. Adaptive-fill washers use sensors to stop filling when water added to the load is adequate. This is both a water and energy saving feature of new washers, compared to older top-load washers that fill to the same water level each time based on the fill setting.

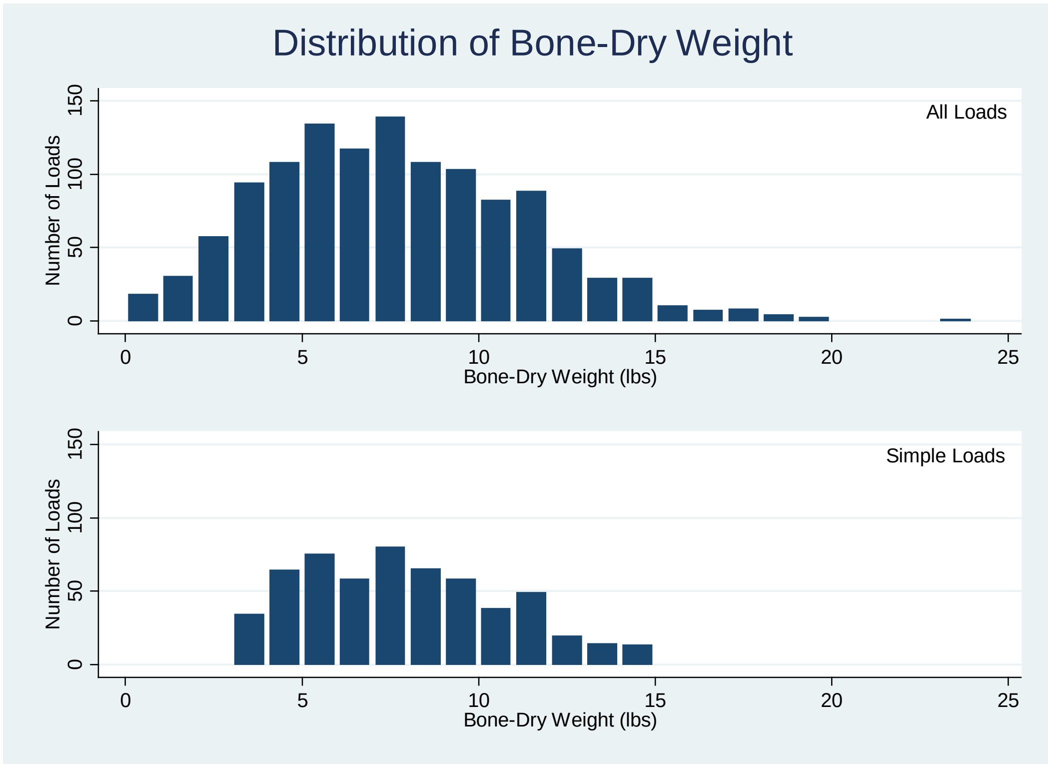
For the size of washers in this study, the minimum test load is 3 lbs, average test load is between 7–9 lbs, and maximum test load is between 11–15 lbs. The calculations use a weighted average for the rating of 12% for the minimum test case, 74% for the average test case, and 14% for the maximum test case. This shows an assumption of symmetry around the average test case, and a big majority of the loads near the average test case. Table 18 shows the percent of loads by bin in the field data and Figure 18 shows the distribution of bone-dry weight for washer loads. For reference, the average bone-dry weight for washer loads in the field was 7.60 lbs. The distribution roughly matches the test procedure loads, but there is a wide range of weights in the middle of the distribution.[5]

Table 19. Distribution of Washer Bone-Dry Clothes Weight

Bone-Dry Weight	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–2 lbs	8.6%	0.0%	107	—	—	—
3–5 lbs	27.7%	0.1%	346	30.0%	0.1%	188
6–8 lbs	29.5%	0.1%	368	35.1%	0.1%	220
9–11 lbs	22.3%	0.1%	278	26.2%	0.1%	164
12–14 lbs	9.1%	0.0%	114	8.8%	0.1%	55
15+ lbs	2.7%	0.0%	34	—	—	—
Total	100.0%	0.0%	1247	100.0%	0.0%	627

[5] The bins are roughly symmetrical to the average test load weight. If we use the test load distribution of 12% low, 74% medium, and 14% high across our data set, the bin cutoffs would be 0–3.3 lbs, 3.4–11.5 lbs, and 11.5+ lbs, which may be a reasonable breakdown for representing the load weights since the low and high case are very close to the minimum and maximum load weights specified by the test procedure.

Figure 18. Distribution of Bone-Dry Weight for Washer Loads



A4.4. Water Temperature Settings

Hot water energy consumption is a parameter in the MEF formula found in Appendix J1, but also may affect dryer energy use. If clothes are warmer going into the dryer, the warm-up time of the dryer may be shorter. Table 6 shows a comparison of the wash and rinse temperature assumptions in the washer test procedure compared to the ratios found in the logbooks. The wash temperature settings observed are very close to the test procedure, with the biggest deviations being fewer extra hot cycles and more warm wash cycles in the metered data. For the rinse temperature, the test procedure assumes a much higher percentage of warm rinse use than seen in the field.

Table 6. Comparison of Test Procedure and Logbook Temperature Load Ratios

Temperature Setting	Test Procedure	Logbook
Extra Hot Wash	5%	1%
Hot Wash	9%	8%
Warm Wash	49%	56%
Cold Wash	37%	34%
Warm Rinse	27%	9%

A4.5. Percent of Wash Loads Mechanically Dried

The J1 test procedure includes an assumption that 84% of the washer loads are dried, but the field data show 93.5% of washer loads dried. There is certainly a discrepancy here, but the new J2 procedure increases the value to 91%, which is closer to the field findings.

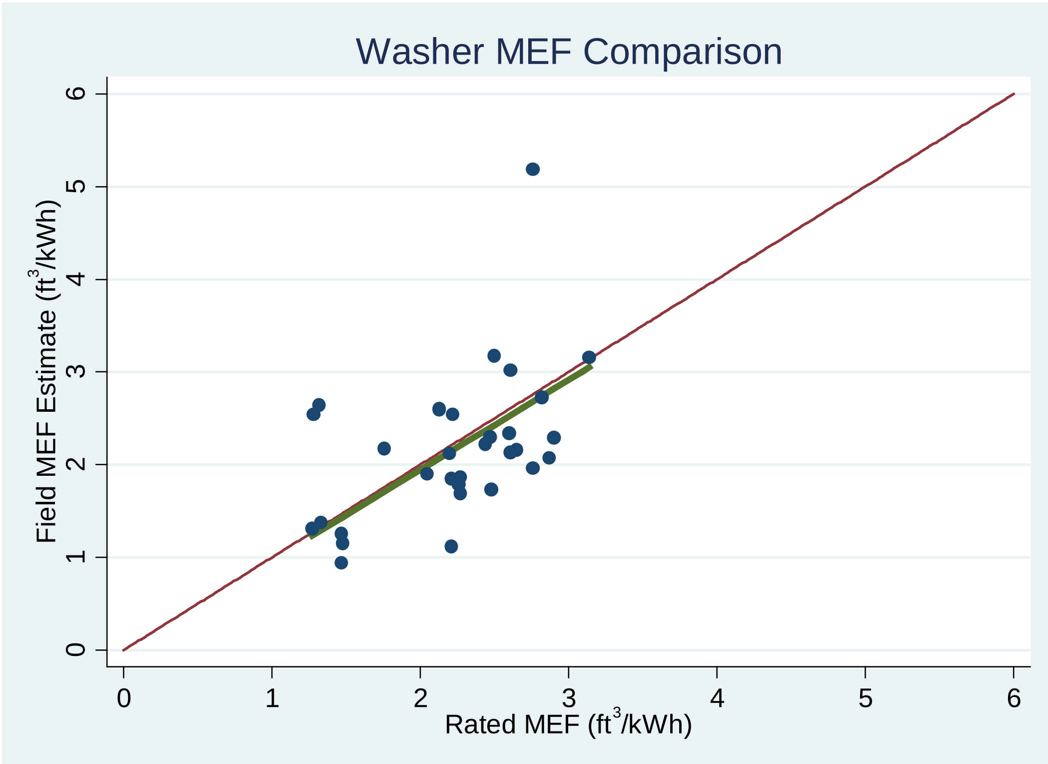
The values above refer to the number of loads dried and not quantity of clothing dried. A load with both a wash cycle and a dry cycle had both load types in the analysis even if the cycle had some items removed between the wash and dry cycle. For a load to have a wash cycle and no dry cycle, all clothing is removed and presumably air-dried.

A4.6. Field Estimated MEF vs Rated MEF

Using the assumptions and results list above we can calculate rough clothes washing MEF values based on the field data. A caution about this analysis is the field data did not include meters on the cold and hot water lines, so the ratio of these values is an estimate from the wash load settings. Other parameters are also estimates (see section 2.4.1). Figure 19 shows the calculated field MEF compared to the rated MEF from the manufacturer. The thin red line is a reference line where the field MEF equals the rated MEF. The thick green line is a linear fit through the origin of the data points, which shows on average the field MEF is matching closely with the rated MEF.

The outlier with a high field MEF is a site that did not do much laundry and all of their wash loads used the cold wash and cold rinse settings. **Removing that site from the linear fit, the green line would then indicate the field MEF being slightly lower than the rated MEF by 0.11 points on average. In terms of percent difference, the field MEF is about 3% lower than the rated MEF on average, and after removing the outlier the field MEF is about 7% lower than the rated MEF on average.**

Figure 19. Comparison of Rated MEF vs Field MEF



A4.7. MEF and Energy Use

The field vs. rated MEF results above implies the MEF does have a relation to the actual energy use, but that there may be other factors contributing to a higher or lower field MEF, and thus a higher or lower energy use per load[6]. The energy use per load used in MEF has a mechanical, hot water, and assumed dryer energy use components, as shown in section A4.1 above. The focus of the following discussion is on the mechanical energy use since the hot water assumptions are in section 3.3.1 and the dryer energy assumptions are in section 3.3.2 and section 2.4.2 (where the assumed dryer EF is 2.0).

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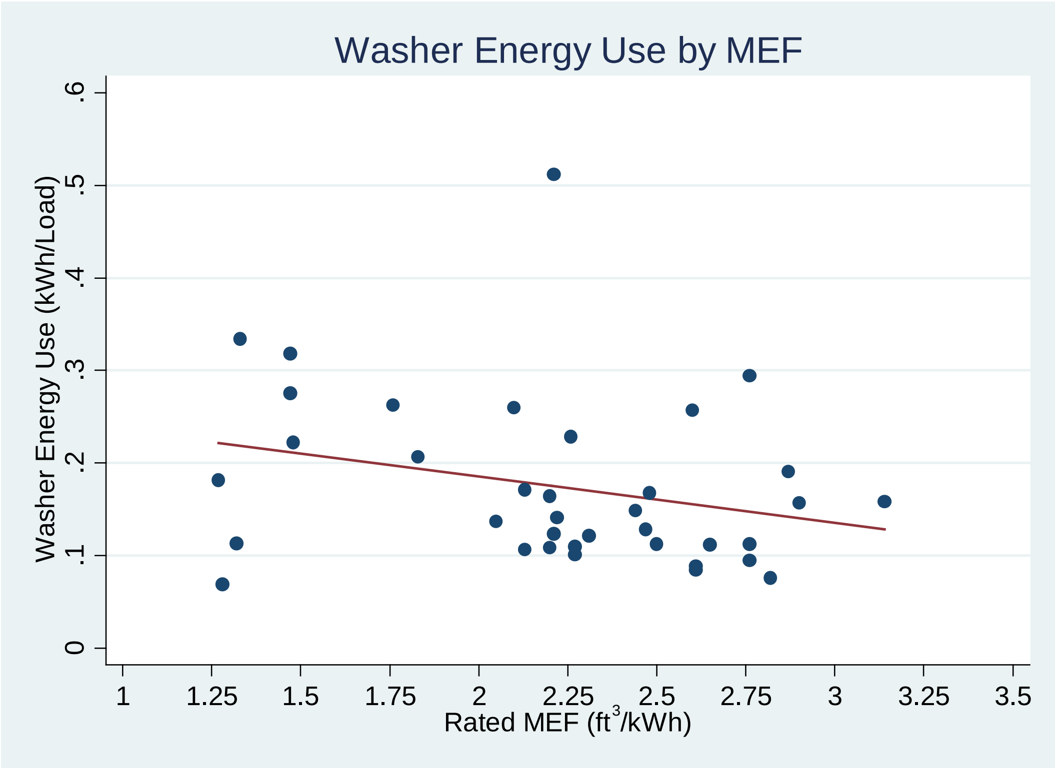
[6] A likely source of error is in the assumptions of the hot water use in the field MEF calculations. The amount of hot and cold water per load was not metered, so the estimates of hot water use are very rough.

Figure 20 shows the average energy use per site by rated MEF. The graph shows an expected trend in relation to rated MEF where the energy use of the washer decreases on average as the rated MEF increases.

Figure 20. Average Washer Energy Use per Site (kWh/load) by Rated MEF



Appendix 5. Washer and Dryer Load Characteristics

The following are load characteristics for washer and dryer loads. Characteristics include machine parameters, laundry parameters, and cycle choice parameters for both washers and dryers.

A5.1. Washer Load Characteristics

The washing machine rated characteristics were looked up online using model numbers. The average rated volume, Modified Energy Factor (MEF), and Water Factor (WF) values are in Table 20 below.

Table 20. Rated Washing Machine Characteristics

Category	Rated Characteristics		
	Mean	EB	n (S)
Volume (cu. ft.)	3.38	0.09	40
Modified Energy Factor (MEF)	2.22	0.14	37
Water Factor (gal/load/cu. ft.)	5.49	0.87	35

General summaries of the washer loads are in Table 21.

Table 21. Washer Load Characteristics

Category	All Loads			Simple Loads		
	Mean	EB	n (L/S)	Mean	EB	n (L/S)
Washer Cycles per Year	313	38	46 S	147	26	44 S
Washed, Not Dried	6.5%	0.0%	83 L	0.0%	0.0%	0 L
Average Load Weight (lbs)	8.43	0.18	1210 L	8.53	0.21	563 L
Average Bone-Dry (lbs)	7.60	0.17	1217 L	7.87	0.19	567 L

Washer characteristics are present in the following tables. Many of these are the characteristics entered into the logbooks and have been translated into the bin categories (i.e., the logbook may say the temperature setting is “Normal” but in order to provide better analysis we look up the details for that machine and find this setting correlates to Warm). Fabric category refers to the type of fabric, where jeans are heavy and linen light. The nominal characteristics of the washing machines also summarize energy use later in the report. These include the volume, modified energy factor (MEF), and water factor (WF).

Table 22. Distribution of Washer Bone-Dry Clothes Weight

Bone-Dry Weight	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–2 lbs	8.6%	0.0%	105	—	—	—
3–5 lbs	27.6%	0.1%	336	30.5%	0.1%	173
6–8 lbs	29.9%	0.1%	364	35.8%	0.1%	203
9–11 lbs	22.4%	0.1%	273	25.6%	0.1%	145
12–14 lbs	8.8%	0.0%	107	8.1%	0.1%	46
15+ lbs	2.6%	0.0%	32	—	—	—
Total	100.0%	0.0%	1217	100.0%	0.0%	567

Table 23. Distribution of Loads by Fabric Weight

Fabric Category	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Light	24.3%	0.1%	307	25.8%	0.1%	145
Medium	60.0%	0.1%	759	58.6%	0.1%	330
Heavy	15.7%	0.0%	198	15.6%	0.1%	88
Total	100.0%	0.0%	1264	100.0%	0.0%	563

Table 24. Distribution of Loads by Wash Temperature Setting

Wash Temperature	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Cold	34.3%	0.1%	419	28.7%	0.1%	156
Warm	56.5%	0.1%	690	61.1%	0.1%	332
Hot	9.2%	0.0%	113	10.1%	0.1%	55
Total	100.0%	0.0%	1222	100.0%	0.0%	543

Table 25. Distribution of Loads by Rinse Temperature Setting

Rinse Temperature	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Cold	91.0%	0.0%	1088	93.5%	0.1%	501
Warm	8.0%	0.0%	96	5.8%	0.1%	31
Hot	1.0%	0.0%	12	0.7%	0.0%	4
Total	100.0%	0.0%	1196	100.0%	0.0%	536

Table 26. Distribution of Loads by Spin Speed

Spin Speed	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Low	9.3%	0.1%	86	6.8%	0.1%	29
Medium	26.7%	0.1%	247	24.1%	0.2%	103
High	64.0%	0.1%	593	69.1%	0.2%	295
Total	100.0%	0.0%	926	100.0%	0.0%	427

Table 27. Distribution of Loads by Fabric Color

Fabric Color	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Color	38.8%	0.1%	437	39.8%	0.2%	200
Mixed	43.3%	0.1%	487	43.0%	0.2%	216
White	17.9%	0.1%	201	17.1%	0.1%	86
Total	100.0%	0.0%	1125	100.0%	0.0%	502

Table 28. Distribution of Loads by Washing Machine Volume

Rated Volume (cu. ft.)	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
<3.2	21.2%	0.1%	238	18.0%	0.1%	93
3.2–3.3	36.0%	0.1%	404	42.6%	0.2%	220
3.4–3.5	16.1%	0.1%	181	18.2%	0.1%	94
>3.5	26.6%	0.1%	299	21.1%	0.1%	109
Total	100.0%	0.0%	1122	100.0%	0.0%	516

Table 29. Distribution of Loads by Nominal Modified Energy Factor (MEF)

Rated MEF	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
<2.0	19.4%	0.1%	203	16.8%	0.1%	83
2.0–2.3	38.5%	0.1%	404	41.2%	0.2%	203
>2.3	42.1%	0.1%	442	42.0%	0.2%	207
Total	100.0%	0.0%	1049	100.0%	0.0%	493

Table 30. Distribution of Loads by Nominal Water Factor (WF)

Rated WF	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
<4.0	51.4%	0.1%	502	52.8%	0.2%	245
4.0–5.9	32.5%	0.1%	317	33.6%	0.2%	156
>5.9	16.1%	0.1%	157	13.6%	0.1%	63
Total	100.0%	0.0%	976	100.0%	0.0%	464

Table 31. Distribution of Loads by Machine Type

Rated WF	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Horizontal Axis	76.9%	0.1%	980	83.2%	0.1%	472
Vertical Axis	23.1%	0.1%	294	16.8%	0.1%	95
Total	100.0%	0.0%	1274	100.0%	0.0%	567

The following are additional tables in a two-way format.

Table 32. Count of Washing Machines by Year and Axis Type

Washer Year	Count of Sites by Axis Type	
	Horizontal	Vertical
2005	4	2
2006	1	2
2007	3	4
2008	5	3
2009	9	1
2010	10	1
2011	1	0
Total	33	13

A5.2. Dryer Load Characteristics

A general summary of dryer data are in Table 33.

Table 33. Dryer Load Characteristics

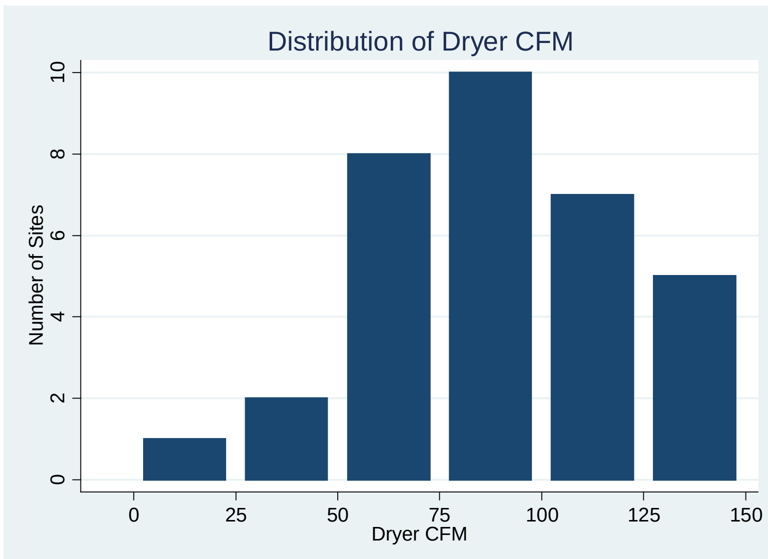
Category	All Loads			Simple Loads		
	Mean	EB	n (L/S)	Mean	EB	n (L/S)
Dryer Loads per Year	311	42	46 S	147	26	44 S
Dried Not Washed (% of Dryer Loads)	6.2%	0.0%	79 L	0%	0%	0 L
Initial RMC (% Water by Weight)	71.0%	2.7%	1209 L	62.9%	1.0%	567 L
Final RMC (% Water by Weight)	7.2%	3.2%	1183 L	3.3%	0.5%	555 L
Average Water Removed (lbs)	4.81	0.13	1134 L	4.73	0.14	553 L
Average Dry Clothes Weight (lbs)	7.94	0.17	1183 L	8.13	0.20	555 L
Average Bone-Dry Weight (lbs)	7.64	0.17	1217 L	7.87	0.19	567 L
Dryer Sheet Use (% of Dryer Loads)	45.3%	2.4%	1199 L	46.2%	3.5%	541 L

Testing for dryer airflow occurred before and after a thorough inspection and lint cleaning. The average improvement was 7.0 CFM, or 9%. Figure 21 shows the distribution of dryer CFM after cleaning.

Table 34. Dryer Performance Before and After Lint Cleaning

Category	Dryer CFM Summary		
	Mean	EB	n (S)
Pre-Cleaning Dryer CFM	80.8	9.3	33
Post-Cleaning Dryer CFM	90.2	11.1	24
Average CFM Improvement	7.0	5.0	24

Figure 21. Distribution of Dryer CFM



Dryer characteristics are present in the following tables. As with the washer summaries, many of these are the characteristics entered into the logbooks and translated into the bin categories.

Table 35. Distribution of Dryer Loads by Fabric Weight

Fabric Weight	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Light	24.5%	0.1%	290	25.8%	0.1%	145
Medium	59.2%	0.1%	700	58.6%	0.1%	330
Heavy	16.2%	0.1%	192	15.6%	0.1%	88
Total	100.0%	0.0%	1182	100.0%	0.0%	563

Table 36. Distribution of Loads by Dryer Sheet Use

Dryer Sheets Used?	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
No	54.7%	0.1%	656	53.8%	0.2%	291
Yes	45.3%	0.1%	543	46.2%	0.2%	250
Total	100.0%	0.0%	1199	100.0%	0.0%	541

Table 37. Dryer Cycle Length

Cycle Length (min)	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
0–14	1.7%	0.0%	21	0.0%	0.0%	0
15–29	9.9%	0.0%	126	7.2%	0.1%	41
30–44	21.7%	0.1%	275	22.8%	0.1%	129
45–59	22.1%	0.1%	281	24.9%	0.1%	141
60–74	26.5%	0.1%	336	28.2%	0.1%	160
75–89	11.7%	0.0%	149	11.5%	0.1%	65
90+	6.5%	0.0%	82	5.5%	0.1%	31
Total	100.0%	0.0%	1270	100.0%	0.0%	567

Table 38. Dryer Temperature Setting

Temperature Setting	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Low	11.3%	0.0%	138	9.7%	0.1%	53
Medium	45.6%	0.1%	555	52.7%	0.2%	288
High	43.0%	0.1%	523	37.5%	0.1%	205
Total	100.0%	0.0%	1216	100.0%	0.0%	546

Table 39. Distribution of Loads by Dryer Dryness Setting

Dryness Setting	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Less Dry	1.3%	0.0%	11	0.7%	0.0%	3
Normal	64.8%	0.1%	528	61.0%	0.2%	256
More Dry	33.9%	0.1%	276	38.3%	0.2%	161
Total	100.0%	0.0%	815	100.0%	0.0%	420

Table 40. Distribution of Loads by Bone-Dry Weight

Load Weight (lbs)	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–2	8.2%	0.0%	100	—	—	—
3–5	27.4%	0.1%	334	30.5%	0.1%	173
6–8	30.2%	0.1%	367	35.8%	0.1%	203
9–11	22.1%	0.1%	269	25.6%	0.1%	145
12–14	9.4%	0.0%	115	8.1%	0.1%	46
15+	2.6%	0.0%	32	—	—	—
Total	100.0%	0.0%	1217	100.0%	0.0%	567

Table 41. Distribution of Loads by Initial RMC

Initial RMC	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
0–32%	8.5%	0.0%	102	—	—	—
33–65%	48.1%	0.1%	579	61.4%	0.1%	348
66–99%	30.4%	0.1%	366	38.6%	0.1%	219
100%+	13.0%	0.0%	156	—	—	—
Total	100.0%	0.0%	1203	100.0%	0.0%	567

Table 42. Distribution of Loads by Dryer CFM

Dryer CFM*	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
<50	8.7%	0.0%	83	8.0%	0.1%	36
50–74	26.7%	0.1%	255	29.5%	0.2%	133
75–99	23.2%	0.1%	221	16.2%	0.1%	73
100–124	21.4%	0.1%	204	25.7%	0.2%	116
125+	20.0%	0.1%	191	20.6%	0.1%	93
Total	100.0%	0.0%	954	100.0%	0.0%	451

* CFM is a single point measurement per site from the beginning of the study

Table 43. Distribution of Loads by Auto-Termination

Auto Setting	All Loads			Simple Loads		
	%	EB	n (L)	%	EB	n (L)
Manual	19.0%	0.1%	241	11.1%	0.1%	63
Auto	81.0%	0.1%	1029	88.9%	0.1%	504
Total	100.0%	0.0%	1270	100.0%	0.0%	567

A5.3. Combined Characteristics

The following figures and tables summarize properties across washers and dryers. The number of washer loads for a given site usually does not equal the number of dryer loads, as shown in Figure 22, but the distributions across sites are similar. Table 44 shows there were more dryer loads than washer loads in this data set, but only by a slight margin. However, on average per site there were a few more washer loads than dryer loads as seen in Table 45. This discrepancy is due to the skewed distribution of the data.

Figure 22. Distribution of Washer and Dryer Loads per Year

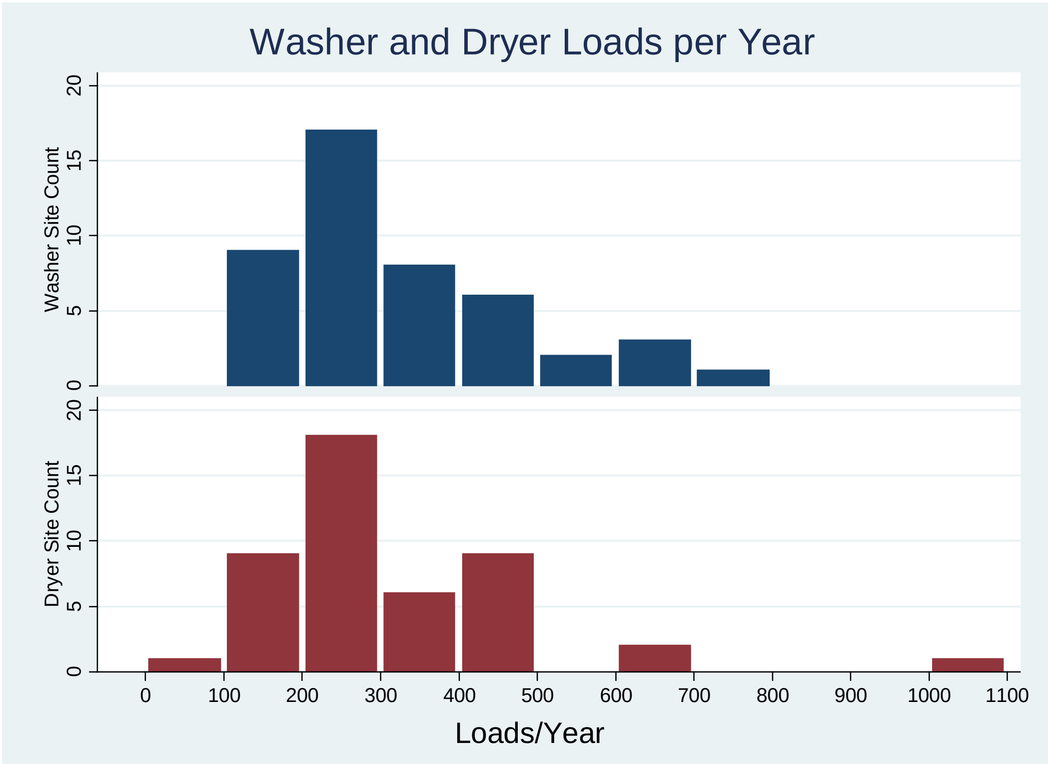


Table 44. Cross-Tabulation of Loads Washed and/or Dried

Wash Cycle	Dry Cycle			
	No	Yes	Total	n (L)
No	0.0%	5.8%	5.8%	79
Yes	6.1%	88.0%	94.2%	1274
Total	6.1%	93.9%	100.0%	1353
n (L)	83	1270	1353	—

Table 45. Summary of Loads per Year by Number of Occupants

Load Type		Loads Per Year by Number of People									
		1	2	3	4	5	6	7	8	All	n (S)
Wash	**Mean**	150	291	278	302	554	407	449	274	313	46
	EB	32	35	25	50	100	0	0	0	23	
Dry	**Mean**	111	291	271	299	574	407	449	249	311	46
	EB	19	32	28	51	164	0	0	0	26	

Figure 23. Washer and Dryer Loads per Year by Number of Occupants and Kids (0-18 years)

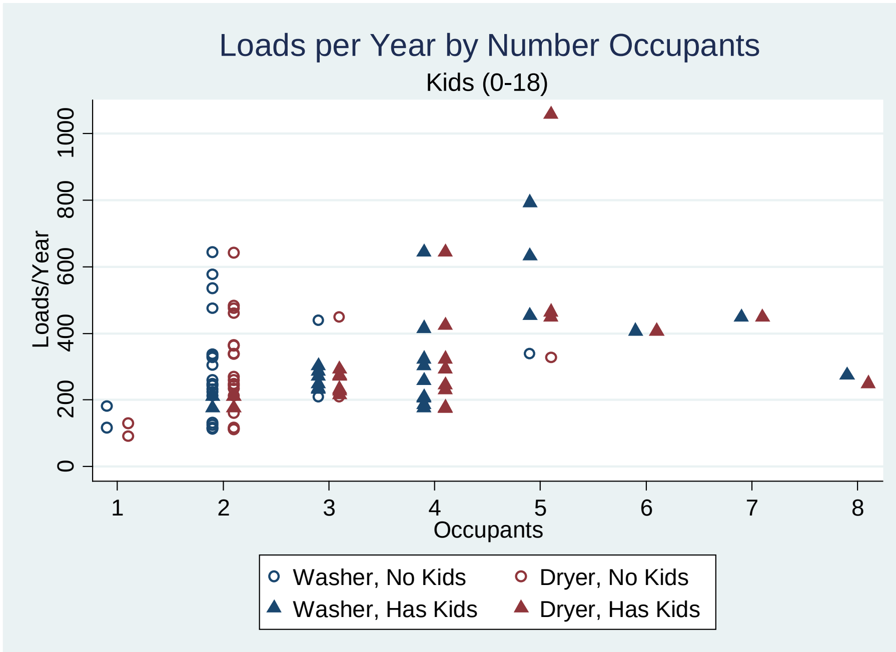
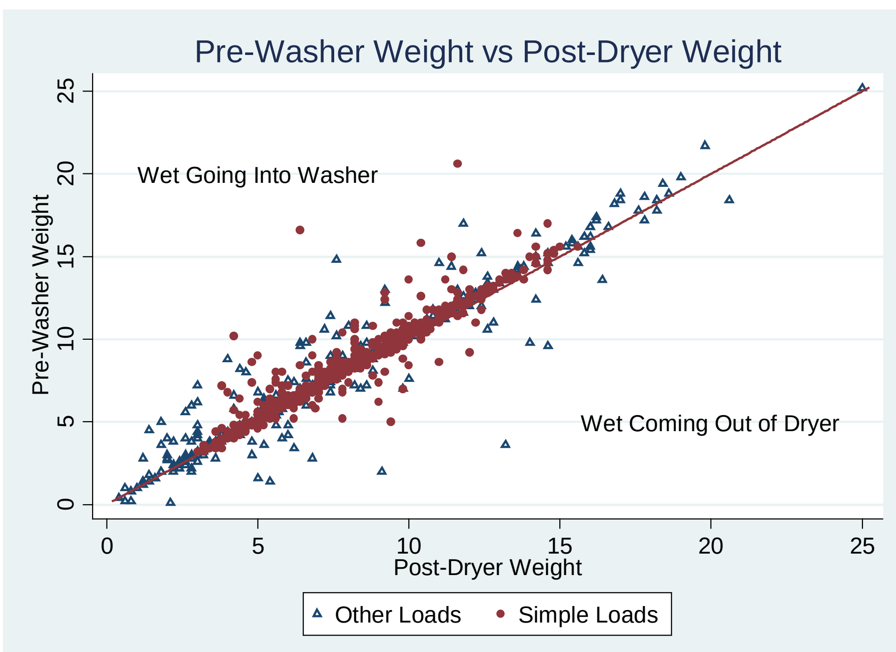


Figure 24. Comparison of Pre-Washer and Post-Dryer Weight by Load Type



Appendix 6. Washer and Dryer Energy Characteristics

A presentation of energy use characteristics is similar to the laundry characteristics in Appendix 5, plus a few examples of what a single load profile looks like for various settings. Appendix 11 contains many more dryer profile graphs based on the normal settings for each site.

A6.1. Washer Energy Characteristics

Washer load characteristics are in Appendix 5. General washer energy characteristics are in Table 46.

Table 46. Washer Cycle Average Summaries

Category	All Loads			Simple Loads		
	Mean	EB	n (L/S)	Mean	EB	n (L/S)
Cycle Length (min)	57.0	0.9	1274 L	59.3	1.2	567 L
Energy Use per Load (kWh)	0.18	0.01	1274 L	0.17	0.01	567 L
Energy Use per Year (kWh)	54.9	9.0	46 S	24.2*	3.5	44 S
Mechanical Efficiency (lb/kWh)	64.4	2.5	1210 L	69.5	3.7	563 L
Washer Standby (W)	0.87	0.28	46 S	n/a	n/a	n/a
Washer Standby (kWh/year)	7.4	2.4	46 S	n/a	n/a	n/a

* Represents yearly estimate for simple loads only. This is a subset of the all loads value.

The tables on the following pages show the energy use by various bin categories, and a scatter plot of energy use follows each of the categorical tables by cycle length for simple loads with color categories corresponding to the table. A higher value on the plot is more efficient, meaning more lbs (bone-dry) of laundry processed per kWh.

The most obvious trends for efficiency are the weight of the load, cycle time, and wash temperature. There also seems to be a trend based on the rated MEF, rated WF, and machine type, which are all related. The low MEF/high WF machines tend to be of the older vertical axis-type of washing machine, which appear to have shorter cycle times.

There appears to be a strong relationship between cycle length and energy use, which makes sense since the main function of the machine is to continue to move the clothes throughout the cycle. Table 57 shows the energy use per load by cycle time. The first two time bins do not have many data, so if we start looking at the third bin we see a decrease in washer efficiency as the time increases. The anomaly in that trend is the 30–44 minute bin, which shows a lower efficiency than expected by the rest of the trend. This is likely due to the inefficient washing machines having the lowest cycle times, as seen in Figure 34 and Figure 35 below.

Figure 25 also shows the energy use by time. The left graph is raw energy use and the right graph is the load MEF. Energy use is linear in time, but the gaps in the left graph are due to each washer having its own slope profile, as shown in the linear fit lines of Figure 26. Therefore, the length of time within a site is linear with respect to energy use, but we cannot compare the energy use of a load between two sites simply based on cycle length. MEF and lb/kWh are ways to normalize the data for better comparison.

Figure 25. Comparison of Washer Energy Use Metrics by Cycle Length

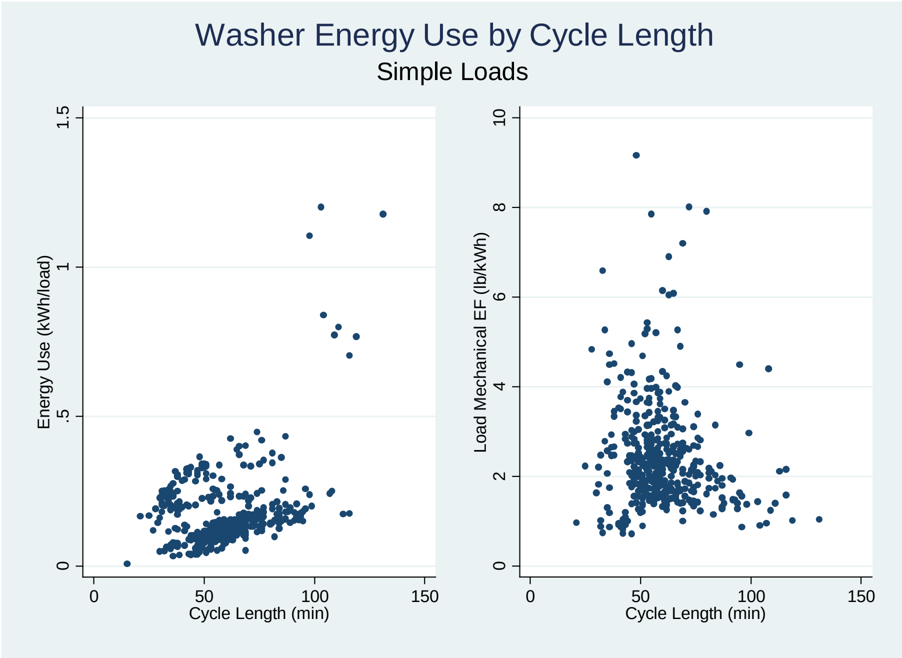


Figure 26. Washer Energy Use Patterns by Siteid

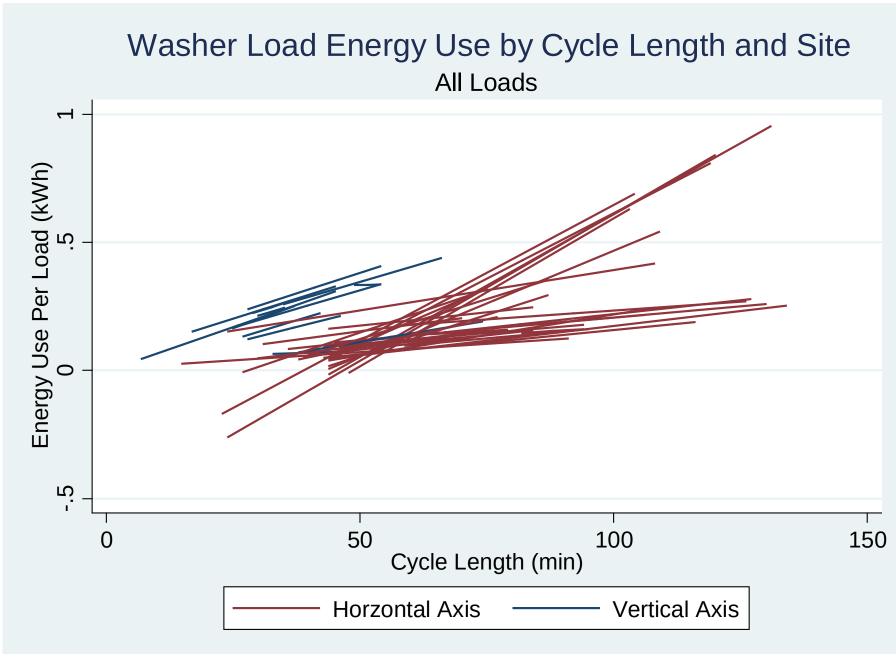


Table 47. Energy Use (lb/kWh) per Load by Bone-Dry Clothes Weight

Washer Dry Weight	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
0–2 lbs	25.0	4.9	104	—	—	—
3–5 lbs	46.2	4.3	334	50.0	7.6	172
6–8 lbs	61.5	3.0	363	63.5	4.1	202
9–11 lbs	83.9	5.9	271	85.8	6.8	144
12–14 lbs	99.8	9.4	106	119.0	16.4	45
15+ lbs	131.9	14.1	32	—	—	—

Figure 27. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Bone-Dry Weight

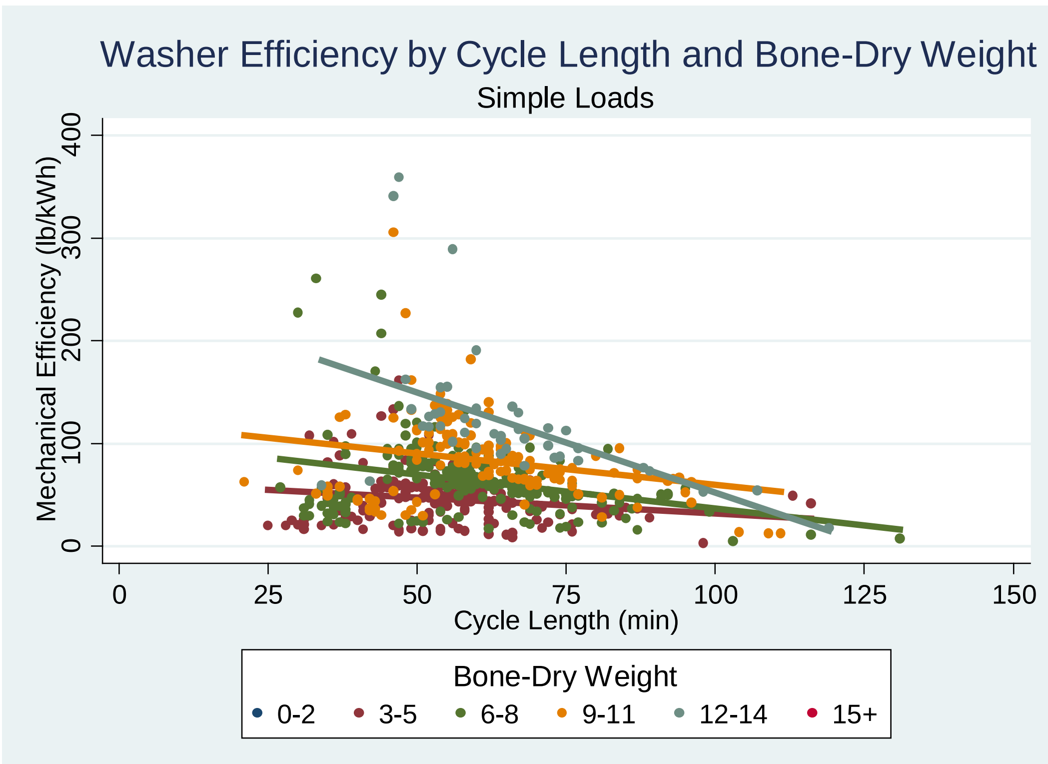


Table 48. Washer Mechanical Efficiency (lb/kWh) per Load by Fabric Type

Fabric Category	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Light	61.7	6.9	300	70.3	10.6	144
Medium	66.9	2.6	703	67.6	3.4	327
Heavy	59.7	6.1	197	75.8	10.4	88

Figure 28. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Fabric Type

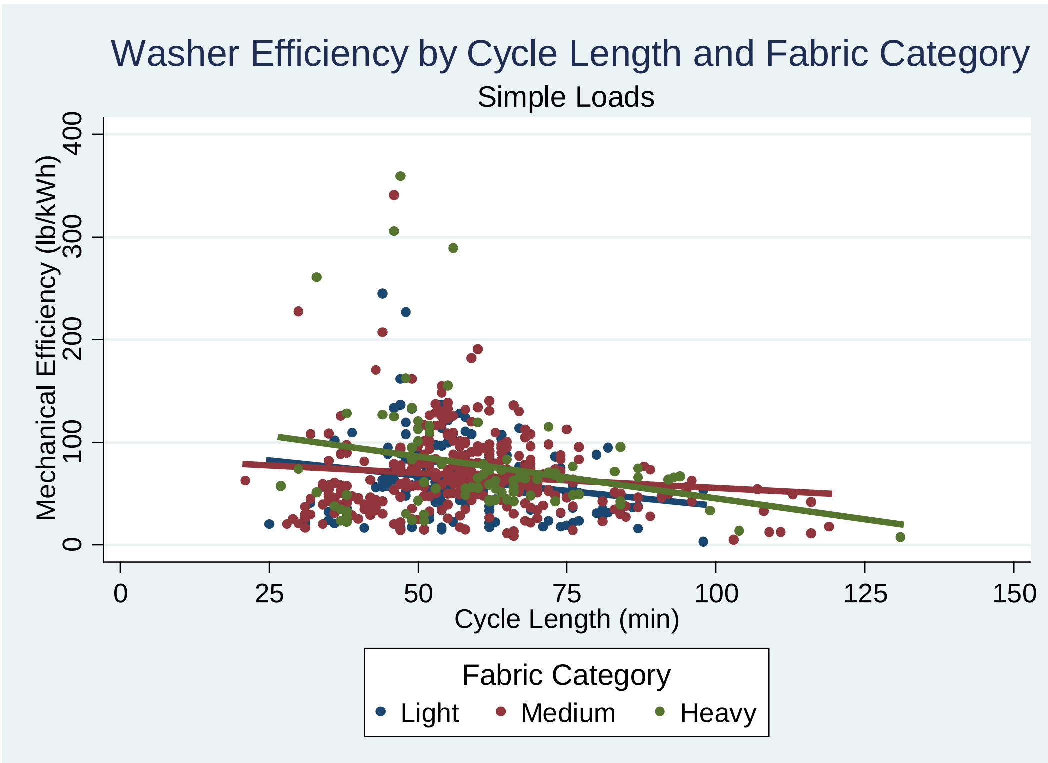


Table 49. Washer Mechanical Efficiency (lb/kWh) per Load by Wash Temperature Setting

Wash Temperature	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Cold	80.4	5.1	368	90.5	8.8	155
Warm	61.4	3.2	683	64.9	4.4	331
Hot	34.3	3.9	107	37.7	5.5	53

Figure 29. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Wash Temperature Setting

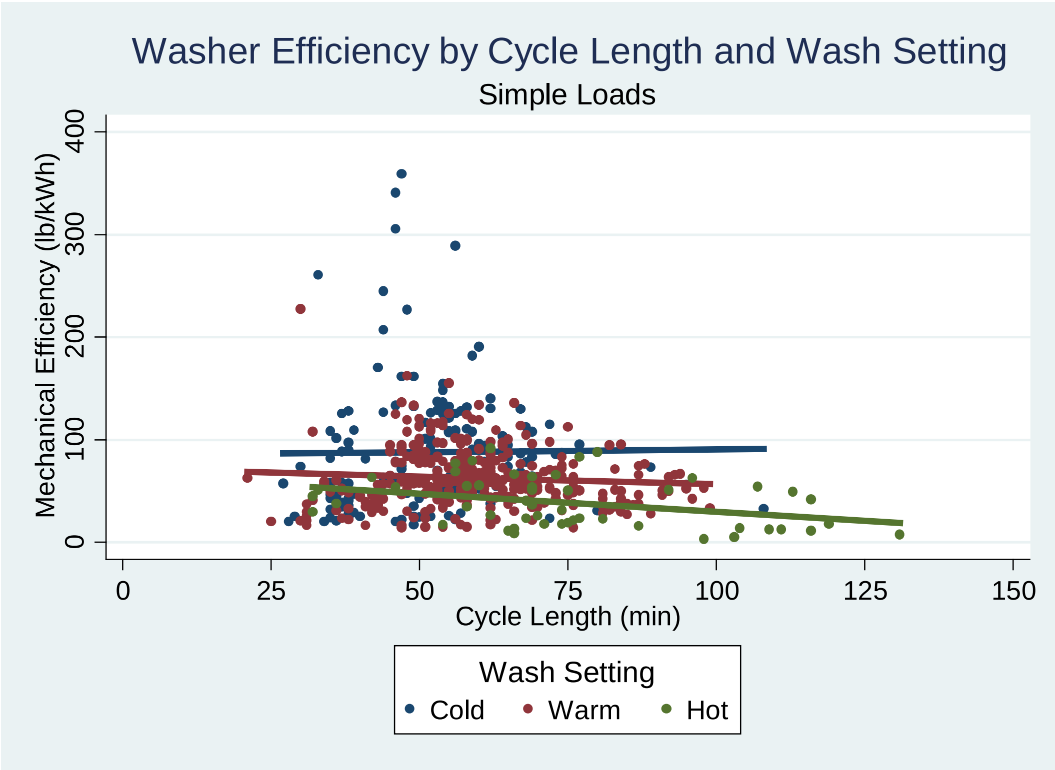


Table 50. Washer Mechanical Efficiency (lb/kWh) per Load by Rinse Temperature Setting

Rinse Temperature	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Cold	65.1	2.8	1032	70.6	4.2	498
Warm	71.1	7.4	92	61.4	8.2	30
Hot	48.3	11.3	8	58.0	5.2	4

Figure 30. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Rinse Temperature Setting

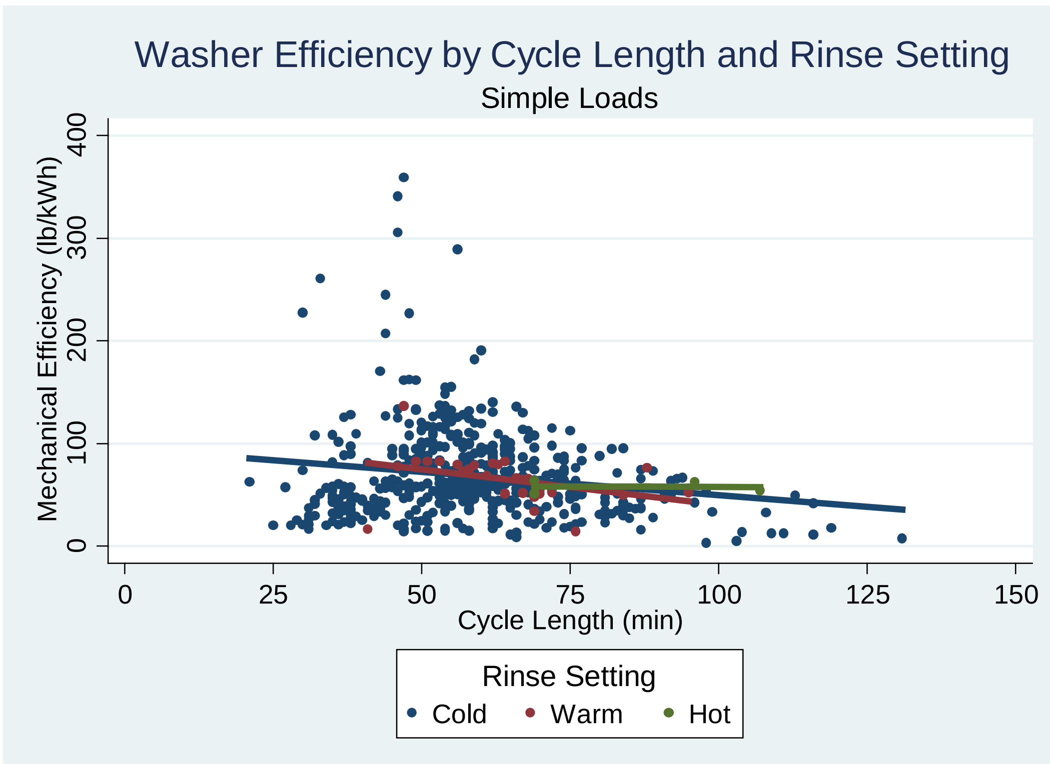


Table 51. Washer Mechanical Efficiency (lb/kWh) per Load by Spin Speed

Spin Speed	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Low	117.9	19.0	72	160.4	34.5	28
Medium	64.6	4.5	209	66.0	5.9	103
High	66.0	3.6	584	67.9	5.0	293

Figure 31. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Spin Speed

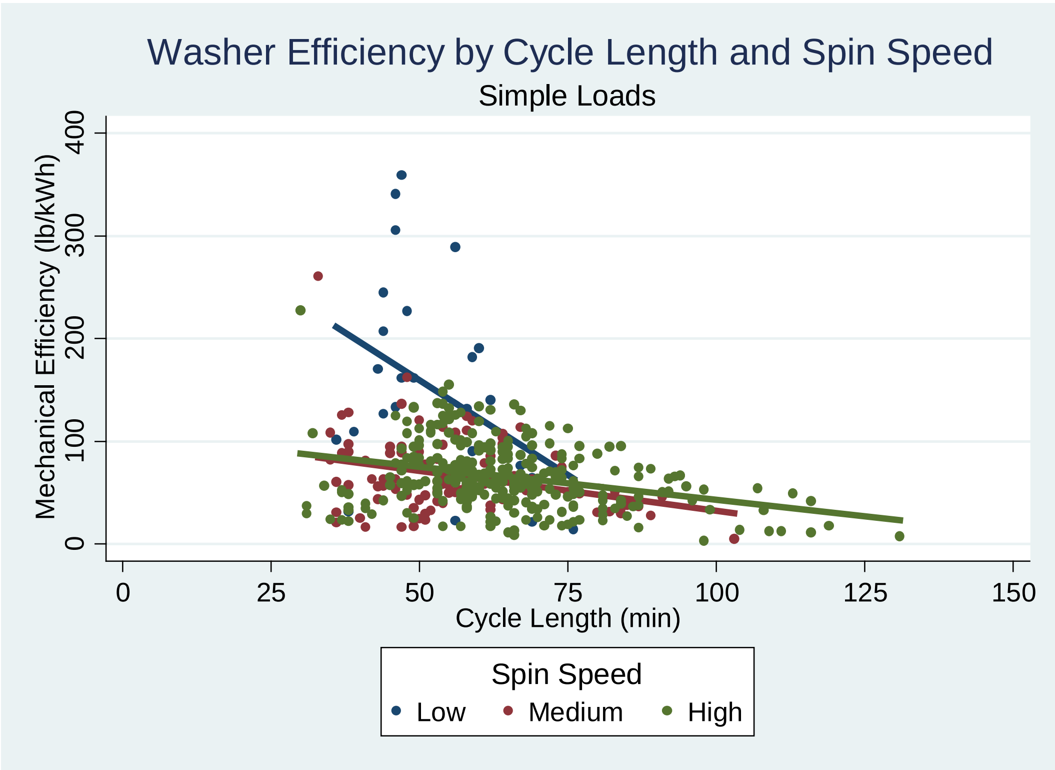


Table 52. Washer Mechanical Efficiency (lb/kWh) per Load by Fabric Color

Fabric Color	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Color	67.0	4.7	434	77.1	8.2	199
Mixed	66.7	3.6	431	71.6	5.1	215
White	57.0	6.4	199	48.5	4.1	86

Figure 32. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Fabric Color

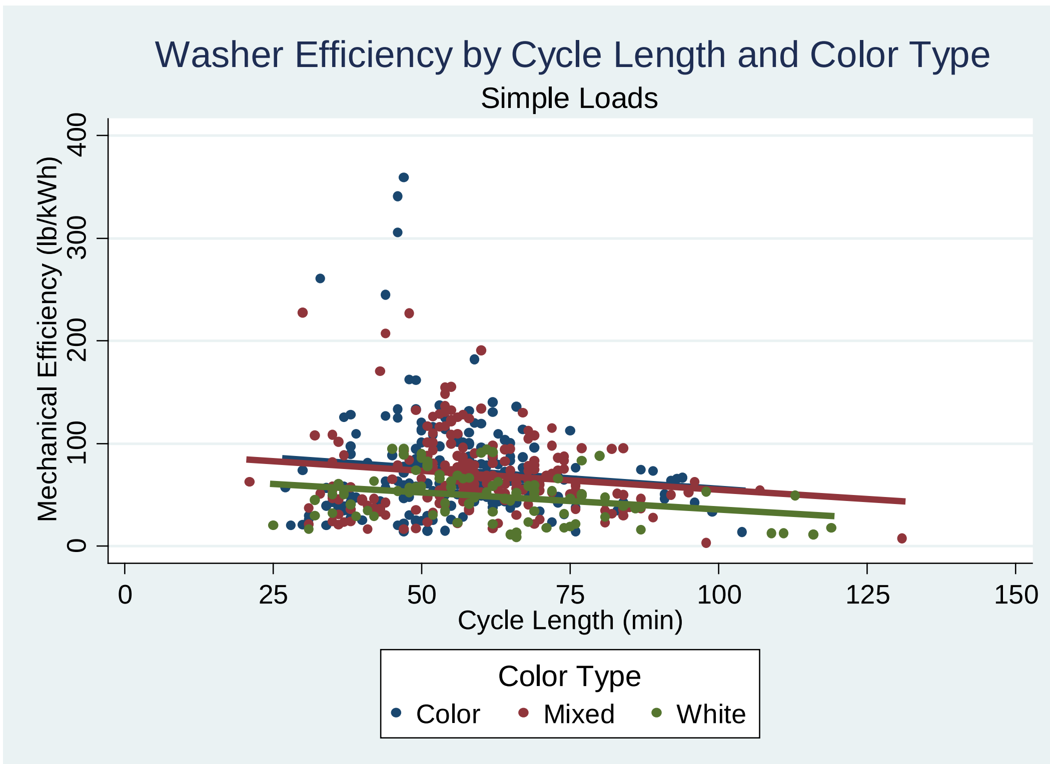


Table 53. Washer Mechanical Efficiency (lb/kWh) per Load by Rated Volume

Rated Volume (cu. ft.)	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
<3.2	60.9	5.5	238	59.1	5.5	93
3.2–3.3	60.2	2.8	400	65.1	3.0	219
3.4–3.5	89.3	9.4	178	101.3	14.2	91
>3.5	69.4	6.4	243	68.8	11.9	109

Figure 33. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Rated Volume

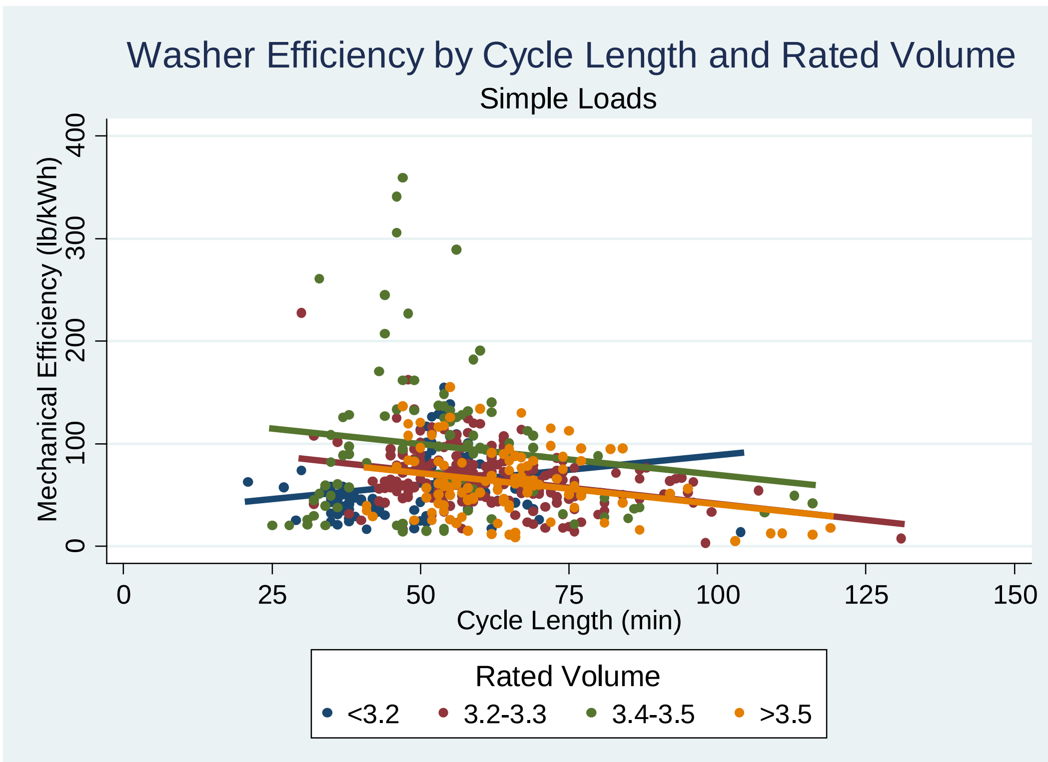


Table 54. Washer Mechanical Efficiency (lb/kWh) per Load by Rated MEF

Rated MEF	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
<2.0	43.0	3.6	201	47.2	6.6	83
2.0–2.3	69.2	2.9	404	72.3	3.4	203
>2.3	82.8	5.7	382	83.1	8.9	203

Figure 34. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Rated MEF

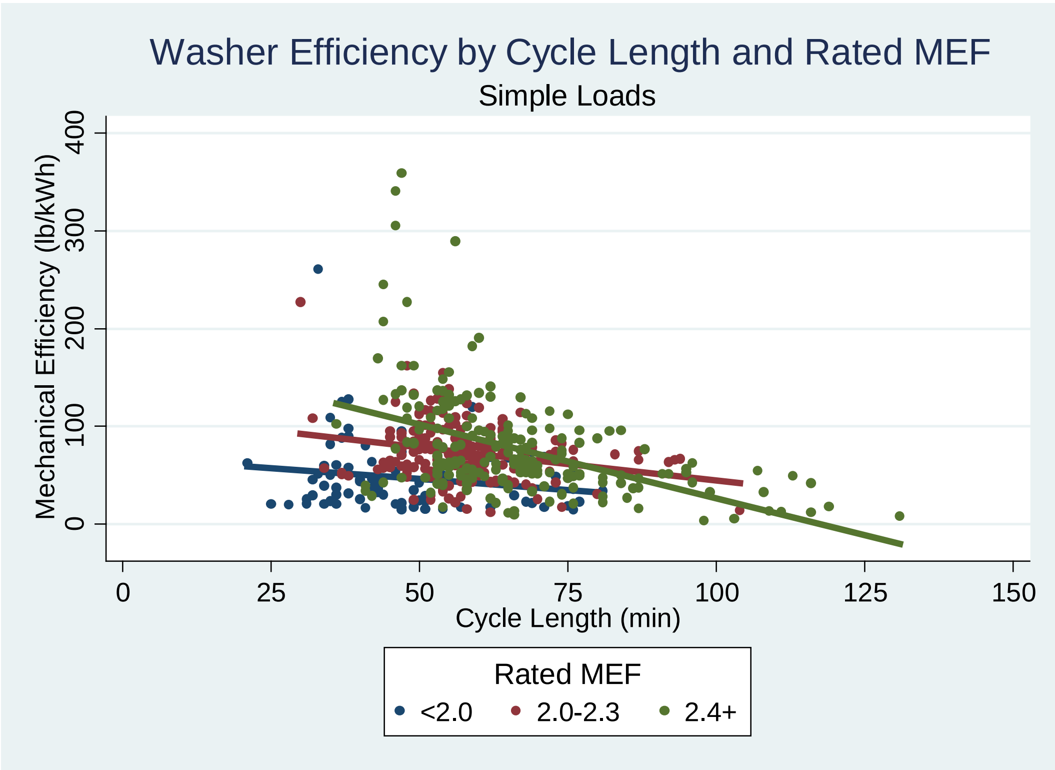


Table 55. Washer Mechanical Efficiency (lb/kWh) per Load by Rated Water Factor

Rated WF	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
<4.0	81.3	5.0	442	81.7	7.6	241
4.0–5.9	72.7	3.3	317	74.5	3.7	156
>5.9	40.9	3.9	157	48.9	8.0	63

Figure 35. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Rated Water Factor

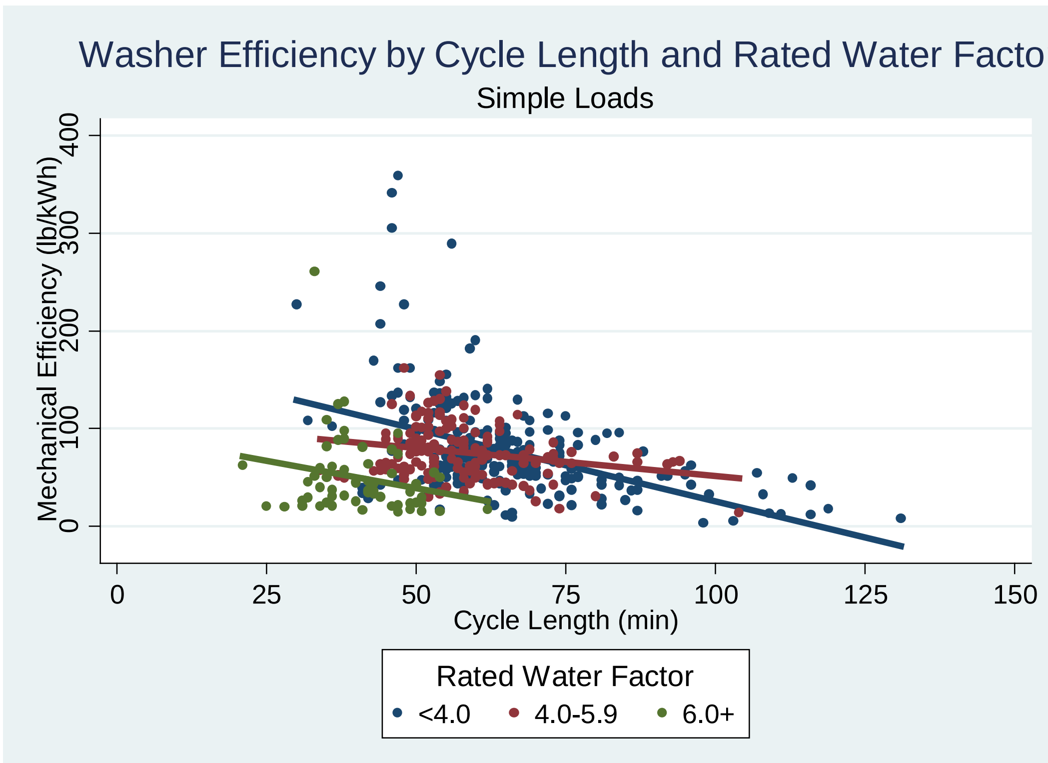


Table 56. Washer Mechanical Efficiency (lb/kWh) per Load by Machine Type

Machine Type	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Horizontal Axis	73.0	2.8	918	74.4	4.3	468
Vertical Axis	37.3	4.3	292	45.4	5.5	95

Figure 36. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Machine Type

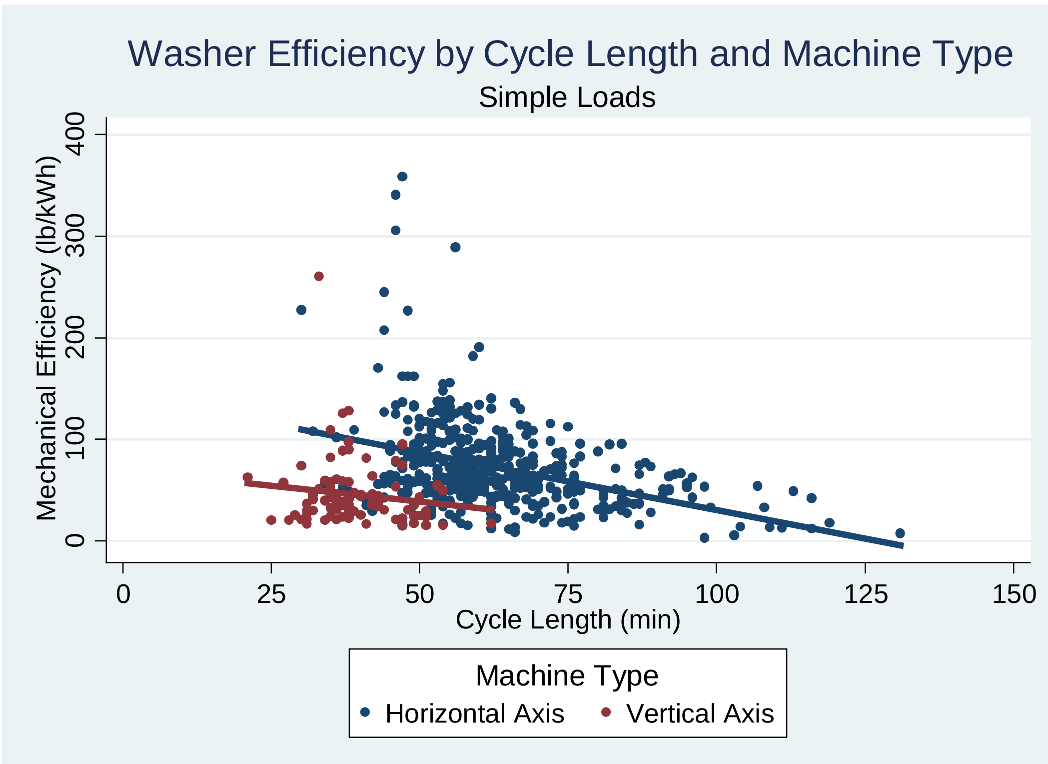
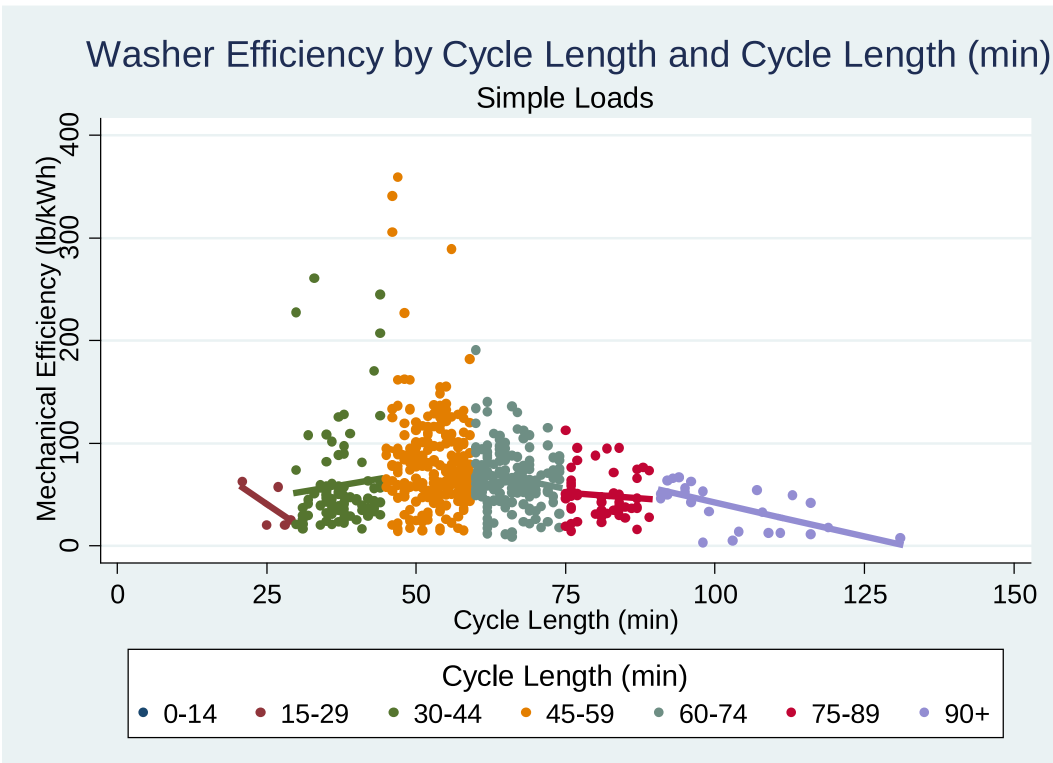


Table 57. Washer Mechanical Efficiency (lb/kWh) per Load by Washer Cycle Time

Cycle Time (min)	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
0–14	657.3	0.0	1	—	—	—
15-29	68.7	50.3	25	159.7	202.3	6
30–44	45.7	4.0	248	59.2	8.6	87
45–59	76.5	4.0	473	81.8	5.8	231
60–74	67.8	3.4	291	66.1	3.7	159
75–89	55.2	4.3	103	49.3	5.3	51
90+	37.6	4.6	69	38.0	6.9	29

Figure 37. Washer Mechanical Efficiency (lb/kWh) by Cycle Length and Washer Cycle Time



The following graphs show the energy use profile of single loads for a single washing machine. Figure 38 through Figure 41 show delicate cycle, normal cycle, hot cycle, and extra hot (sanitary) cycle examples for a single site. The hot and extra hot cycles need an energy boost to achieve the desired water temperature, which is the resistant heat plateau at the beginning of those cycles. These graphs are just examples of single load profiles and are not a summary across loads or across machines. The graphs have similar axis scales for easy comparison. For these four particular loads, the hot cycle uses about five times more energy than the normal cycle, and the extra hot cycle uses more than 13 times the energy of the normal cycle.

Figure 38. Washing Machine Single Cycle Energy Profile – Delicate Cycle

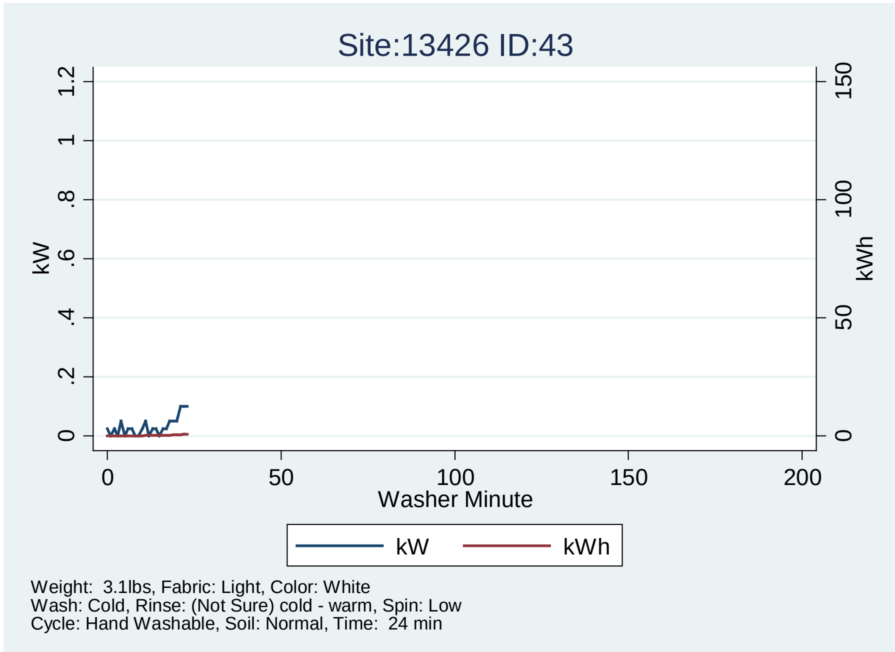


Figure 39. Washing Machine Single Cycle Energy Profile – Normal Cycle

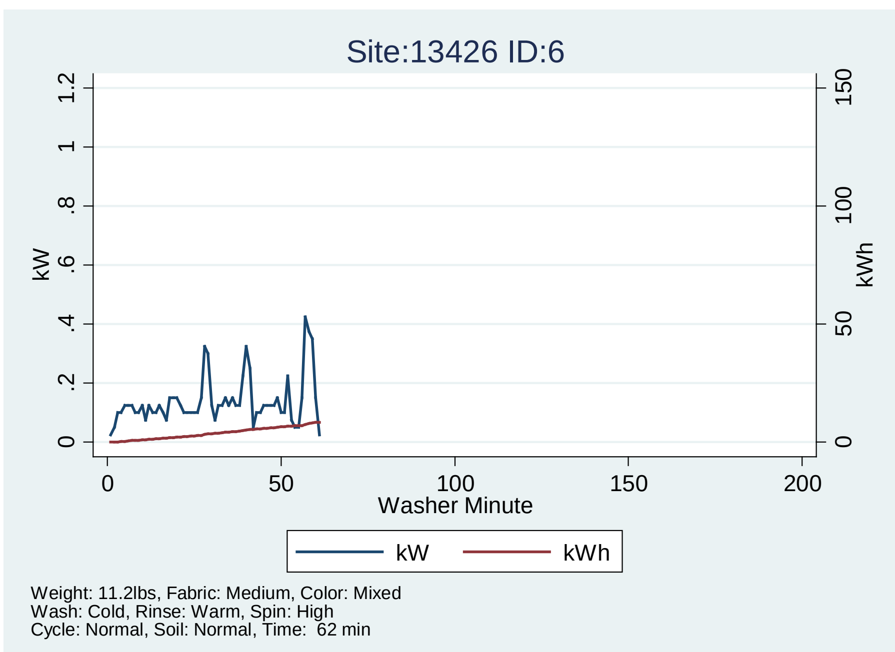


Figure 40. Washing Machine Single Cycle Energy Profile – Hot Cycle

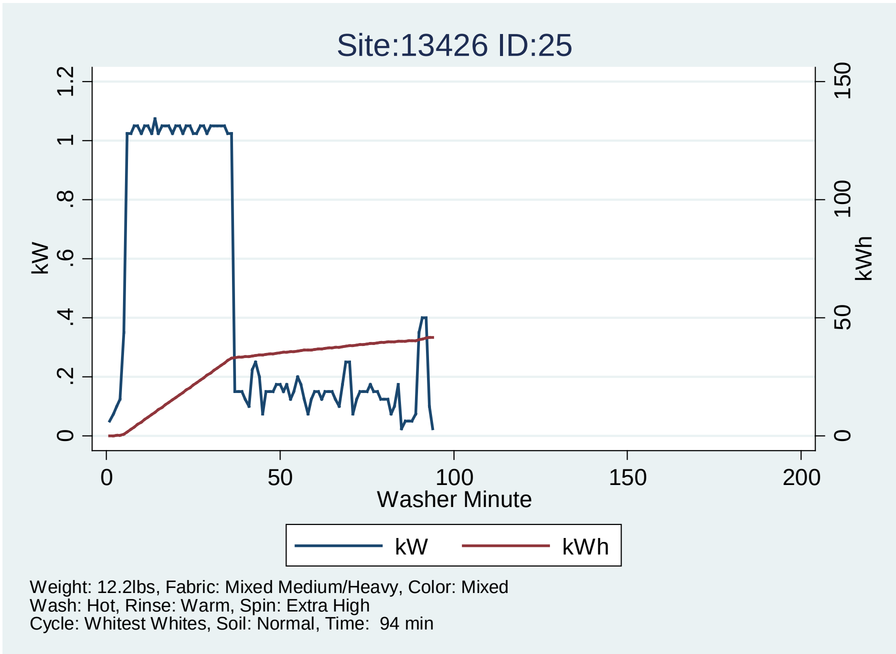
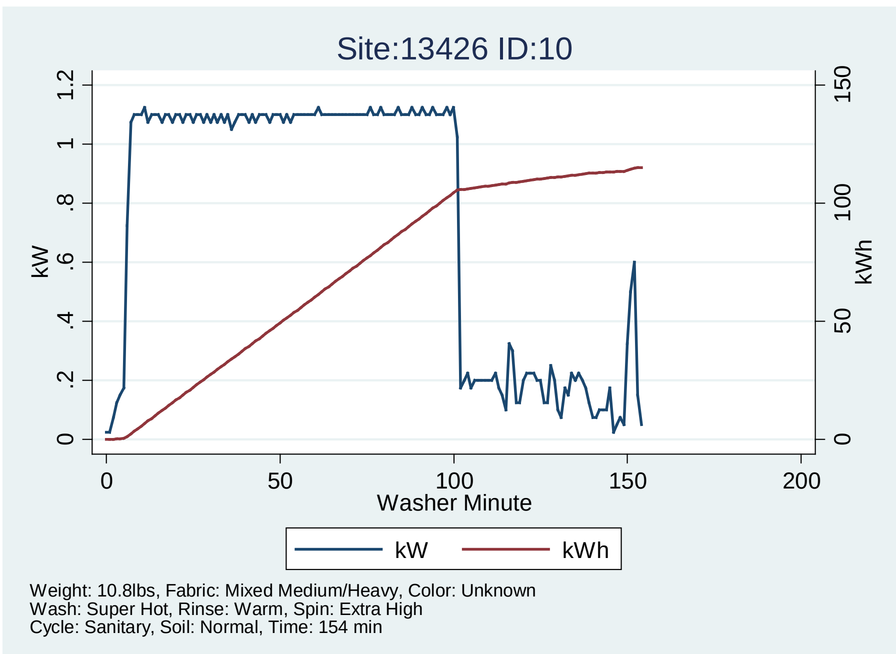


Figure 41. Washing Machine Single Cycle Energy Profile – Extra Hot Cycle



A6.2. Dryer Energy Characteristics

A presentation of the dryer energy summaries is similar to the washer summaries, but starts with the dryer energy use by washer categories and then follows with dryer energy use by dryer categories. Dryer energy use by washer categories may illuminate washing machine properties that affect dryer energy use, such as initial RMC. Each of the tables on the following pages includes a scatter plot of energy use by cycle length for simple loads with color categories corresponding to the table. A higher value on the plot is more efficient, meaning more lbs (bone-dry) of laundry processed per kWh. The most obvious trends for efficiency are the weight of the load, the cycle time, and the initial RMC. The relation of these variables is strong since higher initial moisture content will take longer to dry, and the longer dry cycle will use more energy.

Table 58. Average Dryer Cycle Summaries

Category	All Loads			Simple Loads		
	Mean	EB	n (L/S)	Mean	EB	n (L/S)
Cycle Length (min)	56.0	1.1	1270 L	57.0	1.4	567 L
Energy Use per Load (kWh)	2.96	0.06	1270 L	3.17	0.07	567 L
Energy Use per Year (kWh)	915	132	46 S	460	99	44 S
Dryer Efficiency (lb/kWh)	2.66	0.25	45 S	2.56	0.13	44 S
Dryer Efficiency (%)	45.8%	2.0%	45 S	45.0%	1.7%	44 S
Dryer Standby (W)	0.18	0.08	46 S	n/a	n/a	n/a
Dryer Standby per Year (kWh/year)	1.50	0.69	46 S	n/a	n/a	n/a

Figure 42 and Figure 43 show the energy use by time in two different formats (for all loads and for simple loads, respectively). For both figures, the left graph is raw energy use per load and the right graph is the load EF. Energy use is linear in time, and much more consistently so compared to washing machines. EF in lb/kWh is a way to normalize the data for better comparison, as shown on the right.

Table 59 and Figure 44 begin the energy analysis by dryer characteristic bins.

Figure 42. Comparison of Metrics for Energy Use over Cycle Length for All Loads

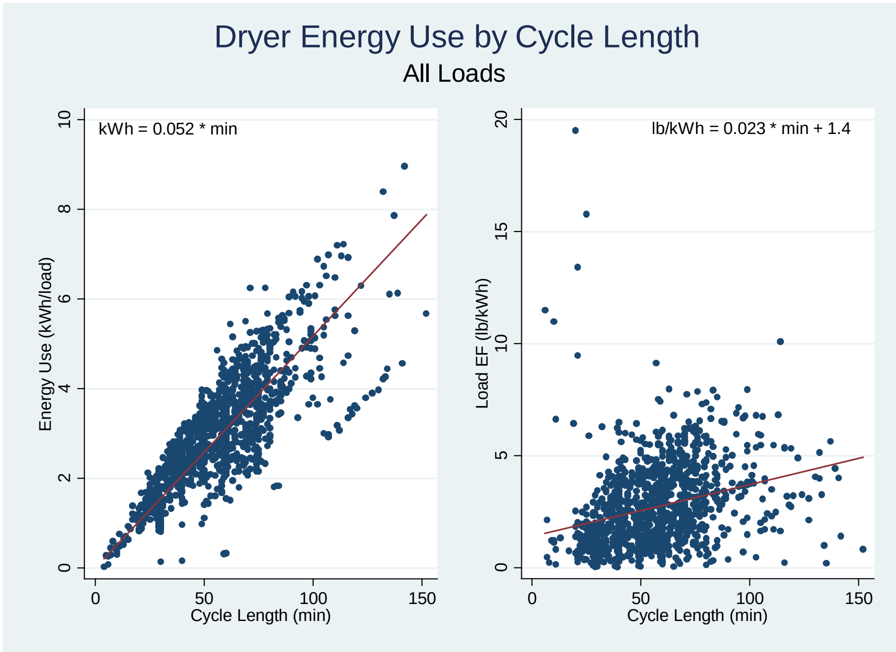


Figure 43. Comparison of Metrics for Energy Use over Cycle Length for Simple Loads

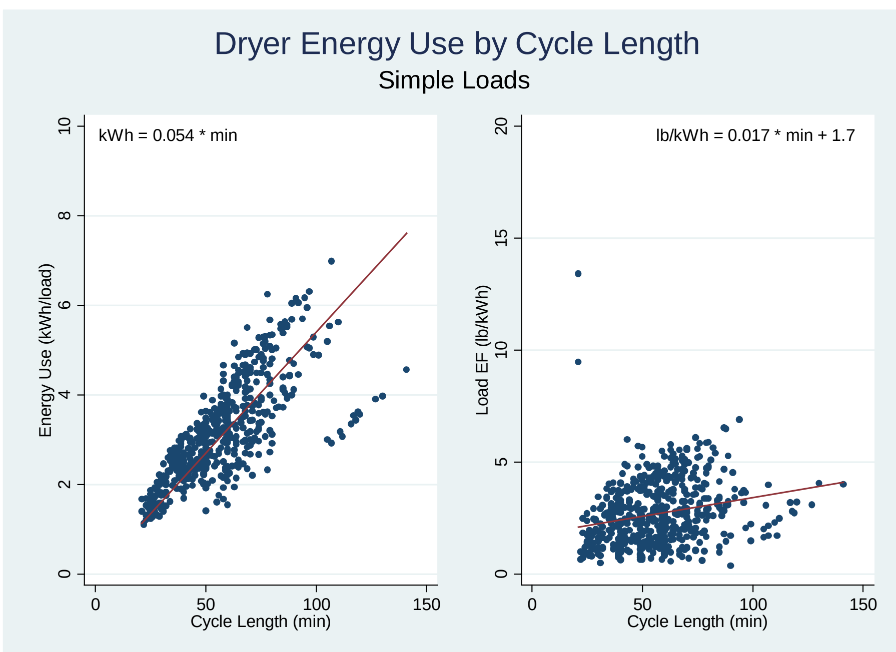


Table 59. Dryer Efficiency (lb/kWh) per Load by Fabric Category

Fabric Category	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Light	2.60	0.20	275	2.74	0.11	142
Medium	2.77	0.11	642	2.70	0.07	322
Heavy	2.51	0.18	192	2.36	0.13	88

Figure 44. Dryer Efficiency (lb/kWh) by Cycle Length and Fabric Category

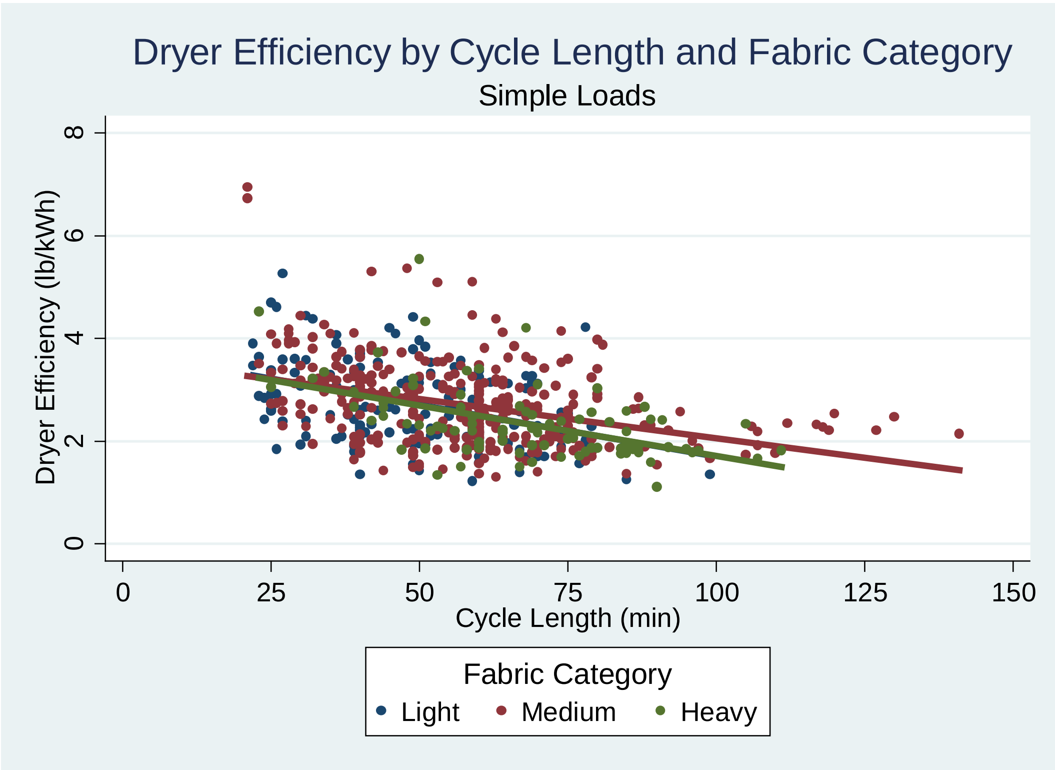


Table 60. Dryer Efficiency (lb/kWh) per Load by Washer Wash Temperature Setting

Wash Temperature	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Cold	2.92	0.14	334	2.80	0.12	150
Warm	2.49	0.07	633	2.58	0.07	329
Hot	3.09	0.66	101	2.57	0.14	53

Figure 45. Dryer Efficiency (lb/kWh) by Cycle Length and Washer Wash Temperature

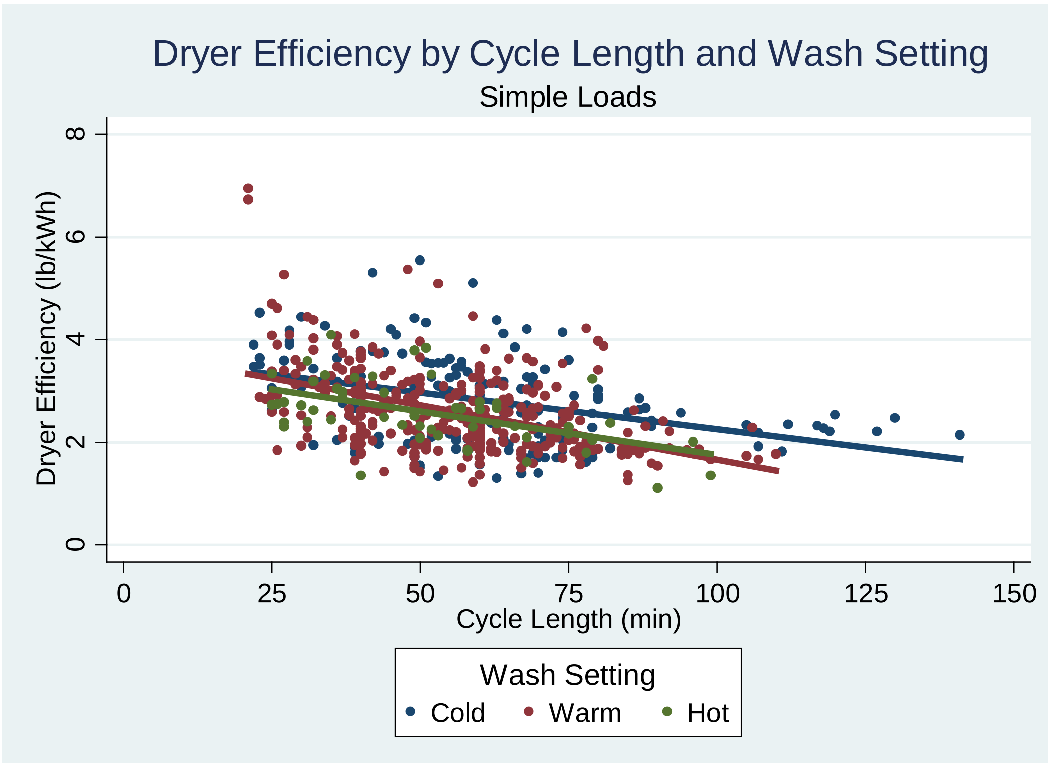


Table 61. Dryer Efficiency (lb/kWh) per Load by Washer Rinse Temperature Setting

Rinse Temperature	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Cold	2.60	0.06	949	2.65	0.06	490
Warm	2.72	0.13	93	2.57	0.19	31
Hot	2.43	0.63	7	2.47	0.38	4

Figure 46. Dryer Efficiency (lb/kWh) by Cycle Length and Washer Rinse Temperature

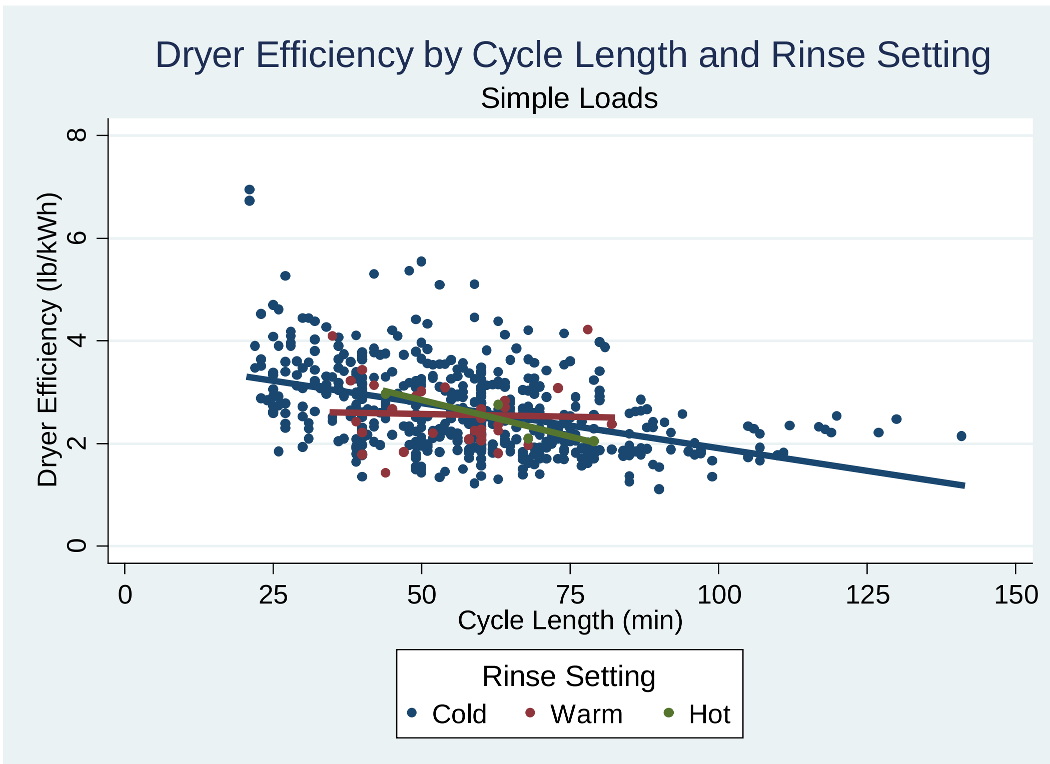


Table 62. Dryer Efficiency (lb/kWh) per Load by Washer Spin Speed

Spin Speed	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Low	2.22	0.25	68	2.29	0.16	26
Medium	2.70	0.14	199	2.71	0.12	101
High	2.84	0.15	567	2.64	0.08	293

Figure 47. Dryer Efficiency (lb/kWh) by Cycle Length and Washer Spin Speed

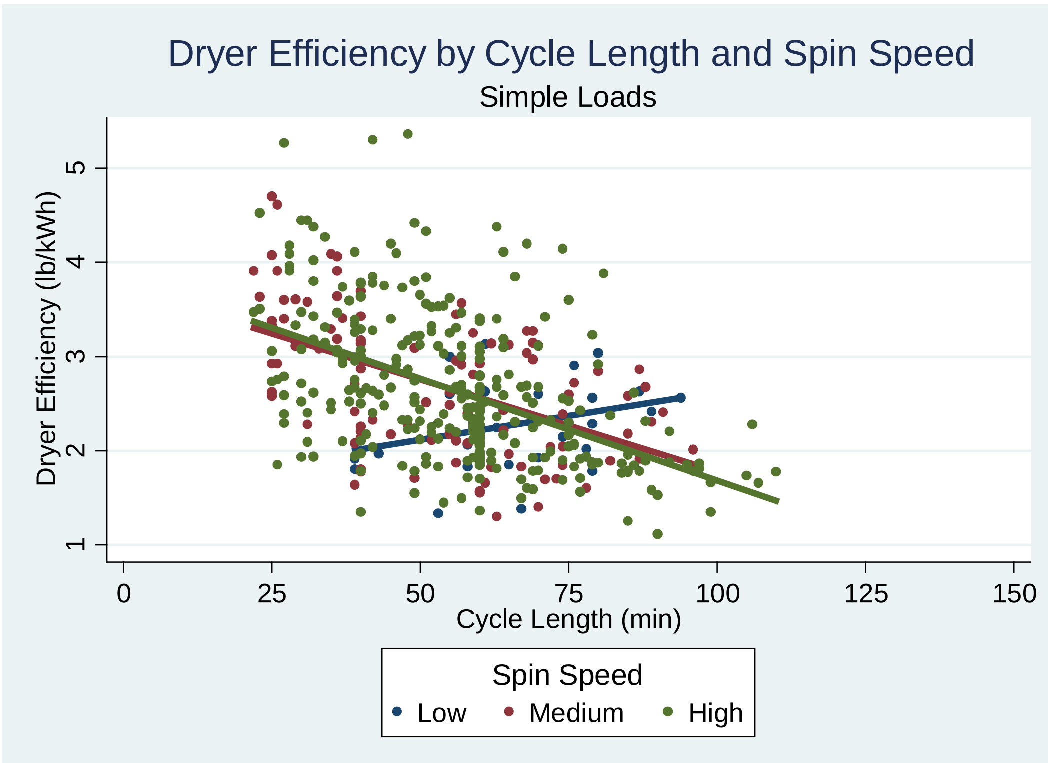


Table 63. Dryer Efficiency (lb/kWh) per Load by Fabric Color

Fabric Color	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Color	2.80	0.14	404	2.64	0.10	194
Mixed	2.63	0.08	410	2.73	0.09	215
White	2.58	0.41	165	2.55	0.12	85

Figure 48. Dryer Efficiency (lb/kWh) by Cycle Length and Fabric Color

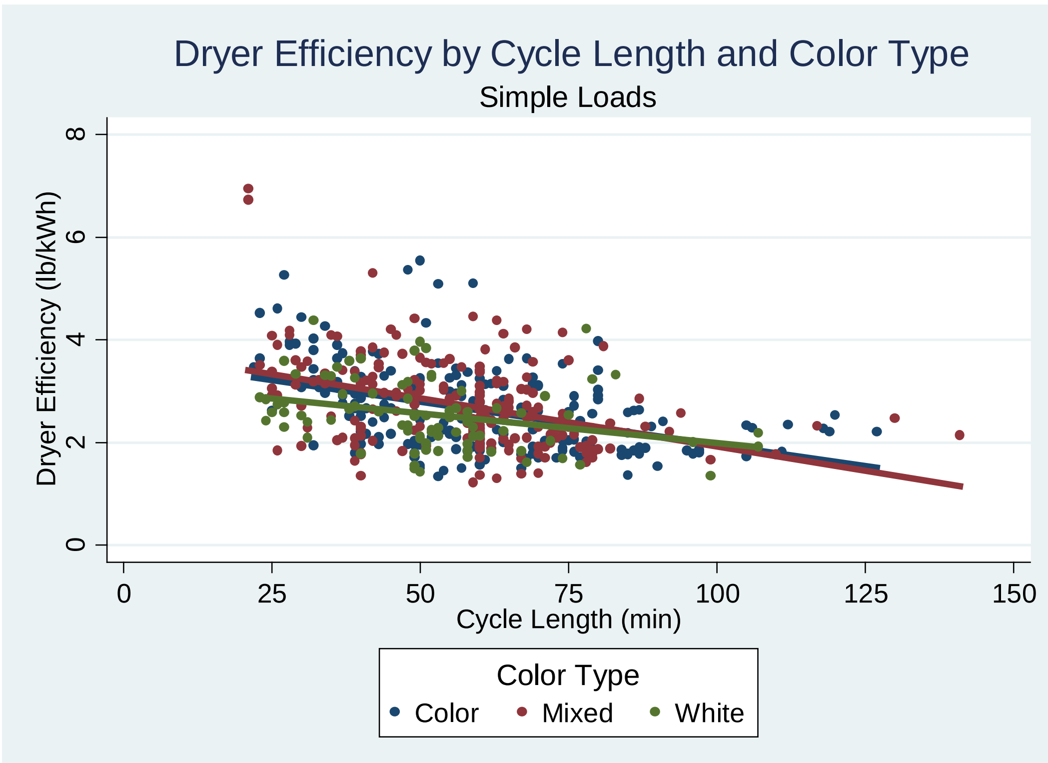


Table 64. Dryer Efficiency (lb/kWh) per Load by Dryer Sheet Use

Dryer Sheets Used?	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
No	2.94	0.07	602	2.83	0.05	289
Yes	3.22	0.16	527	2.46	0.05	245

Figure 49. Dryer Efficiency (lb/kWh) by Cycle Length and Dryer Sheet Use

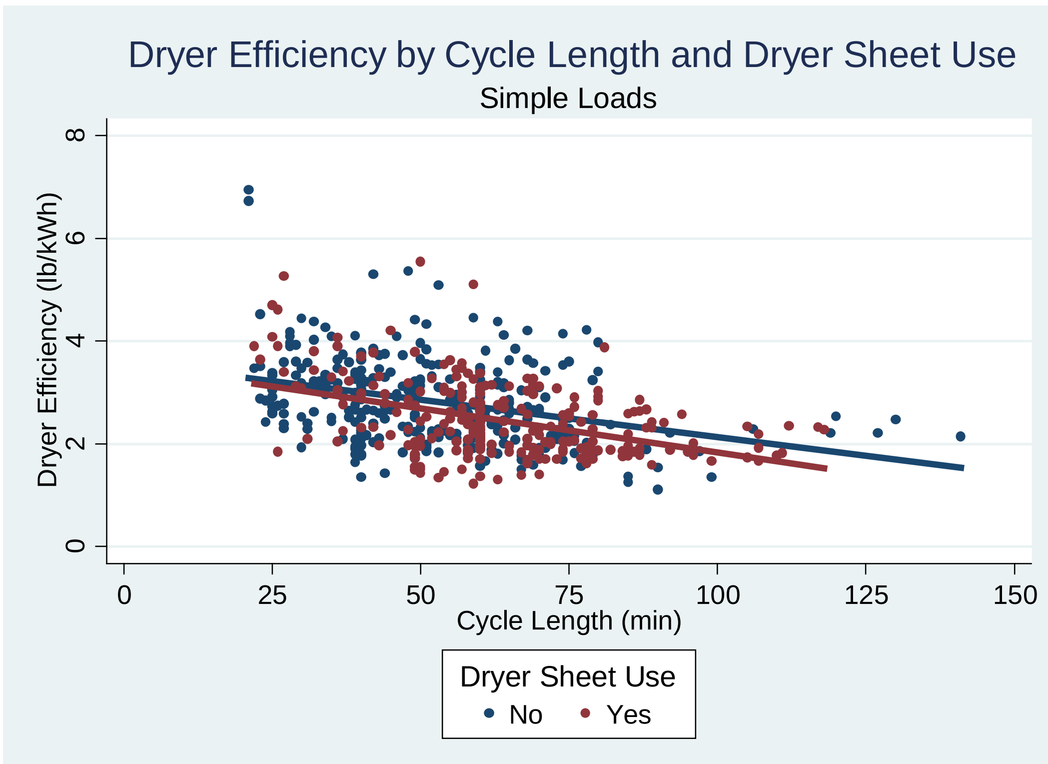


Table 65. Dryer Efficiency (lb/kWh) per Load by Dryer Temperature Setting

Temperature Setting	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Low	4.59	0.51	134	2.76	0.19	50
Medium	2.78	0.11	533	2.61	0.07	282
High	2.86	0.22	473	2.70	0.10	205

Figure 50. Dryer Efficiency (lb/kWh) by Cycle Length and Dryer Temperature Setting

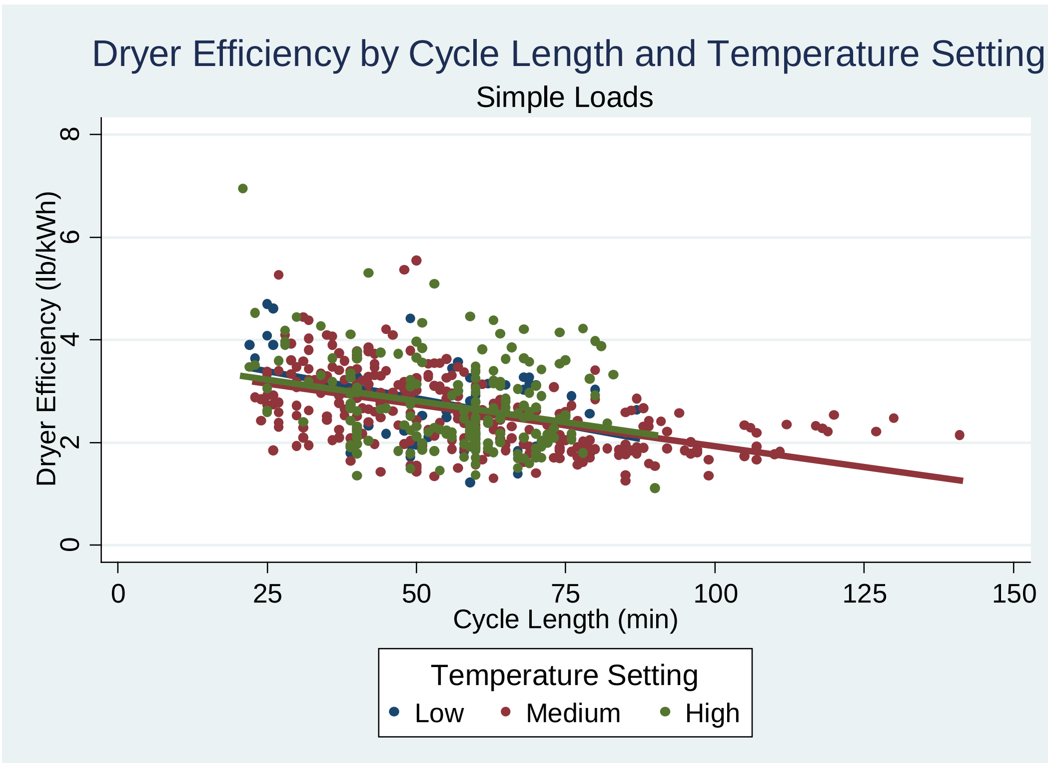


Table 66. Dryer Efficiency (lb/kWh) per Load by Dryer Dryness Setting

Dryness Setting	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Less Dry	4.72	1.92	9	2.07	0.00	1
Normal	3.01	0.19	513	2.77	0.08	254
More Dry	2.58	0.09	270	2.47	0.09	158

Figure 51. Dryer Efficiency (lb/kWh) by Cycle Length and Dryer Dryness Setting

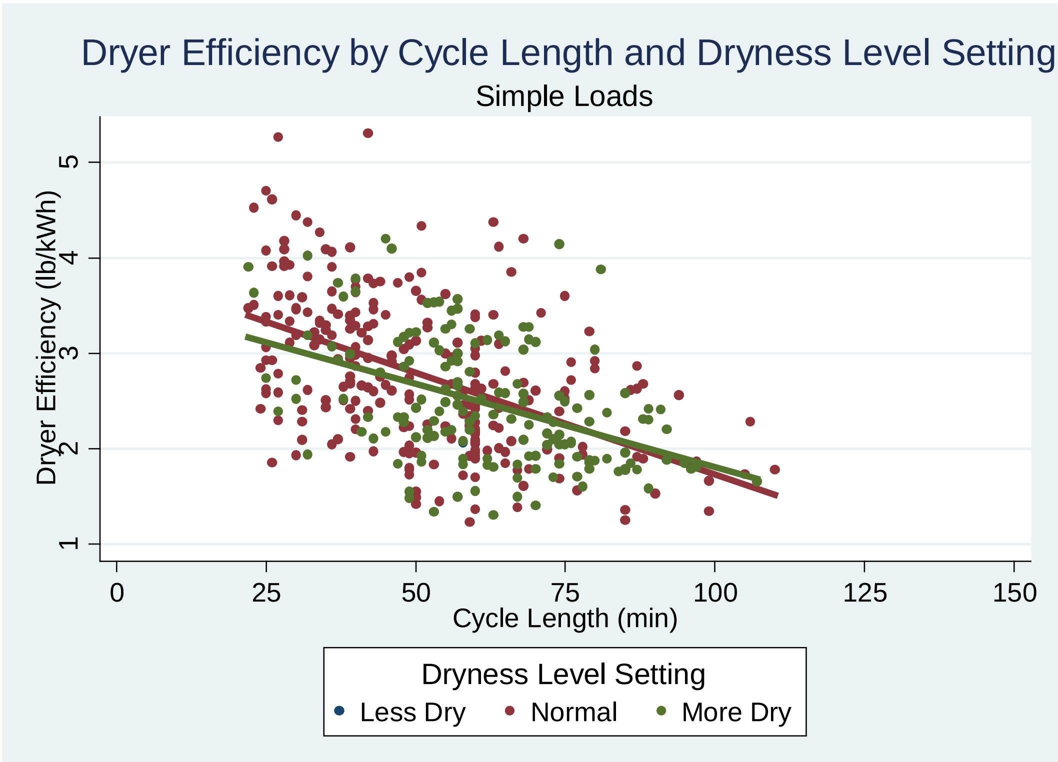


Table 67. Dryer Efficiency (lb/kWh) per Load by Bone-Dry Weight of Load

Dry Weight	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
0–2 lbs	1.55	0.27	92	—	—	0
3–5 lbs	2.63	0.25	323	2.29	0.09	167
6–8 lbs	2.85	0.12	357	2.63	0.08	199
9–11 lbs	3.58	0.30	267	2.97	0.13	144
12–14 lbs	4.70	0.68	113	3.13	0.16	45
15+ lbs	3.96	0.25	31	—	—	0

Figure 52. Dryer Efficiency (lb/kWh) by Cycle Length and Bone-Dry Weight

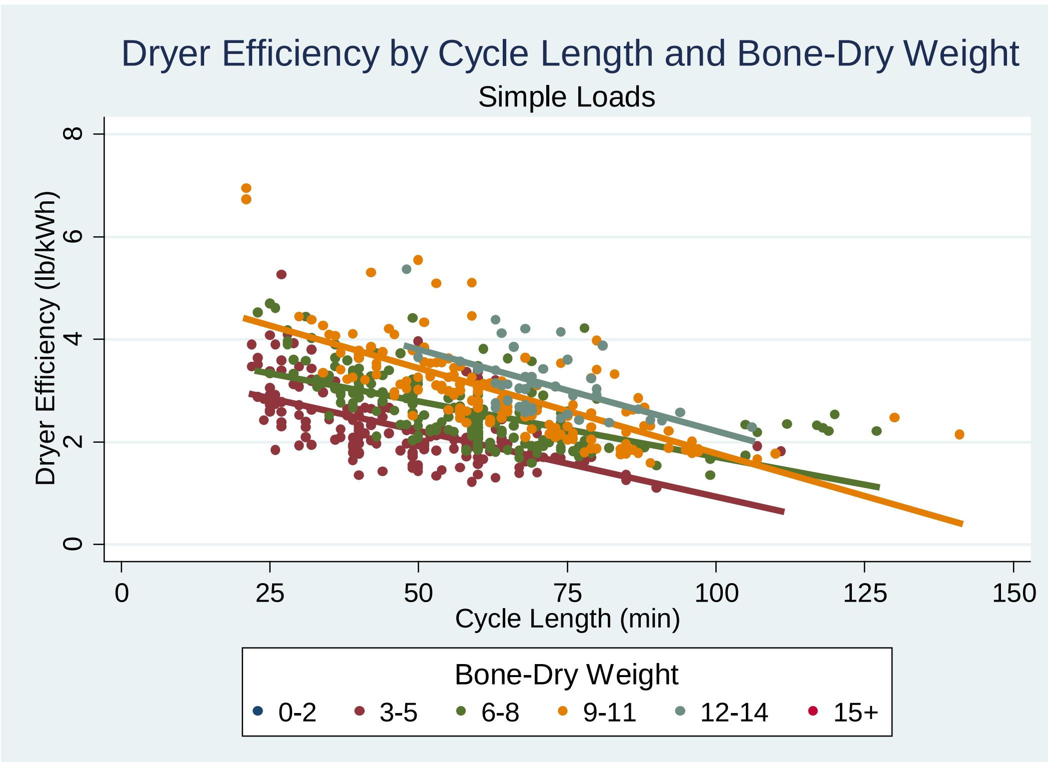


Table 68. Dryer Efficiency (lb/kWh) per Load by Initial RMC

RMC	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
0%–32%	7.11	0.82	99	—	—	0
33%–65%	3.02	0.10	571	2.94	0.07	343
66%–99%	2.30	0.09	353	2.20	0.08	212
100%+	1.95	0.40	150	—	—	0

Figure 53. Dryer Efficiency (lb/kWh) by Cycle Length and Initial RMC for All Loads

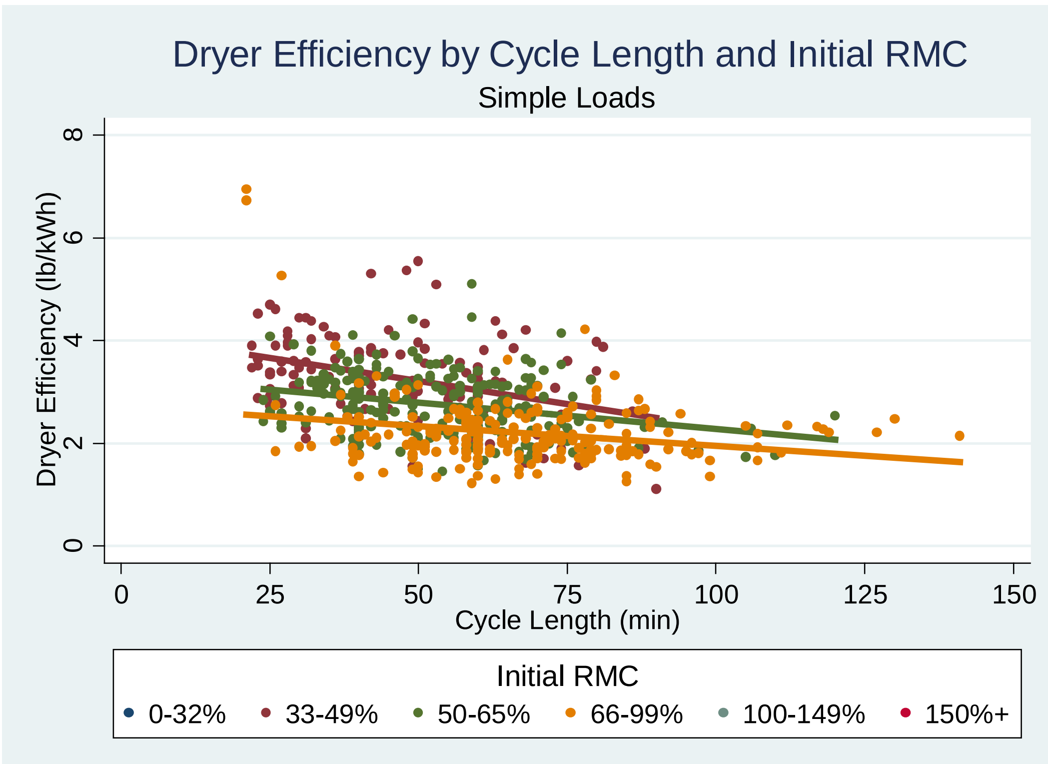


Table 69. Dryer Efficiency (lb/kWh) per Load by Dryer Cycle Length

Cycle Length (min)	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
0-14	13.87	3.88	17	—	—	0
15-29	3.77	0.40	101	3.56	0.28	39
30-44	3.90	0.36	262	2.96	0.11	124
45-59	2.56	0.12	275	2.67	0.12	139
60-74	2.46	0.09	311	2.45	0.08	160
75-89	2.48	0.11	138	2.31	0.13	64
90+	2.15	0.13	79	2.01	0.11	29

Figure 54. Dryer Efficiency (lb/kWh) by Cycle Length and Cycle Length

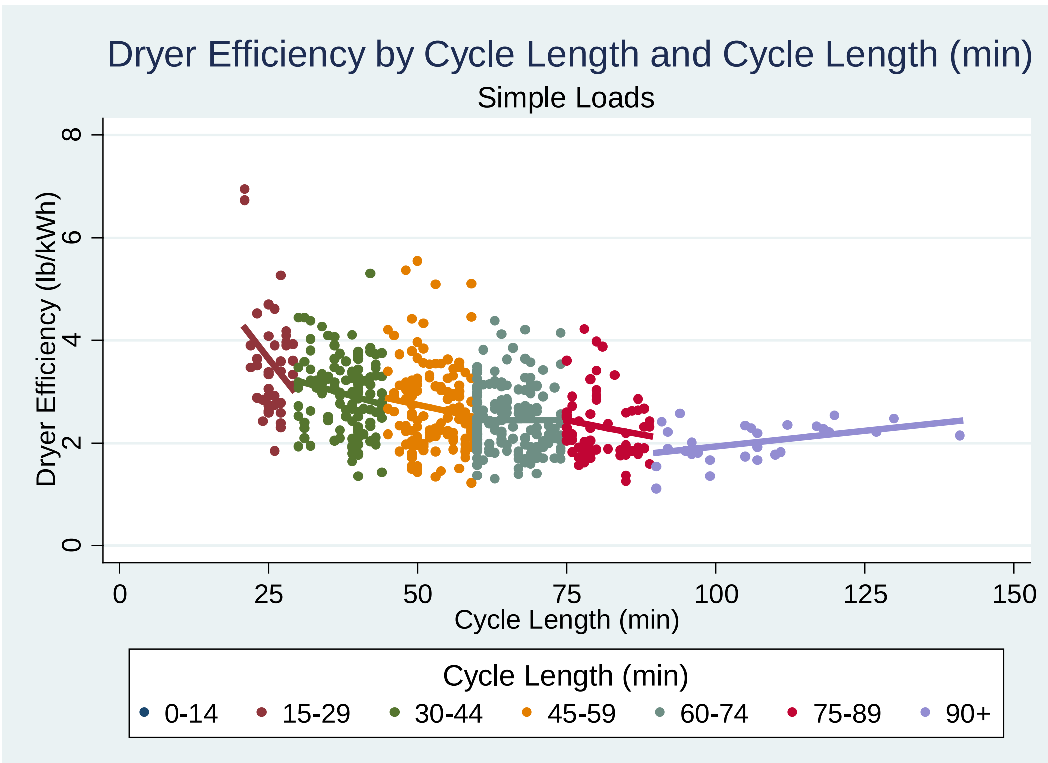


Table 70. Dryer Efficiency (lb/kWh) per Load by CFM Bin

CFM Bin	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
<50	3.24	0.74	83	2.59	0.15	36
50–74	2.72	0.17	245	2.57	0.11	130
75–99	3.38	0.46	208	2.63	0.19	69
100–124	2.65	0.16	197	2.73	0.12	114
125+	4.14	0.43	188	2.44	0.12	92

Figure 55. Dryer Efficiency (lb/kWh) by Cycle Length and CFM Bin

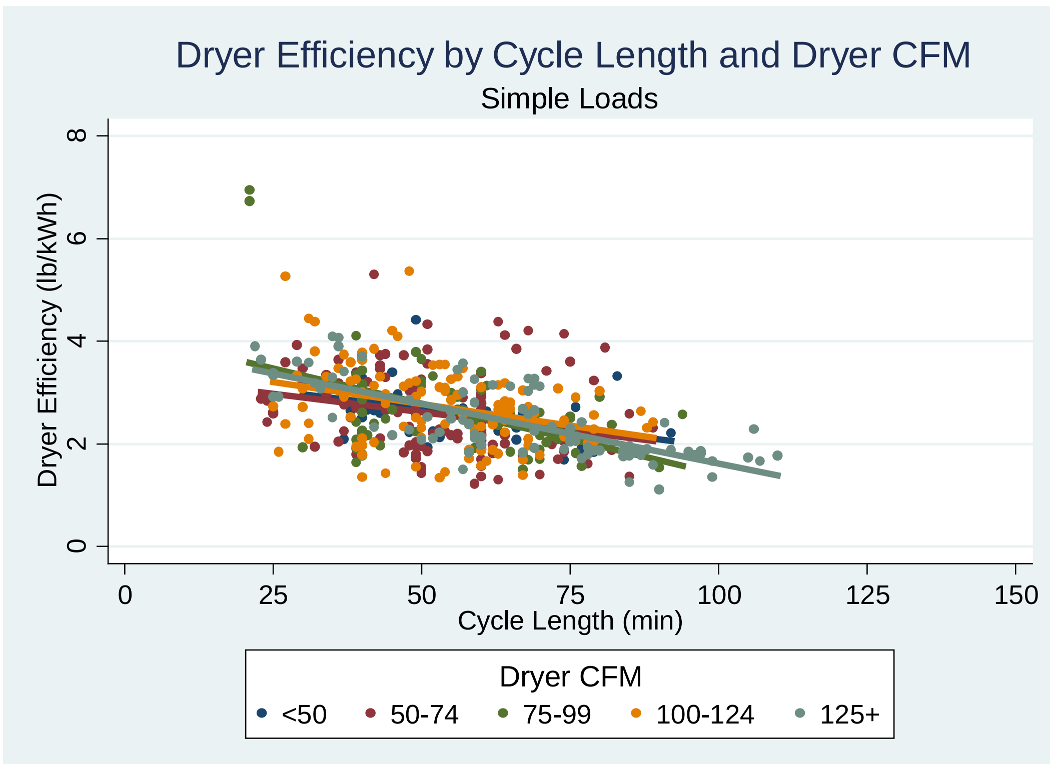
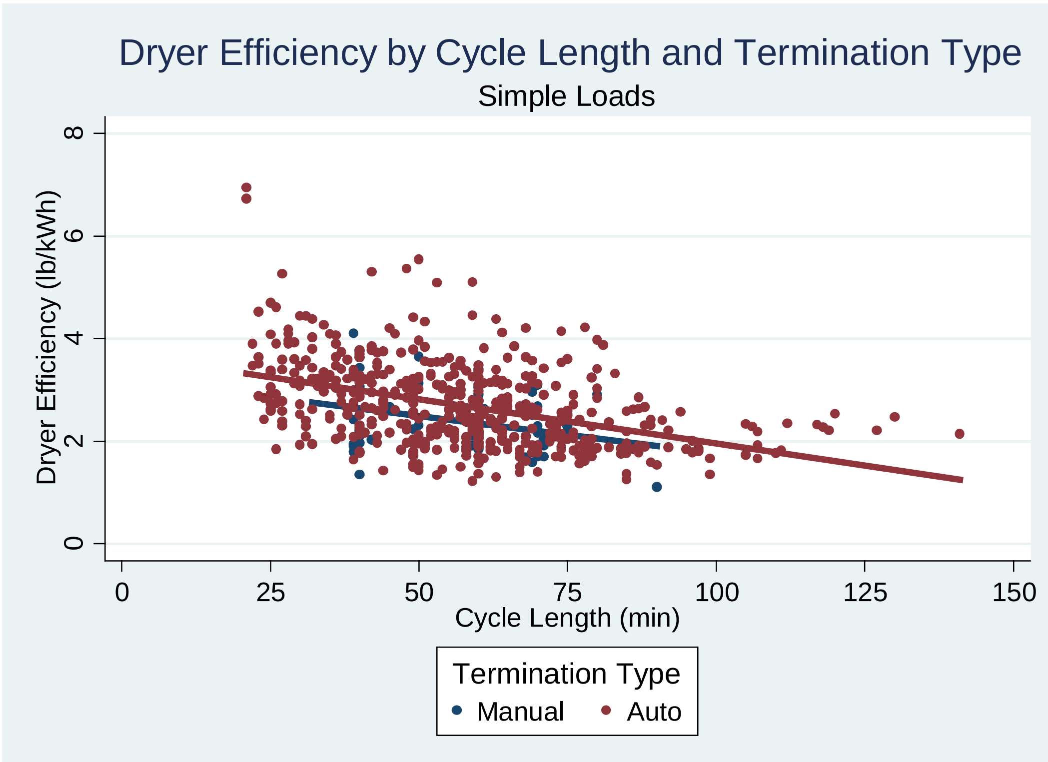


Table 71. Dryer Efficiency (lb/kWh) per Load by Auto-Termination

Auto-Termination	All Loads			Simple Loads		
	Mean	EB	n (L)	Mean	EB	n (L)
Manual	4.23	0.50	233	2.41	0.13	62
Auto	2.77	0.10	950	2.69	0.06	493

Figure 56. Dryer Efficiency (lb/kWh) by Cycle Length and Auto-Termination



The following graphs are examples of dryer loads from a single machine. These graphs are demonstration graphs for informational purposes and are not aggregate summaries of all machines. Each machine may have a slightly different profile for these input settings. The graphs show a light load (Figure 57), normal load (Figure 58), heavy load (Figure 59), and multi-run load (Figure 60). As mentioned in Table 5, multi-run dryer runs account for about 7.9% of dryer loads, so it is not uncommon to have these types of loads. For comparisons across sites, Appendix 11 contains a single normal load for each site.

Figure 57. Dryer Single Cycle Energy Profile – Light Load

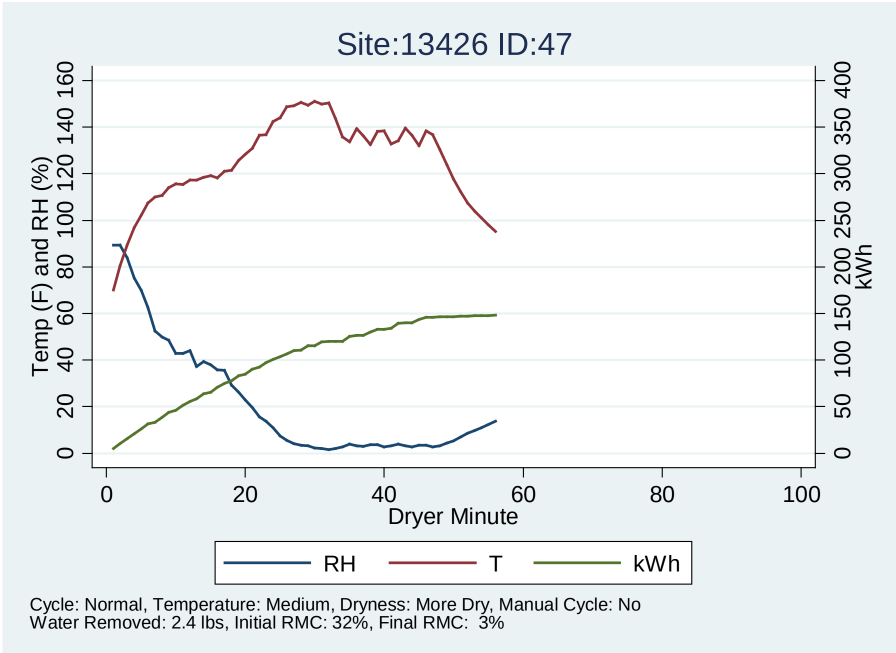


Figure 58. Dryer Single Cycle Energy Profile – Normal Cycle

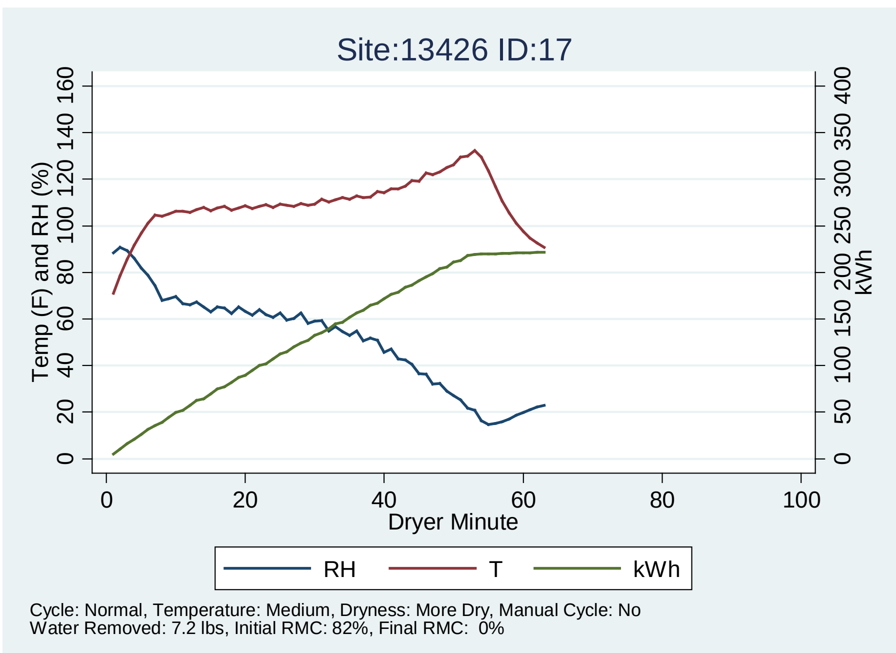


Figure 59. Dryer Single Cycle Energy Profile – Heavy Duty Cycle

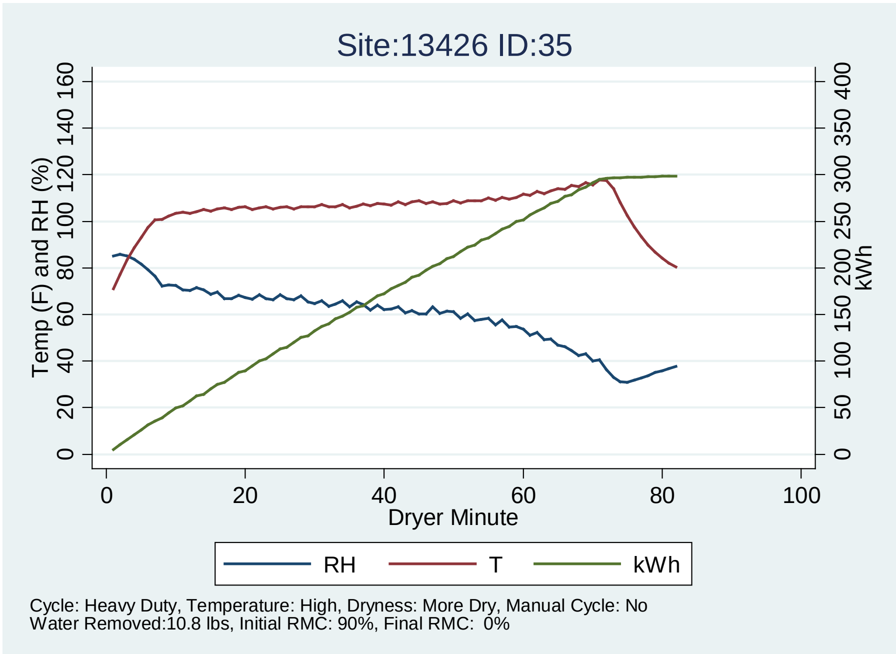


Figure 60. Dryer Single Cycle Energy Profile – Multi-Run Cycle

A6.3. Standby Energy

The energy during an active cycle dominates energy use of both washers and dryers, but when the machines do not have an active cycle they can still draw power. This is particularly true for newer machines with electronic controls. The average standby across all machines is in Table 72.

Table 72. Washer and Dryer Average Standby Energy Use

Machine Type	Standby Energy (W)		
	Mean	EB	n (S)
Washer	0.87	0.28	46
Dryer	0.18	0.08	46

The yearly energy use for standby use for washers and dryers is in Table 73.

Table 73. Washer and Dryer Average Yearly Standby Energy Use

Machine Type	Standby Energy (kWh)		
	Mean	EB	n (S)
Washer	7.41	2.39	46
Dryer	1.50	0.69	46

The washing machine axis type (vertical or horizontal) is a proxy for the older vs newer style of machine, respectively. Using this categorization, we can see in Table 74 the presumed newer machines (horizontal axis) have substantially higher standby losses.

Table 74. Washer Average Standby Energy Use by Equipment Style

Axis	Washer Standby (W)		
	Mean	EB	n (S)
Horizontal	1.05	0.34	33
Vertical	0.42	0.44	13

Another proxy for equipment style is the MEF of the washing machine. The increase in standby energy appears to be more distinct when looking at the higher efficiency machines, although the error bounds overlap for these categories so we cannot be certain of the effect with dividing the sample into these smaller groups.

Table 75. Washer Average Standby Energy Use by Rated MEF

Axis	Washer Standby (W)		
	Mean	EB	n (S)
<2.0	0.90	0.72	9
2.0–2.3	0.93	0.29	13
2.4+	1.17	0.69	15

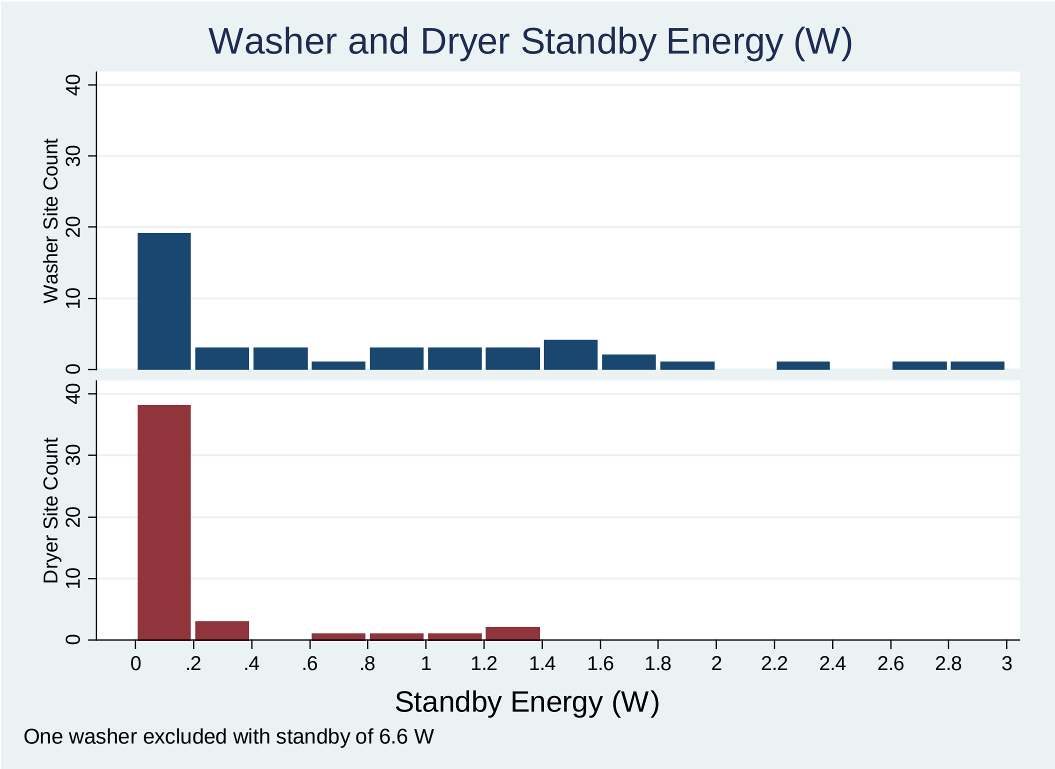
For dryers, the first proxy to use is the presence of auto-termination, shown below in Table 76. Not all occupants use the auto-termination if it is present, but the presence of auto-termination can be an indicator of a more complex machine that will likely have electronic controls with standby use. The table shows the manual-only machines have almost no standby use at all, and while the auto-termination dryers do have standby use, they have much less standby use than the washing machines.

Table 76. Dryer Average Standby Energy Use by Dryer Auto-Termination

Axis	Dryer Standby (W)		
	Mean	EB	n (S)
Manual Only	0.01	0.01	5
Has Auto	0.20	0.09	41

The full range of standby use for washing machines is 0.0 W up to 6.6 W, and for dryers the range is 0.0 W up to 1.3 W. Figure 61 shows the distribution of standby energy.

Figure 61. Distribution of Washer and Dryer Standby Energy



Appendix 7. Initial and Final RMC by Load Characteristics

A7.1. Initial RMC by Characteristics

The following plots are similar to those in Appendix 6 above, with efficiency presented by a number of color-coded characteristics. The section above includes efficiency and characteristics by cycle length, but the following graphs are by initial RMC rather than cycle length. The dryer efficiency metric is bone-dry weight over energy use (lb/kWh) and the moisture content is water weight over bone-dry weight. The general trend in efficiency by initial RMC is a slight decrease in efficiency for higher initial RMC. Some of the graphs show a slight stratification by bin, like cycle length where longer cycles appear less efficient. The one graph that stands out is the auto-termination where manual cycles have the same efficiency across the range of initial RMC, but auto-termination loads show better efficiency for low initial RMC and less efficiency for high initial RMC. More detail is in section 3.5.2.

Figure 62. Dryer Efficiency by Initial RMC and Fabric Category

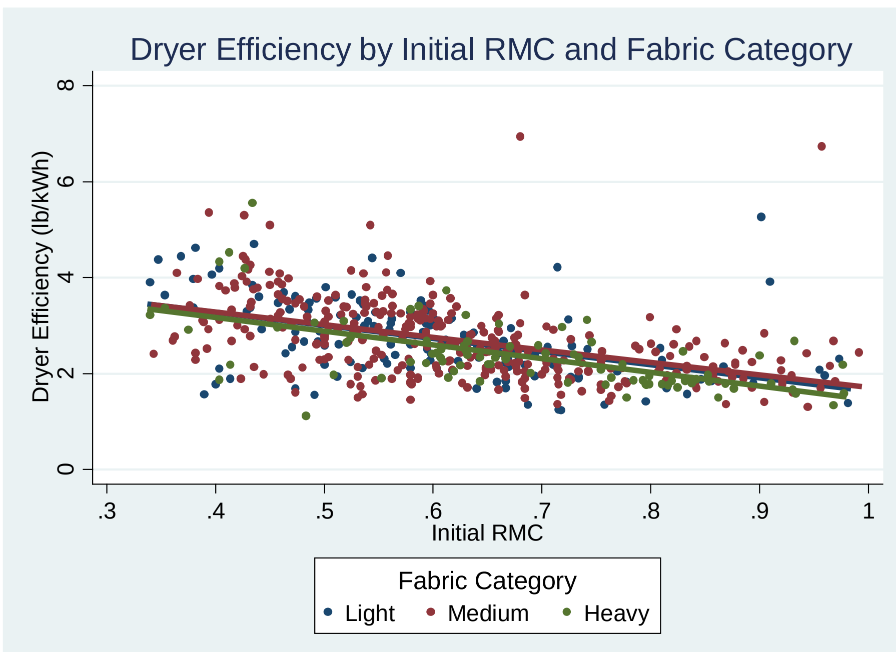


Figure 63. Dryer Efficiency by Initial RMC over Wash Temperature

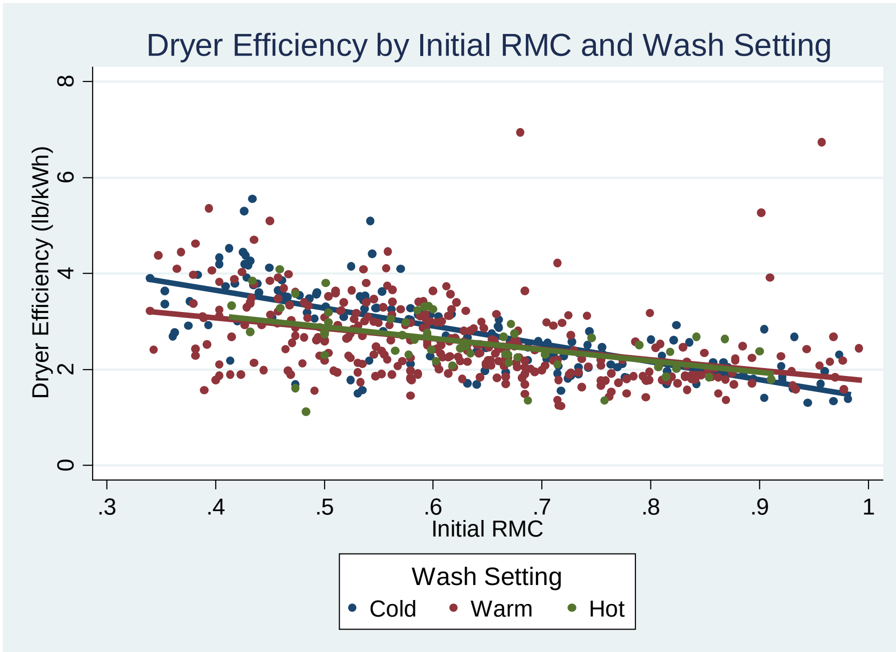


Figure 64. Dryer Efficiency by Initial RMC and Washer Rinse Temperature

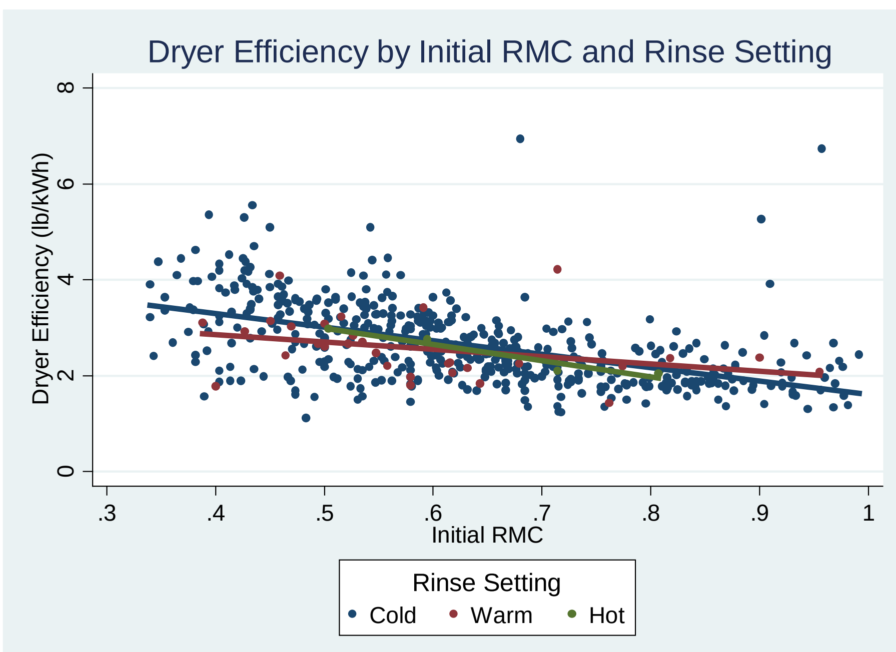


Figure 65. Dryer Efficiency by Initial RMC and Washer Spin Speed

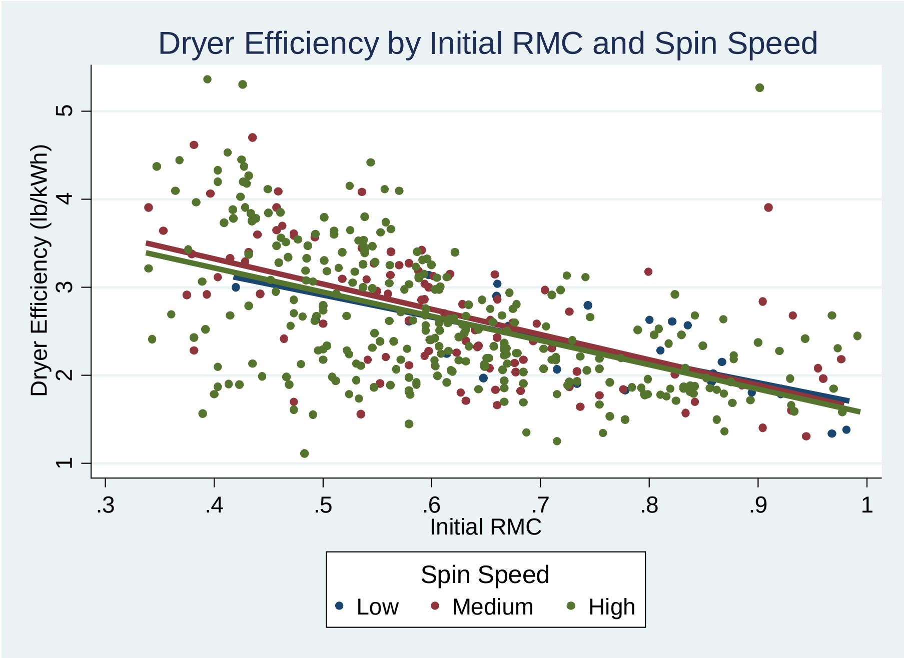


Figure 66. Dryer Efficiency by Initial RMC and Color

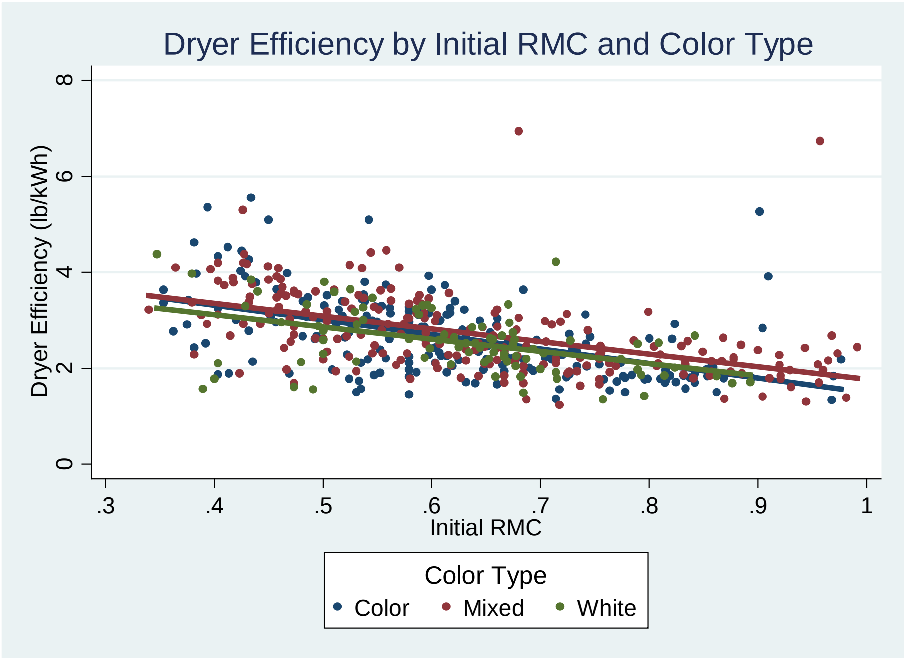


Figure 67. Dryer Efficiency by Initial RMC and Cycle Length

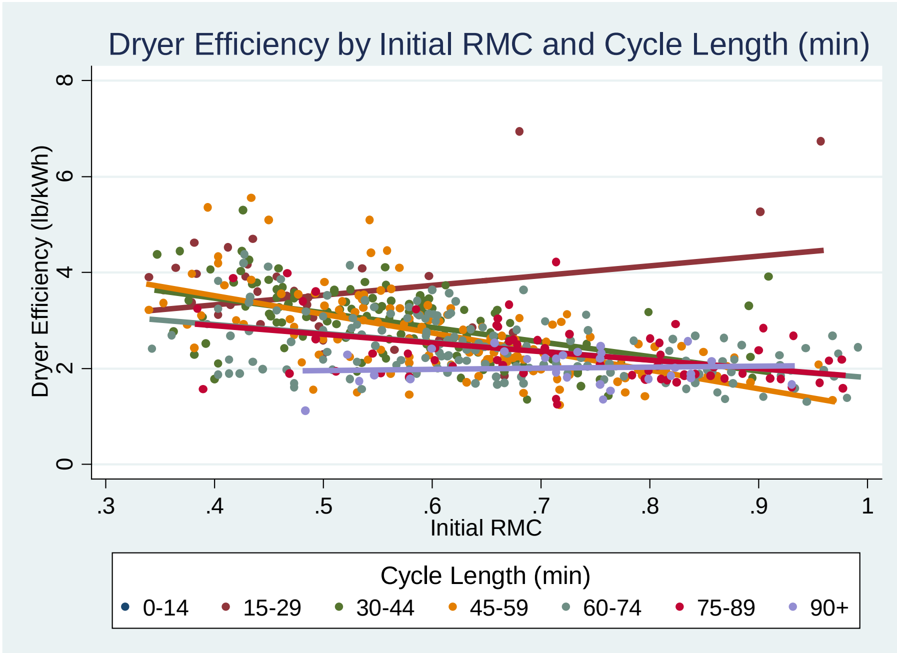


Figure 68. Dryer Efficiency by Initial RMC and Dryer Temperature Setting

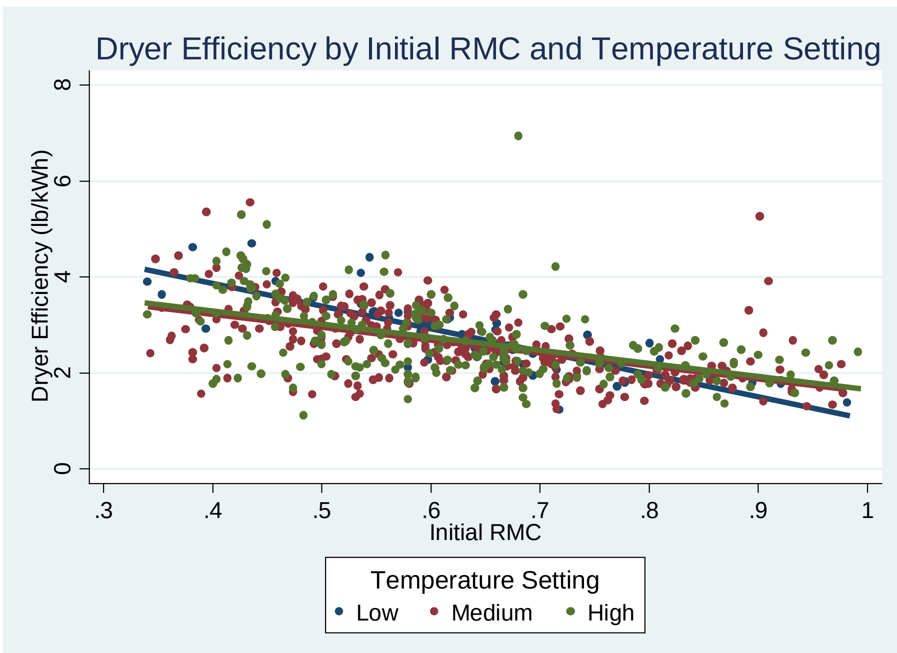


Figure 69. Dryer Efficiency by Initial RMC and Dryness Setting

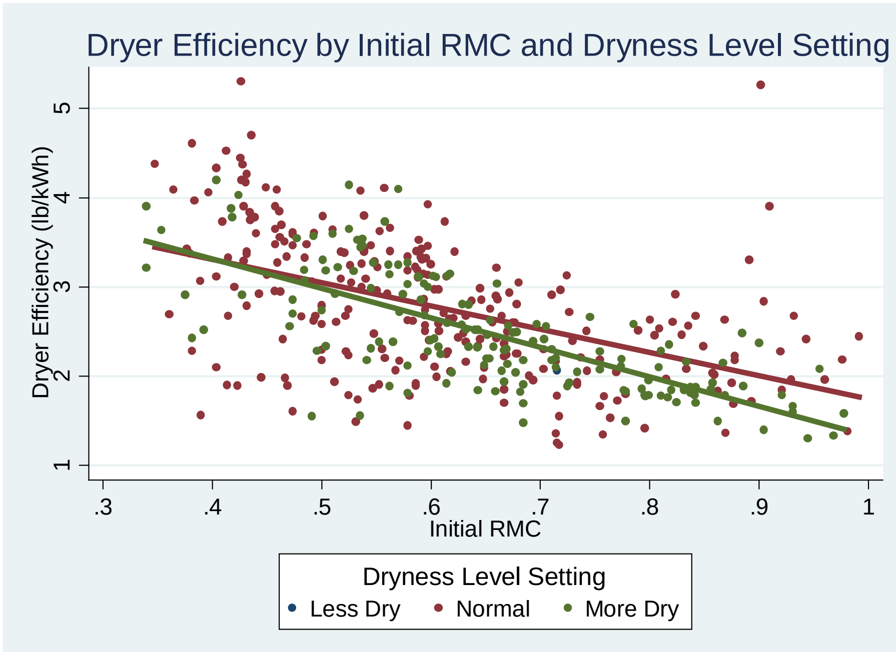


Figure 70. Dryer Efficiency by Initial RMC and Bone-Dry Weight

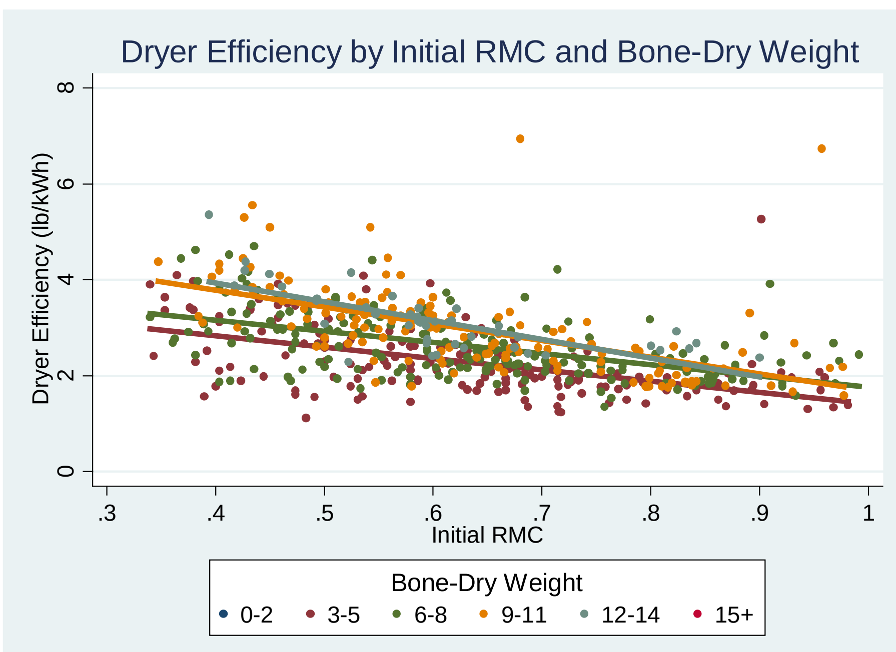


Figure 71. Dryer Efficiency by Initial RMC and Dryer CFM

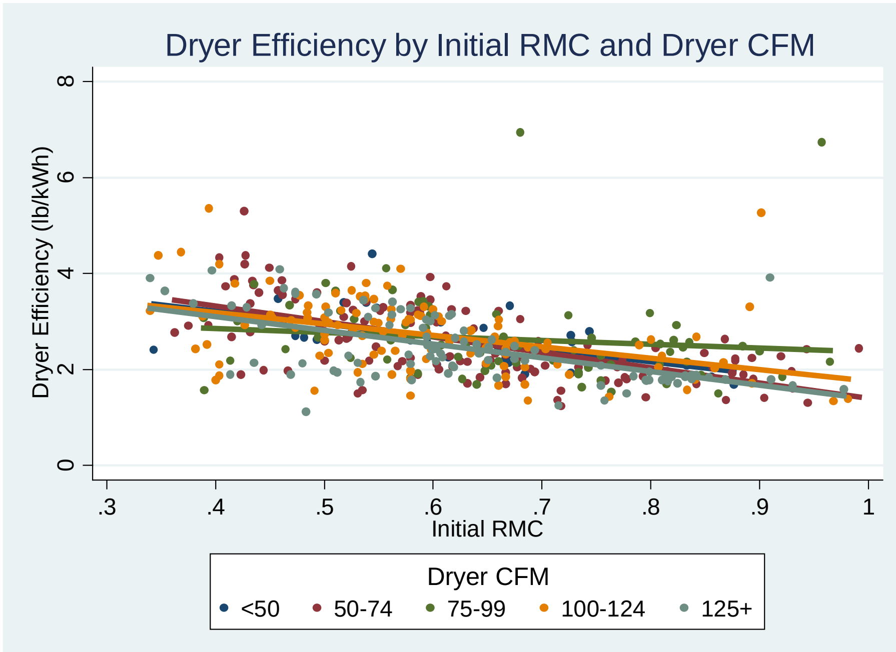
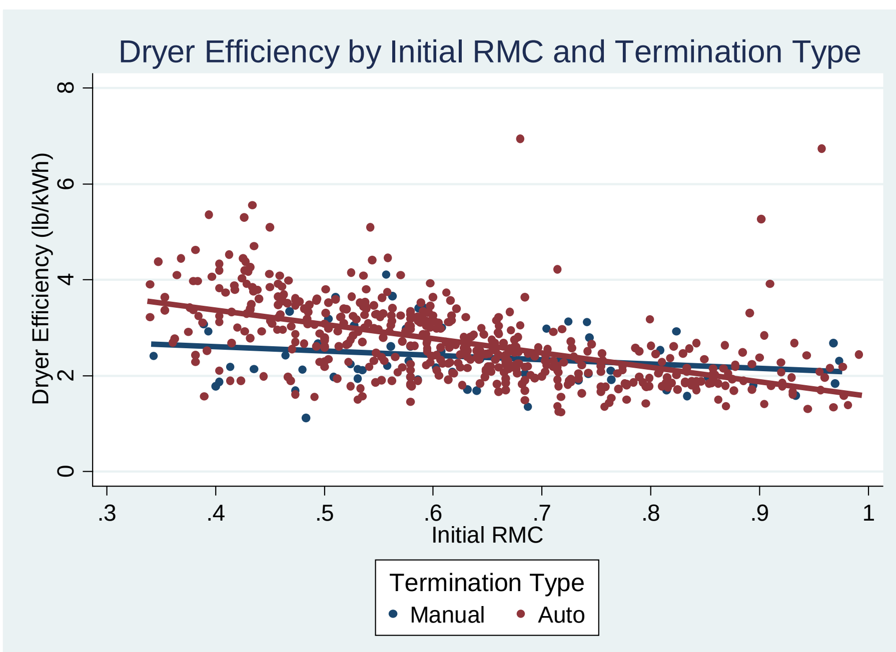


Figure 72. Dryer Efficiency by Initial RMC and Termination Type



A7.2. Final RMC by Characteristics

Similar to the previous section, the following graphs show dryer efficiency by characteristics. The graphs are by final RMC. There are two artificial final RMC lines in the data, one at 0% and the other at 5%. This is due to the estimation of bone-dry weight from the pre-washer load weight and post-dryer load weight discussed earlier. The linear fits do not include these artificial points.

Again, there are some graphs showing some stratification in the regression results, but the most interesting graph is the auto-termination graph showing what appears to be no difference at all between the manual and auto cycles. Between the errors in estimating bone-dry weight and the loss of data points at 0% and 5% this result may not be significant, but it does appear the termination type does not affect the final moisture content based on the limited data.

Figure 73. Dryer Efficiency over Final RMC by Fabric Category

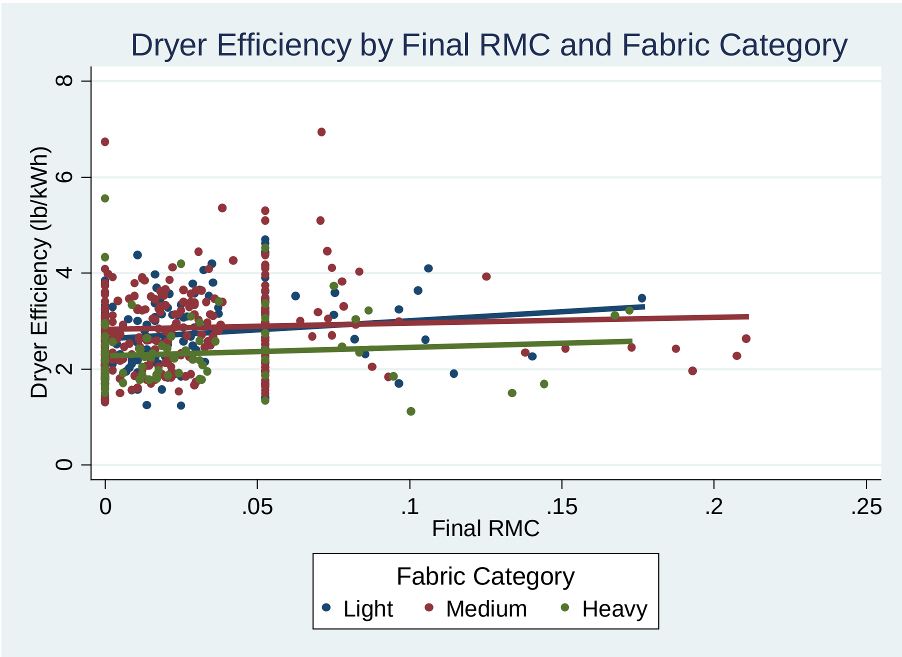


Figure 74. Dryer Efficiency over Final RMC by Wash Temperature

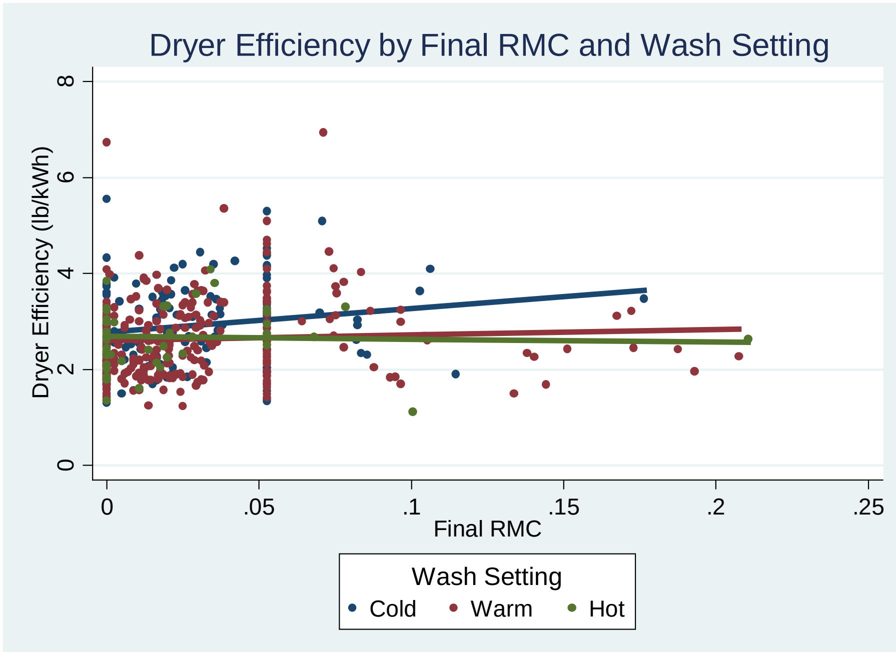


Figure 75. Dryer Efficiency over Final RMC by Rinse Temperature

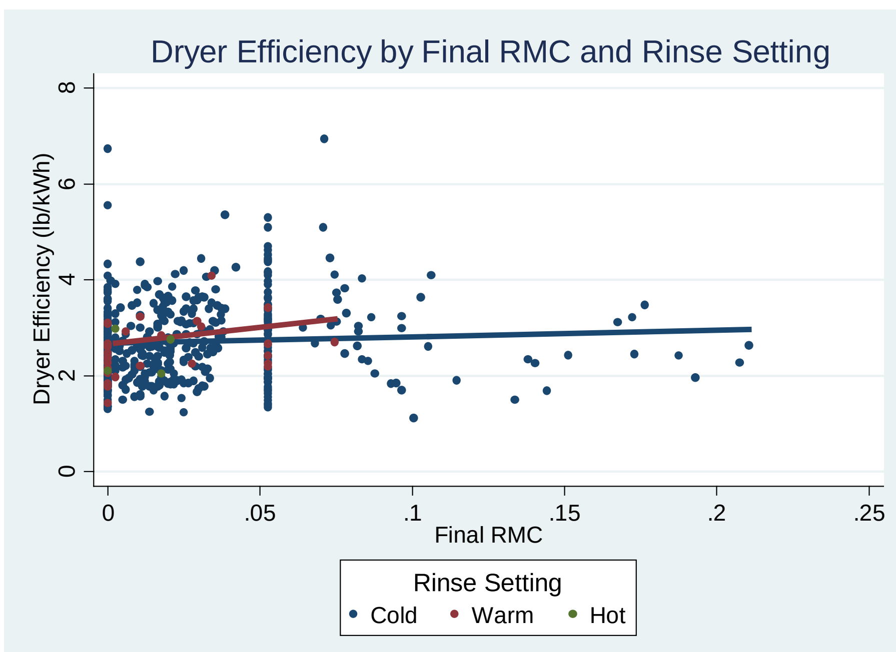


Figure 76. Dryer Efficiency over Final RMC by Washer Spin Speed

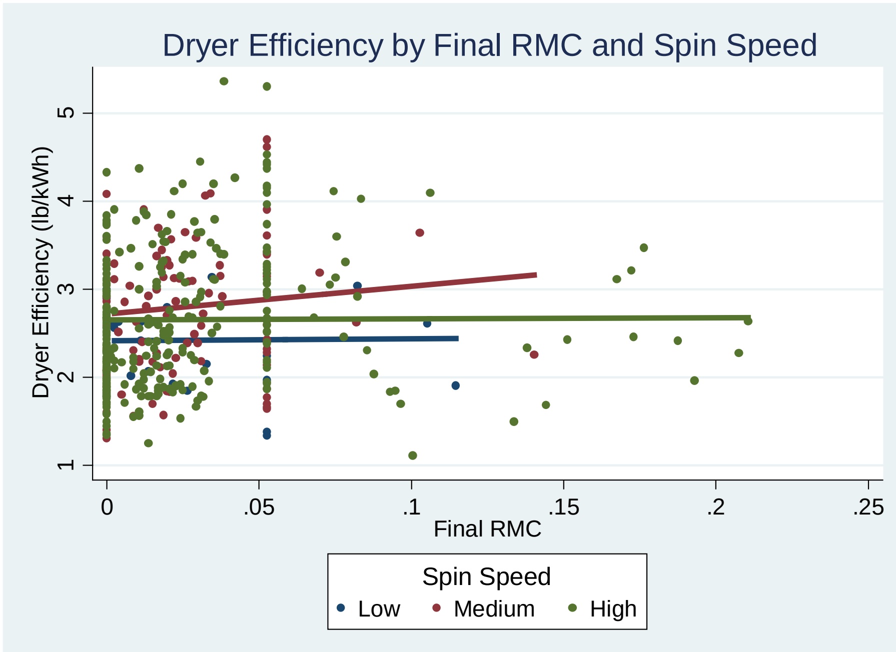


Figure 77. Dryer Efficiency over Final RMC by Color

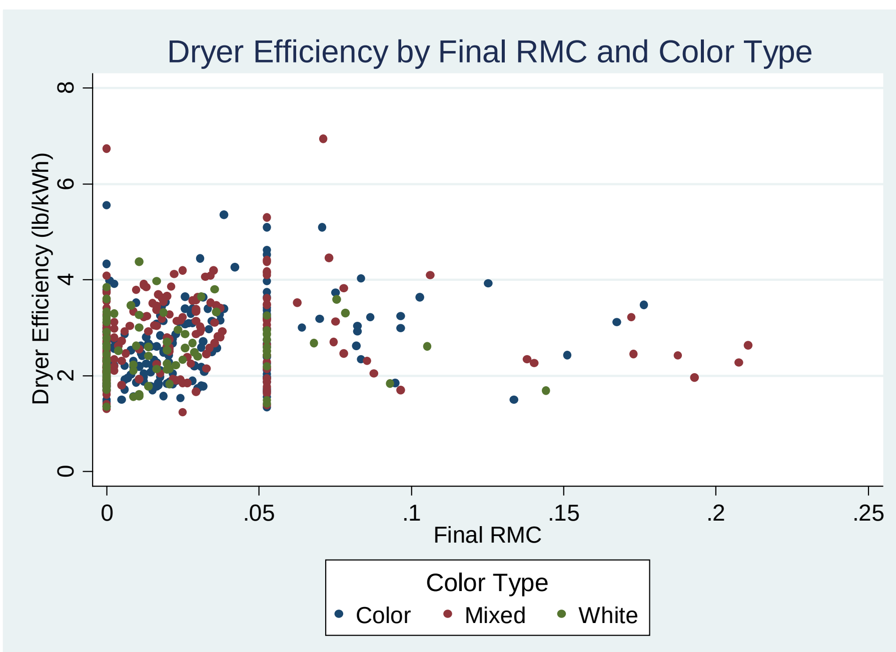


Figure 78. Dryer Efficiency over Final RMC by Cycle Length

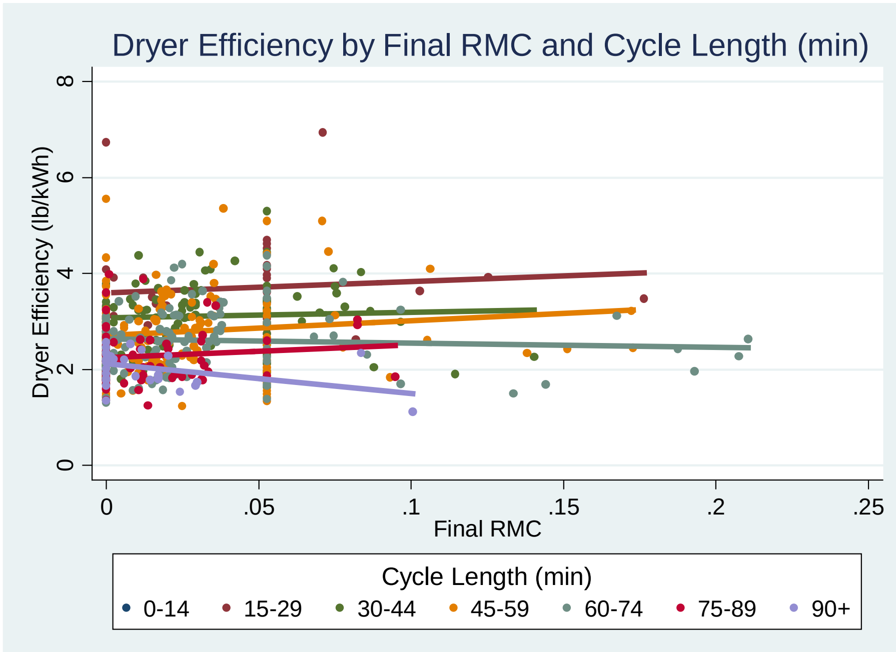


Figure 79. Dryer Efficiency over Final RMC by Dryer Temperature

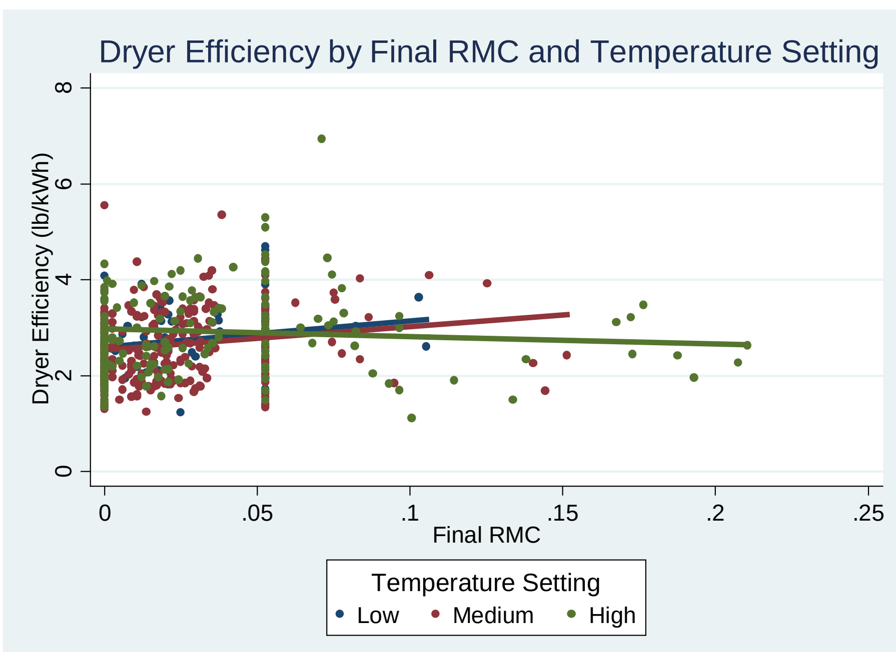


Figure 80. Dryer Efficiency over Final RMC by Dryness Setting

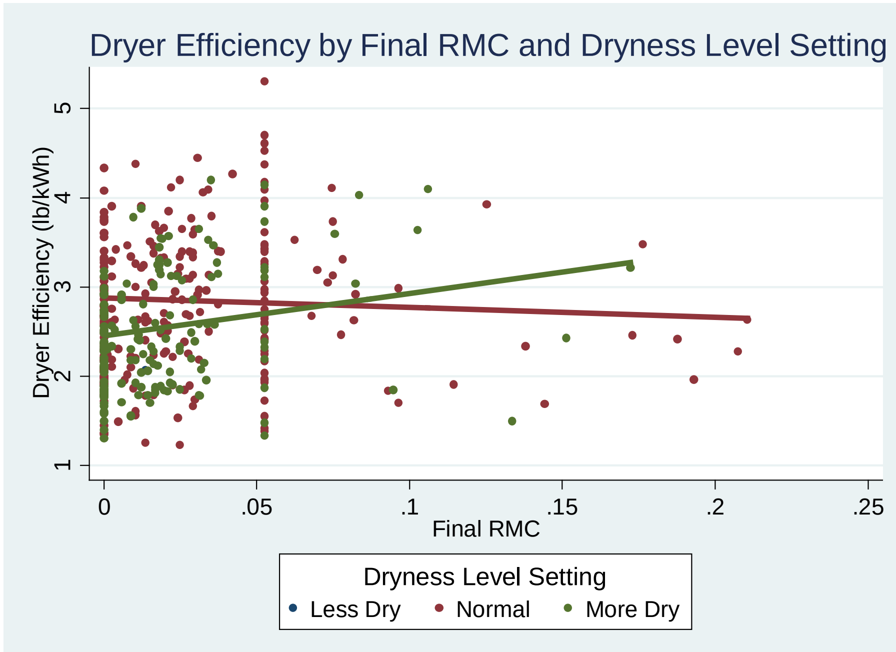


Figure 81. Dryer Efficiency over Final RMC by Bone-Dry Weight

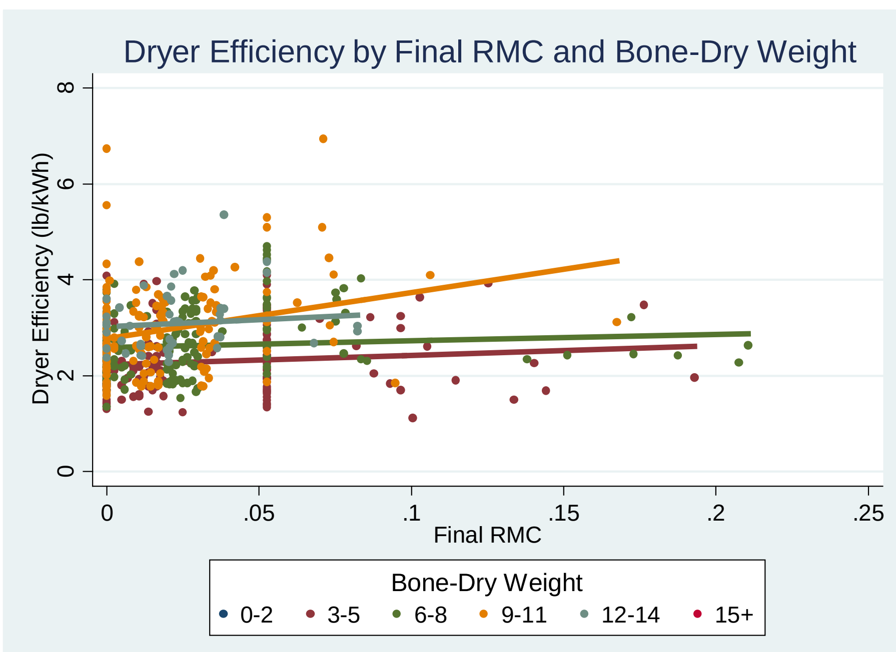


Figure 82. Dryer Efficiency over Final RMC by Initial RMC

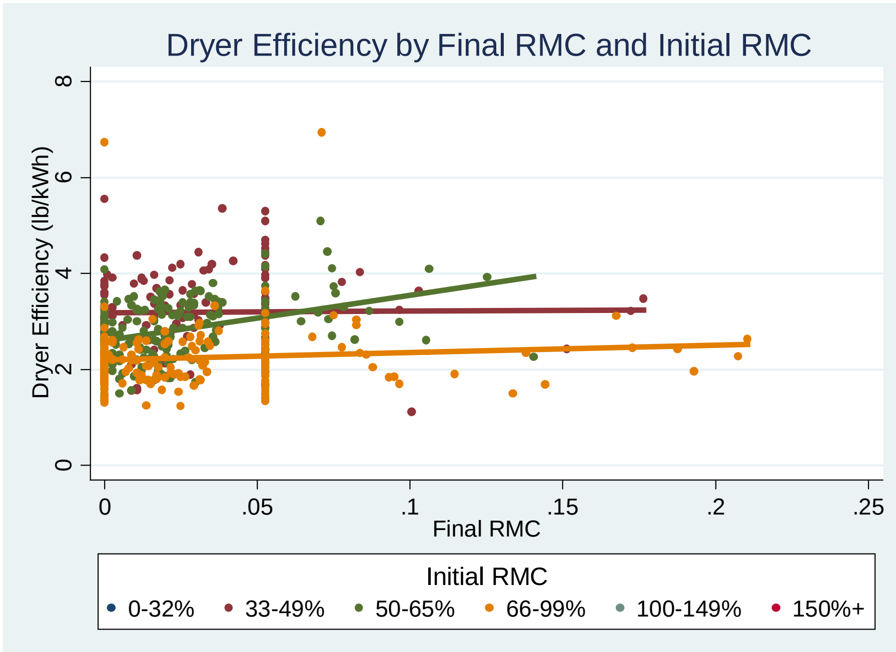


Figure 83. Dryer Efficiency over Final RMC by Dryer CFM

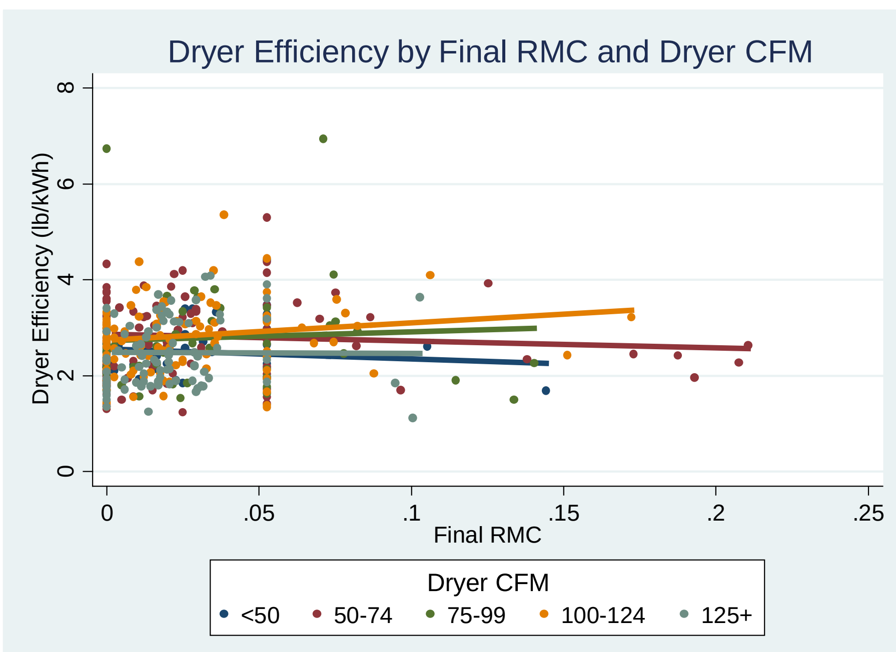
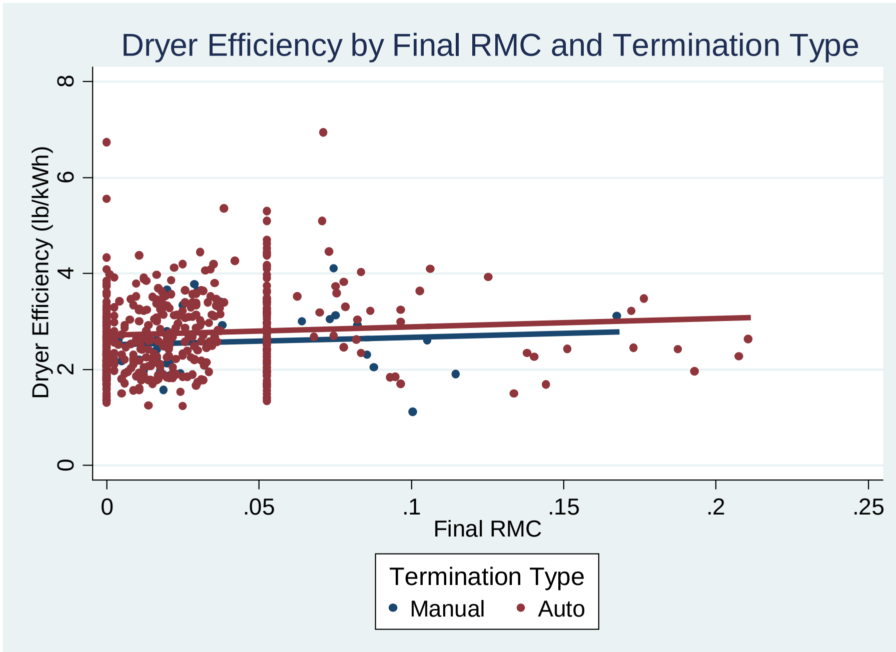


Figure 84. Dryer Efficiency over Final RMC by Termination Type



Appendix 8. Other Site Characteristics

The following are other site characteristics that were not part of the site screening criteria, including equipment location in the home and more detailed family characteristics. Washers and dryers from 11 manufacturers are in the sample. The most popular brand was present in 12 of the 50 sites. Horizontal axis washers accounted for 70% of the sites and 86% of the dryers had some sort of auto-termination. Figure 85 below shows the vast majority of laundry equipment for the study is located inside the home.

Figure 85. Location of Laundry Equipment in the House

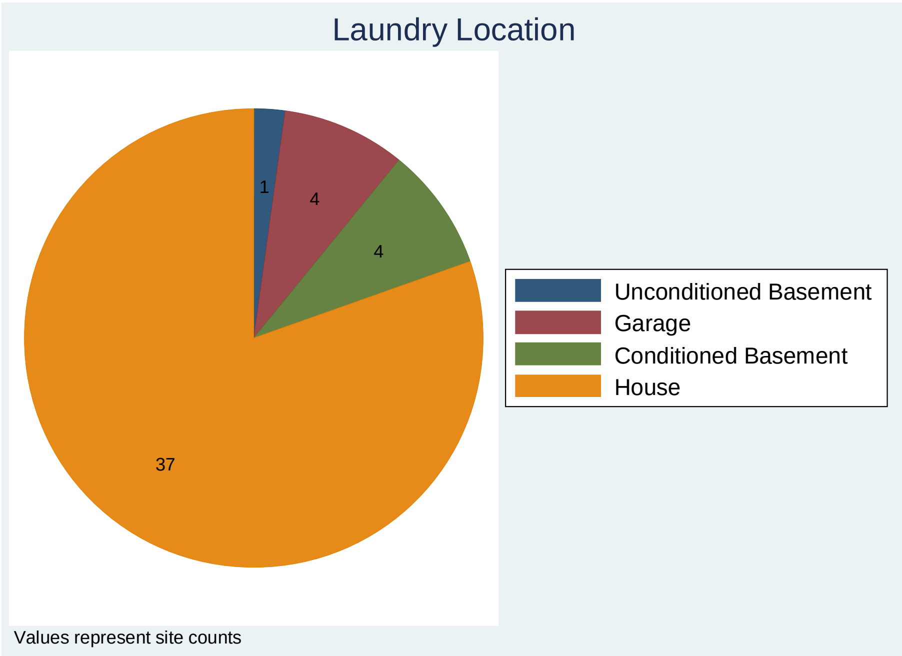
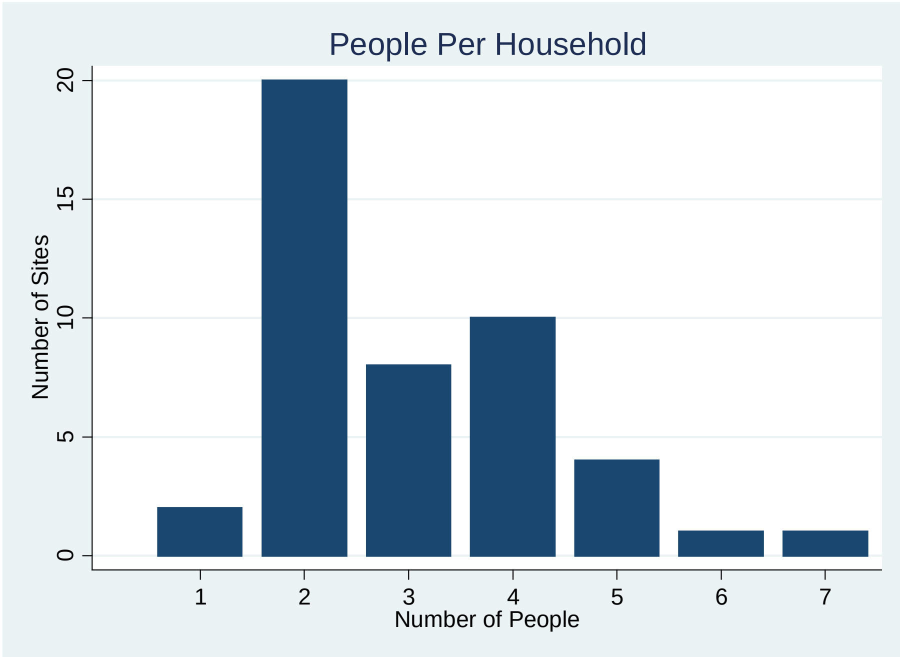


Figure 86 shows the distribution of people per household. Almost half of the sites had only one or two people, as shown in the site selection above in Table 2.

Figure 86. Distribution of Number of People per Household



Half of the sites had children under the age of 18, and a quarter of the sites had children age five or younger. The average household had about three occupants[7].

Table 77. Occupant Summary

Category	Occupant Summary		
	Mean	EB	n (S)
Number of Occupants	3.02	0.32	46
Has Children Age 18 or Younger	50.0%	12.3%	23
Has Children Age 5 or Younger	21.7%	10.1%	10

[7] The occupancy in the RBSA single family survey was 2.7 occupants per household (Baylon, Storm, Geraghty, & Davis, 2012), and 2.5 in the manufactured home survey (Storm, Hannas, Baylon, & Davis, 2013).

Appendix 9. Variable Correlation Screening

The generation of the following graphs was a side task of trying to see if there were any other interesting correlations in the data. These graphs use only the simple loads. The vertical axes represent the numeric output variables of most interest – energy use (kWh), load efficiency (lb/kWh), and water added/removed to the load (lb). The analysis is for both washers and dryers across a wide variety of categorical variables. Each chart is a review of three categorical variables across the three numeric variables listed above, and there are three washer charts and four dryer charts. The red bars are the 90/10 confidence intervals. The labels for categorical variables in the left, middle, and right columns are at the bottom of each graph, and labels for numeric variable labels for the three rows are on the far left of the graph.

Figure 87. Washer Screening – Load Characteristics

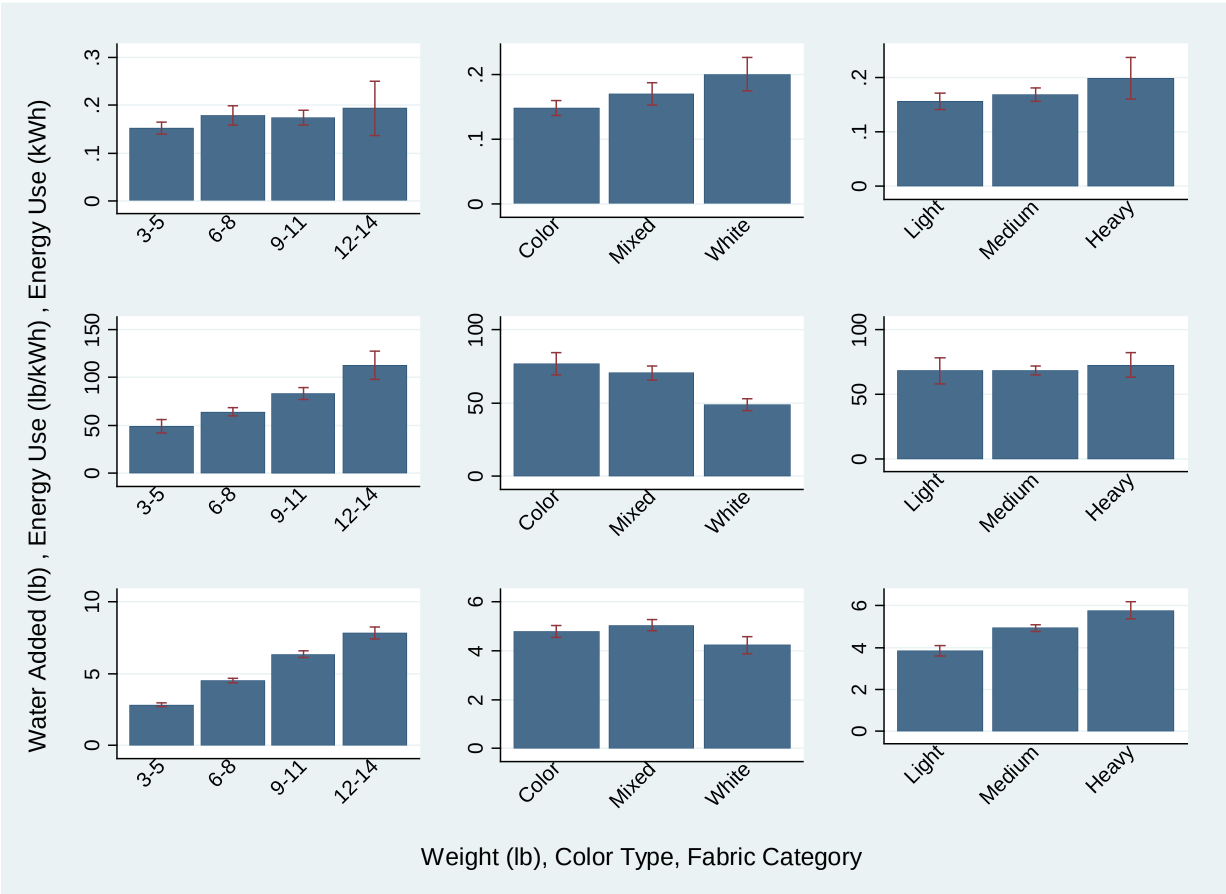


Figure 88. Washer Screening – Equipment Settings

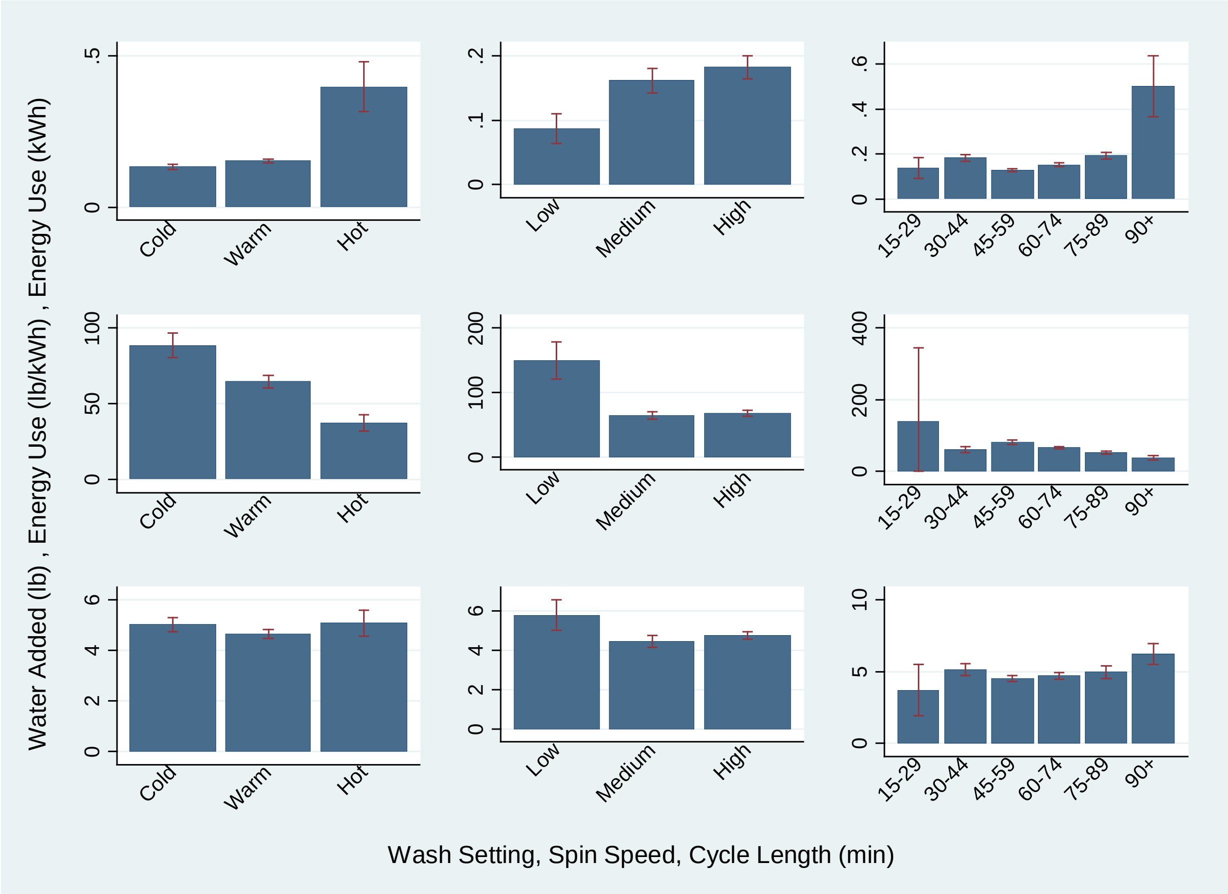


Figure 89. Washer Screening – Equipment Properties

Figure 90. Dryer Screening – Load Characteristics

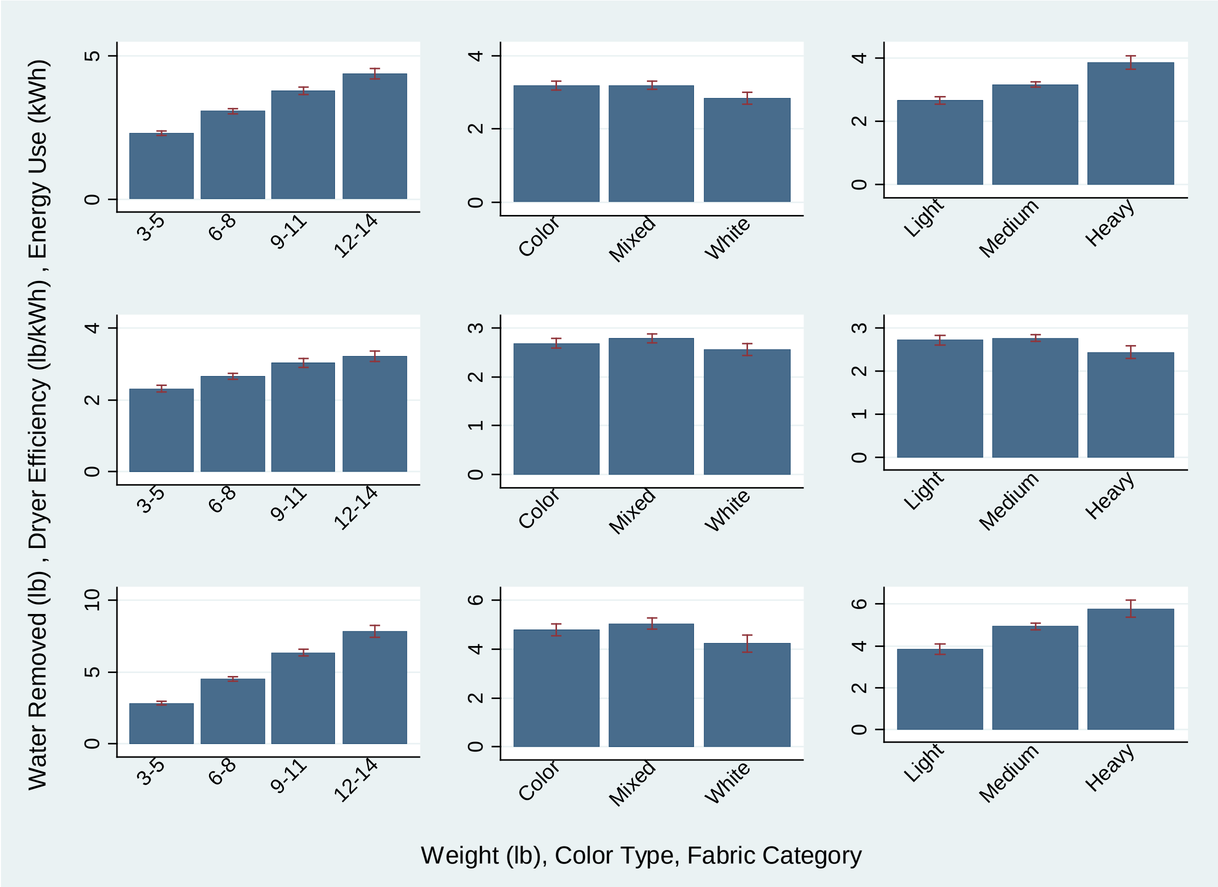


Figure 91. Dryer Screening – Washer Output Characteristics

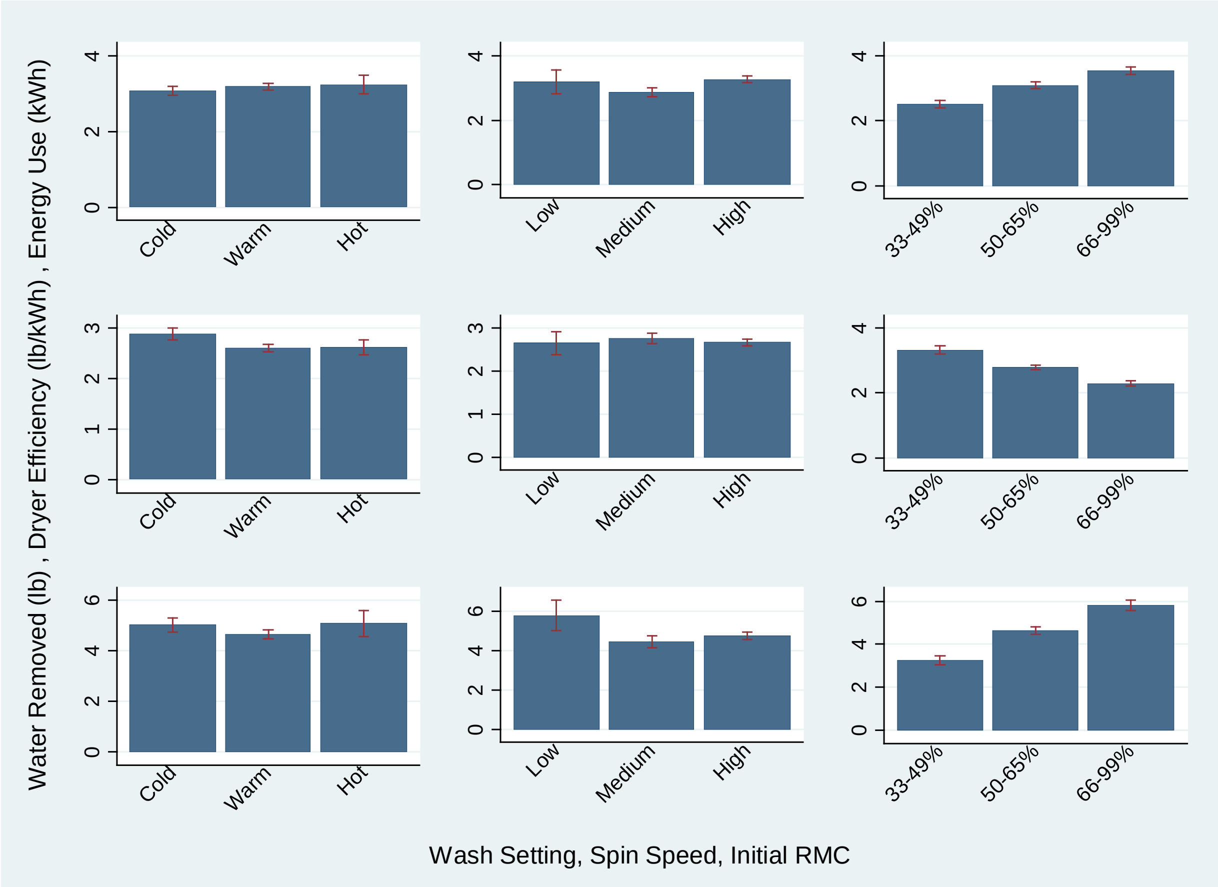


Figure 92. Dryer Screening – Equipment Settings

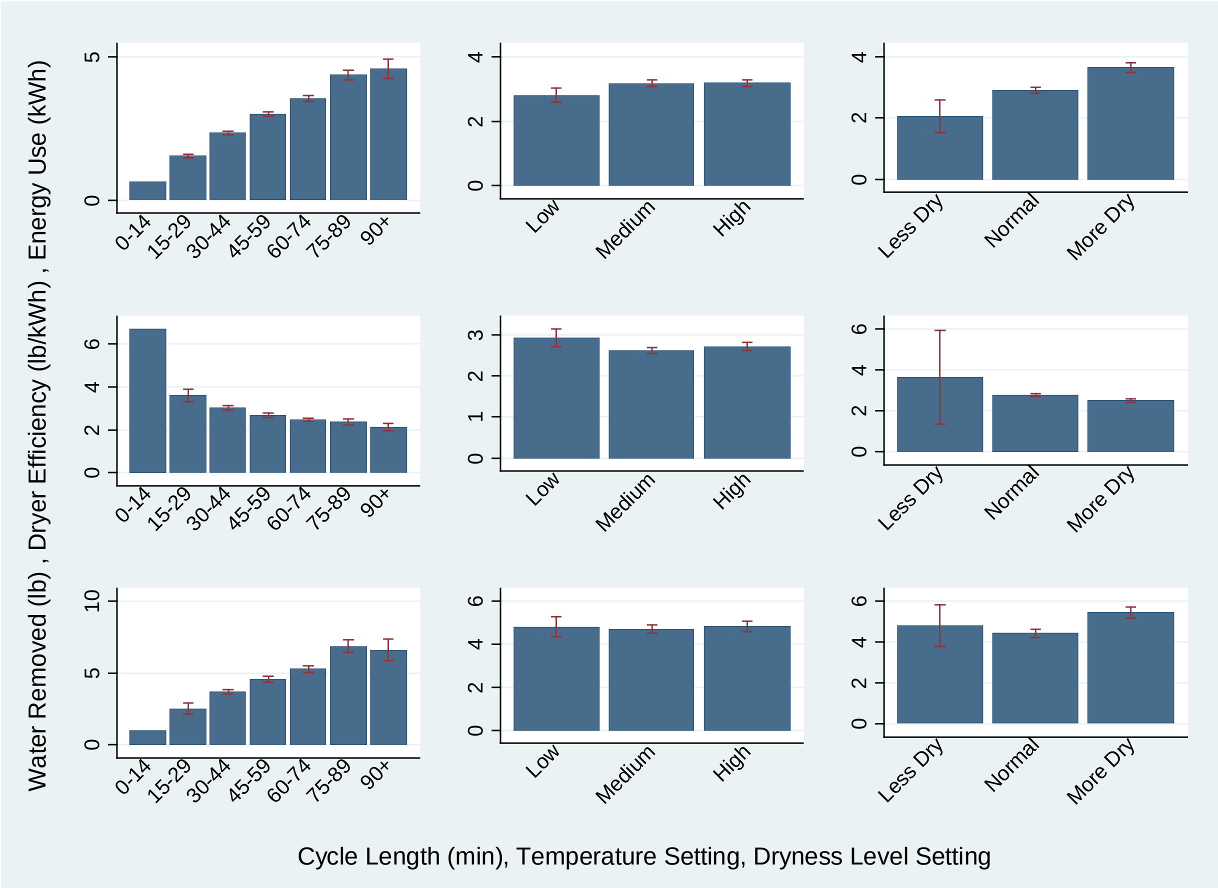
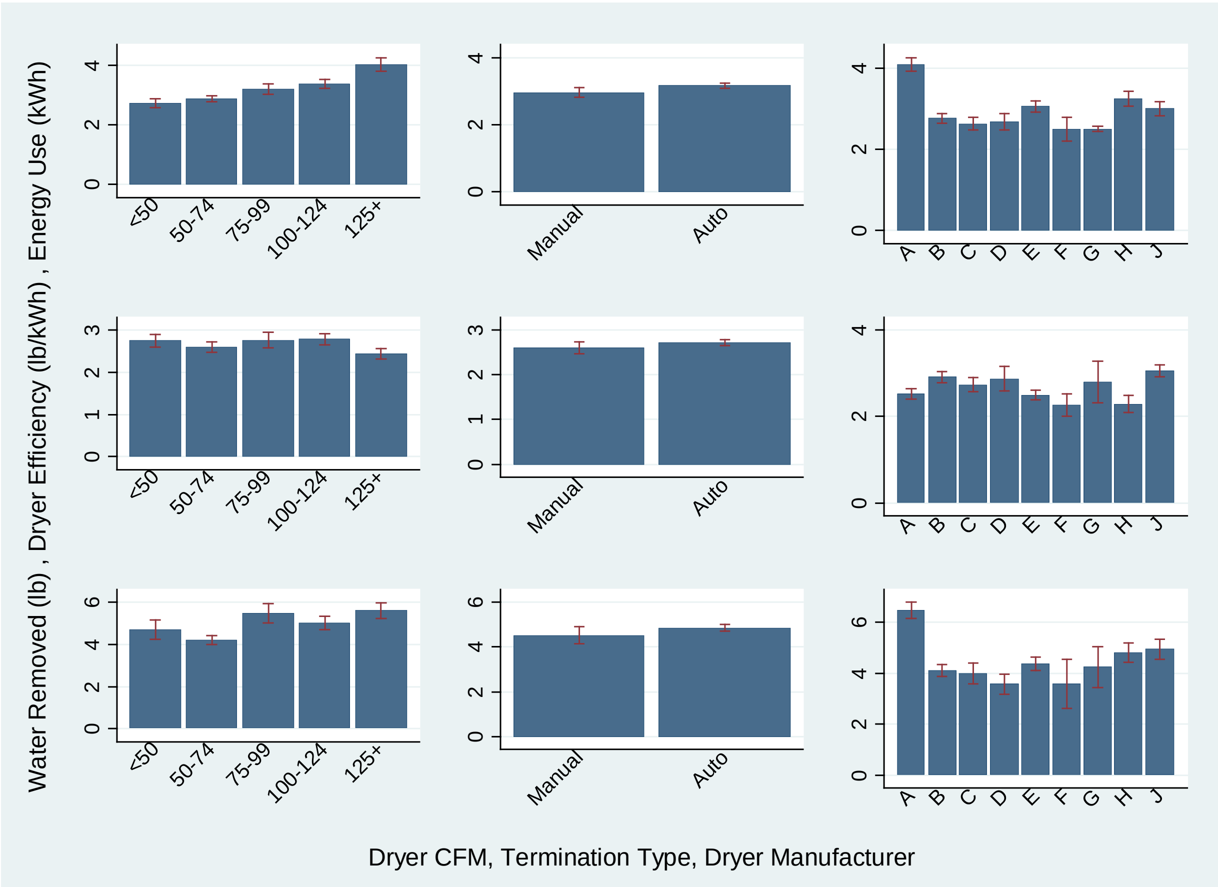


Figure 93. Dryer Screening – Equipment Properties



Appendix 10. Load Types and Cycle Choices

Much of this study focuses on energy use based on characteristics of the machine, but another very important factor is occupant behavior. Setting the washing machine to the extra hot cycle for every load would swamp any possible efficiency gains. This scenario is an extreme example, but the selection of washer and dryer settings can greatly affect the energy use. The tables below show the occupant settings split by load weight.

Table 78. Color Category by Bone-Dry Weight

Bone-Dry Weight (lb)	Color			
	Color	Mixed	White	n (L)
3–5 lb	13.3%	10.0%	6.6%	150
6–8 lb	13.7%	16.1%	6.8%	184
9–11 lb	9.8%	12.7%	3.0%	128
12–14 lb	3.0%	4.2%	0.8%	40

Table 79. Fabric Category by Bone-Dry Weight

Bone-Dry Weight (lb)	Fabric Category			
	Light	Medium	Heavy	n (L)
3–5 lb	11.9%	14.9%	3.6%	171
6–8 lb	8.3%	22.9%	4.8%	203
9–11 lb	4.1%	15.6%	5.7%	143
12–14 lb	1.4%	5.2%	1.6%	46

Table 80. Wash Temperature by Bone-Dry Weight

Bone-Dry Weight (lb)	Wash Temperature Setting			
	Cold	Warm	Hot	n (L)
3–5 lb	8.3%	18.2%	2.8%	173
6–8 lb	7.6%	22.9%	3.9%	203
9–11 lb	7.6%	14.5%	2.1%	145
12–14 lb	4.1%	3.0%	0.9%	46

Table 81. Washer Rinse Temperature by Bone-Dry Weight

Bone-Dry Weight (lb)	Washer Rinse Temperature			
	Cold	Warm	Hot	n (L)
3–5 lb	27.3%	1.4%	—	173
6–8 lb	31.4%	2.3%	0.2%	203
9–11 lb	22.4%	1.4%	0.4%	145
12–14 lb	7.2%	0.4%	0.2%	46

Table 82. Washer Spin Speed by Bone-Dry Weight

Bone-Dry Weight (lb)	Washer Spin Speed			
	Low	Medium	High	n (L)
3–5 lb	1.8%	7.6%	13.1%	173
6–8 lb	1.4%	5.8%	21.5%	203
9–11 lb	1.1%	3.2%	13.2%	145
12–14 lb	0.9%	1.6%	4.2%	46

Table 83. Washer Cycle Length by Bone-Dry Weight

Bone-Dry Weight (lb)	Washer Cycle Length						
	15-29	30-44	45-59	60-74	75-89	90+	n (L)
3–5 lb	0.7%	5.6%	14.6%	6.7%	2.3%	0.5%	173
6–8 lb	0.2%	6.0%	13.9%	10.2%	3.5%	1.9%	203
9–11 lb	0.2%	3.4%	9.3%	8.5%	2.3%	1.9%	145
12–14 lb	—	0.4%	3.0%	3.2%	0.9%	0.7%	46

Table 84. Dryer Temperature Setting by Bone-Dry Weight

Bone-Dry Weight (lb)	Dryer Temperature Setting			
	Low	Medium	High	n (L)
3–5 lb	3.8%	16.3%	10.4%	167
6–8 lb	2.6%	18.1%	14.8%	194
9–11 lb	1.5%	16.3%	8.1%	141
12–14 lb	1.8%	2.0%	4.2%	44

Table 85. Dryer Dryness Setting by Bone-Dry Weight

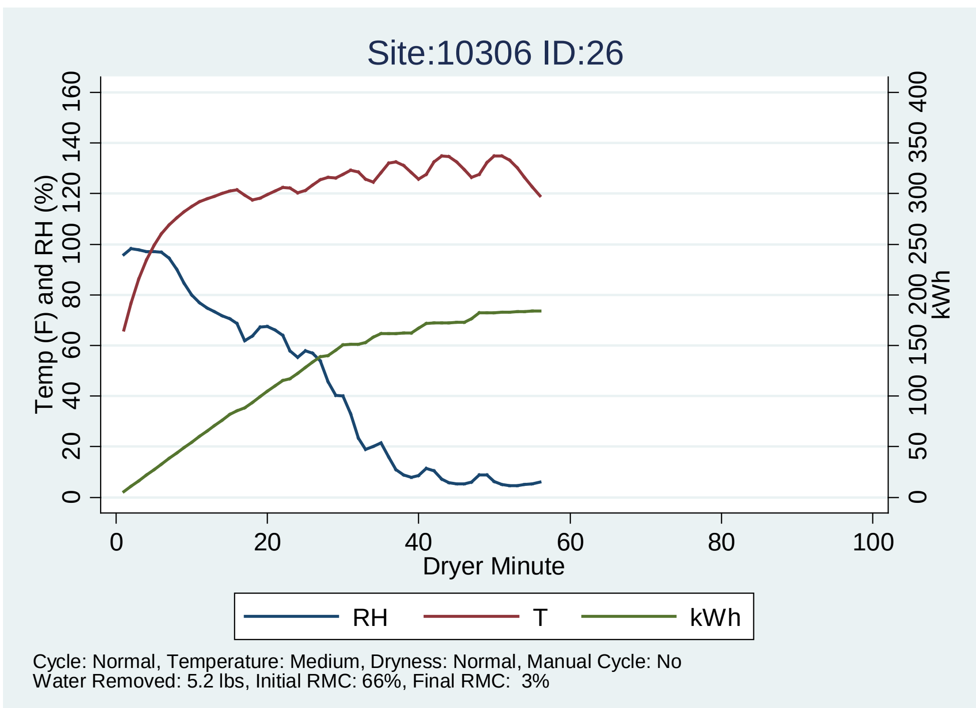
Bone-Dry Weight (lb)	Dryer Dryness Setting			
	Less Dry	Normal	More Dry	n (L)
3–5 lb	0.5%	21.0%	8.3%	125
6–8 lb	0.2%	24.3%	11.4%	151
9–11 lb	—	11.2%	14.8%	109
12–14 lb	—	4.5%	3.8%	35

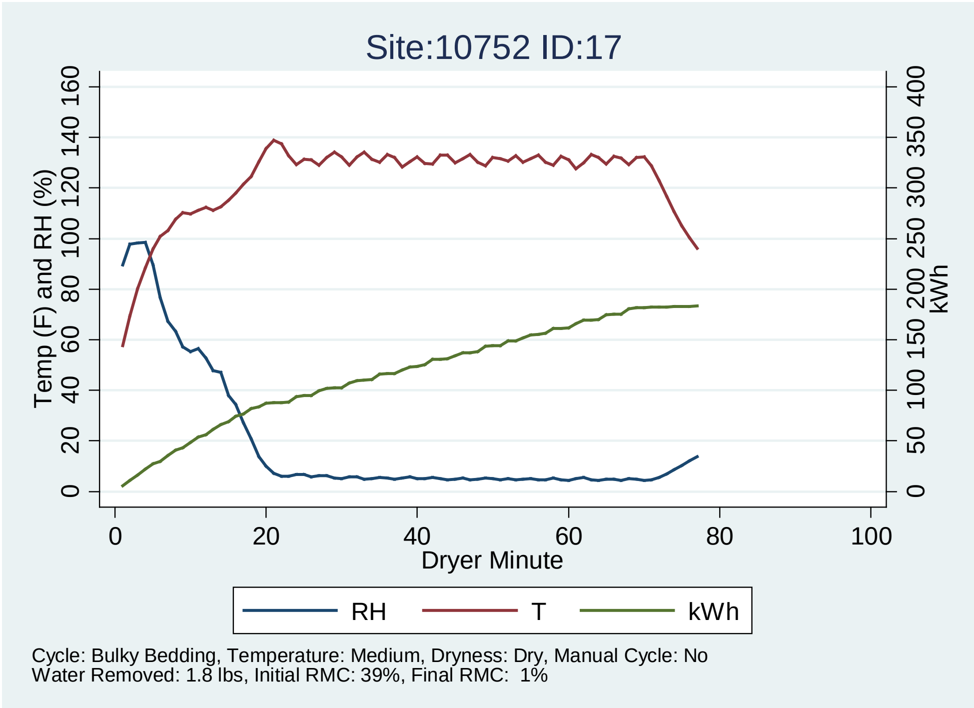
Table 86. Dryer Cycle Length by Bone-Dry Weight

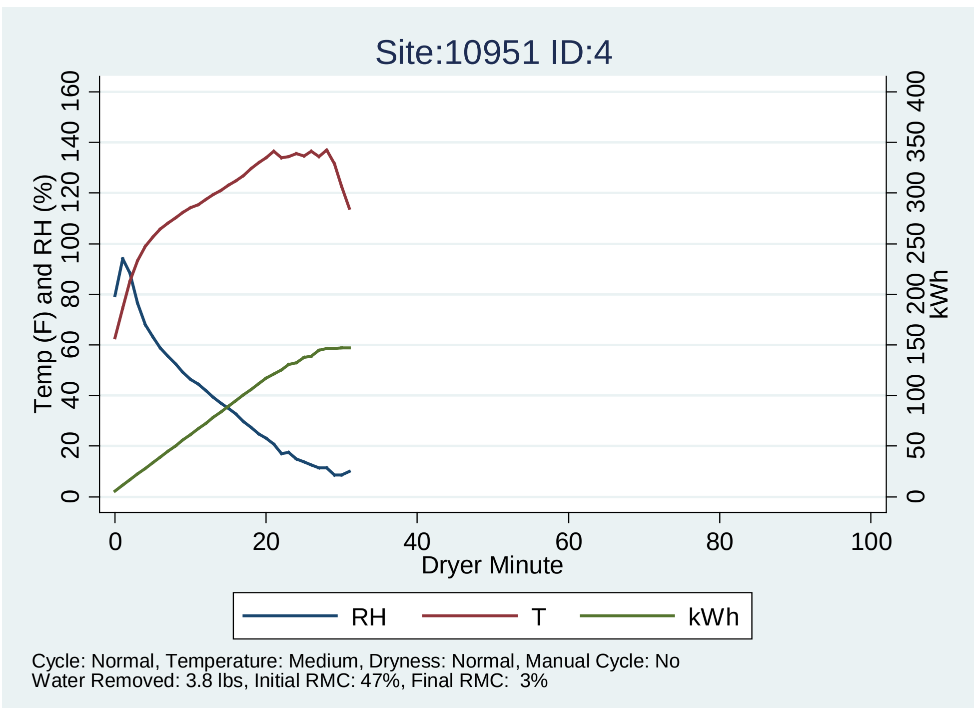
Bone-Dry Weight (lb)	Dryer Cycle Length							
	0-14	15-29	30-44	45-59	60-74	75-89	90+	n (L)
3–5 lb	—	5.3%	10.4%	7.6%	5.8%	0.9%	0.5%	173
6–8 lb	—	1.6%	8.6%	8.6%	12.2%	2.5%	2.3%	203
9–11 lb	—	0.4%	3.7%	8.1%	5.3%	6.2%	1.9%	145
12–14 lb	—	—	—	0.5%	4.9%	1.9%	0.7%	46

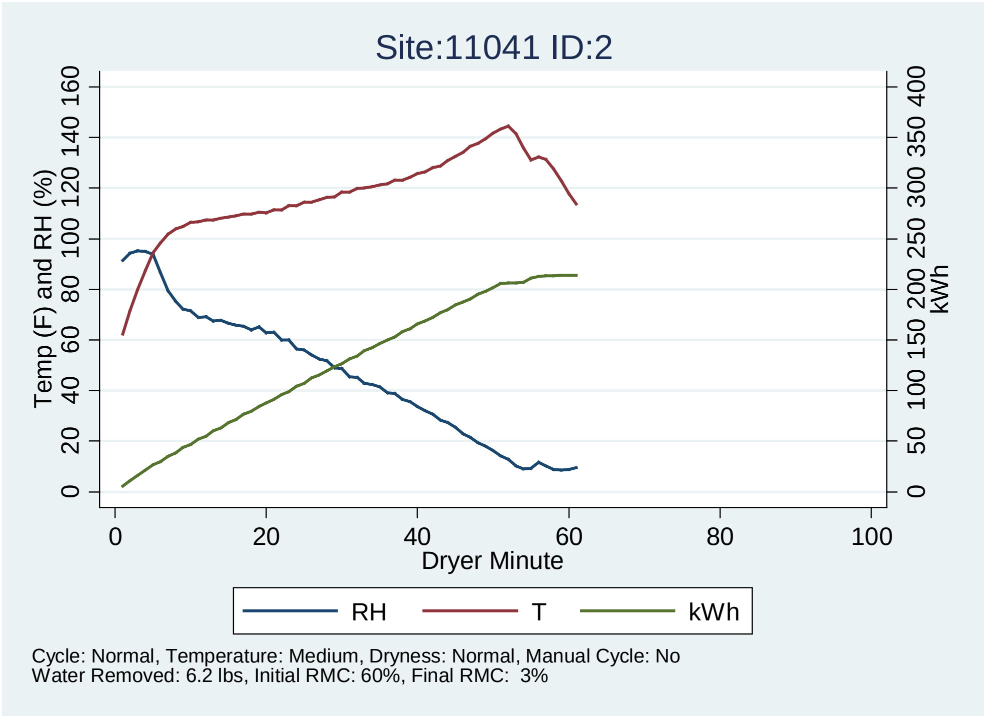
Appendix 11. Normal Dryer Cycles

The following graphs show the typical shapes of the "Normal" dryer cycle for each site with auto-termination. The definition of "Normal" changes from site to site due to inconsistency in cycle naming conventions, so the graphs below are a representation of the best estimate of normal for each site. The basis for cycle screening was to keep only the simple loads that used auto-termination and had information about the dryer setting. The subset produced a summary for each site for average energy use, efficiency (lb/kWh), water removed, and cycle time across the loads that had medium/high heat setting and normal/more-dry dryness setting. The root-mean-square difference of the percent difference for each of these metrics for each site were calculated to obtain a single metric to determine the cycle that is closest to the most normal cycle. The selection of only using medium/high heat and normal/more-dry dryness setting is a way to remove the delicate cycles.

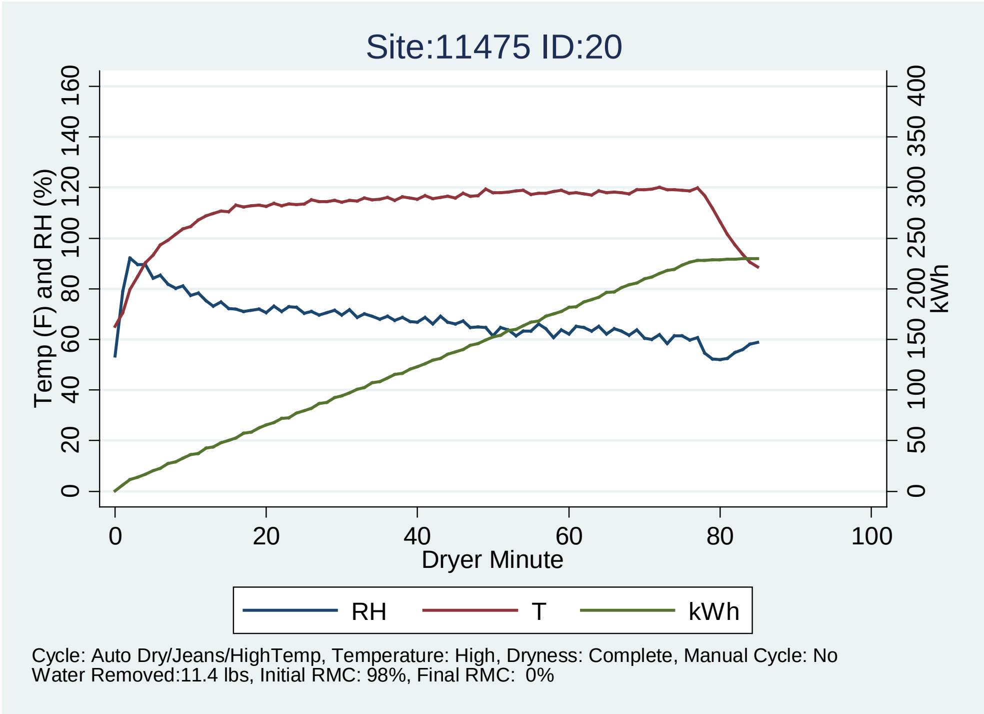



Site:10752 ID:17
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
0 50 100 150 200 250 300 350 400
kWh
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Bulky Bedding, Temperature: Medium, Dryness: Dry, Manual Cycle: No
Water Removed: 1.8 lbs, Initial RMC: 39%, Final RMC: 1%


Site:10951 ID:4
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
0 50 100 150 200 250 300 350 400
kWh
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 3.8 lbs, Initial RMC: 47%, Final RMC: 3%

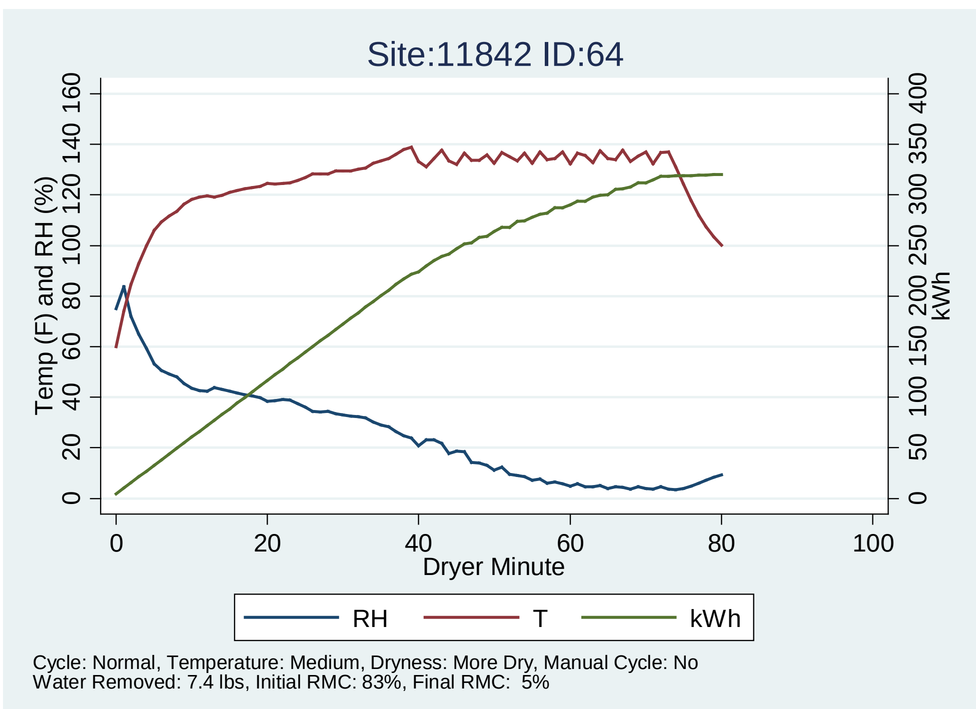


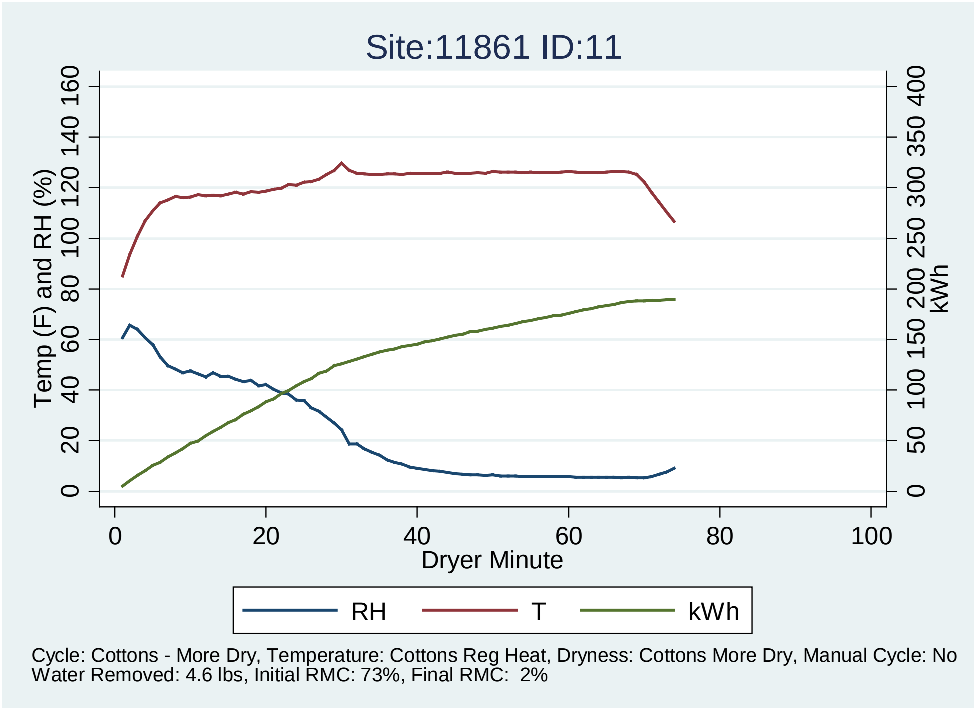
Site:11041 ID:2
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
0 50 100 150 200 250 300 350 400
kWh
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 6.2 lbs, Initial RMC: 60%, Final RMC: 3%



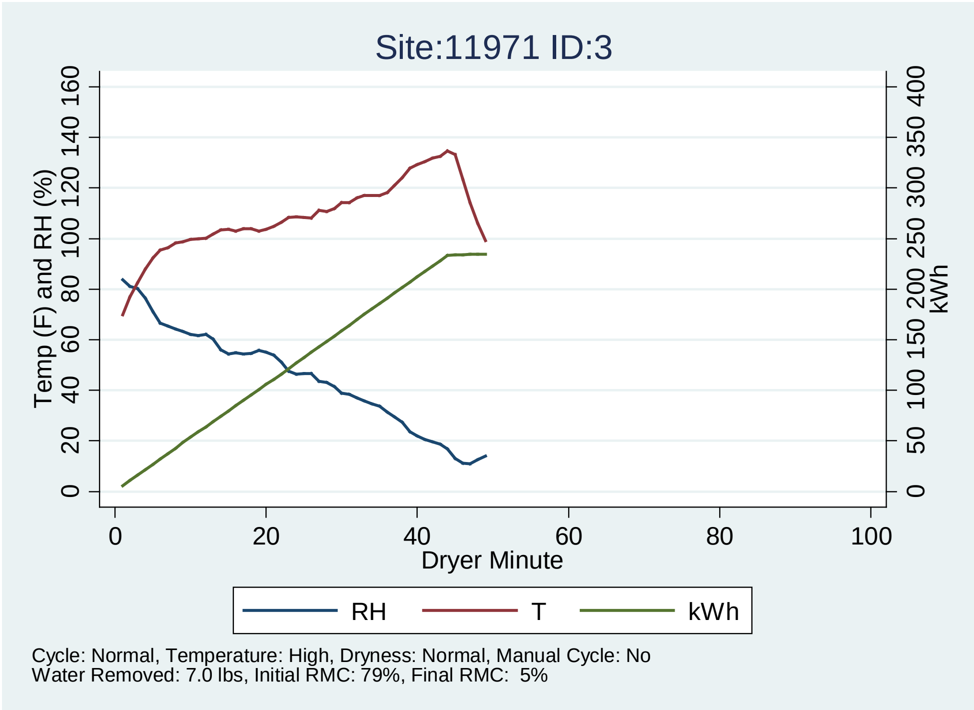
Site:11475 ID:20
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
0 50 100 150 200 250 300 350 400
kWh
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Auto Dry/Jeans/HighTemp, Temperature: High, Dryness: Complete, Manual Cycle: No
Water Removed:11.4 lbs, Initial RMC: 98%, Final RMC: 0%

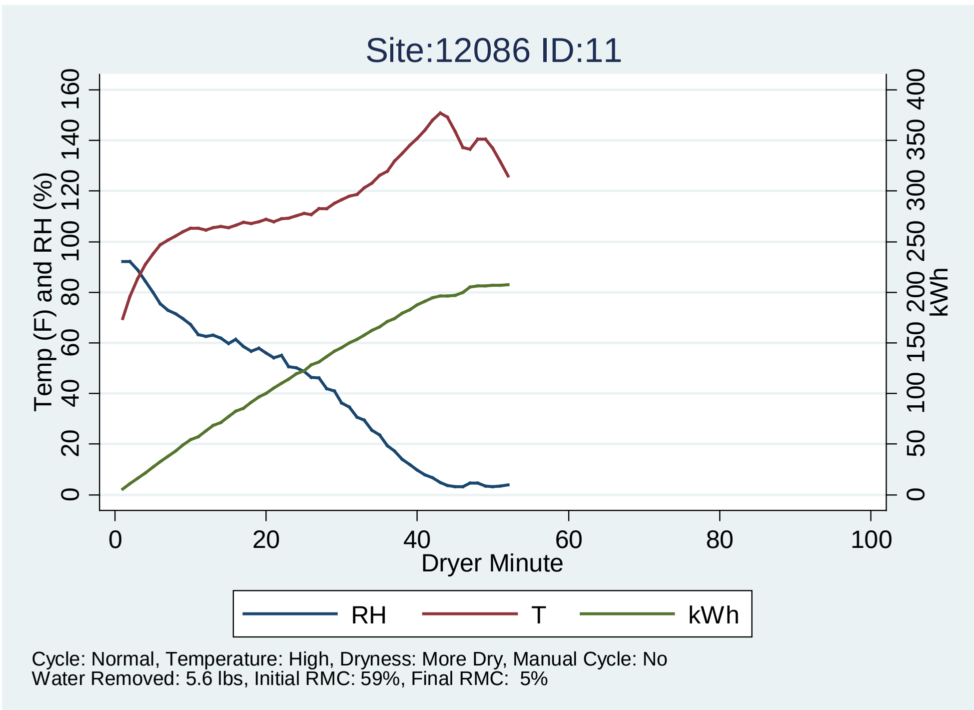

Site:11729 ID:5
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal/TempMedium/DryLevelNormal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 3.5 lbs, Initial RMC: 67%, Final RMC: 3%

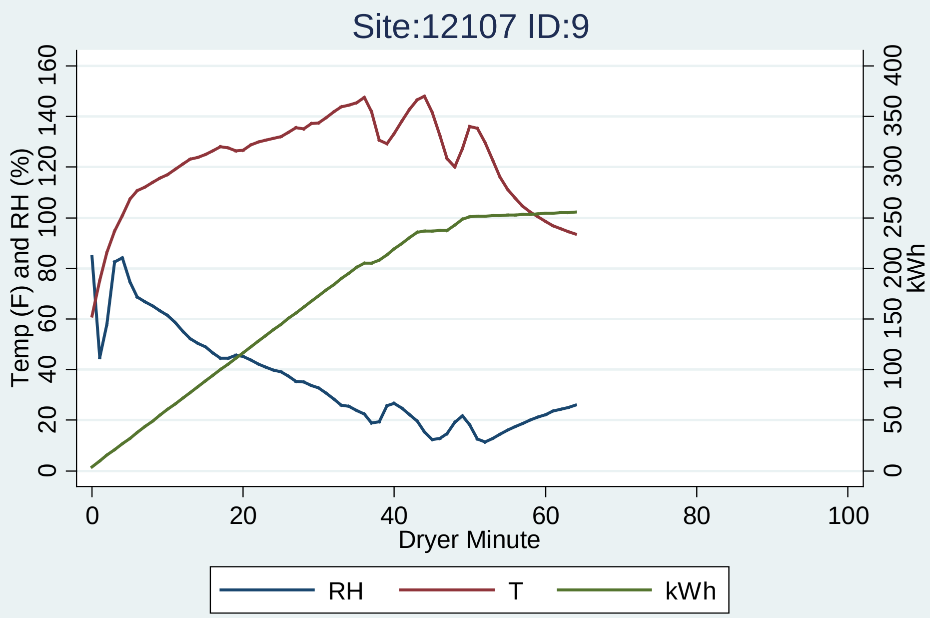

Site:11842 ID:64
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: Medium, Dryness: More Dry, Manual Cycle: No
Water Removed: 7.4 lbs, Initial RMC: 83%, Final RMC: 5%


Site:11861 ID:11
Temp (F) and RH (%)
kWh
Dryer Minute
RH
T
kWh
Cycle: Cottons - More Dry, Temperature: Cottons Reg Heat, Dryness: Cottons More Dry, Manual Cycle: No
Water Removed: 4.6 lbs, Initial RMC: 73%, Final RMC: 2%

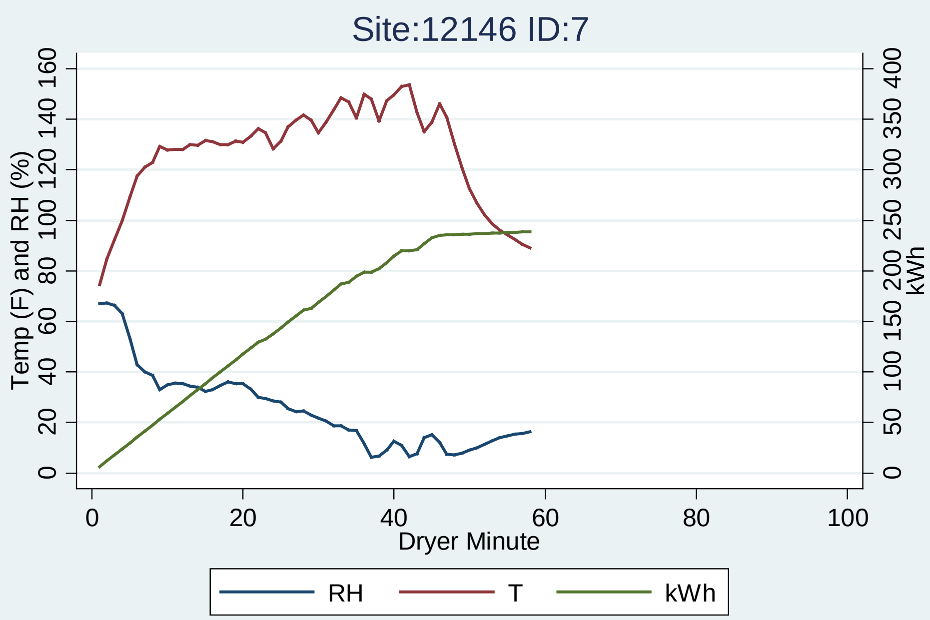

Site:11896 ID:3
Temp (F) and RH (%)
kWh
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 3.6 lbs, Initial RMC: 44%, Final RMC: 0%


Site:11971 ID:3
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: High, Dryness: Normal, Manual Cycle: No
Water Removed: 7.0 lbs, Initial RMC: 79%, Final RMC: 5%

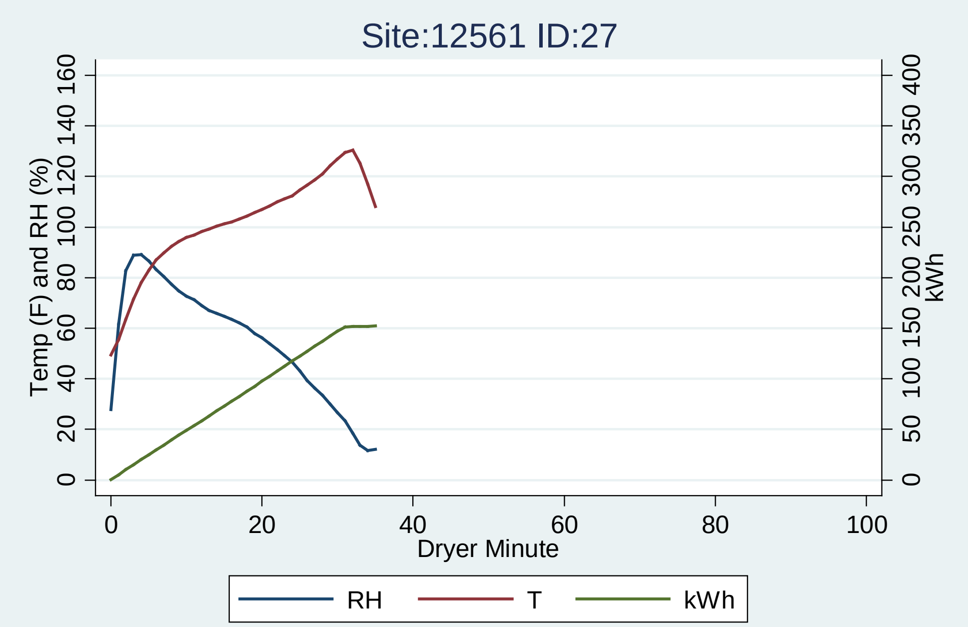

Site:12086 ID:11
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: High, Dryness: More Dry, Manual Cycle: No
Water Removed: 5.6 lbs, Initial RMC: 59%, Final RMC: 5%



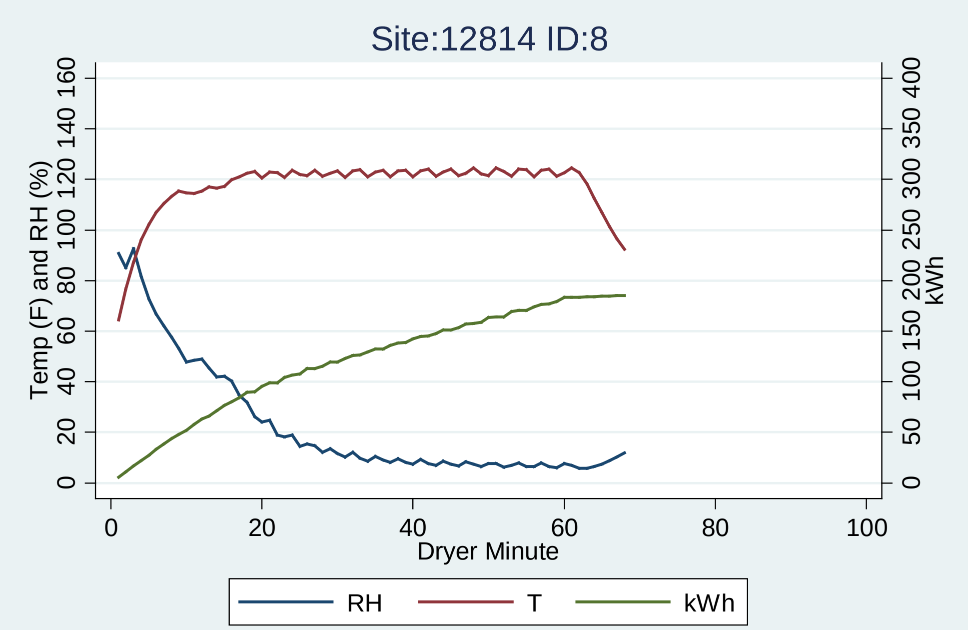
Cycle: Auto Dry - Energy Preferred, Temperature: High, Dryness: Very Dry, Manual Cycle: No
Water Removed: 8.0 lbs, Initial RMC: 79%, Final RMC: 3%



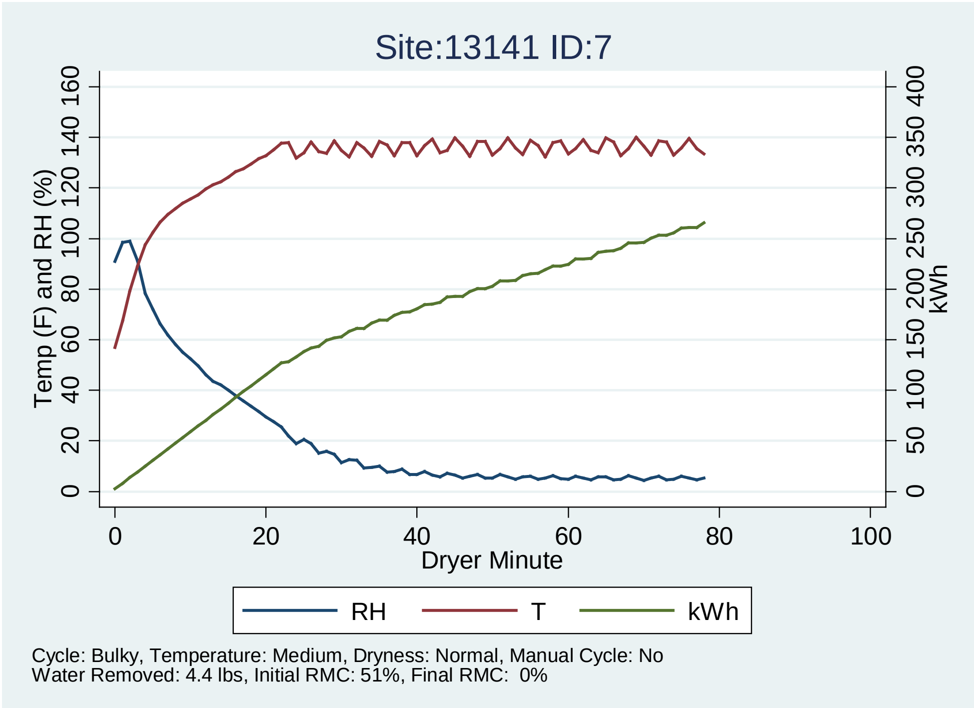
Cycle: Energy Preferred Plus, Temperature: High, Dryness: Dry, Manual Cycle: .m
Water Removed: 6.8 lbs, Initial RMC: 68%, Final RMC: 1%



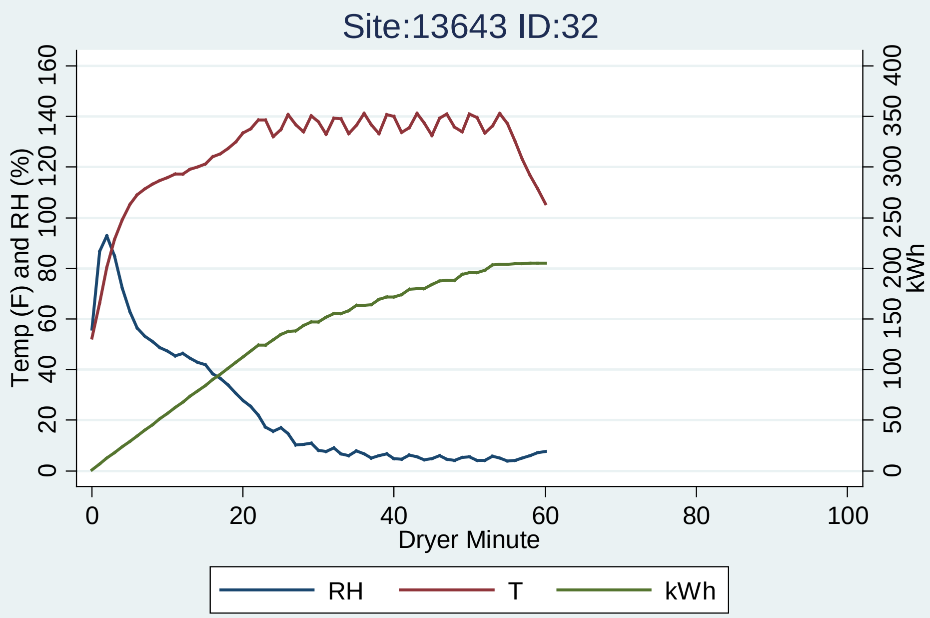
Cycle: Regular Cotton - Regular Dry, Temperature: Regular, Dryness: Regular, Manual Cycle: No
Water Removed: 4.0 lbs, Initial RMC: 77%, Final RMC: 0%



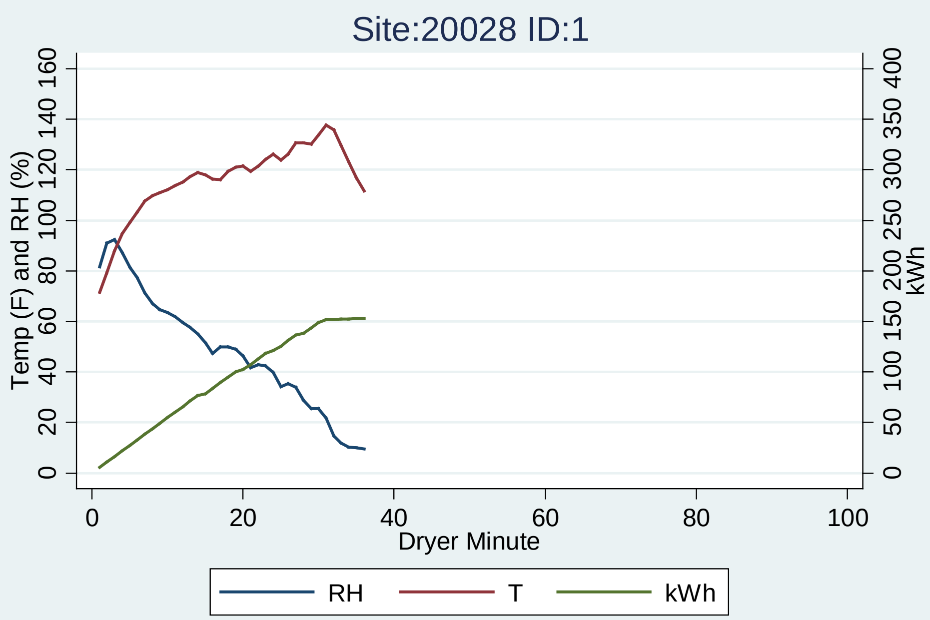
Cycle: Cottons More Dry Automatic, Temperature: Regular, Dryness: Fully dry, Manual Cycle: No
Water Removed: 2.8 lbs, Initial RMC: 52%, Final RMC: 2%


Site:13141 ID:7
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
0 50 100 150 200 250 300 350 400
kWh
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Bulky, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 4.4 lbs, Initial RMC: 51%, Final RMC: 0%

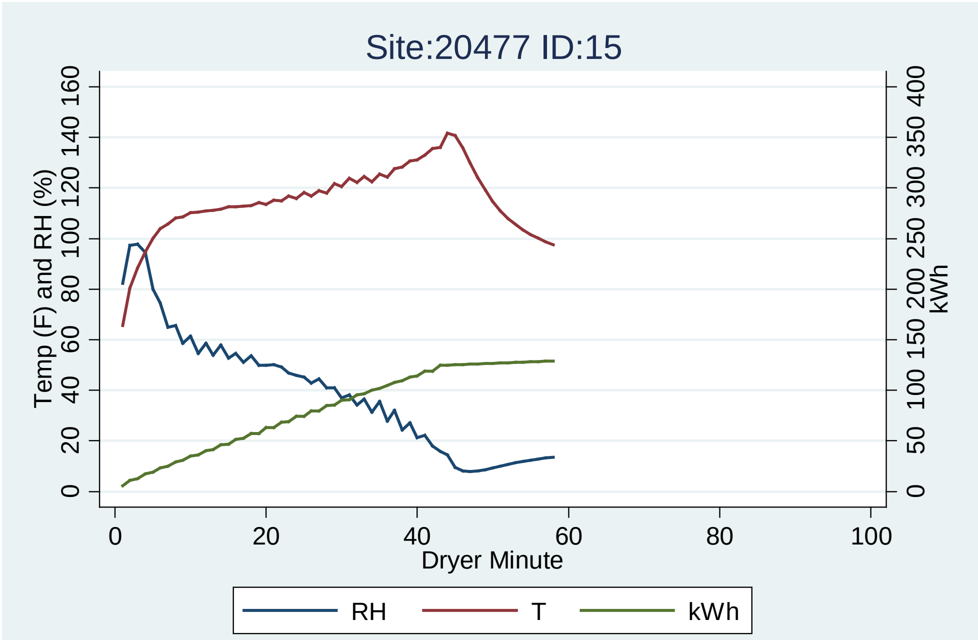

Site:13426 ID:17
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
0 50 100 150 200 250 300 350 400
kWh
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: Medium, Dryness: More Dry, Manual Cycle: No
Water Removed: 7.2 lbs, Initial RMC: 82%, Final RMC: 0%



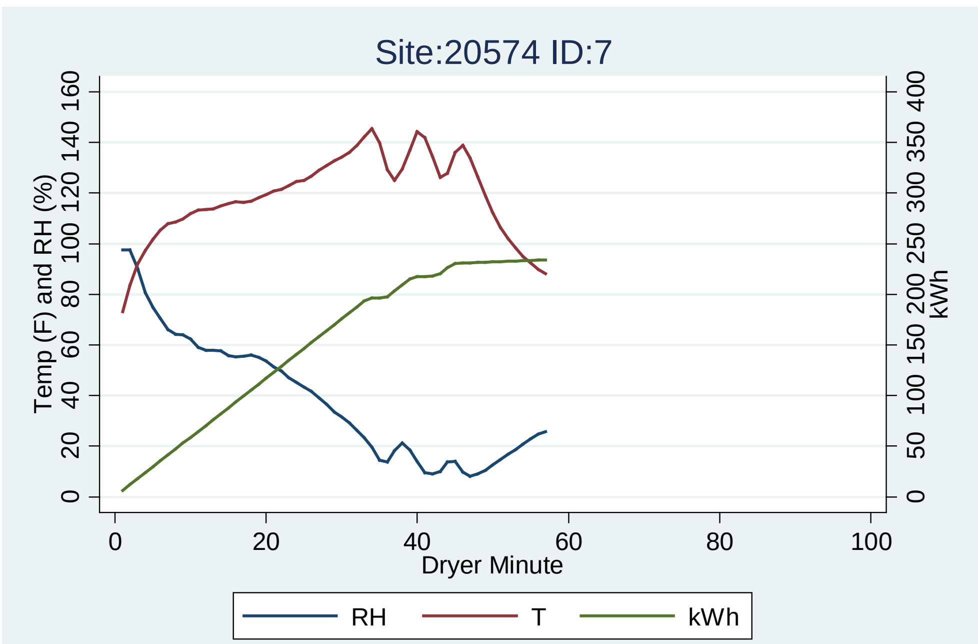
Cycle: Normal, Temperature: Normal, Dryness: More Dry, Manual Cycle: No
Water Removed: 4.0 lbs, Initial RMC: 50%, Final RMC: 0%



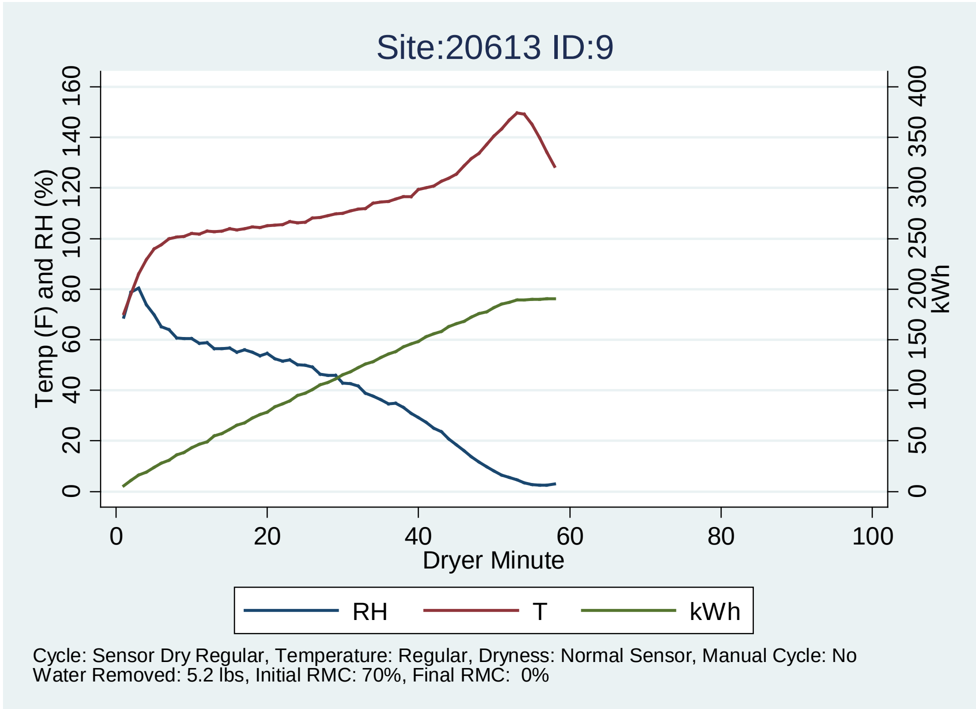
Cycle: Normal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 4.8 lbs, Initial RMC: 55%, Final RMC: 1%

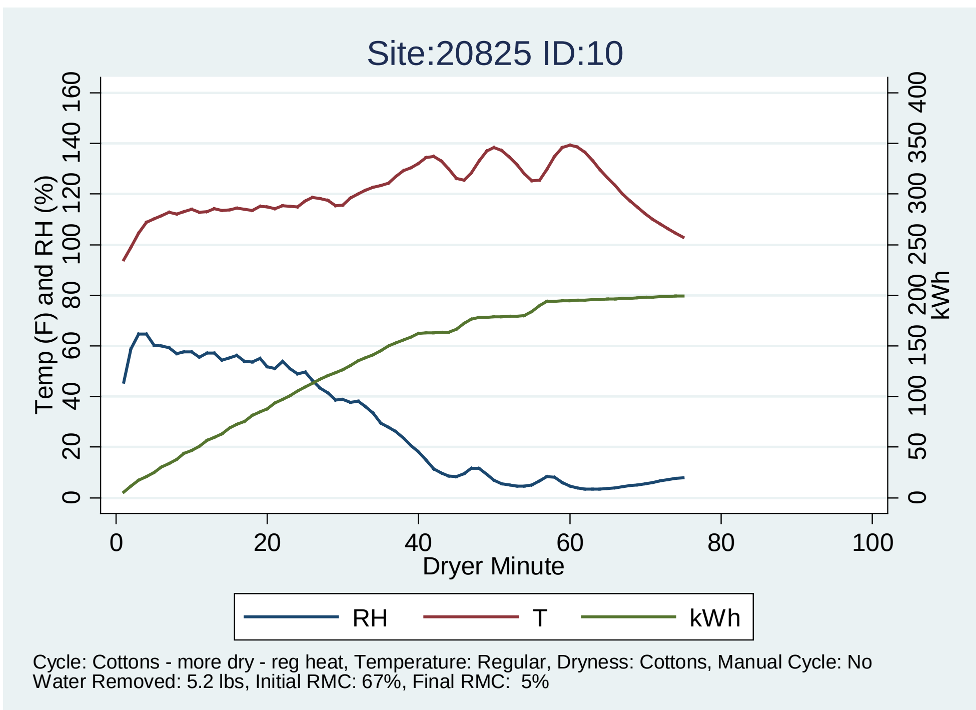


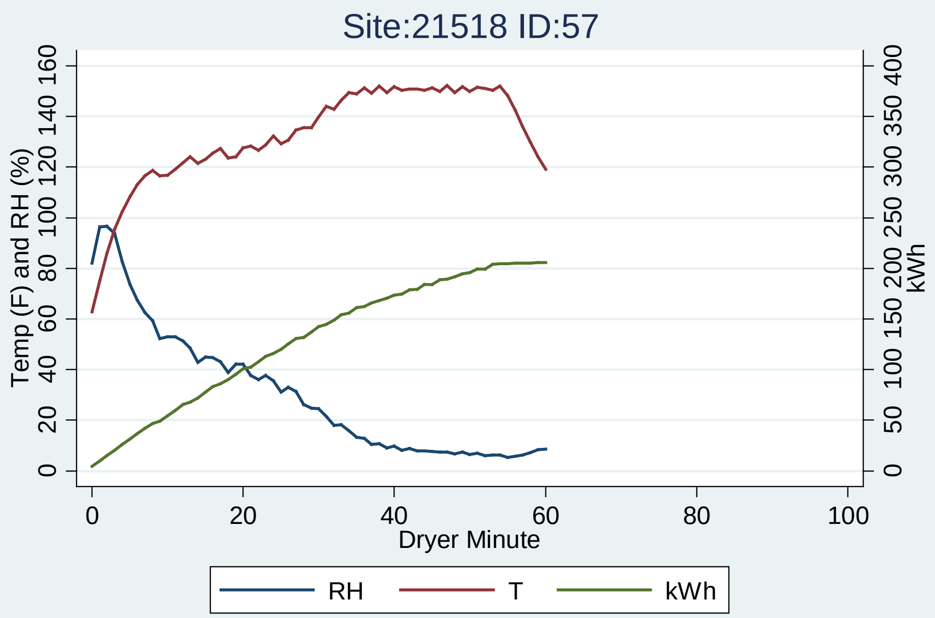
Cycle: Perm Press - More Dry, Temperature: High, Dryness: More Dry, Manual Cycle: No
Water Removed: 4.3 lbs, Initial RMC: 96%, Final RMC: 0%



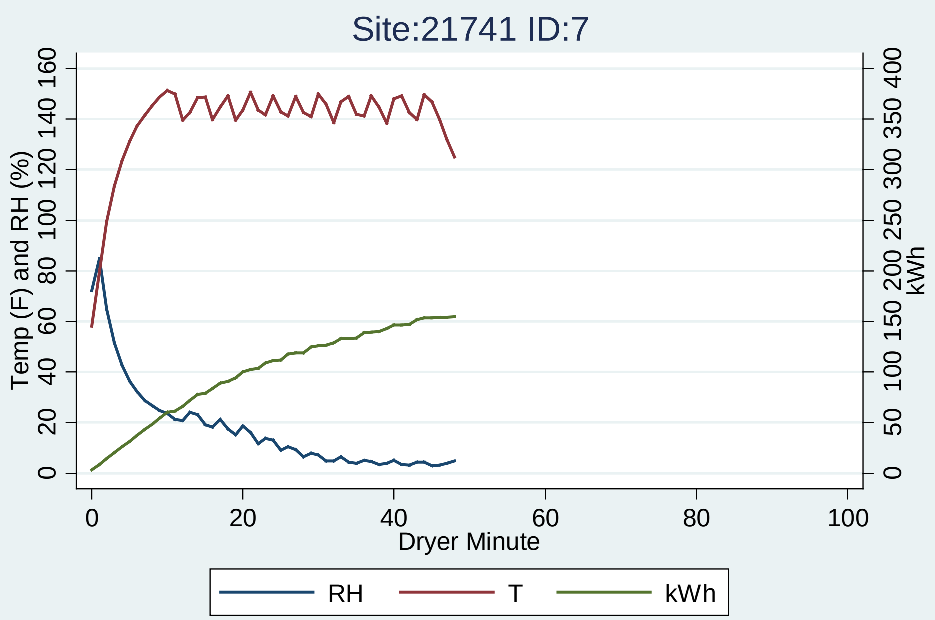
Cycle: Jeans / Medium, Temperature: Medium, Dryness: Jeans, Manual Cycle: .m
Water Removed: 6.2 lbs, Initial RMC: 65%, Final RMC: 1%


Site:20613 ID:9
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Sensor Dry Regular, Temperature: Regular, Dryness: Normal Sensor, Manual Cycle: No
Water Removed: 5.2 lbs, Initial RMC: 70%, Final RMC: 0%

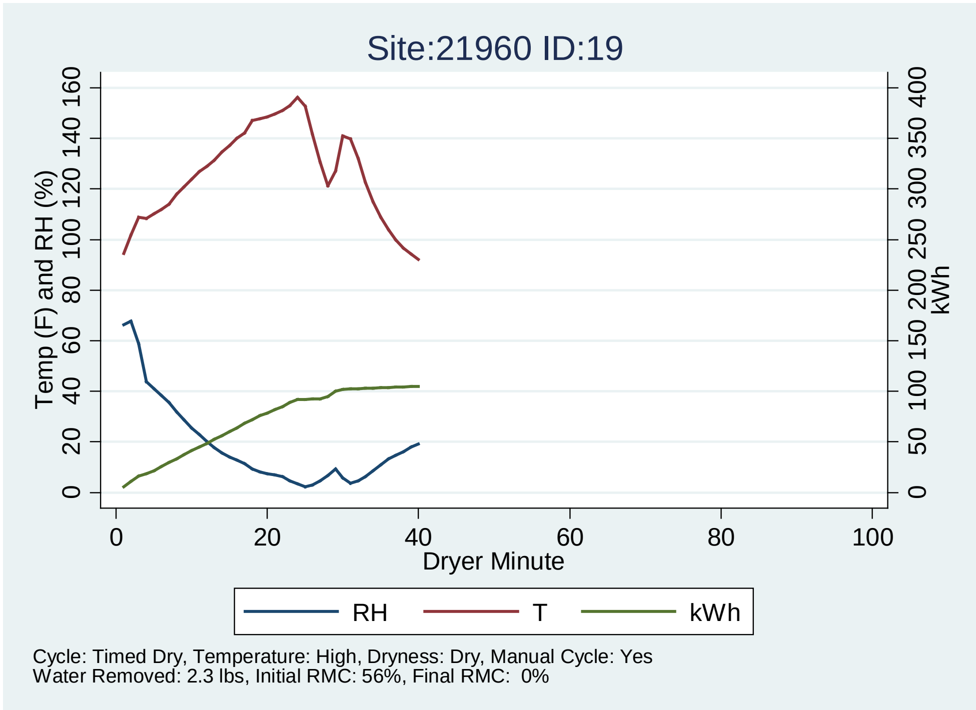

Site:20825 ID:10
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Cottons - more dry - reg heat, Temperature: Regular, Dryness: Cottons, Manual Cycle: No
Water Removed: 5.2 lbs, Initial RMC: 67%, Final RMC: 5%

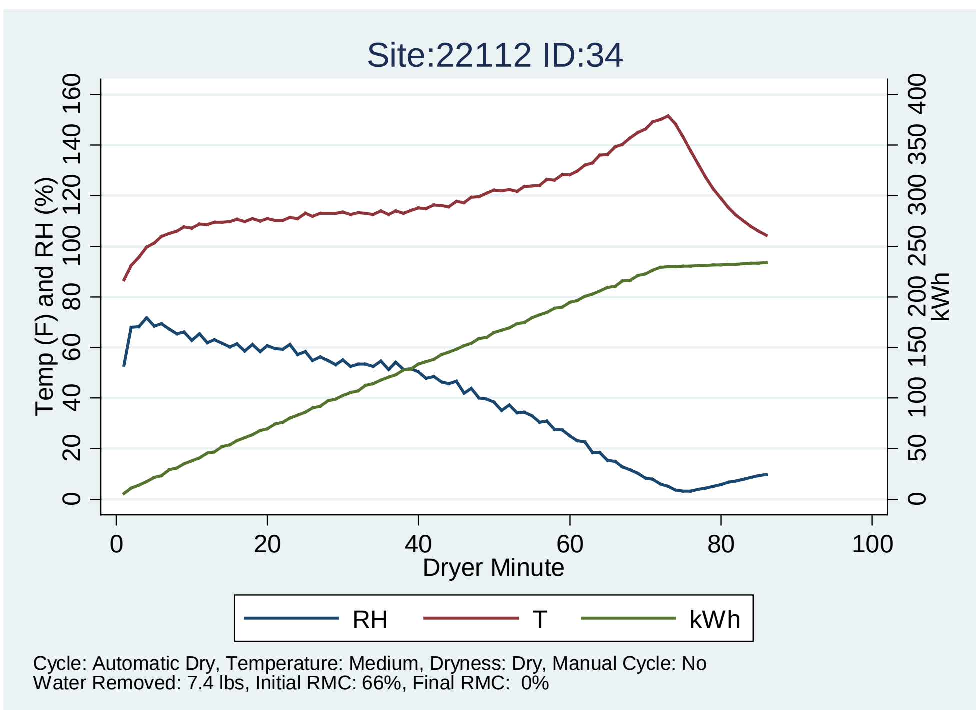


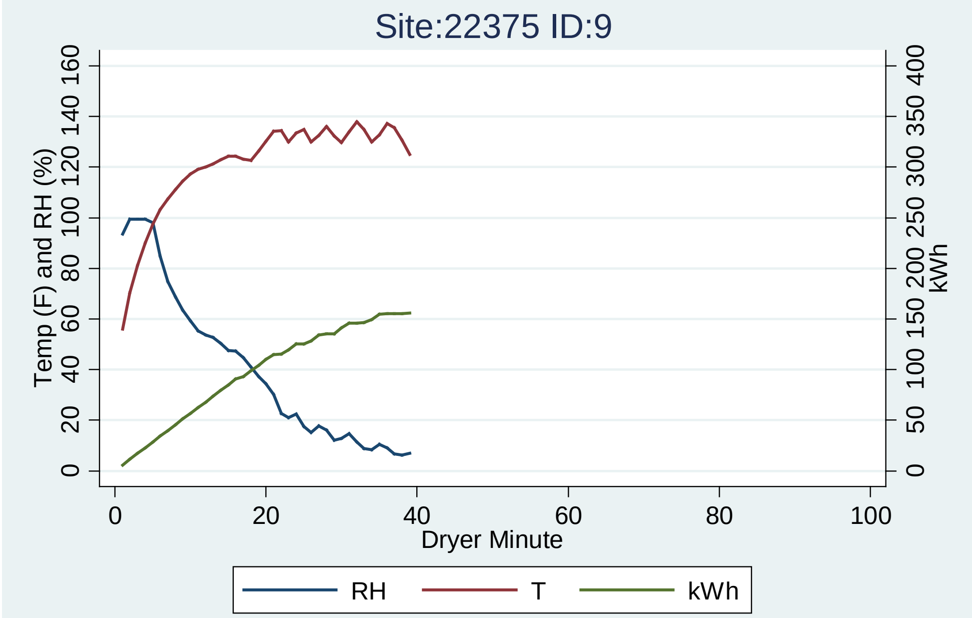
Cycle: Normal High 60min big load, Temperature: High, Dryness: Normal, Manual Cycle: Yes
Water Removed: 4.6 lbs, Initial RMC: 92%, Final RMC: 21%



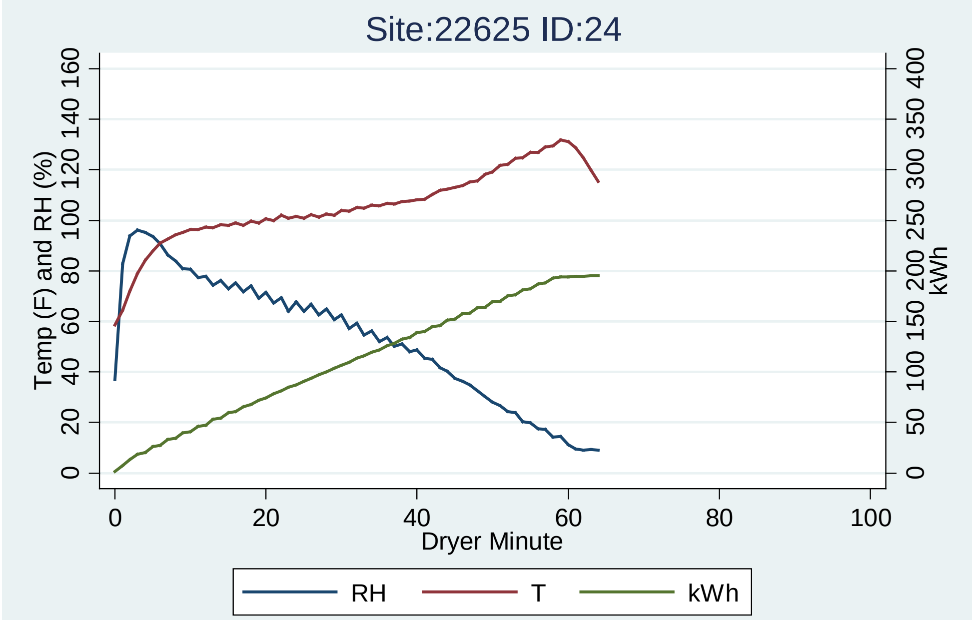
Cycle: Regular, Temperature: Regular, Dryness: Normal, Manual Cycle: No
Water Removed: 3.0 lbs, Initial RMC: 88%, Final RMC: 0%


Site:21960 ID:19
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Timed Dry, Temperature: High, Dryness: Dry, Manual Cycle: Yes
Water Removed: 2.3 lbs, Initial RMC: 56%, Final RMC: 0%


Site:22112 ID:34
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Automatic Dry, Temperature: Medium, Dryness: Dry, Manual Cycle: No
Water Removed: 7.4 lbs, Initial RMC: 66%, Final RMC: 0%

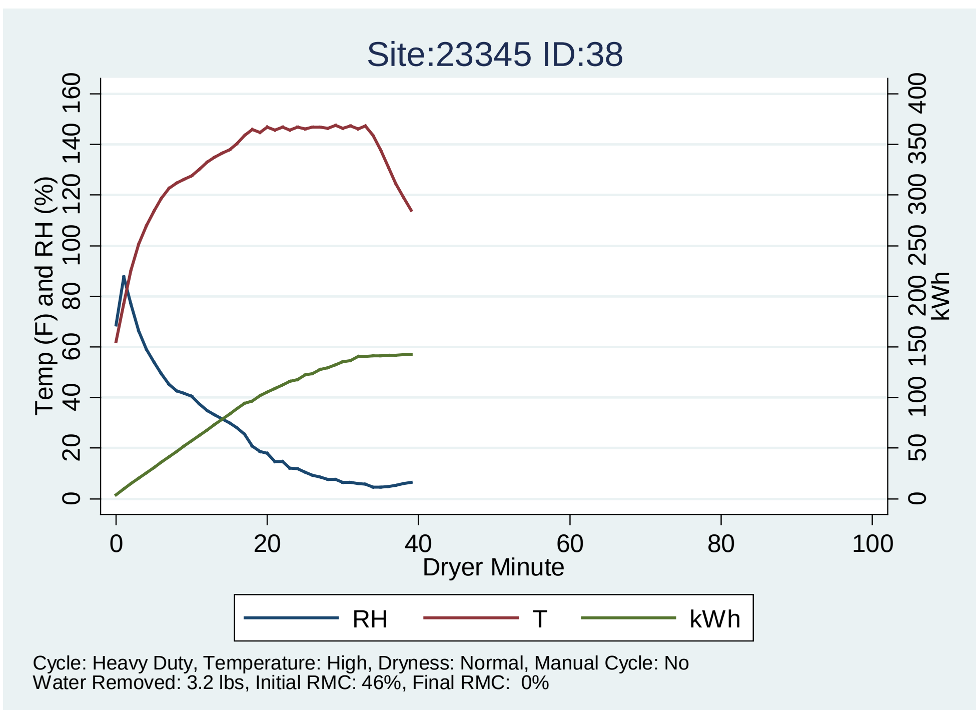


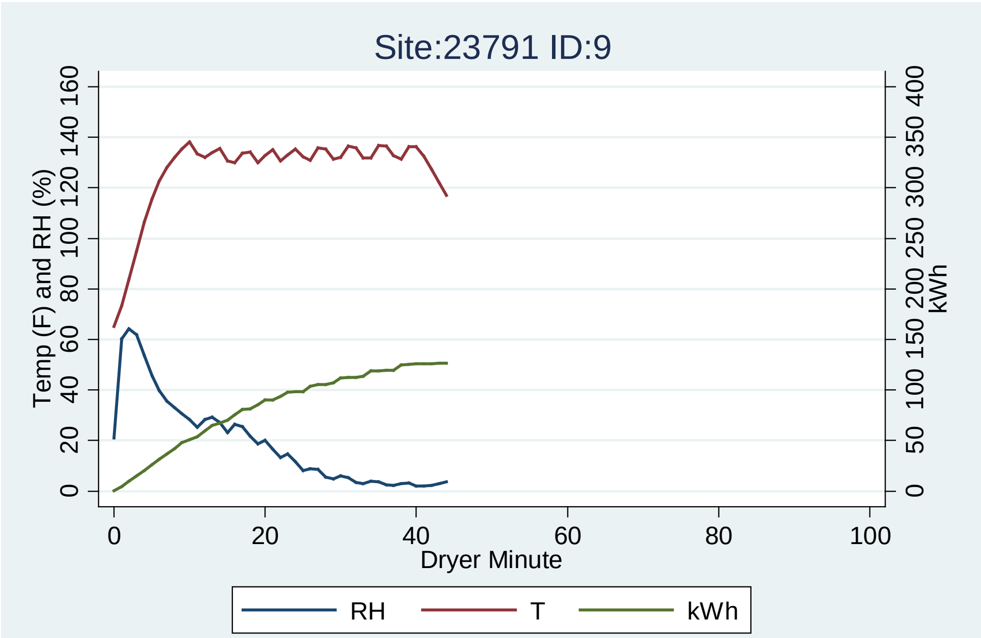
Cycle: Normal/MediumTemp Drylevel-Normal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 4.2 lbs, Initial RMC: 52%, Final RMC: 3%



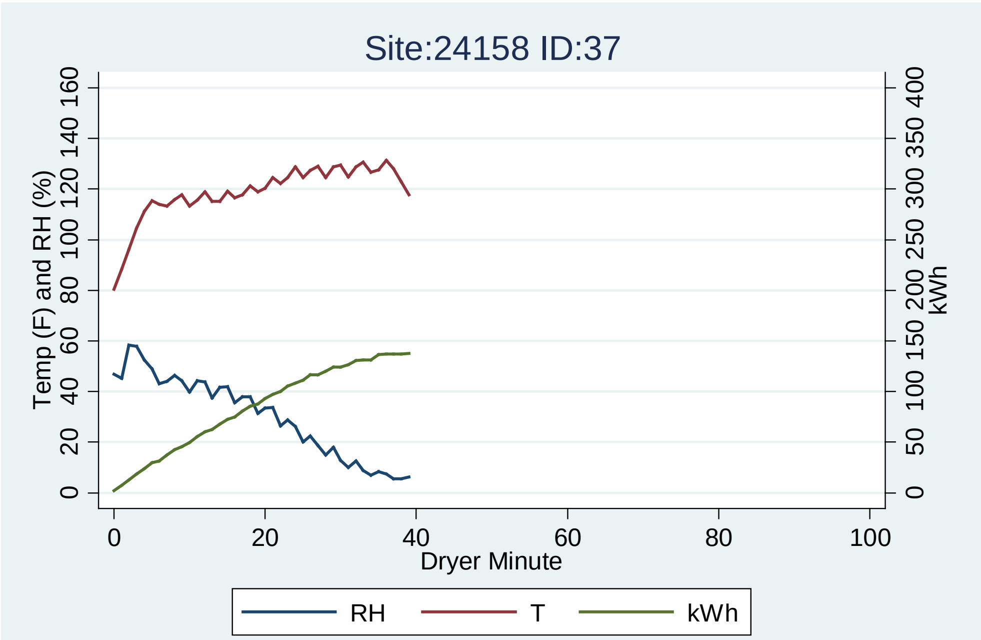
Cycle: Cotton Towels, Temperature: Mid High, Dryness: Normal, Manual Cycle: No
Water Removed: 5.6 lbs, Initial RMC: 45%, Final RMC: 2%


Site:22703 ID:14
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal/DryLevelNormal/TempHigh, Temperature: High, Dryness: Normal, Manual Cycle: No
Water Removed: 3.4 lbs, Initial RMC: 43%, Final RMC: 0%

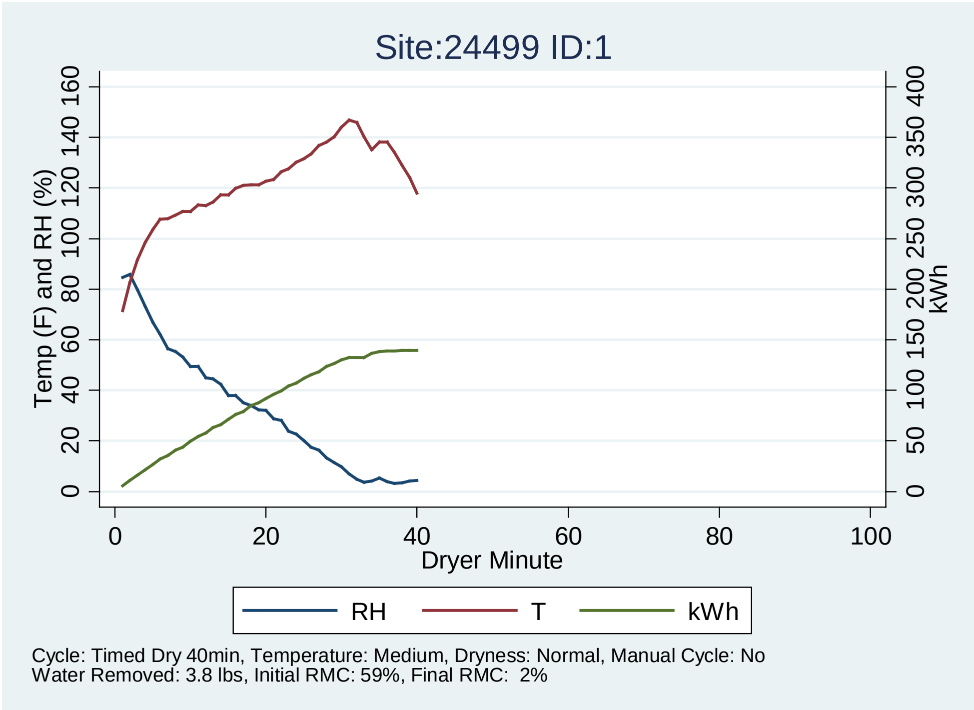

Site:23345 ID:38
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Heavy Duty, Temperature: High, Dryness: Normal, Manual Cycle: No
Water Removed: 3.2 lbs, Initial RMC: 46%, Final RMC: 0%

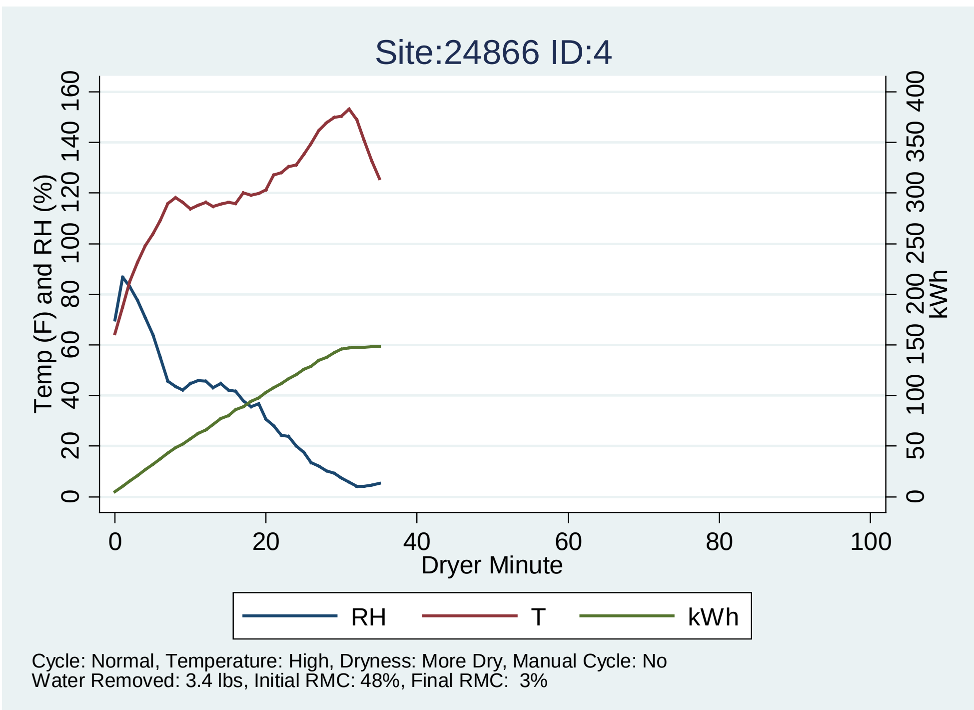


Cycle: Normal, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 2.6 lbs, Initial RMC: 52%, Final RMC: 5%



Cycle: Perm Press/dry normal/ Tempcontrol Med Hi, Temperature: Low, Dryness: Normal, Manual Cycle: No
Water Removed: 3.6 lbs, Initial RMC: 61%, Final RMC: 2%


Site:24499 ID:1
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Timed Dry 40min, Temperature: Medium, Dryness: Normal, Manual Cycle: No
Water Removed: 3.8 lbs, Initial RMC: 59%, Final RMC: 2%


Site:24866 ID:4
Temp (F) and RH (%)
0 20 40 60 80 100 120 140 160
kWh
0 50 100 150 200 250 300 350 400
0 20 40 60 80 100
Dryer Minute
RH
T
kWh
Cycle: Normal, Temperature: High, Dryness: More Dry, Manual Cycle: No
Water Removed: 3.4 lbs, Initial RMC: 48%, Final RMC: 3%

Appendix 12. Comparison to RBSA Metering Report

Another component of the Residential Building Stock Assessment (RBSA) research is a detailed metering report (Larson, et al., 2014) of many end uses in the home. The analysis of data from 101 homes includes detailed energy load shapes for various water heating equipment, heating equipment, cooling equipment, major appliances, consumer electronics, and lighting, as well as whole-house energy use. Laundry equipment findings are in section 3.4.3 of that report and clothes washer and clothes dryer load shapes are in Figure 77 and Figure 78 in Appendix 8 of the metering report.

The metering report recorded energy data for a full year, where this laundry report recorded energy and logbook information for four to six weeks and extrapolated the data to a full year. Obviously, there could be potential estimation errors when doing this, but the average energy use between the two studies is in agreement with the error bounds, though the metering report energy use is at the very low end of the field study error bound. Table 87 shows the side-by-side comparison of the two studies broken out by dryer vintage. The overall estimate for the metering report shown below is not directly from the metering report; it is a weighted average of the two most recent vintages since the metering report included dryers as old as 1990. Both the metering report and laundry report show a drop in energy use for the most recent vintage of dryers, though the error bound in the metering report is quite high. In the field study, this drop in energy use was partly due to a shift from vertical to horizontal axis machine efficiency (see Table 71).

Table 87. Comparison of Yearly Dryer Energy Use to Metering Report

Dryer Vintage	RBSA Metering Report			Laundry Report		
	Mean	EB	n (S)	Mean	EB	n (S)
2005–2009	833	87	30	978	160	36
Post 2009	636	215	5	688	147	10
Overall*	805	unk	35	915	132	46

* For purposes of this comparison, calculation of the average only uses two vintages from the metering report, and no calculation of EB for this. Across all vintages in the metering report the average annual dryer use is 762 kWh ± 58 kWh (n = 64).

The difference in the dryer use could simply be random variation in this size of data set (as calculated by the error bound), but another potential source of the difference could be in the seasonality of data. The laundry report data was from four to six weeks in the late winter and early spring. Figure 94 and Figure 95 are excerpts from the metering report (from Figure 77 and Figure 78 in that report) and show the monthly load shapes for washers and dryers. The shape normalization by the number of days in the month provides a consistent metric for comparing across months. There do seem to be seasonal variations in both the washer energy use and dryer energy use, though the reasons behind this variation were not part of the scope of that metering effort. A quick glance at the following graphs shows energy use during the time of the field study (February through April) seem to be some of the higher dryer energy use months compared to the summer months. Also, the number of occupants in the field study is about 10% higher than in the metering study, so this could account for some of the difference in the field study showing higher energy use.

Figure 94. Washer Monthly Load Shape from RBSA Metering Report Figure 77

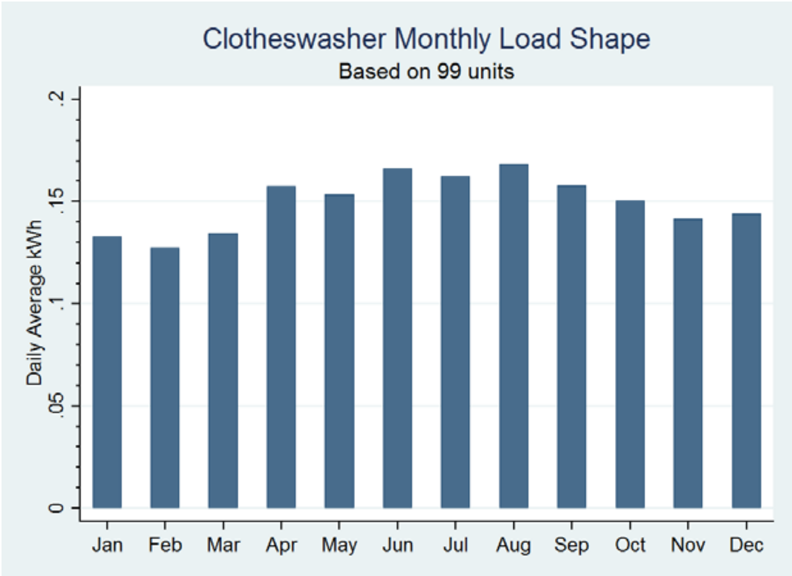


Figure 95. Dryer Monthly Load Shape from RBSA Metering Report Figure 78