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Heat Pump Clothes Dryers in the Pacific Northwest – Abridged Field & Lab Study Report

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Heat Pump Clothes Dryers in the Pacific Northwest

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Abstract

This study presents a summary of lab and field research conducted by the Northwest Energy Efficiency Alliance (NEEA) from 2013 through 2016 on heat pump clothes dryers for the North American Market. NEEA developed a modified lab test protocol that adds four test cycles using real clothing in a variety of load sizes and cycle settings to the US DOE dryer test protocol. The resulting metric has proven to be a better indicator of actual field performance. Lab testing of heat pump equipped clothes dryers are compared to three field studies of clothes washer and dryer pairs in 27 homes. The outcome of these lab and field tests are 1) a multi-tiered dryer efficiency specification that is the basis of utility energy savings estimates 2) a qualified products list used to promote high efficiency dryers sold in the Pacific Northwest and 3) recommendations on how future test protocols can be improved.

Background

Conventional dryer technology and efficiency have not improved since 1981. The small drop in dryer energy use shown in the NRDC graph in figure 1 is actually due to more efficient washers, which extract more water, so that the dryer does not have to work as hard. Northwest consumers own six million electric clothes dryers, more than 80% of which use electric resistance heating to remove moisture. NEEA is interested in advancing the adoption of “Super-Efficient Dryers” (SEDs) because of the potential (180aMW) of energy savings if the 6.6 million conventional electric clothes dryers in the region were replaced with super-efficient models.

Conventional dryers blow heated air into a rotating tumbler of clothing; moist air is then exhausted from the drum to the outdoors. This approach is effective, but very energy intensive, commonly using over 900 kWh per year for an average home, making it the highest energy use appliance. In a conventional electric dryer, only half of the energy is used to vaporize the water from the clothing, and virtually all of the expended energy is exhausted from the home. A conventional electric dryer is rarely capable of drying more than about three pounds of real clothing per kWh expended. By comparison, a heat pump clothes dryer is capable drying more than six pounds of real clothing per kWh expended.

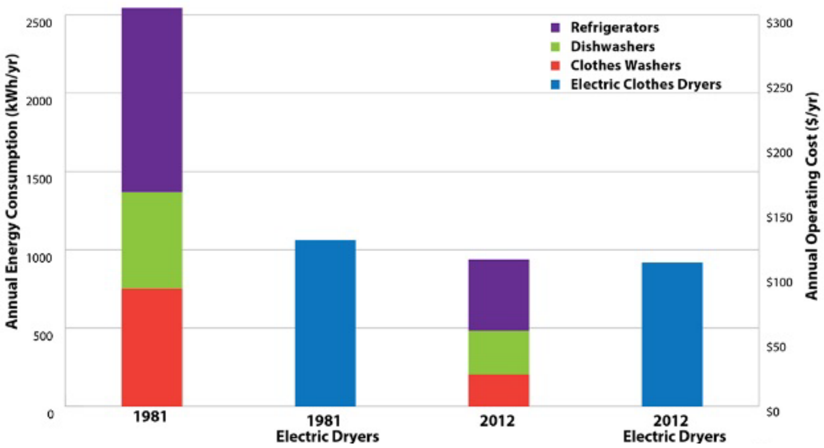

Figure 1 – annual energy consumption of electric clothes dryers vs. other major appliances (Courtesy of the NRDC [1])

Initial Field Study

In 2011 NEEA used fifty homes from its Residential Building Stock Assessment to provide a representative household sample for a field study of laundry energy use. The age of the laundry equipment in the sample homes was less than five years old and included 30% front loading washers. Researchers installed data loggers capable of monitoring the energy use of both the washer and dryer in the homes, and the homeowners were paid to record the setting, load weight, and completion time for each wash and dry cycle. The results [2] provide the following significant insights into dryer operation and usage:

- Average annual clothing weight dried in the Pacific Northwest is 2,342 lbs in 311 loads.
- Cycle settings and load sizes have significant impacts on dryer performance.
- Annual average dryer energy use is 915 kWh/yr, which translates to 2.56 lbs dried per kWh, 43% more energy per pound than is determined using the DOE D1 test procedure.
- About 40% of all loads weigh less than 4 pounds; these loads use nearly twice the energy per pound than loads greater than 12 pounds.
- The average initial moisture content from the washing machines was 62%. Many cycles begin much wetter than the average – the result of an incomplete or unbalanced spin cycle.

Supplemental Test Procedure

From 2012-2014 NEEA and Pacific Gas & Electric (PG&E) contracted the services of Ecova's appliance laboratory in Durango, Colorado to test various dryers, examine test procedure issues and ultimately develop a Supplemental Test Procedure [3] designed to increase the accuracy of energy consumption estimates of clothes dryers. The procedure generated a new metric based on the average performance of 5 different tests: one using the DOE test procedure cloths and setting, and four additional tests using real clothing in a variety of cycle settings and load sizes (see table 1 and figure 2). While the individual tests are not quite as repeatable or precise as the DOE test procedure, the lab results show better accuracy and predictive value than the DOE test procedure. The metric generated was deemed the "Utility Combined Energy Factor" (UCEF) with units of pounds dried per kWh. The UCEF value is a weighted average the "Combined Energy Factor" (CEF) of each of the five different tests.

Table 1 – Supplemental test procedure cycles and settings

Test	Common Test Name	Load Type	Cycle Setting	Cycle Temp	Nominal Load Weight (lbs)	Start Moisture	Max End Moisture
DOE Test (3.3.1.1)	D2	Standard DOE Test Load (4ft3 and larger drum)	Default	High	8.45	57.5%± 0.33%	2%
One (3.3.1.2)	Small	Small Supplemental Test Load	Normal	Medium	4.22	62%± 2%	4%
Two (3.3.1.3)	Large	Large Supplemental Test Load	Normal	Medium	16.9	62%± 2%	4%
Three (3.3.1.4)	Eco	Medium Supplemental Test Load	Mfr Defined	Mfr Defined	8.45	62%± 2%	4%
Four (3.3.1.5)	Fastest	Medium Supplemental Test Load	Heavy Duty	High	8.45	62%± 2%	4%

DOE Test Cloths   Realistic Test Clothing (small load = one of each)

Figure 2 – Dryer test procedure clothing items

In 2015, NEEA and PG&E used the STP to evaluate 12 conventional (non-ENERGYSTAR) dryers and six other dryers of various performance levels. With the closure of the Ecova test lab in 2015, NEEA transferred testing of laundry equipment to a nationally recognized test laboratory and conducted several validation tests to compare laboratory to laboratory results. As new super-efficient dryers entered the market, NEEA provided supplemental testing and feedback to participating manufacturers about how their products performed.

As of December 2016, 11 “super-efficient” dryer models have been tested. Table 2 provides a summary of the results of all testing to date. These dryers have distinctly different operating behaviors but can be generally classified as either a hybrid dryer or a heat pump dryer. The hybrid dryer has both the electric resistance heating elements of a conventional dryer and the vapor-compression cycle used to dehumidify the air and recapture heat of a heat pump dryer. Both vented and ventless dryers were among those tested. Ventless dryers located inside homes in heating climates provided additional energy savings benefits contributing to heat that offsets space conditioning needs. The amount of this offset depends on the home heating system, but in an average Pacific Northwest home this provides a 29-48 kWh/yr increase in annual total energy savings in a home.

Table 1 – Summary comparison of dryer performance supplemental test procedure testing

Test Machine	Model	Tech	Type	Vol	D2 cycle Time minutes	D2 lb/kWh	Small lb/kWh	Large lb/kWh	Eco lb/kWh	Fast lb/kWh	UCEF lb/kWh
Conventional 1	NED4600YQ	Conv	Vented	0.0	71	3.49	1.53	3.23	2.48	2.08	**2.3**
Conventional 2	MEDC300BW	Conv	Vented	0.0	59	3.08	1.50	2.05	3.13	3.16	**2.4**
Conventional 3	AED4675YQ	Conv	Vented	0.0	45	3.27	1.77	3.15	2.64	2.31	**2.5**
Conventional 4	WED4800	Conv	Vented	0.0	42	3.86	2.23	3.01	2.36	2.12	**2.5**
Conventional 5	DV45H7000EW	Conv	Vented	0.0	59	3.32	2.05	3.60	3.04	2.44	**2.7**
Conventional 6	GTDP220	Conv	Vented	0.0	45	3.52	1.84	3.59	3.10	2.65	**2.8**
Conventional 7	HTDX100EDWW	Conv	Vented	0.0	45	3.49	2.23	3.59	2.50	3.15	**2.9**
Conventional 8	MED3100DW	Conv	Vented	0.0	32	4.06	2.32	3.55	2.56	2.49	**2.8**
Conventional 9	FARE1011MW	Conv	Vented	0.0	55	3.19	2.16	3.49	3.61	2.50	**2.8**
Conventional 10	81382.00	Conv	Vented	0.0	48	3.57	2.39	3.64	3.23	2.87	**3.0**
Conventional 11	WED4800BQ1	Conv	Vented	0.0	56	2.99	1.94	3.19	2.80	2.61	**2.6**
Conventional 12	NED4600YQ1	Conv	Vented	0.0	75	2.87	1.26	2.91	2.42	2.31	**2.2**
ENERGYSTAR 1	WGD94HEXW0	Conv	Vented	0.0	57	4.02	2.20	3.82	3.00	2.40	**2.8**
ENERGYSTAR 1	WED87HEDW0	Conv	Vented	0.0	68	4.07	1.96	4.50	3.08	2.03	**2.7**
SED 1	DLHX4072	Hybrid	Vented	7.3	59	4.39	2.09	3.73	3.86	2.91	**3.3**
SED 2	WED99HED##	Hybrid	Ventless	7.3	62	5.43	2.20	4.38	3.64	2.89	**3.3**
SED 3	DHP244012W	HP	Ventless	4.1	76	10.25	5.62	7.78	7.45	7.16	**7.3**
SED 4	WED7990F#	Hybrid	Ventless	7.4	76	5.09	2.12	4.35	3.86	3.56	**3.6**
SED 5	WED9290F#	Hybrid	Ventless	7.4	67	5.43	2.63	4.84	3.87	3.38	**3.7**
SED 6	WHD3090##	HP	Ventless	4.3	99	7.48	3.59	5.53	6.07	5.80	**5.4**
SED 7	WHD5090##	HP	Ventless	4.3	98	7.41	3.25	5.42	4.36	5.53	**4.8**

EF and CEF values are in pounds dried based on bone dry weight starting at 62% remaining moisture content

Field Testing

NEEA completed three field tests of clothes washers and “super-efficient” dryers (see table 3). Field work was performed by staff of Ecotope Inc., while data processing and initial analysis was performed by staff of Ecova Inc. Final analysis and evaluation of the results was performed by NEEA.

The objectives of these field studies were as follows:

- Evaluate the effectiveness of the dryer supplemental test procedure
- Validate the savings difference between conventional and heat pump dryers
- Obtain initial consumer response and experience feedback on heat pump dryers
- Gather data useful in federal rulemaking procedures for washers and dryers

The field studies were performed according to the SEDI Field Test Protocol [4] developed by NEEA and the Super-Efficient Dryer Initiative (SEDI) The data collection included continuous metering of washer and dryer energy use during the study period. The test protocol required considerable effort by participants as they were asked to accurately record data for each load that included: time, weight before the cycle, weight after the cycle, settings used and observation notes on a laundry logging form.

Each field test started with ten households which recorded washer and dryer settings and clothing weights while a data logger recorded the energy consumption of both the washer and the dryer. Participant selection varied by each test, and was not done using a random sampling method, as time and access to willing participants was limited. Compensation was provided for participants in the form of either a discount for the purchase of their machine once the test period was completed, or financial compensation in the form of a gift card.

Each household washed and dried at least five loads using their pre-existing machines to establish a reference performance of conventional washers and dryers. Each household then washed and dried ten or more loads using a new matched pair of efficient machines provided by NEEA and the Manufacturers.

Table 3 – Field Tests

Field Test	SED Manufacturer	Location	PreExisting Machines	Date	General Notes
1	Whirlpool	Portland Metro	Various	Jan-15	*9 households completed*
2	Blomberg	Renton	Stacked Combo	May-15	*8 appartments completed*
3	LG	Boise Metro	Various	Jul-16	*10 households completed*

Data Logger System

The data logger 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 were collected in a few homes to capture the impact of the machine on the room air. Each site venting system was checked prior to the installation of the monitoring equipment to ensure it was not blocked and a reasonable venting system was present.

Each participant was provided with a digital scale accurate to +/- 0.1 lbs with which to weigh the clothes before and after each cycle. The participants were asked to subtract the tare weight of the basket before entering data in the logbook.

Data Sets

Each site generated at least two data sets. The first data set is the raw metering data collected by the data logger. This data set consists of minute level recording of the washer watt-hours, dryer watt-hours and time stamp. The second data set includes the logbook recordings from the participant. These data are hand written paper forms. A third data set was generated in a few homes where temperature and relative humidity recorded using an Onset Hobo MX temp/RH logger.

Ecova staff digitized the customer log book data and double checked entries for reasonableness and missing entries. When analyzing each participant's logbook entries, it was necessary at times to interpret or make assumptions for some specific entries. The Whirlpool logbook gathered the most information from the participants, however it was also the hardest to interpret and analyze.

Customer data and metered data sets were combined and aligned. Each entry in the logbook was identified in the metered data. Because of participant errors or skipped entries not all laundry cycles could be properly identified and aligned between the two data sets. In a few cases the alignment was difficult with less than 50% of entries being accurately identified. For most sites however, more than 90% of all entries were clearly identified and aligned.

The process of aligning the two data sets required matching the start and end timestamps of the logger data to determine a “cycle time”. This was not always possible due to participant errors. In some cases, the date and time that the participant recorded did not exist in the logger data. In other scenarios the participant may have written a single date and time when the logger data would show two separate cycles. These separate cycles could be within an hour of each other or some instances showed the cycles being over 5 hours apart from each other. Care was taken to only accept data where cycles could be clearly aligned.

Data Scrubbing

Consistent with the work done in the in NEEA laundry field study [2] of 50 homes, data was screened for reasonableness. Entries where the logbook entries resulted in nonsensical results the data was discarded. For example, when starting weight of wet clothing in the dryer was less than ending weight of dry clothing.

The primary data scrubbing criteria discarded any wash cycle that ended with moisture content above 100% or below 33%. Lab testing NEEA had conducted of both cotton polyester blends and 100% cotton loads did not produce remaining moisture contents below 36% under any circumstance. Cycles above 100% are suspect as participant logbook failures because this would be indicative of a washing machine malfunction. Data scrubbing also removed cycles where the energy factor (pounds dried per kWh) exceeded the theoretical performance limits of the dryer.

Additional data scrubbing was applied when the logbook did not provide enough information to explain minor gaps within logger interval data within a single cycle. For example, a participant may record a single date and time of a cycle with no other information whereas the logger data shows a dryer cycle of 40 minutes with a 15-minute gap of power consumption and a final 20 minutes of power consumption. When analyzing this data, one would either assume two separate cycles or a single cycle with a gap (possibly participant caused). Assumptions were made throughout the data to best correlate power consumption data to participant transcribed entries. In some cases, data could not be correlated accurately to participant entries and were removed from the final results. Care was taken during analysis to infer that any removed or bad data found from the power logger and information transcribed by the participant were beyond a reasonable doubt to alter the results.

Reasons for Data Removal:

- Customer did not record weight or other relevant information (participant left entry blank).
- Participant removed clothing during the cycle but did not record the weight of clothes removed.
- More cycles recorded by data logger than what they recorded in the logbook.
- Unreasonable values recorded by participant (5.6 lb start weight to 21.2 lb wet weight) lead to high remaining moisture content (RMC) values that skew data.
- Participant logged more cycles than were recorded on data logger for the specified date by participant.
- Participant did not record vital information (time or weight).
- Participant recorded cycles and no logger data was found for that day/time.
- Participant recorded date could not be correlated to logger data.

Field Test Details

Whirlpool Field Study

The study tested the Whirlpool WED99HED “HybridCare™” with the companion Whirlpool WFW87HEDW Duet® washer. The HybridCare dryer was the first full-sized dryer to enter the US market using a heat pump. (Note – US models are based on volume, and do not provide rated capacity by load weight). The study began in late 2014 as part of Whirlpool’s customer use field testing just prior to market introduction. The Whirlpool WED99HED “Hybrid Care™” clothes dryer is a 7.3 cubic foot dryer that has both a 1300W electric resistance heating element and a roughly 900W heat pump compressor cycle. The unit is ventless, meaning it continuously circulates air through the drum rather than venting air to the outdoors. Each time air is cycled, the cold evaporator coil removes moisture and the hot condenser coil re-injects heat. The electric heating element adds additional heat during both startup and when a cycle setting requires additional heat. All condensation is pumped to the same drain location as the washing machine.

Whirlpool generously provided both washer and dryer sets at no cost to the participants in exchange for data collection. The participants were selected by Whirlpool from a group of Energy Trust of Oregon and NEEA staff. The participants in this group tended to have smaller families with above average household incomes. Whirlpool acknowledged that the product was initially targeted at households where energy savings were important and with incomes that could support premium product pricing.

Blomberg Field Study

The second study began in the fall of 2015 soon after the Blomberg DHP24412W became available in retail stores in Washington. The preexisting machines were Whirlpool LTE5243DQ9 units (compact washer/dryer unit). The efficient machines were a Blomberg WM98400SX washer and the DHP24412W heat pump dryer. The Blomberg unit is the 5th generation heat pump compact (24" wide) clothes dryer built by Blomberg. Blomberg is owned by Arçelik A.S., which is based in Turkey, and is a major manufacturer of appliances for Europe and Africa. The Blomberg dryer has no supplemental electric resistance heater. The dryer and matching washer are only sold as a pair because the washer plugs into the dryer and both operate on 240AC. The North American version is based on the European product with component changes needed to achieve UL listing. Blomberg positioned these products for the apartment and condo markets to take advantage of their compact size and ventless characteristics.

The participant households were selected by the property manager of an apartment building from a limited number of respondents. Participating households had family incomes considerably lower than the other field studies. This study was challenged by the indirect nature of working through a property manager rather than directly with the apartment occupants, language barriers, and scheduling visits. The laundry equipment was located in the hallway or spaces adjacent to bathrooms. In many sites, the washer/dryer pair were located behind louvered doors, which limited the air circulation near the equipment.

LG Field Study

The third study began in the spring of 2016 in Boise, Idaho. The energy efficient machines were an LG WM3670HVA washer and the DLHX4072 EcoHybrid heat pump clothes dryer The LG DLHX4072 dryer that was used had been in the market for some time, but with minimal sales. This unit is nearly mechanically identical to the Kenmore hybrid heat pump dryer. Both are vented machines, exhausting air through the same ductwork that a conventional dryer uses and dumping condensed water into the same drain location as the clothes washer. Unlike the Whirlpool hybrid dryer, the LG unit has a larger (2500W) electric resistance heater element, making it capable of operating more quickly when both the heat pump and electric resistance element are on.

Idaho Power selected ten single-family households to participate based on general criteria provided by NEEA. All participants completed the study. All pre-existing washers were top loaders, and many of the pre-existing dryers were very old. Households selected by Idaho Power provided a good representation of size and income levels, with a mixture of largely indoor and some garage laundry locations.

Field Test Results

Laundry Use

Table 3 provides a high level summary of laundry use in the three tests. Cycle temperature settings were not available on the Blomberg and Whirlpool units as these units fully automated that element of the dryer cycle. Total laundry use if extrapolated to an annual amount varied between the different tests, likely because they were taken at different times of the year when clothing weights and the amount of clothing washed may vary.

Table 3 - SED Field Test Laundry Use

	Blomberg	Whirlpool	LG	PreExisting	
Number of Cycles	151	104	275	242	cycles
Valid Cycles	58	79	138	177	cycles
% Valid	38%	76%	50%	73%	%
Total Lbs Clothing	389	712	1158	1440	lbs
Average Load Size	6.70	9.01	8.39	8.13	lbs/cycle

Figure 3 shows the distribution of load sizes bins (pounds) for each machine. While the Blomberg unit specifications indicate it can handle full sized loads, users infrequently loaded the dryer with more than 10 pounds of clothes. No instruction was given to participants on how full they should fill their machines. The size of the washing machine is likely a strong influence in how full the dryer was filled. Thus the larger the washer to drum volume ratio, the more likely the dryer had a fuller load, possibly enhancing drying efficiency. The washer to dryer volume for both the Blomberg and LG machines was 61%, and the Whirlpool machine was 56%.

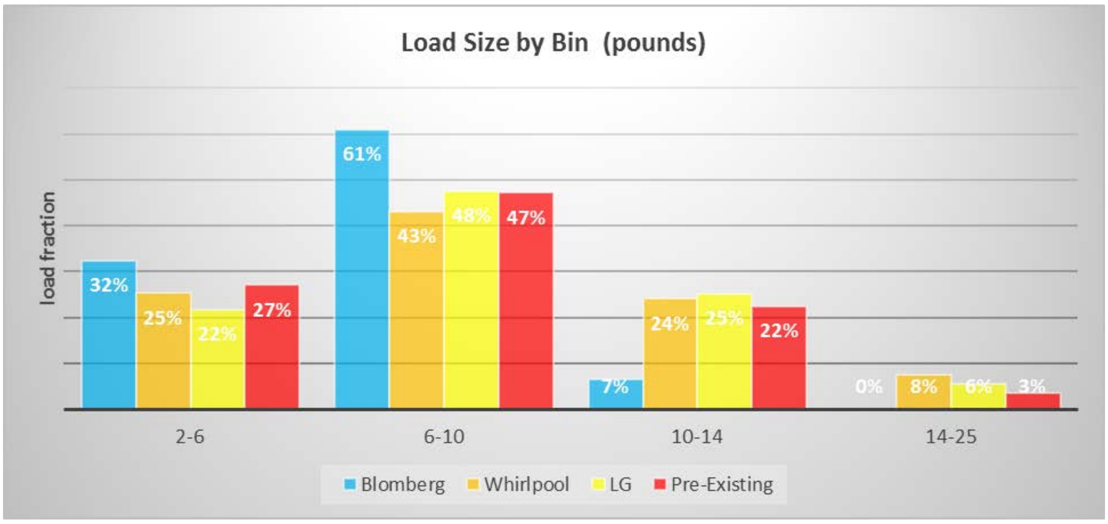

Figure 3 - Load Size by bin

Figure 4 shows cycle time by the same 4lb bins used in figure 3. It is surprising how much longer small loads take on a per pound basis than large loads. This data suggests that it is best to load the washer and dryer full for the fastest overall laundry washing and drying. Breaking the drying into multiple cycles results in a total drying time that is roughly 1.5-2.0 times longer.

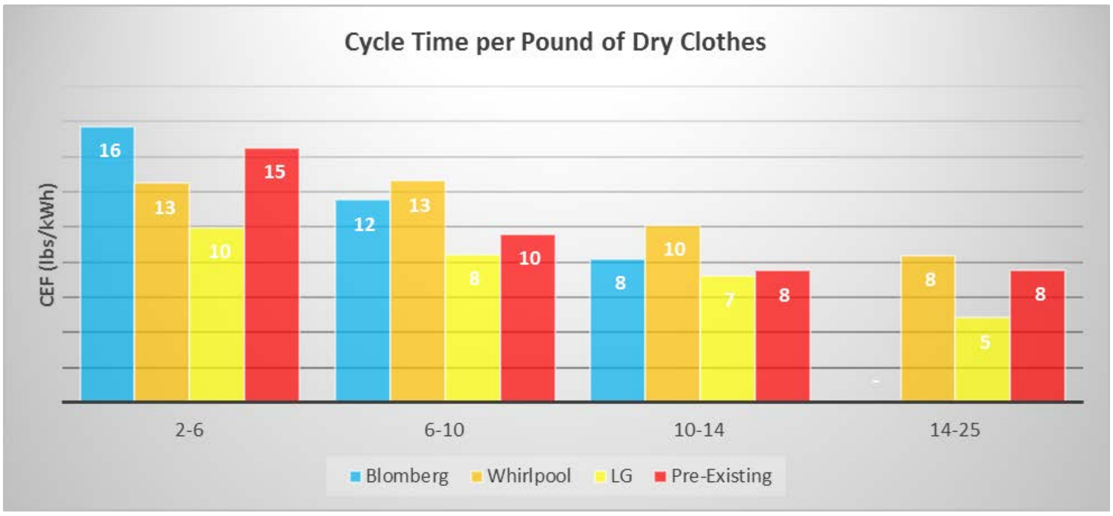

Figure 4 – Cycle Time by load size bin

The time it takes a clothes dryer to complete a drying cycle depends mostly on the start of the load and the amount of water in the clothing. Figure 5 presents the drying speed per pound of water removed. This provides a ranking that is independent of what kind of washing machine was used. A typical laundry load for a compact (24" wide) dryer contains about 3lbs of water, whereas a full sized (27" wide) dryer load contains about 4 lbs of water at the start of the cycle.

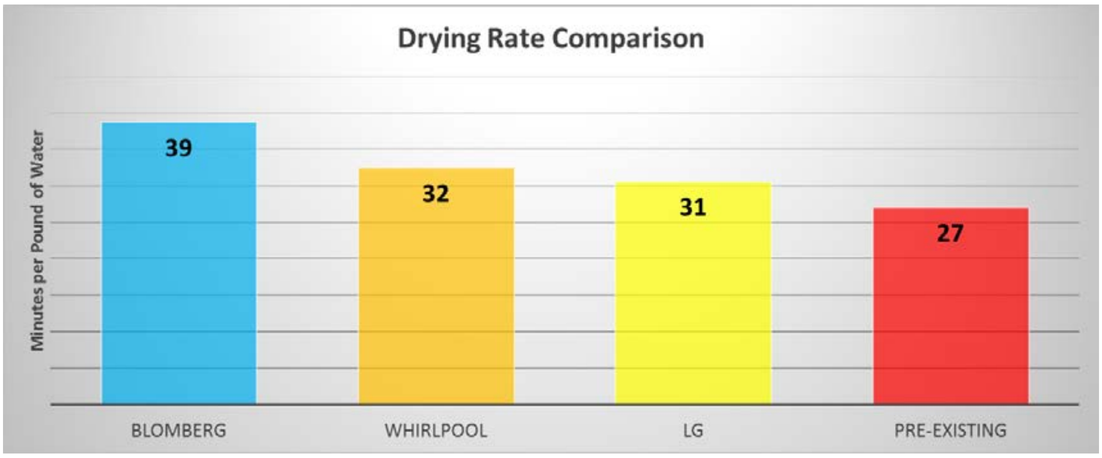

Figure 5 – Drying rate per pound of water

Figure 5 shows hybrid dryers take 16-18% longer and the tested heat pump dryer (Blomberg) took 44% longer per pound of initial moisture. This is not surprizing, given that the heat pump-equipped dryers had 20%-50% less heat injected into circulated area. The true consumer experience is best presented in figure 6 which shows the additional time each machine type took to dry an average load of laundry compared to the pre-existing machines. The difference is not as significant under real world conditions because of the size of the drum and starting moisture the paired washing machines.

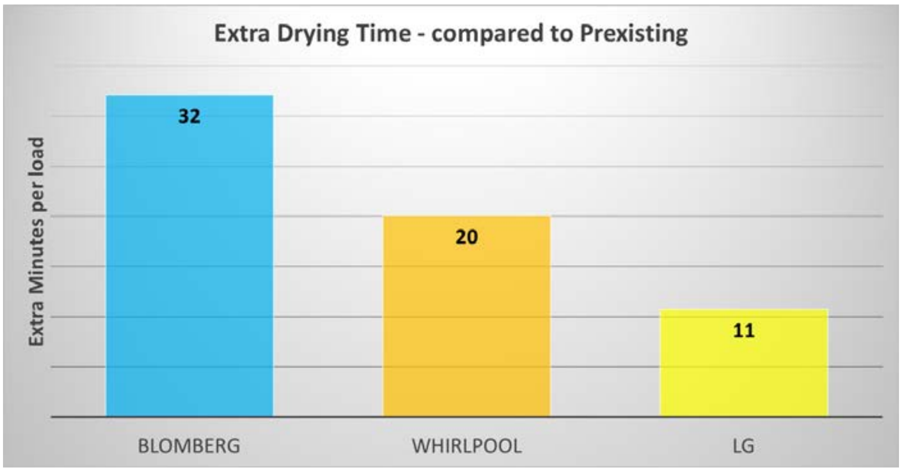

Figure 6 – Extra drying time for typical load compared to pre-existing

Participant Perception

Participants completed a survey about their perception of the dryer in comparison to their expectations and previous experience with other dryers. The survey was used to determine if there were any underlying product problems inherent in hybrid heat pump or heat pump clothes dryers that were different from conventional dryers. While each survey varied slightly, the core questions remained the same. Overall, customers were satisfied with the experience of all heat pump dryers. No significant problems with hybrid or heat pump dryers were identified.

Whirlpool Perceptions

The Whirlpool field study survey asked for participant impressions both at the conclusion of the field study and six months later via a separate questionnaire, but responses remained did not change significantly. A few participant notes on the surveys indicated that the hybrid dryer took longer than desired when drying large loads. Condensate drains on a few of the Whirlpool participants' systems were not properly attached when installed. This resulted in initial complaints because water ran onto the floor under the dryer. This is not a machine failure, but rather likely because the installing crew for these systems were untrained and unfamiliar with condensing dryers.

Blomberg Perceptions

The Blomberg survey indicated that participants were satisfied with overall performance but provided valuable insights on potential concerns. The first insight is the importance of having properly trained installation crews ensure the condensate drain line is connected from the dryer to the washer drain standpipe. The condensed water poured on the floor and the participants assumed the washer had failed. Once the condensate drains were properly connected, there were no further complaints.

A second insight is that drying took longer than expected by some of the participants. The highest fraction of participants that chose "fair/acceptable" related to the drying time of the dryer. Written comments and notes that indicated that a small sample of participants needed to run additional and different dry cycles in order for clothes to become completely dry.

LG Perceptions

Overall those using the LG washer and dryer pair had very high satisfaction levels. All ten participants chose "Very Satisfied". As with both the Blomberg and Whirlpool field tests, installation of the condensate drain was identified as a potential issue. Extra care was taken to ensure the condensate drain was attached and participants understood the purpose of the drain line from the dryer.

Performance

Clothes dryer performance can be investigated using a variety of metrics. The common North American dryer efficiency metric is how many pounds of clothes can be dried per kWh of expended energy (lbs/kWh) assuming the same starting moisture content. This metric is generically referred to as the "energy factor" (EF). Adding in additional energy used in standby mode for over a year generates a "combined energy factor" (CEF). The standby energy is small (typically less than 50 Wh/cycle), and therefore has minimal impact on the energy factor values. The "utility combined energy factor (UCEF) that uses the supplemental test procedure is a lab test metric and more accurately estimates real world energy use the current DOE test procedures (D1 or D2) generate.

Field studies cannot collect data needed to precisely determine the remaining moisture content because the bone dry weight of any load is unknown. We do not know if the clothing placed in the washer was wet or if the clothing removed from the dryer was truly dry. Field study CEF calculations are based on an assumption that both the moisture content of clothing before it went into the washing machines was 4%, and the ending moisture content is the average of how the machines performed in the lab, or 4% when that data was not available.

To compare field CEF values to lab UCEF values requires normalizing the CEF values to the same starting moisture level as the lab tests. For example, if one cycle started at 62% RMC and another started at 41% RMC the results would not be comparable because the two cycles removed different amounts of water from the clothing. CEF values in this study were adjusted to common staring moisture of 62% to be consistent with lab test conditions. This adjustment introduces some error into the CEF values because drying efficiency is not constant during laundry cycle. Lab tests show that the final 10-20 minutes of a drying cycle are less efficient than the bulk drying phase of the drying cycle. To account for this non-linearity, CEF values were adjusted to a common initial moisture content using a two-step approximation for drying that assumes a different drying rate during the "finishing" part of the. We assumed the average finishing efficiency of all dryers to be 0.63 kWh/lb of water during once the clothing achieved 13% remaining moisture content.

While the pre-existing machines are not a market average representation of older machines they do provide a reasonable reference baseline because the both pre-existing and new laundry equipment were conducted in same household, with the same laundry habits, and desired outcomes. For evaluation simplicity, all pre-existing machine performance data was combined into a single data set.

Error cause by data entry mistakes, tare weight errors, logger error, scale accuracy, and possible data scrubbing and filtering mistakes, is estimated at ±0.1 lb/kWh. This is not the same as the uncertainty of the metric however, as it does not include the larger impact of clothing type, cycle type, load size and setting selection. The average CEF of all the pre-existing machines was 2.45 lb/kWh. By comparison, the fifty homes sampled in 2012 had an average CEF value of 2.66 lb/kWh.

The scrubbed performance data is presented in Table 4. The Raw Field CEF values are based on the remaining moisture from the clothes washer, which varies considerably from load to load. The Adjusted CEF values have been normalized using a two-step adjustment to a common remaining moisture content of 62%.

Table 4 – performance summary of field results

	lb/kWh Calibrated Lab UCEF	lb/kWh Raw Field CEF	Ave Field RMC	lb/kWh Nomalized Field CEF	Energy Savings
Blomberg 24412	7.3	8.3	52%	7.1	65%
Whirlpool WED99HED	3.3	3.8	52%	3.3	25%
LG HPDLHX4072	3.3	4.2	49%	3.2	22%
Pre-Existing Dryers	2.6	2.5	59%	2.4	0%

Normalization adjusts field data to same 62% starting RMC (consistent with Lab Test)

Figure 7 presents the performance of the machines as a function of load size. Heat pump-equipped dryers are more efficient with larger loads, whereas conventional dryers appear to perform less efficiently with larger loads.

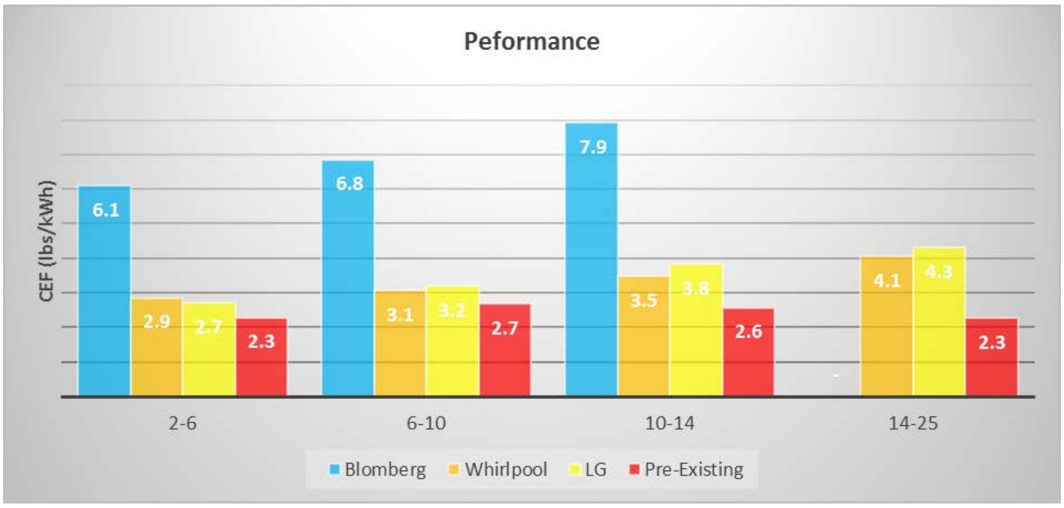

Figure 7 – Performance by load size

Figure 8 presents annual dryer energy consumption assuming 2342 pounds of clothing were dried[1]. “Lab Results with Ave Washer” columns show lab test results with staring remaining moisture of 62%. “Field Results with Ave Washer” are based on field data with the starting remaining moisture of 62%. The shaded bars show the energy use of the dryer as it actually performed in the field with the clothes washer with which it was paired. Field results of Whirlpool and LG are essentially the same with an estimated annual energy consumption of 717 kWh/yr and 742 kWh/yr respectively. The Blomberg dryer however would use an estimated 330 kWh/yr to dry the same amount of clothes.

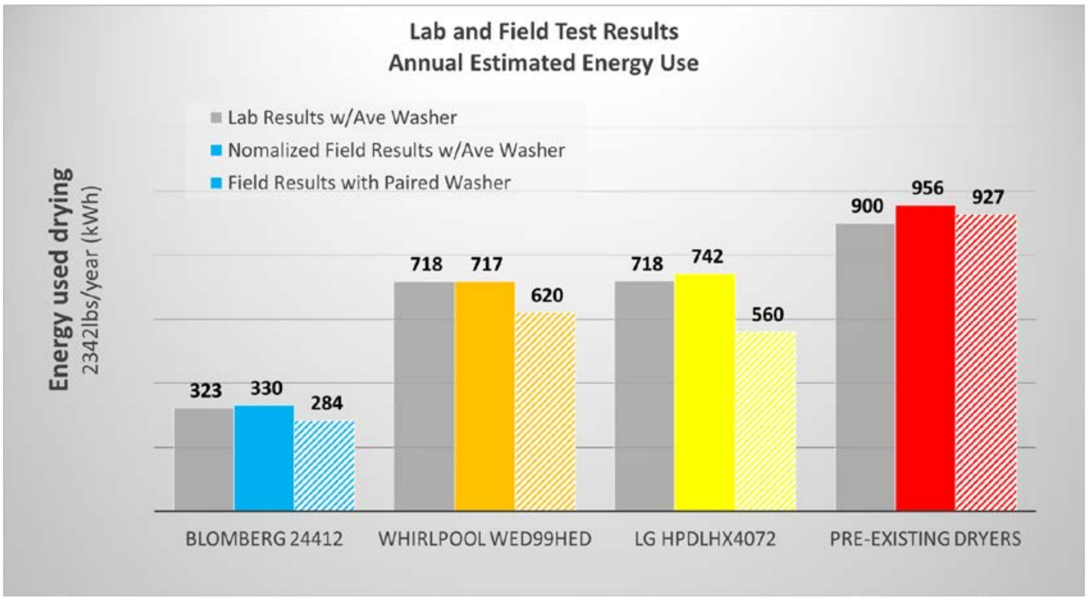

Figure 8 – comparison of lab to field results

Figure 8 also shows the difference between energy a dryer would use if paired with a typical washer that leaves the clothing at 62% remaining moisture content, and the actual remaining moisture content of the paired washer. The bright color columns illustrate the energy use if paired with typical washing machines and the stripped color columns illustrate estimated annual energy when paired with the more energy efficient clothes washer. The LG washing machine was able to spin-dry the clothes to a lower average RMC of 45% helping it achieve an annual energy consumption estimate of

[1] The NEEA field study [2] established that an average household dried of 2342lbs of clothes each year

560 kWh/yr. The Whirlpool washing machine was able to achieve an average RMC of 47% helping it achieve an annual energy consumption estimate of 620kWh/yr. The Blomberg washing machine was able to achieve an average RMC of 50% helping it achieve an annual energy consumption estimate of 284 kWh/yr.

Figure 9 shows the remaining moisture content from the clothes washers for different load sizes. The washing machines are able to extract a consistent amount of moisture in all but the small loads bin. This is consistent with lab testing of washing machines conducted for NEEA in 2015 that revealed that loads of 4 pounds or less had a higher likelihood of incomplete spin cycle resulting in higher RMC values for low weight loads. It should be noted that the data was scrubbed for incomplete cycles by removing load sizes than 2lb load sizes and RMC values greater than 100%.

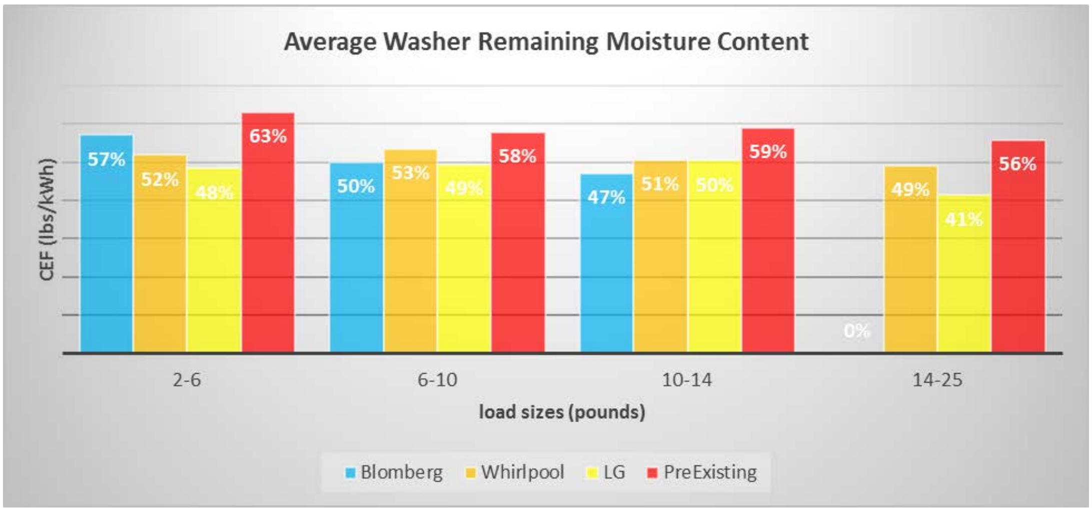

Figure 9 – Average RMC of clothing before being dried by load size bin

Figure 10 breaks out the energy savings resulting from the clothes washer and clothes dryer compared to the pre-existing dryers and washing and the baseline washing machine that leaves clothing with a 62% remaining moisture content. The graph illustrates the interdependence of the washer and dryer on overall performance. The Whirlpool dryer for example is more efficient, but the LG washer does a better job of removing moisture, resulting the paired performance being better with the LG than the Whirlpool. The washer savings of the pre-existing machines is slightly positive (29kWh) because the average RMC of the pre-existing machines in the field test was slightly lower (56%). This is because several of the homes in the field set had more efficient ENERGYSTAR front load washers.

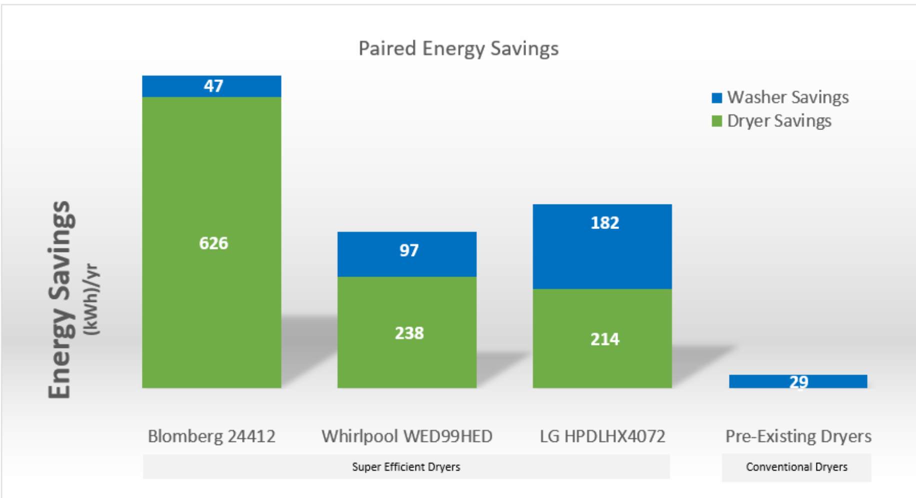

Figure 10 – Energy Savings from washer and dryer

Dryer savings of the three tested machines is consistent with savings estimates generated by lab testing and approved by the Northwest Regional Technical Forum (RTF) prior to the field tests. The RTF savings were estimated at 484 kWh/yr for the Blomberg 183 kWh/yr for the Whirlpool and LG machines.

Laundry Cycle Comparisons

Figure 11 shows dryer energy use versus the weight of the water removed. This provides a clean comparison of dryer performance independent of how well the washing machine spun-dry the clothing before it was placed in the dryer. The LG and Whirlpool machines are more efficient than the pre-existing machines, especially for larger load sizes. For small amounts of water removal, the difference between the hybrid dryers and pre-existing machines is small, whereas the pure heat pump technology used by the Blomberg dryer however is consistently more energy efficient.

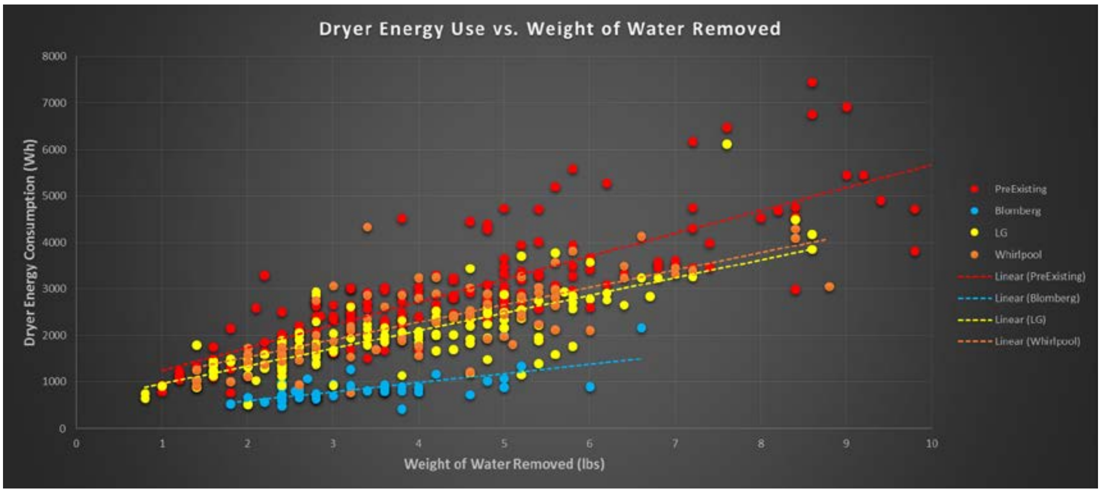

Figure 11– Wash and Dry Energy

Figure 12 shows the total energy consumed by both the clothes washer and clothes dryer compared to the cycle time of the clothes dryer. The Pre-Existing machine data his has greater variability and clearly shows very high energy for some wash and dry cycles, consuming as three times as much energy as the Blomberg pair is used for the same amount of clothing. Closer investigation of the Blomberg paired energy use revealed that the Blomberg's onboard water heater added an average 336 Wh to the wash cycle, which was not present in the LG and Whirlpool machines.

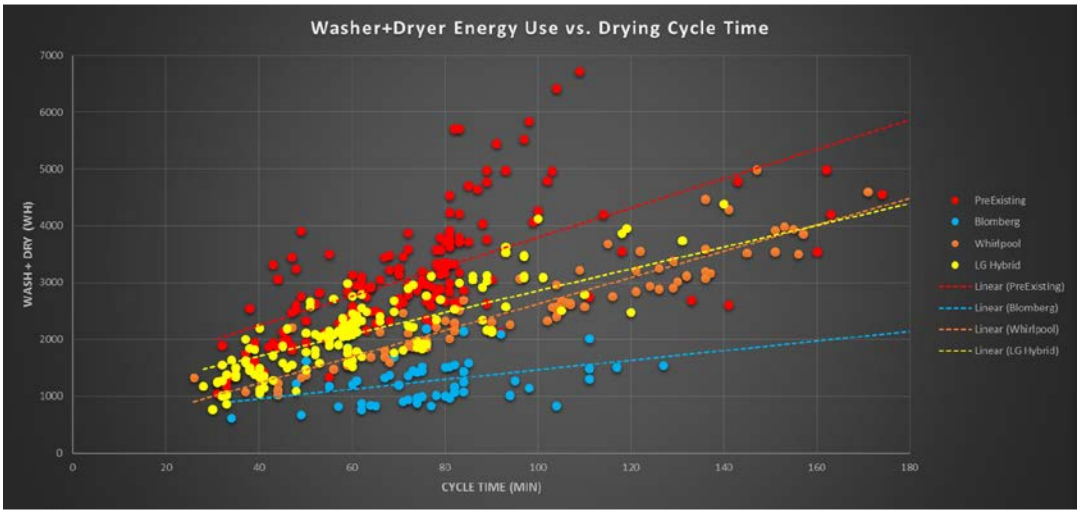

Figure 12 – Washer and Dryer Energy Use Cycle Time

UCEF Metric Calibration

Data gathered in the field was used to calibrate the weighting factors applied to each of the five supplemental test procedure CEF values. Figure 13 shows the proportion of loads used for each machine in the four field tests. Prior to this analysis the weighting factors of the five tests was assumed to be 20% on all cycles. The revised weighting factors of 10%, 30%, 10%, 20% and 30% applied to the test cycles of D2, Small, Large, Eco and Fast respectively

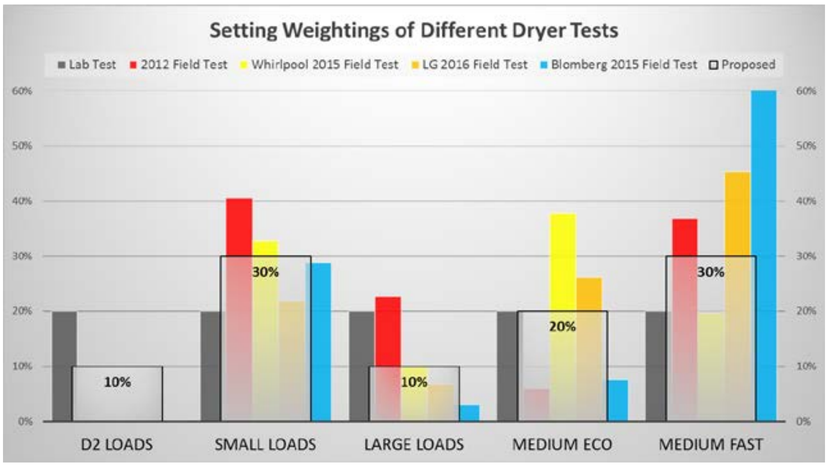

Figure 13 – Revised Weighting Factors based on real world use

Using the DOE D2 test results in an underestimation of annual energy consumption. In addition, the relative performance of different settings are not reflected in the overall dryer performance. *On average*, the D2 metric underestimate energy consumption by 33%. By comparison the energy use estimates based on the supplemental test procedure are on average within 5% real world conditions. Using the supplemental test procedure, while not perfect, is much better at characterizing the dryer energy use by not solely relying on the "as shipped" default cycle setting and testing with dimensionally simple, thin 50% polyester momie cloths as the basis for testing the dryer performance.

Summary

The field studies successfully achieved the study objectives.

First, the supplemental test procedure appears to provide an effective metric for estimating energy use of clothes dryers under real world conditions. The data enabled a change in the weighting factors applied to the five different tests of the supplemental test procedure.

Second, the savings between conventional dryers and SEDs met real world expectations, though just barely. The incremental savings of the hybrid dryers was expected to be approximately 30% better than conventional dryers. The field data however, reveals that the percentage savings was 20-25% for the first generation of US market hybrid models and 65% for the tested compact heat pump model. Recent testing of the second generation US market hybrid dryers will reveals savings in excess of 30% (see table 2).

Third, consumer response was favorable, with no major faults identified. The one issue consistently identified is the need for installation crews to reliably connect the condensate drain to the washer drain. While no long term evaluation was conducted it is reasonable to speculate that training should also be provided to instruct consumers to properly vacuum out the secondary lint filter on machines that have them (e.g. Whirlpool and Blomberg). Recent anecdotal evidence supports this assertion. Drying time may also be a factor that should be explained to consumers. When paired with a good high speed washing machine, SEDs provide drying times that are typically 10-30 minutes longer than conventional machines.

Fourth, considerable data was collected to support improvements in US federal dryer test procedures. Data collected will allow stakeholders to consider the benefit of increasing the number of tests conducted to improve the overall accuracy of energy consumption measurements and the impact of user-selected cycle settings, and user-chosen load sizes and fabric types.

Discussion

Determining how much energy a clothes dryer will use is not simple, especially in hybrid machines that employ two methods of reducing humidity in the air circulated. A performance metric is difficult to validate because of the interaction between the washer and dryer, user cycle settings and fabrics being washed and dried. Developing an absolutely accurate metric is neither necessary nor affordable. This study has confirmed the limitations of the US DOE clothes dryer test procedure. At a minimum, the following minor changes would enhance clothes dryer test procedures:

1. The normal load load sizes should be based on drum volume. 1.0 lb/ft^3 of drum volume would provide a reasonable average of the weight of clothing typically placed in a clothes dryer.
2. A small load size (e.g. 0.3 lbs/ft^3 of drum volume) should be added to capture the inherent inefficiency of under-capacity dryer cycles.
3. Testing should include at least one additional alternative cycle setting. The most logical choice is a high energy consumptive setting. This would avoid the risk of machines being shipped with default settings that are rarely used by consumers and capture a broader range of operating conditions.

A combined washer and dryer pair performance metric is worth serious consideration for two reasons. First, laundry equipment manufacturers commonly design and sell matched washer and dryer pairs for both aesthetic and customer satisfaction reasons. Second, it would simplify the overall performance estimation of laundry equipment and avoid the energy use overlap currently present in the two metrics. The current US DOE Washer metric includes dryer energy that results in both an overestimation of washer energy use, and underestimates the benefit of a pairing a highly efficient clothes dryer with a clothes washer that does an excellent job of spinning out moisture prior to drying.

Although Hybrid clothes dryers are intended to improve customer satisfaction by allowing quicker drying times, the data suggests that this benefit is only moderate. Development of full sized heat pump dryers for the US market should be possible with only moderate impact to drying time.

Data collected on laundry room relative humidity and temperature (while not presented in this report) suggests that unvented machines need to be evaluated for condensation efficiency and the amount of heat being added to the space. Further study is warranted to determine if unvented hybrid machines risk adding too much heat and moisture to laundry rooms in climates where such heat would be a disadvantage.

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[2] Horowitz (2014). National Resources Defence Fund (NRDC) press release.

[3] Utility Test Protocol for Residential Clothes Dryers A Combined Supplemental and DOE D2 Test Procedures, Northwest Energy Efficiency Alliance, can be downloaded from Conduit website https://conduitnw.org/Pages/File.aspx?rid=2843

[4] Wold C., Grand C.,(June 2014) CLASP, *SEDI Field Test Protocol*, downloadable at http://clasp.ngo/en/Resources/Resources/PublicationLibrary/2014/SEDI-Field-Test-Protocol.aspx

Additional Relevant Resources

(not referenced in paper)

[A] Badger C., Foster R., Granda C., Wold C. (2012). 2012 ACEEE Summer Study on Energy Efficiency in Buildings, *Bringing North American Clothes Dryers into the 21st Century: A Case Study in Moving Markets.*

[B] Bend P., (2010) 2010 ACEEE Summer Study on Energy Efficiency in Buildings, *Are We Missing Eenrgy Savings in Clothes Dryers?,* Ecos Inc.

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[E] Denkenberger D., Calwell C., (Ecova) and Ferstrom G. (2014). 2014 ACEEE Summer Study on Energy Efficiency in Buildings *The Time is Ripe for Paying Attention to Clothes Drying Technology and Policy in Relation to Efficiency and Drying Time* by PG&E.

[F] Dymond C. (2014). 2014 ACEEE Summer Study on Energy Efficiency in Buildings *Testy Testing Makes for Better Transformation* by Northwest Energy Efficiency Alliance.

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[I] Northwest Energy Efficiency Alliance, Emerging Technology Research: *Clothes Dryers 2013*, can be downloaded from at http://neea.org

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[J] Wold C., Denkenberger D., Calwell C., Beck N., Trimboli B., Driscol D. (March 2013). CLASP, *Analysis of Potential Energy Savings from Heat Pump Clothes Dryers in North America*.