Clothes Dryer Testing
Testy Testing Makes for Better Transformation

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ABSTRACT

This paper presents results from field-testing of clothes dryers in fifty Northwest households. When combined with previous lab test results, these data support the case for modifying the current dryer test procedures to promote market differentiation of efficient clothes dryers.

Dryers are significant energy-using household appliances, yet manufacturers have not been able to earn an ENERGY STAR® label and very few utility incentives exist. While the U.S. Department of Energy (DOE) has adopted a minimum efficiency standard, it is not meaningfully stringent. The historic rationale for a lack of focus on dryers has centered on perceptions of their undifferentiated energy use.

DOE recently finalized an additional, voluntary clothes dryer test procedure that measures the energy consumption of dryers in automatic termination mode. Dryers tested under this procedure demonstrate more significant differentiation in energy use than those in previous DOE test procedures. While this new procedure is a step in the right direction, a more realistic test procedure would enable utilities to reward manufactures for meaningful efficiency improvements.

Clothes dryers with half the energy use and a third the demand of our current fleet are readily available in Europe and Asia, but not in North America. Alignment of test procedures with utility program structures constitutes the precursor for manufacturers to invest in versions of these products tailored for North America. This paper presents test changes to reward clear efficiency leaders and to build market confidence in such products.

Challenges of Estimating Real World Dryer Performance

Accurately assessing the real-world performance of clothes dryers extends beyond simply measuring how well they perform in the laboratory using test cloths. Energy use in clothes dryers is dependent on a large range of variables, unlike water heaters or televisions, whose energy use is determined merely by how much water they heat per unit of energy or how many hours they run. Under real-world conditions, clothing loads vary by weight, volume, fiber composition, physical structure, and initial water content; in addition, dryer energy use is significantly affected by the settings used by the consumer and ultimately by the dryer's interactions with the home's heating and cooling system.

Evaluating the annual energy performance of dryers in the real world requires two elements: first, using a repeatable lab test that most accurately approximates dryer performance and the rank-ordering of different models; and second, understanding how consumers use the dryers. What types of clothing are used? How often do consumers leave the dryer on its default setting? What are the fractions of different settings used? How often is clothing removed or added in between the washer and dryer cycles? How many cycles are completed per year? What is the impact of duct restriction? – and so forth.

The increasingly nuanced controls of new dryers, with their multitude of clothing type settings, tumble settings, temperature settings and naming conventions such as “gentle,” “eco-normal,” “eco-boost,” and “turbo,” presents a complicating factor. Characterizing these in a way that enables researchers to calibrate lab-testing to field-testing is challenging, and necessitates defining operational conditions that describe how consumers use their dryers independent of the manufacturers’ chosen setting names.

The industry’s ultimate goal is the development of a methodology that uses field experience to generate a calibration factor or multiple calibration factors that appropriately scale lab results to reflect real-world energy use. Doing so requires a test procedure that accurately captures rank-order performance across a sufficiently wide range of consumer operational settings.

Why Are We Being So Testy?

Clothes dryers have until relatively recently constituted a neglected opportunity for electrical energy efficiency. The market/industry has long assumed that most of a dryer’s energy is used to vaporize the water, and that an already-efficient electric resistance heating element supplied the heat. Thus while most major appliances have become twenty to sixty percent more efficient as a result of ENERGY STAR® , stricter federal efficiency standards, and improved technologies and efficiency programs, clothes dryer technologies have remained relatively unchanged since the introduction of the automatic termination sensor in the early 1950s.

As of 1994, the National Appliance Energy Conservation Act set the effective US efficiency standard for clothes dryers at 3.01 pounds of clothing dried per kWh (NAECA 1987), using the 1981 DOE test procedure for clothes dryers with its baseline assumptions that the average home dryer completed 416 cycles/year on a seven-pound load with an initial moisture content of seventy percent from the clothes washer. This translates to 967 kWh per year per average household (Badger, 2012).

The DOE test procedure has remained unchanged since 1981. The DOE dryer test procedure uses very uniform, fifty percent cotton/poly cloths that are essentially two-dimensional (see figure 1). In the 2013 revised version of this test (DOE 2013 (b)), referred to as “Appendix D1,” the technician stops the test when the load achieves 2.5 percent to 5 percent Remaining Moisture Content (RMC). The optional “Appendix D2” (DOE 2013 c)) version of the test requires runs until auto-termination. Almost all dryers tested under the Appendix D1 test procedure demonstrate virtually the same Combined Energy Factor (CEF, lb/kWh) values.

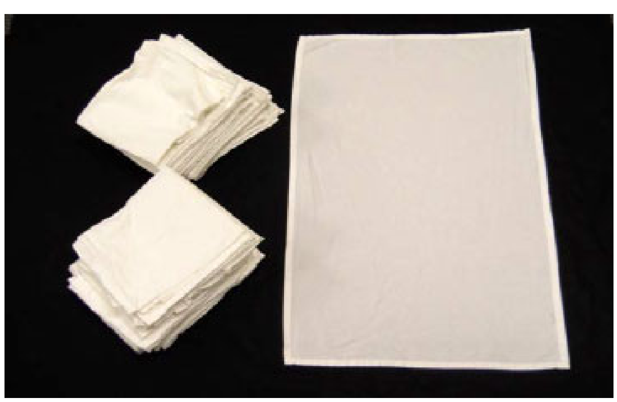


Figure 1. The DOE test load is composed of test cloths that are 24 x 36 inches and that are a blend of 50-percent cotton and 50-percent polyester fabric.

A test procedure that employed a mix of real clothing over a range of operating conditions would increase product differentiation (Denkenberger, 2012). The absence of a realistic test procedure is a key market transformation barrier to establishing performance labeling, ENERGY STAR® designation, aligning the support of utility programs, increasing consumer awareness, and encouraging manufacturer introduction of efficient clothes dryers into the North American market.

The importance of implementing a realistic test procedure can be illustrated by comparing the rank-ordering of dryer performance from several existing test procedures. Figure 2 shows the relative rank-ordering of eight dryer models using three different test procedures (DOE, Jan 2013(a)). The first graph shows rank-ordering using the 2005 DOE test procedure, the second graph shows the ranking when the loads run until the dryer auto-terminates, and the third graph shows the ranking with a more complex Association of Home Appliance Manufacturers' (AHAM) laundry test load.[1]

These three graphs show that the rank-ordering changes for the same products based on the type of test conditions. As examples, the ranking for unit #2 moves from best in class in the first graph to second-worst in class in the latter two graphs, and the ranking for unit #1 moves from worst in class in the first graph to third-best in class in the third (IEC/AHAM load) graph. Such disparities demonstrate that utility programs seeking to highlight real-world differences and to support transformation to the most efficient dryers must pay close attention to the test procedures used. Utilities should not settle for a procedure that is simply repeatable, but should pursue one that represents real-world performance. Indeed, they must be a little "testy" when choosing their dryer test procedures.

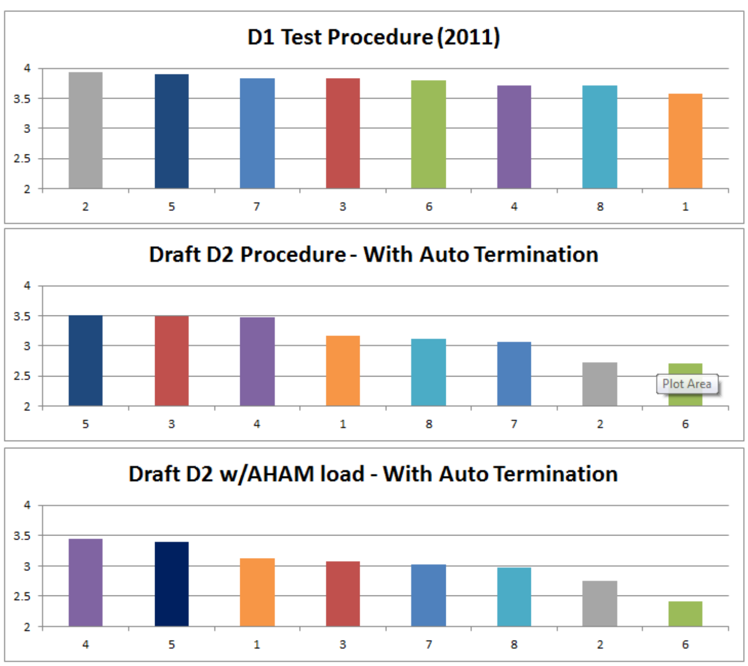


Figure 2. DOE NOPR Data - Relative rank-ordering changes if more realistic conditions are applied.

[1] IEC test load is a partially synthetic, partially cotton load. It has diversity in shape, but does not have diversity in thickness.

NEEA Laundry Field Study

Background

To help inform future program and policy activities, NEEA conducted a comprehensive field study in 2011 and 2012 that measured plug load energy use in over 1,700 homes across the Northwest (Baylon, 2012). NEEA selected a representative sample of fifty homes from this pool to conduct detailed monitoring of laundry energy use and behavior. The selected homes had laundry equipment that was at the time less than five years old, with a market-representative mixture of horizontal- and vertical-axis washers.

The project started in late 2011. NEEA deployed the monitoring equipment in January 2012 and retrieved it by March 2012. Throughout the metering period, the occupants of each house kept a log of their laundry use documenting the time and date of each load as well as the weight and load characteristics. NEEA collected a minimum of thirty days of data at each site. The dataset included both the energy use and the results of the occupant log during the metering period. This dataset is available upon request from the Northwest Energy Efficiency Alliance.

The laundry test protocol was fairly demanding; in addition to metering washer and dryer energy use and cycle information, participants characterized and weighed each laundry load before putting it into the washer and dryer and upon removing it from the dryer. Participants recorded washer and dryer cycle types and temperature settings. NEEA collected usable data from forty-eight of the fifty sites monitored. Participants received $150 for an initial site visit and $150 at project completion upon submitting their logbooks. Metering equipment failed at one site and the second site failed because the logbook records did not correlate to metered laundry use.

The raw data, which consisted of 1,318 dryer cycles, has subsequently been analyzed under two contracts. Ecova conducted the first analysis in early 2013 to help inform comments to federal rule makings around the DOE test procedure and a future EPA ENERGY STAR® specification for clothes dryers, and to address questions regarding dryer vent restriction. Ecotope completed the second analysis in early 2014 (Ecotope 2014). The Ecotope analysis focused on establishing a baseline stock assessment and investigating areas not covered by the Ecova analysis.

The data presented herein contain findings from analyses of the same dataset. The differences between these analyses are largely artifacts of the different algorithms used to match meter data to consumer log data. While NEEA's project collected minute interval data on energy use, the stop and start times of multiple back-to-back loads created difficulties in clearly identifying a new load, a load to which clothing is added, or the addition of a little extra time to just a small portion of the initial load. To illustrate this, Ecova's analysis showed an average of 337 dryer loads per year, whereas Ecotope's analysis showed an average of 303 loads. The difference between these averages is attributable to Ecova's analysis that included all dryer cycles, counting those that consisted of a wash load being divided into two or more small dryer loads as two dryer cycles.

Boiling down field data into single summary numbers such as CEF is not as important as understanding the degree of variability and whether this variability affects energy use. Understanding the settings the consumers chose for the dryer loads and how they defined the loads (heavy, light, permanent press, delicate) are essential parts of understanding the real-world energy performance of clothes dryers, and are core objectives of this field study.

Because the data are based on less than two months of detailed observations, the type and weight of clothing may be skewed. Assuming that clothes-washing in summer is more frequent than in winter, but that the average weight of each article is lower, the annual projected energy use is generally accurate. Future analysis of ongoing data monitoring by Ecotope will reveal how much error this assumption introduces.

Comparisons with DOE Test Protocol

Figure 3 provides a graphical comparison of the annual energy use of clothes dryers as determined from two different DOE test procedures and from the NEEA field study data. Field data of real-world energy use show a considerably higher annual energy use than the DOE values show. The primary differences are that initial moisture contents are higher for the field data and that the number of cycles per year lies between the 2005 and 2013 DOE standard values.

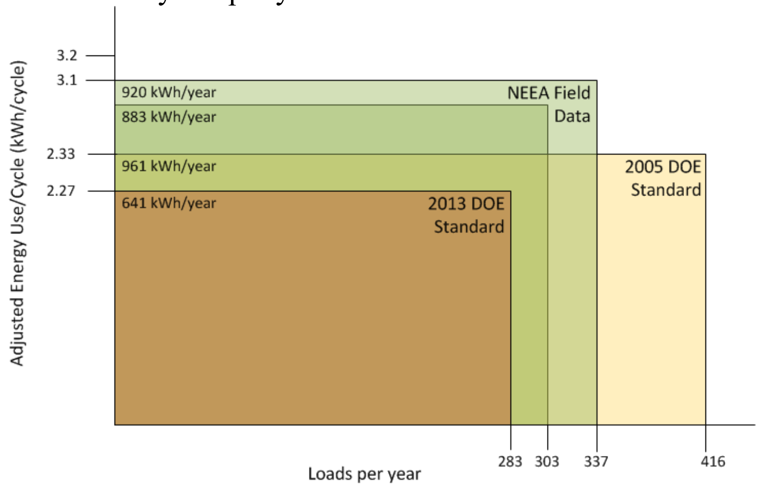


Figure 3. Annual Energy Use of Residential Clothes Dryers (Ecova).

Table 1 provides a side-by-side comparison between the current DOE test procedure, the optional D2 procedure, and both the Ecova and Ecotope analyses of field data.

Table 1. Summary and comparison of field data analyses of Ecova and Ecotope to DOE test

Metric	DOE		NEEA Field Data	
	2005 Test Procedure	2013 Test Procedure	Ecova Analysis	Ecotope Analysis
IMC of Load (%)	66.5%-73.5%	57.2%-57.8%	62%[a]	66%
Final MC of Load (%)	2.5%-5%	<2%	N/A	2%
Water Removed/Load (lb)	4.6	4.6	4.5[a]	4.74
Bone Dry Load Weight (lb)	7	8.45	7.5[a]	7.56
Duct restriction	2 7/8"	2 7/8"	2 11/16"	n/a
Load Composition	DOE Test Cloths		Real clothing	
Average Drying Time (min)	23[e]	N/A	58	56
Raw Energy Use/Load (kWh)	2.24	2.84[b]	3.1[c]	2.94
Field Use Factor	1.04	0.8	1	1
Adj. Energy Use/Cycle (kWh)	2.33	2.27	3.1[c]	2.94
Dryer:Washer Loads Percentage	107%	91%	124%[d]	107%
Loads per Year	416	283	337[c]	303
Energy Use per Dryer (kWh/y)	967	641	920[c]	883
EF or CEF (lbs/kWh)	3.01	3.73	2.4[a]	2.62

[a] These data include the cycles with valid energy, weight, etc. measurements and reflect an adjustment to account for the fact that clothes were not bone dry (3.6% MC) when initially measured by field study participants.

[b] Though automatic termination in the field saves energy relative to timed dry, here we are comparing to technician termination in the

[c] These data include all cycles with metered events in NEEA study (1640 cycles).

[d] The field data showed that many users would commonly run "touch up" loads after the main drying cycle had completed to get
The data showed more drying cycles than washing cycles because of washer load splitting, even though some items that were washed were washed were not subsequently machine-dried.

[e] Based on laboratory testing

The data revealed that the majority of loads were not like those in the laboratory test. To illustrate this, NEEA designated cycles that more closely replicated lab-like conditions into a separate subset referred to as "simple loads," defined as cases in which the dryer was run as one single continuous run (without removal or addition), the weight was between three and fifteen pounds, and the clothing was dry when the cycle stopped. Only 42.9% of all loads fit this description of "simple loads." Table 2 shows that dryers frequently operate in one or more conditions that are uncharacteristic of a simple lab test.

Table 2. Simple load breakdown when loads are similar to lab testing

Criterion	% All Loads
All Simple Loads as a fraction of all loads	42.90%
Washer RMC between 33% and 100%	50.10%
Dry Weight between 3 lbs and 15 lbs	55.30%
No items removed between washer/dryer	71.50%
No multi-run dryer loads	92.60%

The energy use data indicate that simple loads require fifteen percent more energy per pound than the overall average. While multiple reasons exist for this, the most significant appears to be that simple runs include auto termination.

Field data also indicate that the current federal test procedures do not reflect the range of operating conditions under which dryers are used. Table 3 shows the ranges of operating conditions and temperature settings of the clothes dryers. Temperature setting is a consumer-chosen value for which low, medium, and high are common, but not ubiquitous names. For currently-available dryers, drying temperature has an approximate twenty-three percent effect on drying time, but only a three percent effect on energy use (CA IOU, 2013). Notably, however, some of the errors introduced by the limited range of operating conditions cancel each other out in aggregate.

The medium-weight (6.6-10.5 lb) and high-temperature setting section represents the settings at which the DOE test protocol tests clothing. Table 3 illustrates that only 13.1% of the field data fit within the temperature and weight distribution at which the products are tested. While the DOE load does not accurately address the range of real clothing operating conditions, the CEF numbers generated for conventional dryers may be reasonable. The question, however, is whether this is also the case for heat pump-based dryers, and whether the rank-ordering of dryer performance is accurately captured by such a small range of operating conditions.

Table 3. Temperature ranges vs. load sizes found in the field

		Temperature Setting				
		Low	Medium	High	Total	Avg. Wt (lbs)
Load Weight	0-6.5 lbs	6.6%	17.4%	16.5%	40.5%	4.3
	6.6-10.5 lbs	3.0%	20.8%	13.1%	36.9%	8.5
	10.6-25 lbs	3.0%	12.9%	6.7%	22.6%	13.1
Total		12.60%	51.10%	46.10%		

*Load weight represents the net weight of the dry load going into the washer

Drying Time Data

Work by Ecova in preparation for the submittal of California investor-owned utility (IOU) commentary to the EPA ENERGYSTAR rule making, and its subsequent ACEEE paper, shows a clear correlation between drying time and dryer performance (CA IOU 2013). All things being the same, slowing down the rate of drying will result in higher dryer efficiency.

Field data indicate that the current federal test procedure underestimates drying time.[2] Factors that increase the drying time in the NEEA dataset relative to the DOE 2013 parameters include: higher initial moisture content, greater duct restriction, medium instead of high heat, and

[2] Technically speaking, drying time is not measured at all under the current DOE test procedure. However, NEEA's measurements of drying time while running that test procedure yield much shorter time periods for drying than are typically observed in the field.

more diverse and complex load composition (three-dimensional articles with high cotton content).[3] A smaller, dry weight load decreases the drying time in the field study vs. DOE. Figure 4 illustrates the range of drying times measured in NEEA's field study. The degree of divergence between measured field data and the federal test procedures employed to date is remarkable. The average measured drying time in the field is *more than double* the drying time typically measured by the 2005 DOE test procedures for full-size vented electric dryers. Put another way, *more than eighty percent* of the drying cycles measured in the field ran for a longer period of time than a typical dryer runs on the DOE test procedure. The D2 test procedure produces much more realistic drying times, validating DOE's decision to measure actual automatic termination performance instead of awarding a fixed energy savings credit to all products that include that capability.

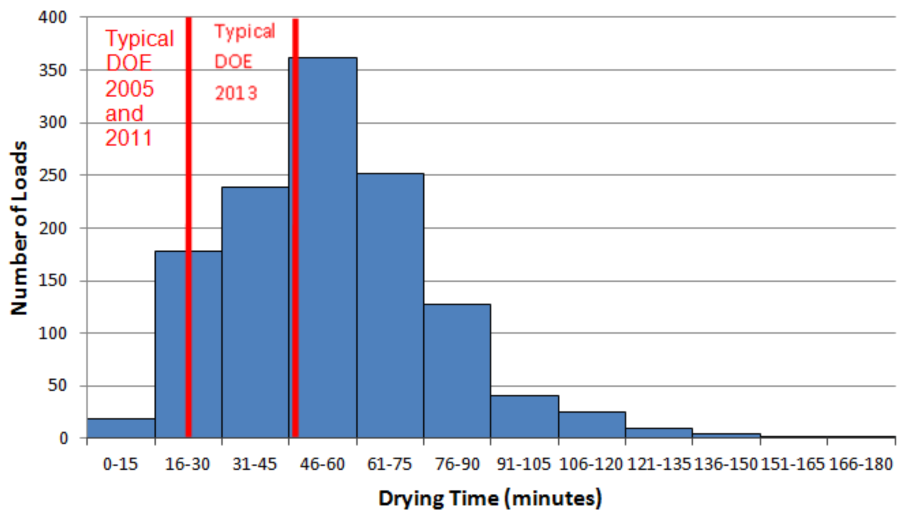
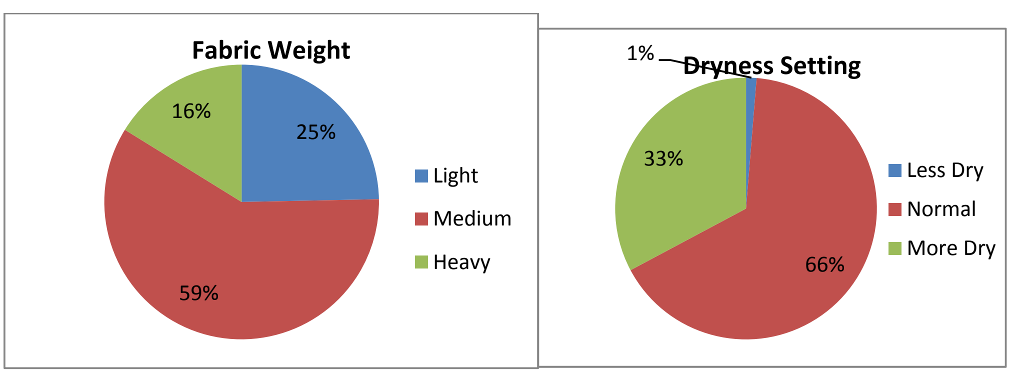


Figure 4. Drying time is longer in real world than under typical lab test conditions.

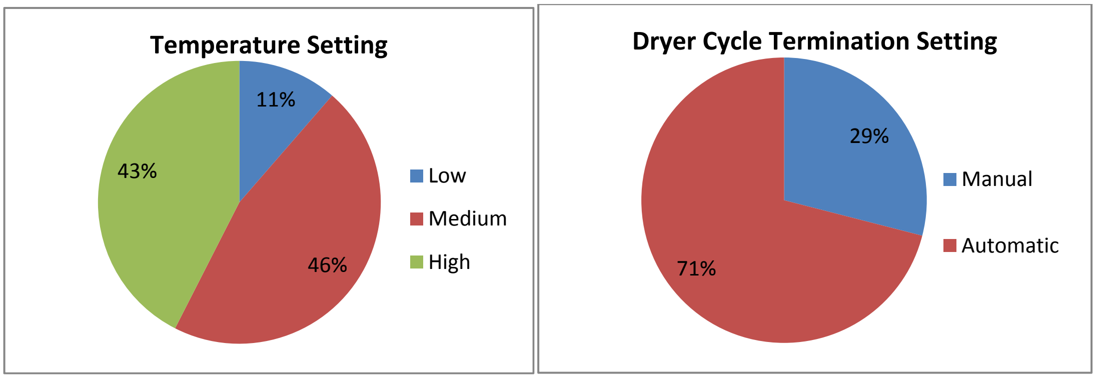
Consumer Settings

Figures 4, 5, 6, and 7 present field results of a variety of consumer setting choices.



Figures 4, 5. Fabric weight and dryness setting as indicated by consumer (Ecotope).

[3] Running a dryer on a medium temperature setting tends to reduce the dryer cycle's energy use because the heater is on a smaller percentage of the time and the dryer gets "free" drying when the heat is off (Ecotope, 2014).



Figures 6, 7. Consumer selected Temperature Setting and presence of Auto-Termination.

Duct Blockage

NEEA also collected field data to investigate how frequently exhaust vent obstructions? from lint, or long and complex duct paths or other obstructions, occur in the field. The data showed air flow rates at the output of the vent as low as six cubic feet per minute (CFM) and as high as 146 CFM, with an average of 79 CFM. This is significantly lower than the average air flow rate of 96 CFM measured in the laboratory on a set of dryers similar to those metered when configured according to the US DOE test procedure. However, this difference had an insignificant impact on dryer performance (NEEA, 2014). Figure 8 illustrates the variability in flow rate found in the field.

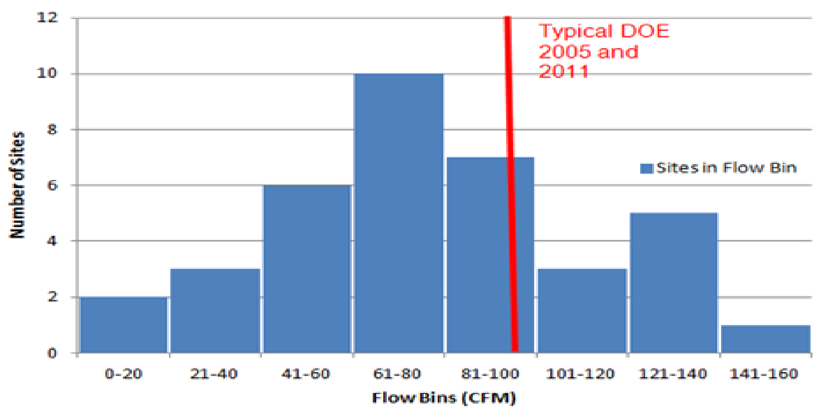


Figure 8. Vent flow rates are lower in the real world than under typical lab conditions.

Moisture Content

The energy required to dry clothing directly correlated to the amount of moisture in the clothing. The data indicate that a substantial proportion of clothing loaded into dryers is considerably wetter than expected. Figure 9 shows that medium and light weight loads dominate the data found in the highlighted “Really Wet Clothes” area. The likely cause is unbalanced spin cycles. Unlike the DOE test cloths, which are small, light, and easily-balanced, real clothing contains large items such as towels, jeans, and sheets that de-stabilize the spin cycle and make it difficult for the washer to extract moisture.

Figure 9 also illustrates the distribution of clothes that do not fall into the "simple-load" data subset. Clothes that are very wet (>100% initial moisture content), very small (<3.0 lbs), extra-large (>15.0 lbs), or very dry (<33% initial moisture content) represent about thirty-five percent of all loads. While the NEEA field data averages are nearly identical to the initial moisture content values used in the current DOE test protocols, the diversity may have a significant impact on accurate and relative rank-ordering of dryer performance.

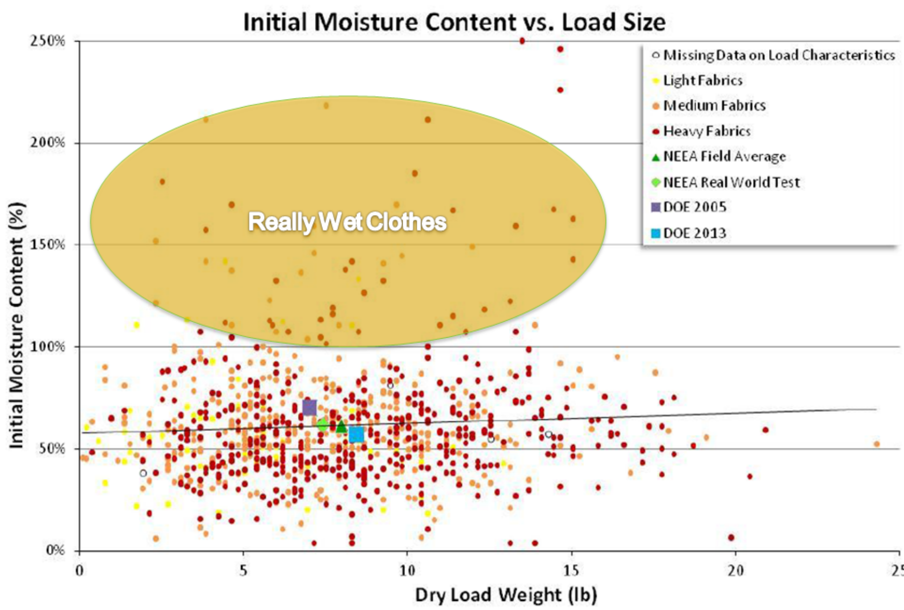


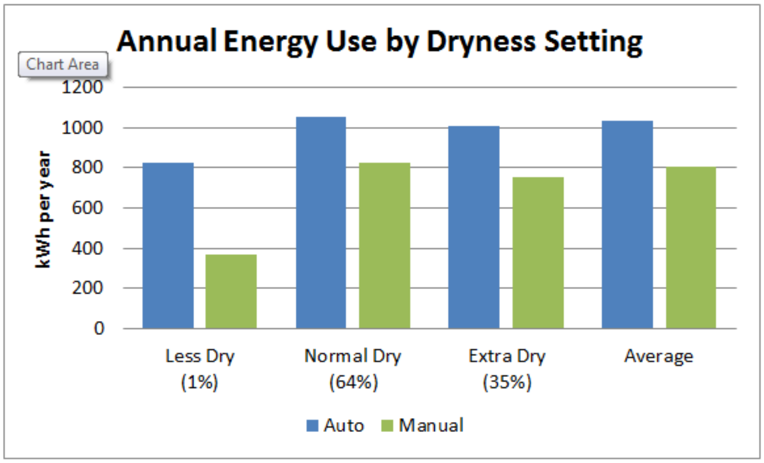
Figure 9. Variability of initial moisture vs. dry load weight.

Auto Termination

Contrary to expectations, the data indicate that the use of auto termination generally *increases* energy use in a dryer. Figure 10 provides both a graphical and a tabular summary of data from the Ecotope analysis. Use of auto termination for all loads increased energy use by over 200 kWh per year. "Simple loads" experienced an average increase of only 115 kWh/year. Recognizing that these are average values and not individual dryers is important. Several of the auto termination dryers performed better than manual termination models, similar to results observed under laboratory conditions.

Clearly, auto termination accuracy is critical for non-simple loads and can significantly affect energy use. The data also indicate that while auto termination performance correlates to initial moisture content, while manual termination performance is more random. This implies that consumers may correctly estimate the length of time to run the manual termination dryers, while many auto termination dryers simply over-dry the clothes.

These findings indicate that the presence of an auto termination feature does not ensure that a dryer will stop when it achieves the desired remaining moisture content. Under the optional federal "Appendix D2" test procedure, the two percent target moisture level is more difficult to accurately achieve than are the termination criteria under appendix D1. The effectiveness of the manufacturer's algorithms in determining when a load is dry will significantly influence a dryer's performance ranking.



Annual kWh by Dryness Setting

	All Loads			Simple Loads		
Setting	Auto	Manual	Delta	Auto	Manual	Delta
Less Dry	825	367	458	825	573	252
Normal Dry	1054	825	229	916	825	92
Extra Dry	1008	756	252	1008	710	298
Average	1031	802	229	939	825	115

Figure 10. Use of auto termination has significant impact on energy use for "non-simple" loads.

Field Study Key Findings

The principal finding of this data collection was a better characterization of the greater complexities of real-world dryer use over the simplified federal test procedures. The key findings are as follows:

- The federal test conditions have similar load size and temperature setting to only thirteen percent of the load conditions experienced in the real world.
- Real world annual energy use is higher than that currently generated from lab tests.
- On average, consumers run more dryer loads than washer loads. This results from homeowners splitting up washer loads, and to a lesser extent, from drying clothing not washed.
- Consumer-operated settings are not the same as test procedure settings. Medium heat is most commonly-used in testing, but many consumers selected high heat. Normal dryness is most commonly-used in testing, but many consumers selected "Extra Dry."
- Duct restriction did not significantly impact energy use within the range experienced in the field.
- A significant percentage of washer spin cycles results in very wet clothes entering the dryer, likely a result of unbalanced loads.
- Cycle times on real clothing are on average twice as long similar dryers tested to the 2005 DOE test procedure.
- Inaccurate auto termination increases energy use, especially for complex or heavy loads.
- Several of the auto termination dryers performed better than manual termination models, just as observed under laboratory conditions.

Future Investigation

Future investigation is needed in several areas. The areas of highest relevance to supporting market transformation are as follows:

1) To what extent is the higher energy use found in the real world a function of load complexity (real clothing) vs. consumer settings? This would help establish adjustment factors that correlate lab results to the real world.
2) To what extent are consumers willing to accept differences in drying time in exchange for higher efficiency? Similarly, to what extent will consumers choose optional "efficient" modes if available on the dryer setting dial?
3) How persistent is the accuracy of a dryness sensor? In other words, when/why/how do they fail to be accurate?
4) Characterize consumer use of dryers, and begin to develop a calculation method to translate the combination of D2 lab tests plus a set of supplemental lab tests with a more complex load into accurate real-world annual energy consumption estimates.
5) Determine whether heat pump technology clothes dryers need separate weighting factors from standard electric resistance dryers. Their lower operating temperatures and greater humidity (for condensing) compared to conventional dryers may affect performance differently, and may require a different lab-to-real-world calibration than conventional electric resistance dryers.
6) Determine the net impact of "smart" technologies on dryer performance. Will these result in post-installation modifications to operating algorithms, and if so, will these increase or decrease the energy use of a dryer?

Conclusions

Accurate estimation of the annual energy usage of dryers is complicated and challenging. The variations in clothing and consumer operational setting choices can introduce significant uncertainty in relative rankings. Accurate annual energy consumption measurement requires a combination of lab and field data. Variations among conventional and heat pump technologies and dryer setting options may have significant influences on real-world performance.

Adjustments to current federal required standards (Appendix D1) with a "field utilization factor" will not result in accurate rankings. The results would not support the market transformation needed to advance individual products that have performed well under real-world conditions but that may perform poorly under D1. The presence of auto termination does not ensure that the dryer will use less energy. Measuring dryer energy use to completion of auto termination cycles is an essential first step to accurate relative rankings.

The current Appendix D1 federal test procedures inadequately rank order and accurately characterize the energy use of dryers. The addition of a supplemental lab test based on real clothing under a range of operational conditions when combined with the voluntary D2 test protocol and field-testing would enable programs to identify the absolute and relative energy savings among top efficiency clothes dryers. The supplemental test should differ from the D2 protocol by 1) using real clothing, 2) running at both small and large load sizes, and 3) operating the dryer in an efficient setting (within a reasonable cycle time limit).

Manufacturers may feel that efficiency advocates are "testy" about the inadequacy of current federal test protocols. The manufacturers in turn may be "testy" that they are being asked to use supplemental test procedures. However, the underlying objective is to better understand dryer energy performance and to provide manufacturers with clear metrics that result in product improvement. The end result will be savings opportunities for this last major household appliance that justify both consumer and utility investment in a cleaner, lower-cost energy solution. The presence of a good test procedure is the cornerstone to transforming the clothes dryer market.

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