What Lurks Beneath: Energy Savings Opportunities from Better Testing and Technologies in Residential Clothes Dryers

David Denkenberger, Serena Mau, Chris Calwell, Eric Wanless and Brendan Trimboli, Ecova

ABSTRACT

In the US, clothes dryers account for approximately 6% of residential electricity consumption and $9 billion in annual energy costs. They are the largest home energy savings opportunity for which no utility incentives or labeling exist.

We conducted laboratory testing on 15 dryer models representing a wide range of technologies, fuel types, features, and load capacities. Our testing identified three key shortcomings in current test procedures that downplay the benefits of more efficient dryers:

- They employ easy-to-dry, uniform partly synthetic test cloths instead of more representative and diverse articles of real clothing
- They do not compare different dryer technologies on source energy use, CO_2, or consumer cost basis, thus overlooking the key advantages of natural gas dryers
- They do not allow dryers to shut themselves off automatically, thus failing to reveal differences in how quickly and appropriately dryers terminate the drying process

As a result, current testing underestimates overall dryer energy use by approximately 20% and minimizes the apparent energy savings from switching to more efficient technologies. We recommend a number of changes to standardized test procedures and efficiency metrics, many of which are drawn from practices already employed internationally.

We also discuss the energy savings potential from incorporating new technologies such as modulating heater and blower power, incorporating exhaust heat exchangers, and employing a heat pump. We conclude with estimates of US energy savings potential from modifying the test procedure and efficiency metrics, labeling competing technologies accordingly, and promoting the most cost effective alternatives to consumers.

Background

Over the last 50 years, clothes dryers have become a standard feature in nearly 85% of American homes (DOE 2010). A typical electric dryer uses about 900 kWh per year and a typical gas dryer uses about 30 therms of gas each year.[1] On average, Americans dry about five loads of laundry a week (DOE 2010), spending about $100 a year to power a typical electric dryer, or $40 a year to operate a similar natural gas dryer. In total, dryers now represent a $9

[1] Field studies yield measured values of 885-1079 kWh/year. Based on its test procedure results and usage frequency, DOE estimates the average dryer consumes 718 kWh/year. DOE points out that the remaining moisture content coming from the washers would have decreased since the field studies were done, but this is only about a 10% effect (see below). Therefore, we believe real-world use is approximately 900 kWh/year. Site energy use of natural gas dryers is approximately 10% higher than electricity, so converting 990 kWh/year yields 33 therms, or 30 therms with one significant figure given the uncertainty.

billion annual national energy bill[2] – about 6% of residential electricity consumption (EIA 2005) and 2% of residential natural gas consumption.[3] They consume as much electricity per year – 60 billion kWh – as the entire state of Massachusetts, and are responsible for 40 million metric tons of annual carbon dioxide emissions.[4] By any measure, their energy use and environmental impact are large enough to be worth doing something about.

While new clothes washers use about 70% less energy than models sold 18 years ago (TopTen 2011; AHAM 2011), clothes dryers have made almost no progress in improving energy efficiency during the same period. Clothes washers continue to be the focus of mandatory and voluntary energy efficiency labeling, utility rebates, and steadily tightening mandatory federal standards. Dryer efficiency has gotten far less attention – dryers bear no EnergyGuide or ENERGY STAR labels and receive no utility rebates – and thus consumers have no easy way to compare the energy use and operating cost of similar models. *As a result, the average new dryer consumes about three times as much annual energy as the average new washer. Making the wrong dryer choice can cost consumers more energy than they will ever save by buying the most efficient clothes washer on the market.*

Ecova's prior research suggested that dryers have been hampered by flawed test procedures and efficiency metrics that tend to mask rather than reveal differences in dryer energy efficiency. The resulting data have led to the mistaken conclusion that all clothes dryers have similar efficiencies, and little can be done to improve them. In fact, the fundamental process of drying and re-condensing water vapor could theoretically take negligible energy, and we outline below technologies to move in this direction.

This paper is largely based on the executive summary for a Natural Resources Defense Council (NRDC) administered EPA grant project (Denkenberger et al 2011) and contains some work done for the Collaborative Labeling and Appliance Standards Program (CLASP).

Research Approach

This report summarizes the results of a recent scoping study conducted by Ecova to answer four key questions:

- ***Test Procedures*** - Is the current energy efficiency test procedure measuring the right things to help differentiate the performance and energy use of one dryer from another and to accurately predict how much energy a dryer will consume operating in the real world?

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[2] Assumptions: 66 billion kWh of annual electricity use at an average rate of 12 cents/kWh yields an electric bill of approximately $8 billion. Gas dryers consume about 0.09 quads of the total residential primary energy use of approximately 20 quads. At an average rate of $1.10/therm, this yields a natural gas bill of approximately $1 billion.

[3] We assume that gas dryers are used the same amount as electric dryers, there are one quarter as many gas dryers as electric dryers, and the primary energy use of gas dryers is about 40% as much as electric dryers. This suggests that the primary energy use of gas dryers is about 10% as much as electric. 63% of residential primary energy is for electricity (Arthur D. Little 1999), and electric dryers are 6% of residential electricity. Therefore, gas dryers would be 1.2% of residential fuel (natural gas, propane, and fuel oil). Since only 1% of dryers are propane (and none are fuel oil), and there is significant residential propane and fuel oil use, the gas dryers would be ~2% of residential natural gas use.

[4] Assuming 0.6 kg CO_2/kWh electric and 0.18 kg CO_2/kWh thermal for gas.

- ***Metrics*** - What energy efficiency metric should be used to appropriately compare dryers?
- ***Measurement of Dryer Energy Use*** - How do various dryer types, sizes, and technologies perform differently when measured according to our recommended test procedure and efficiency metric?
- ***Policy*** - What should government agencies and utilities do to pursue more energy savings from dryers?

To answer these questions, we purchased 15 dryers spanning a wide range of manufacturers; gas and electric fuel types; compact and full-sized capacities; conventional, condensing, and heat pump drying technologies; and entry-level, mid-range and high-end price points and feature sets. These dryers also differed somewhat in their airflow rates and the technology employed to detect when the clothes are dry in moisture sensing modes.

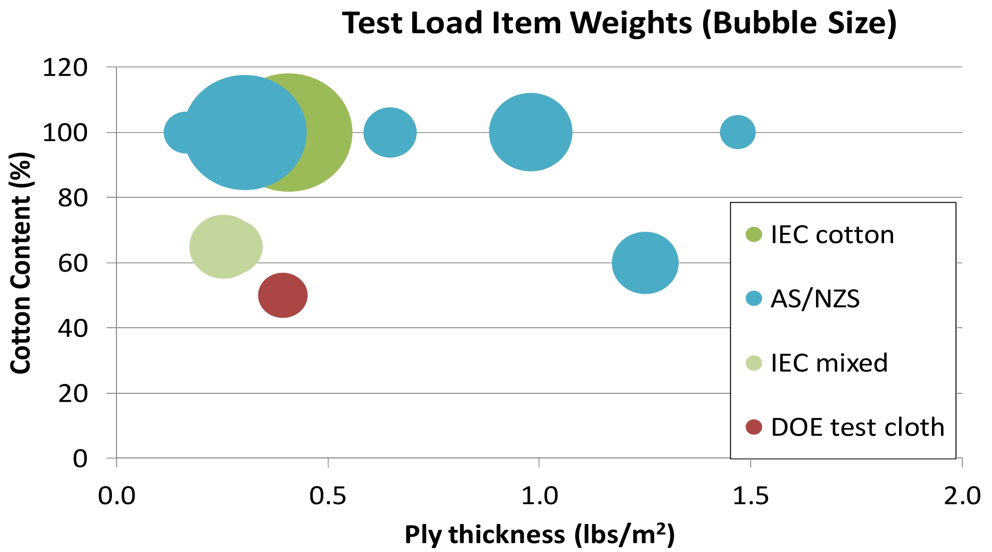
We conducted 58 dryer tests in total, using the US Department of Energy's (DOE) previous and recently updated test procedures, our own real world (RW) test procedure (discussed further below), and a test that estimated the incremental energy impact of "eco mode" and steam mode in select models. Our testing measured: energy used to dry clothes; time to dry clothes; remaining moisture content (RMC) of clothes at the end of the cycle; and airflow, exhaust temperature, and humidity during the drying process. Given the available timeframe and budget, our focus was intentionally broad (a large number of models, tested via multiple procedures and in multiple modes) rather than deep (a small number of models, measured repeatedly and with great precision). Our purpose was to uncover high-level changes that may be warranted in test procedures and efficiency metrics and to inform future detailed research on those topics.

The Importance of Measuring Real Clothing

The DOE recently modified its energy efficiency test procedure to account for ongoing market changes in the capacity of laundry equipment (load size), the number of loads run per year, and the increasing spin speeds and cooler rinse temperatures of washers, and we refer this to the "new DOE" test procedure (DOE 2011a). However, the DOE did not change the composition of the test load, the way it measures automatic termination, or the way it calculates energy use (source versus site) (DOE 2011a). Our previous research suggested that these three issues may have a large impact on measured energy use, so we looked more closely at each.

DOE's test cloths are two-dimensional, thin, uniformly sized pieces of fabric made of a 50% cotton, 50% polyester blend (see figure 1). As such, we found them to be extremely easy and quick to dry. A step in the right direction is the IEC loads (see figure 1). These recognize that some loads are partly synthetic and some loads are nearly all cotton. The partly synthetic load is also generally smaller. These loads use real clothing: pillowcases, hand towels and men's shirts. This captures the fact that most articles of clothing are three dimensional, meaning that they have externally facing and internally facing sides, often with pockets as well. However, the clothing plies are nearly all the same thickness, which is shown by the greenish bubbles stacking on top of each other in figure 1. A further step in the right direction for the cotton load is the Australian/New Zealand (AS/NZS) test load (which is nearly identical to the Association of Home Appliance Manufacturers (AHAM) 1992 test load). This has nine different types of RW clothing with widely different thicknesses, lengths and widths (see figure 1).

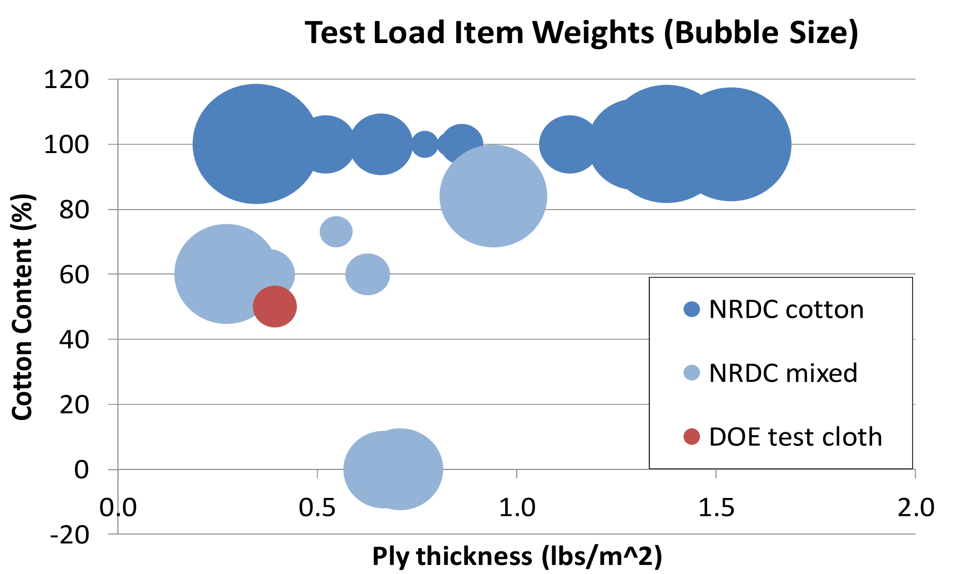
Figure 1. IEC, Australia/New Zealand, and DOE Test Loads



The final step is to have a partly synthetic load that has both diversity in thickness and diversity in synthetic content. This was done for the NRDC draft test method (see figure 2), in addition to a RW-clothing diverse-thickness cotton load. In short, the NRDC cotton and partly synthetic loads are much more challenging to dry than thin test cloths, and should behave much more similarly to loads in the field.

It is important to note that the DOE dryer test procedure measures only one test cloth quantity at one temperature, but repeats that test three times (three tests total). If these three repetitions are used for the two loads in the proposed NRDC test method, this would total six tests. However, this would still be less than the DOE clothes *washer* test procedure, which measures three different weights of cloths at three different wash temperatures (nine tests total).

Figure 2. NRDC proposed and DOE Test Loads



We ran the smaller 50% synthetic, 50% cotton load on the “permanent press” and “normal dry” settings with an initial RMC that is consistent with the 2011 DOE test procedure. We ran the larger 100% cotton load on the “cotton” and “more dry” settings with a higher initial RMC reflecting the fact that it is more difficult to spin water out of cotton clothing. This allows drying time and energy use to vary with changes in the amount and type of clothing (and their corresponding temperature and dryness settings). The results can be considered separately or averaged with different weightings to reflect the mix of clothing dried by households. We pursued this testing to determine whether or not the current test method significantly underreports dryer energy use and how much additional energy is used when RW clothes are used during testing.

Allowing Dryers with an Automatic Shut-off Feature to Shut Themselves Off

The DOE test procedure manually terminates the drying cycle when a technician has determined that the test cloths have reached a target of 2.5-5% remaining moisture content (RMC) based on the bone dry weight of the clothing. This requires stopping the dryer periodically, weighing the clothes to see how close they are to the target RMC, and then restarting the dryer. This type of manual intervention in an energy efficiency test procedure is unusual. It may ensure that all tested dryers are doing a similar amount of “work,” but does not let a feature that is supposed to be energy-saving do its job. As a result, it is impossible from DOE test procedure data to determine if one dryer’s moisture sensing technology works better than another’s.

Our prior research indicated that some dryers are much better than others at stopping the drying process promptly when the test cloths are dry. Therefore, in this research, we allowed the dryers to stop themselves automatically when they determined that the clothes were dry. This is less burdensome for the laboratory technician and more reflective of the way dryers are actually used.

The Results of Our Measurements

At a high level, our test results confirmed that most conventional vented dryers behave similarly when they are drying test cloths and are stopped manually at the target RMC (the current DOE test). Gas dryers took 5 to 10 minutes longer to dry than conventional electric dryers and slightly less time than the compact (120 volt) electric dryer. The unvented condensing and heat pump models took the most time to dry a load (about 25 minutes longer than a typical electric dryer).

But the performance of the various types of dryers differed to a greater extent when drying RW clothing and being allowed to terminate automatically. Drying times were significantly longer with the RW cotton load (often double or more) and a little longer with the RW 50% synthetic, 50% cotton load (even though they had less water to remove than the DOE test cloths). Models that only had modestly longer drying times (Figure 3) usually did not dry clothes enough (Figure 4), and so would need to run even longer to deliver comparable drying performance.

Figure 3. Impact of Test Load and Technology on Cycle Time

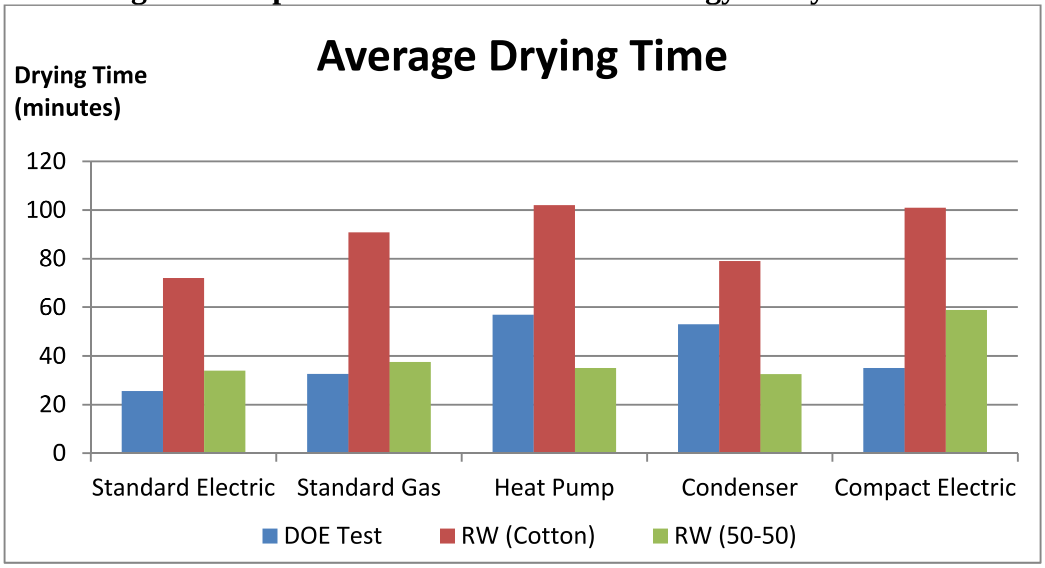
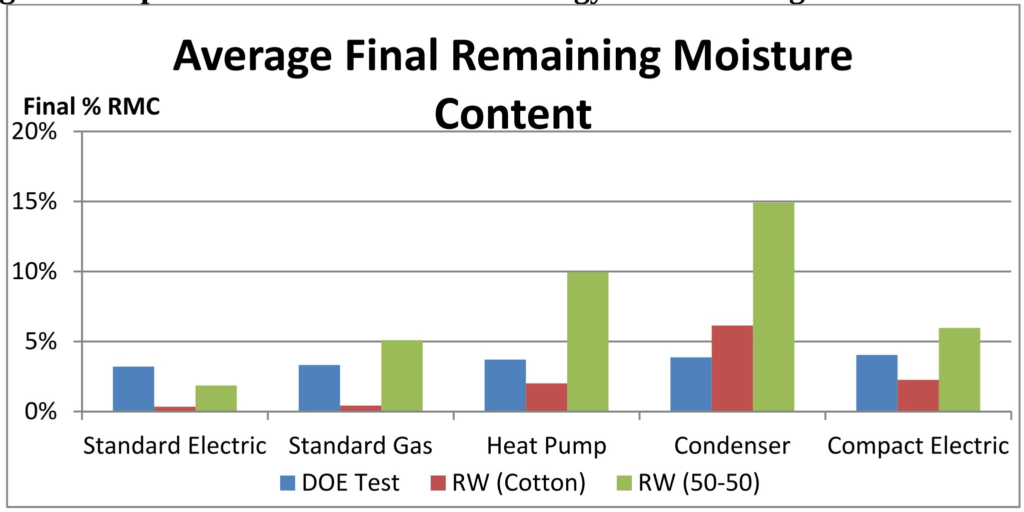
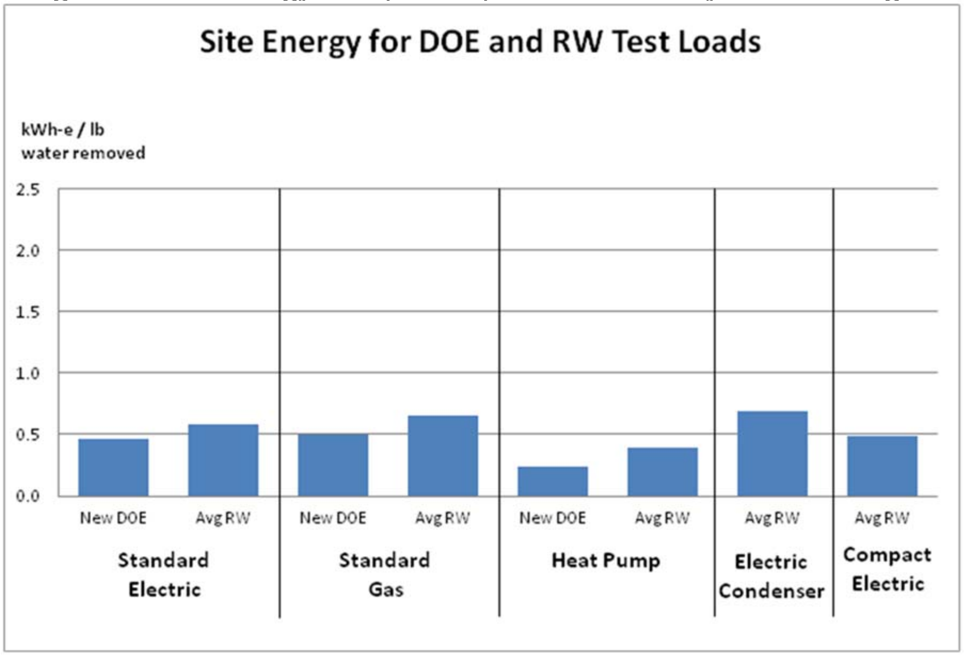


Figure 4. Impact of Test Load and Technology on Remaining Moisture Content



The implications of these findings for energy use and energy efficiency are significant. We found that average RW clothing takes approximately 35% more energy than the DOE test cloths to dry, not because the average power use is higher, but because the drying time is so much longer (see Figure 5). The kWh-equivalent (kWh-e) for natural gas assumes the higher heating value (including the heat from condensing the water vapor from combustion). The difference was significant across all types of dryers, though it varied from one to the other. When evaluating energy use in the home (site energy), the condensing model was the least efficient, natural gas the second least efficient and the heat pump was the most efficient compared to standard electric and gas models.

Figure 5. Site Energy Use (kWh-e) of Different Dryer Technologies

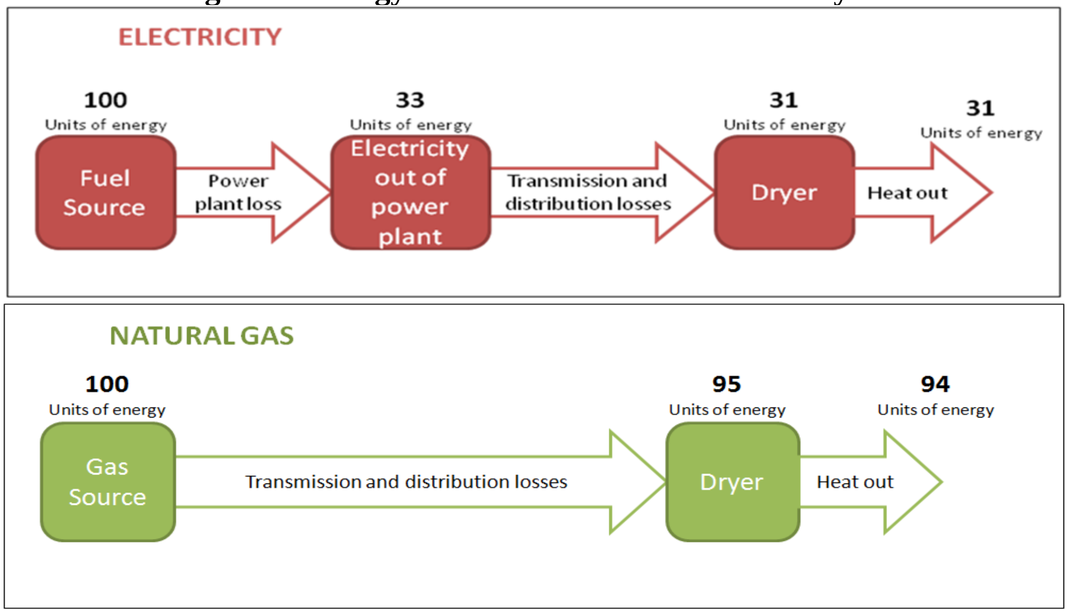


More interestingly, the heat pump's energy savings relative to conventional models drops from about 50% under the new DOE test procedure to about 30% using RW clothing, because it took so much longer to dry, and the heating element did not cycle on and off like conventional dryers do. Similarly, even though the heat pump used significantly less energy per load, it left the clothes wetter, so its site energy efficiency (kWh-e per pound of water removed) is penalized accordingly. Furthermore, since the last amount of water is more difficult to remove, if the heat pump went to the same final RMC, it would be even less efficient. This may not be true of all heat pump models, but was true of the single European model we tested. We also found that the condensing dryer was the least efficient model we tested. This helps to explain why the savings from the introduction of heat pump dryers in Europe have been so high, because ventless condensing dryers are the standard product in Europe against which heat pumps compete.

Counting All the Energy Use

When comparing the energy use of electric and natural gas-fueled dryers, it is important to consider energy used in the home and energy used upstream to convert and deliver that energy. In both the electric and gas cases, there are small, similar losses at the front end of each fuel cycle associated with obtaining the fuel and getting it to a centralized facility for use. These are not accounted for in a site energy comparison or our source energy comparison. But the losses associated with converting heat into electricity at the power plant are far greater (approximately 2/3 (DOE 2010)) and need to be considered. Finally, there are small losses associated with distributing both fuels to the home and converting them to heat in the dryer, which we include.[5] In the case of natural gas dryers, where the fuel undergoes fewer energy transformations, there are far smaller total losses along the supply chain (see Figure 6).[6]

Figure 6. Energy Losses for Electric and Gas Dryers



Once the source energy losses are included in the calculation, the degree of differentiation that emerges in the clothes dryer market becomes much broader. The standard natural gas dryers demonstrate lower source energy consumption than any of the other technologies we tested, which is a very different ranking than with site energy. Note that the combination of testing with RW clothing and comparing energy use on a source basis yields the largest differentiation of all (see Figure 7) – the standard gas model is three times as efficient as the electric condensing model. As a result, we believe that source energy consumed per pound of water removed is an appropriate metric for evaluating the efficiency of dryers.

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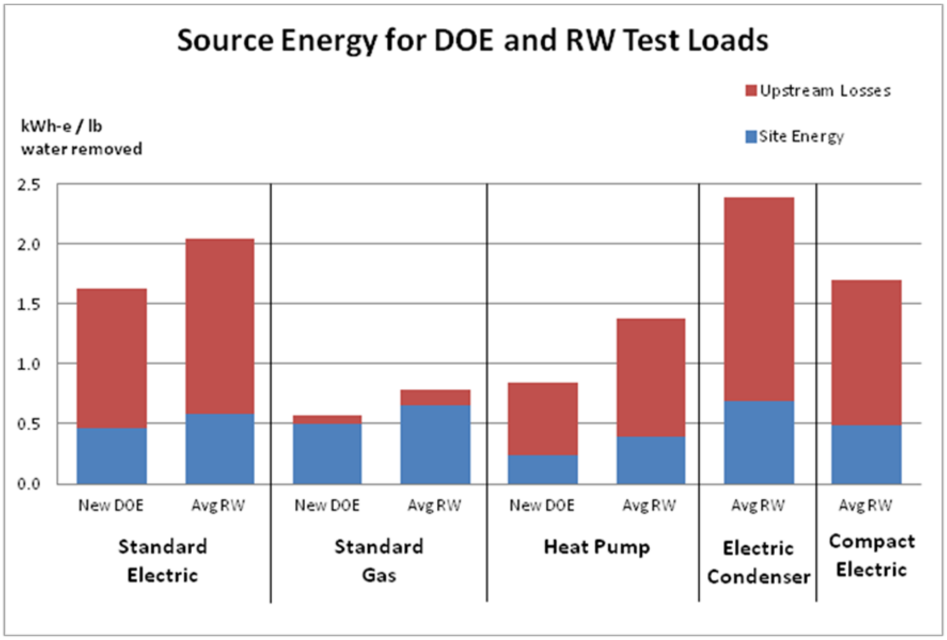
[5] Electric transmission and distribution losses are approximately 7% (EIA 2011).

[6] Natural gas transmission and distribution losses are approximately 5% (ENERGY STAR 2011). If combustion is working properly, the conversion is nearly 100% efficient, but we include the possibility of incomplete combustion.

Figure 7. Site and Source Energy Use (kWh-equivalent) of Different Dryer Technologies and Test Methods



Another holistic energy efficiency metric would be source CO_2 emissions per unit of water removed. It is also possible to evaluate dryer efficiency from a strict consumer perspective, by comparing the amount of money a residential customer pays for the electricity or natural gas needed to remove a unit of water. Both of these metrics rank the efficiency of dryers in a similar order to the one shown in Figure 7, suggesting that we would recommend the same dryers to consumers whether the goal were to minimize societal energy use, CO_2 emissions, or consumer operating costs. These are all for national averages, but source energy, source CO_2, and consumer cost vary by region, utility, and rate structure. Therefore, more specific labeling could be used. However, even if this were not feasible, using national averages for these values is far more realistic than site energy for the actual impact to consumers and the environment. Informing consumers of the economic and environmental benefits of natural gas should encourage fuel switching, which is a cost-effective way of reducing energy costs and environmental impact, even in many cases where a natural gas line would have to be extended within the household.

Individual Dyer Results

Table 1 presents results on an individual dryer level. Note that these values reflect the results of single tests per unit only, not the three tests required by the DOE.

Table 1. Efficiency, Dry Time and Dryness of Individual Dryers

Dryer Type	**Volume** (ft^3)	**Annual Site Energy, DOE Test**[7] (kWh-e/yr)	**Annual Source Energy, Avg RW**[8] (kWh-e/yr)	**Cycle Time, Avg RW**[9] (minutes)	**Auto Terminate Fully Dries Clothes?**[10]
Electric, entry-level 1	6.5	Not tested	3,615	47	No
Electric, entry-level 2	6.5	778	3,243	48	No
Electric, mid-range	7.6	778	3,556	64	Yes
Electric, high-end	7.4	747	3,182	48	Yes
Electric, “high efficiency”	4.5	Not tested	3,543	29	No
Electric, combo (washer/dryer)	1.7	990	4,359	59	No
Electric, compact 120V	2.6	674	2,787	80	No
Electric, condenser	3.9	970	4,071	53	No
Electric, heat pump	3.9	401	2,271	69	No
Gas, entry-level 1	6.0	816	1,006	64	Yes
Gas, entry-level 2	7.0	889	1,139	74	Yes
Gas, mid-range 1	7.4	Not tested	1,085	64	No
Gas, mid-range 2	7.5	877	1,061	59	Yes
Gas, high-end	7.4	758	1,061	65	Yes
Gas, high airflow	8.0	786	1,099	61	No

Key Additional Findings

In our dryer testing we uncovered several points that, while not as important as the results presented above, deserve discussion.

- We tested the “eco mode” on two dyers and discovered that, if clothes are dried to a level that is similar to the dryness reached in other modes, there are no energy savings. In other words, energy savings from current “eco modes” are only possible if

[7] These values reflect site energy only. They do not capture the impact of energy losses upstream for a given dryer. These illustrative tests were also not conducted within DOE’s stated tolerances for the relative humidity, voltage, cool down time, and rinse temperature, so have a higher degree of uncertainty than official DOE test procedure results.

[8] These values reflect source energy – which accounts for both the energy used in the home by the dryer and the upstream losses associated with providing energy to the home. This allows for a fairer comparison of gas and electric dryers.

[9] “Cycle time” reflects the average elapsed time until automatic shutoff, not the time needed to reach 2% RMC.

[10] This column reflects whether the final RMC of clothes was less than or equal to 2%. We believe this value is an appropriate threshold for what most people would consider “dry” clothes when there is significant diversity in thickness.

damper clothes are acceptable. As discussed in Future Work, we believe that an eco mode that truly saves energy could modulate the heater power and fan speed.

- Some dryers continuously tumble the clothing without heat after the drying cycle is finished – this is sometimes marketed as a "wrinkle guard." This typically occurs for one hour after every cycle and causes an approximately 10% increase in energy use. A simple solution that would reduce this additional energy use and maintain performance would be to use periodic tumbling every few minutes (approximately 10% of the time) after the drying cycle is complete, as some dryers already do.
- The impact dryers have on HVAC is smaller than we previously estimated for vented dryers. However, ventless dryers typically release the heat of condensing water into the room. This is a significant benefit in cold climates, but a significant detriment in warmer climates.
- The condenser and heat pump dryer we tested were not able to properly sense when the clothes were dry, at least on the settings at which we tested them. It would be useful to conduct additional testing on these models to determine the cause of this problem.
- Dryer capacity does not have a significant impact on efficiency.
- The steam modes we tested, which are intended to be used in addition to drying modes for removing wrinkles or "refreshing" clothes, used approximately 20% as much energy as a regular drying cycle. We do not expect this cycle to be used very frequently, so its aggregate energy use is likely small, and does not yet justify inclusion in the test procedure.

Recommended Changes to the Current DOE Dryer Test Procedure

We recommend that the current test procedure be changed before an ENERGY STAR specification is developed. We recommend that the DOE change the dryer test procedure in the following ways to better reflect how consumers use dryers and to allow for a more accurate comparison of dryers that use different types of fuels:

1. The test procedure should employ a standardized mix of real articles of clothing, or test cloths that are at least equally challenging to dry.
2. The test procedure should use an efficiency metric that appropriately values the amount of source energy it takes to remove a unit of water. This will allow for a direct comparison of the performance and efficiency of gas and electric dryers.
3. Dryers should be allowed to run until they stop automatically in a variety of modes rather than to a predetermined moisture content in "high heat" mode. In our testing we ran the 100% cotton load in "high heat" and "more dry" auto termination mode and the 50/50 load on "medium heat" and "normal dryness" auto termination mode. We also recommend that dryers be tested in "eco mode" where applicable.
4. The airflow through the dryers should be measured in order to better estimate HVAC impacts.
5. Drying times should also be measured in a standardized fashion to allow buyers to meaningfully compare that aspect of performance across models.

Opportunities for Making Dryers More Efficient

Our research suggests that there are opportunities for significant improvements to dryer technology through taking advantage of several efficiency measures found in dryers currently available on the international market. Simply switching from a standard electric model to a standard gas model (where gas is available) could reduce source energy consumption by approximately 60%.

All but one of the models we tested ran with its heater either fully on or fully off – there was no gradual modulation of the heater output to provide more or less intense heat. Continuously varying the heater power and fan speed has the potential to reduce the energy consumption of a typical dryer by about 20% with a longer drying time and about 15% with an unchanged drying time. These savings are demonstrated in the compact 120 V electric dryer we tested and could be applied to both gas and electric dryers.

There are also opportunities to generate significant savings by using condensing heat exchangers in vented electric or gas dryers. This saves energy by warming up the air coming into the dryer using the warm air being exhausted from the dryer, to reduce the work load on the heating element. This type of heat exchanger is already used in ventless condensing dryers. We estimate that this approach could reduce dryer energy consumption by another 15%. There may also be some efficiency benefits to recirculating the air during the beginning of a drying cycle to shorten warm up times, since little moisture is removed anyway until the drum and clothes are warm.

Finally, we found that US dryers tend to have their moisture sensing strips mounted in a fixed location on the cabinet, which can only detect moisture in the clothes tumbling near the front of the dryer. European models more commonly place those sensors on the rotating part of the drum, to monitor all of the clothing as it tumbles. This may increase accuracy in automatic termination, saving energy and clothing wear, and should be encouraged in the US market as well.

Conclusions

Developing a test procedure that better reflects real world dryer use and that more accurately captures the energy that dryers consume is the first step toward transforming the dryer market. A test procedure that enables a robust comparison of dryer technologies will allow for labels that show annual energy costs and for the development of minimum efficiency specifications for use in voluntary (e.g. ENERGY STAR) and mandatory programs. These specifications will, in turn, allow energy efficiency programs to provide incentives for truly more efficient dryers and drive manufacturers to develop more efficient dryer technologies. Based on its test procedure results and usage frequency, DOE estimates the average dryer consumes 718 kWh per year (DOE 2011b). Field studies yield measured values of 885-1079 kWh/year (33% higher on average) (DOE 2011b). Rising washer spin speeds have probably reduced energy use since these field studies by about 10% given the 13% reduction in initial RMC from the year

2000 to 2008[11] (DOE 2011a), but DOE still underestimates the national energy use of dryers by about 20%.[12] This is roughly consistent with the effect of RW clothing that we measured.

If the opportunities for efficiency improvements described above are adopted, household dryer energy use could be reduced by about 30%. This translates to about 250 kWh in savings each year for an average electric dryer and 10 therms per year for an average gas dryer. On a national level these improvements, coupled with switching to natural gas dryers when gas is available in the house, could:

- Save consumers $4 billion each year in utility bills,
- Save 38 TWh of electricity each year – equivalent to the annual production of more than 13 coal-fired power plants (while using about the same natural gas), and
- Eliminate more than 20 million tons of CO_2 per year – the same as the annual emissions of 4 million cars.

Future Work

One important next step is testing more heat pump dryers with both DOE test cloths and RW clothing with rigorous DOE testing specifications and comparing the efficiency to conventional US dryers. This work is underway funded by CLASP. There are dryer models in existence that have two motors - one to spin the drum and the other to drive the fan. At least one model also has a variable heater power, and this is being tested in eco mode for the CLASP project. It would be relatively straightforward to modify the fan motor such that it is variable speed to achieve full modulation. It would also be relatively straightforward to use an existing condenser dryer heat exchanger to function as an exhaust heat exchanger for a vented dryer. Field testing of efficient dryers would also be important.

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The views and findings expressed herein are solely those of the authors and do not necessarily reflect those of the EPA.

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[11] The initial RMC fell from 53.9% to 47.0% for clothes washer shipments; the energy use is not exactly linear with initial RMC.

[12] The DOE does use a field adjustment factor of 1.04 to represent the actual energy use versus the test procedure for automatic termination (nearly all US dryers have automatic termination capability). This 20% underestimate in actual energy use is after DOE has applied the 1.04 field use factor.

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