Analysis of Potential Energy Savings from Heat Pump Clothes Dryers in North America

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BY

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SEDI SUPER EFFICIENT DRYER INITIATIVE

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This study was initiated as a part of the Super Efficient Dryer Initiative (SEDI). SEDI brings together manufacturers, government agencies, energy efficiency program providers, and appliance retailers in support of a North American market for new, energy efficient, advanced clothes dryers.

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Executive Summary

For the past two decades, there has been little improvement in energy efficiency for North American clothes dryers. Recent innovations in clothes drying technology offer new opportunities for energy savings. One innovation in particular has substantial savings potential: clothes dryers utilizing heat pump technology. This technology has already made significant market gains in Europe and Australia, but is not yet sold in North America. Manufacturers are looking to bring heat pump clothes dryers to North America in the near future.

The successful market introduction of this new, highly efficient technology will require support from energy efficiency program providers and governments in North America through labeling, promotion, and incentives. Programs and governments must have high-quality data on the energy savings that can be expected from heat pump technology before providing this support. Our study compares the energy consumption of currently available European heat pump dryers to North American conventional electric dryers to better understand the potential for energy savings if this technology were introduced into North America.

To develop these data, Ecova procured four European models and three conventional North American models spanning a wide range of sizes, prices, features, and manufacturers. To compare dryer efficiency and performance, each dryer was subjected to the same tests: the current (2005) US Department of Energy (DOE) clothes dryer test procedure and the proposed 2011 DOE test procedure that Ecova modified to include automatic termination in anticipation of a revised DOE test procedure. In 2013, after the testing and analysis was completed, the DOE did indeed propose a revised test procedure. This test procedure is very similar to the anticipated DOE test procedure that was used in this work. The 2011 DOE test procedure, with automatic termination, was also repeated with several alternative test laundry loads that more closely resembles real-world clothing than does the DOE-defined test load.

Key findings include:

- European heat pump dryers use only 40-50% as much energy as North American conventional dryers to dry the same amount of laundry;
- European heat pump dryers took twice as long to dry a load of laundry as North American conventional dryers;
- Drying time and energy consumption increased for all dryers when drying test loads that more closely resemble real-world clothing;
- North American conventional dryers had peak power consumption roughly five times as high as European heat pump dryers;
- Energy consumption and drying time varied significantly between the European heat pump dryers, suggesting that labeling and incentives could be used to promote the sale of the highest performing heat pump technologies.

Key conclusions and recommendations include:

- Heat pump dryers are a globally mature technology with substantial energy saving potential;
- A heat pump dryer designed for North America could still offer significant energy savings even if it were designed to sacrifice some energy efficiency in order to reduce drying time;
- Further modifications to the new DOE test procedure, including the use of a test load that more closely represents real-world clothing, are needed to more accurately predict

actual dryer energy consumption. The recently proposed 2013 revisions to the DOE clothes dryer test procedure includes automatic termination – a significant improvement from the current 2005 test procedure.

This study was funded by CLASP as a part of the Super Efficient Dryer Initiative (SEDI), which brings together manufacturers, government agencies, energy efficiency program providers, and appliance retailers in support of a North American market for new, energy efficient, advanced dryers.

Introduction and Market Overview

Tumble clothes dryers were first introduced to the United States market about 75 years ago, bringing greater convenience to millions of households. As prices steadily declined, sales grew. Today, there are 87 million residential dryers in the US, which account for 6% of US residential electricity use and nearly 2% of natural gas use.[1]

Dryers cost about $9 billion per year to operate, consume as much electricity as does the entire state of Massachusetts (60 billion kWh per year), and are responsible for 40 million metric tons carbon dioxide emissions each year.[2] They are the largest source of residential energy use for which there is currently no ENERGY STAR® or Energy Guide[3] labels, and no utility rebates.

Unlike dryers, clothes washer energy efficiency has improved dramatically over the last 20 years. New models typically employ horizontal axis technology and have more efficient motors and improved controls. As a result, washers have achieved significant reductions in hot water and electricity consumption. Compared to washers built in 1992, new washers have higher spin speeds to extract more water from clothing before it is placed in the dryer, reducing the amount of work dryers need to do. These changes have caused the energy attributed to washer use to fall by 70% during the last two decades (see Figure 1).[4]

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[1] These percentages were derived using the following assumptions: (1) Consumers with gas dryers and consumers with electric dryers use their dryers the same amount of time. (2) There are about one quarter as many gas dryers as electric dryers in the US. (3) The source energy use of a single gas dryer is about 40% of an electric dryer. This suggests that the primary energy use of *all* gas dryers is about 9% of all dryers ((1* 40%)/(1*40%+4*100%) = 9%). Of residential primary energy, 63% is electricity (Arthur D. Little, Inc. 1999. Opportunities for Energy Savings in the Residential and Commercial Sectors with High-efficiency Electric Motors. US Department of Energy Contract No. DE-AC01-90CE23821). Electric dryers consume 6% of residential electricity. Gas dryers consume 1.2% of residential fuel (natural gas, propane, and fuel oil). Since only 1% of dryers are propane (and none are fuel oil), gas dryers represent approximately 2% of residential natural gas use.

[2] Assumptions: 66 billion kWh of annual electricity use at an average rate of $0.12 cents/kWh yields an electric bill of approximately $8 billion. Gas dryers consume about 0.09 quads of the total residential primary energy use, which is approximately 20 quads. At an average rate of $1.10/Therm, this yields a natural gas bill of approximately $1 billion.

[3] The US Environmental Protection Agency (EPA) recently began the process of developing an ENERGY STAR® labeling program for dryers, and Canada has an Energy Guide label for dryers.

[4] Figure 1 shows the relative improvement in measured energy consumption of dryers relative to washers over time based on the current energy consumption test procedures for both machines developed by the US DOE and adopted by Canada's standards and labeling programs. The DOE test procedure for washer energy efficiency takes into account the amount of heated water the washer uses and how much water the washer is able to wring from clothing at the end of the wash cycle. Most of the decrease in clothes washer energy consumption shown in Figure 1 is due to reductions in hot water consumption and reductions in dryer energy consumption resulting from less water in clothing coming from the washer. The DOE test procedure for dryer efficiency only measures the energy used by the itself.

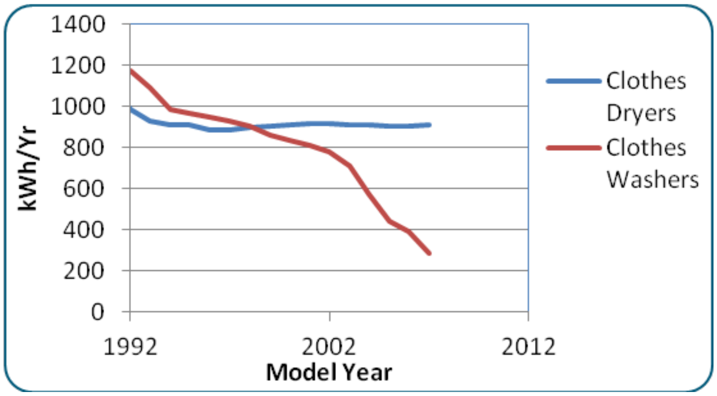

Figure 1. Average annual delivery-weighted energy consumption in Canada

Dryers have achieved very few efficiency improvements during that same period, causing their average energy use to remain relatively flat. Most dryers continue to rely on electric resistance heating elements or gas burners to warm the air that circulates through the clothing drum. The reductions in energy use that have been achieved are due to the elimination of standing pilot lights in gas models and the incorporation of automatic termination capability, which saves energy to varying degrees in different models.

A range of new technologies promises to substantively reduce dryer energy use by:

1. Varying the heat production and airflow (modulation);
2. Appropriately sensing when the clothes are dry;
3. Recovering and reusing waste heat from the drying process.

One technology in particular looks highly promising: Dryers using heat pump technology to dry clothing could potentially save significant energy in North America. Heat pump dryers now sell widely in Europe and Australia (largely on the basis of their energy savings), but are not yet available for sale in North America. This is about to change as manufacturers are looking to introduce heat pump dryers into the North American market in the near future.

Energy efficiency program providers in North America need better data on the real-world energy savings that can be expected from dryers that use heat pump technology before determining the best ways to test, label, and promote more efficient models.

This research is intended to address this need by providing a clear understanding of how different dryer technologies perform relative to each other.

Dryer Characteristics

European heat pump dryers tend to have physically smaller external dimensions and drum volumes than North American conventional dryers (Figure 2). However the manufacturers' rated capacities (explained in the following section) tend to be slightly higher for European dryers than their North American counterparts. As a result, European heat pump dryers are intended to be loaded more densely than North American conventional dryers. An identical 7 pound load in the European dryer (left) and the North American dryer (right) illustrates the difference in drum size.

In addition to differences in size, the typical North American conventional dryer is vented (the dryer evaporates water from the wet clothing and then vents the moist air to the outside); while the typical European heat pump dryer is unvented (the dryer evaporates water from the clothing and then re-condenses the moisture and either drains it or collects it in a reservoir).

Figure 2. Drum size difference between a European (left) and North American (right) dryer

Rated Capacity Differences

The International Electro-technical Commission (IEC) test procedure for clothes dryer energy consumption used in Europe requires dryers to be tested to their claimed capacity by weight using a mixed synthetic and cotton laundry load. In other words, the dryer is tested with an IEC test load that weighs as much as the manufacturer claims the dryer is capable of drying in one load. If the manufacturer does not make a capacity claim, the IEC test procedure provides a formula based on drum volume for determining the weight of the test cloths that make up a dryer load (see the sloped lines in Figure 3). As a result, dryers with the same drum volume are often tested with different weights of test cloth.

North American manufacturers normally rate dryers by drum volume in cubic feet, without any reference to capacity by weight. The DOE test procedure requires dryers to be tested at either a lower fixed weight of 50/50 synthetic/cotton test cloths for "compact" volume dryers, or a higher fixed weight of 50/50 synthetic/cotton test cloths for "standard" volume dryer (shown as the flat, stepped lines in Figure 3). As a result, dryers with widely different drum volumes are typically tested with the same total weight of test cloths in the US.

Figure 3 illustrates how the claimed cotton weight capacities of the European heat pump dryers that were tested vary with the claimed drum volumes of each.[5] It also illustrates how the claimed volume capacities of the North American conventional dryers that were tested vary for the given test weight that DOE specifies for each. "HP" indicates a heat pump dryer and "Conv" indicates a conventional electric dryer.

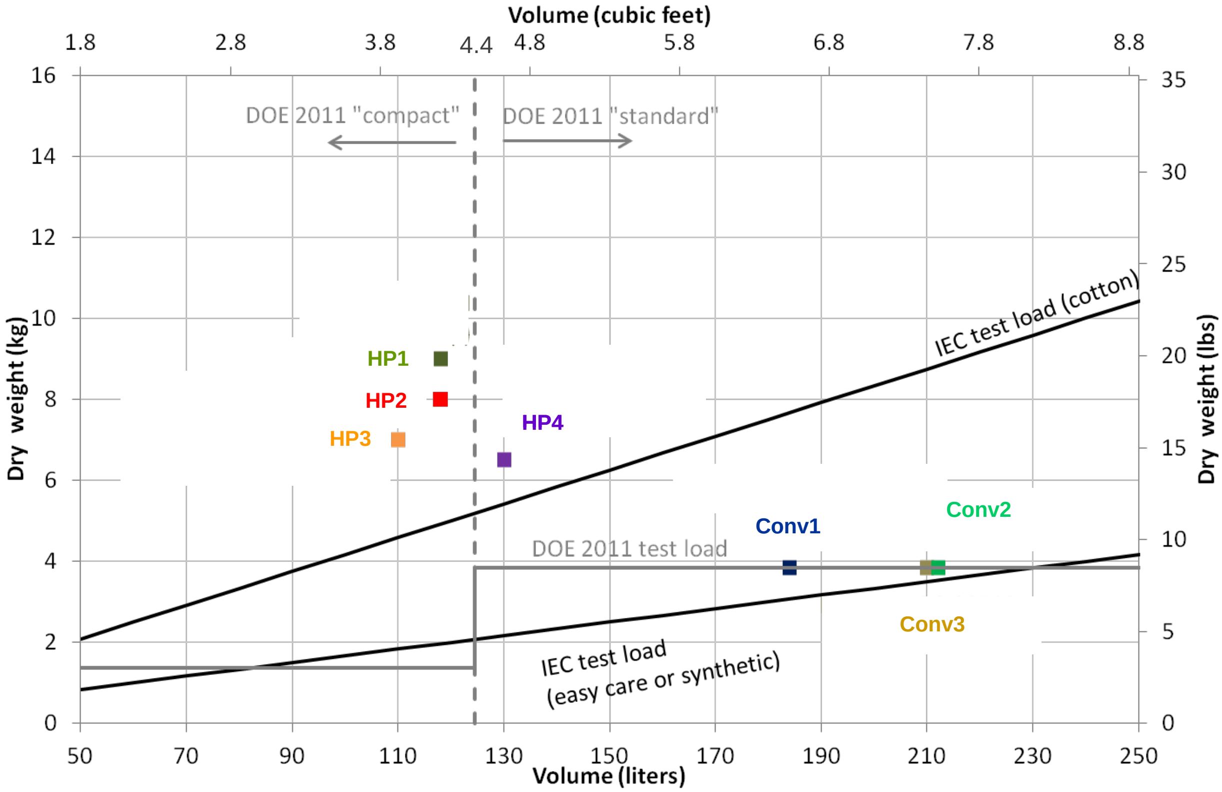

Figure 3. Test procedures load sizes and claimed dryer load and drum sizes

The differences between the methods used to test the performance of clothes dryers in North American and Europe make it difficult to compare the efficiency of technology from the two regions using existing test data. The research presented here provides a better basis for comparison of European heat pump dryers to North American conventional dryers. Dryers from each region were tested in the same lab using the same procedures, requiring the dryers to do the same amount of work with the same test load.

Dryer Selection

Three North American models and four European models were selected for testing and comparison.

North American Dryers

Ecova chose full-size, electric resistance, vented, North American tumble clothes dryers for testing because they represent the majority of the North American market and dryer sales (Table 1). All North American dryers were purchased from retailers in the Durango, Colorado area and delivered to Ecova's lab there. All North American dryers purchased were designed to

[5] The claimed synthetic load size is generally smaller (not shown).

operate on standard 240V/60 Hz, split phase electricity. Models with varying cycle termination features were selected:

1. Conv1 is an entry-level dryer that uses temperature sensing for automatic termination.
2. Conv2 offers an "Eco-mode," which is becoming more common in high-end North American dryers. This dryer can vary its heat output continuously by modulating the heater and claims to be more efficient than a typical US electric dryer. Conv2 uses moisture sensing for automatic termination.
3. Conv3 is a high-end dryer that also uses moisture sensing for automatic termination.

Test Dryer Reference	Conv1	Conv2	Conv3
Purchase Price	$300	$900	$960
Claimed Drum Volume (ft^3)	6.50	7.17	7.17
Key Features	Entry level model with temperature sensing cycle termination only	Modulating heat, high airflow, fast drying	High-end model with moisture sensing

Table 1. Characteristics of the conventional US dryers selected for testing

European Heat Pump Dryers

Heat pump dryers were procured from Europe because the dryer market there is more mature than the Asian or Australian markets and there was more variation in dryer size, features, and price. In addition to offering a large selection of heat pump dryers, Europe has a useful, web-based tool called TopTen that helps consumers evaluate dryer capacity and efficiency.[6] Ecova purchased two European heat pump dryers from European retailers, which were imported to the United States and transported to the Durango, Colorado laboratory. Two European manufacturers each donated an additional heat pump dryer and shipped them to the Durango, Colorado laboratory.[7] The rated loads of these heat pump dryers varied significantly, from 6.5 to 9 kg, although the actual drum volumes were similar. All four heat pump dryers were designed to run on 220V, 50 Hz, single phase electricity and they were tested using power with these characteristics with electricity appropriately modified from the local grid in Durango. These products represent many of the largest manufacturers in the global home appliance market:

1. HP1 had the highest rated efficiency and largest capacity of the consumer-grade heat pump dryers evaluated by TopTen.

2. HP2 is an entry-level residential product.

3. HP3 served as a reference point for comparing current to older generation heat pump models, as it represented the most efficient unit for sale in Europe as of 2010. It is smaller than many of the models sold today.

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[6] http://www.topten.eu. There is also a Top Ten US (www.toptenusa.org), but it does not include clothes dryers.

[7] One of these dryers had to be shipped without refrigerant. Ecova communicated with the manufacturer to make sure that proper refrigerant charging procedures were followed once the dryer reached Durango.

4. HP4 is a semiprofessional dryer. The claimed drum volume places it in the full-size category using the DOE characterization (Table 2). It also has a type of moisture sensor not commonly found in dryers in the US market. This sensor can monitor the moisture content of clothing along its tumble vanes (Figure 4), rather than in a single fixed location at the front of the drum (Figure 5).

Test Dryer Reference	HP1	HP2	HP3	HP4
Purchase Price[8]	~$1,100	~$800	~$1,050	~$3,450
Claimed Drum Volume (ft^3)	4.17	4.17	3.88	4.59
Claimed Capacity (kg of clothing)	9.0	8.0	7.0	6.5
Claimed Efficiency (kWh/kg clothing)	0.23	0.34	0.27	0.24
Key Features	Highest rated 2011 heat pump efficiency and largest rated capacity	Entry level heat pump model	Most efficient European model in 2010; small drum volume	Semi-professional, moisture sensor on drum vanes

Table 2. Characteristics of European heat pump dryers selected for testing

[8] This study did not attempt to estimate the incremental cost of heat pump dryers compared to conventional dryers. The price structure of the European appliance market is generally higher than in North America, and these retail prices may include substantial sales taxes and other charges.

Moisture sensors types vary from dryer to dryer.

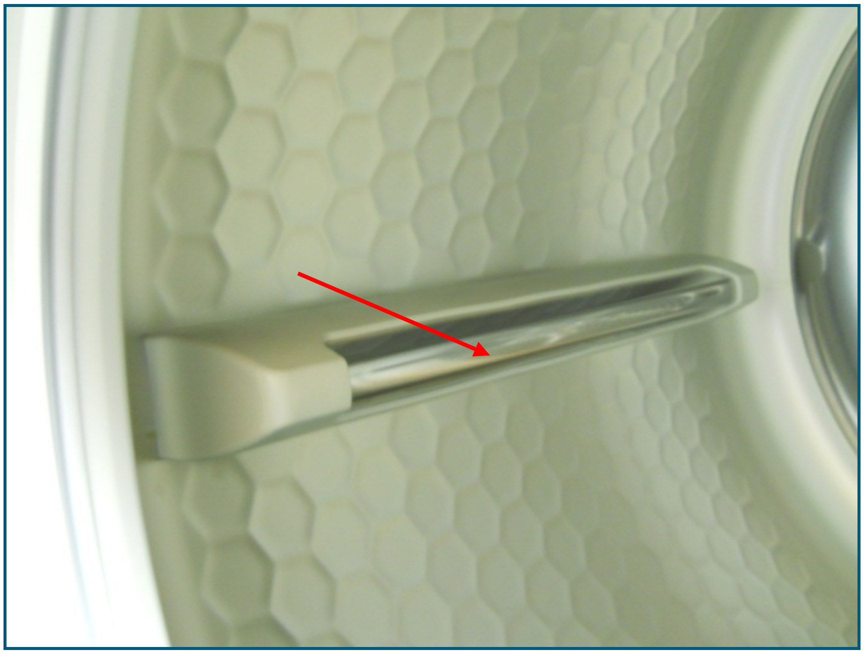

Figure 4. Moisture sensor location in HP4 heat pump dryer (Moves with drum)

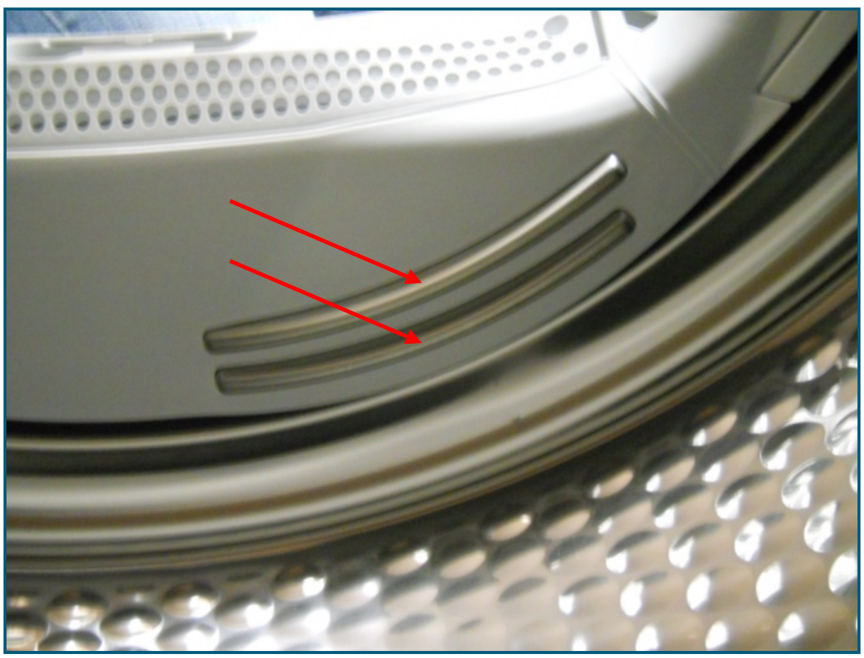

Figure 5. Moisture sensor in most dryers (Does not move with drum)

Testing Methods

All dryers were tested using the 2005 DOE test procedure because that procedure is currently being used for the EPA Emerging Technology specification (Table 3).[9]

In January 2011, the DOE issued a revised test procedure, that did not include a provision for automatic termination. Energy efficiency program providers and advocates, as well as manufacturers responded by petitioning DOE to include automatic termination in a further revision to the test procedure. As a result, DOE reopened the test procedure revision process, and in January of 2013 issued a new revision to the test procedure that does include automatic termination. Our testing and analysis was completed in 2012 after the first revision but before the latest revision. However, Ecova anticipated that the DOE test procedure would eventually include automatic termination, and our testing was conducted in accordance with the DOE 2011 test procedure with automatic termination enabled.

Automatic termination captures the energy savings a dryer can deliver by properly sensing when clothing is sufficiently dry and automatically stopping the drying process. This energy savings can be significant, as Ecova's prior research for the Natural Resources Defense Council (NRDC) demonstrated.[10,11]

The 2011 test procedure with automatic termination enabled is similar to the currently proposed 2013 test procedure. Analysis of the test procedure differences suggest the measured energy consumption results (in kWh per cycle) would change by less than 1%. Combined Energy Factor values (in pounds of water removed per kWh consumed) would change because of differences in field use factors that attempt to account for differences between measured values and real-world dryer operation and changes in final remaining moisture content tolerances. However, the key findings presented here would not change if the recently proposed 2013 DOE test procedure had been used.

[9] Ecova deviated slightly from the 2005 DOE test procedure in that the temperature sensor used to measure the ambient conditions during testing had an accuracy of ±3.6ºF whereas the test procedure specifies an accuracy of ±1ºF. Ecova field calibrated the temperature sensor with a more accurate sensor and found that the average temperature during dryer runs was very similar. We do not believe the use of the less accurate temperature sensor to measure ambient conditions affects the results presented here in any significant manner.

[10] Paul Bendt, Chris Calwell, and Laura Moorefield. 2009. Residential Clothes Dryers: An Investigation of Energy Efficiency Test Procedures and Savings Opportunities. Ecos report for Natural Resources Defense Council, November 6, 2009.

[11] David Denkenberger, Serena Mau, Chris Calwell, and Eric Wanless. 2011. Residential Clothes Dryers: A Closer Look at Energy Efficiency Test Procedures and Savings Opportunities. Ecova and NRDC.

Test Procedures

Test Procedure & Load / Parameter	DOE 2005 DOE load	DOE 2011 with auto-termination DOE load	DOE 2011 with auto-termination AHAM 1992 load	DOE 2011 with auto-termination IEC easy-care load
Cycle termination	Manual	Auto	Auto	Auto
Fabric composition	50% cotton/ 50% polyester	50% cotton/ 50% polyester	100% cotton	35% cotton/ 65% polyester
Fabric shape/type	2D sheets	2D sheets	Variety of clothing and linens; diversity in thickness	Shirts and pillow cases
Bone dry weight	7 lb	8.45 lb	8.45 lb	8.45 lb
Initial remaining moisture content (RMC)	70%	57.5%	57.5%	57.5%
Final RMC	2.5–5.0%	<2 %	<2 %	<2 %
Total water removed standard	4.6 lb	4.8 lb	4.8 lb	4.8 lb
Comment	Emerging Tech basis	Similar to 2013 DOE test procedure	Diversity of thickness: realistic performance	Real clothing, but little diversity in thickness

Table 3. Test load and method comparison

Test Load Requirements

Having the dryers do the same amount of work was one of the goals of this study. Even though some of the European heat pump dryers would be considered compact according to the DOE test method based on drum size, all of the dryers were tested according to DOE's full-size test load requirements. As explained previously, current European heat pump dryers are built to dry at least as much clothing as full-sized US dryers.

Test Load Cloth

The test cloths specified by both the 2005 and the 2011 DOE test procedures consist of thin 50/50 cotton/synthetic, two-dimensional sheets (similar to handkerchiefs). See Figure 6.

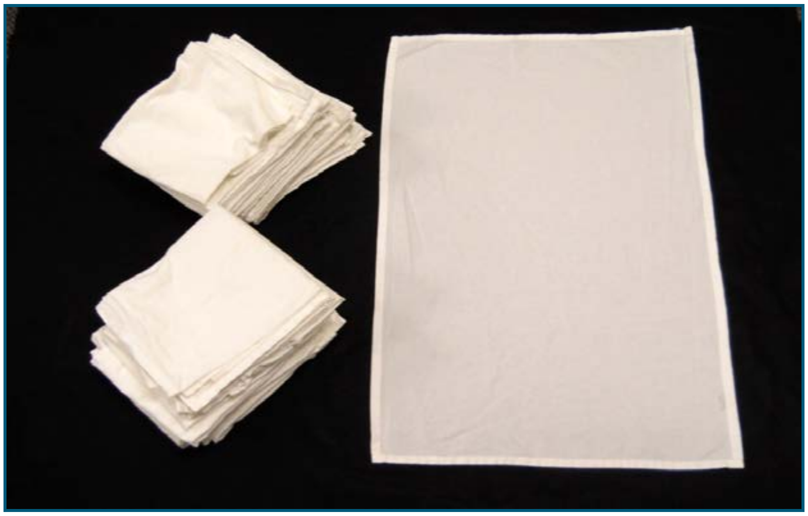

Figure 6. DOE test load appearance

Actual (real-world) clothing has varying thicknesses and cotton content. Previous research work indicated that drying actual clothing usually requires significantly more energy than drying an equivalently sized load of these test cloths.[12] To understand the impact on dryer energy use of real-world clothing of various cotton contents, we conducted tests with two additional test loads: one of 100% cotton and one partially synthetic/partially cotton (35% cotton/65% polyester) also known as the “easy care” load.

The Association of Home Appliance Manufacturers (AHAM) 1992 test load (Figure 7) was chosen for the cotton load because it employs actual clothing and has significant diversity in cloth thickness.

[12] David Denkenberger, Serena Mau, Chris Calwell, and Eric Wanless. 2011. Residential Clothes Dryers: A Closer Look at Energy Efficiency Test Procedures and Savings Opportunities. Ecova and NRDC.

Figure 7. AHAM test load appearance

The IEC test load (Figure 8) was chosen for the partially synthetic, partially cotton load. It has diversity in shape, but does not have diversity in thickness. Unfortunately, a partially cotton test load that has both diversity in shape and thickness could not be identified in official test procedures.[13]

Figure 8. IEC test cloth appearance

As described above, all three test loads have different clothing weights, thicknesses, and fabric content; Figure 9 illustrates these differences. The bubble size indicates individual item weights in each load, the larger the bubble the heavier the items. The position on the horizontal axis indicates the thickness of the clothing.

[13] The NRDC draft test method did have diversity in shape and thickness for a partially cotton load: David Denkenberger, Serena Mau, Chris Calwell, and Eric Wanless. 2011. Residential Clothes Dryers: A Closer Look at Energy Efficiency Test Procedures and Savings Opportunities. Ecova and NRDC.

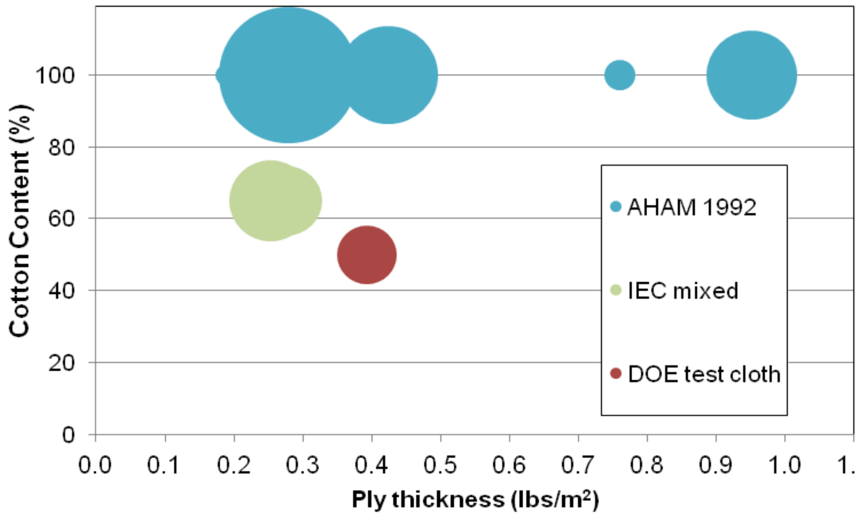

Figure 9. Test load weights and fabric content

Tests Conducted

Both the 2005 and the 2011 versions of the DOE test procedure require three repetitions. To maximize the relevance of this study to the test procedure revisions process, three repetitions of the 2005 test procedure and three repetitions of the 2011 test procedure with automatic termination were conducted, as show in Table 4. All test runs were performed using the DOE test load discussed above.

Test / Dryer	DOE 2005 7 lb	DOE 2005 7 lb Eco-mode	DOE 2005 3 lb	DOE 2011 auto 8.45 lb	DOE 2011 auto 8.45 lb Eco-mode	DOE 2011 auto 3 lb	DOE 2011 auto AHAM cotton 8.45 lb	DOE 2011 auto IEC 35%/65% 8.45 lb
Conv1 (temp sensing)	3			3			1	1
Conv2 (modulating)	3	1		3	1		1	1
Conv3 (moisture sensing)	3			3			1	1
HP1	3			3			1	1
HP2	3		3	3		3	1	1
HP3	3			3			1	1
HP4	3			3			1	1

Table 4. Test and quantity of test runs performed on each dryer

This study also explored the impact on dryer energy consumption when using test cloths that more closely approximate the types of clothing washed in the real-world than the current DOE test load. At the time of this report, DOE was not considering a revision to the test load used in the dryer test procedure. To conserve limited funding for this project, single test runs were conducted using the AHAM and IEC test loads. All tests were conducted using the 2011 test procedure with auto termination.

Neither the 2005 DOE test procedure nor the 2011 DOE test procedure make provision for a user-selected “Eco-mode,” although it is considered in the requirements for the Environmental Protection Agency’s (EPA) ENERGY STAR Emerging Technology Award for Highly Efficient Dryers[14]. To assess energy consumption in this mode, single test runs were conducted with the 2005 test procedure and the 2011 test procedure with automatic termination.

Additional tests were also conducted to explore avenues for future research. A smaller (3 lb) test load was run in the HP2 dryer under both the 2005 test procedure and the 2011 test procedure with automatic termination. Both tests were conducted with the DOE test load.

Research Results

When the same dryer was tested three times with the same procedure and test load the run results were typically within one to three percentage points of each other. The run-to-run efficiency differences were larger among the European heat pump models than among the North American conventional dryers. Drying times varied across the different dryers with each test procedure, and to a lesser extent across test procedures with the same dryer. Drying times and measured efficiencies were very sensitive to small differences in final remaining moisture content (RMC). The 2011 DOE test procedure requires a lower final RMC than did the 2005 DOE test procedure. All of the dryers took longer to complete the 2011 DOE test procedure with automatic termination than they did the 2005 DOE test procedure.

Average Drying Times and Combined Energy Factor

On average, using data from all test scenarios with similar load size, the European heat pump dryers were more than twice as efficient (130%) and took more than twice as long (130%) to dry than the North American conventional dryers, as shown in Table 5 and Figure 10. In other words, the European heat pump dryers used only 40-50% as much energy as the North American conventional dryers to dry the same amount of laundry. The faster-drying heat pump dryers were generally less efficient than the slower-drying heat pump models. In Table 5 Average Energy Use is the electricity consumed during each dryer cycle. Combined Energy Factor (CEF) reflects the weight of water removed (in pounds) per kWh of electricity consumed – larger values are more efficient than smaller values. CEF has been adjusted using a field correction value that is intended to better reflect dryer operation in the real-world in accordance with the DOE 2011 test procedure. While the average energy use (across all tests) would be very similar if the 2013 DOE test procedure had been used, the average CEF (across all tests) would change if the 2013 DOE test procedure had been used. However, the fundamental finding that European heat pump dryers use less than half the electricity that North American conventional dryers do, and take more than twice as long to dry loads, would remain unchanged.

[14] http://www.energystar.gov/index.cfm?c=pt_awards.pt_clothes_dryers

		Average Drying Time (H:MM)	Average Energy Use (kWh)	Average 2011 CEF (lbs/kWh)
Conventional Dryers	Conv1	0:42	2.62	3.02
	Conv2	0:30	2.48	3.19
	Conv3	0:34	2.33	3.39
	Average All	0:35	2.48	3.20
Heat Pump Dryers	HP1	1:23	0.91	8.66
	HP2	1:18	1.01	7.80
	HP3	1:37	1.14	6.93
	HP4	1:09	1.22	6.50
	Average All	1:22	1.07	7.47

Table 5. Average drying time and efficiency of dryers[15]

In the Figure 10 below CEF or Energy Factor (EF) and drying time is plotted for each dryer for each test cloth type. EF is used for DOE 2005 results for consistency with the 2005 test procedure. Note that the DOE 2005 test load is 7 pounds and all other loads are 8.45 pounds.

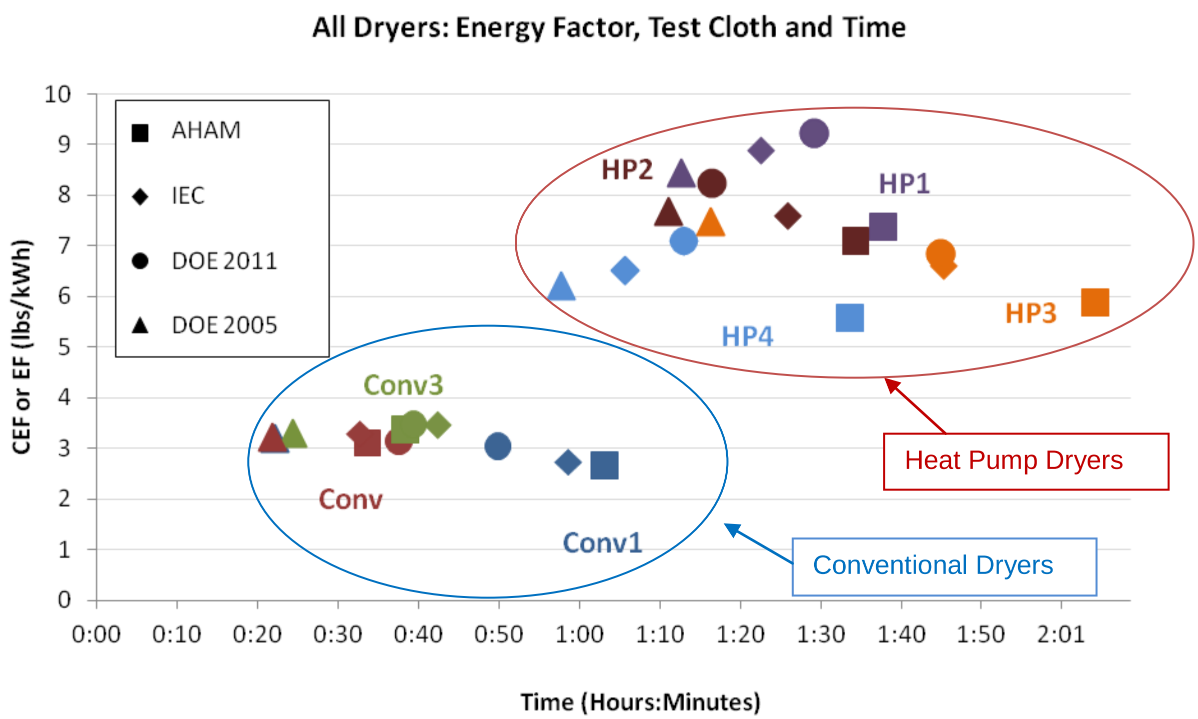

Figure 10. Summary of drying time and Energy Factor (does not include Eco-mode and smaller loads)

15 These numbers are simple averages of the eight tests run for each of the dryers (Table 4), excluding the 3-pound tests and the Eco-mode tests.

DOE 2005 Test Procedure Results with the DOE Test Load

Using the 2005 DOE test procedure and test load, the European heat pump dryers were 1.9–2.6 times as efficient as the North American conventional dryers, but took 1.7 to 3.5 times longer to dry.

There is a linear relationship between drying time and efficiency across all seven models, with the exception of the Conv2 run using Eco-mode (see Figure 11). Generally, higher efficiency meant longer drying times. This correlation also held true for the European heat pump clothes dryers; for example, the HP4 dryer is a semiprofessional model, which was significantly more powerful than the other heat pump dryers tested and therefore dried faster, but was also less efficient.

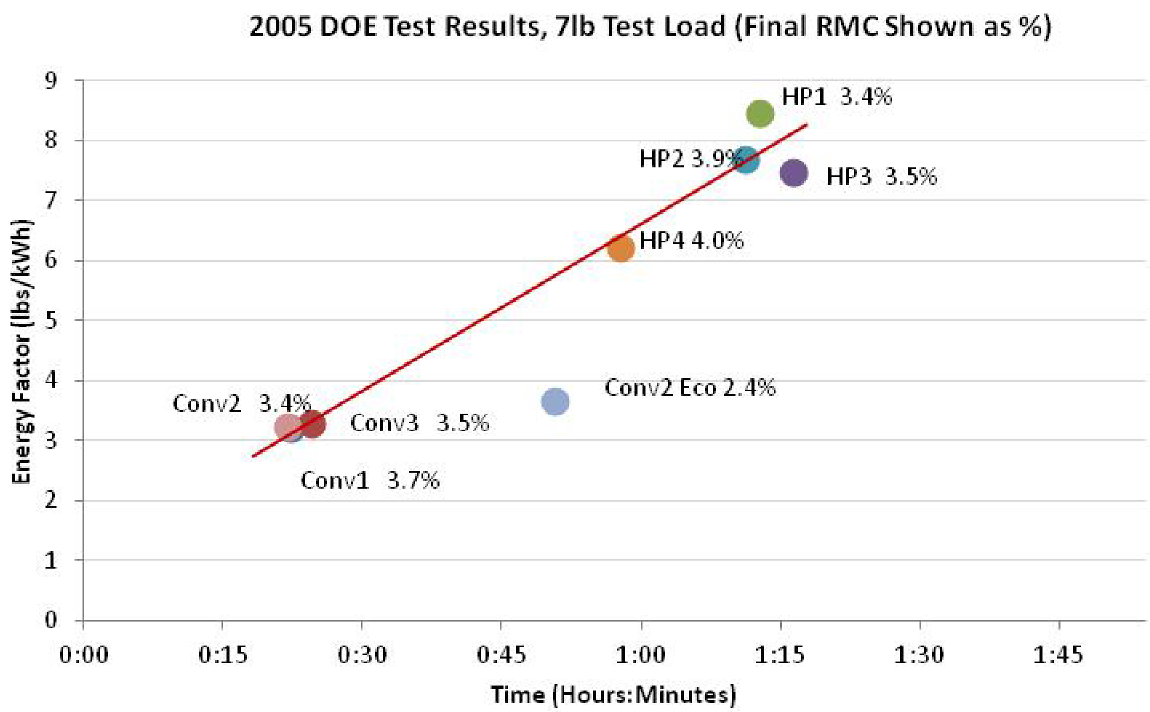

Figure 11. 2005 DOE test results

DOE 2011 Test Procedure (with automatic termination) and DOE Test Load

Using the 2011 DOE test procedure (with automatic termination) and DOE test load, the European heat pump dryers were 2.0 to 3.1 times as efficient as the North American conventional dryers, but took 1.5 to 2.8 times longer to dry.

Unlike under the 2005 test procedure, the relationship between efficiency and drying time was not linear, largely due to the inclusion of automatic termination (Figure 12). When the dryers are tested with manual termination, they are turned off once the clothes have reached a specific final RMC; as a result, all the dryers remove the same amount of water. When the dryers are allowed to automatically terminate the cycle, the dryer determines when the clothes are dry. Depending on the ability of the dryer's sensor to accurately determine when the clothes are dry, each dryer will stop drying the clothes at a different final RMC. This means that dryers that are better at sensing when the clothing is dry will shut off sooner, saving energy.

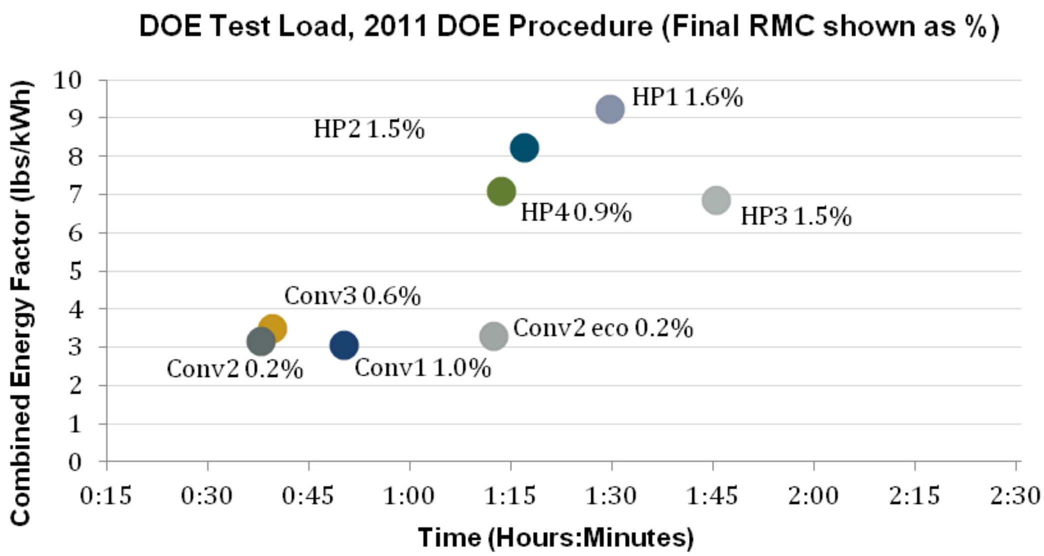

Figure 12. 2011 DOE Test Results

DOE 2011 Test Procedure (with automatic termination) and IEC Test Load

The IEC test load is relatively more similar to actual laundry than the DOE test load because it includes a mix of cotton and synthetic cloth and has more diversity in fabric shape (though not thickness). When tested using the IEC test load, the European heat pump dryers were 1.9 to 3.3 times as efficient as the North American conventional dryers, but took 1.1 to 3.3 times longer to dry.

The fastest European heat pump dryer (HP4) was more than twice as energy efficient but took only about 10% longer than the slowest conventional dryer (Conv1) to dry the IEC load; see Figure 13. The HP4 dryer is a semi-professional dryer and has a larger compressor than the other heat pump dryers, which may account for its faster drying time.

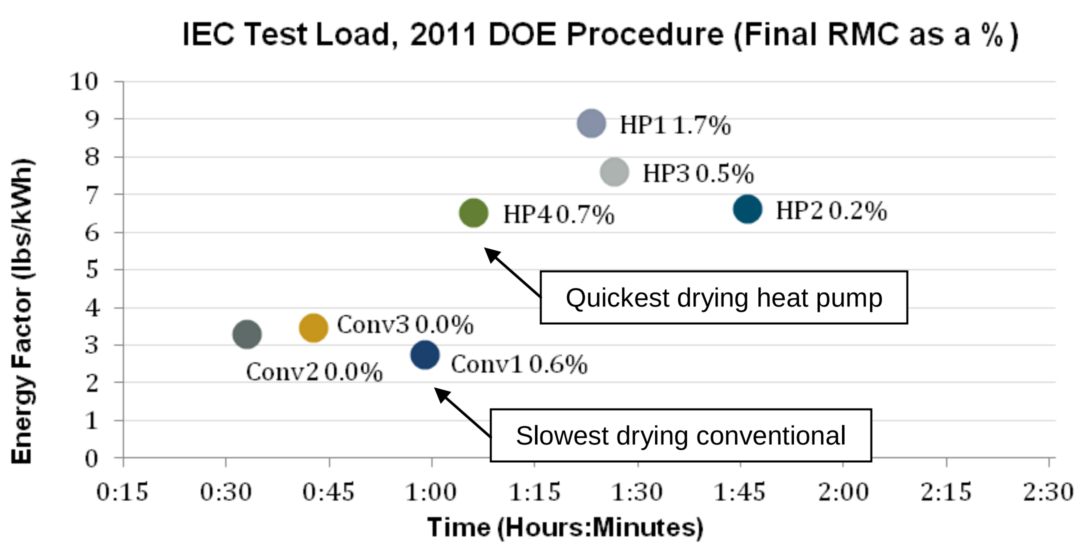

Figure 13. IEC test load, 2011 DOE test procedure

DOE 2011 Test Procedure with the AHAM Test Load

The AHAM test load is the most similar to actual laundry because it uses actual clothing items with different thicknesses. When tested using the AHAM test load, European heat pump dryers were 1.7 to 2.7 times as efficient as North American conventional dryers, but took 1.5 to 3.8 times longer to dry (Figure 14).

When tested with the AHAM test load, all dryers were relatively less energy efficient and took longer to dry than with the DOE test load. These impacts of the AHAM test load were generally less pronounced for the North American conventional dryers, suggesting that the real-world efficiency gains from heat pump dryers may be smaller and the drying time penalty may be somewhat larger than results under the DOE test procedures indicate.

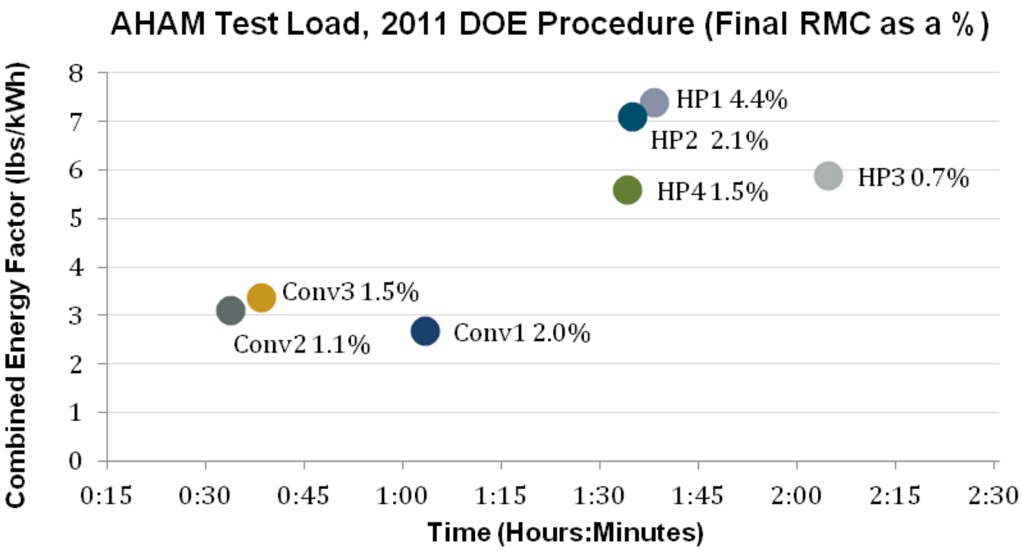

Figure 14. AHAM test load, 2011 DOE test procedure

Energy Efficiency Sensitivity to Final RMC

A common definition for a normal dryness setting was required for testing energy efficiency sensitivity to final RMC. “Normal” dryness was defined as the middle option in the range of dryness settings available on each dryer (this middle option is often labeled “cupboard dry” on European dryers). However, achieving a common final RMC through automatic termination required different settings on different dryers. Some of the dryers had to be set at a dryness level above “normal.” In the following graphs (Figure 15 and Figure 16), “+” indicates that the test was run with the dryer set at one dryness level higher than “normal.” These graphs show the combined energy factor, in pounds of water removed per kilowatt hour of electricity consumed, measured using the 2011 DOE test procedure.

Changing the dryer setting to increase dryness had a negative impact on energy efficiency, particularly for the European heat pump dryers. For example, switching the HP3 dryer to the next highest dryness setting cut the final RMC by 0.3%, but reduced efficiency by 12.5% (Figure 15). Not all of the European heat pump dryers were affected to the same degree, see Figure 16. Therefore, it may be challenging to develop a correction factor to account for the efficiency impact of differences in final RMC. North American conventional dryers did not exhibit this degree of sensitivity to small differences in final RMC, which suggests the need for additional test procedure refinements before the DOE test procedure if correction factors are to be used.

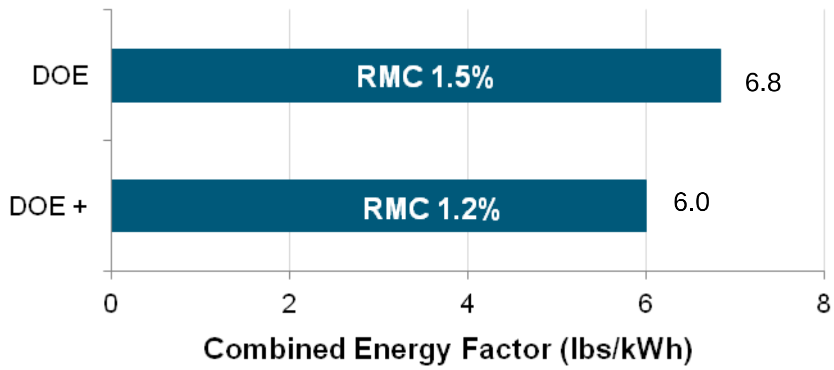

Figure 15. Impact on energy efficiency of HP3 using the DOE 2011 test procedure with dryness setting increased one level

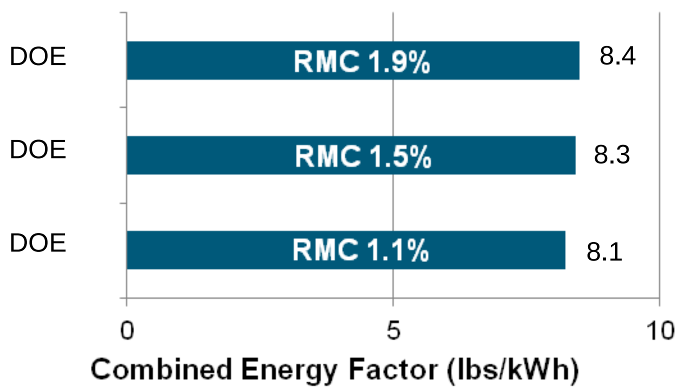

Figure 16. HP2 using DOE 2011 test procedure relationship between efficiency and final RMC (same dryness setting)

Additional Testing with Smaller Test Loads

The entry-level European heat pump dryer (HP2) was tested with a smaller test-load to evaluate the impact of load size on dryer performance. Figure 17 plots Cycle Energy (kWh per cycle) as a function of pounds of water removed per load for HP2 for various types and sizes of rest loads.

Testing shows that there is not a linear relationship between the size of the test load and the amount of energy consumed, indicating that heat pump dryers are about 20% more efficient when drying larger laundry loads. This finding can be explained by the fact that the larger load has a greater wetted surface area, which allows evaporation to take place more efficiently. This allows the heat pump dryer to remove more moisture with less effort, reducing energy use.

This finding could impact a European-sized North American heat pump dryer submitted for the ENERGY STAR Emerging Technology Award. As discussed earlier, the drum size of most European heat pump dryers would be considered “compact” sized according to the DOE test procedure, even though they are rated to dry as much clothing as a standard-sized North American conventional dryer. Therefore, the European-sized North American heat pump dryer would be tested with a 3 pound test load instead of a 7 pound test load. Testing a European sized North American heat pump dryer with the smaller test load could make the dryer look significantly less efficient than testing with the larger test load.

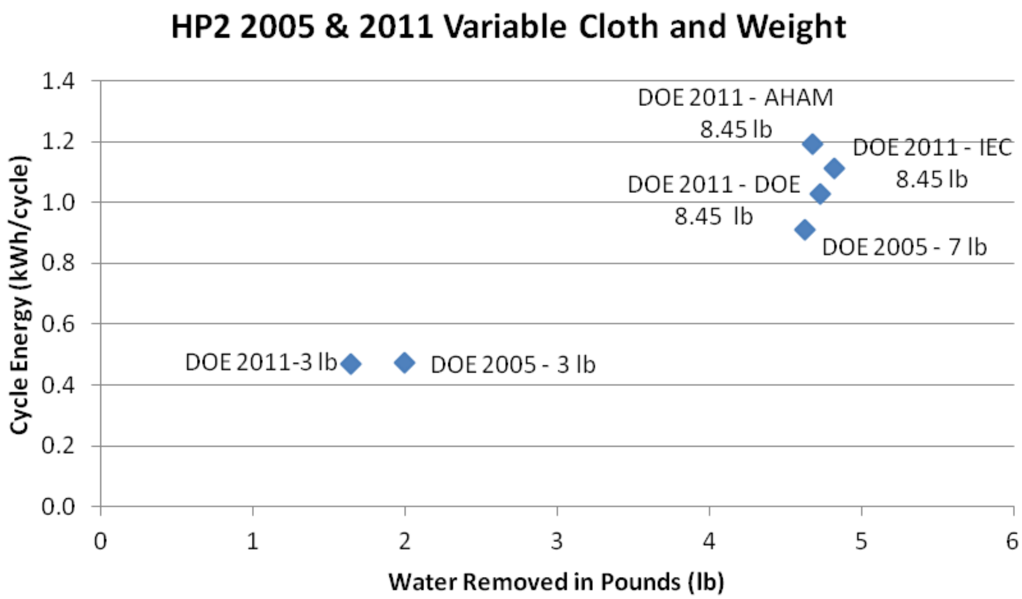

Figure 17. HP2 heat pump dryer tested with various loads test procedures

Additional Eco-mode Testing

A single Eco-mode test was performed for both the 2005 DOE test procedure and the 2011 DOE test procedure with automatic termination. The Conv2 dryer in Eco-mode was approximately 9% more energy efficient on average than its “normal” drying mode, see Table 6. On average, the Conv2 dryer in Eco-mode also left the clothing slightly wetter than in “normal” drying mode.

	Eco-mode is:	Eco-mode takes:	Eco-mode final RMC is:
2005 Test	13% more efficient	2.3 times longer	1% lower
2011 Test	5% more efficient	1.9 times longer	0.1 % greater

Table 6. Conv2 Eco-mode results

The results of this single test on this single Eco-mode equipped dryer showed relatively small reductions in energy consumption and relatively large increases in cycle length when compared to the European heat pump dryers. Furthermore, the peak power draw was not reduced. See Appendix II more detail.

Power Demand

There are significant differences in both the maximum and average power demand by North American conventional and European heat pump dryers. This study found that North American conventional dryers had peak power demands that were roughly five times greater than European heat pump dryers. This finding may be of interest to electric utilities, because dryers are typically used throughout the year and technology choice could have both daily and annual system peak impacts. Table 7 summarizes the dryer power demand when tested using the DOE 2011 test procedure with automatic termination.

Dryer	Peak power demand (W)	Average power demand (W)
Conv1	6,100	3,100
Conv2	6,000	4,400
Conv3	5,900	3,900
HP1	790	630
HP2	1,000	770
HP3	870	710
HP4	1,300	990

Table 7. Peak and average power demand using the DOE 2011 test procedure

Additional Test Data

See Appendix I for detailed analysis on the impact each test load had on drying time, final RMC, and efficiency for each dryer tested.

Conclusions

This study was conducted to provide energy efficiency program and policy-makers with high-quality data on the energy savings that can be expected from currently available heat pump clothes drying technology. Results suggest that heat pump dryers offer a substantial opportunity for energy savings in North America. Several conclusions based on collected data are summarized below:

Dryer Energy Use

The results show that the European heat pump dryers that were tested used only 40 to 50% as much energy as the North American conventional dryers tested to dry the same amount of laundry.

Drying Time

The European heat pump dryers took about twice as long to dry the same load of laundry as the North American conventional dryers. It is worth mentioning that the European heat pump dryers were designed for European customers who are accustomed to condensing dryers, which have longer drying times than vented dryers that are more common in North America.

Our research did not evaluate potential technical options for reducing drying time, but possible methods include using a more powerful compressor, using a hybrid design with supplemental electric resistance heat, or partial venting. For example, HP4 - a semi-professional dryer - demonstrates how a more powerful compressor can shorten drying time. These options may raise costs and reduce efficiency. However, the potential efficiency advantage of heat pump dryers appears to be large enough that dryer manufacturers should be able to develop North American heat-pump dryers that dry quickly, and still offer significant energy savings.

Effects of Test Load Composition on Dryer Energy Use and Drying Time

The energy consumption of all the tested dryers increased when they were asked to dry loads that more closely resemble typical laundry. Compared to the DOE test load, the North American conventional dryers consumed 2% more energy when drying the IEC test load and 6% more energy when drying the AHAM test load. The European heat pump dryers had larger increases in energy consumption; when drying the IEC test load they consumed 6% more energy and when drying the AHAM test load they consumed 17% more energy.

The European heat pump dryers remained significantly more energy efficient than the North American conventional dryers when drying clothing that more closely resembled typical laundry. The average energy savings of European heat pump dryers compared to North American conventional dryers was 58% when drying the DOE test load and 55% when drying test loads that more closely resemble typical laundry. The absolute energy savings for European heat pump clothes dryers per load in kWh were very similar between the DOE test load and the other test loads, because the European heat pump dryers and the North American conventional dryers both consumed more total energy when drying test loads that more closely resembled typical laundry.

Drying clothing that more closely resembled typical laundry also increased drying time. When compared to the amount of time it took to dry the DOE test load, North American conventional dryers took 2% longer to dry the IEC test load and 7% longer to dry the AHAM test load. The impact on drying time for the European heat pump dryers were mixed, there was a 2% *decrease* in drying time when drying the IEC test load and a 18% increase in drying time when drying the AHAM test load.

Test Procedure Development

These research results suggest that in order to test clothes dryer efficiency accurately, the DOE should develop a test procedure that better reflects real-world use. While the most recent 2013 DOE test procedure includes automatic termination, additional test procedure refinements are needed before the DOE test procedure can yield reliable estimates of energy use for heat pump models.

Dryer energy efficiency varies from model to model. As a result, it would be useful to measure all dryers with one or more test loads that more accurately resemble the laundry consumers actually dry. It has been suggested that a correction factor could be developed to correct results obtained when testing the current DOE test load to obtain results closer to what would be experienced with real-world clothing. However, the heat pump dryers and conventional dryers we tested responded differently to real-world clothing. Therefore, our research suggests that an attempt to develop a single correction factor that could be applied to all models and all drying technologies would likely be unsuccessful and that there would need to be different correction factors for different types of dryers.

Specific implications for the revision of the DOE clothes dryer test procedure include the following:

- The DOE test procedure for dryers should define a test load that includes fabrics that are more varied in size, weight, and composition, and more representative of typical laundry;
- The DOE test procedure should allow dryers to shut themselves off using automatic termination – the 2013 test procedure includes this welcome revision;
- The DOE test procedure should be able to account for the fact that small differences in the final RMC achieved by dryers can have large differences in measured energy efficiency.

Heat Pump Dryer Feasibility as an Energy Efficiency Program Measure

The results of this study are consistent with previous work and strongly suggest that heat pump clothes dryers may be attractive for promotion through energy efficiency programs once these dryers become available (Table 8).

Test Cloth - Procedure	Dryer Type	Energy Factor (lbs/kWh)	kWh/ Year	Energy Savings Using Heat Pump (kWh)	Annual Electricity Bill Savings ($US)[16]	Payback Period (Years)[17]
DOE - 2005	Conventional	3.24	898	507	$61	5
	Heat Pump	7.46	391			
DOE - 2011	Conventional	3.22	742	428	$51	6
	Heat Pump	7.60	314			
IEC - 2011	Conventional	3.16	757	434	$52	6
	Heat Pump	7.40	323			
AHAM - 2011	Conventional	3.05	784	415	$50	6
	Heat Pump	6.48	369			

Table 8. Utility program parameters

Emerging Technology Award Implications

The EPA Emerging Technology Award requirements use the 2005 DOE test procedure to determine eligibility. As noted on page 9, the European heat pump clothes dryers we tested were physically smaller, but had equal to - or larger load capacities than the North American conventional dryers we tested. If a European-sized North American heat pump dryer were introduced into the market, the dryer would be considered compact under the DOE test procedure. As a result, it would be tested with a 3 pound test load instead of a 7 pound test load, even though the manufacturer may intend it to dry the same load of clothing as a standard-sized North American conventional dryer. This study suggests that testing a European heat pump dryer with a smaller than full-capacity load may significantly reduce its efficiency, making it more difficult for the dryer to qualify for the ENERGY STAR Emerging Technology Award. The EPA may want to consider modifying the test procedure used for the Award, and test dryers based on the amount of clothing they are intended to dry.

[16] Assumes a residential electricity rate of $0.12 per kWh

[17] Assumes that the incremental cost for heat pump technology is approximately $300. This assumption is based on a comparison of costs of heat pumps used in other applications and conversations with dryer and HVAC contacts. More robust incremental cost estimates are needed before utility programs can be developed.

Recommendations for Further Research

Based on the findings summarized above, further research would be useful in five areas: load size, automatic termination, new heat pump models, the impact of heat pump dryers on clothing wear and tear, and changes in dryer venting.

Load Size

More testing is needed with larger and variable real-world clothing loads in order to properly characterize efficiencies and drying times. To better estimate real-world energy savings that will be useful to utility programs, testing smaller and larger loads would be valuable. Analysis of the recent Northwest Energy Efficiency Alliance field study data, scheduled for release in Summer 2013, would be helpful.

Automatic Termination

More automatic termination tests are required to establish efficiency correction factors for the significant differences in final RMC, which is needed to make more direct efficiency comparisons between dryers.

New Heat Pump Models

Testing larger, faster US heat pump models (including vented designs) in the lab and in the field will be important when they become available. Additionally, for ENERGY STAR®, testing non-heat pump technologies that promise significant, cost-effective energy savings would be valuable.

Ecova's prior research suggested that there could be ways to simultaneously lower the cost, increase the efficiency, and speed the drying time of heat pump clothes dryers. Investigating the components of heat pump dryers to see why one dryer is more efficient or faster than another could result in heat pump dryers that are more acceptable to North American consumers.

Clothing Wear and Tear

An important piece of future work is assessing the net impact of heat pump dryers on clothing wear and tear, as the impact of different dryer technologies on clothing wear and tear could be very important to the typical US consumer.

Based on the estimated cost of clothing, the cost of the wear and tear on the clothing per dryer load may be greater than either the cost of the wear and tear on the dryer itself per load or the cost of energy per load.[18]

The lower air temperature associated with heat pump dryers may reduce clothing wear and tear, but the greater amount of tumbling involved with longer cycle lengths may increase it. Because the size of the increase or decrease is not known, the net effect on clothing wear and tear is also unknown.

Dryer Venting HVAC Impacts

Studying the impacts on total home energy use associated with different dryer venting options and residential HVAC effects would help utility programs develop cost-effectiveness calculations. Initial modeling of these impacts suggest that HVAC savings from unvented dryers

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[18] Mary Ann Morris and Harriet H. Prato. 1975. Edge abrasion of durable press fabrics due to laundering and wear. *Home Economics Research Journal*, 3, 333, pp. 171–185, March 1975.

could be significant, but actual measurements in the field are necessary to better understand HVAC interactions in different housing types and across a range of climate conditions.

Appendix I: Individual Dryer Testing Results

Figure 18 through Figure 24 illustrate the impact of the different test loads on drying time, final RMC, and efficiency for each dryer tested. All tests were conducted using the DOE 2011 test procedure with automatic termination.

There were significant differences on the impact of the different test clothes between the European heat pump and North American conventional dryers. Generally, the final RMCs for European heat pump dryers were higher than the final RMCs for North American conventional dryers. Also, sufficiently drying (<2% final RMC) the AHAM test load often required the European heat pump dryers to be set at higher dryness setting and also required more time.

Conventional Dryer #1

Conv1 took the longest to dry and was the least efficient of the North American conventional dryers.

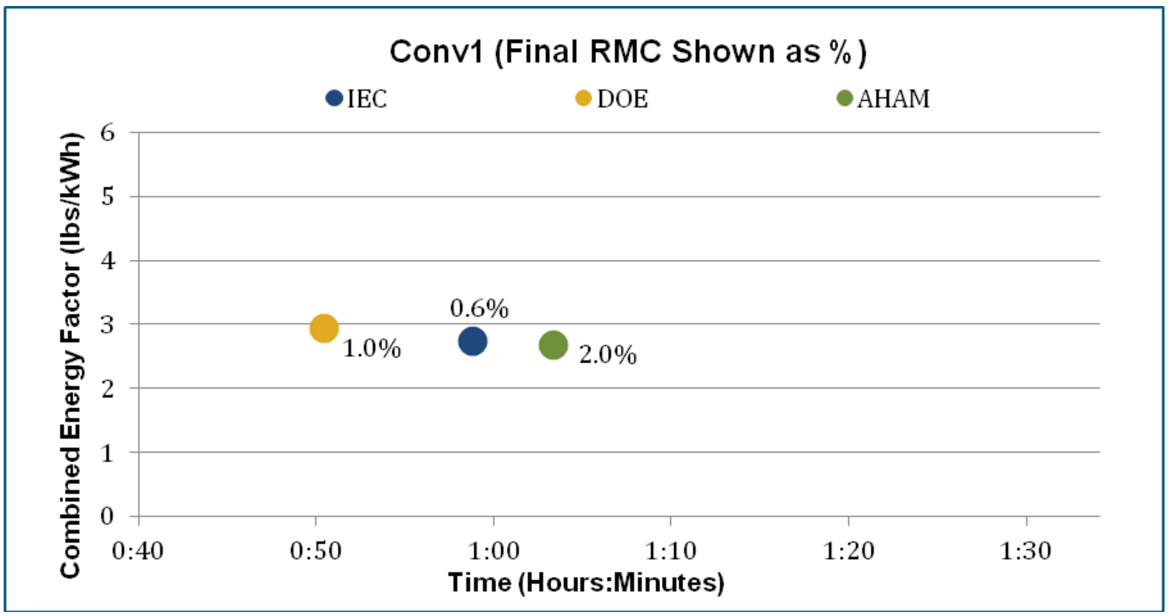

Figure 18. Conv1 DOE 2011 test procedure

Conventional Dryer #2

Conv2 was the fastest North American conventional dryer. Surprisingly, it dried the AHAM test load more quickly than the DOE test load, however it sacrificed some efficiency and left a higher final RMC.

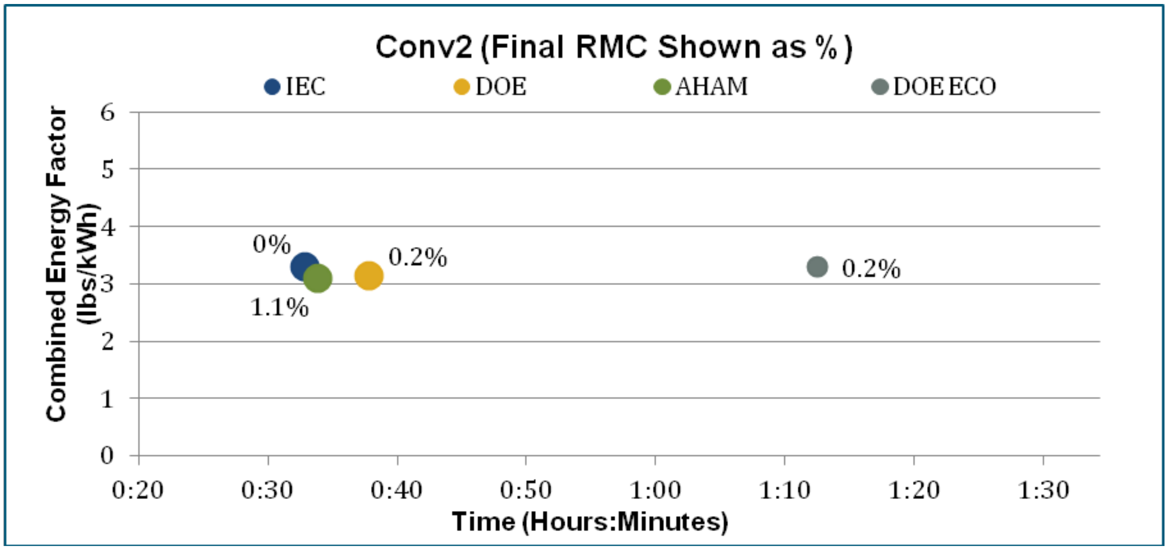

Figure 19. Conv2 DOE 2011 test procedure

Conventional Dryer #3

Conv3 had less variation in drying time, efficiency and final RMC between the different test loads than the other North American conventional dryers.

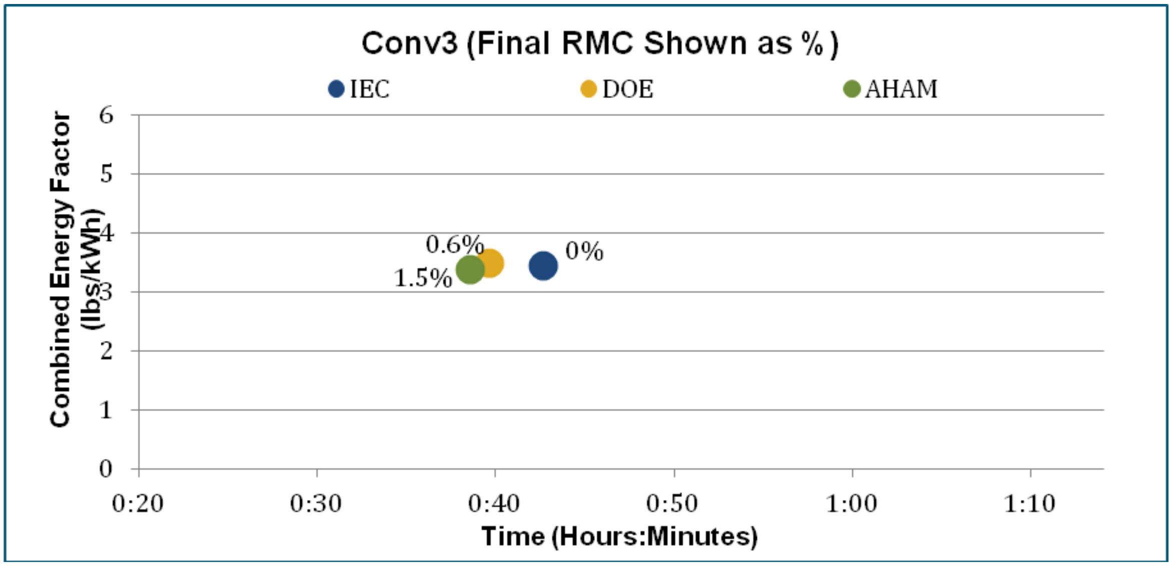

Figure 20. Conv3 DOE 2011 test procedure

Heat Pump Dryer #1

HP1 at the highest dryness setting could not reach the 2% final RMC threshold for DOE's 2011 test procedure when it dried the AHAM load. HP1 yielded a higher energy factor when it dried the IEC test load than it did when it dried the DOE load. It also took less time to dry the IEC load that the DOE load, which indicates that the heat pump compressor may have been running a greater percentage of the time for the IEC load.

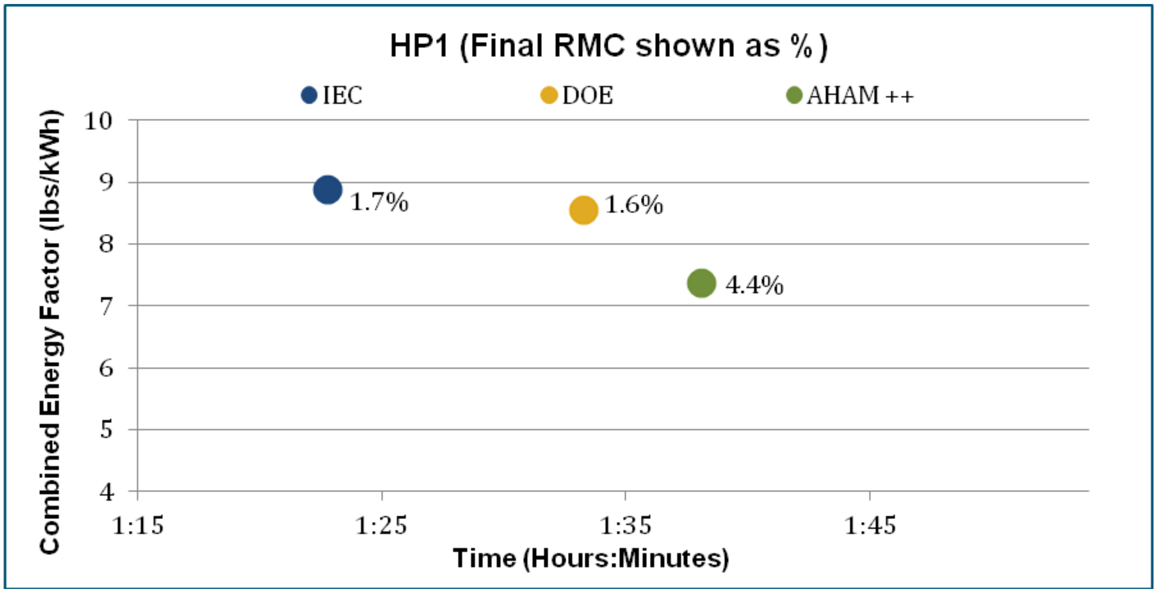

Figure 21. HP1 DOE 2011 test procedure

Heat Pump Dryer #2

The auto sensors on HP2 performed the best at determining when the AHAM test load was dry, as defined by DOE's 2011 test procedure. HP2 also sufficiently dried the AHAM load in the "normal" dry setting.

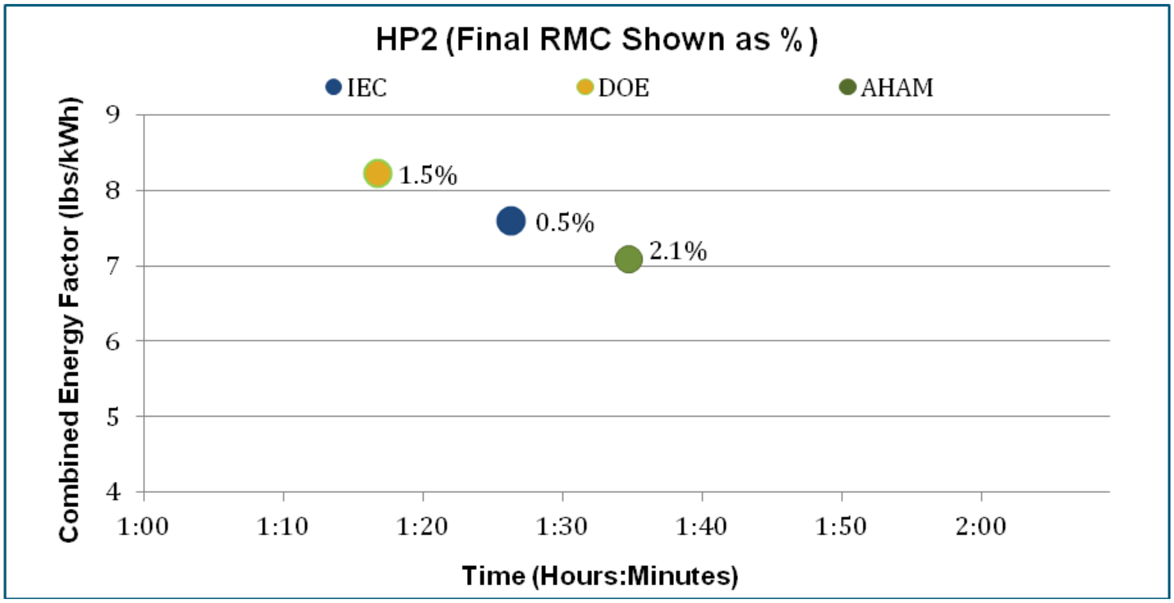

Figure 22. HP2 DOE 2011 test procedure

Heat Pump Dryer #3

HP3 required the highest setting to dry real-world clothing to <2% final RMC.

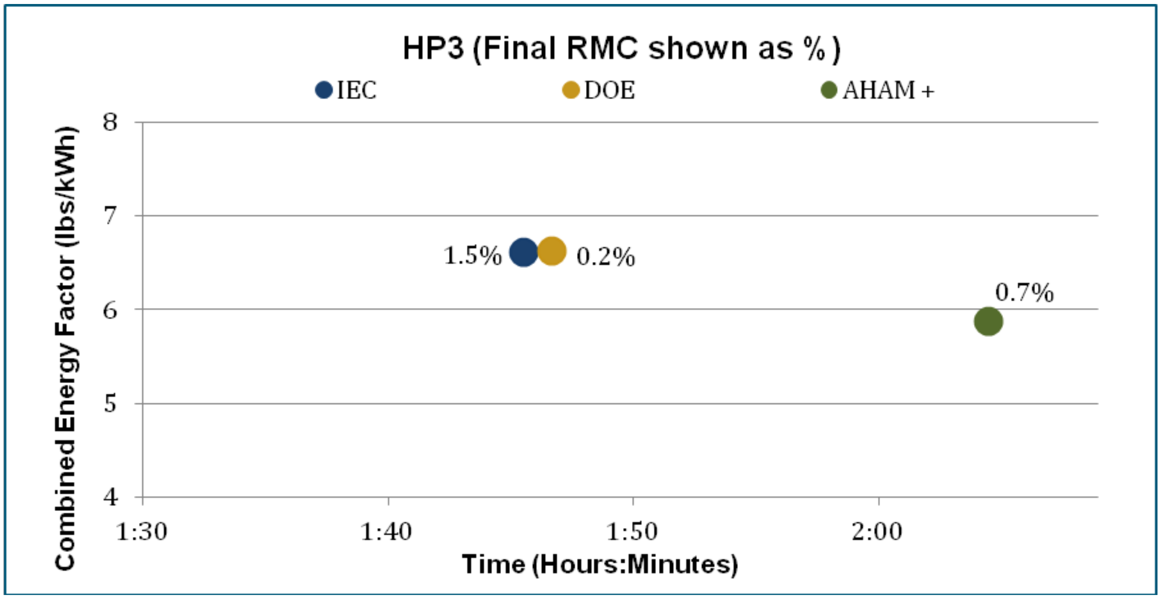

Figure 23. HP3 DOE 2011 test procedure

Heat Pump Dryer #4

HP4 was less efficient at drying the IEC test load than the DOE load. The HP4 had a shorter IEC load drying time when compared to the DOE load.

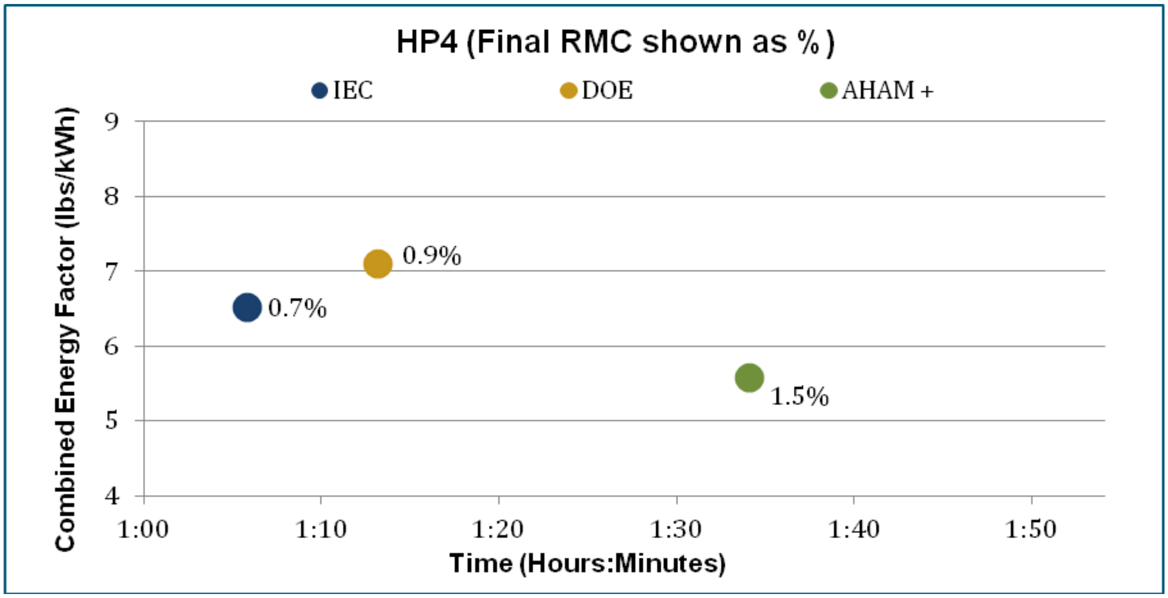

Figure 24. HP4 DOE 2011 test procedure

Appendix II: Eco-mode

Figure 25 shows the Conv2 dryer power demand when run in standard mode using the 2005 DOE test procedure. As the figure shows, the dryer draws about 6,000 watts continuously and then turns off. The dryer was advertised as having reverse tumbling. This was confirmed and explains the momentary reduction in power at three points. Using the 2011 DOE test procedure with automatic termination and running the dryer in non-Eco-mode the dryer similarly demanded 6,000 watts but modulated the heater at the end of the cycle (Figure 26).

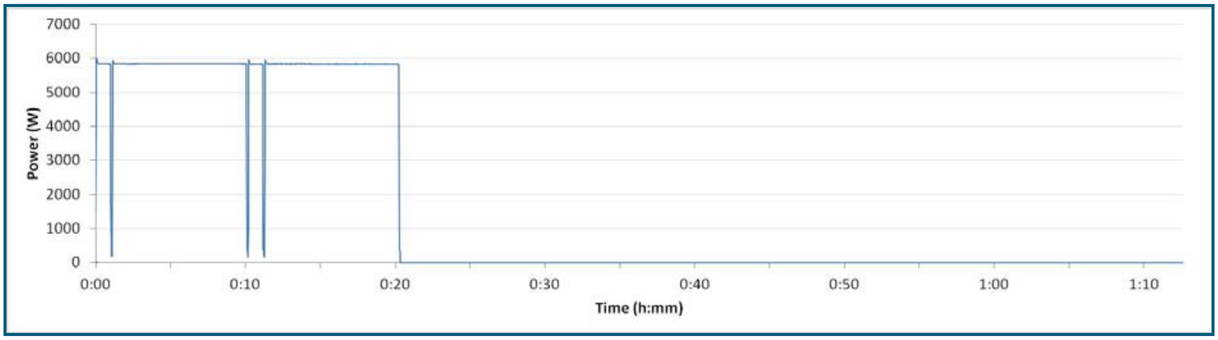

Figure 25. Conv2 Using 2005 test procedure and non-Eco-mode

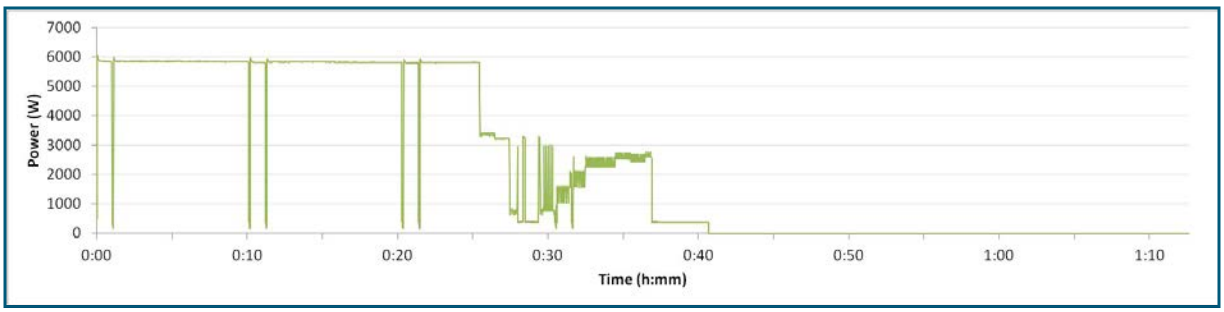

Figure 26. Conv2 Using DOE 2011 test procedure, DOE test cloths, non-Eco-mode

Figure 27 shows the power over time when the dryer is in Eco-mode using DOE 2011 test procedure with automatic termination and DOE test cloths. The average power is less than half that of non-Eco-mode cycles, which explains the much longer drying time. However, the peak power draw was not reduced relative to non-Eco-mode tests.

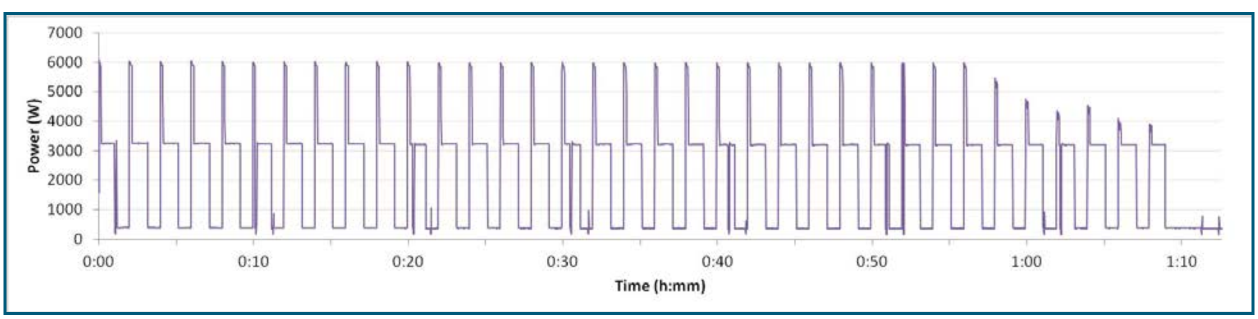

Figure 27. Conv2 Using DOE 2011 test procedure, DOE test cloths, Eco-mode

Appendix III: Research Plan

Research Team

- Chris Calwell – Principal investigator and account manager. Reviewed presentation and report.
- Dave Denkenberger – Project manager and technical specialist. Contributed to the presentation and report.
- Nathan Beck – Tested dryers. Contributed to the presentation and report.
- Brendan Trimboli – Helped prepare the experimental setup and tested dryers. Contributed to the presentation and report.
- Craig Billingsley – Helped prepare the experimental setup and tested dryers.
- Philip Walters – Helped prepared the experimental setup.
- Debbie Driscoll – Reviewed the presentation and report.

Test Room Setup

Figure 28 shows the test setup outside the test chamber. Voltage regulators (near center) condition the power for the US dryer. Data collection occurred on the wheeled cart. The dryer under test sat in the plastic room behind the cart, which allowed the equipment to control ambient air temperature and humidity in the testing environment.

Figure 28. Exterior test setup

The following items were installed outside the chamber:

- One Climate Technologies, Integra Cooler Portable, 6200003 evaporative cooler. For ventless dryers, the evaporative cooler was placed outside the chamber and airflow was provided to the chamber through a hole cut on the side of the chamber and sized to fit the body of the evaporative cooler. We sealed the hole by taping the plastic to the outside of the evaporative cooler. The ventless dryers added a significant amount of heat into the space. Therefore, outside air was needed to cool down the space.
- Two Sola HD 5000VA Constant Voltage Transformers with catalog number 23-23-250-8 were used for the 60 Hz dryers.
- One Yokogawa WT500 measured power data.

- One Newport PID Controller Model number ith-i8DH44-5 turned the evaporative cooler ON and OFF based on temperature.

Changes in average environmental conditions can adversely affect the outcomes of dryer tests and make repeatability a challenge. Ecova created a climate-controlled environment to mitigate the influence of changes in relative humidity and temperature, two major influences that can skew results. As outlined in the DOE test procedure, the test area temperature must be maintained between 72°F and 78°F. Relative humidity must remain between 40% and 60%. The requirements were achieved through the creation of an enclosed chamber and the use of humidifiers, a heater, an evaporative cooler, programmable sensors, and vents. Ecova used a temperature senor to monitor ambient temperature that is less accurate than the 2005 DOE test procedure specifies. However, this sensor was later field-calibrated with a sensor that did meet the 2005 specifications and we are confident that the average ambient air temperature was within DOE's tolerances.

The photograph (Figure 29) shows the dryer under test inside the environmentally controlled room. The scale on the cart was used to weigh test loads. An evaporative cooler (on the right) regulated temperature and humidity in the enclosure.

Figure 29. Inside the dryer test chamber

Dryers were tested in an enclosed chamber that measured 9 feet in height, 7 feet in width, and 8 feet, 8 inches in depth. The chamber walls were constructed with translucent 3.5-mil plastic sheeting that was hung from the ceiling with tape and tacks. A 10-inch by 8-inch vent was cut in the back left-hand chamber wall to allow pressure equalization.

The following items were installed inside the chamber:

- One Climate Technologies, Integra Cooler Portable, 6200003 evaporative cooler. For vented dryers, the evaporative cooler was placed inside the chamber. No sensors were used to turn the cooler ON or OFF, so the evaporative cooler ran for the duration of the test. The vented dryers were vented outside the chamber, which meant a significant amount of air was brought into the enclosure. This air had to be humidified because the natural air in the test site in Durango, Colorado, is dry. For ventless dryers, the cooler was placed outside of the chamber.
- Two Sunbeam SU12512 humidifiers. They were set to maintain 55% relative humidity, although the level varied depending on the ambient conditions of the building.

- One Honeywell Quiet Care humidifier to use when the air was particularly dry.
- One Pelonis HB211 space heater to use on the low setting for the vented dryers only.
- One Holmes "1 Touch" HAOF951THD Fan, set on high speed, to circulate the air and promote even distribution of heat and relative humidity.
- One Extech Instruments HD500 Psychrometer with IR thermometer to record the temperature and relative humidity. The Extech was connected to a computer with an installed copy of the Extech data logging software. The computer was located outside the chamber and connected to the Extech via a USB chord fed through a small hole in the chamber wall.
- One Visicomm Frequency Converter to test European dryers at 50 Hz.
- One Garrhs-fabricated exhaust simulator to simulate back-pressure effects for vented dryers

A GE Profile washing machine was used to wet all test loads to meet DOE test specifications (*Figure 30*).

Figure 30. Washing machine used to wet test loads

Test Controls and Technologies

Vented Dryers

For vented dryers, the evaporative cooler was on at all times and located inside the test chamber. The heater was kept on low heat and two Sunbeam humidifiers were used to help maintain humidity levels. The humidifiers were generally set to 55% humidity, but that setting changed based on the ambient air conditions of the building. No sensors were used to control the evaporative cooler; the cooler ran for the duration of the test. The vented dryers were vented out of the chamber using a Garrhs-fabricated exhaust simulator (to DOE specifications) that simulates backpressure effects for vented dryers.

Ventless Dryers

For ventless dryers, the evaporative cooler was located outside the chamber and connected through a hole in the chamber wall. The pump that wet the mat was uncoupled from the fan so that the mat was always wet. The fan for the evaporative cooler was controlled by a sensor that turned the fan ON when the temperature reached 77°F and turned it OFF when the temperature reached 74°F. Two to three small humidifiers were used depending on the ambient air conditions of the building. Because the ventless dryers do not vent their heat, more of it remained in the chamber and eliminated the need for a space heater. For ventless dryers, the challenge was to keep the chamber cool. The evaporative cooler was used to cool and humidify air pulled in from outside the chamber.

Temperature and Humidity in Data Analysis

Analysis was performed to ensure that the test environment was within the boundaries defined by the DOE test procedures. Post-test processing included finding the maximum and minimum temperature and relative humidity that occurred during each test. If the values were outside the defined temperature and humidity requirements for more than 5% of the test time, the test was redone. If the setpoints were within the parameters 95% or more of the test time, the test results were incorporated into the final data set.

Test Cloth Procurement

The test cloth used in the dryer tests met standard requirements. The test cloths procured are used in dryer test procedures around the world (Table 9).

Test Cloth Procurement Sources		
Test Cloth	Source	Website
DOE	SDL-Atlas	www.sdlatlas.com
IEC	WFK-TESTGEWEBE GMBH	www.testgewebe.de
AHAM	SDL-Atlas	www.sdlatlas.com

Table 9. Test cloth procurement sources

Cloth Conditioning and Wetting

The DOE test procedure requires that all test cloths be put through an identical conditioning procedure. In particular, the water that is used to wet/wash the test cloth must be within a defined range of temperature and softness. The requirements were met by installing the following equipment in the lab:

- GE Smart Water Softening System
- GE 40M06AAG – 40-gallon water heater
- GE Profile washing machine to wet and spin down cloth before drying
- Easy Weigh PX-60B+ Table scale
- Extech EA15 7 Thermocouple Type Dual Input Data logger to record the temperature of the wash water
- Dogain TS300K floor scale to measure the dryer drum volume

In order to ensure that the temperature inside the washer met the test procedure requirements, a valve was installed that redirected the wash water to a container. The temperature of the water was measured as it flowed into the container until the recorded temperature met the test procedure parameters. The valve was then closed and the wash cycle started. The water temperature was adjusted using the heater setting in the hot water heater and controlling the proportion of hot to cold water.

Test Problems Encountered

Significant delays and costs were experienced procuring the dryers, particularly with US Customs. Shipping the HP2 dryer by airfreight required the removal of its heat pump refrigerant. The dryer required a nonstandard refrigerant and filling procedure, which was done incorrectly by an outside technician. When the dryer did not perform as the manufacturer predicted, the refrigerant was drained and refilled correctly, which then resulted in efficiency values that agreed with the manufacturer. This problem suggests that unfamiliarity with European heat pump dryers could create some challenges for US appliance installation and maintenance technicians.

Another difficulty was maintaining the small test space temperature between 72°F and 78°F, and maintaining the relative humidity between 40% and 60%. (See Test Room Setup above.)

In the 2011 test procedure, a maximum final RMC of 2% is specified. If the normal dryness setting resulted in greater than 2% final RMC, the entire test had to be rerun at a greater dryness setting. As a result, it was common for the total number of tests conducted to be significantly higher than the number of valid tests that produced usable data.

The final problem encountered was that the 2005 test procedure specified using a timed drying mode, but it was not possible to put the Conv2 dryer on Eco-mode in timed dry. Therefore, the automatic termination setting was used. The clothing was removed and weighed to make sure the final RMC was between 2.5–5%.

Test Procedure Validation

The Conv1, when tested using the 2005 test procedure, had an energy factor (EF) of 3.15, 3.22, and 3.24 on the three respective test runs, yielding an average of 3.21. The published EF value for this dryer in the California Energy Commission database was 3.10, yielding a difference of less than 4%.

This difference could be due to slight difference in test parameters (but still within the allowable limits of the DOE test procedure), or it could indicate that efficiency is slightly higher at higher elevations. Durango's elevation is 6,500 feet.

There were no published values for heat pump dryers using the DOE test procedure. However one manufacturer previously conducted DOE tests on the HP2 dryer. The test performed on this dryer in

Durango was 5% more efficient, providing further evidence that high-altitude drying is slightly more efficient even with a condensing dryer.

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