NATURAL RESOURCES DEFENSE COUNCIL

NRDC's Response to CEC's Invitation to Participate in the Development of Appliance Energy Efficiency Measures

2013 Appliance Efficiency Pre-Rulemaking on Appliance Efficiency Regulations: Docket Number 12-AAER-2D - Commercial Clothes Dryers

May 9, 2013

Submitted by:
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On behalf of the Natural Resources Defense Council and our more than 250,000 members and online activists in California, we respectfully submit this response to the Energy Commission's Invitation to Participate in the Development of Appliance Energy Efficiency Measures, posted on March 25, 2013.

In 2009, NRDC commissioned Ecos Consulting[1] to study opportunities for energy efficiency improvement in residential clothes dryers (attached as Appendix A). While, the Ecos study was specific to residential dryers, many of the findings and conclusions are relevant to the consideration of standards for commercial clothes dryers. Ecos found that dryers are the single largest residential energy use for which there are no voluntary or mandatory labeling programs in the US, despite technology options, such as heat recovery, better controls, and heat pump dryers, that can cut energy use by 30 to 50 percent. The fact that there is little distinction between dryers in the US is largely due to issues with the current DOE test procedure for residential clothes dryers, which does not adequately capture variation in energy efficiency. DOE recently proposed modifications to its test procedure[2] that would help it better capture these variations in efficiency and could serve as a basis for a commercial clothes dryer test procedure.

More recently, field research by the Northwest Energy Efficiency Alliance (NEEA), found that clothes dryers are tied with lighting for the third largest end-use in homes. Findings in the NEEA

[1] Now Ecova.
[2] See http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-TP-0054-0006

field study corroborated those of Ecos that the current residential dryer test procedure does not accurately capture in field energy use and variation in efficiency.[3]

HMG/TRC has conducted testing on commercial clothes dryers on behalf of the California IOUs which finds that commercial clothes dryers consume a significant amount of energy. As indicated in the California IOUs response to this ITP, average annual consumption for an electric commercial dryer was found to be 4300 kWh/year and average annual consumption for a gas commercial dryer was found to be 147 therms/year.[4]

Given the large potential for efficiency improvements in the residential clothes dryers market, the similarities in the design and controls strategies in the commercial clothes dryers market, and the large amount of energy used by commercial dryers, there are very likely opportunities for energy savings in the commercial clothes dryers market and we encourage CEC to analyze a potential standard for commercial clothes dryers.

1. Basic Information

1.1 Product definition: what differentiates a commercial clothes dryer from a residential dryer?

No response.

1.2 Estimated unit costs.

No response.

1.3 Duty cycle and per unit estimated energy consumption per cycle, per volume, per weight of cloth, and per year.

No response.

1.4 Design life cycle and incremental cost of energy efficiency improvement.

No response.

2. California-specific Data and Test Methods

2.1 California sales by model and estimated retail price. What proportion use natural gas as a fuel source?

No response.

2.2 How many commercial clothes dryers are there currently in operation in California?

[3] See comments submitted by NEEA to DOE in response to the Residential Clothes Dryer Test Procedure SNOPR (Docket EERE–2011–BT–TP–0054; RIN 1904–AC63).
[4] For dryers used in multi-family Laundromats.

No response.

2.3 Test methods used to measure product efficiency and performance?

We are not aware of any test methods specific to commercial clothes dryers. The Department of Energy (DOE) has established a test method for residential clothes dryers, which is codified at CFR Part 430, Subpart B, Appendix D, which may be applicable or adaptable to commercial clothes dryers. We note that DOE is in the process of revising this test procedure and issued a Supplemental Notice of Proposed Rulemaking (SNOPR) in January 2013.[5] Given the similarities between residential and commercial dryers, we believe the DOE residential dryer test procedure could be adapted to commercial dryers.

2.4 What are the limitations of the test methods? Any improvement needed?

There are limitations to the existing DOE test method for residential dryers, some of which are improved upon in DOE's January 2013 SNOPR. Ecos' testing found that actual drying energy for conventional electric dryers could vary by 20 to 30 percent for the same load, but that this difference was not being measured under the current test procedure. In particular, Ecos found that the current test procedure was not capturing energy used during the final, high-heat stage of the drying cycle because the test stops at 5 percent remaining moisture content, and therefore does not test the effectiveness of termination control strategies. Under the current test procedure, clothes dryers get a blanket credit for the presence of automatic termination controls without testing their effectiveness. In the January 2013 SNOPR, DOE proposed to modify the test procedure so that clothes dryers with automatic termination controls would run until the end of cycle. This modification is an improvement over the existing test procedure.

NEEA's field use data also found differences between the DOE test procedure and real-world loads, which are summarized in the table below. In general, the NEEA data indicates that the DOE test procedure underestimates real-world energy use, further underlining the opportunity for energy savings.

Table 1: Comparison of DOE Test Procedures with 2012 NEEA Field Study Findings and Associated Real World Test Procedure[6]

[5] See 78. Fed Reg. 152 (January 2, 2013)

[6] From comments submitted by NEEA to DOE in response to the Residential Clothes Dryer Test Procedure SNOPR (Docket EERE–2011–BT–TP–0054; RIN 1904–AC63).

	DOE			NEEA	
	2005 Test Procedure, Standard	2013 Test Procedure, Standard	2013 Test Procedure, Lab Tests	Field Study Averages	Real World Test Procedure
IMC of Load (%)	66.5%-73.5%	57.2%-57.8%		62%[a]	61.7%-62.3%
Final MC of Load (%)	2.5%-5%	<2%		N/A	<2%
Water Removed/Load (lb)	4.6	4.6		4.5[a]	4.5
Bone Dry Load Weight (lb)	7.0	8.45		7.5[a]	7.4
Duct restriction level (cap hole diameter in inches)	2 7/8"	2 7/8"		2 11/16"	2 11/16"
Auto vs. Manual Termination	Manual	Auto		Auto	Auto
Temperature Setting	High	High		Medium	Medium
Dryness Setting	N/A	Normal		Normal	Normal
Load Composition	2-dimensional, uniform thickness	2-dimensional, uniform thickness		Mostly 3-dimensional of varying thickness	Mostly 3-dimensional of varying thickness
Average Drying Time (min)	23[e]	N/A	47	58	47
Raw Energy Use/Load (kWh)	2.24	2.84[b]	2.2	3.1[c]	2.5
Field Use Factor	1.04	0.8	0.8	1	1
Adj. Energy Use/Load (kWh)	2.33	2.27	1.7	3.1[c]	2.5
Washer loads dried (%)	107%	91%		124%[d]	124%[d]
Loads per Year	416	283		337[c]	337[c]
Energy Use per Dryer (kWh/y)	967	641	570	920[c]	840
EF or CEF (lbs/kWh)	3.01	3.73	4.2	2.4[a]	3.0

a. These data include the cycles with valid energy, weight, etc. measurements and reflect an adjustment to account for the fact that clothes were not bone dry (3.6% MC) when initially measured by field study participants.
b. Though automatic termination in the field saves energy relative to timed dry, here we are comparing to technician termination in the laboratory to a final moisture content that is greater than the automatic termination moisture content.
c. These data include all cycles with metered events in NEEA study (1640 cycles).
d. The field data showed that many users would commonly run "touch up" loads after the main drying cycle had completed to get particular articles fully dried, but these are not counted. The data showed more drying cycles than washing cycles because of washer load splitting, even though some items that were washed were not subsequently machine-dried.
e. Based on laboratory testing

In addition to variation in automatic termination control effectiveness, both NEEA and Ecos identified differences in the test load from real world loads. While the January 2013 DOE SNOPR does not correct all of these issues, if finalized it would better approximate residential clothes dryer energy use. CEC should be aware of the other issues in developing test procedures and standards for commercial clothes dryers, but should not let any unsolved issues act as a barrier to the standards rulemaking for commercial clothes dryers. Given the fact that commercial clothes dryers are currently unregulated and use a large amount of energy, a standard based on either the current or revised DOE test procedure likely has the potential to result in significant energy savings.

3. Technology Options and Existing Standards

3.1 Are there new technologies or add-on controllers that offer better efficiency in existing units (retrofits)?

No response.

3.2 What are the energy efficient technologies in the market today? How much energy do they save? How commonly are they implemented?

Ecos identified several opportunities for improving energy efficiency of dryers, many of which are available on the market today. These included:

A. Reducing leakage in the air transport system and keeping it insulated so nearly all of the heat makes it to the drum.

B. Using effective sensors and control strategies to avoid overheating the clothes and to terminate heating when the clothes are dry.

C. Using an adjustable (modulating) heat source to avoid overheating the clothes, especially as they approach dry. This will also reduce the current draw and reduce losses in the distribution wiring, as well as minimizing peak demand impacts from powerful heating elements.

D. Using a heat pump on electric dryers to increase the heat delivered per kWh of electricity.

E. Using heat recovery, especially condensing heat recovery, to preheat the incoming air from the exhaust air.

F. Using effective power management to reduce or eliminate power consumption during standby.

G. Using more efficient motors for rotating the drum and for the blower.

H. Using sensors to monitor for resistance to the air flow, such as a clogged lint screen.

I. Using microwave heating to transfer heat to the water more effectively.

3.3 Are there commercial clothes dryers designed to work specifically with a particular commercial clothes washer?

No response.

3.4 Are there any existing commercial clothes dryer efficiency specifications or standards?

No response.

4. Additional Information

4.1 Sources of test data

As discussed above, we are aware of test data on residential dryers done by Ecos and attached as Appendix A and NEEA's more recent field study. NEEA would likely be able to provide more detailed data than is provided in these comments if requested. We are also aware of the testing conducted on behalf of the California IOUs on commercial clothes dryers which has been submitted in their response to the ITP.

4.2 Energy Use Metrics

No response.

4.3 Product Development Trends

No response.

4.4 Market barriers to Energy Efficiency

No response.

4.5 How do businesses identify efficient products on the market?

No response.

4.6 Is there any survey done to gauge consumers' acceptance and performance of the new units?

No response.

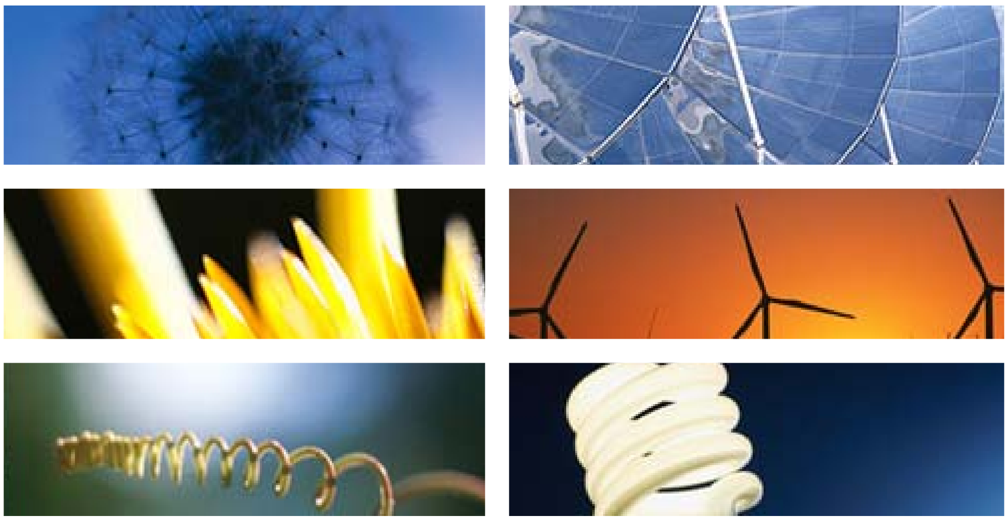
4.7 How many small businesses are involved in the manufacture, sale, or installation of these products?

No response.

4.8 Any other data relevant to this proceeding

No response.

Making a World of Difference



Portland, OR | San Francisco, CA | Seattle, WA | Durango, CO

Residential Clothes Dryers: An Investigation of Energy Efficiency Test Procedures and Savings Opportunities

Paul Bendt, Chris Calwell, and Laura Moorefield

Ecos

November 6, 2009

FINAL DRAFT

Prepared for:

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This research was funded by a grant from the US Environmental Protection Agency's ENERGY STAR program to NRDC. The views expressed herein are solely those of the authors. We are particularly indebted to Southwest Appliance in Durango for allowing us to conduct detailed measurements of various new residential clothes dryers and to utilize washers as needed to prepare the test cloths for drying.

Executive Summary

Residential clothes dryers consume about 66 TWh/year in the U.S., or approximately 6% of residential electricity use. Their contribution to residential gas consumption is much smaller – approximately 1%, because electric models represent such a large fraction of the installed base of dryers and new dryer sales.

Dryers are also responsible for a significant amount of cooling, heating, and ventilation energy use. This is needed to replace the conditioned air they exhaust from the home during the periods of the year when home windows are closed and HVAC systems are operating. We estimate that including associated HVAC energy use would push the energy total for dryers at least 50% higher, and probably more than that in some housing types and climate zones.

As a result, clothes dryers are the single largest residential energy use for which there are currently no voluntary or mandatory labeling programs and no utility incentives. Even the test procedure and efficiency metrics that exist for these products are quite old, and were not really designed to reveal the performance differences among competing products. In particular, the DOE allows dryers with a moisture sensor to receive an automatic, fixed energy savings credit on the test procedure, rather than measuring its actual effectiveness at stopping the drying cycle when the load is dry. The only mandatory efficiency standards that exist for clothes dryers are quite old and not very stringent, requiring that they be *able* to sense when the load is dry and cease operation, but not actually requiring that they be operated in that mode.

Publicly available information about clothes dryers generally suggests that all of them have fairly similar energy use, and so there is no particular need or opportunity to seek out an energy efficient model. As a result, the energy that efficient dryers *could* save is largely inaccessible to the U.S. market transformation community. The energy efficiency of U.S. clothes dryers has improved only modestly over the last decade, and is not likely to improve much more without policy changes. A handful of condensing models are for sale in the U.S.; no heat pump models are for sale.

This is not the case in Europe and Australia, where different test procedures, efficiency metrics, and mandatory categorical labeling have helped to highlight differences in the energy use of dryers. Both regions have seen a steady progression of products from simple timed drying cycles to designs that effectively sense how much remaining moisture is in the clothing and stop the load accordingly. The newest product introductions in Europe and Australia now include heat pump technology as well, cutting energy use by an additional 30 to 50% relative to standard dryers.

Ecos conducted testing to determine the actual, real-world energy use of popular dryer models when allowed to run until they shut themselves off, with a wide variety of load sizes and fabric types, full and empty lint traps, and relatively wet and dry starting conditions. We conclude that even conventional electric dryers vary by about 20 to 30% in the amount of energy required to dry the same load of clothes. These differences are not being measured or disclosed today.

Simple and inexpensive design changes could capture even greater energy savings, by reducing the amount of HVAC energy lost through outside venting, by better modulating heat output over time, and by recovering and reusing waste heat. Additional energy could be saved with heat pump technologies and by encouraging clothes washers to spin more of the moisture from clothing before it is placed in the dryer.

Changes to the efficiency metric for dryers (Table ES-1) are needed to more accurately reflect real-world product performance and the resulting cost and environmental impact differences between electric and natural gas models. Once those new procedures are in place, there is much the market transformation community could do to draw highly efficient conventional and heat pump models into the US marketplace.

Table ES-1. Comparing Various Dryer Technologies with Different Efficiency Metrics and Test Procedures

Test Procedure / **Efficiency Metric**	DOE Test		Ecos Test		Ecos Estimates		
Dryer Technology	Standard electric	Standard gas	Standard electric	Efficient electric	Standard gas	Efficient gas	Heat pump
Energy factor	3.12	2.79					
Site kWh-equivalent / pound of water removed	0.486	0.543	0.581	0.484	0.649	0.533	0.314
Pounds CO_2 emitted / pound of water removed	0.648	0.367	0.772	0.643	0.440	0.341	0.417
Source BTUs of natural gas / pound of water removed	4867	2925	5823	4851	3507	2691	3144
Energy cost (cents) / pound of water removed	5.83	2.76	6.97	5.81	3.31	2.50	3.76

The savings on source BTU energy, dollars, and greenhouse gas emissions are quite large from simply burning gas in the dryer to create heat at the site, rather than burning natural gas in a power plant to make electricity that is transmitted to the home and eventually converted back to heat in an electric resistance element. If the conventional natural gas dryer were further improved with modulating burner technology, we believe it would be roughly equivalent to or superior to many heat pump dryers on a CO_2, source energy BTUs, and energy cost basis, while also offering faster drying times and a lower initial purchase price.

The potential exists to save 25 to 30 billion kWh/year or more than $3 billion annually by undertaking a deliberate effort to more effectively test, label, and improve the energy efficiency of residential clothes dryers.

I. Introduction

Clothes dryers are perhaps the largest residential energy end use in the United States for which no labeling, incentive, or promotion efforts exist to help consumers purchase the most energy efficient products. ACEEE notes that a typical clothes dryer uses about two to four times more energy than a new clothes washer and twice as much energy as an energy efficient new refrigerator. Yet its *Consumer Guide to Home Energy Savings* tells consumers, "From an energy perspective, it makes little sense to replace a well-functioning dryer before the end of its useful life – typically 12 or 13 years… In terms of energy use, the performance of electric and gas dryers does not vary widely."[1] The widespread perception is that all clothes dryers are fairly similar in energy use, so there is no value in urging customers to purchase one model instead of another.

Ecos conducted this research in 2008 and 2009 on behalf of NRDC to determine if this perception is true and if changes to test procedures, labeling, and incentive strategies are warranted to capture additional energy savings from clothes dryers. The research had three key goals:

- Measure and understand the "real world" energy use of residential clothes dryers
- Assess the strengths and weaknesses of current energy efficiency test procedures, efficiency metrics, and labeling programs for clothes dryers and recommend alternative approaches
- Explore technological options for improving clothes dryer efficiency and estimate approximate energy savings potential

In our experience, there are almost always significant energy efficiency differences among competing designs in any energy-using product. Additionally, it is easy to demonstrate that useful energy routinely leaves a clothes dryer in the form of waste heat. Since the purpose of a clothes dryer is to *dry* the clothing and not *heat* the clothing (or the dryer itself, or the room in which it is located, or the air that leaves the unit), any dryer that creates a stream of exhaust air significantly warmer than ambient air is demonstrating an opportunity to save energy.

We also hypothesized that if differences in dryer energy use are not showing up in the testing of current products, that does not necessarily mean those differences do not exist in reality. Either the test procedure is not measuring the right things and/or the manufacturers have not yet found it profitable to differentiate their products from their competitors' on the basis of efficiency.

[1] See Jennifer Thorne Amann, Alex Wilson, and Katie Ackerly, *Consumer Guide to Home Energy Savings 9th Edition*, ACEEE, August 2007, p. 178.

II. Market Background

In 2008, U.S. consumers purchased nearly 7 million clothes dryers, of which 5.62 million were electric and 1.35 million were natural gas. Sales of both have been declining over time: electric unit sales dropped by about 10% from 2004 to 2008 and gas unit sales dropped by about 19%. Whirlpool accounts for approximately 70 to 74% of units sold, while General Electric is 10 to 16%, Electrolux (through Frigidaire) is 5 to 8%, and all other manufacturers combined represent 6 to 11% of units sold. This means that about 5% of U.S. households acquire a new clothes dryer each year. In 2001, about 59% of US households had an electric dryer and 19% had a gas dryer. Today, that split is about 62% electric and 20% gas, so overall saturation is rising steadily, while the electric share of installed units is remaining fairly steady at 75%.[2]

Clothes dryers typically last about 12 years (the range varies from a low of 8 to a high of 15 years), so about 5.3 to 5.8 million units are needed each year to replace older units that are traded in or discarded. The market is not growing rapidly; if anything, the challenge for manufacturers has been to persuade all of the consumers that have clothes washers to also purchase dryers, which are far more prevalent in high income households than low income households. DOE surveys (Figure 1) found that less than half of the lowest income households own a washer and a dryer, but 92% of the wealthiest households do. It is also fairly common for households with less than $30,000 of annual income to wash their clothes at home, but line dry them instead of using a dryer.[3]

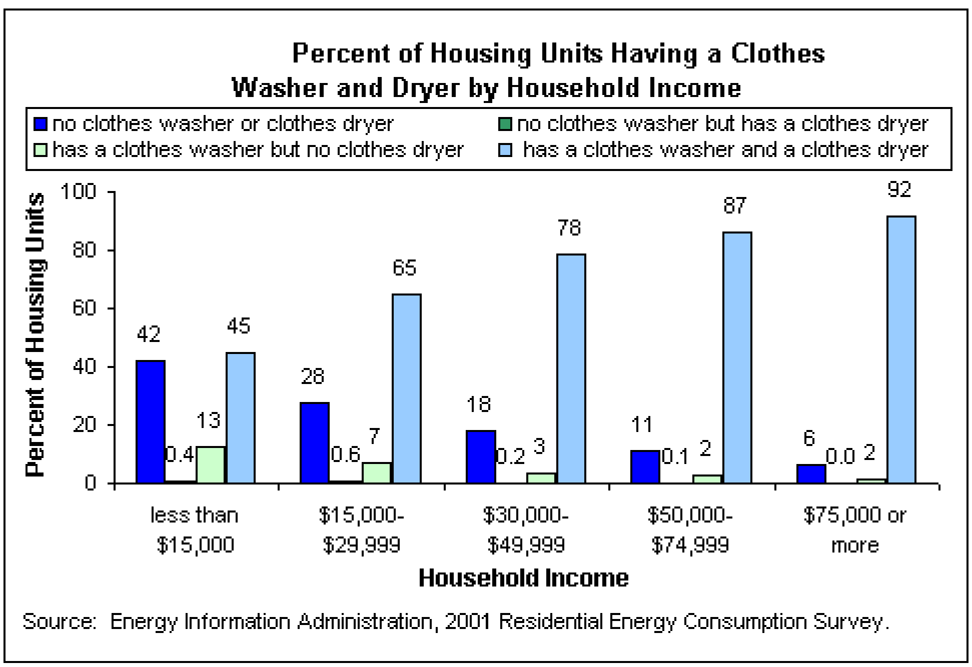

Figure 1. Clothes Washer and Dryer Prevalence in US Homes by Household Income Level

[2] *Appliance*, April 2009 and September 2009.

[3] http://www.eia.doe.gov/emeu/recs/appliances/appliances.html

DOE estimates that the average electric clothes dryer consumes 1079 kwh/year, or a total of 65.9 billion kwh/year across all households.[4] That is about 5.8% of national residential electricity use – making clothes dryers the sixth largest residential end use after air conditioning, refrigerators, space heating, water heating and lighting (see Figure 2). Dryers are also responsible for slightly more than 1% of residential natural gas use.[5] Together, gas and electric dryers are responsible for nearly 55 million metric tons of CO_2 emissions per year —the equivalent of 10 million cars, light trucks, and SUVs being driven for one year.

In 2001, ESOURCE estimated that clothes dryers accounted for much larger percentages of residential energy use—nine percent of electricity and 13 percent of natural gas—than the more recent EIA estimates above.[6] Dryers' share of energy use has likely decreased for several reasons—newer dryers are often more efficient than older ones, other residential energy end-uses like consumer electronics have increased substantially, and today's clothes washers do a much better job of spinning water out of clothing than older washers did thereby reducing the work needed from the dryer. Nonetheless, clothes dryers remain one of the single largest energy end-uses in U.S. homes, closely following refrigeration.

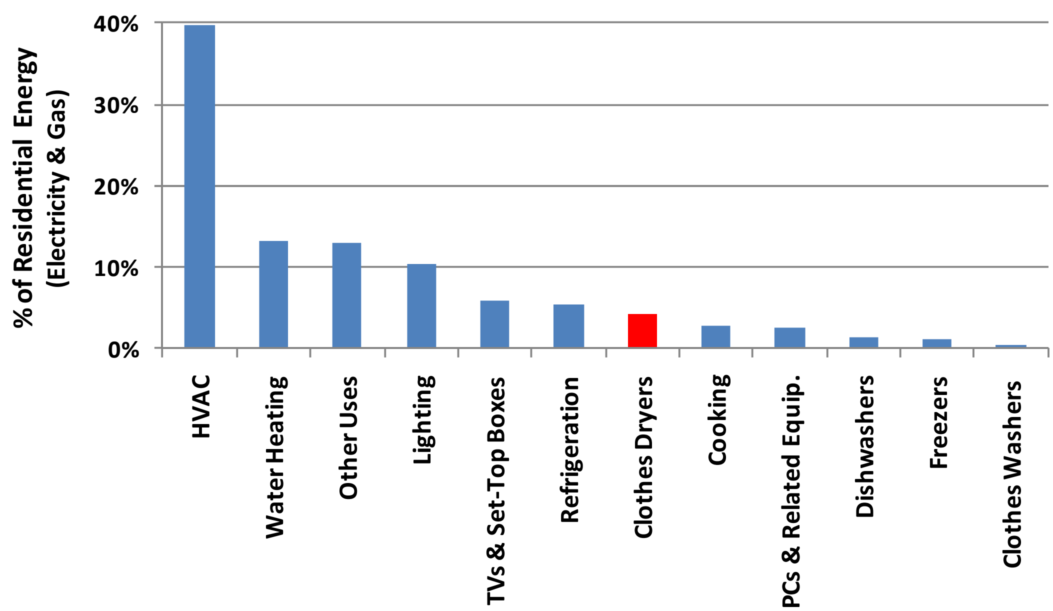

Figure 2. Energy Consumption by Various Residential End Uses

In addition to consuming a significant amount of residential energy, clothes dryers can at times be the largest single electrical load in a home. Heating elements in full-size dryers draw about 5 kW—similar to that of an electric oven operating at full power.

[4] This equates to 2.59 kWh/drying cycle and 416 cycles per year – slightly more than 1 per day.
5 http://www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html
[6] Ira Krepchin and Jennifer Thorne, *Residential Appliances Technology Atlas*, ESOURCE, 2001, p. 135.

III. Dryer Operation and Technology

Typical Dryer Construction

A dryer consists of a rotating drum in which the clothes are tumbled. Warm air is blown through the drum, evaporates water from the clothes, and is exhausted.

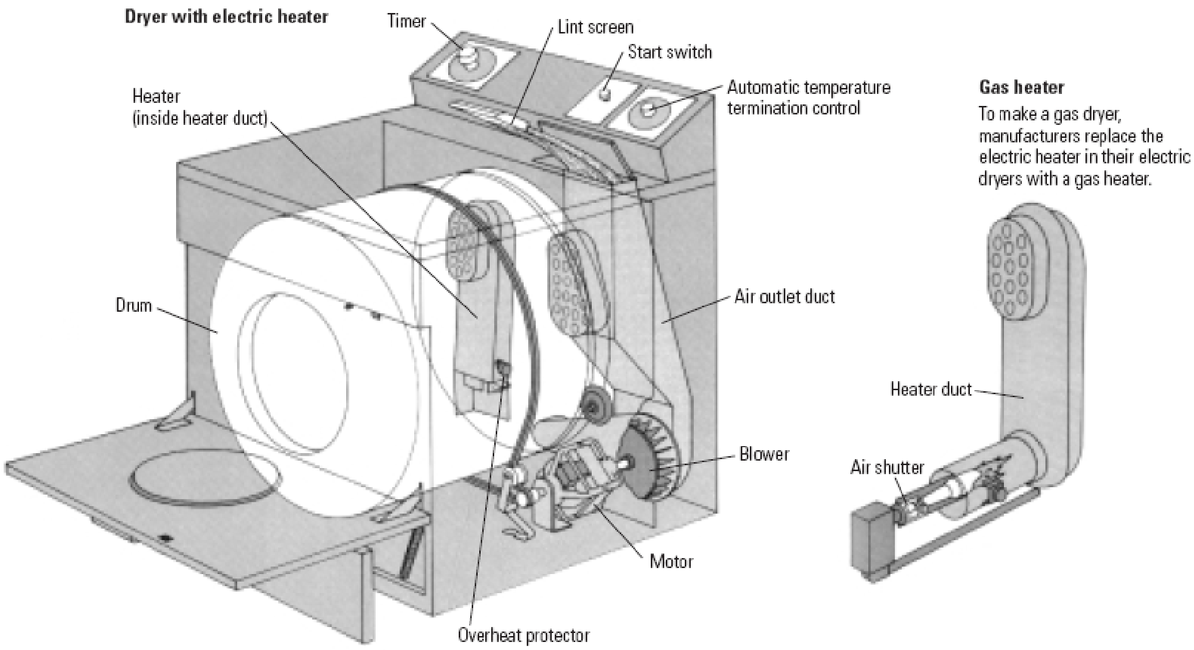

Figure 3. Typical Dryer Construction.
Source: ESOURCE, 2001, p.139, adapted from *Reader's Digest Fix It Yourself Manual*

Dryers contain the following components:

A. A metal cabinet - Room air is drawn into the cabinet through openings in the back.
B. A motor to rotate the drum and drive a fan to move the air - The motor typically draws 200 to 300 watts of electricity. Waste heat from the motor heats the air in the cabinet.
C. A heater, either an electric resistance heater or a gas burner - Electric heaters typically draw about 5,000 watts (230 volts and 22 amps) and gas burners are typically 20,000 to 25,000 BTU/hour (6 to 7 kW). The air from the cabinet is drawn into the heater duct and heated to 200°F to 300°F.
D. The drum, which typically rotates about 40 rpm and where the heated air evaporates water from the clothes - The evaporating water cools the air to 90 to 170°F and increases its humidity.

E. A lint filter, to trap lint which would otherwise build up in the air ducts creating an obstruction and a fire hazard.
F. The fan, which draws the air through the other components at 100 to 150 CFM.
G. An exhaust duct through which the hot, moist air is vented outside.
H. Sensors, which detect temperatures at different locations and, in some dryers, sensors to monitor the humidity of air or the moisture content of the clothes.
I. A timer and other control circuitry.

Most dryers sold in Europe are somewhat different. Instead of exhausting the warm, wet air, they use a condenser that cools the air and condenses the moisture. This air is then returned to the heater and reused. This design avoids the requirement for an exhaust vent. The condenser transfers heat to either room air or water. Those that heat the room air are advantageous in the winter heating season, but put a heavy load on air conditioning in the summer. Our analysis is limited to typical US dryers, which do use an exhaust vent.

Typical Dryer Operation

During the first few minutes of dryer operation, clothes dryers are typically running their heating elements and fan motors continuously, consuming about 5000 watts. Most of this energy warms the air inside the dryer, the clothes themselves, and the metal drum in which they tumble, but does not lead to much moisture removal. The associated energy use and time can be thought of as largely fixed – about this amount of work needs to be done before any meaningful drying can occur for a load of any size. We refer to this as the *warm-up stage*.

Thereafter, a typical drying cycle has two main stages, a ***bulk drying stage*** and a ***high-heat stage***.

During the bulk drying stage, the exhaust air is usually 90 to 120°F and 60 to 80 % relative humidity. These conditions are relatively constant for 15 to 40 minutes as most of the water is evaporated. The heater may stay on continuously through the bulk drying stage or it may cycle on and off. We found no dryer models that employed a continuously variable heating element, so the on/off cycling leads to instantaneous changes in power use of thousands of watts. About 2/3 of the heat energy evaporates water and about 1/3 is heating the air that is drawn through.

During the high-heat or "cook your clothes" stage, the exhaust air is 130 to 170°F and very low humidity. The clothes have little or no water left in them, so there is no significant evaporation and associated evaporative cooling of the air. The heater cycles on and off to avoid creating even higher temperatures and the associated risk of a fire in the exhaust duct. Almost all the heat energy is spent heating air, metal, and cloth. The high-heat stage is usually 5 to 20 minutes long, depending on how successfully a particular dryer can detect that it is occurring and cease operation.

The end of the bulk drying and beginning of the high-heat stage is a 5 to 10 minute ***transition time***. During this transition, the exhaust temperature rises and the air moisture content drops rapidly. We use 5% remaining moisture content (RMC) as the dividing line between the bulk drying and high-heat stages. This 5% RMC is considered "dry" in current test procedures and is usually about the middle of this transition time.

Finally, there may be a ***cool-down stage*** at the end. If present, this is a time during which the clothes continue to tumble and air continues to flow through the system, but the air is not heated. Very little energy is consumed, since only the motor is on, not the heater. The clothes are cooled toward room temperature. If there were some remaining moisture, the warmth of the clothes helps to evaporate it.

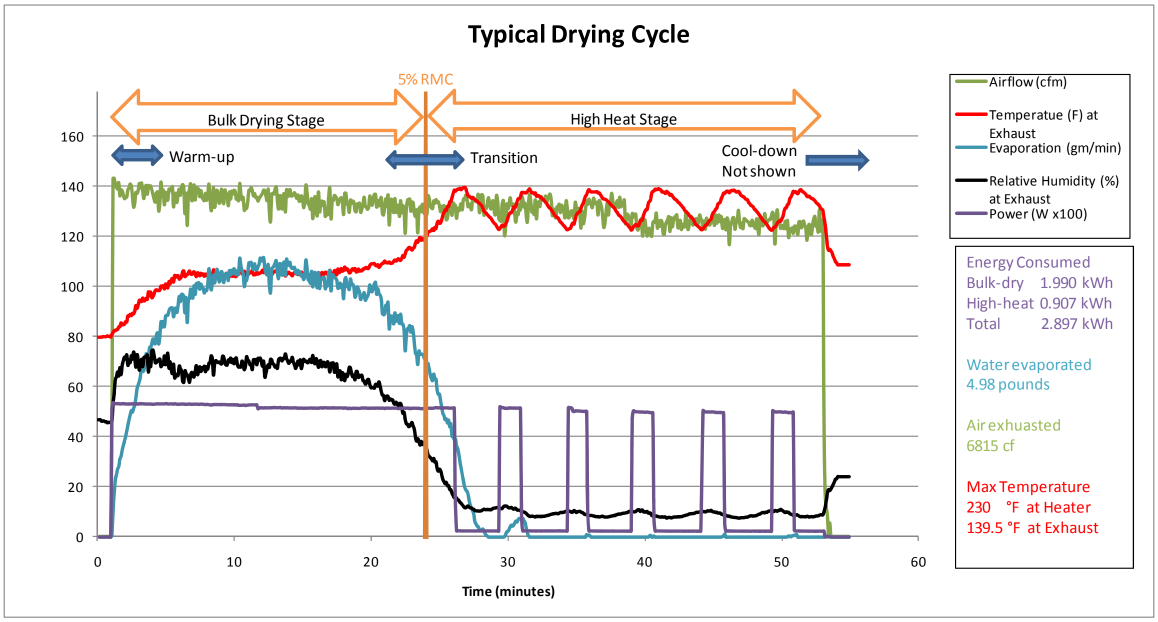

Figure 4. Typical Drying Cycle

These stages can be seen in Figure 4, which shows a data log of a typical dryer cycle. The airflow (green) driven by the fan is nearly constant for the entire cycle. The fluctuations are caused by pieces of cloth momentarily blocking the air vents of the drum. The gradual decrease through the cycle is probably caused by lint accumulating in the lint filter. The heating element (purple) is on continuously during the bulk dry stage and cycles on/off during the high-heat stage. We can see the 240 W drawn by the drum motor and fan when the heater is off. The exhaust temperature (red) climbs during warm-up, stays nearly constant through the bulk dry stage, rises again during transition, and cycles with the heater during the high-heat stage. The exhaust humidity (black) stays fairly high during bulk drying, then drops to a very low value for the high-heat stage. The evaporation rate (blue) shows that most of the water is removed during the bulk-drying stage. The last 5% of moisture is removed during the later part of the transition time.

Dryer Energy Consumption

Energy is consumed by the following processes:

A. Energy to heat the air, provided by electricity or gas (either natural gas or propane). This heat ends up accomplishing four things:
    a. Evaporating water from the clothes
    b. Heating the clothes
    c. Heating the metal (and plastic) parts of the dryer
    d. Heating the air that is exhausted
B. Energy to rotate the drum and move the air.
C. Energy to operate the controls. Of particular concern is the standby mode energy when the dryer is not in use.
D. Energy to condition the room air that is used and vented by the dryer, or equivalently, energy to condition the outside air sucked into the room to replace the air vented by the dryer. Since most residences use air conditioning for a significant part of the year, using energy to cool outside air and keep the room comfortable, and then using more energy to reheat that air in the dryer is very inefficient.
E. Energy required for air conditioning to remove the waste heat that the dryer releases to the room.[7]

The useful task performed by this energy is the removal of water from the clothes. Converting water from a liquid state to a vapor state requires about 500 kcal of heat per kg of water (0.308 kWh per pound). One can measure the efficiency by measuring the water removed, multiply by 0.308 kWh per pound, and divide by the energy consumed. Typical dryers are about 50 to 70% efficient. Note that, with this measure, it is possible to achieve efficiencies well over 100% by using heat recovery, heat pumps or the desiccating potential of dry air. In fact, outdoor clotheslines are infinitely efficient because they evaporate the water without using any (purchased) energy.

How Can Energy Be Saved in Dryers?

Strategies to improve efficiency include:

[7] Energy used in item 5 during cooling season is balanced, to some extent and depending on the climate, by “free” heating energy the dryer furnishes to the home during heating season. However, item 4 is still a problem in the winter when dryers push heated air outside, requiring the home heating system to replace it.

A. Using outside air instead of room air for the intake.
B. Reducing leakage in the air transport system and keeping it insulated so nearly all of the heat makes it to the drum.
C. Using effective sensors and control strategies to avoid overheating the clothes and to terminate heating when the clothes are dry.
D. Using an adjustable (modulating) heat source to avoid overheating the clothes, especially as they approach dry. This will also reduce the current draw and reduce losses in the distribution wiring, as well as minimizing peak demand impacts from powerful heating elements.
E. Using a heat pump on electric dryers to increase the heat delivered per kWh of electricity.
F. Using heat recovery, especially condensing heat recovery, to preheat the incoming air from the exhaust air.
G. Using heat recovery to provide heat for another use, such as space heating or hot water preheating.
H. Using effective power management to reduce or eliminate power consumption during standby.
I. Using more efficient motors for rotating the drum and for the blower.
J. Using sensors to monitor for resistance to the air flow, such as a clogged lint screen.
K. Using microwave heating to transfer heat to the water more effectively.
L. Using outdoor clothes lines or indoor drying racks.
M. In dry climates, using air dry only (no heat) in a conventional dryer.

These ideas are not new. All (except maybe microwave drying) were proposed in the 1960's or 1970's. Most were not pursued because energy efficiency was not a high priority. In fact, many were studied for other reasons (such as faster drying or other convenience) and the energy impacts were never analyzed. It is appropriate to revisit them now to see how significant energy savings can obtained.

Note that improving the efficiency of the motor is not an energy savings strategy per se. It turns out that dryers generally use the incoming air to cool the motor, so any inefficiency in the motor warms the air that would have needed to be heated with electric resistance anyway.

Advanced Technologies

Five of these energy savings strategies have been the focus of most recent research and product development: centrifugal water removal, microwave drying, modulating gas burners, heat recovery, and heat pumps.

Centrifugal water removal

The simplest strategy for reducing dryer energy use is to accomplish some of the drying in the clothes washer by spinning much more of the moisture out of clothes. As typical clothes washer configurations changed from a vertical axis with a central agitator to a horizontal axis, it became possible to increase spin speeds from approximately 600 RPM to much higher levels. Spin speeds of more than 1000 rpm are increasingly common in new clothes washers. Some websites claim that European models have achieved speeds of more than 3000 RPM, but it is difficult to find examples in the literature that run at more than 1600 to 1800 RPM.[8] Small diameter washing machine drums have to be spun at more revolutions per minute than large diameter drums to achieve equivalent water removal rates.

Achieving a 50% remaining moisture content, instead of 70% in average laundry loads would save about 209 kwh/year in a typical dryer, according to the Washington State Energy Office. Whirlpool has asserted that it is 19 times more energy efficient to spin water out of clothing than to evaporate it with heat. Other sources indicate that mechanical extraction of water is as much as 70 times more efficient as drying, and that it is relatively easy to reduce remaining moisture content in clothing from 65% to something in the range of 41 to 47% just by increasing spin speed by 200 to 300 rpm.[9] An analysis by the UK Market Transformation Programme concluded that higher washing machine spin speeds would reduce remaining moisture content from 60 to 70% down to about 45%, cutting dryer electricity use by 25%.[10]

A detailed recent European analysis found that every 400 RPM increase in spin speed (from 800 to 1200 and from 1200 to 1600 RPM) causes the washing machine to use about 50 additional watt-hours per load of laundry and adds about 30 Euros to the washing machine's purchase price. However, the remaining moisture content drops from 72 to 56% with the first speed increase, and down to 49% with the second speed increase. This significantly cuts the energy and time needed by the dryer to do its job. The lifetime energy savings in the dryer range from 50% higher to 12 times higher (depending on usage patterns) than the energy usage increase in the washer from spinning the clothes 400 RPM faster.[11] So, while the estimates vary widely on how much energy can be saved by additional centrifugal water removal, there is very little

[8] Ira Krepchin and Jennifer Thorne, *Residential Appliances Technology Atlas*, ESOURCE, 2001, p. 122; http://en.wikipedia.org/wiki/Washing_machine; and http://www.appliancist.com/washers_dryers/

[9] See Frank Kreith and D. Yogi Goswami, *Handbook of energy efficiency and renewable energy,* CRC Press, 2007, p. 12-55.

[10] See http://www.mtprog.com/spm/download/document/id/685.

[11] Milena Presutto, *Spinning speed of washing machines: an analysis of the trade-off with the penetration and use of tumble dryers*, EEDAL '09, Energy Technologies, Renewable Energy Sources and Energy Saving Department, 2009.

disagreement in the literature that it is more efficient than conventional heated drying and worth doing.[12]

Dedicated centrifugal spinners are also available for the purpose of extracting as much moisture from clothing as possible, and can supplement existing clothes washer operation. One unit, the Spin Dryer (Figure 5), operates at 3200 rpm and claims to cut drying times in half by spinning clothes for 2 to 3 minutes with 300 watts of motor power. If such a device could remove half of the water in a load of clothing for about 0.015 kWh (3 minutes * 300 watts), it would save a significant amount of dryer energy per load. The device has a maximum capacity of 2.2 pounds of dry clothing, dimensions of about 14 x 14 x 24 inches, and costs $135.[13]

Figure 5. The Spin Dryer

Ecos tested a sample of the unit and found that it could indeed remove more water from clothing that had already been spun at 1300 RPM by a front loading washing machine. But the capacity was much smaller than a washing machine, requiring a large load to be divided into two to four portions and spun separately before it could be dried. Water also continued to come out of the clothing for 5 to 7 minutes of spinning, suggesting that cycle times would need to be longer and that drying time savings may be overstated. By our measurements, this product removed about 5 to 14 pounds of water per kWh of electricity consumed (depending on the size and type of load), making it at least 2 to 7 times as efficient as a typical electric dryer.

Microwave drying

Microwave dryers work like a microwave oven. A magnetron tube converts electricity to microwave energy, which is directed to the wet clothes. The microwaves heat the water in the clothes to evaporate the water, which is then vented. Some test models have been made by EPRI and American Micro-Tech. Problems are encountered with any metal in the clothing, such as zippers, buttons, or coins. They cause arcing which can start the clothes on fire. Further development has led to a hybrid design which uses microwave heating while the clothes are wet (and won't burn) and uses hot air to finish the drying.

[12] We estimate that horizontal axis clothes washer consume 300 to 500 watts when spinning clothing at high speed and the Spin Dryer consumed 205 watts, while electric dryers generally consume 4000 to 6000 watts when operating. Within reason, washers should spin out as much water as possible before clothes are placed in a dryer.

[13] See http://www.laundry-alternative.com/drying.htm.

Microwave dryers are faster than conventional hot-air dryers, but not likely to be much more efficient. It takes just as much microwave energy to heat the clothes and evaporate the water as from any other energy source. The only savings is that one does not have to heat a large volume of air. However, the energy losses in the magnetron roughly balance the energy saving of not heating as much air. Some energy savings has been reported if the drying is slow, but conventional dryers also save energy if they are allowed to dry more slowly. Microwave dryers may enter the marketplace for rapid drying of very small loads. But they will not become an energy-efficient technology for mainstream clothes drying.

Modulating gas burners

Gas dryers often run at a single maximum heat output level and simply turn on and off as needed to maintain a particular air temperature. If the gas burner in those dryers could be modulated to respond more subtly to changes in dryer temperature and humidity levels, the potential exists to reduce energy use and drying times, without subjecting clothing to overly high temperatures.

A TIAX prototype incorporating this feature achieved 13 to 23% energy savings and 20 to 40% time savings relative to a conventional natural gas dryer. These features could provide significant value to consumers, who want to make sure their dryers keep pace with the cycle time of their washer to allow them to complete multiple loads of laundry as rapidly as possible.[14]

A second prototype effort with Camco, General Electric's Canadian subsidiary, confirmed the shorter drying times but did not achieve equivalent energy savings.[15] The technology is more prevalent in commercial drying equipment, where the energy savings can be significant due to high duty cycles and large loads.[16]

Heat recovery

Heat recovery uses an air-to-air heat exchanger to take heat from the exhaust air and use that heat to preheat intake air. The technology is quite simple. Because the heat exchanger usually condenses water out of the exhaust air, it is sometimes called condensing heat recovery. A small pump is required to pump this condensed water out to a drain. Air-to-air heat exchangers are used on many dryers in Europe to avoid the need for an exhaust vent. In the European dryers, the exhaust air is cooled (using room air) and recycled to the heater.

[14] Peter Pescatore and Phil Carbone, *High Efficiency, High Performance Clothes Dryer*, Final Report to Department of Energy, TIAX, March 31, 2005, pp. 2-1 to 2-10.
[15] See http://www.ctgn.qc.ca/en/Download/NGTC%20-%20Modulating%20Clothes%20Dryer.pdf
[16] See http://www.hotelworldnetwork.com/laundry/dryers-save-energy-and-prevent-heat-loss-3864

Condensing dryers are available in the U.S. from at least three European manufacturers: Bosch (1 model), Asko (3 models), and Miele (2 models). These units typically cost $950 to $2050 and are available in small and medium capacities, but not usually the largest capacities. They are marketed as "ventless" because they allow dryers to function in spaces without access to an exterior vent (apartments and condominiums). They are generally not marketed as more energy efficient, though that claim does appear in some marketing materials.

These European condensing dryers are not using heat recovery. They contain a condensing heat exchanger, as would a heat recovery dryer. But the heat exchanger is not being used to preheat air on its way to the heater and the drum. Instead, the heat exchanger is used to heat the room air, that is, to dissipate waste heat from the dryer.

ESOURCE noted that US tests of condensing dryers in 1993 and 1997 indicated, if anything, that condensing dryers with air-to-air heat exchangers were consuming *more* energy than conventional dryers. This is likely due to energy usage associated with an extra fan and the fact the recirculated air often has a higher humidity than room air, providing less spare moisture carrying capacity.

We analyze below the energy that can be saved by using a heat exchanger as a pre-heater and exhausting the moist air outdoors after the heat exchange has occurred, instead of recirculating it. Because the same heat can be cycled through the dryer more than once, it is possible to achieve efficiencies greater than 100%.

This configuration is different from using the heat exchanger to dissipate waste heat, though it requires the same components. Because heat exchangers are in wide use in Europe, the technology should be considered mature and commercially feasible, even if the particular design concept is different.

Heat pumps

A heat pump operates much like a small air conditioner. It extracts heat at one temperature (such as a 70°F room) and releases that heat at a higher temperature (such as 100ºF outdoors). Electrical energy is used to drive this process. A typical heat pump uses 1 kWh of electricity to move 2 kWh of heat. Heat pumps work well when the temperature difference is small and become much less efficient as the temperature difference increases.

In a heat pump dryer, the air moves in a closed loop (see Figure 6). The heat-dissipating (condenser) side of the heat pump heats the air. The hot air is blown through the drum, where it evaporates water from the clothes. The air cools somewhat and its humidity increases. Then the air passes the heat extracting (evaporator) side of the heat pump. Here the air is further cooled, and in the process the moisture is condensed out. This air can then be recycled and heated again.

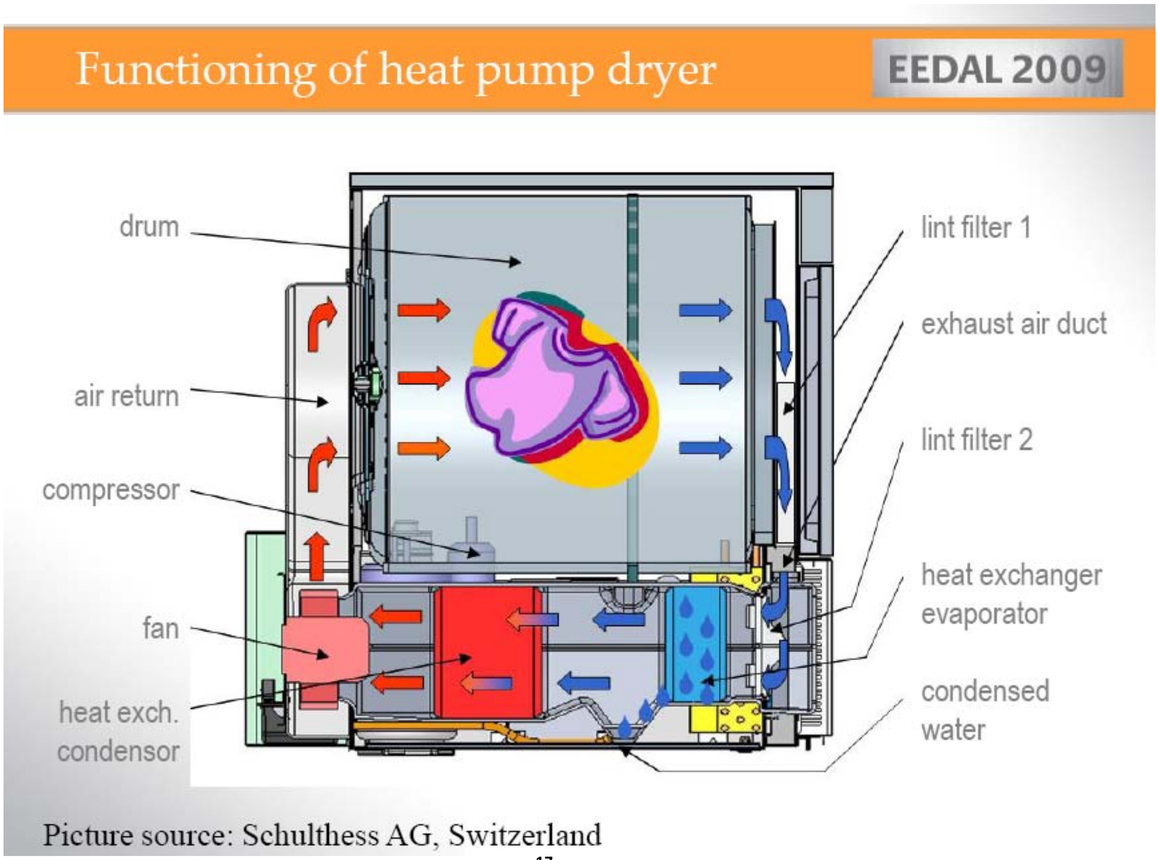

Figure 6. How a Heat Pump Clothes Dryer Works[17]

Heat pump dryers are readily available in Europe and Australia from Miele, Bosch, Siemens, and many other manufacturers.[18] Though their market share is less than 4% in most European countries, it has reached 11% in Italy and 15.6% in Switzerland.[19] They are quite efficient, but have drying times that are usually about twice as long as a typical US dryer. Some prototypes have been developed for US markets that use higher temperatures and airflows to keep drying times more similar to typical models. The results show energy savings of 31 to 44% and drying times ranging from 8% longer to 35% shorter than conventional dryers. However the drying times were still 20 to 60% longer than with a modulating gas dryer, so more work is needed for heat pump dryers to be competitive with more conventional technologies. Typical fabric temperatures were also 10 to 35 degrees F lower, which will tend to increase clothing lifetimes.[20]

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[17] Jürg Nipkow and Eric Bush, *Promotion of Energy-Efficient Heat Pump Dryers*, EEDAL '09, S.A.F.E. Swiss Energy for Efficient Energy Use, 2009, p. 3.
[18] See http://www.topten.info/index.php?page=one_familiy_house
[19] Jürg Nipkow and Eric Bush, 2009, p. 1.
[20] Peter Pescatore and Phil Carbone, *High Efficiency, High Performance Clothes Dryer*, Final Report to Department of Energy, TIAX, March 31, 2005, p. 1-12.

Commercially available heat pump dryers have achieved similar efficiency gains in Europe, at list prices ranging from less than 800 Euros to more than 2500 Euros. By European efficiency metrics, heat pump dryers consume only about 0.23 to 0.43 kWh/kg, compared to 0.56 to 0.64 kWh/kg for more conventional units, suggesting an energy savings potential of 23 to 67%. However, drying times are estimated at 90 to 150 minutes per cycle – significantly longer than comparable washing cycle times.[21] A conventional electric dryer that could operate on those cycle times would also be substantially more energy efficient than ones that dry loads in 30 to 60 minutes.[22]

Building a heat pump dryer is essentially like combining a dryer and an air conditioner. The technology is readily available, but there is some complexity and cost. Further work will be necessary to optimize the designs before they will be popular in the US marketplace for those that can afford them.

IV. Regulatory History

Energy Efficiency Test Methods

There are two widely-used test methods in the United States for measuring the energy consumption of dryers. The first is published by the Association of Home Appliance Manufacturers (AHAM) and was last revised in 1992. The second is the DOE test method, which was an adaptation of the AHAM method.[23] Both methods require drying a carefully-specified test load under controlled conditions. Both test methods require stopping the dryer while there is about a 5% residual moisture content in the test load. This can be a difficult requirement to meet, and also means that the tests do not determine the effectiveness of any sensors or control strategies. The major differences between the test methods are shown in Table 1:

Table 1. Major differences between the test methods for clothes dryer energy consumption.

	AHAM test method	DOE test method
Amount of cloth	2 to 23 pounds	7 pounds
Type of cloth	100% cotton	50/50 cotton/polyester
Size of cloths	Varies	24”x36”
Initial moisture content	100% ± 5%	70% ± 3.5%
Temperature of load	100°F ± 5°F	100°F ± 5°F
Residual moisture content	4% to 6%	2.5% to 5%

[21] Jürg Nipkow and Eric Bush, *Promotion of Energy-Efficient Heat Pump Dryers*, EEDAL ‘09, S.A.F.E. Swiss Energy for Efficient Energy Use, 2009, p. 7; and http://www.topten.info/index.php?page=one_familiy_house.

[22] The UK Market Transformation Programme reports that a conventional electric dryer with a 7 hour cycle time has matched the efficiency of a heat pump dryer also sold in the UK. See http://www.mtprog.com/spm/download/document/id/685.

[23] 10 CFR Part 430 Subpart B, appendix D, *Uniform Test Method for Measuring the Energy Consumption of Clothes Dryers*, section 4.4).

The DOE test method further specifies the conversion of gas consumed by gas dryers to the kWh heat equivalent, so that they can be regulated on a pounds of clothing dried per kWh or kWh equivalent basis, regardless of which fuel they use.[24]

DOE then applies a "field use factor" which adds 4% to the energy consumed (18% if the dryer uses only a timer for the controls, a configuration which is no longer available on new dryers). This is an attempt to consider the fact that dryers continue to use energy after the bulk drying is complete, though, as we discuss further below, it *assumes* all dryers have equally effective controls systems, rather than measuring the actual effectiveness of their controls.

Finally, DOE calculates the "Energy Factor." This is defined as the pounds of cloth dried per kWh of energy used, adjusted to represent removal of water weighing 66% of the cloth weight. Typical energy factors are about 3 pounds per kWh, which corresponds to an efficiency of 61%.

The IEC also has a test procedure for dryers – IEC 61121 – which does not yet allow natural gas dryers to be compared with electric ones, though some work is underway to include gas dryers in the future.[25]

Mandatory Efficiency Standards and Labeling Programs

The US and Canada employ similar test procedures and regulatory frameworks for dryers, but Natural Resources Canada and the California Energy Commission have done more with the resulting data than US DOE has. Both NRCan and the CEC maintain consumer-accessible, online databases of available dryers (California considers them "listed products"). The California database allows users to categorize or sort products by clothing capacity, gas versus electric fuel, manufacturer, model name or number, and energy factor. The CEC also makes consumer information available on how to choose and operate dryers in an energy efficient manner. See www.consumerenergycenter.org/home/appliances/dryers.html.

When tested by the DOE test procedure, current dryers show rather little variation in their energy factors. Standard size (>4.4 cubic feet) electric dryers range from 3.01 to 3.40 pounds per kWh with an average of 3.12. Significantly wider variation is observed in the smallest units, with the best models exhibiting about 60% higher efficiency than the worst:

[24] This is different from a calculation that would determine how much natural gas would be consumed at a power plant to provide a particular amount of end use electricity.
[25] See http://www.mtprog.com/spm/download/document/id/592.

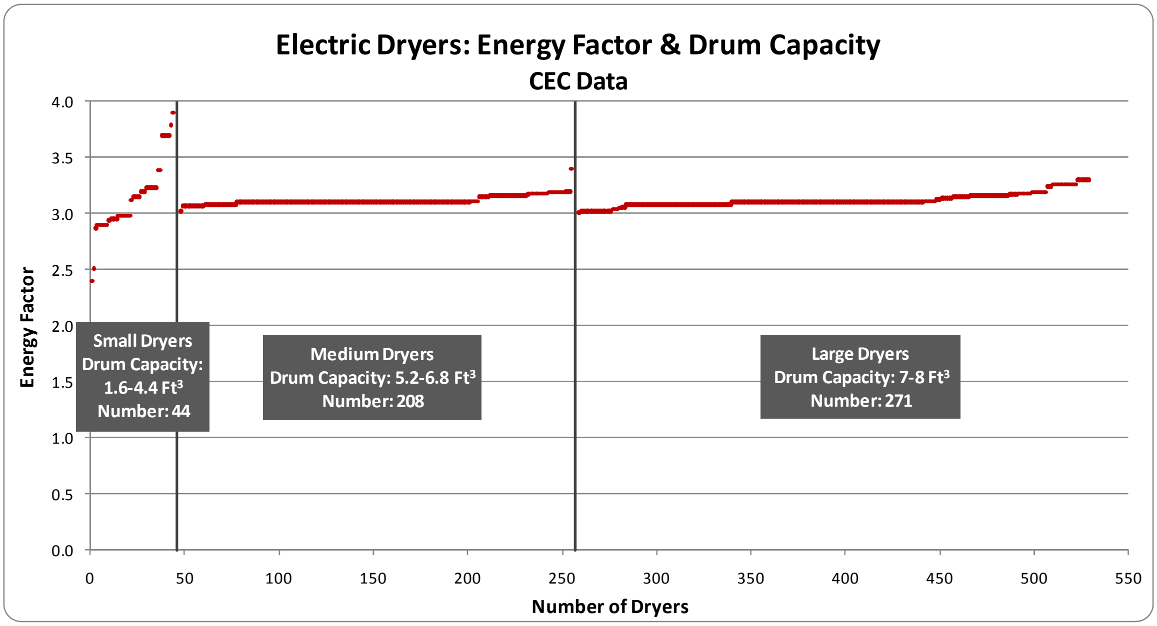

Figure 7. Energy Factor and Drum Capacity of Electric Dryers

Energy factors in standard size natural gas dryers range from 2.67 to 3.02 with an average of 2.79. The most efficient model is about 25% better than the least efficient model:

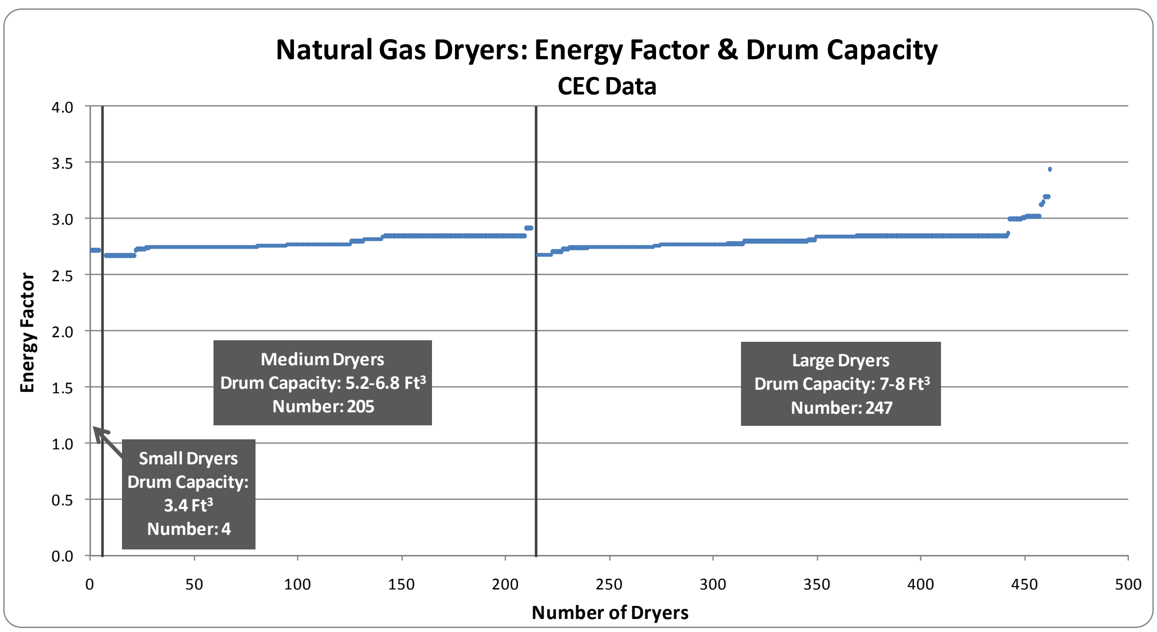

Figure 8. Energy Factor and Drum Capacity of Natural Gas Dryers

The fact that natural gas dryers tend to have lower average energy factors than electric dryers could lead consumers to believe that electric dryers are generally more efficient. In fact, by most measures, the conventional gas dryers that have been available for 30 years have significantly less source energy use and environmental impact than today's efficient electric dryers. The heat pump dryers that may reach the US market in the future have only slightly lower impacts than conventional gas dryers (see additional discussion below).

Because of the narrow range of variation in most models, there are no Energy Star programs, no Energy Guide labels, and no rebate programs (except occasional efforts by electric or gas utilities to persuade consumers to switch fuels). Dryers are subject to DOE minimum requirements for energy factor (3.01 for electric, 2.67 for gas) and are given an automatic credit toward that score if they have a moisture sensing feature (regardless of how it actually works – see below). There has also been a requirement since 1988 that gas dryers must use an electric igniter rather than a standing pilot light.

Canada has generally given more regulatory and labeling attention to clothes dryers than the U.S., publishing data that allow consumers to compare their options against each other and make informed purchasing decisions.[26] The Canadian database discloses annual energy use (a more familiar value to consumers than energy factor) and "second price tag," which is essentially annual electricity use at current electricity prices multiplied by 18 to estimate the lifetime energy bill for the product. These two pieces of information are likely to be more useful to the average consumer, and help buyers understand that the $300 to $1000 they are about to spend purchasing a dryer is not nearly as much as they will spend to operate it over its lifetime.

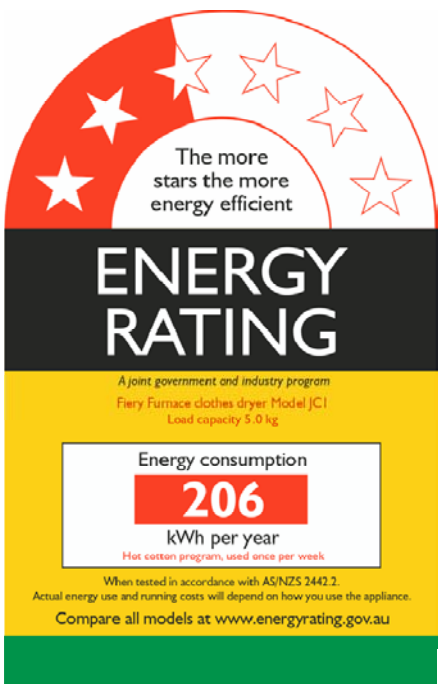

Figure 9. Australia's Dryer Energy Rating Label

Source: CLASP 2008

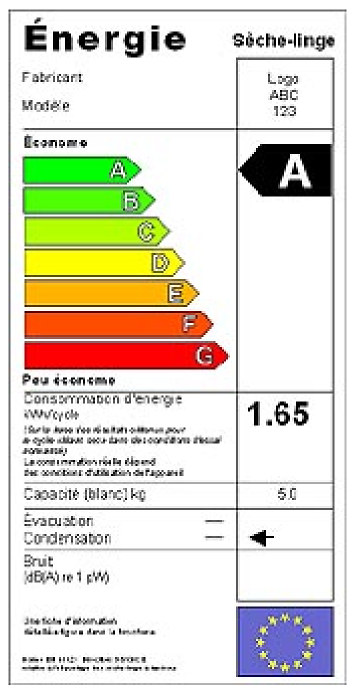

Figure 10. Switzerland's Dryer Energy Rating Label

[26] See, for example, http://oee.nrcan.gc.ca/publications/infosource/pub/electromenagers/2007/pdf/07-Clothes-Dryers.pdf).

Despite their high energy use and electrical demand, the U.S. does not require energy efficiency labels on clothes dryers. According to the Collaborative Labeling and Appliance Standards Program (CLASP), the European Union member countries as well as nine additional countries have mandatory dryer labeling programs in place or under consideration.[27] Australia began mandatory efficiency labeling for dryers in 1989 (Figure 9). Their current dryer efficiency label uses a six-star graphic to categorize dryers from least efficient (one star) to most efficient (six stars). Estimated annual energy consumption is also displayed prominently. Switzerland has joined the EU labeling approach by adopting the A-G categorical label for dryers (Figure 10). Virtually all conventional electric dryers in the EU have migrated steadily upward from the F and G-rating to the C-rating since the EU adopted categorical labeling for the products. A few units with advanced sensing capabilities have been able to achieve a B-rating; A-rated units are almost all heat pump models. Miele now claims to have a heat pump dryer for sale in Europe and Australia that is 40% more efficient than required to achieve an A-rating.[28] Gas dryers are excluded from EU energy labeling, even though they offer compelling financial and greenhouse gas advantages over most conventional electric drying technologies.[29]

Some countries also have energy efficiency standards for dryers. For example, Switzerland recently enacted standards that, in practice, only heat pump dryers will be able to meet after 2012.[30]

V. Field Testing and Modeling

Ecos conducting its own field testing of four different electric dryer models. One was a "bare-bones" model with an electromechanical timer for the control. It was a new unit of a current model, but the design is the same as has been used for roughly 20 years. The other three were also current models, but with electronic controls and moisture sensors. They claimed to be "energy saving" models, but did not specify how that was achieved.

The dryers tested were:

A. LG DLE7177RM
B. General Electric WBSR3140GWW
C. Fisher/Paykel DE62T27G
D. Bosch WTMC532CUS16821195

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[27] See http://www.clasponline.org/clasp.online.worldwide.php?product=12
[28] Tim Somheil, "Ease and Efficiency," *Appliance*, September 2009, pp. 28-30.
[29] See http://www.mtprog.com/spm/download/document/id/685.
[30] Jürg Nipkow and Eric Bush, *Promotion of Energy-Efficient Heat Pump Dryers*, EEDAL '09, S.A.F.E. Swiss Energy for Efficient Energy Use, 2009, p. 10.

Testing included data logging of the power input and the temperature, humidity, and flow rate of the exhaust air. Humidity was measured using two thermocouples in a wet-bulb and dry-bulb configuration. Data were sampled every 5 seconds. Also the ambient temperature and humidity were recorded. The tests were conducted at 6600 feet elevation. The air density at this elevation (1006.6 gm/m^3) is less than at sea level (1225.0 gm/m^3). The lower density means it takes less heat to warm a given volume of air. The drying process is slightly more efficient at higher elevation (given the lower typical relative humidity levels as well), but all the variations observed are still significant.

The test loads were 100% cotton bath towels, DOE test cloths (50/50 cotton-polyester blend), or a mix of the two. Test cloths were pre-conditioned according to the DOE test method. For each load, the bone-dry weight, wet weight, and final weight were recorded. For some tests, the load was also weighed every five minutes during drying to determine the evaporation rate.

The data gathered allow for a separate calculation of the evaporation rate. The exhaust temperature, density, and humidity enable us to calculate the absolute moisture content (grams of water per cubic meter) of the exhaust air. A similar calculation can be done for the ambient air. Subtracting the intake moisture content from the exhaust moisture content gives the moisture added to the air as it goes through the dryer. Finally, multiplying this by the airflow gives the rate of evaporation (grams of water per minute). This calculated evaporation rate agreed well with the changes in test load weight. Further, the calculated rate of evaporation is available every 5 seconds without interrupting the drying process and altering the way it would typically occur, as is the case with the DOE test procedure.

A total of 35 test runs were made. Each drier was tested under conditions very similar to the DOE procedure. Additional tests were done under conditions that more closely represent actual use. For example, instead of stopping the drying at 5% RMC, we used the normal (default) and permanent press cycles, allowing the dryer to stop itself. Additional tests were done on one dryer model where we varied one parameter at a time to determine which factors most affect the drying efficiency.

Results

The main results of all 35 tests are shown in Appendix A. **Measured efficiencies varied from 17% to 82%.** We will look first at some of the obvious variations that are easy to understand. Then we will look at the data logs to see some more subtle effects.

The first factor that has a huge effect on efficiency is size of the dryer load. The larger the load, the more efficient the drying. Small loads are inefficient because the “fixed cost” energy required to heat the air and metal remains high even though little water is evaporated. We had expected that there might be an optimum value and that very large loads would dry slowly and inefficiently. This was not observed. Even the largest, a very full 14-pound load, still showed increased efficiency. At some point, presumably, the clothes could become so tightly packed that it would be difficult to circulate air throughout the individual items and dry them uniformly, but that would need to be an even larger load than we tested.

The second factor is the initial moisture content. With a lower moisture content, the energy required is reduced, but not proportionately. The energy used to evaporate water is reduced but not the energy to heat air, cloth, and metal. Thus a lower moisture content results in lower percentage efficiency of the drying process. This is not the same thing as stating that lower initial moisture content increases absolute energy use, of course. All other things being equal, the less moisture that needs to be removed, the less total energy will be required to dry the clothes.

These first two factors are illustrated in Figure 11, which shows the energy consumption for all tests versus the amount of water removed. Much of the scatter in the data is due to differences in the types of individual tests conducted, rather than fundamental efficiency differences in the products.

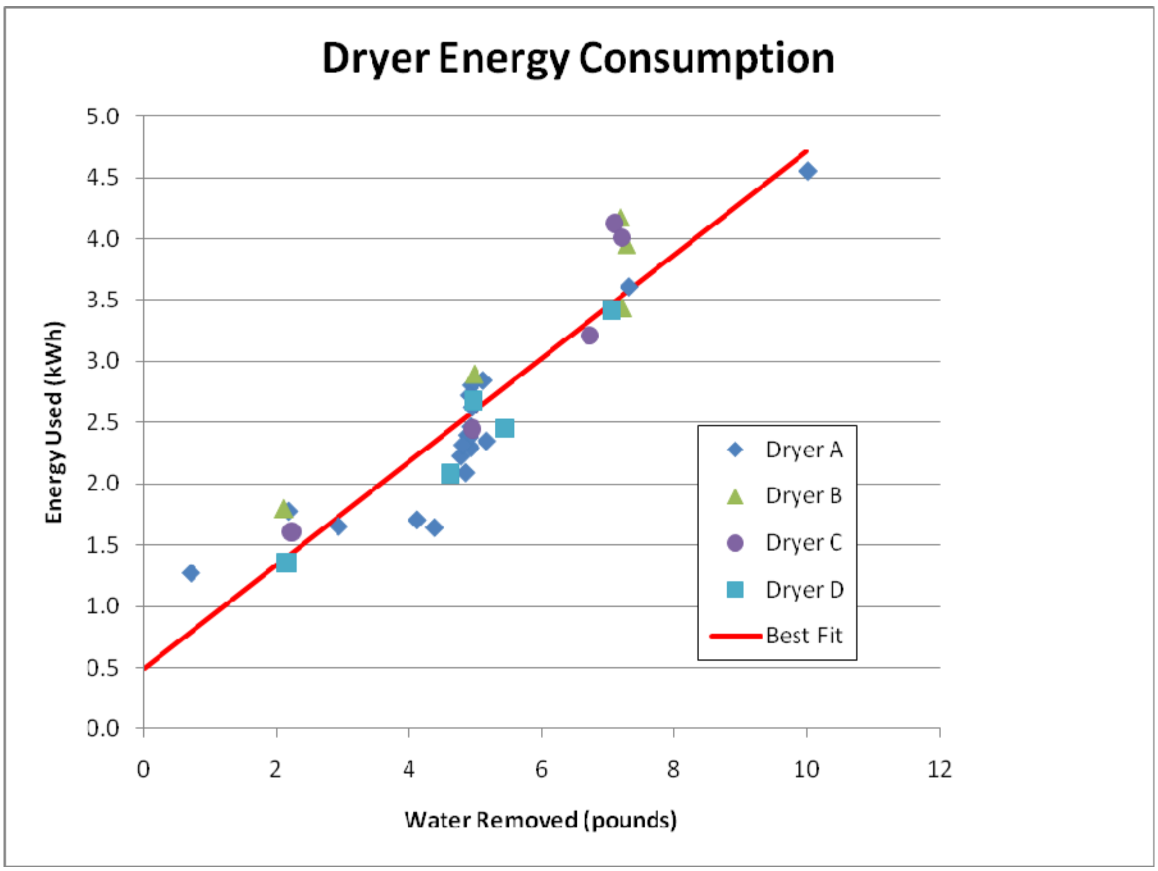

Figure 11. Dryer Energy Consumption versus Water Removed.

The third factor affecting efficiency is the dryer heat setting. A lower heat setting reduced energy consumption and increased the efficiency. The savings here is because less energy is spent heating air, cloth and metal. The difference in energy consumption between the highest and lowest heat settings for Dryer A was 13%, when drying the same load. A tradeoff is that the drying time increased (from 35 to 49 minutes), but very similar levels of final dryness were reached.

A fourth factor is the dryness setting. Using a “less dry” setting rather than a “more dry” setting saves energy and increases the efficiency. We found that a “normal” setting removed practically all the water (less than 1% RMC), making the “more dry” setting appear to be unnecessary. “Normal dry” used about 12% less energy than “more dry.” “Less dry” saved another 18%, but did leave residual moisture in the clothes. In all but the highest humidity climates, the “less dry” setting may be fully adequate and would give considerable energy savings.

We had expected a clogged lint filter to reduce the efficiency. This was not observed. We simulated a badly-clogged filter by taping plastic over the lint filter and cutting a 2-inch hole in the plastic. This reduced the air flow by about half. (For comparison, the first drying of a full load of brand-new bath towels generated enough lint to reduce the airflow by about 10%). The clogged filter actually increased the efficiency very slightly. We attribute this to less energy spent heating air. The drying time did increase, but the reduced heating rate still dominated, so there was less total air to heat.

We tested one load with no heating -- just air dry. The ambient conditions were somewhat cool, 65°F and 65% relative humidity. In two hours, about half of the moisture had been removed, so the drying time is expected to be 4 to 5 hours. The efficiency was quite high, 166%. In effect, the heating element consumes so much more electricity than the motor that is possible to run the dryer for a long time without substantial energy use, as long as the heating element stays off. Even much better efficiencies are theoretically possible with better motors.

We also ran tests to see how dryers dealt with loads of mixed fabrics. These mixed loads consisted of 5 pounds of 100% cotton bath towels and 2 pounds of 50/50 polyester blend DOE test cloths. We had heard anecdotally that dryers often stop when the synthetic blend fabrics are dry but the cotton is still damp. For dryers with electronic dampness sensors, this was the case. (These sensors measure the electrical current conducted through the fabric to estimate the water content.) We started with the same moisture content in both types of fabric, even though if they had been spun together in the washer the synthetic would probably hold less water. The dryers often stopped with the synthetic quite dry (<2% RMC) but the cotton still damp (>6% RMC). This suggests that consumers will get better drying performance by keeping different fabric types separate.

Several tests were done to compare the different dryers. These were:

1. Testing similar to the DOE test procedure. The main difference is that we ran the drying cycle until the cloths were bone dry instead of stopping at 5% RMC. However, because we track the evaporated water in the exhaust air, we can later look from the end of the cycle back to determine when 5% RMC occurred. From the data logs, we can then compute the energy used to this point, as if the drying had been stopped at 5% RMC. Our calculated Energy Factors were between 3.00 and 3.38, and within 6% of the DOE reported values for each dryer.

2. A "worst case" cycle consisting of a mixed load of very wet fabric, high heat and very dry settings, and a clogged lint filter. This test could not be done on one dryer that had a self-cleaning lint filter. Another stopped with a lint filter error early in the cycle. This test proved not to be very useful.

3. The same load of fabric, but with a clean lint filter and low-heat and less-dry settings. This run did indeed use less energy, consistent with the savings described above. Some dryers did not give a choice of heat settings (separate from fabric types), so it is not clear that this test provides a good basis to compare dryers. It is also probably not the way most consumers use their dryer.

4. A 7-pound load of 100% cotton run using all the "normal" and default settings. This is probably typical of the majority of the loads that consumers actually run. The energy consumption varied by 22% among the 4 dryers tested. This run and the one below appear to be quite good for comparing dryers and are discussed below.

5. A 3-pound load of synthetic blend cloths using the permanent press cycle with all other settings at normal or default. This is probably typical of those loads in which the consumer wishes to dry something quickly to wear that day. The energy consumption for this load varied by 33% among the dryers tested.

For loads 4 and 5, all the dryers used about the same amount of energy in the bulk-drying stage (within 0.20 kWh). However, the energy used in the high heat stage varied considerably. With load 4, Dryer D used only 0.01 kWh compared to Dryer B with 0.75 kWh. These results are shown in Figure 12.

Dryer B is the bare-bones dryer with electromechanical controls, and is clearly the least efficient of the dryers tested. Dryer D is much more effective at determining when the clothes are actually dry and shutting off this high-heat stage. **The difference in energy consumption is about 0.76 kWh per load or nearly 5,000 kWh over the typical useful life.** This is a very significant energy savings and suggests that even apparently small differences in measured energy use are worth recognizing and promoting in a product used as heavily as a clothes dryer.

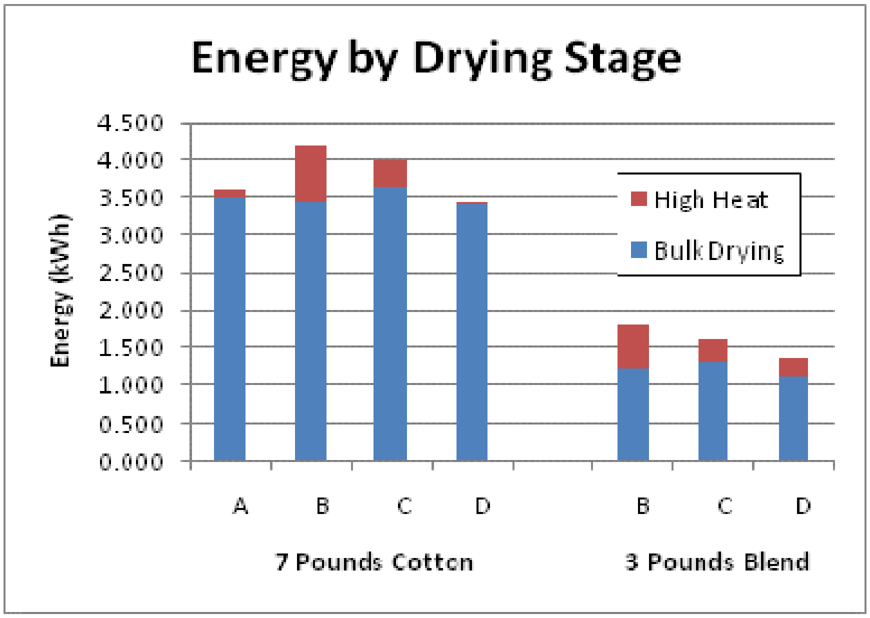

Figure 12. Energy by Drying Stage

The figures below show how this improvement in efficiency is achieved. After reaching 5% RMC, Dryer B continues with about 30 minutes of high-heat stage, consuming power the whole time. By contrast, Dryer D detects the 5% RMC and stops applying heat. Instead, there is about 5 minutes of cool-down during which the last of the moisture is evaporated. Dryer D is not only more efficient, it also get done about 20 minutes faster.

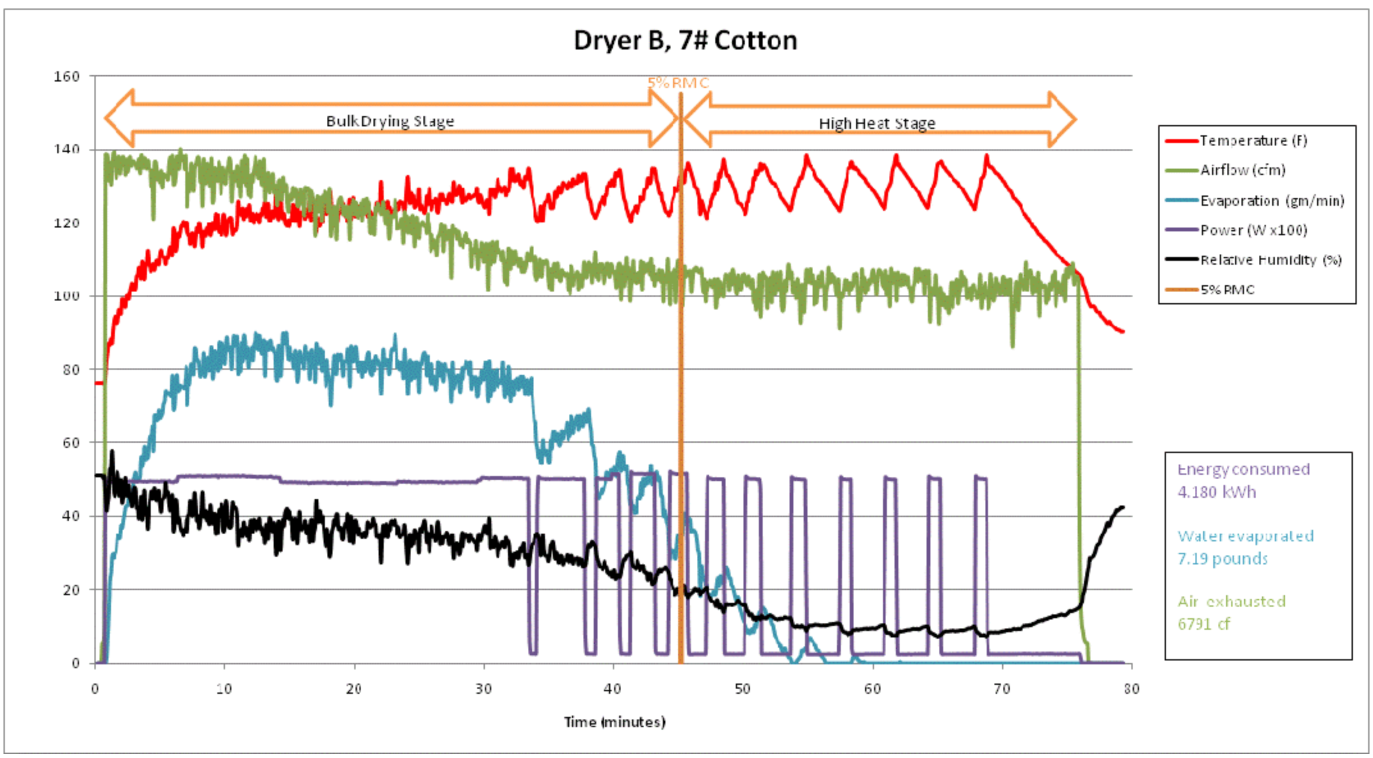

Figure 13. Measured Data for Dryer B

Standby power demand was essentially zero for the dryer with electro-mechanical controls. This is expected since most mechanical timers contain a hard-off switch. The dryers with electronic controls used from 1.4 to 3.1 watts in standby. Dryer D was the lowest at 1.4 W. Even this is higher than necessary. The standby energy consumption can add up to another 180 to 400 kWh over the life of the dryer. The current technology of switch-mode power supply controller ICs allow the standby power to be kept in the range of .03 W to .05 W, or only 4 to 6 kWh over the life of the dryer.

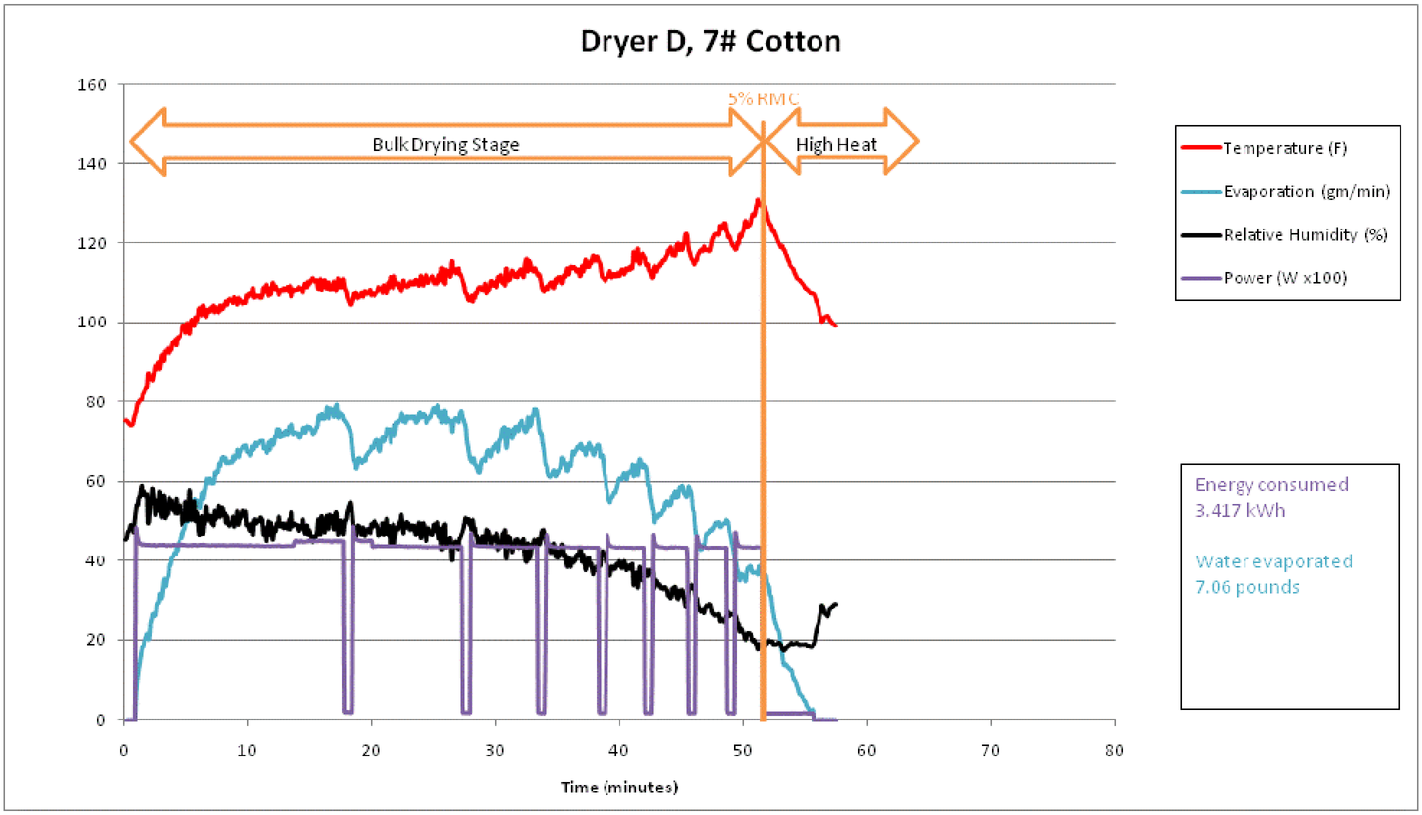

Figure 14. Measured Data for Dryer D

Calculations

There are three questions we wished to explore by modeling:

A. What is the load that the dryer places on the building HVAC system, and are there significant differences between one dryer and another?
B. How much energy can be saved by using a heat exchanger for heat recovery?
C. How much energy can be saved by using an outside air intake for the dryer?

Our answers to these questions are very approximate (roughly ±25%) because we did not try to include the details of how many consumers live in what climate zone. But even very rough results can help illustrate where there might be potential for significant energy savings.

The load that the dryer places on the HVAC system has two components: the energy required to condition the air that the dryer sucks out of the building, and any energy required to remove the heat dissipated by the dryer into the room. We will calculate the first quantity only, as it is usually much larger. The assumptions made for these calculations are included in Appendix B.

The results are shown in Table 2. The columns of this table are for the various dryers with test loads 4 (7 pounds of cotton towels) and 5 (3 pounds of 50/50 synthetic blend). Also shown is the total air volume used for the drying cycle, in cubic feet (cf). The rows are different outside temperatures (degrees F). Each row also has the energy (Wh) required by the HVAC system for each thousand cubic feet (Mcf) of infiltrated air. When this HVAC energy is included, more than 7 kWh can be required to dry the larger load (<30% efficiency) and more than 4 kWh for the smaller load (<15% efficiency). Dryer B is least efficient under all conditions and dryer D is most efficient. The yellow columns show the savings that are possible by using dryer D rather than dryer B. The savings are typically about 1 kWh per load.

Table 2. Dryer energy consumption (in kWh per load) for various weather conditions.

		Fabric:	Cotton	Cotton	Cotton	Cotton	Cotton	Synthetic	Synthetic	Synthetic	Synthetic
		Dryer:	A	B	C	D	Savings	B	C	D	Savings
		kWh:	3.605	4.180	4.011	3.417	B-D	1.798	1.606	1.352	B-D
Temp F	Wh/Mcf	Air cf:	6589	8489	9071	6931		6057	4981	3176	
-40	590.9		5.941	7.190	7.227	5.874	1.315	3.945	3.372	2.479	1.467
-30	537.2		5.729	6.916	6.935	5.651	1.265	3.750	3.211	2.376	1.374
-20	483.5		5.516	6.642	6.642	5.428	1.215	3.555	3.051	2.274	1.281
-10	429.7		5.304	6.369	6.350	5.204	1.165	3.360	2.890	2.171	1.188
0	376.0		5.092	6.095	6.058	4.981	1.115	3.165	2.730	2.069	1.096
10	322.3		4.879	5.822	5.765	4.757	1.064	2.969	2.569	1.967	1.003
20	268.6		4.667	5.548	5.473	4.534	1.014	2.774	2.409	1.864	0.910
30	214.9		4.454	5.274	5.180	4.311	0.964	2.579	2.248	1.762	0.817
40	161.2		4.242	5.001	4.888	4.087	0.914	2.384	2.088	1.659	0.724
50	107.4		4.030	4.727	4.596	3.864	0.863	2.188	1.927	1.557	0.632
60	53.7		3.817	4.454	4.303	3.640	0.813	1.993	1.767	1.454	0.539
70	0.0		3.605	4.180	4.011	3.417	0.763	1.798	1.606	1.352	0.446
80	122.1		4.088	4.802	4.676	3.925	0.877	2.242	1.971	1.585	0.657
90	219.0		4.471	5.296	5.203	4.328	0.968	2.594	2.261	1.770	0.824
100	338.1		4.941	5.902	5.851	4.823	1.079	3.027	2.616	1.997	1.030
110	484.6		5.521	6.648	6.649	5.432	1.216	3.559	3.054	2.276	1.283
120	665.4		6.236	7.569	7.633	6.184	1.385	4.216	3.595	2.621	1.595

Outdoor clotheslines require no energy and place no load on the HVAC system. Indoor drying racks are not as simple. In the winter, evaporation of the moisture cools the air and the furnace must work a little harder to replace this heat. To a first approximation, the additional energy required is the heat of evaporation, 308 Wh/pound. This implies 100% efficiency or, for the cotton test load of Table 3, 2.19 kWh.

In the summer, the evaporation cools the room air and would appear to reduce the load on the air conditioning system. However, the air conditioner must then remove more moisture from the indoor air, and the latent heat of this moisture is the same as the amount by which it cooled the room. These effects cancel. So, to first approximation, an indoor drying rack will not affect the HVAC load in the summer.

Our next calculation is to estimate the energy that could be saved by using heat recovery. For these calculations, we will consider Dryer D, already the most efficient dryer, to see how much more energy can be saved. We will consider only the load of cotton towels. We assume an air-to-air counter-flow heat exchanger between the exhaust and the intake. We assume a 90% efficiency and ignore the heat capacity of the exchanger.

The average exhaust temperature for this run was 110.3°F. A 90% efficient heat exchanger would heat the intake air from 70°F to 106.3°F on average. This pre-heating of the intake air would save 1.348 kWh of heater energy, or about 40% of the energy consumed by the dryer. This raises the efficiency of the dryer to 105% (though it does not reduce the load placed on the HVAC system). The heat exchanger would condense some of the moisture out of the exhaust air, so a small drain pump would be required.

This heat exchanger could save about 8,000 kWh over the life of the dryer. Even if it added $100 to the cost of the dryer, the energy savings would repay that amount in only 2 years.

Our final calculation is the potential energy savings by using an outside air intake. This would avoid placing any load on the HVAC system, summer or winter. But in the winter, the dryer would need to heat colder air. Without heat recovery, there is no advantage to using outside air in the winter. Again, we assume dryer D is drying the load of towels. Figure 15 compares the energy required when using room air (including HVAC energy) to the energy when using outside air, both with and without heat recovery. The energy savings are considerable, about 1 kWh per load. Using outside air and heat recovery provides considerable savings, about 1.35 kWh per load for heat recovery and another 1.0 kWh per load for outside air.

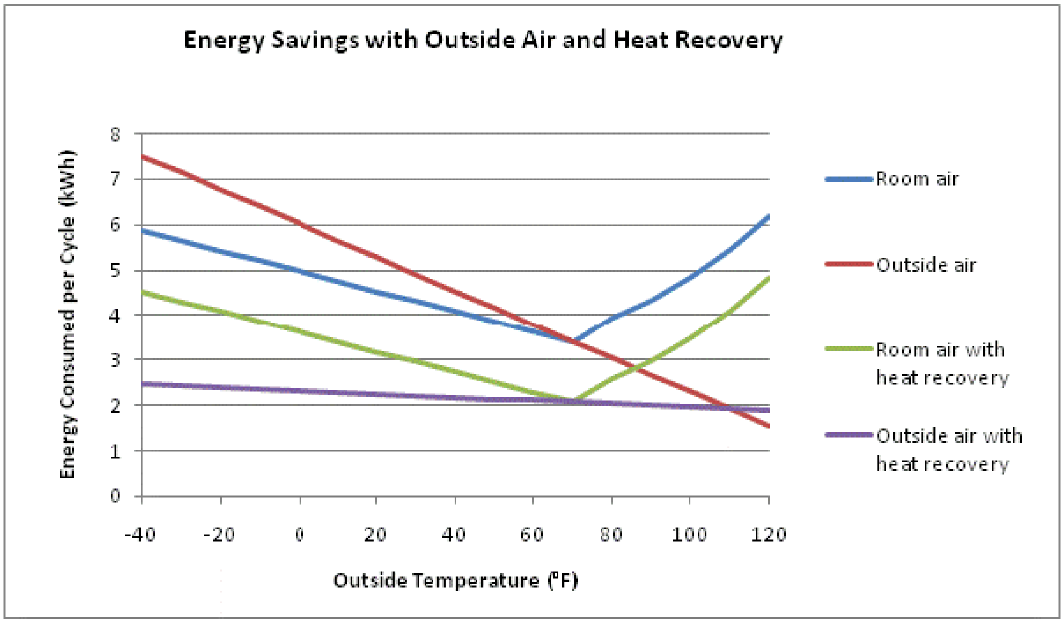

Figure 15. HVAC Impacts on Dryer Energy Use

Note in Figure 15 that the inflection point of the blue and green curves is a simplification of the more general situation in which the outside air temperature is comfortable enough to the home's occupants for them to have the windows open. As a result, the use of air from the house results in no net HVAC energy consumption to warm up or cool down and dehumidify outside air. Likewise, the inflection point of the blue curve represents the energy used by the dryer itself, illustrating that wasted HVAC energy represents a major portion of clothes dryer energy use in most situations. The additional 0 to 2.5 kWh consumed per load as temperatures get lower or higher than 70 degrees represents additional HVAC energy consumption. Also note that, without heat recovery, using outside air is only advantageous in the summer. With heat recovery, it is advantageous year-round.

We should also note that the increasing trend in residential new construction is toward much tighter building envelopes. As a result, the actual airflow leaving the dryer can be lower in practice and the depressurization impacts more profound (leading to potential radon and indoor air quality problems). In general, we would argue that the need for a separate outside air source goes up as homes get tighter and tighter.

One additional design improvement would be straightforward. It is possible to add a summer/winter selector so that in the winter all the heat is delivered to the building instead of being vented inside. The air passages would be reconfigured similar to the European designs. The heat exchanger would keep lint and moisture from the room air. By keeping the waste heat in the building, one can reduce the amount of heat required from the HVAC system. About 60% of the energy used by the dryer evaporates water and the other 40% is available as waste heat to the room.

While this testing and modeling has focused on electric dryers, all the same design improvements can be used with gas dryers and will give similar proportional energy savings.

VI. Recommendations and Conclusions

Improve the Current Testing and Regulatory Approach

It is frequently stated that there is not much variation in dryer efficiency. Given that the test methods measure only the energy of the bulk drying stage, it would be more accurate to say that there is not much variation in the efficiency of the bulk drying. We do see considerable differences in the energy consumption of the high-heat stage, which is not measured. The total energy required to dry the same load varies by 20% to 33% among the dryers we tested. We believe that these differences merit recognition by ENERGY STAR and Energy Guide labeling programs.

Dryers appear to use similar amounts of energy because the test procedure is not currently structured to spot the differences. There are a number of elements in the current test procedure that should be updated or modified to better reflect ongoing developments in washer and dryer technology and the way the products are actually used.

Determination of End-of-Cycle

The biggest shortcoming of the DOE test method is that it ends the cycle in a very unrealistic manner. The technician is required to determine when the specified residual moisture content has been reached and immediately stop the drying. This means that only the bulk-drying stage is tested, since the cycle is stopped before the high-heat stage.

The way consumers tend to use dryers is very different, allowing them to run until they stop themselves. Newer dryers are *capable* of moisture-sensing drying, but that feature can be (and likely routinely is being) over-ridden by consumers that continue to operate dryers on a timed basis like they always have. Typically, this leaves clothes much drier than the test methods would, since the dryer usually spends at least some time in the high-heat stage. By not testing the high-heat stage, the test methods (1) overestimate the efficiency of the dryer, and (2) do not give credit to dryers that use more effective controls to limit the energy consumption of the high-heat stage.

DOE’s test procedure is not designed to detect or account for such differences, but instead just gives a 14% energy savings credit if a moisture sensor is present. Both our testing and earlier testing by *Consumer Reports* confirmed wide variation in how effectively moisture sensors operate. In its testing, some electronically controlled dryers could detect the clothes were already dry and shut down after 5 to 15 minutes, while electromechanically controlled dryers needed up to 50 minutes before shutting down.[31]

DOE should change its test procedure to measure *past* the 5% remaining moisture condition with the sort of logging equipment that allow the test lab to calculate when that point was reached, and how long the dryer continued to run thereafter. The current procedure is both more cumbersome (requiring the technician to frequently stop the test and weigh the clothes) and less accurate (since it doesn't keep measuring until the dryer automatically detects a low moisture condition and stops operation).

DOE should also require manufacturers to incorporate moisture sensing into the timed cycle to ensure that the heating element shuts off and that airflow is greatly reduced once the clothes are dry.

Standard Load Size and Type

DOE specifies a 7 pound test load for standard sized dryers and a 3 test load for compact dryers, even though it allows washing machine test loads to vary from 3 to 15.4 pounds in proportion to different washing machine sizes. Today's dryers can comfortably accommodate loads of 10 to 17 pounds or more. Likewise, DOE specifies a "standard sized dryer" as larger than 4.4 cubic feet, but more 7 to 8 cubic feet models are now on the market than models smaller than 7 cubic feet. It is probably time to acknowledge a wider range of differences in dryer size than simply "compact" and "standard." In general, increasing load size increases the energy efficiency of the drying process until the drum becomes too full to allow easy tumbling of the clothes.

DOE should test a mix of cotton and synthetics of various sizes, including large sheets, towels, and jeans, rather than only testing small, uniform synthetic-blend test cloths. The results would more closely approximate real-world performance. This procedure would be a more accurate reflection of the challenge dryers face drying fabrics that can ball up if only rotated in one direction continuously. It would also deal more fairly with the very real situation in which some fabrics have finished drying before others, causing the load to either finish before everything is dry or after some of the fabrics have been over-dried. If DOE were to test each model across a wide range of load sizes and types and report multiple values, it would help consumers choose the appropriate sized dryer and to fill it with the recommended amount of clothing to dry as efficiently as possible.

Standard Remaining Moisture Content

DOE's assumptions for remaining moisture content after the wash cycle is finished (100% for cotton, 70% for 50/50 cotton/synthetic blend) are typical for older, top-loading, agitator-type washers. However, most modern washers use longer spin cycles and faster spin speed to significantly reduce water content. With these spin cycles, we

[31] ESOURCE, 2001, p. 143.

measured approximately 70% remaining moisture content in cotton bath towels and about 40% in the 50/50 DOE test cloths.

Table 3. Results from running test loads in new Samsung WF338 washing machine and conventional electric dryer, including optional Spin Dryer supplemental drying

	Load weight in pounds and (remaining moisture content %)				
Load	Initial Dry	Wet (Medium Spin)	Wet (1300 RPM Spin)	Wet (3200 RPM Spin)	Bone Dry
DOE Test Load	7.18		9.65 (38%)	8.92 (27%)	7.00
Whites	11.29	17.00 (56%)			10.92
Mixed Medium	10.42		15.39 (52%)		10.13
Sheets	7.01		9.74 (43%)		6.82
Comforter	7.11	24.26 (236%)	10.24 (42%)		7.21
Mixed Large	16.93		23.78 (44%)	21.99 (33%)	16.50

In a set of “real world” tests conducted at one of the authors’ homes with a new, 4 cubic foot capacity, 1300 RPM Samsung washer, remaining moisture content was typically between 40% and 56% after the wash and spin cycle concluded, rather than 70 to 100% as DOE assumes (see Table 3). As even faster spin speeds become widely available, this discrepancy will grow even wider.

With lower water content, the dryer uses less energy, but not proportionately less. The energy used to evaporate water is reduced, but not the energy used to heat and move air, and the energy used to heat cloth and metal. DOE should conduct its dryer testing with a lower initial moisture content to better reflect the state of current washer technology.

Consider HVAC Effects

The current test procedure makes no distinction among dryers that significantly warm the room, those that leave its temperature largely unchanged, and those that cool the room. Similarly, the test procedure makes no distinction between dryers that vent their exhaust air outside (and require makeup air to be conditioned), and those that are unvented. Based on our research findings so far, including these effects could be almost as important as measuring the energy use of the dryer itself.

Consider Washer/Dryer Synergies More Fully

DOE should consider a testing and labeling program for washer/dryer combinations to reward manufacturers for achieving synergies and communication between the two devices. It would make sense to determine total energy use, cost, and CO_2 emissions for washing and drying a standard load of clothing rather than arbitrarily assigning eventual dryer energy use to washers at an assumed value of 500 Wh/pound of water left to be removed. The use of highly efficient clothes washers can greatly reduce the amount of work clothes dryers need to do (and the energy available to be saved through more efficient dryer technologies). The flip side of this is that dryers are less efficient when drying loads that have had most of the water spun out. The overhead energy required to heat cloth, metal, and plastic is not reduced when the moisture is reduced, but we can still save energy overall by doing more of the "drying" in the washer.

Many washer models today can weigh the dry clothing before determining how much wash and rinse water to put in. They should also then be able to weigh the wet clothing between spin cycles to determine how much water has been spun out and how much remains. That information can, in turn, be fed to the dryer to allow it to calculate how much dryer power and time should be needed to remove the remaining water from the clothes. Likewise, if the dryer measures the actual amount of water removed from the clothes and it knows how much water was in them to begin with, it can more intelligently determine when the drying process should stop. Given the comprehensiveness and complexity of DOE's current washing machine test procedure and energy use calculation process, it might actually simplify things if manufacturers were to report total energy used to wash and dry one load.[32]

Change the Efficiency Metric

The current energy factor efficiency metric is not intuitive and fails to really capture meaningful differences between electric and natural gas models and among the various loads dryers face. Energy factor measures pounds of standardized clothing saturated to a standardized extent that can be dried per electrical kWh or per "equivalent" kWh of natural gas consumed.

It would be preferable and more meaningful to measure the amount of *water* removed per unit of energy consumed, since that is the truest measure of the work actually being performed by the dryer. A dryer might need to remove 3 pounds of water from a typical load for one of two reasons, for example: either because it is a heavily saturated small load of absorbent fabrics like cotton, or a lightly saturated larger load of synthetics. Testing both situations and reporting the results would help consumers choose the most efficient dryers.

Similarly, it makes no sense to convert natural gas consumption into equivalent electrical consumption on a *site* basis, because that ignores all of the losses that occur in the electrical generation and transmission process at the *source* of that electricity. It has had the effect of shielding from consumer attention the substantial efficiency

[32] See http://www.energystar.gov/ia/products/appliances/clotheswash/modcwefcalc.pdf

advantage enjoyed by most gas dryers – that they convert their fuel directly into heat at the site where it is needed, avoiding upstream losses.

There are three ways to compare gas and electric dryers more fairly:

- Source BTU basis
- Total CO_2 emissions basis
- Energy cost basis

Examples of all three metrics are illustrated below. For the first metric, energy factor, higher numbers correspond to higher efficiencies. For all of the subsequent metrics, lower numbers correspond to higher efficiencies:

Table 4. Comparing Various Dryer Technologies with Different Efficiency Metrics and Test Procedures

Test Procedure / **Efficiency Metric**	DOE Test		Ecos Test		Ecos Estimates		
Dryer Technology	Standard electric	Standard gas	Standard electric	Efficient electric	Standard gas	Efficient gas[33]	Heat pump
Energy factor	3.12	2.79					
Site kWh-equivalent / pound of water removed	0.486	0.543	0.581	0.484	0.649	0.533	0.314
Pounds CO_2 emitted / pound of water removed	0.648	0.367	0.772	0.643	0.440	0.341	0.417
Source BTUs of natural gas / pound of water removed[34]	4867	2925	5823	4851	3507	2691	3144
Energy cost (cents) / pound of water removed	5.83	2.76	6.97	5.81	3.31	2.50	3.76

Note in Table 4 that the standard natural gas dryer uses less source energy, costs less, and emits less carbon dioxide per pound of water removed than any other option except (in some cases) a heat pump dryer. However it appears on an energy factor basis to be a worse option than a standard electric model. Analysis by the UK Market Transformation Programme has reached a similar conclusion: "In the UK, gas-heated tumble driers offer a simple and relatively cheap way to dry laundry with a carbon efficiency that matches the more expensive and highly efficient electrically powered heat pump driers."[35]

If the conventional natural gas dryer were further improved with modulating burner technology, we believe it would be roughly equivalent to or superior to many heat

[33] Assumes 29% electricity savings and 13% natural gas savings from modulating burner technology.
[34] Assumes the use of natural gas to generate electricity.
[35] See http://www.mtprog.com/spm/download/document/id/592.

pump dryers on a CO_2, source energy BTUs, and energy cost basis, while also offering faster drying times and a lower initial purchase price.

Conclusions

The belief that all clothes dryers are similarly energy efficient is fundamentally incorrect. Consumers can save about 5,000 kWh over the lifetime of their dryer by simply buying a slightly more efficient electric model than the one they might have purchased instead, if only they can be furnished the means to fairly and easily compare efficiencies.

The potential exists to save 25 to 30 billion kWh/year or more than $3 billion annually by undertaking a deliberate effort to more effectively test, label, and improve the energy efficiency of residential clothes dryers. These savings would be compelling to individual dryer purchasers as well, who have the potential to save 1 to 1.5 kWh per load. This is roughly $60 per year or nearly $1,000 over the lifetime of the dryer – roughly equivalent to the entire purchase price of the dryer.

With additional design changes to furnish an outside air source to clothes dryers and/or recover and reuse waste heat, these savings could be even greater. While a national effort to encourage the use of heat pump clothes dryers would be worthwhile, there is much that can be done in the interim to capture meaningful energy and carbon dioxide savings by encouraging greater use of efficient natural gas dryers, more effective moisture sensing, and less depressurization of houses. Given the urgent need to reduce energy use and greenhouse gas emissions, it is time for clothes dryers to participate in the effort. They have much to contribute.

Appendix A. Test Results

Test	Dryer	DOE cloths	Towels	Moisture	Cycle	Temp	Dryness	Duration	RMC	kWh	Efficiency	kWh bulk	EF	kWh high	Air cf
5	A	1.01		69.3%	Timed	High		20	0.0%	1.268	17.0%				2509
6	A	3.01		70.1%	Timed	High		25	-2.0%	1.772	37.7%				3803
5min	A	7.02		72.4%	Timed	High		40	-0.4%	2.840	55.4%	2.114547	3.257951	0.725	4850
7	A	14.02		71.4%	Timed	High		70	0.0%	4.549	67.3%				
8	A	7.02		41.7%	Timed	High		20	0.0%	1.648	54.3%				2402
9	A	7.00		70.1%	Normal	High	Damp Dry	30	2.0%	2.222	66.1%				
10	A	7.02		69.7%	Normal	High	Normal	35	0.3%	2.394	62.7%				
11	A	7.00		70.3%	Normal	High	Very Dry	40	-0.1%	2.800	54.3%				
12	A	7.02		70.2%	Normal	Medium	Damp Dry	23	11.7%	1.702	74.4%				
13	A	7.00		70.1%	Normal default	Medium	Normal	37	-0.1%	2.292	66.1%	1.583747	3.348893	0.303	4423
14	A	7.02		70.1%	Normal	Medium	Very Dry	41	0.3%	2.382	63.4%				
15	A	7.00		70.3%	Normal	Ultra Low	Damp Dry	34	7.9%	1.639	82.2%				
16	A	7.02		70.1%	Normal	Ultra Low	Normal	49	1.1%	2.088	71.4%				
17	A	7.00		70.5%	Normal	Ultra Low	Very Dry	58	0.3%	2.462	61.5%				
18	A	7.02		70.1%	Perm press	Low	Normal	59	0.3%	2.720	55.5%	2.064574	3.224137	0.655	7086
19	A		7.02	71.1%	Normal default	Medium	Normal	48	0.7%	2.623	58.0%				
20	A		7.02	106.0%	Normal default	Medium	Normal	55	1.9%	3.605	62.5%	3.479963	2.967789	0.125	6589
22	A	7.00		73.5%	Normal - air flow restricted	Medium	Normal	75	-0.1%	2.345	67.8%	1.99853			5238
23	A	7.00		73.5%	Air dry	Air Only		120	33.6%	0.517	166.9%				
23	A	2.02	5.1	72.5%	Normal default	Medium	Normal	37	5.2%	2.313	63.9%				
31	B	7.08		70.3%	Timed	High cotton			0.0%	2.897	53.0%	1.989836	3.387021	0.908	6815
33	B	2.05	5.08	101.4%	Normal	High cotton	More dry		-0.7%	3.957	56.7%				
34	B	2.05	5.08	101.3%	Normal	Low	Normal		0.6%	3.439	64.7%				
35	B		7.04	101.0%	Normal	High cotton	Normal	77	-1.1%	4.180	53.0%	3.432279	2.868394	0.743	8489
32	B	3.02		70.9%	Perm press	Medium	Normal	43	1.3%	1.798	36.0%	1.217932	2.379186	0.580	6057
26	C	6.99		71.0%	Timed	High denim		30	0.1%	2.447	62.3%	2.238593	3.000514	0.208	4857
28	C	2.02	5.06	100.1%	Denim	High denim	Extra dry	78	-0.1%	4.125	53.0%				
29	C	2.02	5.06	101.3%	Delicate	Low delicate	Damp	55	6.4%	3.209	64.5%				
27	C		7.04	102.5%	Regular	Regular	Dry	70	0.1%	4.011	55.4%	3.637355	2.750853	0.374	9071
30	C	3.07		71.0%	Perm press	Low	Dry	39	-1.3%	1.606	42.5%	1.289226	2.290025	0.317	4981
37	D	7.01		70.5%	Timed	No option		50	-0.4%	2.679	57.2%	1.588756	3.362069	0.690	6332
38	D	2.12	5.10	101.3%	Regular	Cotton	Extra dry	74	37.3%	2.081	68.4%				
40	D	2.12	5.10	101.9%	Regular	Cotton	Damp dry	38	26.6%	2.453	68.3%				
36	D		6.96	104.5%	Regular	Cotton	Regular dry	55	3.0%	3.417	63.7%	3.404676	2.961956	0.012	6931
39	D	3.03		70.3%	Perm press	No option	Regular dry	25	-0.7%	1.352	49.0%	1.107499	2.602648	0.245	3176

Appendix B. Assumptions and Details for Calculations

These are the assumptions we made to calculate the HVAC load created by the dryer.

Each building (before using the dryer) has a balance between air infiltration and air exfiltration. If the building is very tight (meaning very little infiltration and exfiltration), then the dryer will significantly depressurize the building and cause enough infiltration to balance its flow. Conversely, if the building is very leaky, then the dryer will create only a slight depressurization, but enough to increase the infiltration and decrease the exfiltration by enough to balance its flow. If the infiltration and exfiltration are balanced, a small pressure change will increase one and decrease the other by equal amounts. In this case, half the dryer's air flow will be met by increased infiltration and the other half by decreased exfiltration. So the increase in infiltration must be between half of the dryer's air flow and the full air flow. Even in newer residences, the airflow for the dryer is generally less than the air exchange rate, so we expect to be closer to the one-half value. We will assume that the infiltration increases by 60% of the dryer air flow.

We calculate the energy consumed for a range of outside temperatures. We assume the outside humidity to be 75%. The indoor temperature is assumed to be 70°F. For winter heating, we calculate the kWh of heat required to heat the air. With electric resistance heating, this translates directly to kWh consumed. With other heating fuels or heat pumps, the calculations are the same but the numbers will different. In the summer, we assume the indoor humidity is 50%, which corresponds to the evaporating coils of the air conditioner being at 50°F. We assume the air conditioner is electrically powered and has a coefficient-of-performance of 3.00 when viewed as a heat pump (meaning that for each kWh of electricity consumed, the air conditioner removes 2 kWh of heat from the building and dissipates 3 kWh of heat to the outside).