Are We Missing Energy Savings in Clothes Dryers?

Paul Bendt, Ecos

ABSTRACT

Dryers use a lot of energy: 66 billion kWh per year or 5.8% of all residential electricity consumption. Current models vary by 33% or more in the energy used to dry the same load of clothes. Yet there are no labeling, incentive, or promotional programs to direct consumers toward the most efficient models. The current DOE test procedure measures only part of the drying cycle and misses important differences. This has led to a false impression that all dryers are about equally efficient.

This paper describes dryer operation and testing undertaken by Ecos and explains the differences that have been observed. Emphasis is placed on simple and inexpensive changes that could reduce energy consumption by half. Dryers also place a large load on the home's HVAC system, and dramatic savings are possible here as well. Further results show that gas dryers have lower environmental impacts than electric dryers, often lower than even the hoped-for improvements of advanced technologies. We recommend changes to the test procedures and metrics so that energy efficiency can be recognized and rewarded.

These results will provide the basis for effective programs and policies that could save 50 billion kwh per year in energy spent drying clothes.

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. Approximately 84 million dryers in the US consume 66 billion kWh annually. 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" [Amann 2007, p. 178]. 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.

Our research has found that this perception is not true. There are substantial differences among currently available dryers. These differences have been missed because the Department of Energy (DOE) test method measures energy consumption for only part of the drying cycle. The greatest variation occurs during the part of the cycle that is not measured by the DOE test method. Improved testing followed by market transformation efforts could generate very substantial energy savings.

This paper summarizes research performed for Natural Resources Defense Council (NRDC) [Bendt 2009]. It is organized as follows: Section II describes the basic operation of typical clothes dryers, using our test results to illustrate several key points. Section III describes our testing and the results observed. Section IV presents an analysis of HVAC energy consumption that is caused by operating a dryer and some simple design strategies to reduce energy consumption. Section V presents recommendations for saving energy while drying clothes. This includes recommendations for consumers, manufacturers, efficiency advocates, and governmental policy.

Dryer Operation

The components and construction of dryers are described in numerous publications [Bendt 2009; ESOURCE 2001, p.139] and haven't changed much in 30 years. They operate by blowing heated air through a rotating drum containing the clothes. The motor turning the drum and fan of a typical, standard-sized dryer (>4.4 cubic feet) draws 200 to 300 watts. The heater draws about 5 kW of electrical power or 20,000 to 25,000 BTU/hr of gas. This heats 100 to 150 cfm of air to a temperature of 200°F to 300°F. The air cools to 90°F to 170°F as it evaporates water from the clothes and is then vented outdoors.

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

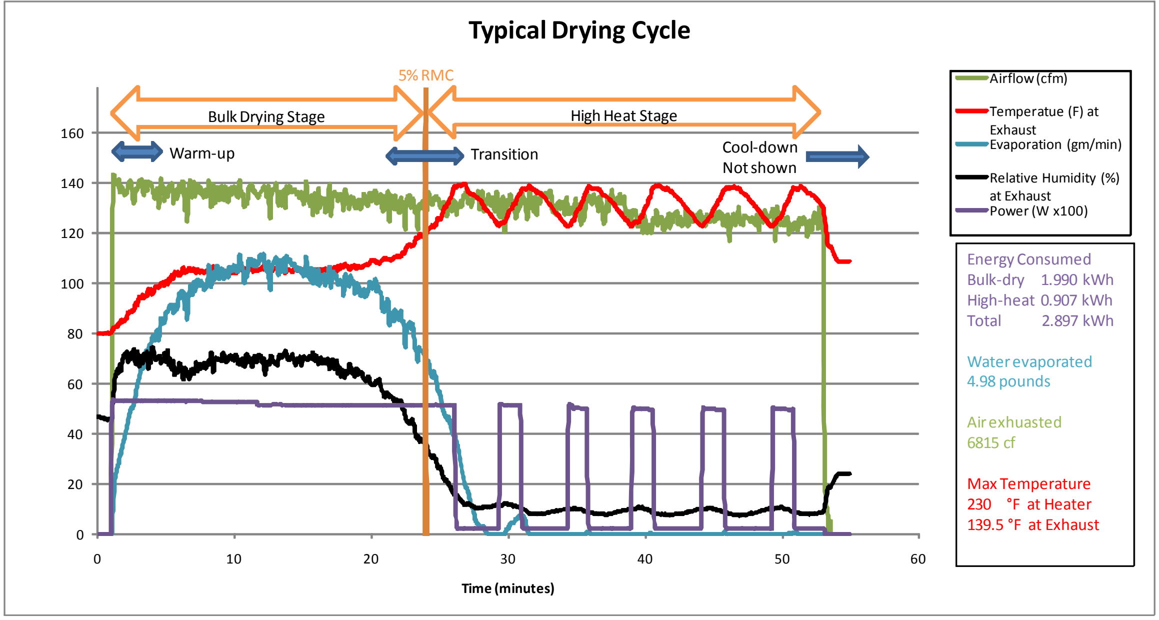
During the bulk drying stage, the exhaust air is usually 90 to 120°F and 60 to 80% relative humidity. These conditions are relatively constant for the bulk-drying stage, which lasts 15 to 40 minutes (depending on the amount of water in the clothes) as most of the water is evaporated. The heater may stay on continuously through the bulk drying stage or it may cycle on and off. 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. Almost all the heat energy is spent heating air, metal, and cloth. The high-heat stage is usually 5 to 30 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. There may also be a ***warm-up time*** at the beginning and a ***cool-down time*** at the end of the drying cycle.

These stages can be seen in Figure 1, 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.

Figure 1. Typical Drying Cycle



Dryer Energy Consumption

Energy is consumed by the following processes:

- 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
- Energy to rotate the drum and move the air.
- Energy to operate the controls. Of particular concern is the standby mode energy when the dryer is not in use.
- 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.
- Energy required for air conditioning to remove the waste heat that the dryer releases to the room.

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 0.308 kWh per pound of water (500 kcal/kg). 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 (gas and electric) are about 50 to 70% efficient. Note that, with this measure, efficiencies over 100% are thermodynamically possible.

Dryer Testing

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 and was last revised in 1992 [AHAM 1992]. The second is the DOE test method, which was an adaptation of the AHAM method [Department of Energy 1981]. Both methods require drying a carefully specified test load under controlled conditions. Both test methods require stopping the dryer when there is about a 5% residual moisture content remaining 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. Thus, energy consumption is measured only for the bulk-drying stage and not for the high-heat stage. (This stopping procedure has been used for more than 40 years and dates from a time before dryers had automatic termination controls.)

The DOE test method specifies a 7 pound load of 50/50 blend cloths with 4.9 pounds of water. It uses the bulk-drying energy consumption with this load to compute an “energy factor.” This is the number of pounds of cloth dried per kWh, corrected to represent removing water equal to 66% of the cloth weight. DOE requires a minimum energy factor of 2.67 for gas dryers and 3.01 for electric dryers. Test data on current dryers shows a range of 2.67 to 3.02 for gas dryers and 3.01 to 3.30 for standard sized electric dryers. (A very few electric dryers claim up to 3.70.) These values correspond to typical efficiencies of 56% to 63% for gas or 63% to 69% for electric (based on energy used in the bulk-drying stage only). Due to of the narrow range of variation between 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).

In an analysis to estimate the energy used for full drying cycles, Ecos conducted its own field testing of four different standard-sized 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 more than 20 years. The other three were also current models, but with electronic controls and moisture sensors. They claimed to be “energy saving” models, but offered no documentation to support the claims.

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 sampling was taken every 5 seconds. Also the ambient temperature and humidity were recorded

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 preconditioned according to the DOE test method. For each load, the bone-dry weight, wet weight, and final weight were recorded. The rate of evaporation of water from the clothes was calculated by multiplying the air flow by the difference between exhaust and ambient absolute humidity. This method was validated by 4 test runs in which the load was weighed every 5 minutes and the loss in water weight was compared to the calculated evaporation rate.

A total of 35 test runs were made. Each dryer 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

Measured efficiencies varied from 17% to 82%. The single most important factor affecting energy consumption and efficiency is the amount of moisture to be removed. The total amount of water depends on both the size of the load and its moisture content. Figure 2 shows energy consumption versus water removed for all the tests conducted. More energy is required to remove more water, but the effect is less than proportionate. This is due to the overhead energy required to heat metal, cloth, and air even when no water is being removed. The results show that energy can be saved by:

- Removing more water from the clothes before drying, for example, by increasing the spin speed of the washer.
- Drying full loads rather than a larger number of partial loads.
- Using a lower heat setting to reduce the energy spent heating air, cloth, and metal. The clothes get just as dry, though drying time may be longer.
- Using the “less dry” setting. (Most dryers have a “dryness” control independent of the temperature setting. The “less dry” setting usually gets clothes fully dry, while “normal” and “more dry” use more time and energy. The “damp dry” setting usually leaves noticeable moisture in the clothes.)

Interesting to note, tests with a clogged lint filter showed little difference in efficiency, though the drying time increased considerably.

The most useful test-runs for comparing dryers were: the DOE test load and settings, a default cotton cycle, and a default permanent press cycle. Although we ran the DOE test load through a full drying cycle, we computed an energy factor by using only energy consumed during the bulk-drying stage. The energy factors calculated in this way agree with, within 6%, reported results for each dryer model. The last two tests are considered the most representative of typical use and are discussed further.

For the two default cycles, all the dryers used about the same amount of energy in the bulk-drying stage (within 0.20 kWh). This was expected since the energy factors are similar. However, the energy used in the high heat stage varied considerably. With the cotton load, one dryer used only 0.01 kWh while another used 0.75 kWh. This represents a 22% difference in the total energy required to dry the load. The data logs show how the energy savings are achieved [Bendt 2009]. After reaching 5% RMC, the less efficient dryer continues for an additional 30 minutes of a high-heat stage, consuming power the entire time. At the same 5% RMC, the more efficient dryer stops applying heat and runs for only 5 additional minutes of cool-down time. This not only saves energy, it also gets the drying done 20 minutes faster. For the small load of blended fabric, the energy savings were even greater: 33%. These results are shown in Figure 3.

Figure2. Dryer Energy Consumption versus Water Removed

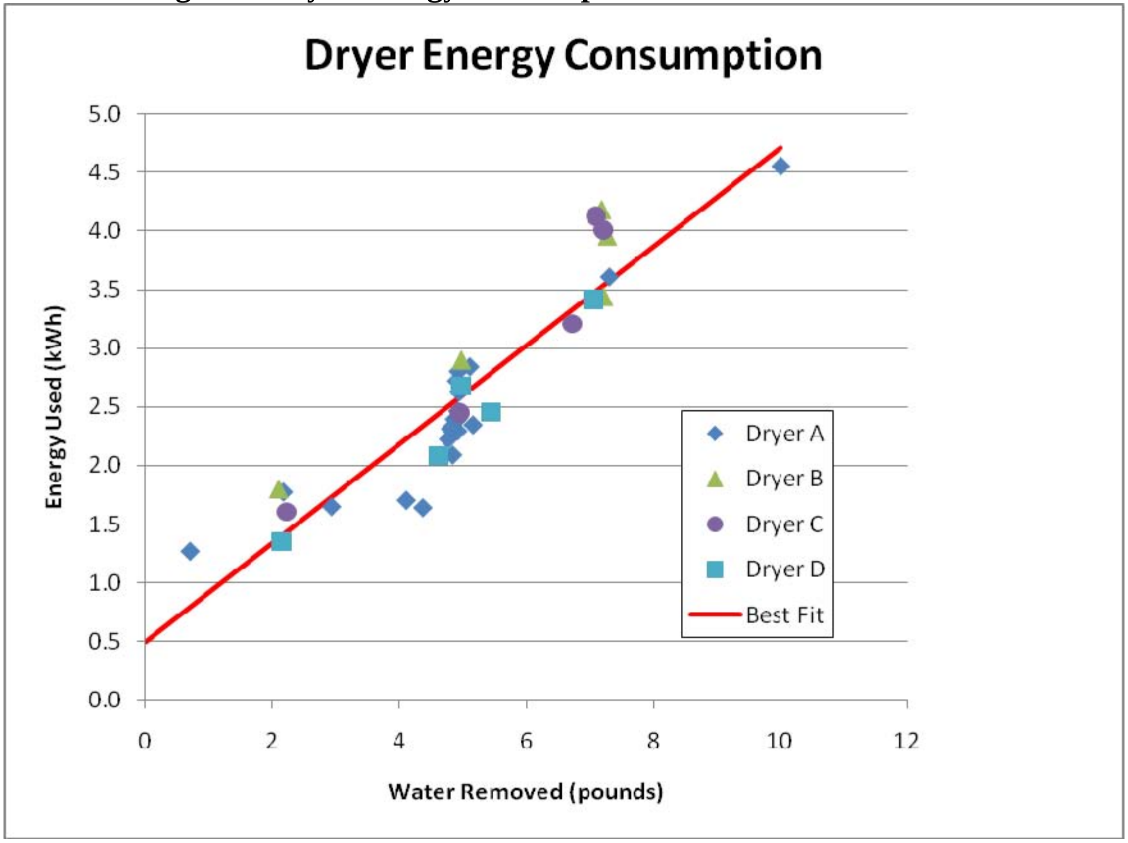
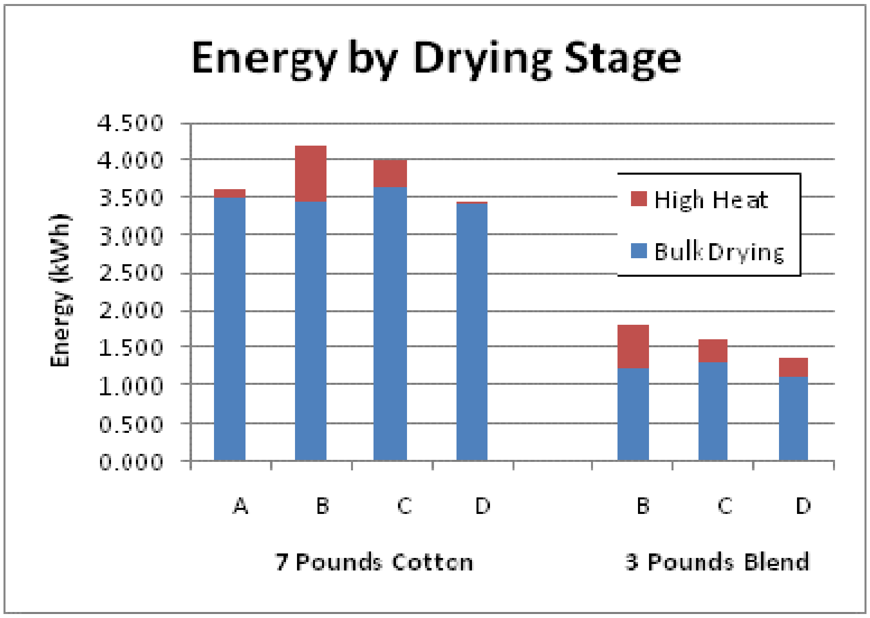


Figure3. Energy by Drying Stage (Dryer A was not tested with the 3-pound load)



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 the high-heat stage. **The difference in energy consumption is**

about 0.76 kWh per load or nearly 5,000 kWh over the typical 16-year useful life. This is a very significant saving in energy 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.

Standby power demand was essentially zero for the dryer with electromechanical controls. This was 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.

Modeling HVAC Energy Load and Design Options

There are three questions we wished to explore by calculations:

- What is the load that the dryer places on the building HVAC system, and are there significant differences between one dryer and another?
- How much energy can be saved by using a heat exchanger for heat recovery?
- 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 these very rough results can help illustrate where there may 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 calculated the first quantity only, as it is usually much larger for vented dryers. The assumptions made in the calculations and the full results are in the NRDC report. [Bendt 2009].

The various dryer cycles evacuate from 3000 to over 9000 cubic feet of air. When the outside temperature is near 70°F, no HVAC energy is needed to condition the replacement air. As the outside temperature gets either colder or warmer than 70°F, more HVAC energy is needed to warm or cool the replacement air. The heating energy can be as much as 3.2 kWh (electricity or fuel heat-equivalent) per load at -40°F and the cooling energy can be up to 3.6 kWh per load at +120°F. Since temperatures near 70°F are more common than either extreme, the average HVAC energy in the US is probably about 1 kWh per load.

Dryer D, our most efficient dryer, was also close to the lowest for volume of air exhausted. This is mostly a consequence of its very short high-heat stage, not a lower air flow rate. Compared to Dryer B, this resulted in HVAC savings of up to 1 kWh per load at extreme temperatures. Again considering that mid-range temperatures are most common, the average HVAC savings is probably about 0.3 kWh per load. Combined with the direct energy savings, Dryer D is better than Dryer B by more than 1 kWh per load.

Using Heat Recovery

Our next calculation was to estimate the energy that could be saved by using heat recovery. For these calculations, we considered Dryer D, already the most efficient dryer, to see how much more energy could be saved. We considered only the load of cotton towels. We assumed an air-to-air counter-flow heat exchanger with a 90% efficiency between the exhaust and intake airflows. We ignored the heat capacity of the exchanger and any additional fan energy that would be required. This is a best-case scenario, but is useful for an estimate of the energy opportunity. A heat exchanger will condense some of the moisture out of the exhaust air, so a small drain pump is also required.

Heat recovery is sometimes confused with ventless dryers. Ventless dryers, also called "condensing dryers," are common in Europe and are recently available in the US. Both heat recovery and ventless dryers use a heat exchanger and both condense moisture from the exhaust air. The difference between them is what happens to the warmed air from the secondary side of the heat exchanger. In a ventless dryer, the warm air is blown into the room to dissipate waste heat from the dryer. In a heat recovery dryer, the warm air is channeled into the heater as preheated air.

The average exhaust temperature for the default cotton cycle with dryer D 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 from 64% to 105% (though it does not change the load placed on the HVAC system).

A 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.

Using Outside Air

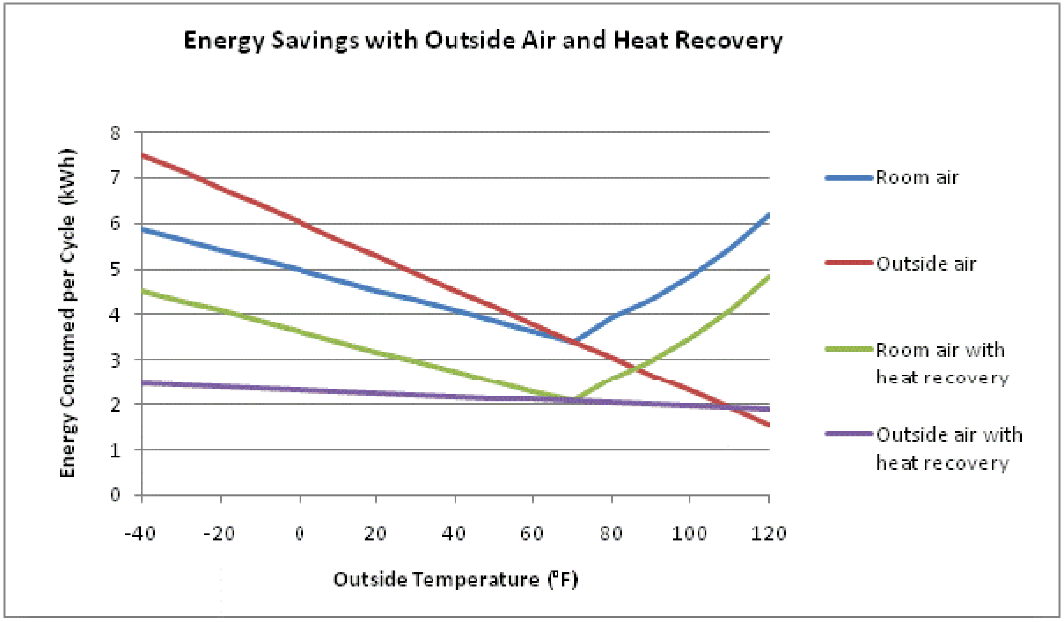
Our final calculation is the potential energy savings by using an outside air intake. This would avoid placing any load on the HVAC system, summer or winter. But in the winter, the dryer would need to heat colder air. Without heat recovery, there is no advantage to using outside air in the winter. Again, we assume dryer D is drying the load of towels. Figure 4 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 both outside air and heat recovery provides additional savings, about 1.35 kWh per load for heat recovery and another 1.0 kWh per load for outside air.

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 an increasing trend in residential new construction is towards 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 increases 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 heat is delivered to the building instead of being vented outside. By keeping the waste heat in the building, one can reduce the amount of heat required from the HVAC system.

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 energy savings.

Figure 4. HVAC Impacts on Dryer Energy Use



Analysis of Source Fuel

Gas dryers consume both gas (for heating the air) and electricity (for operating the drum, fan, controls, and igniter). The current DOE test method combines these quantities into a single reported energy consumption. The conversion factor DOE uses is based on heat-equivalence, 3412 BTU/kWh. Heat-equivalence fails to recognize the differences in thermodynamic potential, environmental impact, or cost between these fuel sources.

For example, let's compare a typical natural gas dryer and a hypothetical upgrade that uses a more efficient electric motor. The model with the more efficient motor will use less electricity, perhaps 0.1 kWh (per load). However, the waste heat from the motor effectively preheats the incoming air, so this modified model will burn slightly more gas to make up for less waste heat. A typical gas burner has a 90% combustion efficient, so the modified model requires 379 BTU of additional gas. Using the DOE conversion, this gas is counted as 0.111 kWh, so the modified dryer is reported as being *less* efficient by 0.011kWh.

For both the consumer and the environment though, the modified dryer is better. The current consumer costs of electricity and gas are about $0.12/kWh and $6/MMBTU. Thus the electricity saved is worth $.012 and the gas expended costs only $.0023 per load. Similarly for the environment, CO_2 releases in the US are about 1.33 #/kWh of electricity and .117#/MBTU of gas. The savings in electricity reduces CO_2 emissions per load by 0.133 # and the gas that replaces it releases only 0.044 #.

The current DOE testing, conversion and reporting procedure ranks these dryers in the wrong order. It gives the manufacturer an incentive to produce a dryer which has higher energy costs and greater environmental impacts. This can hardly be considered as promoting "efficiency." A better measure is needed for comparing dryers. In any practical sense, burning gas is a more efficient way to heat air than using electricity. This is important for comparing one gas dryer with another, and also for comparing gas dryers with electric dryers.

There are at least three ways to compare dryers more fairly:

- Source BTU basis,
- Total CO_2 emissions basis, and
- Energy cost basis.

Examples of all three metrics are illustrated below, along with the current energy factor and water removed per kWh heat equivalent. 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 1. Comparing Various Dryer Technologies with Different Efficiency Metrics and Test Procedures

Test Procedure / **Efficiency Metric**	DOE Test[1]		Ecos Test		Ecos Estimates		
Dryer Technology	Standard electric	Standard gas	Standard electric	Efficient electric	Standard gas	Efficient gas[2]	Heat pump
Energy factor	3.12	2.79					
Site kWh heat-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[3]	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

Table Notes: [1] The DOE test method assumes that total energy use is 4% greater than the bulk-dry stage energy use. Our tests show that it actually varies from 0.3% to over 30%.
[2] Assumes 29% electricity savings and 13% natural gas savings from modulating burner technology.
[3] Assumes the use of natural gas to generate electricity.

Note that in the Ecos estimates in Table 1, the standard natural gas dryer uses less source energy, costs less, and emits less carbon dioxide per pound of water removed than an efficient electric model. It is roughly comparable to the performance of prototype heat pump units. However it appears, on an energy factor basis, to be a worse option than even 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” [Market Transformation Programme, 2007].

If the conventional natural gas dryer was further improved with modulating burner technology, it is expected it would be superior to a heat pump dryer on a CO_2, source energy BTUs, and energy cost basis, while also offering faster drying times and a lower purchase price.

Recommendations

Advice to Consumers

Consumers can dry clothes with less energy by using (in order of energy savings):

1. Outdoor clothes lines get clothes dry using no energy and with no HVAC impacts.
2. Indoor drying racks use no direct energy but do have an HVAC impact. The total energy impact is lower than any currently available dryer.
3. A natural gas dryer is cheaper to operate and has lower environmental impacts than an electric dryer.
4. High washer spin speeds are more efficient than evaporating the water in the dryer.
5. Drying full loads is more efficient than a larger number of partial loads.
6. A "low heat" setting is more efficient than higher heat settings.
7. A "less dry" setting is more efficient than "normal" or "more dry."

Improving Dryer Design to Save Energy

This paper has analyzed three design strategies which result in significant energy savings:

- Improved sensors and controls to terminate the cycle and prevent over-drying.
- Using heat recovery to preheat the incoming air.
- Using outside air instead of room air for the intake.

Several other design strategies may also provide efficiency improvements. These ideas are not new. We expect them to be more costly or less effective than the strategies above, but they may still make important contributions to efficiency.

- Using a heat pump on electric dryers to increase the heat delivered per kWh of electricity.
- Using more efficient motors for rotating the drum and for the blower.
- Reducing leakage in the air transport system and keeping it insulated so nearly all of the heat makes it to the drum.
- Using an adjustable (modulating) heat source instead of on/off cycling 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.
- Using effective power management to reduce or eliminate power consumption during standby.
- Using sensors to monitor for resistance to the air flow, such as a clogged lint screen.
- Using microwave heating to transfer heat to the water more effectively.
- In dry climates, using air dry only (no heat) in a conventional dryer

Possible energy conservation measures include:

- Using heat recovery to provide heat for another use, such as space heating or hot water preheating.

Improving the Current Testing and Regulatory Approach

Dryers appear to use similar amounts of energy because the current test procedure is not 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. 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.

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 the dryers to run until they stop themselves.

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, *Consumer Reports* found that 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 [ESOURCE 2001, p. 143]. Voluntary programs, such as Energy Star or utilities incentives, could use prompt detection and halting as a program requirement.

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 dryer with the clothes in it) 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 there are now more models on the market in the range of 7 to 8 cubic feet than models smaller than 7 cubic feet. It is 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 that dryers face when drying fabrics that can ball up if 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 appropriately sized dryer and to fill it with the recommended amount of clothing to dry as efficiently as possible.

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 HVAC 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 or communication between the two appliances. 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). 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 [Department of Energy 2007].

Change the efficiency metric. For gas dryers, report separately the consumption of gas and electricity. This makes it possible for both consumers and market researchers to make valid comparisons between models. If these must be combined into total energy consumption for a standard, use a conversion that is more relevant than heat-equivalent. We would recommend conversion based on CO_2-equivalence, which is 11380 BTU (gas) = 1 kWh (electricity).

Market Transformation Programs

Market transformation programs, such as utilities incentives, Energy Star, or Top Ten, can use testing and comparisons that are different from the DOE test method. We recommend that programs evaluate dryers using the criteria described in this paper and recognize dryers that do have the lowest environmental impacts.

Dryers with heat recovery and outside air intakes are not currently available. Incentives programs could change this. If, for example, reasonable rebates were offered for dryers with these features, then probably at least one manufacture would introduce a few qualifying models. These models could be appropriately recognized and would quickly become the state of the art.

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, the total savings could be even greater, 50 to 60 billion kWh/year. 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.

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