Energy Test Results of a Conventional Clothes Dryer and a Condenser Clothes Dryer

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A conventional clothes dryer and a condenser clothes dryer were tested for their energy performance following the U.S. Department of Energy (DOE) test procedure. The energy required to dry one kilogram (or pound) of moisture and the resulting energy factors were presented. The effect of test room humidity on the energy consumption of the conventional clothes dryer was found to be 0.79% per 10% relative humidity change. Test results indicated that the condenser dryer did not satisfy the requirement of the current DOE energy factor standard. However, when a higher test load than the DOE prescribed test load was used, the dryer exceeded the required standard. Additional tests conducted on the conventional dryer with variable test loads also confirmed the sensitivity of the test load on the energy factor. The study suggests that relating variable test loads directly to the dryer drum volume might alleviate this conflict.

INTRODUCTION

National Institute of Standards and Technology (NIST) tested a conventional clothes dryer and a condenser clothes dryer in 1996 and in the early part of 1997 to obtain energy performance data. The tests were conducted following the Department of Energy (DOE) test procedure as specified in appendix D of subpart B of the DOE appliances regulations Part 430 (DOE 1981).

The DOE test procedure divides clothes dryers into two groups in accordance with their clothes container volumes. "Compact size" dryers have container capacities less than 125 L (4.4 ft^3) and are required to be tested with 1.36 kg (3 lb) of test loads. "Standard size" dryers have container capacities of 125 L (4.4 ft^3) and greater, and are required to use 3.18 kg (7 lb) test loads. For electric clothes dryers, appendix D requires that the moisture content of the test cloths be dried from between 66.5% to 73.5% of the bone-dry weight of the test load to between 2.5% to 5% of the bone-dry weight. The

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recorded electric energy consumption is then normalized to that equivalent to the removal of moisture equal to 66% of the bone-dry weight of the test load. The normalized energy is then multiplied by a field use factor, FU, to obtain the total per-cycle energy consumption of the dryer. The field use factor accounts for the control method used by the dryer. For clothes dryers having time termination controls, the field use factor is 1.18. For clothes dryers equipped with automatic control systems (sensing temperature and/or moisture content), the field use factor is 1.04. This total per-cycle energy consumption is used in DOE regulations to calculate the energy factor. Energy factor is defined as the quotient of the weight of the standard bone-dry test load (3 or 7 pounds) divided by the total per-cycle energy consumption. The current DOE regulation requires that, for clothes dryers manufactured after May 14, 1994, the energy factor be no less than 1.37 kg/kWh (3.01 lb/kWh) and 1.42 kg/kWh (3.13 lb/kWh) for the "standard" size and "compact" size dryers, respectively. Since the termination control methods are independent of the dryer thermal efficiency, the energy calculations and discussions in this report focus on data before (without) applying the field use factors. However, energy factors are presented in most cases with and without field use factors, so that comparisons with DOE energy requirements may be made.

In this investigation, tests were conducted in two phases. In the first phase, a conventional clothes dryer was tested with test loads as required in the DOE test procedure and a condenser dryer was tested with both 3.18 kg (7 lb) and 1.36 kg (3 lb) test loads. The reason for using two levels of test loads for the condenser dryer will be discussed later. In the second phase, only the conventional dryer was tested with a range of test loads.

TEST DRYERS AND TEST CONDITIONS

The conventional clothes dryer is a domestically made machine with a clothes container capacity of 178 L (6.3 ft^3), thus, by DOE's definition, it is a standard dryer. The container rotates at a constant speed in one direction only. The dryer requires 120/240 volt electric supply. Clothes drying can be terminated by setting either the timer or temperature sensing control.

The condenser clothes dryer is a European made machine with a container capacity of 100 L (3.54 ft^3); thus, by definition it is a compact dryer. It rotates in two directions alternately in the first few minutes and then, continues in a single direction. The unit draws room air to cool the moist drying air and condenses the moisture that is removed from the load. The condensate is drained and discarded. The "dehumidified" drying air is heated and recirculated to dry the load again and the warm condenser air is discharged back to the room. The design purpose of the condenser dryer is not for improving energy efficiency. Rather, it is used to simplify installation requirements, such

as in an apartment building, so that exhaust ducts to outside of building is not needed. The electric voltage requirement shown on the dryer name plate is 120/240 V or 120/208 V. The maximum drying capacity is labeled as 5 kg (11 lb). The dryer can be terminated by either the timer or automatic termination control. However, the timer control is very limited in selections and can be set only for a 15 min cold air or a 20 min warm air drying.

The temperature of the test room was maintained within the DOE test procedure requirement of 23.9 $\pm$ 1.7 °C (75 $\pm$ 3 °F). The test room humidity varied between 20% and 55% relative humidity (rh) depending on the climate conditions at the time of testing. During the first series of the conventional dryer tests, the average room humidity was 54% rh. The average room humidity for the second series of tests for this dryer was 20% rh. The DOE test procedure calls for a 50% $\pm$10% rh in the test room.

Since the condenser dryer is classified as compact size, the test load should be 1.36 kg (3 lb) as required in the DOE test procedure. However, the maximum drying capacity of this dryer is labeled as 5 kg (11 lb) by the manufacturer which is much higher than the DOE requirement. The decision was made to test this dryer with both 1.36 kg (3 lb) and 3.18 kg (7 lb) test loads in order to explore the effect of load size on energy consumption. The average room humidities during the condenser dryer testing were 35% and 43% rh for the two test loads, respectively.

Both units were provided with 120/240 volts electricity during tests. The discharge duct of the conventional dryer was provide with an AHAM specified exhaust simulator (AHAM 1986).

Since the test results of the condenser dryer showed substantial differences on the energy effects from the two test loads, the second phase of tests concentrated on the effect of load on energy performances. During this phase, the conventional dryer was tested with variable test loads ranging from 0.91 kg (2 lb) to 6.8 kg (15 lb). The average room humidity of the test room was 38% for these tests.

TEST RESULTS AND DISCUSSION

Phase I Tests (1.36 kg (3 lb) and 3.18 kg (7 lb) Test Loads)

a. Conventional Dryer

Table 1 summarizes the test results of the two series of tests for the conventional clothes dryer. All tests were conducted with 3.18 kg (7 lb) of test loads. The average

Series 1						
Test No.	1	2	3	4	5	Average
Room temp., C	22.3	22.8	22.8	23.3	22.2	22.7
Room temp., F	72.2	73.0	73.0	74.0	72.0	72.8
Room humidity, %	56	54	54	54	52	54
Measu. bone-dry wt, kg	3.165	3.165	3.165	3.165	3.165	
Measured dry wt, kg	3.255	3.250	3.250	3.250	3.255	
Measured wet wt, kg	5.270	5.290	5.290	5.270	5.270	
Measured kWh	2.032	2.079	2.070	2.034	2.045	
Moist. content, wet, %	66.51	67.14	67.14	66.51	66.51	
Moist. content, dry, %	2.84	2.69	2.69	2.69	2.84	
Per-cycle energy, kWh	2.107	2.129	2.120	2.103	2.120	2.116
kWh/kg moist. removed	1.008	1.019	1.015	1.007	1.015	1.013
kWh/# moist. removed	0.457	0.462	0.460	0.457	0.460	0.459
Energy factor, kg/kWh	1.50	1.49	1.49	1.50	1.49	1.50
Energy factor, lb/kWh	3.31	3.28	3.29	3.32	3.29	3.30
Series 2						
Test No.	1	2	3	4		Average
Room temp., C	22.5	22.5	22.5	22.5		22.5
Room temp., F	72.5	72.5	72.5	72.5		72.5
Room humidity, %	20	20	20	20		20
Measu. bone-dry wt, kg	3.170	3.170	3.170	3.170		
Measured dry wt, kg	3.275	3.240	3.270	3.275		
Measured wet wt, kg	5.300	5.305	5.310	5.315		
Measured kWh	2.027	2.082	2.042	2.016		
Moist. content, wet, %	67.19	67.35	67.51	67.67		
Moist. content, dry, %	3.31	2.21	3.15	3.31		
Per-cycle energy, kWh	2.094	2.109	2.094	2.068		2.091
kWh/kg moist. removed	1.001	1.008	1.001	0.988		1.000
kWh/# moist. removed	0.454	0.457	0.454	0.448		0.453
Energy factor, kg/kWh	1.51	1.50	1.51	1.53		1.52
Energy factor, lb/kWh	3.34	3.31	3.34	3.38		3.34

Table 1 Conventional Clothes Dryer Test Results

room temperature and humidity for the first series of tests were 22.7 °C (72.8 °F) and 54% rh, respectively. Without applying the usage factor, the average per-cycle energy consumption, the energy required to dry one kilogram of moisture, and the energy factor were (2.116 ±0.010) kWh, (1.013 ±0.004) kWh/kg [(0.459 ±0.002) kWh/lb] of moisture removed, and (1.50 ±0.01) kg/kWh [(3.30 ±0.02) lb/kWh], respectively. Uncertainties expressed in this study are estimated at the 90% confidence level. If the field use factors are applied, the mean energy factors for time termination control (FU=1.18) and for automatic termination control (FU=1.04) are 1.27 kg/kWh (2.80 lb/kWh) and 1.44 kg/kWh (3.17 lb/kWh), respectively. Note again that all the per-cycle energy consumption and energy factors shown, unless stated otherwise, are those without applying field use factors.

The room temperature and humidity for the second series of tests were 22.5 °C (72.5 °F) and 20% rh, respectively. The average per-cycle energy consumption, the energy required to dry one kilogram of moisture, and the energy factor were (2.091 ±0.020) kWh, (1.000 ±0.010) kWh/kg [(0.453 ±0.004) kWh/lb] of moisture removed, and (1.52 ±0.01) kg/kWh [(3.34 ±0.03) lb/kWh], respectively. With field use factors of 1.18 for time termination control and 1.04 for automatic termination control, the mean energy factors were 1.28 kg/kWh (2.83 lb/kWh) and 1.46 kg/kWh (3.21 lb/kWh), respectively.

Comparing the energy consumption of the two series of tests based on uncertainties given above (at 90% confidence level), at the average room condition of 22.5 °C (72.5 °F) and 20% rh, the energy required to dry a kilogram of test load would range between 2.6% less than or equal to that at the average room condition of 22.7 °C (72.8 °F) and 54% rh. Since the average room temperature difference between these two series of tests was small (0.2 °C (0.3 °F) and the fact that at these room conditions, the effect on air enthalpy from a 10% change in relative humidity is much stronger than that of a 0.6 °C (1 °F) temperature change, the entire energy consumption difference may be attributable to the difference in humidities of the two series of tests. Therefore, for the tests, the estimated maximum effect of room humidity on the per-kilogram (or pound)-load energy consumption was found to be (2.7%/(54-20)x10 =) 0.79% per 10% rh difference. If more precise accounts of the effects of room temperature and humidity on the drying energy consumption is desired, a more vigorous statistically oriented test method, such as factorial design for multiple variable tests, could be used.

The temperature and humidity conditions at the dryer discharge (not at the exhaust simulator discharge) were recorded for two drying cycles at two room temperature and humidity conditions. Figure 1 compares these recorded results. The temperature and humidity plotted are 30-second and one-minute averaged recorded values, respectively (to smooth out erratic readings as recorded at ten second intervals; humidity data being more erratic than temperature data). The enthalpy values plotted are calculated values.

These curves indicate that the cycle with a higher enthalpy entering air also has a higher enthalpy leaving air that reflects the adiabatic drying process of heated air at different temperature and humidity levels.

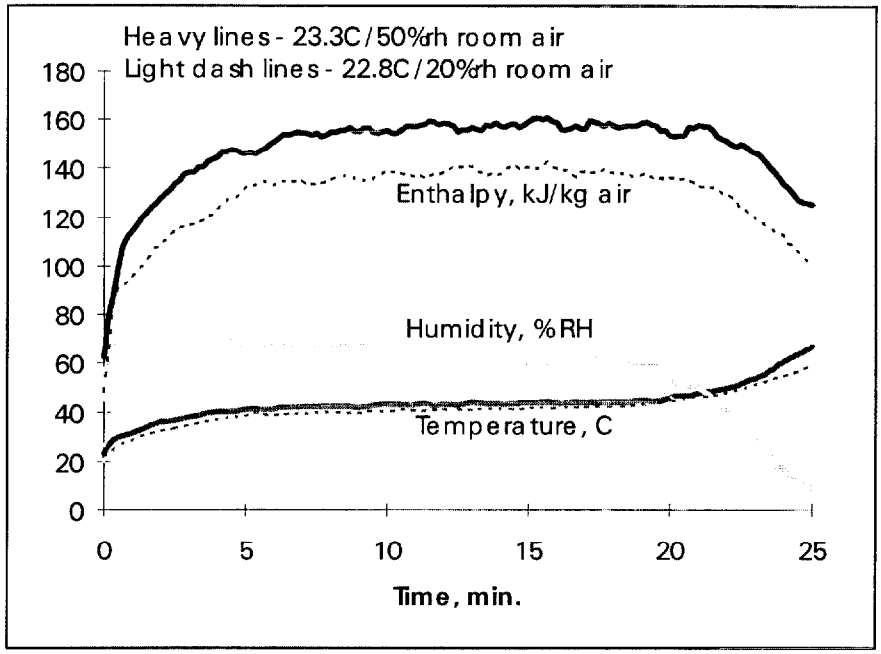

Figure 1 Temperature, Humidity, and Enthalpy of Discharge Air

b. Condenser Dryer

As stated previously, the condenser dryer was tested for both 1.36 kg (3 lb) and 3.18 kg (7 lb) test loads, since the labeled drying capacity of 5 kg (11 lb) of this dryer is 3.7 times the DOE specified test load for the clothes container capacity of this dryer. Although it is generally known that higher test loads usually can produce better drying performance, the substantial difference between the labeled capacity and the required test load of the DOE test procedure was the reason that NIST also tested this dryer with the test load of a standard size dryer. Test results are shown in table 2. With 1.36 kg (3 lb) test loads and at an average room condition of 23.6 °C (74.5 °F) and 43% rh, the average per-cycle energy consumption, the energy spent to remove one kilogram of moisture, and the energy factor without FU were (1.157 ±0.008) kWh, (1.288 ±0.009) kWh/kg [(0.584 ±0.004) kWh/lb] of moisture removed, and (1.18 ±0.01) kg/kWh [(2.59 ±0.02) lb/kWh], respectively. With FU, the mean energy factor was 1.13 kg/kWh (2.49 lb/kWh) for automatic termination control. For 3.18 kg/kWh (7 lb) test loads and at an average room condition of 23.0 °C (73.4 °F) and 35% rh, the average per-cycle energy consumption, the energy spent to remove one kilogram of moisture, and the energy

factor without FU were (2.205 ±0.009) kWh, (1.054 ±0.004) kWh/kg [(0.478 ±0.002) kWh/lb] of moisture removed, and (1.44 ±0.01) kg/kWh [(3.17 ±0.01) lb/kWh], respectively. With FU, the mean energy factor was 1.38 kg/kWh (3.05 lb/kWh) for automatic termination control.

1.36 kg (3 lb) Nominal Test Loads						
Test No.	1	2	3	4	5	Average
Room temp., C	23.1	23.4	23.8	24.1	23.8	23.6
Room temp., F	73.5	74.1	74.8	75.4	74.8	74.5
Room humidity, %	42	42	40	49	44	43
Measu. bone-dry wt, kg	1.361	1.361	1.361	1.361	1.361	
Measured dry wt, kg	1.405	1.395	1.400	1.395	1.405	
Measured wet wt, kg	2.355	2.305	2.340	2.330	2.275	
Measured kWh	1.210	1.179	1.218	1.203	1.121	
Moist. content, wet, %	73.03	69.36	71.93	71.20	67.16	
Moist. content, dry, %	3.23	2.50	2.87	2.50	3.23	
Per-cycle energy, kWh	1.144	1.164	1.164	1.156	1.157	1.157
kWh/kg moist. removed	1.274	1.296	1.296	1.287	1.289	1.288
kWh/# moist. removed	0.578	0.588	0.588	0.584	0.584	0.584
Energy factor, kg/kWh	1.19	1.17	1.17	1.18	1.18	1.18
Energy factor, lb/kWh	2.62	2.58	2.58	2.60	2.59	2.59
3.18 kg (7 lb) Nominal Test Loads						
Test No.	1	2	3	4	5	Average
Room temp., C	23.3	23.1	22.4	23.1	23.0	23.0
Room temp., F	74.0	73.5	72.3	73.6	73.4	73.4
Room humidity, %	35	34	35	35	38	35
Measu. bone-dry wt, kg	3.170	3.170	3.170	3.170	3.170	
Measured dry wt, kg	3.270	3.305	3.280	3.305	3.300	
Measured wet wt, kg	5.280	5.290	5.275	5.300	5.310	
Measured kWh	2.117	2.102	2.110	2.098	2.105	
Moist. content, wet, %	66.56	66.88	66.40	67.19	67.51	
Moist. content, dry, %	3.15	4.26	3.47	4.26	4.10	
Per-cycle energy, kWh	2.204	2.216	2.213	2.200	2.191	2.205
kWh/kg moist. removed	1.053	1.059	1.058	1.052	1.047	1.054
kWh/# moist. removed	0.478	0.480	0.480	0.477	0.475	0.478
Energy factor[1], kg/kWh	1.44	1.43	1.43	1.44	1.45	1.44
Energy factor, lb/kWh	3.17	3.15	3.16	3.18	3.19	3.17

Table 2 Condenser Clothes Dryer Test Results

[1]Technically, the energy factor for a compact dryer is defined in the DOE regulations for only a 1.36 kg (3 lb) test load.

Based on uncertainties as shown at 90% confidence level, the energy required to dry one kilogram of test load decrease in a range of 19.0% (maximum) to 17.3% (minimum) when the test load was changed from 1.36 kg (3 lb) to 3.18 kg (7 lb) while the energy factor increased in approximately similar magnitudes. With the 1.36 kg (3 lb) test load the dryer is far from meeting DOE minimum performance requirement [mean energy factors of 1.13 kg/kWh (2.49 lb/kWh) vs DOE's 1.42 kg/kWh (3.13 lb/kWh)] while with the 7 lb tests it would meet the standard [mean energy factor of 1.38 kg/kWh (3.05 lb/kWh) vs DOE's 1.37 kg/kWh (3.01 lb/kWh)], assuming automatic termination controls. These test results lead to a further study of the effect of test loads on dryer energy consumption (see phase II tests below).

The difference between the conventional and condenser dryers in this study is not only in the drying processes (i.e., noncondensing and condensing), but also in construction (e.g. clothes container size, direction of container rotation, etc.). Therefore, it would be difficult to draw conclusions comparing test results. However, the test results can give some "feeling" on these two types of dryers while keep the construction differences in mind. At 3.18 kg (7 lb) of test load, the energy needed to remove one kilogram of moisture for the condenser dryer [at 23.0 °C (73.4 °F) and 35% rh] was 104.0% of that of the conventional dryer [at 22.7 °C (72.8 °F) and 54% rh]. The mean energy factor (without FU) for the condenser dryer decreased to 96.0% of that of the conventional dryer. The reason that the condenser dryer used more energy than the conventional dryer can only be speculated, as this study did not investigate the efficiencies of the two types of drying processes. One reason might be that the savings of recirculating the warm drying air in the condenser dryer was overcompensated by the inefficiency of heat transfer process between the drying air and the condenser air through the condenser.

Phase II Tests - A Range of Test Loads

Since the energy factors of the condenser dryer, between the two test loads of 1.36 kg (3 lb) and 3.18 kg (7 lb), gave varied conclusions as to the dryer's ability to meet the DOE energy requirements and since the DOE test procedure for clothes washers is in the process of adopting variable test loads in the future, it would be useful to examine the effect of test loads on the energy consuming characteristics of clothes dryers. Therefore, a second phase of this study was performed on the conventional dryer with a range of test loads.

Test No.	1	2	3	4	5	6	7	8
Room temp., C	23.4	23.6	23.2	22.9	23.2	23.4	23.6	23.6
Room temp., F	74.1	74.4	73.8	73.3	73.8	74.1	74.4	74.4
Room humidity, %	40	38	38	33	42	38	40	36
Nom. bone-dry wt, lb	2	3	5	7	9	11	13	15
Measu. bone-dry wt, kg	0.904	1.356	2.261	3.174	4.078	4.982	5.902	6.807
Measured dry wt, kg	0.930	1.390	2.345	3.265	4.130	5.245	6.155	7.125
Measured wet wt, kg	1.540	2.315	3.855	5.395	6.960	8.610	9.995	11.595
Measured kWh	0.953	1.159	1.593	2.112	2.667	3.250	3.796	4.384
Moist. content, wet, %	70.30	70.67	70.52	69.99	70.67	72.81	69.35	70.34
Moist. content, dry, %	2.84	2.48	3.73	2.88	1.28	5.27	4.29	4.67
Per-cycle energy, kWh	0.932	1.122	1.574	2.077	2.537	3.176	3.851	4.406
kWh/kg moist removed	1.562	1.253	1.055	0.992	0.942	0.966	0.989	0.981
kWh/# moist removed	0.708	0.568	0.478	0.450	0.427	0.438	0.448	0.445
Energy Factor, kg/kWh	0.97	1.21	1.44	1.53	1.61	1.57	1.53	1.54
Energy Factor, lb/kWh	2.14	2.67	3.17	3.37	3.54	3.46	3.38	3.41
EF / FU (1.04), kg/kWh	0.93	1.16	1.38	1.47	1.55	1.51	1.47	1.49
EF / FU (1.04), lb/kWh	2.06	2.56	3.05	3.24	3.41	3.33	3.25	3.27

Table 3 Conventional Clothes Dryer Variable Test Load Test Results[2]

Table 3 shows the test results of the second phase tests. All of the second phase tests were conducted following the DOE test procedure with the only exception of the test loads. Test loads varied from 0.91 kg (2 lb) to 6.8 kg (15 lb) at 0.91 kg (2 lb) intervals between 1.36 kg (3 lb) and 6.8 kg (15 lb).

Figure 2 plots the energy needed to dry one kilogram of moisture and the energy factors for the various test loads for the conventional dryer, as well as the two energy factors obtained in phase I for the condenser dryer. The energy factors for both dryers assume automatic termination controls. The current DOE standards for the standard and the compact clothes dryers are shown in dotted lines on the same figure for reference.

[2]Technically, the energy factor for a standard dryer is defined in the DOE regulations only for a 3.18 kg (7 lb) test load.

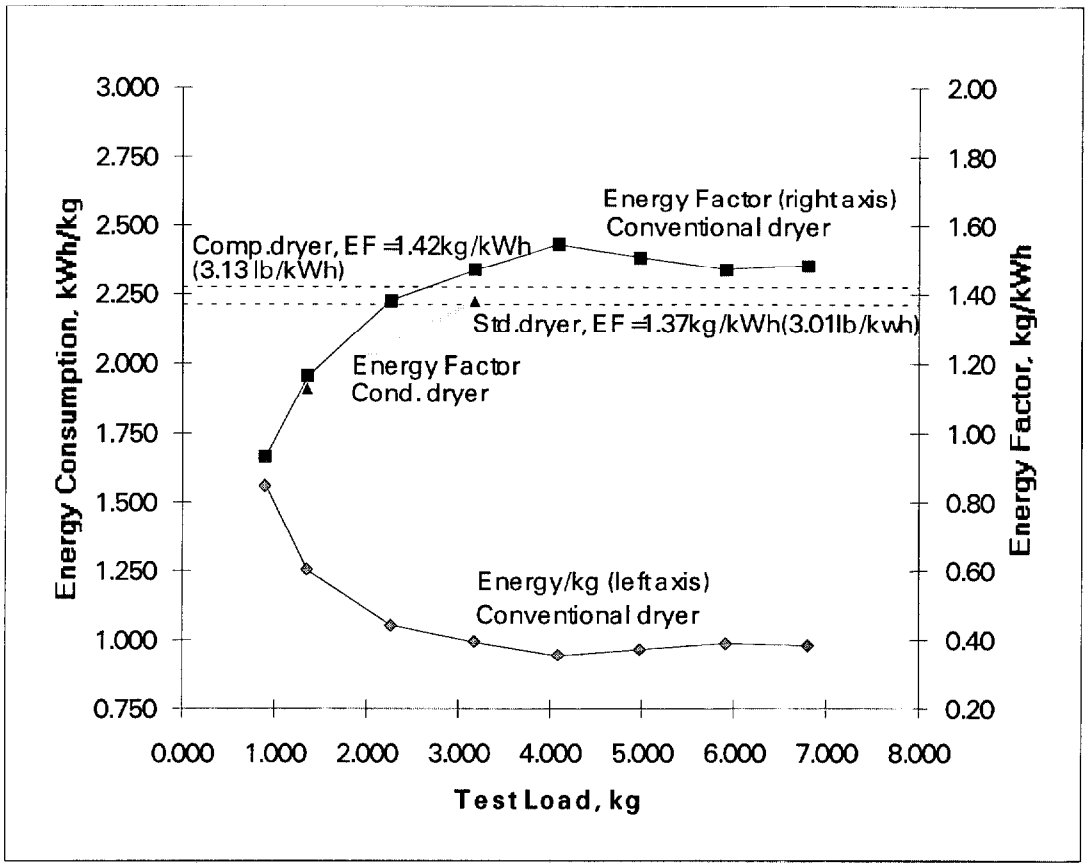

Figure 2 Energy Factor and Energy Consumption for Variable Loads

For the conventional dryer, table 3 and figure 2 indicate that the energy needed to evaporate the moisture of the test loads increased rapidly from 0.91 kg (2 lb) of test load to approximately 4.08 kg (9 lb) and decreased slightly thereafter for the conventional dryer. This reflects the clothes dryer efficiencies at various drying loads (for the same dryer). Each clothes dryer may have a different curve depending on its construction and operating conditions (e.g., the clothes container size, air flow rate, heater size, etc.). The energy factor has a similar curve except that the direction is opposite to that of the energy consumption per kilogram of moisture. From figure 2 it can be seen that this conventional clothes dryer can satisfy the DOE minimum standard at any test load just below 2.26 kg (5 lb) and have the highest energy factor when the test load is approximately 4.08 kg (9 lb).

SUMMARY

1. The energy required to dry one kilogram of moisture and the energy factor for the standard sized conventional dryer using 3.18 kg (7 lb) test load were (1.013 $\pm$0.004)

kWh/kg [(0.459 ±0.002) kWh/lb] and (1.50 ±0.01) kg/kWh [(3.30 ±0.02) lb/kWh], respectively, without applying the field use factor.

2. The energy required to dry one kilogram of moisture and the energy factor for the compact sized condenser dryer using 1.36 kg (3 lb) test load were (1.288 ±0.009) kWh/kg [(0.584 ±0.004) kWh/lb] and (1.18 ±0.01) kg/kWh [(2.59 ±0.02) lb/kWh], respectively, without applying the field use factor.

3. The maximum effect of room humidity to clothes dryer energy consumption was found to be 0.79% per 10% rh based on uncertainty calculated at 90% confidence level.

4. A 3.18 kg (7 lb) test load decreased the energy consumption of the condenser dryer 17.3% to 19.0% from that of a 1.36 kg (3 lb) test load. When the field use factor for automatic termination control was applied, the energy factor of the higher test load exceeded the DOE minimum standard while that of the lower test load was substantially lower than the standard.

5. Tests performed on the conventional dryer with a range of test loads indicated that the dryer energy consumption and energy factor (based on test load weight) were sensitive to a range of the test loads. When the field factor for automatic termination control was applied, the energy factor for any test load above approximately 2.26 kg (5 lb) would satisfy the DOE minimum standard.

6. Items 4. and 5. above imply that the current DOE standard may be improved by relating energy consumption criteria (e.g. energy factor) directly to test load weights or their equivalent clothes container volumes.

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