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Commercial Tumble Dryers

Codes and Standards Enhancement (CASE) Initiative
For PY 2016: Title 20 Standards Development

Analysis of Test Procedure Proposal for
Commercial Tumble Dryers
Docket #12-AAER-2D

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1. Executive Summary

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Appliance Efficiency Regulations (Title 20) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and Southern California Gas Company (SoCalGas) – sponsored this effort (herein referred to as the CASE Team). The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve the energy and water efficiency of various products sold in California. This report and the code change proposal presented herein is a part of the effort to develop technical and cost-effectiveness information for potential appliance standards. This CASE report covers a test procedure proposal for commercial tumble dryers.

In California, more than 500,000 commercial tumble dryers operate in shared apartment laundromats, coin-operated laundromats, and on-premises laundries in hotels, motels, nursing homes, hospitals, and other buildings where textile cleaning is required to conduct business. These tumble-type dryers installed in California use approximately 900 GWh and 260 million therms per year, costing businesses more than$440 million per year to operate. Through their operation they emit 1.8 million $MTCO_2e$ annually. Readily-available technologies, such as burner/fan modulation, heat exchangers, and sensing/control, can save 20% to 50% of total energy used by commercial tumble dryers. Many of these technologies are already in use in current models.

Although smaller residential dryers have a federal and international energy efficiency test procedures that enable comparison among various models, no test procedure exists that addresses energy efficiency of commercial tumble dryers. As a result, buyers of these units, such as laundromat operators, law enforcement stations, health clubs and hospitals, have little to no information about the energy efficiency or energy use of this equipment even while many of these organizations are concerned about rising utility prices.

The CASE Team revises its July 2013 recommendations to the Energy Commission and recommends that California adopt a test procedure developed specifically for gas and electric commercial tumble dryers with drum volumes up to 65 cubic ft. (approximately 210 pound textile load rating). This protocol, given in full as an attachment to this document, will enable reliable information on the efficiency of commercial tumble dryers for businesses, utility incentive programs, and state mandatory energy efficiency standards. A literature review of residential and commercial tumble dryer technology, a detailed market survey (including site visits), and extensive exploratory testing at PG&E's Applied Technology Services (ATS) facility all informed the development of the IOU-recommended test protocol. In addition, the IOU-team used the protocol to collect efficiency data on seven commercial dryers ranging from 30 to 120 pounds in size. This practical lab experience confirms testing costs for conducting the procedure are reasonable.

Adopting this test procedure is the first step to realizing the energy, dollar, and greenhouse gas emissions savings available from commercial tumble dryers. Reducing commercial dryer energy use by 20 percent for California businesses would mean 180 GWh and 50 million therms annually after full stock turnover, delivering nearly $90 million in utility bill savings, and is the equivalent of reducing carbon dioxide emissions annually by 360,000 $MTCO_2e$. Adopting this test procedure supports California's aggressive goal of reducing emissions 40 percent below 1990 levels by 2030 (SB32 2016) as well as other long-term energy and air-quality goals.

2. Standards Proposal Overview

2.1 Proposal Description

This proposal recommends the adoption of a test procedure for commercial tumble dryers up to 65 cubic feet of drum size that operate on gas or electricity. This will create new section of Title 20 code. Although commercial tumble dryers use significant energy in California (900 GWh and 260 million therms per year) and there are technologies available to reduce that energy use by 20 to 50%, there is no test procedure that measures the energy performance of commercial tumble dryers. Adopting this test procedure is the first step to enabling savings from these appliances, allowing California to meets its long term energy, climate and air quality goals.

2.1.1 Proposal History and Policy Background

In the summer of 2013, The California Energy Commission (CEC) issued an invitation to participate and an invitation to submit proposals to gather information from stakeholders on a possible standard for commercial tumble dryers. The CASE Team and other stakeholders, including manufactures and advocates for energy efficiency provided comments to the CEC under docket #12-AAER-2D. In 2013, the CASE Team submitted a CASE report to that docket proposing that the Commission pursue a mandatory standard for commercial tumble dryers smaller than 13 cubic feet (30 pound) and employ the U.S. DOE residential test procedure and metric to evaluate energy performance these dryers (U.S. DOE 2013). Manufacturers, in particular, had concerns with applying the residential procedure to the commercial market and cited a number of differences between the two markets.

In response to these concerns and to address more of the commercial market and capture more energy savings for the state, the CASE Team revises its recommendation with this updated CASE Report focused on a test procedure proposal for commercial tumble dryers. The CASE Team recommends that the California Energy Commission continue to pursue standards for commercial tumble dryers, but with a broader scope than recommended in 2013. Specifically, the CASE Team recommends a test procedure and standard for commercial tumble dryers up to 65 cubic feet drum capacity (approximately 210 pound). This CASE report gives justification for this recommendation and analyzes the IOU-recommended test procedure for commercial tumble dryers. Adopting the IOU-recommended commercial tumble dryer test procedure is the first step toward commercial tumble dryer standards. The CASE Team intends to present a full standards proposal to the Commission in 2017.

Although the CASE Team is aware of custom incentives provided by utilities to businesses for dryer retrofits in California, creating a standard program offering is limited by available data on commercial tumble dryers. This test procedure would support further development of commercial dryer incentive programs.

The DOE does not regulate this appliance, so there are no federal preemption concerns for the state. ENERGY STAR has no program for commercial tumble dryers. The CASE Team is not aware of any voluntary specification for these appliances in the U.S.

3. Product Description

Commercial tumble dryers use forced air circulation to dry clothes, uniforms, sheets, towels, pillowcases and other textiles as they tumble in a drum. These appliances are commonly used after textiles have been washed or other otherwise treated in a commercial washer and operate in in apartment buildings, coin-operated laundromats, hotels and motels, health clubs, nursing homes, jails and prisons, universities and colleges, fire and law enforcement stations, hospitals, restaurants, dry cleaners, and laundry service companies. DOE's efficiency metric (called combined energy factor or CEF) divides pounds of bone dry clothing by total energy used by the appliance in standby modes and active mode (in kWh). The CASE Team metric discussed herein proposes a similar metric (called the cost-benefit factor) and leaves open the opportunity for stakeholders to combine energy from gas and electricity using different means other than site energy, including converting those energy values to dollars, greenhouse gas emissions, etc.

Commercial tumble dryers are generally rated by capacity, in pounds of dry textiles for a full load, or by drum volume (in cubic feet). Commercial tumble dryers range from approximately 7.5 cubic feet (18 pound) to 145 cubic feet (400 pound). They are most commonly operated by electricity, natural gas and propane (with electric controls and motors) and steam (with electric controls and motors). At the time of purchase, many of the models available can be specified by the buyer to use one of these fuel types. Some of the larger models may also require compressed air service for operation.

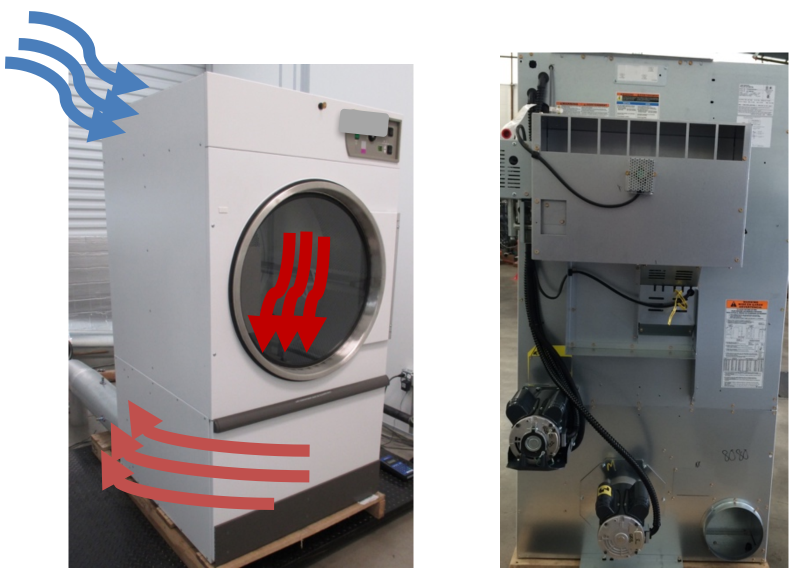

Figure 3.1 Airflow through a commercial tumble dryer (left) and photo of rear of tumble dryer (right)

Source: CASE Team

Most commonly, a commercial tumble dryer has an electric motor-driven fan that pulls air through the intake port and it passes across heater, where it is warmed. Then, the hot air travels to the drum of the tumbler, which enables exposure of the textile surface area to the hot air. Water evaporates from the textiles into the warm air. Lastly, the warm air is exhausted through a port, usually in the rear, but sometimes in the top.[1] In an electric tumble dryer, air is heated by electric resistance elements or by a heat pump, whereas in a gas tumble dryer, air is heated using a direct burner (gas combustion products mix with the dryer's airstream). The fan and drum are driven by the same motor or different motors, depending on the configuration, and belts and pulleys may or may not be used.

Commercial tumble dryers are either single-pocket or dual-pocket. A dryer with two drums and independent controls that are stacked for increased space efficiency are considered dual-pocket. A dryer with a single drum is considered single pocket. An illustration of dryers of different sizes and configurations are shown in Figure 3.2 and Figure 3.3.

Figure 3.2 Commercial tumble dryer examples: 18, 30, 50, 120 and 310 pound capacity dryers (from left to right)

Source: Zhang 2013

Figure 3.3 Commercial dual-pocket (stacked) dryers: 18 pound (left) and 30 pound (right)

Source: Zhang 2013

[1] Note that electric heat pump tumble dryers and condensing tumble dryers are configured slightly differently than the description and illustration here. Heat pumps use a compressor to extract heat from the exhaust air instead of a conventional burner. Condensing dryers (heat pump or otherwise) use a condensing loop and drain (or water storage box) to take the water out of the air before the air is reheated and returned to the drum. Then typically a separate dry air loop exhausts heat into the room.

Dryers have two basic types of controls that can be specified at the time of purchase: vended or on-premises. The first enables coins, cash or a card to be inserted to enable payment for operation. These typically are found in multifamily apartment buildings and laundromats. The second, generally called on-premises controls, are specified when employees of a business operate the machine. (Figure 3.4).

Figure 3.4 Control options for commercial tumble dryers: vended (coin-op) on left and on-premises style on right

Source: CASE Team

Figure 3.5 shows a typical high-heat drying cycle for a commercial tumble dryer. At the beginning of the cycle, the textile load[2] is placed in the machine and the machine is turned on. First, the drum starts spinning and fan starts blowing. (Note the blue line: the total power in kilowatts is just under one kW at this phase.) Once the dryer's automatic safety checks are complete, then the burner turns onto full power (blue line up to nearly 40 kW). Water starts to evaporate from the textiles: the humidity of the exhaust (green line) rises, and the weight of the load (which includes the weight of the textiles plus the weight of the water) starts to slowly slope downward.

The majority of the moisture evaporates in the bulk drying stage. (For this dryer, about 90 % of the total water is evaporated in the bulk drying stage.) Humidity of the exhaust is highest at the beginning of the bulk stage, as the water rapidly evaporates from the textiles. As the stage continues, it becomes more difficult to evaporate the water. The humidity of the exhaust declines and the temperature of the air exiting the drum rises.

Once a certain temperature set point is reached, then the dryer moves to a high heat stage to evaporate the remainder of the water from the textiles. This stage is characterized by the burner cycling on and off according to high and low temperature set points. The humidity of the exhaust is relatively low in the high heat stage because most of the moisture has already been removed.

If the operator of the dryer has chosen the appropriate time to get the textiles dry, then the textiles can be removed at approximately 31 minutes, which is the 4% remaining moisture content (RMC) annotated on the figure. However, if the time to dry the textiles is misjudged by the operator, typical dryers will continue in high heat mode until the timer stops. If the textiles are dried in extended high heat mode for the full 38 minutes (instead of 31 minutes), this dryer uses about 15% more energy than it otherwise would to achieve a similar result.

[2] This particular dryer is a 17.3 cubic foot (55 pound) commercial tumble dryer loaded with an IEC cotton full-sized load (2.5 pounds per cubic foot of drum volume) at 60% initial moisture content (IMC).

Finally, nearly all the dryers tested by the CASE team had a wrinkle prevention stage enabled by default. If, at the end of the cycle, the textiles are not removed, the drum will tumble and fan will blow for less than a minute although the burner does not turn on. This tumbling happens every few minutes to prevent wrinkles from forming. Note that this stage is not shown in Figure 3.5.

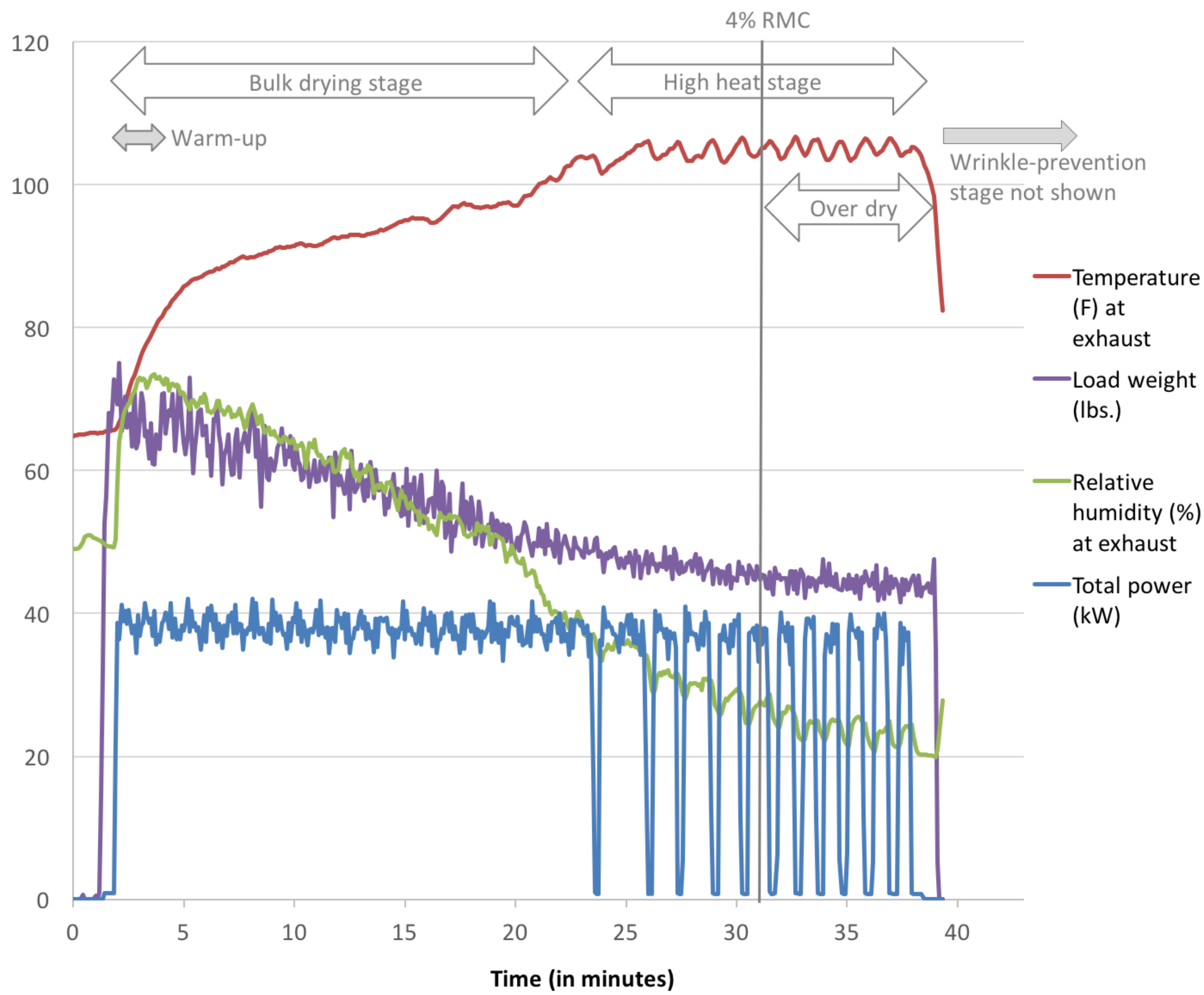

Figure 3.5 Typical drying cycle for commercial tumble dryer (shown: 17.3 cubic foot, 55 pound capacity dryer)

Source: CASE Team

Given the low production volume of these products, we assume that they are redesigned infrequently, and rarely in totality. Most of the new features being marketed and sold appear related to the control interface, but not necessarily to the full design of the product.

For the purposes of test procedure definitions and energy savings estimates, the CASE Team uses drum capacity, in cubic feet. All commercial dryer specification sheets surveyed by the team included dryer capacity in cubic feet. Not all dryers have a weight capacity given in pounds. Furthermore, volume is a measurable quantity that can be confirmed. Drum capacity (in pounds) is a useful tool for manufacturers to communicate to customers, but is a manufacturer-recommended rating that is not verifiable.

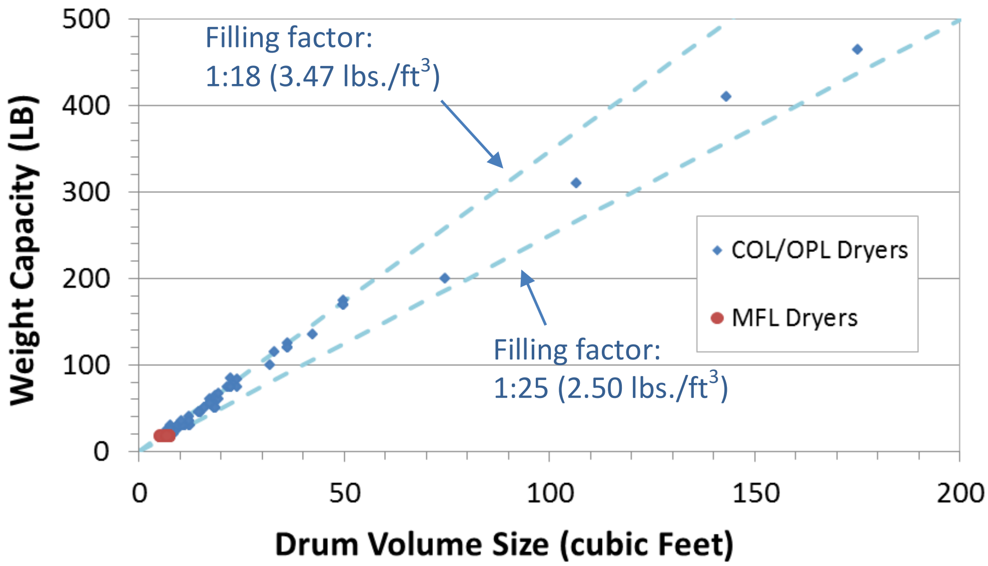

Figure 3.6 Relationship between drum volume (cubic feet) and load weight capacity in commercial dryer specification sheets (up to 200 cubic feet)

COL/OPL: Coin-operated laundry/on-premises laundry, MFL: multifamily laundry dryers (smallest commercial dryers built on a residential platform); Source: Zhang 2013

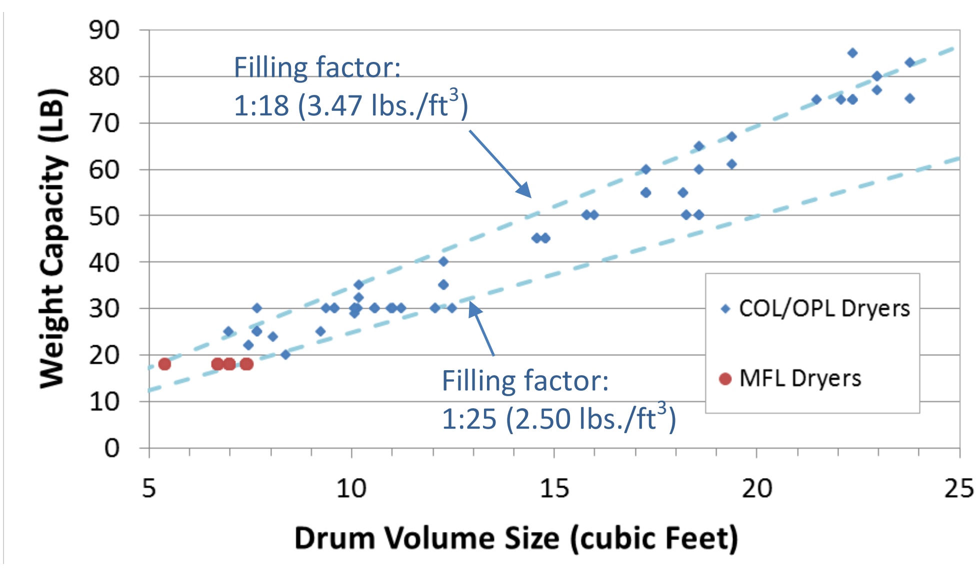

Figure 3.7 Relationship between drum volume (cubic feet) and load weight capacity in commercial dryer specification sheets (up to 25 cubic feet)

COL/OPL: Coin-operated laundry/on-premises laundry, MFL: multifamily laundry dryers (smallest commercial dryers built on a residential platform); Source: Zhang 2013

As outlined in the 2013 IOU CASE report submitted to docket #12-AAER-2D, dryer load weight capacity (pounds) generally increases as drum volume increases (Figure 3.6), but there are exceptions. In Figure 3.7, drum volume size for 30 pound dryers range from 7.7 to 12.5 cubic feet. Similarly, dryers with the same or very similar drum volumes can have different weight capacities. All dryers surveyed had specifications above or equal to a filling factor of 1:25, which corresponds to 2.5 pounds of dry textile per cubic foot of capacity (Zhang 2013). [3]

4. Market Analysis

4.1 Market Structure

In 2013, the CASE Team collected product and market information on commercial textile dryers (Zhang 2013). This section is modified from that original report submitted to this docket in 2013. At that time, the CASE study team utilized a number of methods to collect product and market information on commercial dryers in California. These data collection methods included:

- Market study literature reviews
- Interviews with manufacturer representatives
- Interviews with distributors and industry associations
- Manufacturer product lines and specification sheet reviews

The CASE team engaged manufacturers and industry associations at the beginning of the study period to inform study objectives. The CASE study team contacted and interviewed major manufacturers and distributors to obtain information about market characteristics.

Table 4.1 Commercial clothes dryer manufacturers and products

Manufacturer	Commercial tumble dryer capacity rating (pounds of dry textiles)
Alliance Laundry Systems (Includes Cisell, Huebsch, IPSO, SpeedQueen and Unimac)	18 to 170
American Dryer Corporation	20 to 464
Continental Girbau	25 to 175
Dexter	30 to 83
Electrolux	29 to 135
Maytag (Includes Maytag and Whirlpool)	18 to 75
Wascomat	30 to 135

Source: Zhang 2013

[3] Drum filling factor is defined as the ratio of load weight, in kilograms, to drum volume, in liters, is used in some product specification sheets to indicate product weight capacity. Filling factors observed were between 1:18 (3.47 pound/cu.ft.) and 1:25 (2.50 pound/cu.ft.) (Zhang 2013).

Table 4.1 shows the major commercial tumble dryer manufacturers in the United States and their product ranges in weight capacity. The information was collected through review of manufacturer product literature obtained from manufacturer websites in 2013. Some of the smallest commercial tumble dryers (approximately 5.6 to 7.5 cubic feet/18 pound rated capacity) are built on a residential platform with heavier duty components and housings designed for higher cycle use over their lifetimes. Generally, ratings above 18 pound (7.5 cubic feet) capacity are machines designed for commercial. Some manufacturers have several subsidiaries or brand names. For example, Cisell, Huebsch, IPSO, SpeedQueen and Unimac are all brands of Alliance Laundry Systems. Based on input from different manufacturers, it seemed that some manufacturers, e.g. Alliance Laundry Systems, represented larger shares of the commercial dryer market than others. However, for purposes of this study, the market shares by manufacturer are unknown.

Commercial dryers have relatively simple distribution channels. Dryers are typically sold through local and regional distributors. Small quantities of the smallest commercial dryers can also be purchased directly from specialty retail stores. Most distributors indicated that they typically enter agreements with manufacturers to only carry products from selected manufacturers.

There are also third party repair service companies that contract with apartment building owners, laundromats, and other businesses to provide service and maintenance to machines. The agreements between these third-party providers and the businesses they serve vary, but may include service of machines only or service plus ownership of the machines. The third-party entity may earn the revenue associated with vending. Utility costs and service up time may or may not be included in the contracts with third-party providers.

Given the low production volume of these products, these machines are not expected to be redesigned often, leaving the same models on the market for years. Most of the new features being marketed and sold seem related to the control interface, but not necessarily to the full design of the product. There are many component suppliers that have more efficient components (heat wheels, two stage burners, more efficient motors, etc.) that may not yet be connected with manufacturer supply chains.

There has been consolidation in the industry not only of ownership, but possibly even of manufacturing, likely reducing manufacturing costs and improving profit margins for manufacturers. Alliance Laundry Systems owns many of the brands, and we have evidence of at least one other manufacturer outsources their manufacturing to Alliance Laundry. This consolidation seems to have also reduced market innovation in design as cost-focused simplification of the manufacturing line seems to have been the priority for manufacturers.

CASE Team observations and tests of the standby power of seven machines suggest opportunities for efficiency improvements (Figure 4.1). For example, three of the models have standby power higher than 10 watts, with three more models higher than 6 watts. One vended model with volume of 10.2 cubic feet (35 pound) has a standby power of less than a quarter (3.3 watts) of the highest standby observed (17.7 watts), confirming better designs exist in the marketplace today. Even for dryers with the same drum volumes, standby power can differ by a factor of two (e.g. 7.0 watts compared to 14.5 watts).

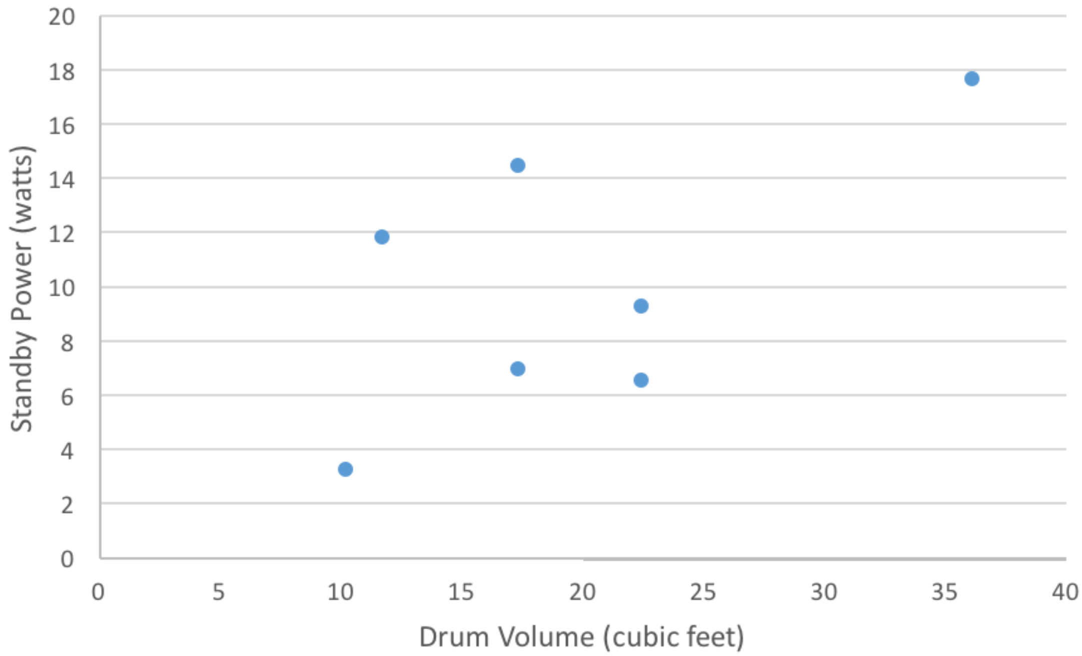

Figure 4.1 Standby power of seven commercial tumble dryers

Source: CASE Team measurements

Significant differences in efficiency are also observed when a dryer performs its primary function: drying textiles. Table 4.2 shows two dryers of similar capacity with very different efficiencies. The measure of efficiency for dryers is cost-benefit factor (CBF), and a higher CBF indicates a higher efficiency. The first dryer (Dryer 4) has an average site energy cost-benefit factor (CBF) of 1.36 pounds of bone dry textiles per site kWh when tested per the IOU-proposed test protocol for commercial tumble dryers. The second dryer (Dryer 6) is nearly 60 percent more efficient than the first when tested under the same protocol (CBF of 2.15 pounds of bone dry textiles per site kWh). The more efficient dryer has a lower standby power (3.3 watts) and employs motor and controls power factor correction, reducing energy losses in building wiring and the utility line. Furthermore, the less efficient dryer took an average of 40 percent longer than the more efficient machine (nearly an hour compared to the more efficient machine that completed in just over half an hour). Finally, the price of the more efficient dryer ($3145) is approximately $300 lower than the less efficient dryer ($3422).[4] In summary, the more efficient dryer (Dryer 6) has a lower first cost, completes its drying cycle more quickly, and reduces wiring energy losses when compared to the less efficient dryer.

[4] The CASE Team purchased these dryers at these prices from California distributors in 2015.

Table 4.2 Comparison of two commercial tumble dryers of similar size

	Efficiency (Site Energy CBF) (lbs. of bone dry textiles/site kWh)	**Power Factor**[a] (expressed as a percent)	**Low power modes** (watts)	**Average Program Time** (minutes)	**2015 Price** (U.S. Dollars)
Dryer 4 (30 lbs. and 11.7 ft^3 drum volume, vended controls)	CBF: 1.36	64%	Standby: 11.9 W Wrinkle prevention: 37.0 W	56	$3422
Dryer 6 (35 lbs. and 10.2 ft^3 drum volume, vended controls)	CBF: 2.15	93%	Standby: 3.3 W Wrinkle prevention: 55.9 W	34	$3145

[a] Average over five different active drying cycles specified in the IOU-proposed test protocol. Source: CASE Team measurements

4.2 Annual Sales and Stock

The CASE Team used three sources for developing stock and sales estimates.

1) For commercial dryers with drum volume less than 7.5 cubic feet, the CASE Team uses shipment numbers for electric and gas dryers from AHAM's letter docketed in 2013 (Messner 2013a, p. 2). Shipment numbers are considered a proxy for sales numbers. Stock numbers are calculated by multiplying the shipments by a 15-year design life (assuming flat market growth). These numbers agree relatively well with the 2013 CASE Report numbers (Zhang 2013).

2) For commercial dryers with drum volumes greater than or equal to 7.5 cubic feet and less than or equal to 13 cubic feet, the CASE Team uses shipment numbers in the IOU CASE Report from 2013 (Zhang 2013). Stock numbers are calculated by multiplying the shipments by a 15-year design life (assuming flat market growth).

3) The CASE Team references its On-premises Market Survey to determine stock in California (On-premises Survey 2015) for remainder of the commercial tumble dryer sizes (greater than 13 cubic feet to less than 65 cubic feet). Annual sales are then calculated by dividing stock by the 15-year design life (assuming flat growth).

Although AHAM provided dryer fuel type in its numbers, all other sources used did not quantitatively include fuel type. General market research indicates that in California gas tumble dryers account for almost all sales. For the purposes of estimating electric units, the CASE Team assumes 5 percent of stock and 5 percent of annual sales are electric, and the remaining 95 percent are gas.

Table 4.3 California shipments and stock

Dryer Size (in cubic feet of drum volume)	Annual Shipments (units)		Stock (units)		Total (units)	
	Gas	Electric	Gas	Electric	Annual Shipments	Stock
< 7.5 [a]	14,750	5,250	221,250	78,750	20,000	300,000
>/= 7.5 and <13 [b]	12,255	645	183,825	9,675	12,900	193,500
>/=13 and < 17 [c]	176	9	2,553	134	185	2,687
>/= 17 and <21 [c]	485	26	7,232	381	510	7,613
>/=21 and < 37 [c]	413	22	6,169	325	435	6,493
>/=37 and <65 [c]	85	4	1,276	67	90	1,343
Total	**28,164**	**5,956**	**422,305**	**89,332**	**34,120**	**511,637**

Source: [a] Messner 2013a, [b] Zhang 2013, [c] On-Premises Survey, 2015

5. Test Methods

5.1 Current Test Methods

No test procedure for commercial tumble dryers exists today5 although there are four main procedures in use to measure the energy efficiency of residential tumble dryers. They include an industry-developed ANSI/AHAM protocol (ANSI/AHAM HLD-1-2010), a protocol developed by the International Electrotechnical Commission (IEC) (IEC 61121:2012), a U.S. DOE protocol developed via a federal standards rulemaking (U.S. DOE 2013), and the Utility Test Protocol, developed by the Northwest Energy Efficiency Alliance (NEEA) and Pacific Gas and Electric (Clothes Dryer Utility Test Protocol 2015). They vary in their purpose and in characteristics, which are summarized in Table 5.1 Full references to each protocol can be found in Appendix A.

[5] The European Committee for Electrotechnical Standardization is in the process of developing a test procedure for commercial tumble dryers under CLC/TS 50594.

Table 5.1 Summary of residential tumble dryer energy efficiency test procedures

	ANSI/AHAM HLD 2010	IEC	DOE 2015	Utility Test Protocol
Purpose	Performance and Efficiency	Performance and Efficiency	Efficiency	Efficiency
Test series (1 run is 1 active mode drying cycle)	Reference to 3 or 1, flexible	5 runs per test series, flexible on the number of series performed	1 run on two dryers	5 runs per test series
Load material	IEC-specified cotton	IEC-specified cotton and IEC-specified synthetic	DOE test cloths	Real-world clothing, DOE test cloths
Textile allowed age	Age-weighted load, 80 total runs on an article	Age-weighted load, 80 total runs on an article	25 total runs	25 total runs
Termination method	Technician termination[a] and automatic termination	Automatic termination, language on timed unclear	Technician termination and automatic termination	Automatic termination
Ambient conditions	75 ± 3°F; 50 ± 10% relative humidity	73.4 ± 3.6°F; 55 ± 5% relative humidity	75 ± 3°F; 50 ± 10% relative humidity	75 ± 3°F; 50 ± 10% relative humidity
Textile moisture content target	Initial: 70%; Remaining: 5%	Initial: 40% to 70%; Remaining: 0% to 8%[b]	Initial: 57.5%; Remaining: 2%	Initial: 57.5% and 62%; Remaining: 2% and 4%
Settings	High/max heat	Range	High/max heat	Range
Program time measured?	Sometimes	Yes	No	Yes
Entities using the protocol	Industry	Europe, Australia [c]	U.S. DOE and EPA	NEEA and PG&E
Low-power mode measured?	No	Yes—IEC 60456 (washer) and IEC 62301 referenced	Yes— IEC 62301 referenced	Yes—IEC 62301 referenced

[a] In technician termination, the dryer is set to the maximum time length and then the door is opened by the technician when the load reaches the target remaining moisture content (RMC) for the test. The dryer is not allowed to terminate via its own timer, as it does during real-world use. [b] The IEC defines remaining moisture content differently than the other procedures. The value is calculated relative to the textiles equilibrated with a certain humidity, not comparable to the bone dry RMC the other test procedures use. For the purposes of this comparison, the CASE authors adjusted the RMC values in the table to approximate the range of RMC relative to bone dry weight. [c] Countries known to the CASE Team to use the protocol. This list is not necessarily comprehensive.

A few observations can be made about the differences and similarities among the residential test protocols. Firstly, the number of active mode dryer test cycles, or runs, in a test series ranges from one to five, with DOE having the fewest number of required runs and the IEC and Utility Test Protocol requiring 5 runs in a test series. Note that the IEC requires 5 runs per test series, but depending on the purpose, more than one test series may be performed (e.g. cotton load test series and a synthetic load test series).

Secondly, there are a total of three load types used for the protocols. AHAM/ANSI and the IEC use a cotton load specified by the IEC washer test protocol (IEC 60456:2010), the Utility Test Protocol and the DOE test procedure use DOE test cloths (U.S. DOE 2013), and the Utility Test Protocol also uses real-world clothing specified from a U.S. retailer. The age allowances of the loads differ with the load type. The protocols that specify the IEC cotton loads use an age-weighted load and allow for 80 runs per article, whereas the other protocols allow for only 25 runs on the testing textiles before they are disposed of.

Thirdly, some protocols use a range of settings (high heat, medium heat, low heat, etc.) and specify a range of moisture levels in the textiles going in and coming out of the dryer whereas other protocols limit these parameters to just a single setting and single moisture levels before and after. The range of initial moisture content of loads going into the dryer is 40 to 70 percent, and the range of final moisture content of loads coming out of the dryer is 0 to 8 percent.

Finally, all the protocols that measure low power modes of the tumble dryer reference the IEC 62301 protocol for standby that is widely employed by the U.S. DOE for the measurement of low power modes (IEC 62301:2011).

As cited by industry in the Commission docket related to this product (docket # 12-AAER-2D) there are several differences between residential and commercial dryers that make it challenging to apply any of the residential test procedures to a commercial dryer. AHAM and Alliance Laundry had the following concerns (Messner 2013a, Manthei 2013):

- Commercial dryers dry heavier loads than residential
- Cycle time is shorter
- Timed drying generally used (Messner 2013a)
- Come in "stacked" versions with dryer over dryer (dual-pocket)
- Larger and wider range of drum volumes and capacities (20 to 200 pound)

In addition, the IOU team research and testing identified the following additional challenges:

- Larger physical size
- Different types of controls
- Different load types (home versus facility type loads)
- Air intake–unconditioned air for laundromats and on-premises (apartment laundries seem to operate on conditioned air, more like residential tumble dryers).
- Installed in a broad range of facilities
- Differing levels of business optimization

- Operated by people with different levels of training

Given these challenges, the CASE team agrees with AHAM and Alliance Laundry Systems that the residential test procedures are inapplicable to commercial dryers.

However, commercial dryer energy efficiency is important to California businesses that rely on dryers for daily operation. When the Coin Laundry Association asked laundromat owners to list the biggest problems they face, high cost of utilities was the most frequent answer (65 percent of respondents) (Coin Laundry Industry Survey 2015). The total share of utilities for laundromats as a percentage of gross revenue, has been increasing nationwide since the 1980s, and now averages between 25 and 35 percent of gross revenues (Deal 2006, Coin Laundry Industry Survey 2015). 10 percent of respondents of the 2015 survey indicated that their share of utilities was above 35 percent (Coin Laundry Industry Survey 2015). As hotels, motels, and other businesses seek to lower their energy consumption to meet aggressive corporate energy reduction goals outlined in their sustainability plans, lighting, HVAC, and water measures are not enough, suggesting improving the efficiency of tumble dryers is an opportunity for these businesses as well. Also, utility costs of shared spaces in apartment buildings is passed onto occupants or a managing entity, affecting the lowest-income residents of California.

Unfortunately, businesses and apartment managers currently have little information to help inform purchasing decisions for commercial tumble dryers. Product specification sheets promise high efficiency operation while mentioning design technologies such as "axial air flow patterns", "reversing drum action", "efficient heater box", "residual moisture control", and "over-dry prevention technology." Only occasionally is a quantitative percentage savings given, but even when that is provided, it is not at all clear on what basis that percentage is measured nor whether that savings will be realized once installed.

5.2 Proposed Test Methods

Given the inapplicability of the existing residential test procedures to the commercial tumble dryer market, the market demand for more information on energy efficiency, and the opportunity for commercial dryer standards, the CASE Team developed a test procedure specifically designed for commercial tumble dryers, the "Energy Efficiency Test Procedure for Commercial Tumble Dryers," attached with this document and listed in the cited sources (Foster Porter 2016). A summary of its characteristics is given in Table 5.2. The CASE Team intends to further update the test procedure language in 2017 to include special instructions for the largest of dryers as well as "stacking" (dual-pocket) tumble dryers. Expected updates including details on compressed air service set up for large dryers and cost-effective approaches to creating large loads. These two areas of language update will be supplied to the Commission in early 2017. The CASE Team recommends that the Energy Commission adopt the "Energy Efficiency Test Procedure for Commercial Tumble Dryers," with the forthcoming language updates in 2017.

Table 5.2 Summary of IOU-proposed commercial tumble dryer test procedure in the context of existing residential dryer test protocols

	ANSI/AHAM HLD 2010	IEC	DOE 2015	Utility Test Protocol	IOU-proposed Commercial
Purpose	Performance and Efficiency	Performance and Efficiency	Efficiency	Efficiency	Efficiency
Test series (1 run is 1 active mode drying cycle)	Reference to 3 or 1, flexible	5 runs per test series, flexible on the number of series performed	1 run on two dryers	5 runs per test series	5 to 6 runs per test series
Load material	IEC-specified cotton	IEC-specified cotton and IEC-specified synthetic	DOE test cloths	Real-world clothing, DOE test cloths	IEC-specified cotton
Textile allowed age	Age-weighted load, 80 total runs on an article	Age-weighted load, 80 total runs on an article	25 total runs	25 total runs	Age-weighted load, 80 total runs
Termination method	Technician termination [a] and automatic termination	Automatic termination, language on timed unclear	Technician termination and automatic termination	Automatic termination	Timed and automatic termination
Ambient conditions	75 ± 3°F; 50 ± 10% relative humidity	73.4 ± 3.6°F; 55 ± 5% relative humidity	75 ± 3°F; 50 ± 10% relative humidity	75 ± 3°F; 50 ± 10% relative humidity	65 ± 1.5°F; 50 ± 5% relative humidity
Textile moisture content target	Initial: 70%; Remaining: 5%	Initial: 40% to 70%; Remaining: 0% to 8% [b]	Initial: 57.5%; Remaining: 2%	Initial: 57.5% and 62%; Remaining: 2% and 4%	Initial: 60% and 75%; Remaining: 1.5% to 8%
Settings	High/max heat	Range	High/max heat	Range	Range
Program time measured?	Sometimes	Yes	No	Yes	Yes
Entities using the protocol	Industry	Europe, Australia [c]	U.S. DOE and EPA	NEEA and PG&E	CASE Team (Newly proposed)
Low-power mode measured?	No	Yes—IEC 60456 (washer) and IEC 62301 referenced	Yes— IEC 62301 referenced	Yes—IEC 62301 referenced	Yes—IEC 62301 referenced

[a] In technician termination, the dryer is set to the maximum time length and then the door is opened by the technician when the load reaches the target remaining moisture content (RMC) for the test. The dryer is not allowed to terminate via its own timer, as it does during real-world use. [b] The IEC defines remaining moisture content differently than the other procedures. The value is calculated relative to the textiles equilibrated with a certain humidity, not comparable to the bone dry RMC the other test procedures use. For the purposes of this comparison, the CASE authors adjusted the RMC values in the table to approximate the range of RMC relative to bone dry weight. [c] Countries known to the CASE Team to use the protocol. This list is not necessarily comprehensive.

The IOU CASE Team goal for the commercial dryer test procedure development was to establish an effective energy performance test procedure, metric and standard for all commercial clothes dryers. The procedure is intended to be repeatable and reproducible, to be representative of real-world energy use, to cover all modes of operation, and to minimize testing burden. A repeatable test procedure will give the same result (within an expected error tolerance) when a single laboratory performs the procedure twice on the one dryer. Results from a test procedure are reproducible if different labs can perform the test procedure on the same dryer and get the same result. Making the test procedure representative of real-world use helps ensure that when a dryer is used by a business, the energy use predicted by the test procedure is not significantly different than the energy use measured in that business. Finally, minimizing test burden means meeting the other test procedure goals in a low-cost way. The cost to perform the test procedure should be below the value of the data collected and the savings achieved from the effort. A test procedure that covers all modes of operation means that the protocol requires measurements in all energy consuming modes, including the drying cycle and other lower power modes, such as standby and wrinkle prevention.

To inform the development of the test procedure, the IOU CASE Team conducted a literature review, performed a survey of various organizations that use on-premises laundry equipment (On-premises Survey 2015), interviewed experts, visited sites, and conducted laboratory testing on one residential dryer and eight commercial tumble dryers ranging from 7.5 to 36.1 cubic feet (18 to 120 pound). The team reviewed test procedures, energy efficiency reports, government rulemakings, laundry industry market information, and web marketing materials. The experts interviewed were engineers familiar with the use of efficiency retrofits on dryer equipment. Eight businesses with dryers were visited by the team, including multifamily laundry facilities, laundromats, and a hotel. Lab tests were conducted in detail on two dryers and the full testing protocol was applied to all eight dryers. Even with extensive research, the CASE Team could not find ideal data on every aspect to inform the development of the protocol. In those instances, assumptions were made based on the research and information available.

The CASE Team started with the U.S. DOE test procedure for residential dryers (U.S. DOE 2013) and modified it to be applicable to commercial tumble dryers. The structure of the document is retained, but significant changes were needed to enable applicability to commercial dryers. Examples of common sense adjustments made include:

- Altered specifications for duct simulators for all exhaust duct sizes found on commercial dryers, ranging from 4 inches to 24 inches. The commercial dryer specified simulator, designed to approximate 50 linear feet of duct (or a shorter straight run with bends) is based on the simulator specified in the industry-developed residential tumble dryer test procedure (ANSI/AHAM HLD-1-2010).
- Added a requirement for tumble dryer drum cleaning with alcohol and a soft cloth to remove manufacturing oil residue on the inside of the drum before testing. This prevent the residue from getting onto the test textile and altering its characteristics.
- Included additional electrical service voltages applicable to the commercial products.
- Included a definition of a basic dryer model given the customizable nature of commercial products.

The CASE Team made other adjustments to the DOE test procedure to meet the CASE Team goals of a repeatable, reproducible, reasonable, and representative protocol. This section summarizes key area of the test procedure that differ from the U.S. DOE test method, including:

- Scope
- Changes to reduce test procedure cost and improve repeatability/reproducibility
- Textile load characteristics
- Test series
- Ambient conditions
- Test metric

In addition, this section includes a discussion of the data collected with the IOU-proposed test procedure along with a summary of known gaps in the test procedure that the CASE Team intends to address in early 2017. Please note that this section is not intended to be a comprehensive overview of the test procedure and is not recommended to substitute for a review of the IOU-proposed test procedure itself.

5.2.1 Scope

The scope of the "Energy Efficiency Test Procedure for Commercial Tumble Dryers" applies to commercial tumble dryers with drum volumes equal to or less than 65.0 cubic feet (approximately 210-pound load rating) that operate on electricity, natural gas and/or propane (liquefied petroleum) gas. The test procedure covers machines built on residential platforms but sold for commercial use, and machines whose platforms are designed for commercial and industrial use. The test procedure excludes dryers that are sold into the consumer market as defined by 42 U.S.C. 6291(16), and those dryers that operate entirely or in part on steam power.

The scope of this test procedure covers 85 percent of total on-premises laundry throughput (On-premises Survey 2015, p. 18) and 100 percent of all machines sold for use in apartment laundries and laundromats. The IOU CASE team recommends this expanded scope (when compared to the 2013 IOU recommendation (Zhang 2013)) to enable the larger expected energy savings from a greater share of the market. By expanding to include on-premises dryers of larger capacities, the CASE Team expects significantly more energy savings for California.

5.2.2 Reducing test procedure cost and improving repeatability/reproducibility

All test procedures specify the allowable error for each measurement as well as detailed instruction to enable repeatable and reproducible results that policymakers, manufacturers, distributors, and businesses can trust. The CASE team conducted a comprehensive review of the DOE residential dryer instrumentation tolerances and testing instructions that impact repeatability, reproducibility, and cost and looked for cost-effective changes that would improve repeatability and reproducibility and/or reduce overall test burden for commercial tumble dryers.

Some of the test instructions and instrumentation parameters in the test procedure are relaxed relative to DOE's requirements as they are not expected to significantly impact repeatability or reproducibility. However, in the context of commercial dryers, making these changes is expected to reduce cost for test procedure implementation relative to original DOE tolerances. The IOU CASE team made the following modifications from the DOE residential test procedure to reduce overall burden (cost) and/or increase flexibility for implementation:

- Specified a direct geometry-based measurement method using a tape measure, a caliper set, and a metal rod to determine drum volume for commercial dryers that have constructed drums. (The DOE drum volume measurement method continues to be specified for residential-platform dryers with molded drums.)
- Changed the method of distributing the wet textiles into the tumble dryer when loading to be less burdensome given the larger loads expected in commercial.
- Added language that enabled ambient temperature and humidity conditions to be within the tolerances specified only 95 percent of the time. A strict interpretation of DOE's test procedure required maintaining humidity and temperature 100 percent of the time.
- Removed requirement to check BTU rate of burner and adjust to be within tolerance.
- Eliminated requirement for the continuous flow calorimeter, enabling the use of a gas chromatograph for measuring BTU content of gas supply to gas dryers. Increased error on the actual heating value from 0.2 to 1.0 percent.
- Relaxed requirements for the electrical energy meter used with gas dryer measurement from +/- 1 percent to +/- 5 percent. (Electrical meter tolerances for measurement of electrical dryers were maintained.)
- Increased the allowable error on voltage and line frequency supply from +/- 1 percent to +/- 10 percent for the electrical supply for the gas and propane tumble dryers. (Electrical dryer remains the same.)

These changes are expected to reduce the cost of test procedure implementation relative to DOE's tolerances. Table 5.3 provides a summary of the relative cost reductions.

In addition, the IOU CASE Team identified some opportunities to improve repeatability and reproducibility at relatively low cost. The CASE Team made the following modifications from the DOE residential test procedure to improve repeatability/reproducibility:

- Included reasonable fabrication tolerances for the exhaust simulator to improve reproducibility.
- Added detailed requirements for handling textiles, when transferring textiles from the washer to the dryer or the dryer to the scale, including vessel types, time allowed between the washer and dryer, and the option of an insulated tub to enable more time flexibility in the testing process.
- Reduced the allowable error of the textile scale from 0.3 percent to 0.1 percent of the measured value to improve measurements on initial moisture and final moisture of the textiles before and after the dryer cycle.
- Reduced error in textile moisture content three ways: created tighter window for bone dry weight repetition tolerance (from less than 1.0 percent to less than 0.2 percent change), specified how often a load needs to be bone dried to reconfirm textile load bone dry weight, tightened the spinning IMC tolerance, removed provision that allows for misting textiles with water if load is too dry when removed from the washer, and added a more sophisticated IMC correction factor.

- Improved thermal control of ambient conditions and dryer start conditions. The CASE Team found that temperature had a significant impact on the energy efficiency measurement of the dryer, and significant error could be reduced by tightening this tolerance. The Team tightened the window for the ambient temperature and humidity conditions from +/- 3 degrees F to +/- 1.5 degrees F and tightened +/- 10 percent humidity to +/- 5 percent. Additionally, requiring that the dryer run on no heat mode before each test ensures thermal stability and improves repeatability.
- Specified location of ambient temperature measurement relative to the dryer in the chamber to reduce possibility of effects associated uneven mixing of the air.
- Enabled custom remaining moisture content (RMC) correction for each dryer through the test series instead of using a "standard" correction applied to all dryers. This custom correction developed in the procedure allows for higher repeatability and reproducibility of the results of a single dryer, as RMC corrections differ depending on dryer design.
- Added electrical conductivity to the rinse cycle for the textiles to enable consistent results with in-drum moisture sensors. Electrical conductivity of the water is controlled carefully in the IEC test procedure for dryers.
- Added provision for atmospheric pressure minimums to avoid low pressures that occur at high altitude with low pressure that may impact testing results.

Table 5.3 summarizes the changes that were made to improve repeatability and reduce costs. Cost increases and decreases were calculated by considering the cost difference of two scenarios:

1) Baseline scenario: performing the test series of 5 to 6 runs (dryer cycle tests) on a commercial dryer using requirements the U.S. DOE test procedure.
2) IOU-proposed test procedure scenario: performing the test series of 5 to 6 runs (dryer cycle tests) on a commercial dryer using the updated requirements in the IOU-proposed test procedure itemized in the table.

A negative cost indicates a cost savings for the IOU-proposed test series relative to the test series performed with DOE requirements. A positive cost indicates a change from DOE where the IOU-proposed approach adds to the cost of implementation. These changes to the instrumentation and test instructions relative to the DOE protocol were made in the interest of developing a test procedure that is repeatable and reproducible at the lowest possible cost for implementation. Other higher cost changes were considered by the CASE Team to further tighten reproducibility and repeatability but were rejected as unreasonable.

All changes made to the DOE test procedure that are required to accommodate the size and scale of the commercial tumble dryers were excluded from this analysis. These scaling costs would be incurred regardless of the test procedure used. In addition, manufacturers conducting performance testing for the purposes of research, design and development are likely to already have much of this larger equipment already in their facilities, and so the maintenance cost associated with their additional use under the IOU-proposed protocol would be minimal. Examples of costs associated with size and scale intentionally removed from this cost analysis include: the cost of a large commercial washer for textile load preparation, the cost of additional test cloths for larger loads, and the cost associated with increased size of the HVAC system supporting the environmentally-controlled chamber, among others.

Table 5.3 Summary of cost reduction and repeatability/reproducibility changes relative to DOE test procedure and their associated costs

Test procedure change	Improves Repeatability / Reproducibility?	Relative incremental cost[a]	Notes on cost
Drum volume measurement	Neutral	($$$)	Significant equipment required to measure drum volume of commercial dryers as specified in DOE, including a very precise large scale, specialized water system, and possible crane.
Method of distributing textiles in the drum	Yes	($$)	Less handing time by the technician when loading the drum with wet textiles. Changes in water content of the textiles is more important than initial distribution of the textiles when considering repeatability.
Ambient conditions 95 percent of the time, requirement for average ambient conditions	Neutral	($$)	A small deviation in ambient conditions requires a repeat of the entire test run in the DOE framework.
Remove BTU rate adjustment to rated value	No	($) to ($$)	Technician time to measure and adjust BTU rate is not required.
More flexibility for gas BTU content measurements	No	($$$)	A gas chromatograph is allowed, but should not be required with the looser tolerances.
Relaxed requirements for electrical energy meter for gas dryers	Neutral	0 to ($$)	This savings is only realized in the circumstance where a lab is outfitted to test commercial gas dryers only (no electric dryers).
Increased range of electrical supply voltage for gas dryers	Neutral	0 to ($$)	This savings is only realized in the circumstance where a lab is outfitted to test commercial gas dryers only (no electric dryers). Assumption is that grid frequency is sufficient to meet testing requirements, so only regulating voltage.
Introduced exhaust simulator fabrication tolerances	Yes	0 to $	Introducing reasonable tolerances may not change the cost of simulator fabrication.

Test procedure change	**Improves Repeatability / Reproducibility?**	**Relative incremental cost[a]**	**Notes on cost**
Textile handling details	Yes, significantly	$	Vessel specification gives flexibility, but technicians need to understand textile handing requirements and plan accordingly.
Reduced error tolerance on textile scale	Yes, significantly	$	Incremental cost of a more accurate scale is relatively low.
Reduced error in textile moisture content measurements	Yes, significantly	$$$	May require additional 10-minute drying cycle to determine bone dry weight, may introduce additional bone dry cycles compared to DOE test procedure, may require more time to prepare load to correct initial moisture content (IMC).
Improved thermal control of test chamber and dryer start conditions	Yes, significantly	$	HVAC equipment used for the test procedure is programed to a tighter algorithm. This cost represents technician time for additional algorithm control and a few minutes each test to start the dryer and confirm thermal stability before proceeding with run.
Location of ambient temperature sensor	Yes	$	Additional small time to place sensor near each dryer intake instead of in an arbitrary location in the test room.
Custom RMC correction	Yes, significantly	$	Extra calculation performed on data collected in test series.
Electrical conductivity control of water	Yes	$$$	Either automatic system to adjust conductivity of pressurized water or a batch process and then re-pressurization.
Atmospheric pressure requirement	Likely	0 to $$	Only applicable at high altitudes.
Total overall	Yes	($$)	

[a] relative to DOE test procedure approach or specification applied to commercial dryers, $: low cost, one to nine dollars per test series, $$: medium cost, tens of dollars per test series, $$$: high cost, hundreds of dollars per test series, a value in parentheses ($) indicates a cost reduction (negative cost) relative to DOE. Costs are CASE Team calculations assuming 140 dryers tested over the lifetime of the equipment with 7 runs per test series dryer (1000 test runs total). Based on current number of models in the market, this would represent one of six consolidated test facilities. Source: CASE Team

5.2.3 Textile load characteristics

The textile load proposed in the "Energy Efficiency Test Procedure for Commercial Tumble Dryers" is the IEC-specified cotton load outlined in the IEC washer test procedure (IEC 60456:2010) and used in the IEC residential dryer test procedure (IEC 61121:2012) and the U.S. industry residential dryer test procedure (AHAM/ANSI HLD-1-2010). This load was selected from a number of textile loads considered during the CASE Team's test procedure development for four key reasons:

- *Representative results.* Three textiles articles make up the load: bed sheets, pillowcases, and hand towels. These articles are representative of the types of loads used in on-premises facilities. In CASE Team lab testing, the load's energy performance characteristics at full load were indistinguishable from the load of real-world residential clothing and towels specified in the Utility Test Protocol (Clothes Dryer Utility Test Protocol 2015).

- *Availability.* Because the load is also used in the AHAM/ANSI protocol, the test load is readily available from multiple distributors in the U.S.

- *Reproducibility and Repeatability.* Because the textiles are very tightly specified in the IEC washer protocol (IEC 60456:2010), and the load has been in use for some time, the likelihood of the load enabling reproducible results is high. CASE Team testing revealed very good repeatability (within 1 percent error at the 95 percent confidence interval) with this load when the same machine was tested the same way multiple times.

- *Industry-acceptance.* This load has been specified for multiple years and was developed in an IEC process that included industry members, energy efficiency experts, and other stakeholders. It is in use today by AHAM's own members to measure the performance of residential machines.

The IOU-proposed commercial test procedure harmonizes with IEC dryers and AHAM/ANSI HLD-1-2010 by using an age-weighted approach to the load. The age weighted approach enables repeatability/reproducibility while minimizing the materials cost of test textiles. Harmonization means that labs that already perform the IEC or AHAM protocol will be able to more easily integrate the load building approach in the commercial dryer test procedure into their lab operations.

Unlike the residential DOE protocol, which addresses two basic sizes of dryers: compact and regular, commercial dryers have a wide range of drum sizes, from approximately 7.5 to 65 cubic feet. As such, a single load size that would be used for all dryers would be inappropriate and not representative. To address this issue, the CASE Team proposes that the load of the dryer be specified based on drum capacity. As drum volume increases, so does the load size.

Two sizes of loads are used in the test procedure: full capacity and partial capacity. Full capacity is defined as 2.5 pounds per cubic foot of drum volume (1:25 kilograms to liters). Because all models of dryers reviewed by the CASE Team can operate with this loading condition, it was chosen as full load (Figure 3.6 and Figure 3.7). Any larger standardized load could mean that some machines would be overloaded beyond their design capacity, and so using higher filling factors sometimes cited on specification sheets (up to approximately 3.5 pounds per cubic foot) was rejected. Partial load is one-half of full (1.25 pounds per cubic foot of drum volume). AHAM and Alliance Laundry

Systems mentioned that commercial dryers are often operated with larger loads than residential machines (Messner 2013a, Manthei 2013). However, CASE Team site visits and interviews with industry experts also revealed partial loaded machines are also common. Both load sizes have filling factors greater than what is specified in the DOE procedure (8.45-pound load in approximately 7 cubic foot drum, or 1.2 pounds per cubic foot drum volume[6]).

To determine the initial moisture content (IMC) of loads in the commercial tumble dryer test procedure, the CASE Team used data of remaining moisture content (RMC) values of commercial washers, as the RMC of a commercial washer is generally the IMC of a commercial dryer. Publically-available data on residential-platform commercial washers in the California Energy Commission database (CEC 2016) revealed that commercial washers had very similar RMC values to the residential washers in the same database (an RMC average of about 43 percent). However, this RMC value is based on loads with DOE test cloths, which are 50 percent synthetic, small, and uniform, making it easier for washers to spin water out of the load at the end of a cycle. The Northwest Energy Efficiency Alliance field study, which included residential washers of the same vintage and technology as those in the CEC database, had an average measured washer RMC of approximately 62 to 68 percent[7] when loads consisted of real-world clothing, sheets, and towels (Dymond 2014, p. 9-129). The CASE team could not find publically-available RMC data on larger washers, but did collect its own data on two large machines in laundromats using official DOE test cloths. The Team found washer RMCs at 46 percent and 50 percent[8], which is higher than the RMC average for residential platform washers in the CEC database.

Using the range in RMC value of the NEEA field study and the range in washer RMCs, the CASE Team developed a relationship between real-world textile washer RMC and DOE test cloth washer RMC. Using this relationship, the CASE Team adjusted the washer RMC values with DOE test cloths to represent more real-world textiles. The result is a washer RMC (dryer IMC) between 64 and 78 percent[9]. These data collected are likely indicative, but not statistically representative of commercial dryer IMC overall, and so a simple value that was easy to produce in the laboratory with reasonably-priced large commercial washer was chosen (60 percent IMC) for all but one of the tests. 75 percent was chosen to represent a "worst-case scenario" for energy efficiency. This represents the case where the washer spin performance is worse than the average expected. The two dryer IMC values are used in the procedure, 60 percent and 75 percent, support the test procedure goal of the CASE Team, to create a test procedure that is representative as possible within reasonable test burden.

The CASE Team expects that textiles in commercial tumble dryers are dried to varying levels of RMC. Some textiles need to be sanitized with high heat (such as in a hospital setting), or they are over dried due to lack of attention by a consumer or operator. Other textiles need to be slightly damp at the end of the cycle to be ready for ironing or to avoid heat damage to the fibers. The

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[6] CASE Team filling factor calculation using load specified in U.S. DOE test procedure for residential dryers and average drum volume size of residential dryers from Bendt 2009, Figure 7, p. 21.

[7] This range was developed based on two slightly different approaches to the analysis of the data by two different consultants. More information can be found in Dymond 2014.

[8] The CASE Team adjusted the RMCs to Lot 1 DOE test cloths (the standard of comparison); Lot 21 cloths were used to evaluate the RMCs of the laundromat washers.

[9] The CASE Team noted that the residential CEC database value of 42% IMC corresponded to 62% IMC as a lower bound with realistic clothing. Since the CEC database for small commercial washers had 43% IMC, linearly scaling the value produced 64% IMC for realistic clothing. Then the team took the average large commercial washer value of 48% IMC and scaled it according to the upper bound from the NEEA field study of 68% to yield 78% IMC.

RMC values chosen in the test procedure were primarily to represent a range of possible scenarios (between 1.5 and 8 percent RMC).

The choices for the load textile type, load size, and IMC/RMC were selected by the CASE Team to balance the CASE Team goals. This textile approach best represents real-world conditions for commercial dryers (including facility-type textiles, full and partial load sizes), harmonizes with industry-accepted textiles and load-aging methods, and minimizes cost and complexity associated with load preparation.

5.2.4 Timed test termination method

The IOU-proposed commercial dryer test procedure alters instructions for conducting a single run (measurement of one dryer cycle) in the timed dry testing scenario. The DOE method of test cycle termination in the timed dry setting instructs the technician to set the dryer to the maximum time, and then open the door precisely when the remaining moisture content is expected to be within the RMC range specified (2.5 to 5 percent RMC). In the test procedure, manufacturers are explicitly prohibited from getting credit for employing one the simplest and cost-effective energy saving measures: turning off the burner and cooling down the load at the end of the cycle. U.S. DOE residential test procedure explicitly states, "do not permit the dryer to advance into cool down." (U.S. DOE 2013, Section 3.3). In order to make the test procedure more representative of how dryers are used in the field (operated with different lengths of time, depending on the load), and to give manufacturers more opportunity to use innovative energy-saving moisture sensing and control within the timed dry cycle (including a short cool-down period), the IOU-proposed test procedure specifies that the technician set the number of minutes into the dryer to achieve the target RMC window, and allow the dryer to self-terminate. This, coupled with the dryer-specific RMC correction enables the test procedure to be more representative of real-world use and improves repeatability without significantly increasing burden relative to the U.S. DOE test protocol for residential dryers.

5.2.5 Test series

Commercial tumble dryers go into a variety of location types: hospitals, health clubs, jails, law enforcement facilities, apartments, laundromats, nursing homes, and laundry service companies, among others. Tumble dryers are operated by consumers and/or operators with varying levels of training and with laundry processes with varying levels of optimization. Although smaller residential-platform dryers tend to operate in conditioned spaces, dryers in laundromats and on-premises facilities frequently draw air from outdoors or unconditioned spaces to save on energy associated with heating ventilation and air-conditioning (HVAC) equipment. The location of the machine, how it is installed, and who operates it all influence the characteristics that most impact the energy efficiency of a dryer: initial moisture content of the load, settings, intake air temperature and humidity, load size, and textile type. To meet the goal of making the test procedure representative, a single test with only one set of these combined variables was highly unlikely to match the condition a business might experience, or even what may be considered representative or "typical."

To address this, the CASE Team conducted testing to identify the most important variables that impact energy performance of a dryer. The energy efficiency of two dryers (11.4 and 17.3 cubic feet, 30 pound and 55 pound), one of conventional technology and one with burner modulation technology installed as a retrofit, were evaluated with a baseline test and then by changing one variable at a time to identify the impact to the energy performance. The testing revealed that the variables that most influenced the energy efficiency[10] of the dryer (in order of highest to lower impact) were:

- Partial load size (small load)
- Over drying the load
- Higher IMC (wetter) load
- Increase in ambient (dryer intake) temperature

Differences in textile type between the IEC cotton load and the real-world load were not found to be significant at full load size. Changes in humidity (within what was possible in the lab) were also not found to be significant. Serial loads (one right after the other) represented a smaller change relative to the most important variables identified above (Figure 5.1).

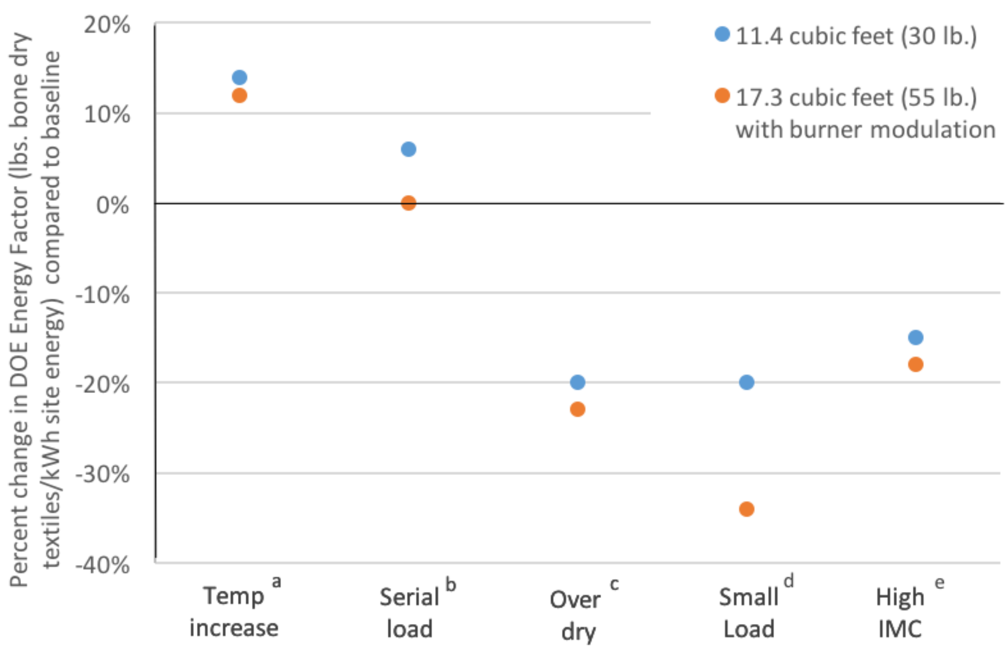

Figure 5.1 Efficiency impact associated with isolated variable change for two dryers (11.4 and 17.3 cubic feet).

[a] The CASE Team increased the ambient temperature of the dryer testing chamber from 75 degrees F for baseline to 95 degrees F. [b] The CASE Team simulated a serial load by running the dryer at high heat with no textile load for a duration of 30 minutes prior to the test, inserted a load matching baseline characteristics and measured the DOE energy factor. [c] To simulate a scenario where the load is dried too long, the CASE Team added 15 minutes to the time required to reach 4 percent RMC for the same full-sized load. [d] The baseline load (full load) was determined using 3.0 pounds bone dry textiles per cubic foot of drum volume. The small load was 1.0 pound bone dry textiles per cubic foot of drum volume. [e] To test the impact of initial moisture content (IMC), a baseline load of 60 percent IMC was compared to an IMC of 95 percent. The high IMC illustrated here is an interpolation between those tests to compare the more realistic load with 75 percent IMC. Source: CASE Team

[10] Because this was at the early stages of the CASE Team test procedure development and a specific metric had not yet been developed for commercial tumble dryers, the CASE Team used DOE's energy factor for this investigation. The energy factor is the pounds of bone dry textiles divided by the total cycle energy (in kWh). This metric does not include energy use from low power modes.

Using these data and the information gathered about the range of conditions in the field, the CASE Team developed five to six runs to complete on a single dryer. These five to six runs are called the test series, and are not meant to be typical of any one dryer's use pattern, but instead represent the range of variables expected when the dryers are installed in California. Also considered by the CASE Team was the reasonableness of performing the test series. Altering some variables (such as ambient temperature and humidity) is more difficult than others, requiring more cost and labor time. These tests represent a compromise of what is reasonable to perform in the lab. A summary of the 5 to 6 runs in the test series is in Table 5.4.

Table 5.4 Commercial tumble dryer test series

Run	Run sequence	Load size	IMC	RMC	Settings
A	Shortest timed	Full-sized	60%	1.5% - 4%	Timed, high heat
B				4% - 8%	
C	Over dry timed	Full-sized	60%	≤ 4%	
D	Challenging timed	Partial	75%	2% - 7%	
E	Favorable timed	Full-sized	60%	4% - 7%	Timed, low heat w/ cool down
F	Automatic termination	Partial	60%	≤ 4%	Automatic termination, medium heat

Source: Foster Porter 2016

The complete test series includes runs A through E for a dryer without automatic termination and runs A through F for a dryer with automatic termination. Each run is one dryer active mode drying cycle with the conditions specified in the table. The dryer is tested as-designed with full load for the majority of the runs, but there are two tests with a partial load condition. High heat is used for four of the runs, but a low heat with cool down and medium heat are also included. All but one of the runs are with 60 percent IMC.

A number of user scenarios are represented in the test series. Firstly, the test series measures the condition where the operator or consumer values cycle time above efficiency or wear and tear to textiles associated with high heat. Runs A and B use high heat with a full-sized load. There are two runs performed to confirm that the technician has indeed identified the shortest run time. Runs A and B are also used to develop a dryer-specific RMC correction that significantly improves repeatability and reproducibility of the test series.

Secondly, Run C measures the energy performance of the scenario observed in CASE Team site visits, reported by interviewed industry experts, and documented in industry product literature: the operator/consumer wants to minimize time to dry the textiles but sets a longer length of time than required to get the textiles dry, leading to a situation where the textiles may be over dry when removed. In this scenario, if the dry continues with high heat, a significant amount of energy is expended unnecessarily, as the textiles are already dry. Technologies, such as moisture sensing and control, are already incorporated in commercial dryers today and can be employed in this type of scenario to reduce energy consumption.

Then, there are two runs (Runs D and E) that are not meant to represent user scenarios (as in A through C) but instead are designed to provide the range of energy efficiency expected under conditions that make the efficiency of drying textiles more favorable and under conditions that make drying efficiently more challenging. These two runs provide a bracket of expected efficiency performance to policymakers, businesses that purchase these dryers, and program implementers that may provide incentives for more efficient dryers. These two tests represent expected energy efficiency under "worse" and "best" case scenarios. More information on how variables impact drying energy efficiency can be found in Table 5.5.

Table 5.5 How operational and environmental condition variables impact dryer efficiency

Operational Variable	Favorable conditions for efficiency	Challenging conditions for efficiency
Load material	Synthetic fibers, uniform, two-dimensional, individual pieces small in size. Example: DOE test cloths.	Cotton or other natural fibers, different thicknesses, three dimensional, variety of size. Example: utility test protocol load
Load size	Load size in upper quartile of rated capacity	Load size significantly smaller than rated capacity
Ambient conditions (air temperature)	High temperature of ambient or air intake temperature	Low temperature of ambient or air intake temperature
Initial textile moisture content going into dryer	Textiles with lower initial moisture content (low IMC)	Textiles with higher initial moisture content (high IMC)
Remaining textile moisture content coming out of dryer	Textiles with higher remaining moisture content (high RMC)	Textiles with lower remaining moisture content (low RMC)
Settings	Low heat—longer program time	High heat—shorter program time
Cycle time	Length of time for drying load is adjusted properly for heat setting (either with timer or by using automatic termination)	Length of time for drying load is too long for heat setting, resulting in very low RMC and lower efficiency (either with timer or by using automatic termination)

Source: CASE Team literature review and 2016 testing

Finally, although many commercial tumble dryers do not have automatic termination (particularly for vended models used by consumers), there are dryers on the market that have automatic termination to prevent over drying and possibly operate at a lower heat level to save energy when time is not at a premium. The last run, Run F, is only for those models that have automatic termination as a setting, and is not performed for dryers that only include timed dry settings.

5.2.1 Ambient conditions

Ambient air conditions are one of the more important variables that impact the energy efficiency measurement of a dryer. While residential dryers tend to operate in spaces where conditioned air from the room is drawn into the dryer,[11] commercial dryers generally draw air from unconditioned spaces. To enable high oxygenation in the combustion chamber, these unconditioned spaces are designed to be well-vented to the outdoor air supply. This means that intake air temperature of most commercial dryers is similar to the outdoor air temperature. Typically, dryers are in a row parallel to an exterior wall (left, Figure 5.2). Between the back of the dryers and the exterior wall is a service access (right, Figure 5.2). Open grates in the exterior wall or ceiling of the service access area enable outdoor air to reach the dryer intake (Figure 5.3). Exhaust air is pushed through a duct that penetrates the wall or the ceiling of the building, usually taking a path through that same service access area (right Figure 5.2).

Figure 5.2 Laundromat dryer installation. Left: dryers installed parallel to exterior wall, Right: unconditioned service access area between wall of dryers and exterior wall

Source: CASE Team site visits

[11] The Northwest Energy Efficiency Alliance has pointed out that some residential dryers operate in unconditioned spaces, such as basements and garages. Therefore, the combined energy factor measurement under the DOE test procedure (where 75 degrees F ambient air is used) would not accurately represent these dryers that have different ambient conditions.

Figure 5.3 Example of wall grate in service area enabling outdoor air flow to dryer intake (photo taken from exterior of building)

Source: CASE Team site visits

Exceptions to the general rule of outdoor air could be possible, even for larger commercial dryers. Some dryers may be in interior building locations where access to the roof or exterior wall that enables an outdoor air supply may be limited. In these scenarios, running extra ducting for air intake could be expensive and viewed as unworthy of the extra cost. The CASE Team assumes this type of installation would be unlikely given that most dryers[12] must exhaust to the outdoors to prevent overloading the HVAC system with moisture and heat. Additionally, gas dryer exhaust also contains by-products of gas combustion that, for safety reasons, must be vented outside.

A more common exception to the general rule of outdoor air is likely for the smallest of commercial tumble dryers (<7.5 cubic feet) often installed in multifamily/apartment buildings. These dryers, usually built on residential platforms, more often draw air from conditioned space inside the laundry room. Because there tend to be fewer dryers that are also smaller and overall dryer load throughput is lower (Manthei 2013), less make up air for the HVAC system is needed for these installations, making it possible to draw ambient air from the room. The CASE Team considered requiring different temperature set points for different sizes of dryers to make the test procedure as representative as possible. However, burden increases with multiple set points on an environmentally-controlled chamber. The test lab would not only need to develop a unique control algorithm for each of the different set points, but also may need to incorporate additional HVAC equipment to achieve those set points. Because this burden seemed relatively high, the CASE Team simplified the test procedure to only have one ambient condition for testing.

Ambient conditions for all tests in the series are 65° F and 50 percent relative humidity. The CASE Team selected 65° F after conducting a population-weighted analysis of the annual average of the daily low, average, and high temperatures of the four most populous metro areas in California: The

[12] The exception to this rule is condensing dryers, which are more common in Europe.

Bay Area, the Greater Los Angeles Area, San Diego County, and Sacramento County. These metropolitan areas represent 80 percent of California's total 2015 population. Population values from the U.S. Census Bureau and temperature values from the National Oceanic and Atmospheric Association (NOAA) used to conduct that analysis are shown in Table 5.6. The population weighted average of the low temperature is 54.6° F, the average annual temperature is 62.0° F, and the average annual high is 69.4° F. Given this analysis, the CASE Team chose 65° F ambient test condition because commercial dryers tend to be operated during the day when the outdoor air temperature is warmer. Although a less important effect, jackets of the dryers (the housing of the dryers) are likely to be higher temperature than outdoor air as one side is in contact with conditioned air in the room where consumers/operators control the dryer and another side may be adjacent to another operating dryer giving off some radiant heat. The CASE Team's research showed that the temperature impact was more important than relatively humidity, and so chose the same value for relative humidity used for residential dryers in the U.S. (ANSI/AHAM HLD-1-2010, U.S. DOE 2013, Clothes Dryer Utility Test Protocol 2015).

Table 5.6 CASE Team outdoor air temperature analysis

Area	2015 Population[c] (in millions)	Annual Average Low (°F) [d]	Annual Average (°F) [d]	Annual Average High (°F) [d]
Greater Los Angeles Area[a]	18.7	56.2	63.3	70.3
San Francisco Bay Area [b]	7.7	50.3	58.0	65.8
San Diego County	3.3	58.0	64.2	70.3
Sacramento County	1.5	48.6	61.3	73.9
Population-weighted average:		54.6	62.0	69.4

[a] Includes Los Angeles County, Orange County, Riverside County, San Bernardino County and Ventura County, [b] Includes Alameda County, Contra Costa County, Marin County, Napa County, San Francisco County, San Mateo County, Santa Clara County, Solano County and Sonoma County, [c] Source: U.S. Census Bureau 2015, [d] Temperatures are the average from 1980 to 2010 (30-year normals) for the metropolitan areas shown. Source: NOAA 2016.

In its selection of ambient temperature conditions, the CASE Team balanced two competing priorities: making the test procedure representative and keeping test burden reasonable. The ambient temperature for the commercial tumble dryer test procedure (65° F) is cooler than all residential test procedures developed to date because commercial dryers are expected to operate with outdoor air intake. Although dryers in apartment laundries more commonly operate on conditioned air, the additional test burden of having multiple temperature set points for the environmentally-controlled chamber is relatively high. The CASE Team simplified the test procedure and reduced overall burden by including one ambient condition for testing: 65° F and 50 percent relative humidity.

5.2.2 Test metric

Unlike many electric-only appliances, the clear majority of today's commercial tumble dryers operate on two fuels: electricity and gas.[13] When determining the energy efficiency of these dryers, the energy use of both fuels must be combined and compared to a quantity that represents the useful work from the appliance to calculate the total energy use of the appliance. DOE combines the energy from these two fuels by converting site BTUs to site kWh and adding the energy values of the two fuels. This approach considers the most important system, the appliance itself, and ignores fuel costs to the business, other impacts of fuel production and distribution upstream of the appliance, including environmental impacts (greenhouse gas and air quality emissions), as well as other societal costs.

Equation 5.1 U.S. DOE's combined energy factor (CEF) used for residential dryers

$$CEF = \frac{W_{bone}}{(E_{low} + E_{cycle})}$$

where CEF is "combined energy factor", the metric used by U.S. DOE to regulate the energy efficiency of residential dryers, W_{bone} is weight of the bone-dry load of textiles (in pounds), E_{low} is the electrical energy use of low power modes associated with one active mode cycle in kilo-watt hours (kWh), and E_{cycle} is the combined electrical and natural gas energy associated with one active mode cycle (in kWh).

The CASE Team has created opportunity for these broader impacts to be considered by setting forth an alternative metric to DOE's energy factor shown in Equation 5.1. The numerator of the CASE Team metric, pounds of bone dry textiles, remains the same as DOE, and the denominator still combines the energy associated with gas and the energy associated with electric together, but also allows for a constant in front of each energy quantity to enable these energy values to be converted to other quantities that are most important to different stakeholders who may be using the data from this procedure. For example, a business owner may want to look at the pounds of dry textiles per dollar of utility cost. A state policymaker trying to meet greenhouse gas reduction goals may want to consider tons of carbon removed from the atmosphere resulting from a utility incentive program. The test procedure does not set a value for the two constants, defined in the test procedure as alpha ($\propto$) and beta (β), nor does it even define the units of those constants (e.g. dollars per kWh, tons of carbon dioxide per BTU), but the format included in the test procedure enables others using the procedure to do so. Setting the constants equal to one with no dimensions enables test procedure users to add gas and electricity quantities together as site energy, just as DOE does.

Equation 5.2 IOU-proposed cost-benefit factor (CBF) for commercial dryers

$$CBF = \frac{W_{bone}}{(\beta E_{low} + \propto G_{cycle} + \beta E_{cycle})}$$

where CBF is "cost-benefit factor", the metric proposed to evaluate the energy efficiency of commercial dryers, W_{bone} is the weight of the bone dry load of textiles (in pounds), E_{low} is the electrical energy use of low power modes associated with one active mode cycle in kilo-watt hours (kWh), G_{cycle} is the energy associated with the natural gas for

[13] Also electricity and steam, but those units are excluded from the scope of the test procedure.

the drying cycle (in kWh), E_{cycle} is the electrical energy use associated with one active mode cycle (in kWh), $\propto$ is the conversion cost/benefit constant for natural gas,[14] and β is the conversion cost/benefit constant for electricity.

As California has many different policy goals for carbon emission reductions, air quality improvements, and zero net energy buildings, the flexibility of this metric gives more information to stakeholders focused on different goals, making the test procedure as useful as possible to wide array of parties. Also, it has an opportunity to make it as applicable as possible to the real-world conditions of business owners.

5.2.1 CASE Team data collected with the test procedure

Using the IOU-proposed protocol, the CASE Team collected efficiency data on seven tumble dryers with capacities ranging from 30-pounds to 120-pounds. Standby power, wrinkle-prevention mode power, cycle energy use and cycle power factor were all measured per the test procedure. The cost-benefit factor (CBF) was calculated for each run in the series (AB, C, D, and E), and an average of those CBFs was calculated. None of the dryers had automatic termination control, and so Run F was omitted from the test series and the average CBF. A summary of these data is in Appendix B.

The tumble dryers tested with the IOU-proposed test series demonstrated a wide range of average site energy cost-benefit factors. Figure 5.4 illustrates site energy CBF, expressed in pounds of bone dry textiles per kWh of site energy. A higher CBF indicates a higher efficiency. The dryer with the highest CBF (2.26) is more than 60 percent more efficient than the dryer with the lowest CBF (1.36).[15] Other observations of the results include:

- The smallest (Dryer 6) and largest (Dryer 22) dryer were among the most efficient (2.15 and 2.22 pounds of bone dry textiles per site kWh respectively), suggesting efficiency may not be dependent on size.
- Advertisement of efficiency by a manufacturer gives no guarantee of efficiency to the business owner/operator. Dryer 3 was marketed as an "Eco" model. The "Eco" brand appeared not only on the marketing materials, but also conspicuously on the front of the dryer itself. Dryer 2 was a model of the same size and manufacturer as Dryer 3, but it was offered as the "standard" model with no advertised efficiency improvement. However, underneath the IOU protocol, the dryers performed very similarly. Some of the test runs had slightly different values, but the average site energy CBF under the test series A through E was nearly identical for both models (Figure 5.4).
- More efficient dryers can cost less and perform better than less efficient dryers of similar size. The average efficiency of Dryer 6 is nearly 60 percent better than Dryer 4. Further inspection of Dryer 6 reveals that efficiency has been given some attention by its designers. It has a lower standby power (3.3 watts) and employs power factor correction, reducing losses in building wiring and utility lines. Furthermore, Dryer 6 has a lower first cost than Dryer 4 and completes its drying cycle about 40 percent faster (a little over half an hour compared to nearly an hour drying time for Dryer 4).

[14] A different value could be used for propane.

[15] For this discussion, site energy CBF is used, and so alpha ($\propto$) and beta (β) are both equal to one.

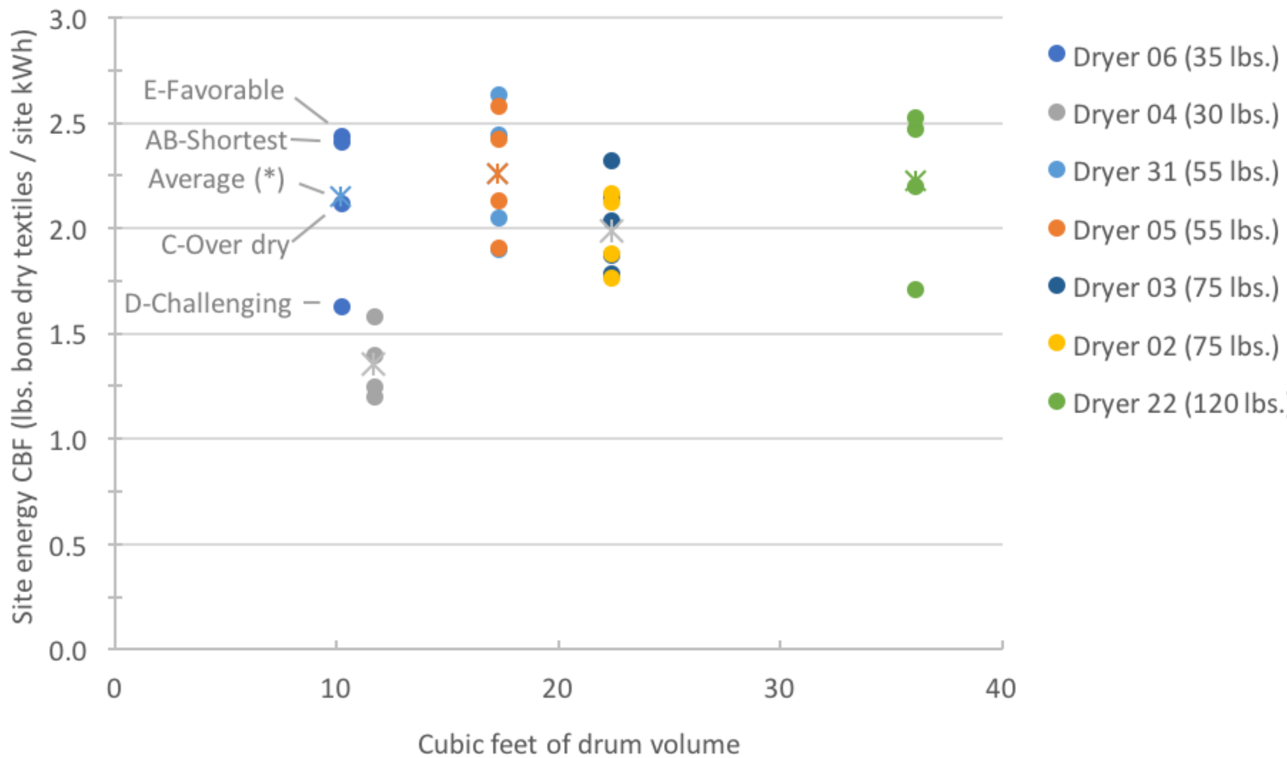

Figure 5.4 Summary of CASE Team measurements of commercial dryer energy efficiency

Source: CASE Team measurements

While considering the cost-benefit factor (CBF) in terms of pounds of dry textiles per kWh may be of most interest to policymakers and utilities focused on energy, the cost of operation is often a more important consideration for many business owners and institutions. If the only metric available is site energy CBF, then a business owner or commercial dryer distributor must identify gas and electricity cost per kWh. Also, assumptions about the share of energy supplied by gas service and electric service must be made. The alternative is to use an operational cost CBF to easily calculate utility costs for facilities (Table 5.7). Simply taking the total annual load of textiles (in pounds) for a facility and dividing by the operational cost CBF gives the expected annual utility bill for dryer operation. (for an example of facility calculations, see Table 5.7).

The CASE Team test data revealed significant differences in estimated operational costs among the dryers that were tested. For example, the cost to dry 100 pounds of textiles can be as low as $1.83, or can be more than 60 percent higher: $3.01 (Table 5.8). A difference of one dollar to dry 100 pounds of textiles may not seem significant, but over the course of a single year, this difference in operational expenditures associated with electric and gas utility bills is thousands of dollars. Table 5.7 summarizes the average operational cost for three categories of organizations that use dryers: universities and colleges, hotels and motels, and nursing homes. Facilities using dryers with performance characteristics like Dryer 4 pay thousands of dollars more on their utility bills per year than facilities that use dryers like Dryer 5. Over the 15-year life of the dryer, this amounts to tens of thousands of dollars of expense for the institution. In the case of nursing homes, where there is a significant daily linen load for resident clothing, bed sheets, towels, table cloths, etc. the savings is more than $100,000 over the lifetime of the dryer.

Table 5.7 Operational cost differences for two commercial tumble dryers

Institution type	Total number of lbs. of textiles per year[a]	Approximate annual operational cost of Dryer 4, CBF: 37.67 lbs./$	Approximate annual operational cost of Dryer 5, CBF: 61.32 lbs./$	Annual Cost difference	Dryer lifetime cost difference[b]
Universities and Colleges	128,100	$3,900	$2,400	$1,500	$22,500
Hotels and Motels	321,100	$9,700	$5,900	$3,800	$57,000
Nursing Homes	653,400	$19,700	$12,100	$7,600	$114,000

[a] Multiplied the average daily loads (On-premises Survey 2015, p. 10) by 365 days in a year. Assumed that the average size of the load of the dryer was 75 percent of the dryer capacity. [b] 15-year life assumed. Value is an estimate based on expected price of energy in 2020 and is given in 2015 equivalent dollars. See Appendix A for further detail. Source: CASE Team

Given California's aggressive greenhouse gas emissions targets, accounting for the greenhouse gases (GHGs) emitted as result of dryer operation may be another useful metric of dryer efficiency. The California Global Warming Solutions Act of 2006 (AB32) set a statewide goal to reduce GHG emissions to 1990 levels by 2020. In 2016, California lawmakers passed Senate Bill 32, which added goals beyond the approaching 2020 limit. These new goals require California to cut greenhouse gas levels to 40 percent below their 1990 levels by 2030 (SB32 2016). One possible approach to a greenhouse gas emissions CBF for dryers would be to take the total bone dry weight of the load (in pounds) and divide by the kilograms of carbon dioxide equivalent (CO_2e) associated with the dryer's gas and electricity use. This would enable policymakers to consider dryers based on their GHG emissions from operation.

Table 5.8 gives a summary of potentially useful metrics for dryer energy efficiency, including site energy CBF (highlighted in Figure 5.4), greenhouse gas emissions (GHG) CBF, and operational cost CBF (highlighted in Table 5.7). For all CBF values, a higher CBF indicates higher efficiency. The dryers are sorted top to bottom by operational cost CBF. The top dryer (Dryer 22) has the lowest operational cost of the dryers tested by the CASE Team, and the bottom dryer has the highest operational cost (Dryer 4). For each dryer, there are slight differences in the share of total energy use that is electrical and the share of total energy use that is gas, so the ranking order of dryers with similar site energy CBFs differ slightly under the three metrics. For example, Dryer 22 scores best with operational cost CBF, but is ranked second under GHG CBF and third under site energy CBF. For dryers with efficiencies that are quite different, the ranking order is identical under each metric (Dryers 6, 3, 2, and 4).

Table 5.8 Average cost-benefit factor for dryers tested by the CASE Team

Dryer ID	Site energy average CBF for test series (lbs. of bone dry textiles /site kWh) [a]		GHG average CBF for test series (lbs. of bone dry textiles /kg CO_2e) [b]		Operational cost average CBF (lbs. of bone dry textiles /$) [c]		U.S. dollars to dry 100 lbs. of textiles [d]	Ratio of range of CBF for test series to average CBF for test series (%)
	CBF	Rank	CBF	Rank	CBF	Rank		
22	2.22	3	11.9	2	54.5	1	$1.83	37%
5	2.26	1	12.0	1	54.1	2	$1.85	33%
31	2.26	1	11.9	2	53.7	3	$1.86	30%
6	2.15	4	11.2	4	49.6	4	$2.02	38%
3	2.03	5	10.8	5	49.3	5	$2.03	27%
2	1.98	6	10.6	6	48.5	6	$2.06	20%
4	1.36	7	7.26	7	33.2	7	$3.01	28%

[a] For site energy average CBF, alpha ($\propto$) and beta (β) are both equal to one. [b] For greenhouse gas (GHG) average CBF, the CASE Team converted gas energy values from kWh to therms and then used 5.316 kg CO_2e per therm (CARB 2008) for alpha ($\propto$). 0.437 kg CO_2e per kWh was used for beta (β) (CARB 2010). More details on the development of these values can be found in section 10.2. [c] For operational cost average CBF, 2015 equivalent dollars were used. The CASE Team converted gas energy values from kWh to therms and then used the forecasted 2020 price of $1.10 per therm (CEC 2014) for alpha ($\propto$). The expected 2020 price of $0.18 per kWh was used for beta (β) (CEC 2016). More details on the origin of these values can be found in Appendix A: Electricity and natural gas rates. [d] U.S. dollars to dry 100 pounds of textiles was derived by taking the reciprocal of the operational cost average CBF and multiplying by 100 for 100 pounds of textiles. Source: CASE Team measurements

Given the variety of facilities that use tumble dryers, the CASE Team expects load size, moisture content and settings to differ widely across facilities. Some businesses may be more interested in considering certain test runs under the IOU-proposed test procedure to inform their purchasing decisions. For example, a clothing manufacturing company in the Los Angeles Area uses relatively small and moist loads in its tumble dryers as a necessary part of the process to fabricate and finish designer jeans (Nexant 2015, p.3). For these types of facilities, using the Challenging Run (Run D) of the test procedure that provides the energy efficiency and operational cost of the dryer under smaller, wetter loads is likely a more appropriate test when considering which dryer to purchase for the facility.

Unfortunately, the average CBF is not necessarily a good predictor of the energy efficiency of the Challenging Run (Run D) because the difference between the CBF of the Challenging Run and the average CBF varies by dryer. For example, two dryers have a very similar average operational cost CBF of approximately 61.5 pounds of dry textile per dollar (Figure 5.5). However, their Challenging Run (Run D) CBFs differs by approximately 4.5 pounds per dollar (47.7 versus 52.3 pounds per dollar). When considering the average CBF, the dryers may appear equally efficient. However, with the additional information made available by the Challenging Run CBF, it becomes clear that one dryer will cost $2,000 more per year to operate, and over a 15-year lifetime, $30,000 more to operate (Table 5.9). Retaining the dryer longer than the estimated lifetime of 15-years would make the difference between the dryers even larger. With the economic pressures on U.S.-based manufacturing facilities, enabling California businesses to optimize their operational costs helps support the economic vitality of the State while reducing energy use and emissions.

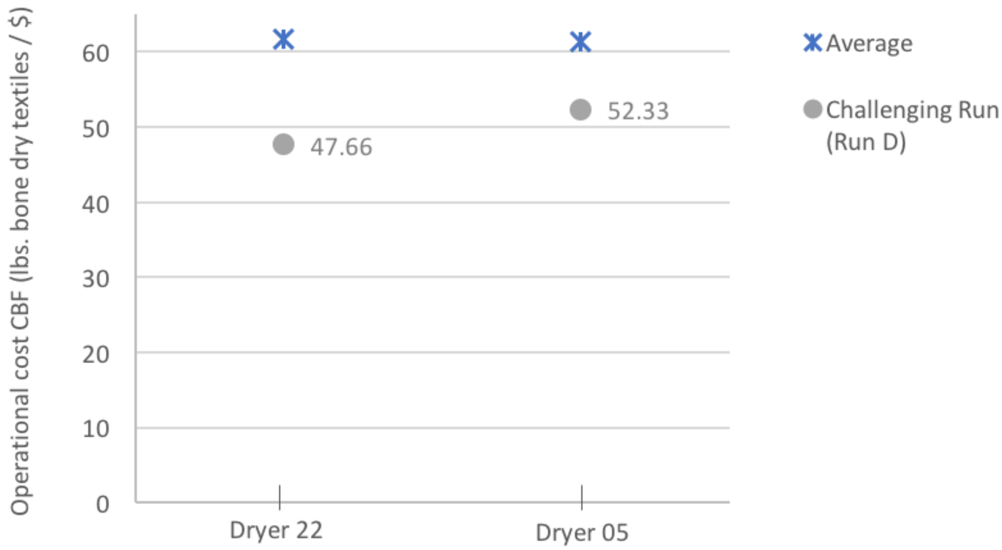

Figure 5.5 Difference between Average CBF and CBF of Run D for dryers tested by the CASE Team

Source: CASE Team measurements

Table 5.9 Cost savings for textile manufacturing facility when considering CBF of Run D instead of average CBF

Institution type	Total number of lbs. of textiles per year[a]	Approximate annual operational cost of Dryer 22, Run D CBF: 47.66 lbs./$	Approximate annual operational cost of Dryer 05, Run D CBF: 52.33 lbs./$	Annual Cost savings	Dryer lifetime cost savings
Textile Manufacturing	1,110,000	$26,000	$24,000	$2,000	$30,000

[a] Multiplied the average daily loads (On-premises Survey 2015, p. 10) by 365 days in a year. Assumed that the average size of the load of the dryer was 50 percent of the dryer capacity. Assumed that a laundry service company was a reasonable proxy for a textile manufacturing company. Source: CASE Team

The variation in the way the dryers operate is not limited to the Challenging Run (Run D). The average CBF is not a good predictor of the CBF of any individual run (AB, C, D, E, and F) underneath the IOU-proposed test series. Dryers are unique in the way they dry each textile load.

One way to illustrate this is to consider, for each dryer, the range of CBFs measured under the test series compared to the average CBF[16] of all the tests for that dryer (far right column, Table 5.8). When the full test series (Runs AB, C, D, E and F) is applied to some dryers, the range from lowest to highest CBF is only 20 percent of the average CBF of all the runs in the series. Whereas, for other dryers, ranges from the lowest to the highest CBF may be as high as 40 percent of the average CBF (Table 5.8). Applying a simple adjustment factor to the average CBF of a dryer to predict performance under a specific run in the protocol would be rudimentary, at best.

5.2.2 Known gaps in current IOU-proposed test procedure

The CASE Team intends to further update the test procedure language in 2017 to include special instructions for the largest of dryers as well as "stacking" (dual-pocket) tumble dryers. Expected updates including details on compressed air service set up for large dryers and cost-effective approaches to creating large loads. The CASE Team intends to supply these language updates to the Commission in early 2017.

6. Energy Usage and Savings

6.1 Efficiency Measures

The CASE Team survey of the market found that many of the dryer models that are available today have technology that has been employed for a decade or more. There are limited models that have started adoption of high efficiency technology, and there are many mature technologies available to improve the energy efficiency of commercial tumble dryers that may or may not be in today's models. Heat exchanger, heater and/or fan modulation, heat pump, and other technologies represent opportunities for savings between 20 and 50 percent of today's baseline use. This savings estimate does not include nascent technologies under development in the laboratory. Technologies not yet to market maturity, including the microwave dryer (Gerling, 2003), radiofrequency dryer (CoolDry, 2016), ultrasonic dryer ("Good Vibrations," 2016), mechanical steam compression dryer (Palandre, 2003) and a natural gas heat pump dryer are unlikely to be appropriate for standards consideration, and not included in this discussion.

6.1.1 Heat exchanger

A heat exchanger recovers the heat from the dryer exhaust and uses that heat to pre-warm the air before it goes into the burner. Pre-warmed air reduces energy use of the burner because less heat is required to get the intake air to the target temperature before it goes into the drum. Because this technology directly reduces the energy needed for the burner, it can save a significant portion of total dryer energy use (Figure 6.1).

[16] Arithmetic average of CBF for Runs AB, C, D, E, and F, as defined in the IOU-proposed test procedure.

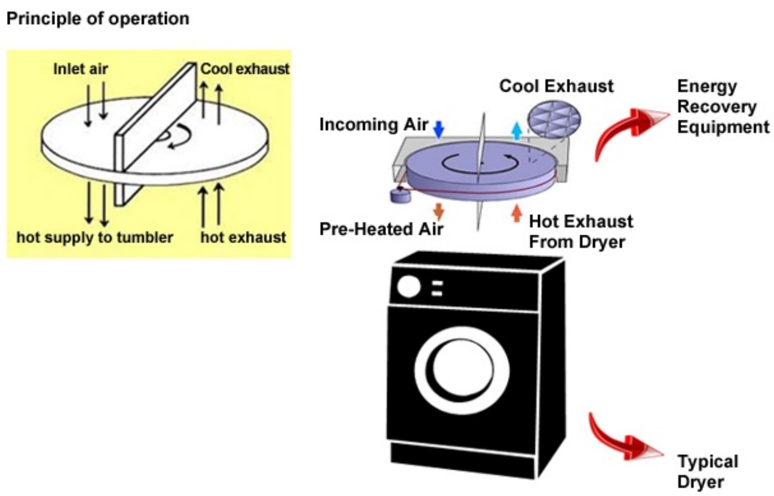

Figure 6.1 How a heat exchanger works with a dryer

Source: http://www.greentechcorp.net/rototherm/, used with permission

Heat exchangers are not widely employed in current dryers, but the technology is in the market today. When reviewing specification sheets for commercial gas and electric resistance tumble dryers, the CASE Team documented at least three manufacturers advertising the use of heat exchangers or heat recovery in tumble dryer models ("Electrolux Dryers for OPL" 2012, Stahl 2016, "Xeros 80XP Dryer" 2016). Two of these manufacturers distribute in the United States, and the other is in the European market.

Additionally, dryers in California and the U.S. have been retrofitted with heat exchangers to redcue energy use. Four companies in the U.S advertise a heat exchanger retrofit for commercial tumble dryers.[17] The CASE Team confirmed that two of these companies, Rototherm and 360 Mechanical Systems, have installed rotary heat exchangers[18] as retrofits on large dryers in situ. On one such installation in South Gate, California, a third-party engineering firm confirmed savings of 32 to 43 percent (Nexant 2012) in a Southern California Gas Company Emerging Technology Report. The CASE Team learned from a pioneer of the retrofit technology heat recovery installations are in California and around the U.S. and are functional and saving energy as-designed (Ben Herschel, personal communication, 2016). Furthermore, additional heat recovery wheels have been installed in a textile manufacturing plant in Mexico (Jon Columbo, personal communication, 2016). There was a patent on this technology for tumble dryers, but it is now expired.

The CASE team was not able to find measured results for commercial or residential dryers with factory-installed heat exchangers. However, residential dryer heat exchanger studies have documented savings as high as 26 percent. A 2014 study documented 17 percent improvement to

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[17] 360 Mechanical Systems (www.dryercube.com), Air Enterprises' ThermoDry (http://airenterprises.com/?s=thermodry&x=0&y=0), Rototherm, and Aqua Recycle's Thermal Recycle (http://thermalrecycle.com)

[18] Sometimes called heat recovery wheels

energy efficiency and 18 percent reduction in drying time when an air to air heat exchanger was installed on a conventional residential clothes dryer (Denkenberger 2014). This was a similar result to a 1984 study by Lawrence Berkley National Laboratory (LBNL) which showed a 20 to 26 percent efficiency gain (Heckmat 1984) with an analogous installation.

Given the promising savings opportunity, the CASE Team conducted a detailed investigation of the energy savings opportunity of a rotary heat exchanger in a commercial application. Using the IOU-proposed test procedure, the CASE Team measured the baseline energy efficiency of a dryer with drum volume of 36.1 cubic feet, load capacity of 120 pounds, and airflow of 1600 cubic feet per minute (site energy CBF results shown on left in Figure 6.3). The CASE Team then retrofitted the dryer to include a rotary heat exchanger of approximately 37 inches in diameter (left, Figure 6.2). The rotary heat exchanger was installed to enable the transfer the heat from the exhaust air stream to the intake air stream (right, Figure 6.2).

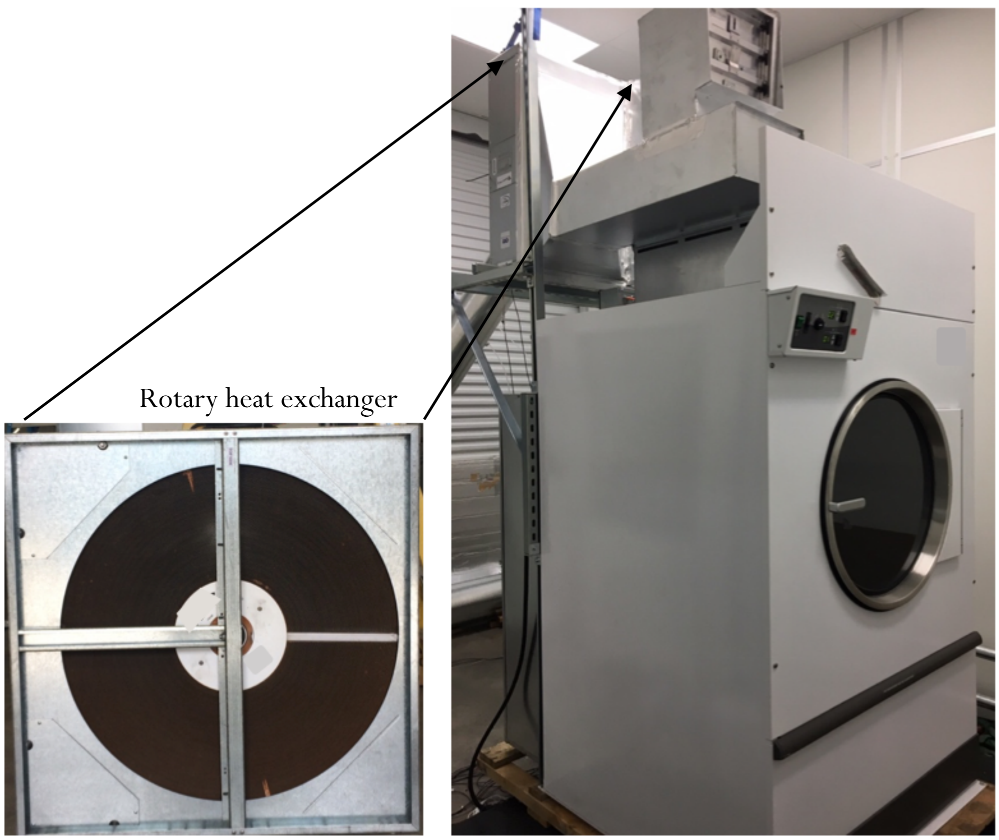

Figure 6.2 Rotary heat exchanger before installation on dryer (left); dryer with retrofitted heat exchanger in test chamber (right)

Source: CASE Team

After installation, the energy performance of this dryer improved by an average of 11 percent over the test series, even without any alterations to the dryer controls/programs to optimize the benefit of the heat exchanger (Figure 6.3). The run with the least amount of improvement was Run C, the over dry test, which showed an improvement of 8 percent over the baseline. The site energy CBF improved by 13 percent in both Run E (Favorable) and Run D (Challenging) (Figure 6.3). Further analysis of the effectiveness of the heat exchanger system could reveal opportunities to increase the energy savings further. The CASE Team found that program time was unaffected by the installation of the heat exchanger (+/- 1 or 2 minutes, depending on the run), even though other studies showed a reduction in program time with a heat exchanger. Manufacturer-optimized controls of a dryer with a heat exchanger may lead to reduced program time.

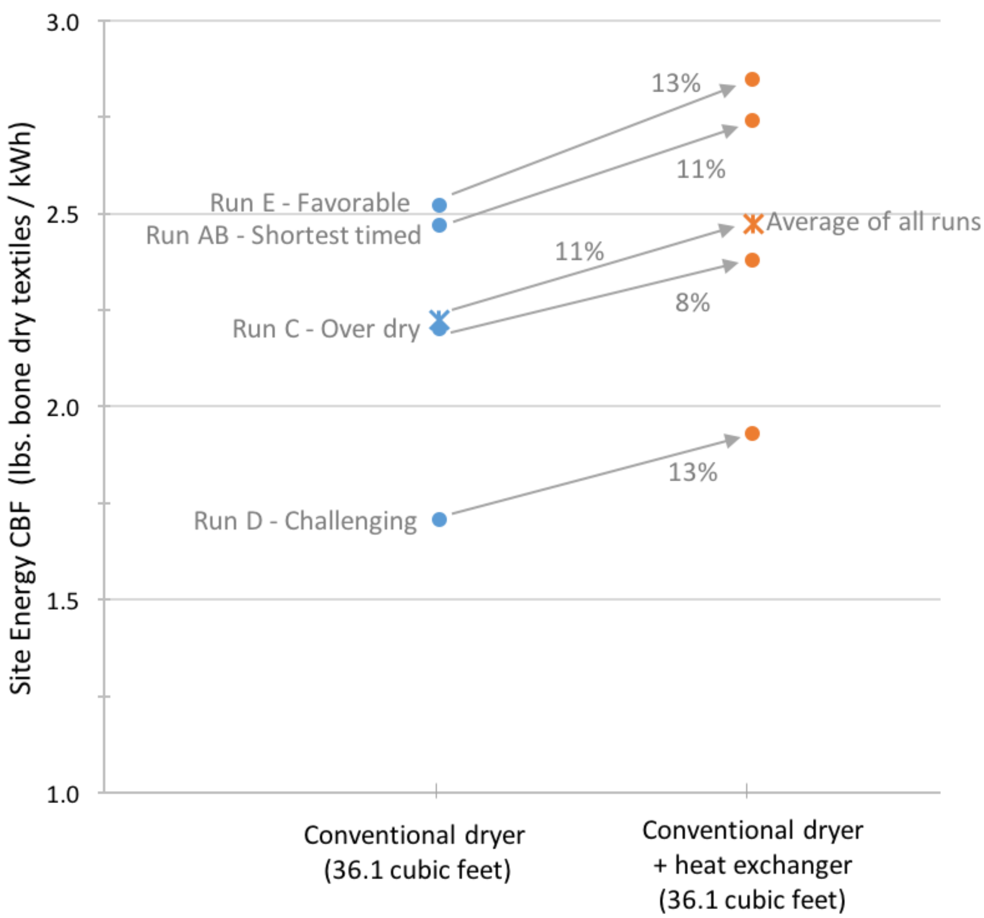

Figure 6.3 Test results of commercial tumble dryer with heat exchanger installed

Source: CASE Team

The rotary heat exchanger installed by the CASE Team is self-cleaning because it is reversing flow, with the airflow of the intake in the opposite direction of the exhaust in the same channels. Lint that accumulates from the exhaust is continuously blown out by the intake side of the recovery wheel (Figure 6.4). For large, high duty cycle installations, an automated heat wheel blow off system can be used to further keep the heat wheel free of lint (Nexant 2012). These systems employ compressed air, which is already available at facilities where these dryers are installed, as the dryers themselves often require compressed air service for operation. For smaller dryers with a lower duty cycle, it is likely that a regular maintenance schedule to vacuum or blow out the exchanger at the frequency that ducts are recommended for cleaning would sufficiently maintain performance of the heat exchanger and eliminate fire hazard.

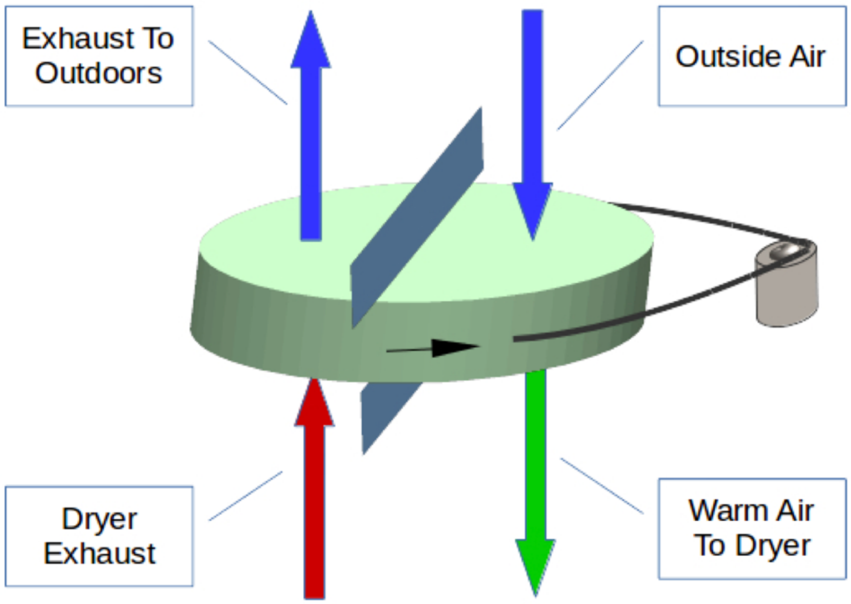

Figure 6.4 Heat recovery wheel with self-cleaning reversing airflow

Source: Desiccant Rotors International, 2016. Used with permission.

6.1.2 Heater/fan modulation

To reduce drying time, commercial dryers are generally designed to have fast airflow and high temperature. A high exhaust rate has little benefit when the dryer is coming up to temperature at the beginning of the cycle and when the load is nearly finished drying at the end of the cycle. Slower air movement during the beginning and end of the cycle allows more time for heat transfer and evaporation, while still removing moisture from the load. Further energy savings can be achieved through matching (or modulating) the heat input rate to the moisture content of the load as well, by turning down the heat input rate later in the cycle. A key consideration is that drying time may be slightly longer with modulation, depending on temperature settings and loads.

Even though gas modulation is a relatively mature technology, CASE's Team has not been able to confirm that any of today's commercial tumble dryers are taking advantage of fan/burner modulation. They are instead equipped with constant heat input burners and fixed-speed fans generally driven by single speed alternating current (ac) motors. Depending on the cycle settings and the exhaust flow temperatures, the burner cycles between full on and completely off, and the airflow stays relatively constant. Dryers using this technology would need to incorporate a higher efficiency fan motor that can operate on more than one speed. Two stage gas valves, common in high-efficiency furnaces, are readily-available and would be needed for burner modulation. Figure 6.5 shows an example of a typical dryer gas valve on the left and a two-stage gas valve that is made by the same component supplier used in today's efficient furnaces. The match in form factor and fittings make replacement easy. Fabric moisture sensors in the drum along with standard exhaust temperature sensors could provide more detailed feedback to the modulation controller enabling further refinements to the modulation algorithms employed.

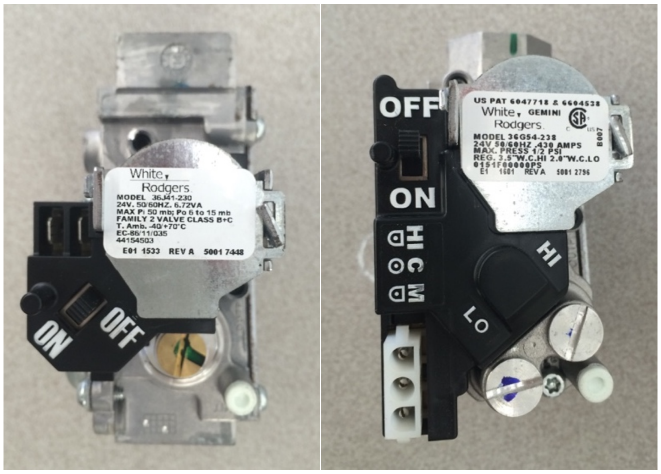

Figure 6.5 Single-stage gas valve (left) and two-stage gas valve (right)

Source: CASE Team

Burner and fan modulation that has been studied in residential gas dryers has yielded encouraging results. A U.S. Department of Energy report from 2005 shows up to a 25 percent reduction in energy consumption for small to medium loads. Large loads showed a 10 to 15 percent energy reduction, and up to 35 percent time savings. Delicate loads resulted in 18 percent energy reduction, along with reduced fabric temperatures and dry times (Pescatore, 2005).

Energy savings results from burner modulation (without fan modulation) have also been documented in the commercial sector. Installations of burner modulation retrofit kits on existing commercial tumble dryers in Illinois hotel, laundromat, healthcare and dry cleaning facilities showed an energy savings between 12 and 13 percent. Total installation cost was approximately $525 per dryer (Scott 2014). A similar burner modulation technology was also installed in a facility in Burlingame, California. Measurements of this installation revealed a 25% reduction in energy use per pound of moisture removed (Cindy Hoogerhyde, personal communication, 2016).

6.1.3 Heat pump

Heat pump clothes dryer technology has been in existence for years as an alternative to electric resistance heating models. As utilities and other entities have started to provide incentives for these technologies in the residential market, heat pump residential models are now available in the U.S. ("Super-Efficient Dryers" 2016). Commercial heat pump models are available in Europe (e.g. Electrolux Tumble Dryer T5190LE).

Although the technology is improving, concerns about long drying time remain. Adding electric resistive to "boost" up heat output when required could help trade off efficiency with drying time to find an optimal market balance. Integrated heat recovery exhaust condensers could capture heat, increasing efficiency and shortening dry time. Under a demonstration project funded by the U.S. DOE and led by TIAX, a modified heat pump clothes dryer delivered 40 to 50 percent energy savings with 35 degree Fahrenheit lower fabric temperatures and similar drying times for regular loads. Delicate loads benefitted from a 10-30° F reduction in temperature with up to 50 percent energy savings and 30 to 40 percent-time savings (Pescatore 2005).

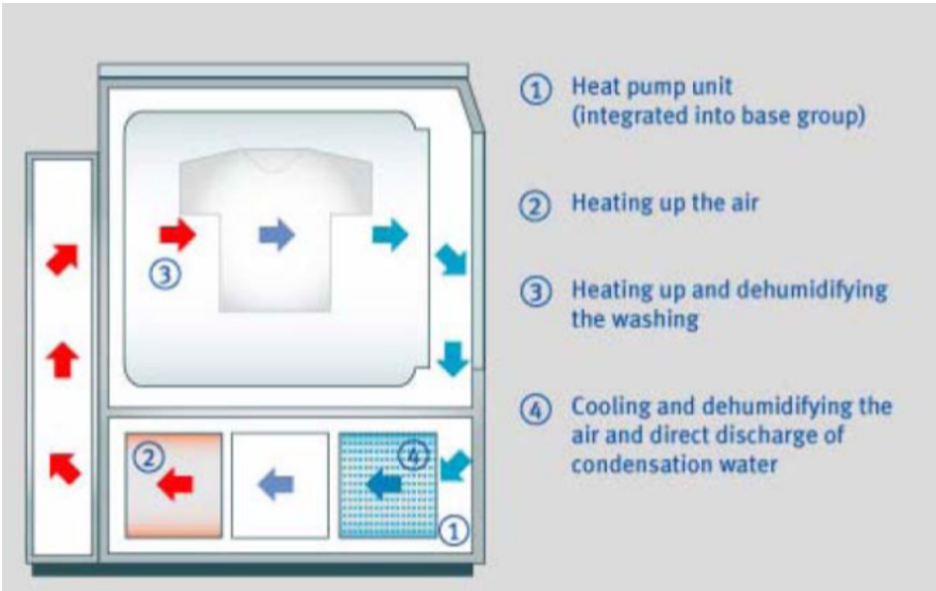

Figure 6.6 How an electric heat pump dryer works

Source: Meyers 2010

6.1.4 Other technologies[19]

Other technologies are available to improve the efficiency of commercial tumble dryers, including automatic termination, air sealing and insulation, improved motor efficiency, and improved standby power design.

Automatic termination. Moisture sensors and/or temperature sensors can be used to support modulation of the burner and fan in timed dry, but can also be used to automatically terminate dryer operation when the textiles are dry. This method of control and termination is commonly used for residential dryers, and the moisture sensing feature is available from at least six commercial dryer manufacturers today.

Reliable sensors are key to the performance of automatic termination specifically and effective control generally. Numerous studies have been dedicated to advancing more reliable sensing technologies and more accurate end-of-cycle moisture content estimation. In general, automatic termination control based on moisture sensors can perform better than those based on temperature sensors. Moisture strips, one of the more advanced moisture sensor technologies, detect textile moisture content by measuring the conductivity of the clothes in the dryer drum. They can accurately measure middle-range clothes' moisture content and can be further improved to measure low-range, i.e. below 15 percent, moisture content. Measuring exhaust air relative humidity is another moisture sensing technology, but its performance can also be impacted by condensation, lint trapping and sensitivity issues. A study shows that these issues can be partially

[19] This section was modified from the 2013 CASE Report by the CASE Team (Zhang 2013).

mitigated by incorporating a control scheme with measurements of ambient humidity levels (Deng 2008).

While automatic termination may not have historically be used for vended laundry where consumers have come to expect to get a certain number of minutes for a fixed price, there are some market trends that suggest this may be acceptable to consumers and laundromat owners. In a Coin Laundry Association laundry customer survey, 33 percent of consumers said that they would prefer a fixed price for drying their loads as an alternative to paying by the minute ("Laundry Customer Profile" 2006, p. 21). In a 2015 industry survey of laundromat owners, 11 percent said they were currently offering fixed price dryer cycles ("Coin Laundry Industry Survey" 2015).

Efficient motors, insulation, and standby power. Installing more efficient motors to turn the dryer drum and fan, as well as air sealing and insulation of the cabinet are additional strategies to improve commercial tumble dryer efficiency.

Opportunities also exist to reduce standby power. The CASE Team measurements of standby power of seven dryers revealed standby as high as 14.5 watts and as low as 3.3 watts for models with vended (coin operated) controls (Figure 4.1). On-premises style controls varied from 6.5 watts to 17.7 watts (Figure 4.1). Inefficient models were equipped with large heat sinks on the control boards while the efficient model with little waste heat had its low power controls in a small enclosed package (Figure 6.7).

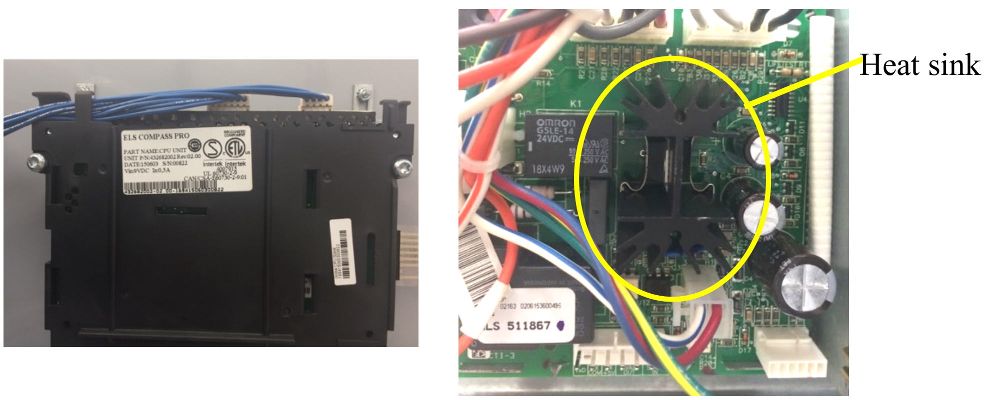

Figure 6.7 Control circuits for vended Dryer 6 (left) with 3.3 W standby power and vended Dryer 5 (right) with 14.5 W standby power

Source: CASE Team

6.1.5 Efficient technology summary

Table 6.1 summarizes the efficient technologies and the applicable dryer types. Also listed in the table is the range of savings expected from the technology. Please note that while some of the sources documenting savings are from studies on residential dryers, the basic design and technology for commercial and residential tumble dryers is the same, meaning the same thermal, airflow and related science applies. The savings studied in residential models is expected to translate into commercial models.

Table 6.1 Efficient dryer technology summary

Technology	Applicable dryer type	Energy Savings (as a percent from baseline)	Program (cycle) Time Change (compared to baseline)
Heat exchanger	Gas and electric	8%[a] to 40%[b]	Shorter or the same
Burner/fan modulation with controls	Gas and electric	3%[c] to 25%[d]	Longer or shorter, depending on implementation
Heat Pump	Electric	13%[e] to 60%[f]	Longer or the same, depending on the use of electric resistance boost and other supporting technologies
Other (automatic termination, improved motors, insulation, exhaust recirculation)	Gas and electric	15%[g] to 20%[h]	Various: some shorter, some longer, some are the same.

[a] CASE Team measurements, [b] Nexant 2012, [c] CASE Team measurements, [d] Pescatore 2005, [e] EPA 2014, [f] Denkenberger 2013, [g] Hannas 2014, Denkenberger 2014: estimates include automatic termination and improved insulation only, [h] Denkenberger 2014: estimates include automatic termination and improved insulation only

6.2 Per Unit Energy Use Methodology

This section presents an estimate of the per unit energy use for commercial tumble dryers by drum volume in cubic feet.

6.2.1 Annual Per Unit Energy Use Methodology

The per unit energy use of a commercial tumble dryer is calculated by taking the product of the following:

1) the estimated weight of textiles dried per year per dryer
2) the number of kWh (or therms) used per pound of bone dry textiles

This calculation yields annual therms of gas and annual kWh of electricity for gas dryers and annual kWh for electric dryers. The table below gives a summary of the values used for the calculation and a description of the sources used for each of the values.

Table 6.2 Values and sources for unit energy consumption calculations

Dryer size (cubic feet of drum volume)	**Weight of textiles dried annually** (lbs.)	**Electric energy use of gas dryers** (kWh per lb. of textile)	**Gas energy use** (Therms per lb. of textile)	**Electric energy use of electric dryers** (kWh per lb. of textile)
< 7.5 [a,c,c,c]	7,711	0.043	0.0169	0.489
>/= 7.5 and <13 [b,f,f,f]	29,200	0.017	0.0189	0.518
>/=13 and < 17 [d,f,f,f]	123,889	0.013	0.0146	0.402
>/= 17 and <21 [d,f,f,f]	524,707	0.013	0.0146	0.402
>/=21 and < 37 [d,f,f,f]	546,821	0.010	0.0161	0.438
>/=37 and <65 [d,f,f,f]	908,520	0.009	0.0151	0.410

Sources for values in each column are listed left to right in the far-left column. Sources: [a] Weight of textiles dried annually is calculated by taking the product of the number of loads per day (2.5 loads per day, Manthei 2013), the weight of textiles per load, and the operational days per year (year-round operation is assumed: 365 days). The CASE Team assumes load size of the smallest machines to be similar to a residential load, so the Team used the U.S. DOE load weight of 8.45 pounds (U.S. DOE 2013). [b] Weight of textiles dried annually is calculated by taking the product of the number of loads per day (4 loads per day, Manthei 2013), an assumed 20 pounds of textiles per load (Zhang 2013, p. 19), and the number of operational days per year (year-round operation is assumed: 365 days). [c] CASE Team measurements of baseline residential gas dryer efficiency under the utility test protocol (Clothes Dryer Utility Test Protocol, 2015) are assumed to be similar to commercial gas tumble dryers of similar size tested under the IOU-proposed commercial tumble dryer protocol. [d] Calculated by weighting the total daily load (30.4 million pounds) in the CASE Team market survey (On-Premises Survey 2015, p. 18, Table 8) by dryer size category and then dividing that total weighted daily load by stock of that same size category given in the same document (On-Premises Survey 2015, p. 14, Table 6) to yield weight of textiles dried annually. [f] CASE Team measurements of market-available commercial tumble dryers in PG&E ATS laboratory. Values are derived from the average site energy cost-benefit factor (CBF) under the IOU-proposed test procedure factor (α and β are to one (1) to enable the calculation of site CBF). The average of all the dryers in the drum volume category is used to represent the energy use.

6.2.2 Peak Demand Methodology

Peak demand was calculated by dividing daily electricity average use by the assumed load factor of 0.73, the factor used for this category of electric loads in commercial buildings (Brown & Koomey 2002).

6.3 Summary of Per Unit Energy Use Impacts

Annual per unit energy impacts are presented in Table 6.3 below. The methodology used to calculate these estimates is presented above in Section 6.2.

Table 6.3 Annual per unit energy use

Dryer Size (in cubic feet of drum volume)	**Electricity Use (kWh/yr.)**	**Peak Demand (kW)**	**Natural Gas Use (therms/yr.)**
Gas: < 7.5	330	0.05	130
Electric: < 7.5	3,800	0.6	-
Gas: >/= 7.5 and <13	500	0.1	550
Electric >/= 7.5 and <13	15,000	2.4	-
Gas: >/=13 and < 17	1,600	0.3	1,800
Electric: >/=13 and < 17	50,000	7.8	-
Gas: >/= 17 and <21	7,000	1.1	7,700
Electric: >/= 17 and <21	210,000	33	-
Gas: >/=21 and < 37	5,300	0.8	8,800
Electric: >/=21 and < 37	240,000	37	-
Gas: >/=37 and <65	8,200	1.3	14,000
Electric: >/=37 and <65	370,000	58	-

Source: CASE Team analysis 2016

7. Estimated Statewide Energy Savings

Because adoption of the commercial tumble dryer test protocol proposed in this report does not have direct energy and environmental impacts, the purpose of this section is to describe the methodology the CASE Team used to estimate energy, cost, and greenhouse gas emissions associated with current commercial tumble dryer use. Additionally, the CASE Team presents an estimated savings value based on technology surveyed to date. This is not energy savings associated with a potential standards level, and is estimated based on measurements and technical research by the CASE Team.

7.1 Statewide Energy Savings Methodology

Statewide use and savings estimates were calculated by applying unit energy savings to the statewide stock and sales numbers presented in Section 4.2. Based on the technology opportunities outlined in Section 6.1 and summarized in Table 6.1, the CASE Team estimates that energy use of these appliances can be reduced by 20 to 50 percent. Two savings values are given, and are both calculated by taking the product of the percent savings and current energy use.
Statewide Energy Savings

Table 7.1 provides the current statewide energy use associated with commercial tumble dryers. Because natural gas is the preferred fuel for these appliances, that fuel dominates the total energy expended in the state. Note that approximately half of the energy use is from dryers less than 13 cubic feet and approximately half of the use is from the larger machines more commonly used in on-premises laundry.

Table 7.1 Current California statewide commercial tumble dryer energy use

Dryer Size (in cubic feet of drum volume)	**Annual Shipments**			**Stock**		
	Natural Gas Use (million therms/ yr.)	Electricity Use (GWh/yr.)	Electricity Demand (MW)[a]	Natural Gas Use (million therms/ yr.)	Electricity Use (GWh/yr.)	Peak Demand (MW)[a]
Gas: < 7.5	1.9	4.9	0.8	29	73	11
Electric: < 7.5	-	20	3.1	-	300	46
Gas: >/= 7.5 and <13	6.8	6.1	1.0	100	92	14
Electric >/= 7.5 and <13	-	9.8	1.5	-	150	23
Gas: >/=13 and < 17	0.3	0.3	0.05	4.6	4.2	0.7
Electric: >/=13 and < 17	-	0.5	0.1	-	6.7	1.0
Gas: >/= 17 and <21	3.7	3.4	0.5	56	50	7.9
Electric: >/= 17 and <21	-	5.4	0.8	-	80	13
Gas: >/=21 and < 37	3.6	2.2	0.3	54	32	5.1
Electric: >/=21 and < 37	-	5.2	0.8	-	78	12
Gas: >/=37 and <65	1.2	0.7	0.1	17	10	1.6
Electric: >/=37 and <65	-	1.7	0.3	-	25	3.9
Totals	**18**	**60**	**9.4**	**260**	**900**	**140**

Source: CASE Team analysis 2016; [a] Statewide demand (and demand reduction) is quantified as coincident peak load, the simultaneous peak load for all end users, as defined by Koomey and Brown (2002).

Table 7.2 provides an estimate of potential savings associated with a future commercial tumble dryer standards proposal. Values for energy savings associated with the first year of sales (annual shipments) and total stock turnover (stock) are both given. Methodology used for the estimate is summarized in Section 7.1.

Table 7.2 California statewide commercial tumble dryer energy savings potential

Total Market	**Annual Shipments**		**Stock**	
	Natural Gas Use (million therms/ yr.)	Electricity Use (GWh/yr.)	Natural Gas Use (million therms/ yr.)	Electricity Use (GWh/yr.)
20% reduction of total energy use	3.5	12	52	180
50% reduction of total energy use	8.8	30	130	450

Source: CASE Team analysis 2016

8. Economic Information

The adoption of this test procedure does not have direct savings associated with it, and so a detailed economic analysis on compliance to a future standard is not included in this report. However, The CASE team has some preliminary information on incremental cost and design life.

8.1 Incremental Cost

The CASE Team plans to conduct a full investigation of incremental cost in 2017 as part of its CASE Report for commercial dryer standards. However, the limited information that we have today suggests many of the technologies for savings are highly cost effective. For example, the component cost of a rotary heat exchanger that serves a 36 cubic foot (120 pound) dryer is between $1600 and $2000 (Mark Clark, personal communication, 2016). If this rotary heat exchanger were incorporated into dryer design, some capital costs for manufacturers would need to be applied for redesign, re-tooling of assembly lines, etc. However, these dryers are rarely redesigned, and so re-tooling and design costs can be applied over multiple years. Given the way product lines are developed, it is possible that costs could even be applied over multiple models. Assuming this capital cost adds an additional $1000 per dryer, or even more, the total incremental cost of the equipment (per unit) would be likely be less than $5000.

The approximate cost to operate a gas dryer of that size is between $10,000 and $16,000 annually, depending on duty cycle, etc.[20] If the heat exchanger saves even a modest 15 percent of the energy use (and energy costs), operational costs would go down by $1500 to $2500 annually. Even an incremental first cost of $5000 would pay pack very quickly (2 to 3 years) in equipment that has an overall lifetime of 15 to 20 years.

8.2 Design Life

In 2013, the CASE team conducted interviews with manufacturers and distributors and docketed a summary of that information for public review (Zhang 2013). From that report:

> *Based on interviews with manufacturers and distributors, the useful life of commercial dryers is about 14 years. However, distributors believe that owners of commercial dryers often opt to fix old dryers rather than replace them with new ones for cost considerations. Therefore, the effective equipment life including service time after repairs is longer.*

In a subsequent CASE Team telephone survey of customers using this equipment in a range of facilities, the lifetimes of commercial tumble dryers ranged from 15 to 30 years, with longer lifetimes reported for larger equipment (On-premises Survey 2015 p. 11). In a laundromat industry market report, which approximately represents machines 7.5 to 17 cubic feet (18 to 55 pound), dryer optimal lifetime reported was 12 to 15 years (Deciding When, Date Omitted). Reliability, repair costs, parts availability, efficiency, and (for vended machines) customer appeal influence replacement decisions. Given this information, the CASE Team uses a simplified 15-year lifetime to develop energy use and savings estimates although there is evidence that for the largest dryers, a more appropriate lifetime may be 20 years.

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[20] Energy costs using expected rate in 2020 (CEC 2016 and CEC 2014). 2020 rate is sales-weighted average of the largest California utilities. Electric rates and gas rates are in 2015 equivalent dollars. More information on how rates are calculated can be found in Appendix A.

9. Test Procedure Implementation Issues

9.1 Infrastructure issues

Because the test procedure has just been developed, there are no labs today that are testing to the IOU-proposed test procedure. However, there are many aspects of the test procedure that are similar to the U.S. DOE dryer test procedure and the ANSI/AHAM HLD-1-2010 test procedure that make it possible to adapt facilities that currently test residential products to commercial products. Examples include:

- Temperature and humidity controlled room required
- Same test cloths and age-weighted approach as AHAM/ANSI procedure.
- Same water hardness, water temperature requirements, and standard detergent (AHAM Formula 3) for wash and rinse as U.S. DOE.
- Same bone dry procedure as U.S. DOE
- Same measurement approach for the drum volume as U.S. DOE for the smallest residential-platform commercial dryers
- Same termination approach as U.S. DOE for the test run that uses automatic termination (Run F)

Knowledge of basic procedure for DOE gives familiarity to technicians testing to the new proposed procedure. However, there are number of changes that need to be made to accommodate the larger dryers. Most notably, larger gas flow meters that accommodate the rates of flow, a larger (commercial) washing machine, and a larger scale to weigh larger loads.

9.2 Stakeholder Positions

Several stakeholders prepared comments in 2013 under California Energy Commission docket #12-AAER-2D. Comments from 2013 from industry association AHAM and manufacturers Whirlpool and Alliance Laundry Systems focused on providing information on the differences between residential and commercial tumble dryers (Messner 2013a, Gillespie 2013, Manthei 2013). Additionally, AHAM recommended that no standard be pursued given the possibility of other California laws regulating consumer increments of drying time for vended dryers may be conflicting with a standard that requires automatic termination, among other reasons (Messner 2013b).

Natural Resources Defense Council provided findings from its own 2009 research (Bendt, 2009) and encouraged the Energy Commission to continue pursuing commercial dryer standards (Waltner 2013). Additional organizations that submitted comments of support for standards included The American Council for an Energy-Efficient Economy (ACEEE), The Appliance Standard Awareness Project (ASAP), National Grid, and the Northeast Energy Efficiency Partnerships (Amann 2013, deLaski 2013, Coughlin 2013, Coakley 2013).

The CASE Team expects manufacturer concerns about the overall burden/cost of implementing the test procedure, specifically the requirement for 5 to 6 runs in a test series. Given the variety of placement, location, and operation of these machines, the CASE Team recommends a test procedure that gives all stakeholders, including business, utilities, and policymakers more data points that provide information for "as designed" operation, but also provide other scenarios, including a range of performance for consideration.

Although DOE only requires one run on two dryers to qualify a product, this is an inordinately low burden compared to other similar appliances. For example, the washer test procedure that the DOE uses for washer standards requires, for most washers, 9 runs for a test series (U.S. DOE Washer 2015) each on 2 to 3 different units (U.S. DOE Washer Sample 2015) for a total of 18 to 27 runs. The IEC dryer test procedure suggests 5 runs per load type (cotton or synthetic). If conducting a test for both cotton and synthetic, 10 runs may be conducted.

Finally, California businesses that rely on dryers for daily operation may support a test procedure for commercial tumble dryers as a first step to reduce operational costs of their facilities. High cost of utilities is a significant concern for owners of coin laundries (Coin Laundry Industry Survey 2015). However, businesses and apartment managers have little information to help inform purchasing decisions for commercial tumble dryers and, it is not at all clear on what basis that percentage is measured nor whether that savings will be realized once installed.

10. Environmental Impacts

10.1 Hazardous Materials

Although the test procedure does not mandate any energy efficiency requirement for commercial tumble dryers, all the technological opportunities to improve gas and conventional electric dryers reviewed in this report have no known incremental hazardous materials impacts associated with them.

10.2 Greenhouse Gases

Table 10.1 presents the annual and stock greenhouse gas (GHG) potential savings for the first year of sales and the potential savings after full stock turnover. The CASE Team calculated the avoided GHG emissions from the adoption of the standard assuming 437 metric tons of carbon dioxide equivalent ($MTCO_2e$) per GWh of electricity savings (CARB 2010) and 5,316 $MTCO_2e$ per one million therms (CARB 2008).

For natural gas, avoided GHG emissions are relatively static, however the avoided GHG emissions associated with electricity shift as more renewables are added to the grid. The CASE Team used California Air Resources Board (CARB) data to determine an avoided carbon dioxide emission factor for electricity. CARB prepared an analysis of increasing California's renewable portfolio standard from 20 percent renewables by 2020 to 33 percent renewables by 2020 with different future electricity demand scenarios.[21] The electricity savings emissions factor used in this report is intended to provide a benchmark of emissions reductions attributable to energy efficiency measures that would help achieve the low load scenario. The emissions factor is calculated by dividing the difference between California emissions in the high and low generation forecasts by the difference

[21] CARB calculated GHG emissions for two scenarios: (1) a high load scenario in which load continues at the same rate and (2) a low load rate that assumes the state will successfully implement energy efficiency strategies outlined in the AB32 (Global Warming Solutions Act) scoping plan, which would reduce overall electricity load in the state (CARB 2010). The CASE Team calculated the emissions factors of the incremental electricity savings between the low and high load scenarios.

between total electricity generated in those two scenarios. While emission rates may change over time, 2020 is a representative year for this measure.

As shown in Table 10.1 below, the estimated annual statewide GHG savings is between 24,000 and 60,000 $MTCO_2e$ for the first year and between 357,000 and 892,000 $MTCO_2e$ after full stock turnover.

Table 10.1 Estimated California statewide greenhouse gas savings potential

Total Market	Annual GHG Savings First Year Sales ($MTCO_2e$/yr.)			Stock GHG Savings ($MTCO_2e$/yr.)		
	Natural Gas	Electricity	**Total**	Natural Gas	Electricity	**Total**
20% reduction of total energy use	19,000	5,000	**24,000**	280,000	78,000	**360,000**
50% reduction of total energy use	47,000	13,000	**60,000**	700,000	200,000	**890,000**

11. Proposed Code Language

The proposed changes to the Title 20 code language are provided below.

11.1 Summary of Proposed Language

The proposed code language change is the test procedure for evaluating the energy efficiency of commercial tumble dryers included in the citation list and as an attachment to this report (Foster Porter 2016). The test procedure sections include scope, references, definitions, basic dryer model selection, testing conditions, drum capacity determination, energy performance test, and calculations from derived results.

The CASE Team intends to further update the test procedure language in 2017 to include special instructions for the largest of dryers as well as "stacking" (dual-pocket) tumble dryers. Expected updates including details on compressed air service set up for large dryers and cost-effective approaches to creating large loads. The CASE Team intends to supply these language updates to the Commission in early 2017. The CASE Team recommends that the Energy Commission adopt the "Energy Efficiency Test Procedure for Commercial Tumble Dryers," with the forthcoming language updates in 2017.

11.2 Proposed Changes to the Title 20 Code Language

The proposed code language is "Energy Efficiency Test Procedure for Commercial Tumble Dryers" document in full (Foster Porter 2016) with expected updates to the document in 2017. It is referenced in the references section, and was submitted along with this CASE Report.

12. References

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Appendix A: Electricity and natural gas rates

The electricity rates used in the analysis presented in this report were derived from projected future prices for residential, commercial and industrial sectors in the CEC's Draft "Mid-case" projection of the 2017-2027 Demand Forecast (CEC 2016), which provides prices in 2015 dollars. The sales weighted average of the 5 largest utilities in California is given by year below in in Table A.1.

Table A.1 Statewide sales-weighted average commercial electricity rates 2018 – 2030 (PG&E, SCE, SDG&E, LADWP and SMUD - 5 largest utilities) in 2015 cents/kWh

Year	Commercial Electricity Rate (2015 cents/kWh)
2018	16.95
2019	17.27
2020	17.56
2021	17.68
2022	17.61
2023	17.56
2024	17.66
2025	17.68
2026	17.73
2027	17.77
2028	17.81
2029	17.86
2030	17.90

The natural gas rates used in the analysis presented in this report were derived from projected future prices for residential, commercial and industrial sectors in the CEC's "Mid-case" projection of the 2014-2024 Demand Forecast (CEC 2014), which provides prices in 2012 dollars. The sales weighted average of the 5 largest utilities in California was converted to 2015 dollars using an inflation adjustment of 1.03 (U.S. DOL 2016). Values for 2026 to 2030 are extrapolated based on finding in the Demand Forecast Report. See the rates by year below in Table A.2.

Table A.2 Statewide sales-weighted average natural gas rates 2018 – 2030 (PG&E, SCE, SDG&E, LADWP and SMUD - 5 largest utilities) in 2015 dollars/therm

Year	Commercial Natural Gas Rate (2015 $/Therm)
2018	1.05
2019	1.07
2020	1.10
2021	1.11
2022	1.14
2023	1.16
2024	1.21
2025	1.25
2026	1.30
2027	1.34
2028	1.39
2029	1.44
2030	1.49

Appendix B: Summary of CASE Team data collected under the IOU-proposed test protocol for commercial tumble dryers

Table B.1 Summary of commercial tumble dryer data collected by CASE Team

Dryer ID	Rated drum volume (ft^3)	Rated load capacity (lbs.)	Standby power (watts)	Wrinkle-prevention mode power (watts)	Average power factor for test series	Average program time (min)	Average CBF for test series (lbs. of bone dry textiles /site kWh)	Average CBF for test series (lbs. of bone dry textiles /kg CO_2e)	Average CBF (lbs. of bone dry textiles /$)	Ratio of range of CBF for test series to average CBF for test series (%)
6	10.2	35.5	3.3	56	0.93	34	2.15	11.20	49.60	38%
4	11.7	30	11.9	37	0.65	56	1.36	7.26	33.24	28%
31	17.3	55	7.0	173	0.82	37	2.26	11.91	53.68	30%
5	17.3	55	14.5	NA	0.81	34	2.26	11.95	54.12	33%
2	22.4	75	9.3	196	0.63	36	1.98	10.58	48.48	20%
3	22.4	75	6.5	181	0.63	41	2.03	10.80	49.26	27%
22	36.1	120	17.7	309	0.64	34	2.22	11.88	54.52	37%