CPSC Staff Statement on the
Southwest Research Institute Report,
"Internal Cabinet Temperature Evaluation of Three Models of Commercially Available Resistive Element Clothes Dryers"
July 2015

The report titled, "Internal Cabinet Temperature Evaluation of Three Models of Commercially Available Resistive Element Clothes Dryers," presents the findings of research conducted by Southwest Research Institute (SwRI) under a contract with the U.S. Consumer Product Safety Commission (CPSC). SwRI performed this research to characterize the surface temperatures in electric clothes dryer cabinets (outside the tumbler) with and without thermal insulation added. This research was completed in support of CPSC's work on reducing deaths and serious injuries associated with fires in clothes dryers. CPSC staff will consider this information in evaluating possible proposals to amend the voluntary standard, UL 2158, *Electric Clothes Dryers*.

This report will be posted on CPSC's website to keep stakeholders informed of the progress of technical research related to the agency's voluntary standards activities.

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INTERNAL CABINET TEMPERATURE EVALUATION OF THREE MODELS OF COMMERCIALLY AVAILABLE RESISTIVE ELEMENT CLOTHES DRYERS

FINAL REPORT
Consisting of 59 Pages

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ABSTRACT

Southwest Research Institute® (SwRI®) conducted a series of tests to evaluate the effectiveness of insulation in reducing the temperature of surfaces in the dryer cabinet on which lint, fibers or dust may accumulate, without adversely affecting dryer performance. Three dryers were selected as a representative sample set of commercially available, resistive-element electric clothes dryers. Pre-tests were performed to identify hot spots in each dryer. The dryers were instrumented with thermocouples at select locations, and the power cables were connected to circuitry to monitor voltage and current draw of each dryer during testing. First, the unmodified dryers were operated with a standardized clothing load to characterize the temperatures, voltage, and current draw during typical operation. Dryers 1 and 3 were modified by installing flexible insulation material to the dryer heating element duct. Dryer 2 was modified by installing a second wall to the dryer heating element duct using sheet metal essentially creating a double wall duct with an air space between each wall to provide insulation. Additional thermocouples were added to the exterior surface of the insulation to compare the temperature measurement during the dryer cycles. Finally, the insulated dryers were operated with the same standardized clothing load to determine the effect of the insulation on the hot spot temperatures, and voltage and current draw.

The unmodified dryer cycle evaluations found that the surface of the heating element duct provided the hottest measured surfaces in the dryer cabinet. Each of the modifications reduced the external surface temperature in those areas and also reduced the air temperature in the space below the tumbler. The insulation techniques utilized did not have a significant effect on the apparent power consumption of the dryers. This information could be used to consider producing dryers with added insulation that could reduce the surface temperatures in areas that are expected to have elevated temperatures that could ignite dust, lint or fibers.

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1.0 INTRODUCTION

According to the U.S. Consumer Product Safety Commission's (CPSC) 2009-2011 *Residential Fire Loss Estimates*, clothes dryers were attributed to an annual average of 6,000 fires, with fewer than 10 deaths, 200 injuries, and $75.3 million in property damage. In 2010, the National Fire Protection Association (NFPA) reported an estimated 16,800 fires, 51 deaths, 380 injuries and $236 million direct property damage attributed to clothes dryer and clothes washer fires (92 % of the fires were attributed to clothes dryers). NFPA reported the leading cause of the clothes dryer fires was ignition of dust, fiber, or lint (29 % of fires and 85 % of deaths). Frequently, dust, fibers, or lint will accumulate in the dryer cabinet (the portion of the appliance outside the tumbler). Exposure to excessive heat can lead to ignition.

Southwest Research Institute's (SwRI) Fire Technology Department in San Antonio, Texas, was awarded Contract No. HHPS2332014000536G to conduct a series of tests to evaluate the effectiveness of thermal insulation in reducing the temperature of surfaces in the dryer cabinet on which lint, fibers or dust may accumulate without adversely affecting dryer performance. Three dryers were selected as a representative sample set of commercially available, resistive-element electric clothes dryers. Pre-tests were performed to identify hot spots in each dryer. The dryers were instrumented with thermocouples (TCs) at select locations, and the power cables connected to circuitry to monitor voltage and current draw of each dryer during testing. First, the unmodified dryers were operated with a standardized clothing load to characterize the temperatures, voltage, and current draw. Next, insulation was added to the heating element duct in each dryer, and instrumented with additional TCs to monitor the insulation external surface temperatures. Finally, the insulated dryers were operated with the same standardized clothing load to determine the effect of the insulation on the hot spot temperatures, and voltage and current draw. This report discusses the test setup and procedures, and compares the performance of the unmodified and the insulated dryers.

The information acquired under this contract may be used in support of voluntary standards proposals for electric clothes dryers.

2.0 TEST SPECIMENS

2.1 Dryers

Three commercially available, resistive-element electric clothes dryers were selected by SwRI for this test series. A single dryer was selected each from a low, medium, and high price-tier to represent the range of options currently on the market. Figures 1 – 3 show the front and back of each dryer (back panels removed for pre-test characterization and instrumentation). The dryers were elevated for initial inspections and instrumentation. During operation, the dryers were placed on the ground and connected to a standard exhaust duct for both unmodified and insulated testing.

Figure 1. Dryer 1 – Front (Left); Back with Panel Removed (Right).

Figure 2. Dryer 2 – Front (Left); Back with Panel Removed (Right).

Figure 3. Dryer 3 – Front (Left); Back with Panel Removed (Right).

All three dryer designs have the same basic airflow path. Air enters the dryer cabinet through louvered vents located on the dryer back panel and is drawn through a duct containing an electric resistive heating element, then enters the rear of the tumbler. The moist, cooled air exits the tumbler through the lint screen which then passes through a duct and into the blower. The blower forces the air through the exhaust duct out the back of the dryer. The Dryer 1 heating element duct is located at the back of the dryer cabinet in a vertical orientation; the heating elements for Dryer 2 and Dryer 3 are located in the bottom of the dryer cabinet in a horizontal orientation. Figure 4 provides drawings of the air flow path of the dryers.

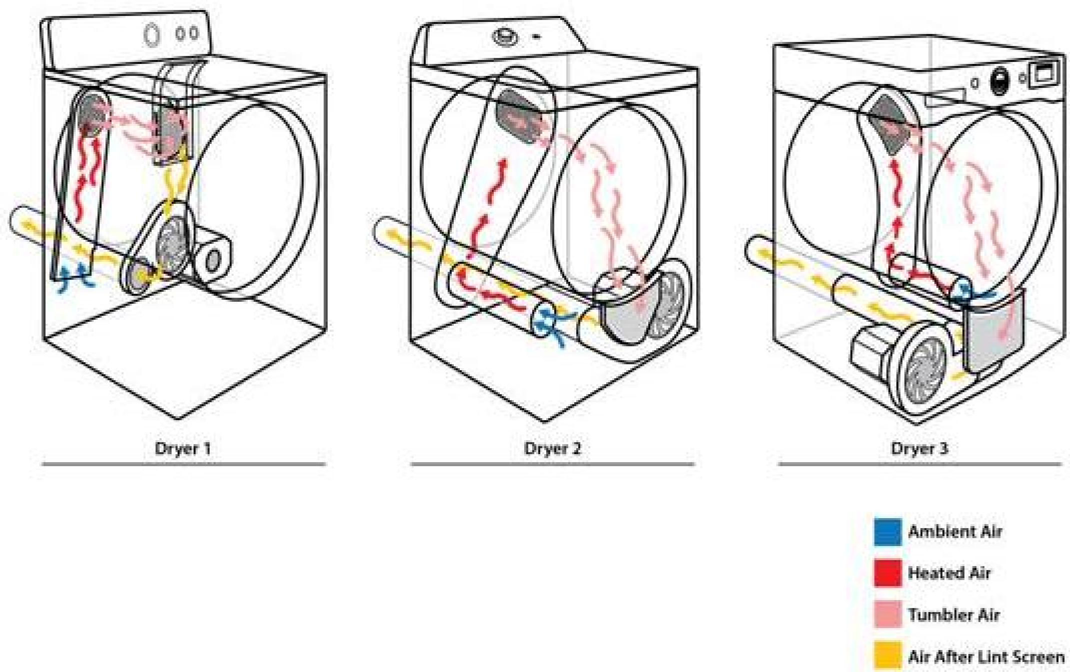


Figure 4. Air Flow Path Schematic.

A Modified AHAM Exhaust Simulator was attached to each dryer exhaust connection to provide back pressure. Figure 5 shows a drawing of the restrictor design, in accordance with AHAM HLD-1-2009, Section 3.3.5.2.

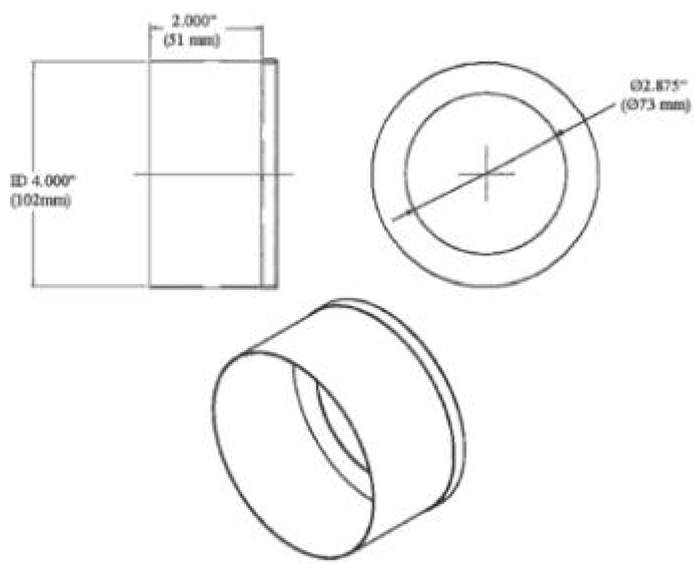


Figure 5. Modified AHAM Exhaust Simulator (from AHAM HLD-1-2009).

A 4-in. diameter, 10-ft long duct was attached to the restrictor to vent the dryer exhaust outside of the test building. No weather hood was connected to the end of the exhaust duct. Figure 6 shows the dryers set up side-by-side in the test facility.

Figure 6. Overall Dryers Setup (Dryers 3, 2, 1, Left to Right).

2.1 Standardized Clothing Load

The standardized clothing load used for all testing consisted of 10 test cloths. The cloths are bleached cotton terrycloth, cut and hemmed to 14 × 15 in., with an approximate weight of 306 g/m^2 (equivalent to style TWC BR or TWC BR TAG at www.testfabrics.com). No cloth was used in testing more than 25 times, per AHAM HLD-1-2009, and new test cloths were washed and dried before use in testing. All washings were performed in a residential clothes washer without detergent, fabric softeners, or other additives.

Before each test, the test cloths were in a "bone dry" condition as described in Section 3.3.1 of AHAM HLD-1-2009, *Household Tumble Type Clothes Dryers*. An electric clothes dryer was used to create "bone dry" test loads. During testing, all test cloths were wetted as described in AHAM HLD-1 2009, Section 3.3.2. However, San Antonio water is much harder than the 0 – 17 ppm hardness stated in Section 3.3.2, creating a deviation from the standard. This deviation was approved by CPSC personnel.

3.0 PRE-TEST THERMAL CHARACTERIZATION

Prior to performance testing, the back panel of each dryer was removed, the dryer operated, and the dryer cabinet monitored with an infrared (IR) camera and IR thermometer to identify surface areas that produced elevated temperatures. These characterization tests were performed to determine where to place the TCs during performance testing. Figures 7–9 show the IR video images captured for each dryer during the pre-tests.

The characterization tests validated the TC locations specified in the CPSC *Description of Services* document. In addition, two TCs were placed in each dryer to monitor the air temperature in the bottom of the dryer cabinet, and a TC was placed on the Dryer 2 deflector plate at the heating element duct intake.

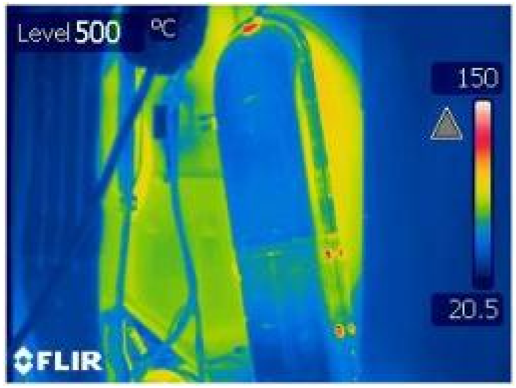


Figure 7. Dryer 1 IR Image – Hot Spots at Holes in Heating Element Cover.

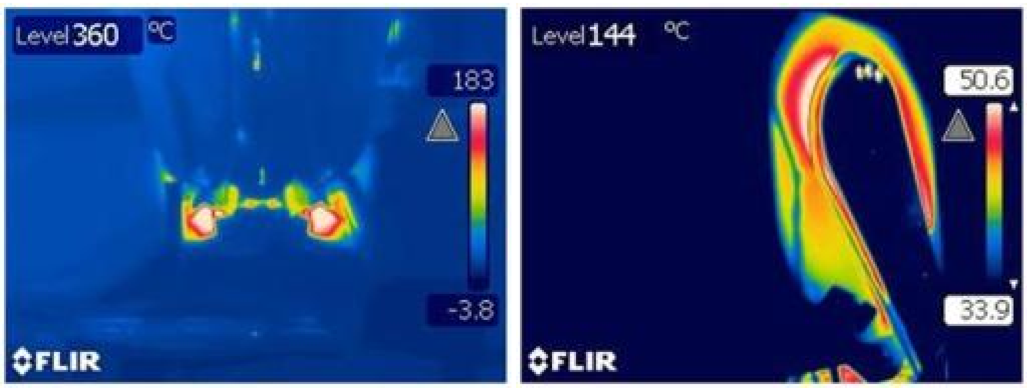


Figure 8. Dryer 2 IR Images – Air Intake Deflector Plate (Left), and Tumbler Cover (Right).

Figure 9. Dryer 3 IR Images – Lint Filter Housing (Left), and Motor Coil (Right).

4.0 TEST PROCEDURE

The three dryers were each tested four times unmodified, and four times after the addition of insulation. Each test consisted of a 60 minute drying cycle on the “high heat” temperature setting. Temperatures, voltage, and current draw were monitored throughout the tests for each dryer. The room temperature was maintained at 15 – 27 °C, per AHAM HDL-1-2009.

Both unmodified and insulated dryer testing was performed in general accordance with AHAM HLD-1-2009, Section 5.4 (omitting thermolabel procedures). The following general procedure was followed for each test:

1. Dry test load until "bone dry" and record weight.
2. Wet test load until "wetted" and record weight.
3. Measure and record test room temperature and relative humidity.
4. Operate test dryer without a load and without heat until the air exhaust temperature is within 6 °C of the room temperature.
5. Clean dryer lint filter.
6. Insert test load to test dryer.
7. Start data acquisition.
8. Initiate 60 min drying cycle on high heat.
9. Within 3 min after dryer cycle completion, insert three TCs into the test load and record the maximum load temperature.
10. Remove the test load and record weight.

Testing was initially performed on unmodified dryers to provide baseline performance data for each dryer. Research was then conducted on thermal insulation applicable to clothes dryer environments. Among the factors considered for use in testing were:

- Temperature range to which the material will be exposed
- Thermal conductivity and heat transfer
- Expected durability over the service life of a clothes dryer
- Potential ease of installation during manufacture
- Heath and environmental exposure factors
- Material costs

Insulation techniques were selected, and the modifications documented. Drying cycle testing was then repeated with additional temperature measurements on the surface of the insulating samples or modified air duct in addition to the previously measured locations. Again, the voltage and current draw were recorded throughout the testing.

5.0 INSTRUMENTATION

Temperature measurements were made using 24-ga GDW/GB, Type "K" (Chromel-Alumel), exposed-junction thermocouples (TCs). Air TC measurement junctions were left exposed to measure the air temperature at the specific location. Each surface TC measurement junction was placed under a small felt pad to reduce the influence of ambient air temperature. The TC and pad were held in place with foil tape and, if possible, mechanically secured with wire. Figure 10 shows an example of the TC and pad.

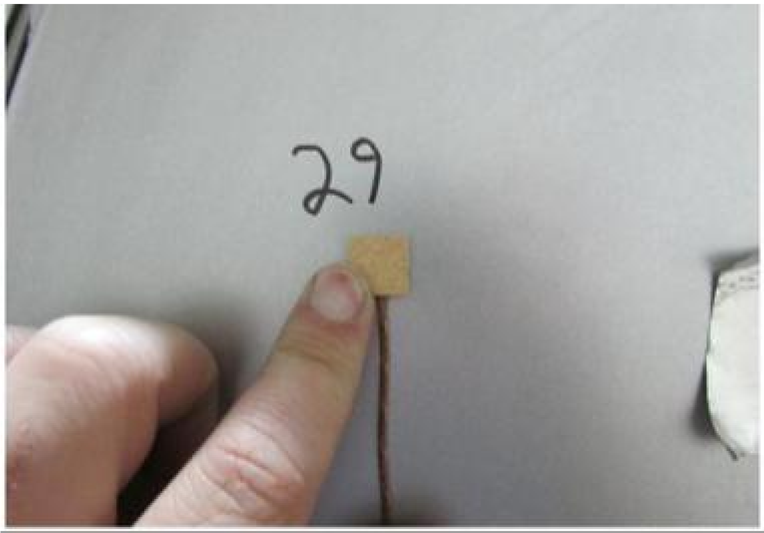


Figure 10. Example Surface Thermocouple and Felt Pad.

For the insulated dryer tests, 20-ga GDW/GB type K thermocouples were utilized to monitor the external insulation surface temperatures at select locations.

Table 1 lists the general locations of the TCs in the dryers. The actual location varied slightly between the dryer designs. Digital photographic details of the TC placement are provided in Appendix A. Three additional TCs were secured to a wand 3-in. apart. Figure 11 shows a photograph of the wand. The wand was inserted into the clothes load at the conclusion of the drying cycle immediately following cool down to measure the maximum temperatures in accordance with AHAM HLD-1-2009, Section 5.4.6.

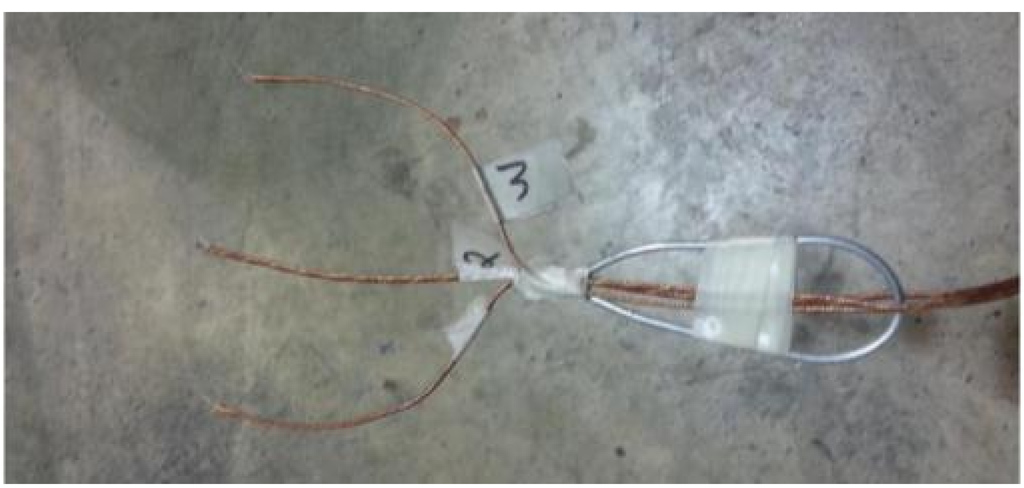


Figure 11. TC Wand used to Measure Cloths Temperature after Drying.

The voltage supply and current draw for each dryer were measured during each test. In order to accommodate the requested 1 Hz sample rate, the 60 Hz electrical data was reduced with a root mean square (RMS) calculation. The RMS calculation on the voltage and current data was performed using five True RMS signal conditioning modules. These modules perform a True-RMS calculation on the input waveform and provide a 0-10V_{DC} output proportional to the input voltage RMS measurement. The supply voltage was input directly to the signal conditioning modules. Current was measured with a clamp-on current transformer, which provided the input to the signal conditioning modules. By multiplying the RMS voltage and RMS current, apparent power can be calculated (Volt Amps, VA). The RMS calculation does not provide the phase difference between the current and voltage, so real power (kW) and power consumption (kW-hr) cannot be calculated from the data collected during this testing.

Table 1. Data Acquisition Channel Descriptions.

DAQ Channel			**Channel Description**
Dryer 1	**Dryer 2**	**Dryer 3**	
1	12	24	Air temperature at the intake into the heating element area
2	13	25	Air temperature at the exit of the heating element area
3	14	26	Heating element duct surface temperature at the air intake area
4	N/A	27	Heating element duct surface temperature at the midpoint
N/A	15	N/A	Air duct surface temperature below the air entrance to the tumbler
5	16	28	Heating element duct surface temperature at the air exit
6	17	29	Air duct surface temperature at the air entrance to the tumbler
7	18	30	Blower temperature
8	19	31	Motor temperature
9	20	32	Dry exhaust air temperature
10	21	33	Bottom right cabinet air temperature
11	22	34	Bottom left cabinet air temperature
N/A	23	N/A	Heating element deflector plate surface temperature
35			Voltage 1
36			Voltage 2
37	38	39	Current
40,41,42			Wand temperatures
43	48	46	Heating element duct insulation surface temperature at the air intake area*
44	49	47	Heating element duct insulation surface temperature at the midpoint*
45	N/A	N/A	Heating element duct insulation surface temperature at the air exit*

*TC 43-49 for modified dryer tests only; insulation surface refers to either insulation or double wall added to the heating element.

Data was logged on a dedicated PC-based data acquisition system at a rate of 1 Hz. The data acquisition card has an accuracy of 0.02 % for voltage signals and ± 0.5 °C for thermocouple signals.

Ambient temperature and relative humidity were measured and recorded manually prior to each test using a calibrated hand-held device. Weight measurements were made using a calibrated scale and recorded by hand. A thermal imaging camera was used for the initial dryer inspections to identify locations with the highest surface temperatures inside the dryer cabinet.

6.0 RESULTS

6.1 Unmodified Dryer Performance Tests

Testing of the new dryers was completed on December 10–12, 2014. These tests were conducted without modification of the dryers in order to establish a baseline under normal drying conditions. Table 2 provides the test results. Graphical temperature data can be found in Appendix B.

Table 2. Unmodified Dryer Performance Test Results.

Dryer	Measurement Description	Run 1	Run 2	Run 3	Run 4	Avg.	St. Dev.
1	"Bone Dry" Weight of Test Load (lbs)	0.870	0.870	0.870	0.870	0.870	0.000
	"Wetted" Weight of Test Load (lbs)	2.330	2.350	2.345	2.350	2.344	0.009
	Test Room Temperature (°C)	23.39	22.39	22.61	22.56	22.74	0.45
	Test Room Relative Humidity (%)	48.0	62.3	65.1	61.8	59.3	7.7
	Max. Post-Test Load Temp (°C)	31.44	34.57	35.27	34.83	34.03	1.75
	Weight of Test Load Post-Test (lbs)	0.990	0.905	0.895	0.895	0.921	0.046
	Apparent Power Consumption (kVA-hr)	2.78	2.58	2.63	2.61	2.65	0.09
2	"Bone Dry" Weight of Test Load (lbs)	0.865	0.865	0.865	0.865	0.865	0.000
	"Wetted" Weight of Test Load (lbs)	2.340	2.345	2.360	2.335	2.345	0.011
	Test Room Temperature (°C)	23.35	22.34	22.61	22.55	22.71	0.44
	Test Room Relative Humidity (%)	48.0	62.3	65.1	61.8	59.3	7.7
	Max. Post-Test Load Temp (°C)	29.29	35.13	26.76	26.82	29.50	3.93
	Weight of Test Load Post-Test (lbs)	0.895	0.980	0.945	0.925	0.936	0.036
	Apparent Power Consumption (kVA-hr)	2.57	2.52	2.53	2.63	2.56	0.05
3	"Bone Dry" Weight of Test Load (lbs)	0.870	0.870	0.870	0.870	0.870	0.000
	"Wetted" Weight of Test Load (lbs)	2.340	2.355	2.350	2.335	2.345	0.009
	Test Room Temperature (°C)	23.39	22.39	22.61	22.55	22.74	0.45
	Test Room Relative Humidity (%)	48.0	62.3	65.1	61.8	59.3	7.7
	Max. Post-Test Load Temp (°C)	42.82	40.04	40.21	43.76	41.71	1.87
	Weight of Test Load Post-Test (lbs)	0.880	0.885	0.885	0.880	0.883	0.003
	Apparent Power Consumption (kVA-hr)	3.15	3.17	3.15	3.07	3.14	0.05

6.2 Insulated Dryer Performance Tests

The insulated dryer tests were performed on January 19, 22, 23, and 26, 2015. Commercially available flexible insulation was applied to the heating elements on Dryer 1 and Dryer 3. Dryer 1 insulation materials had an adhesive backing that was rated for an acceptable temperature range and provided a simple task of installing the insulation to the heating element duct. Dryer 3 flexible insulation materials did not have any adhesive and the material exterior had a silicone weather coating; therefore the material was wrapped around the duct and taped in place. Dryer 2 had a second sheet metal wall added to the outside of the heating element duct, creating a double wall duct. Tape was used to cover the sheet metal seam in order to prevent dust, fibers or lint from accumulating within the double wall. The second wall of the duct was notched to provide clearance for the duct electrical sensors. Table 3 provides the test results. Graphical temperature data can be found in Appendix C.

Table 3. Insulated Dryer Performance Test Results.

Dryer	Measurement Description	Run 1	Run 2	Run 3	Run 4	Avg.	St. Dev.
1	"Bone Dry" Weight of Test Load (lbs)	0.870	0.870	0.870	0.870	0.870	0.000
	"Wetted" Weight of Test Load (lbs)	2.335	2.350	2.340	2.345	2.343	0.006
	Test Room Temperature (°C)	18.33	21.22	24.39	20.05	21.00	2.55
	Test Room Relative Humidity (%)	42.3	41.6	33.1	49.1	41.5	6.6
	Max. Post-Test Load Temp (°C)	29.53	27.99	30.14	22.92	27.65	3.28
	Weight of Test Load Post-Test (lbs)	0.890	0.925	0.890	0.955	0.915	0.031
	Apparent Power Consumption (kVA-hr)	2.97	2.81	2.57	2.72	2.77	0.17
2	"Bone Dry" Weight of Test Load (lbs)	0.865	0.865	0.865	0.865	0.865	0.000
	"Wetted" Weight of Test Load (lbs)	2.340	2.365	2.335	2.340	2.345	0.014
	Test Room Temperature (°C)	17.94	18.05	18.17	20.00	18.54	0.98
	Test Room Relative Humidity (%)	41.6	38.1	38.0	32.6	37.6	3.7
	Max. Post-Test Load Temp (°C)	22.75	24.89	23.75	24.24	23.91	0.90
	Weight of Test Load Post-Test (lbs)	0.910	0.935	0.930	0.910	0.921	0.013
	Apparent Power Consumption (kVA-hr)	2.90	2.75	2.83	2.66	2.79	0.10
3	"Bone Dry" Weight of Test Load (lbs)	0.870	0.870	0.870	0.870	0.870	0.000
	"Wetted" Weight of Test Load (lbs)	2.330	2.335	2.340	2.340	2.336	0.005
	Test Room Temperature (°C)	18.33	21.22	24.29	20.05	20.97	2.51
	Test Room Relative Humidity (%)	42.3	41.6	33.1	49.1	41.5	6.6
	Max. Post-Test Load Temp (°C)	38.98	39.76	41.11	41.01	40.22	1.03
	Weight of Test Load Post-Test (lbs)	0.880	0.875	0.875	0.875	0.876	0.003
	Apparent Power Consumption (kVA-hr)	3.22	3.19	3.08	3.25	3.18	0.73

6.3 Apparent Power Results

The RMS voltage provided to the three dryers was monitored and recorded, and the RMS current for each dryer was also monitored and recorded throughout each test. The product of the RMS voltage and RMS current gives a calculated apparent power value for each test for each dryer. The apparent power consumption, or the area under the apparent power curve, is provided in Tables 2 and 3. Table 4 provides additional dryer cycle details for the unmodified and insulated tests.

Table 4. Dryer Operating Results.

Dryer	Metric Description	Unmodified Tests				Insulated Tests			
		Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4
1	Number of Heating Element Cycles	17	11	13	13	15	15	13	13
	Duration of 1st Cycle (s)	320	342	341	347	160	344	306	364
	Heaters On during Test (%)	41%	37%	38%	38%	45%	41%	38%	40%
	Avg. Apparent Power Heaters On (kVA)	5.79	5.76	5.76	5.77	5.80	5.78	5.68	5.80
	Avg. Apparent Power Heaters Off (kVA)	0.71	0.71	0.70	0.70	0.71	0.71	0.69	0.71
2	Number of Cycles	23	22	22	25	24	19	24	22
	Duration of 1st Cycle (s)	242	257	260	275	340	342	297	313
	Heaters On during Test (%)	45%	44%	45%	47%	51%	49%	50%	47%
	Avg. Apparent Power when Heaters On (kVA)	5.07	5.05	5.04	5.05	5.14	5.09	5.10	5.10
	Avg. Apparent Power when Heaters Off (kVA)	0.52	0.51	0.51	0.52	0.53	0.53	0.53	0.53
3	Number of Cycles	4	4	4	4*	3	4	4*	3
	Duration of 1st Cycle (s)	359	366	363	374	464	379	340	460
	Heaters On during Test (%)	16%	16%	16%	16%	16%	16%	15%	16%
	Dryer at mid-power during Test (%)	73%	74%	73%	71%	73%	74%	72%	74%
	Avg. Apparent Power when Heaters On (kVA)	5.53	5.53	5.51	5.51	5.53	5.59	5.48	5.58
	Avg. Apparent Power when mid-power (kVA)**	3.03	3.01	3.00	2.98	3.04	3.02	3.01	3.05
	Avg. Apparent Power when Heaters Off (kVA)	0.73	0.72	0.72	0.71	0.75	0.75	0.74	0.76

*Dryer 3 also had a few cycles while at mid-power for these tests.
**Dryer 3 had a mid-power range that it maintained for the majority of tests performed.

The addition of insulation to the three dryers resulted in a slight increase in measured apparent power consumption for each dryer. The data shows less than 10 % apparent power consumption increase for Dryer 2, with lower (less than 5 %) increases for Dryers 1 and 3. Comparing the unmodified and insulated data for Dryer 2, the apparent power consumption increased by 0.23 kVA-hr. If we approximate the cost of a kVA-hr to the cost of a kW-hr this would be an increase to average operation cost of 2.65 cents (based upon the national average electricity rate of 11.54 cents per kW-hr). As stated previously, apparent power was measured, not real power. This is a relatively minimal increase in operating costs for a significant reduction of fire risk. The goal of this project was to use insulation to reduce hot spots on the dryer, not improve dryer efficiency. The reduction in efficiency was an unexpected result and SwRI has two working theories on why the additional insulation may have had this effect.

The first theory focuses on the air as the working medium in drying the clothing. In all dryers, the air is pulled into the heating duct, heated from the resistive element, and then flows into the drum. As heated air enters into the drum, cooled air is removed from the drum. This method of clothes drying requires a large volume of air to be cycled through the system and heated. By design, the majority of heat from the resistive element is transferred to the process air. Due to the high volumetric air flow rate, insulation does little to improve the heat transfer to the air in the heating duct. The insulation technique for Dryer 2 may have provided a heat sink for the heating duct and conducted the heat more easily to the outer shell.

The second theory focuses on heat dissipation from the heating duct. With the heating duct left un-insulated it will warm the air within the cabinet and heat everything within proximity. Without insulation on the heating duct, the cabinet air, which is the primary source of air used in the drying process, rises to an elevated temperature before entering the heating duct. The exposed heating duct radiates heat elsewhere within the cabinet as well, contributing to extra heating on the drum. With insulation, the duct can no longer provide as much pre-heating to the cabinet air. This forces cooler air to be heated in the limited time it has in the heating duct, not allowing it to get as hot before entering the drum. In typical operation, the heater duct dissipates some of the heat to various locations within the dryer, heating the sensor faster to turn off the heater. When insulated the only heating method is the process air, which takes longer to trigger the sensor. This could directly relate to the longer first heater cycle. This theory is a direct side effect of the project objective.

7.0 CONCLUSIONS

SwRI's Fire Technology Department conducted a series of tests to evaluate the effectiveness of insulation in reducing the temperature of surfaces in the dryer cabinet on which lint, fibers or dust may accumulate without adversely affecting dryer performance. Three dryers were selected as a sample set of commercially available, resistive-element electric clothes dryers. An initial characterization was performed to determine areas inside the cabinet with the highest surface temperatures for each dryer. Four evaluations were conducted on the new dryers to measure temperatures throughout the cabinet and the RMS voltage and RMS current draw during normal operations. Each dryer was then modified with a different insulation technique to evaluate the effectiveness. Then four additional evaluations were conducted on the modified dryers with additional temperature measurements on the external surfaces of the insulation. As observed, the insulation increased the duct surface and air temperatures as expected. However, comparison of the unmodified duct surface temperatures and the insulation surface temperatures, as well as comparison of the unmodified and insulated cabinet air temperatures show the impact of the insulation.

The flexible insulation with the adhesive backing applied to Dryer 1 proved to be the most efficient application, and provided the most temperature reduction to the insulated surfaces. Comparing the results of the unmodified to the insulated tests for Dryer 1, the insulation reduced the exposed surface temperature by about 30 °C, on average. The average insulation surface temperature was comparable to the cabinet air temperatures for the insulated tests. However, the hottest surfaces in the dryer, which are most likely to ignite dust, lint, or fibers, had the greatest temperature decrease when insulated. Table 5 compares the results of the maximum and overall average temperatures of the unmodified tests to the insulated tests for Dryer 1. The heating element duct surface temperatures and the heating element insulation surface temperatures are bolded to highlight the effect of the insulation. The italicized temperatures are TCs which are below the insulation and are expected to be higher than the unmodified tests.

Table 5. Dryer 1 Results Summary.

TC Location	Unmodified Tests Averages (°C)		Insulated Tests Averages (°C)	
	Max. Temp	Avg. Temp	Max. Temp	Avg. Temp
Air Temperature at the Intake into the Heating Element Area	93.9	52.8	91.9	51.4
Air Temperature at the Exit of the Heating Element Area	255.9*	170.7*	200.9	97.2
Heating Element Duct Surface Temperature at the Air Intake Area	**114.9**	**57.3**	*119.7*	*62.5*
Heating Element Duct Surface Temperature at the Midpoint	**207.1**	**84.7**	*262.5*	*122.2*
Heating Element Duct Surface Temperature at the Air Exit	**145.9**	**77.4**	*148.9*	*83.9*
Air Duct Surface Temperature at the Air Entrance to the Tumbler	136.8	77.4	139.4	77.4
Blower Temperature	76.4	61.9	75.7	61.6
Motor Temperature	94.2	79.7	91.5	68.5
Dry Exhaust Air Temperature	82.2	63.4	74.0	60.6
Bottom-Right Cabinet Air Temperature	50.0	42.5	45.9	37.6
Bottom-Left Cabinet Air Temperature	43.1	37.9	39.8	34.2
Heating Element Duct Insulation Surface Temperature at the Air Intake Area	–	–	**53.5**	**34.1**
Heating Element Duct Insulation Surface Temperature at the Midpoint	–	–	**76.6**	**43.0**
Heating Element Duct Insulation Surface Temperature at the Air Exit	–	–	**63.2**	**41.9**

*Unmodified Run 2 temp spikes removed from calculations

The double wall modification, installed on Dryer 2, could be incorporated into the assembly of the heating element duct during manufacturing; however, the existing locations of the electrical powered sensors required notching of the second wall material. A double wall insulated duct design would need to ensure that dust, lint and fibers could not accumulate within the double wall. Table 6 compares the results of the maximum and overall average temperatures of the unmodified tests to the insulated tests for Dryer 2. The heating element duct surface temperatures and the heating element insulation surface temperatures are bolded to highlight the effect of the insulation.

Table 6. Dryer 2 Results Summary.

TC Location	Unmodified Tests Averages (°C)		Insulated Tests Averages (°C)	
	Max. Temp	Avg. Temp	Max. Temp	Avg. Temp
Air Temperature at the Intake into the Heating Element Area	70.7	49.1	102.0	60.3
Air Temperature at the Exit of the Heating Element Area	296.1	155.8	299.8	154.4
Heating Element Duct Surface Temperature at the Air Intake Area	**87.3**	**59.5**	107.3	67.7
Air Duct Surface Temperature below the Entrance to the Tumbler	89.4	63.4	93.3	64.0
Heating Element Duct Surface Temperature at the Air Exit	151.7	84.0	159.4	92.1
Air Duct Surface Temperature at the Air Entrance to the Tumbler	70.7	51.6	74.6	52.7
Blower Temperature	54.3	48.1	53.5	46.8
Motor Temperature	64.0	54.8	59.8	51.9
Dry Exhaust Air Temperature	63.9	51.5	87.4	49.7
Bottom-Right Cabinet Air Temperature	47.2	42.3	44.1	39.4
Bottom-Left Cabinet Air Temperature	42.4	36.9	41.3	35.0
Heating Element Deflector Plate Surface Temperature	48.7	40.7	50.2	39.2
Heating Element Duct Insulation Surface Temperature at the Air Intake Area	–	–	**53.9**	**42.0**
Heating Element Duct Insulation Surface Temperature at the Midpoint	–	–	59.0	41.4

The flexible insulation without adhesive and with a weather barrier, applied to Dryer 3, was difficult to install and will require additional installation techniques and material for securing the material in place. The insulation reduced the exposed surface temperature by less than 5 °C. This could be because of the installation difficulty, or because the heating element duct surface for Dryer 3 was relatively cool compared to the other dryers. The heating element duct surface temperature was an average of 46.8 °C for the unmodified tests, and the insulation surface temperature was an average of 43.7 °C for the insulated tests. Dryers 1 and 2 heating element duct surfaces reached higher temperatures. Table 7 compares the results of the maximum and overall average temperatures of the unmodified tests to the insulated tests for Dryer 3. The heating element duct surface temperatures and the heating element insulation surface temperatures are bolded to highlight the effect of the insulation.

Table 7. Dryer 3 Results Summary.

TC Location	**Unmodified Tests Averages (°C)**		**Insulated Tests Averages (°C)**	
	Max. Temp	**Avg. Temp**	**Max. Temp**	**Avg. Temp**
Air Temperature at the Intake into the Heating Element Area	46.6	38.8	44.3	37.4
Air Temperature at the Exit of the Heating Element Area	268.7	166.3	285.9	200.2
Heating Element Duct Surface Temperature at the Air Intake Area	**49.6**	**41.1**	50.2	41.1
Heating Element Duct Surface Temperature at the Midpoint	**86.0**	**52.5**	86.0	55.4
Heating Element Duct Surface Temperature at the Air Exit	78.7	55.0	75.7	51.1
Air Duct Surface Temperature at the Air Entrance to the Tumbler	98.9	67.3	93.6	65.4
Blower Temperature	64.9	57.6	64.0	55.5
Motor Temperature	63.2	54.7	59.2	50.7
Dry Exhaust Air Temperature	74.3	62.8	74.4	61.6
Bottom-Right Cabinet Air Temperature	37.7	34.8	36.5	33.4
Bottom-Left Cabinet Air Temperature	42.1	38.0	39.8	35.8
Heating Element Duct Insulation Surface Temperature at the Air Intake Area	–	–	**45.3**	**39.3**
Heating Element Duct Insulation Surface Temperature at the Midpoint	–	–	**58.5**	**46.5**

Overall, each of the modifications reduced the external surface temperature in those areas and also reduced the air temperature in the dryer cabinet space below the tumbler. The insulation techniques utilized did not have a significant effect on the apparent power consumption of the dryers. Therefore, this study proved that it is possible to reduce the dryer cabinet space and exposed surface temperatures without negatively affecting the dryer performance. This information could be used to consider producing dryers with products that would reduce the surface temperatures in areas of the dryer cabinet that are expected to have elevated temperatures that could ignite dust, lint or fibers.

APPENDIX A

THERMOCOUPLE PLACEMENT

PHOTOGRAPHIC DOCUMENTATION

(CONSISTING OF 11 PAGES)

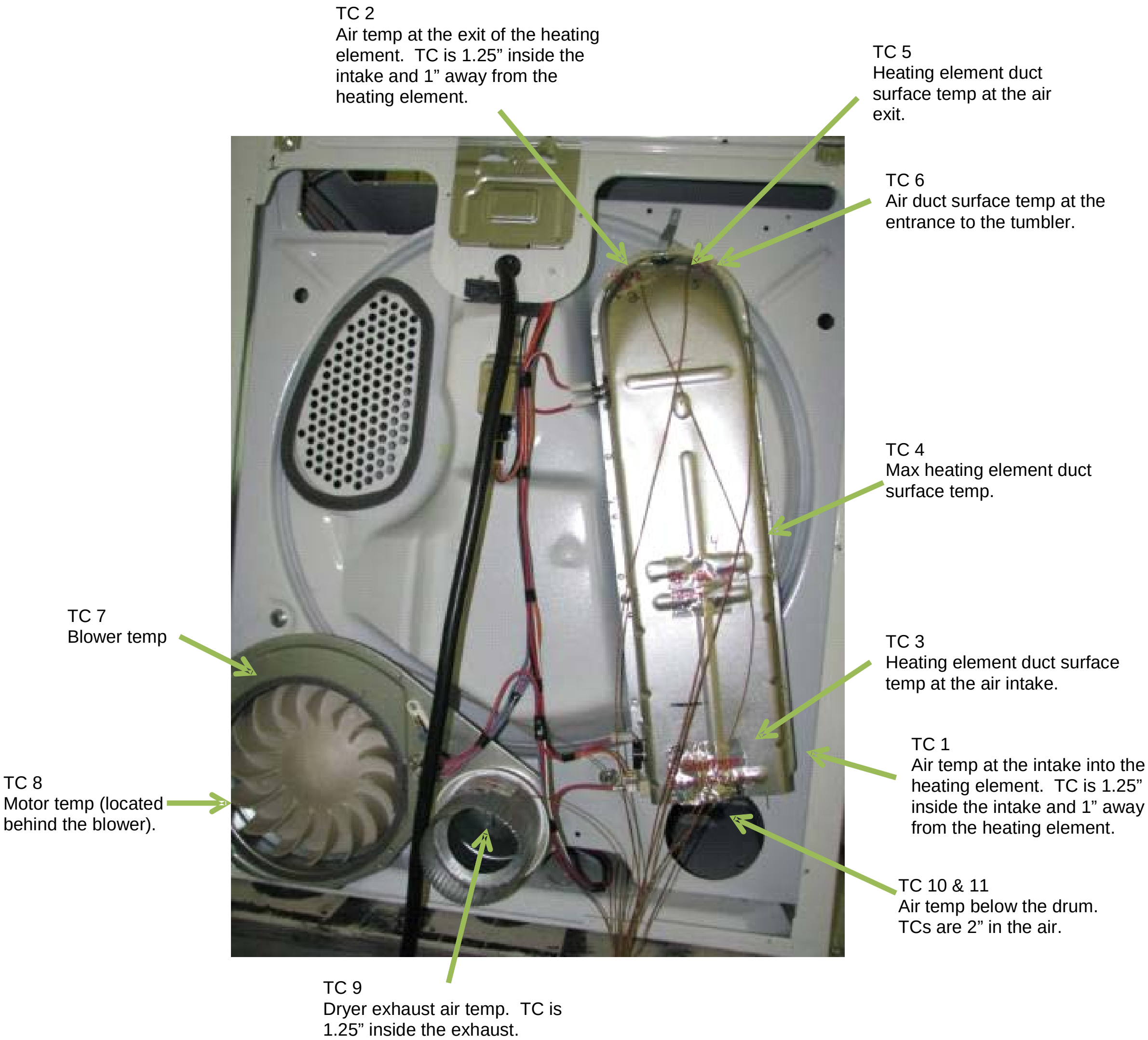


Figure A-1. Dryer 1: Thermocouple Locations.

Figure A-2. Dryer 1: Location of TC 1.

Figure A-3. Dryer 1: Location of TC 6.

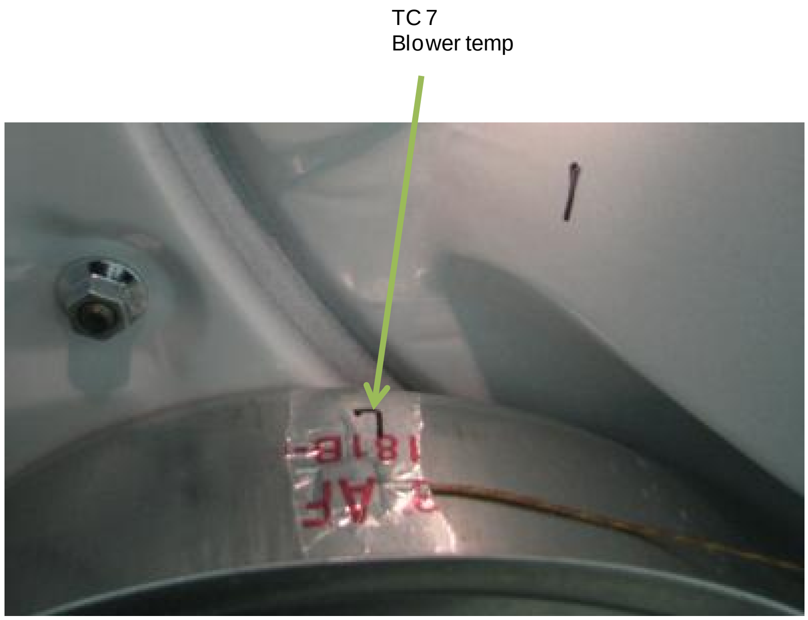


Figure A-4. Dryer 1: Location of TC 7.

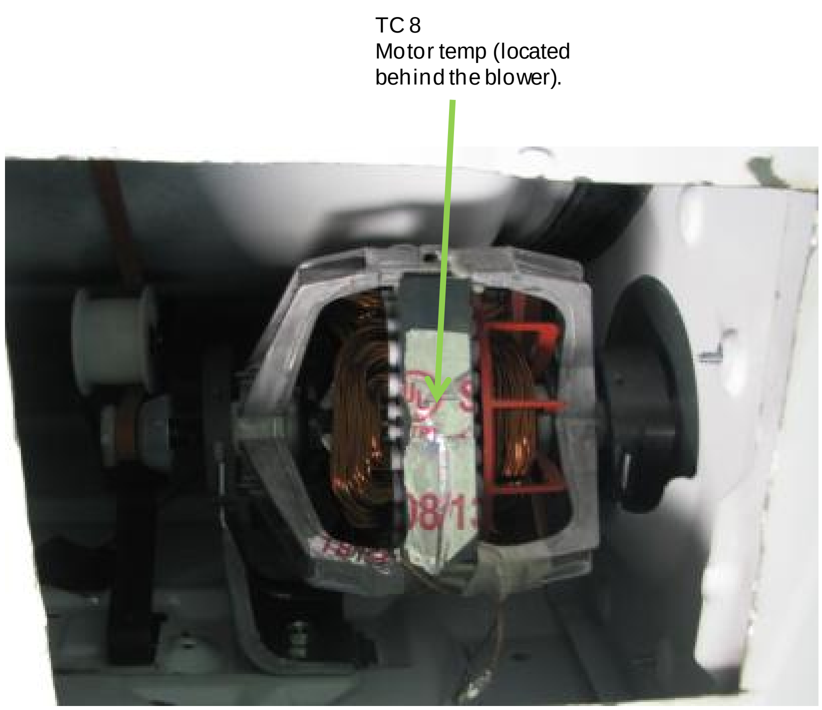


Figure A-5. Dryer 1: Location of TC 8

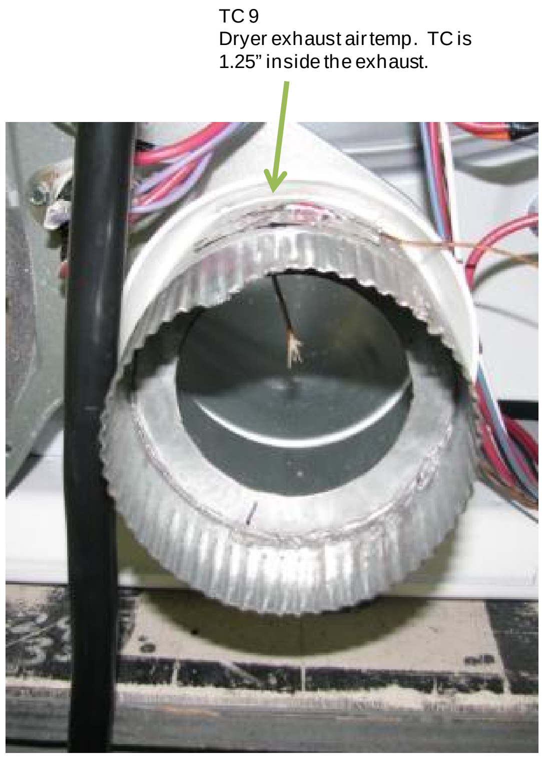


Figure A-6. Dryer 1: Location of TC 9.

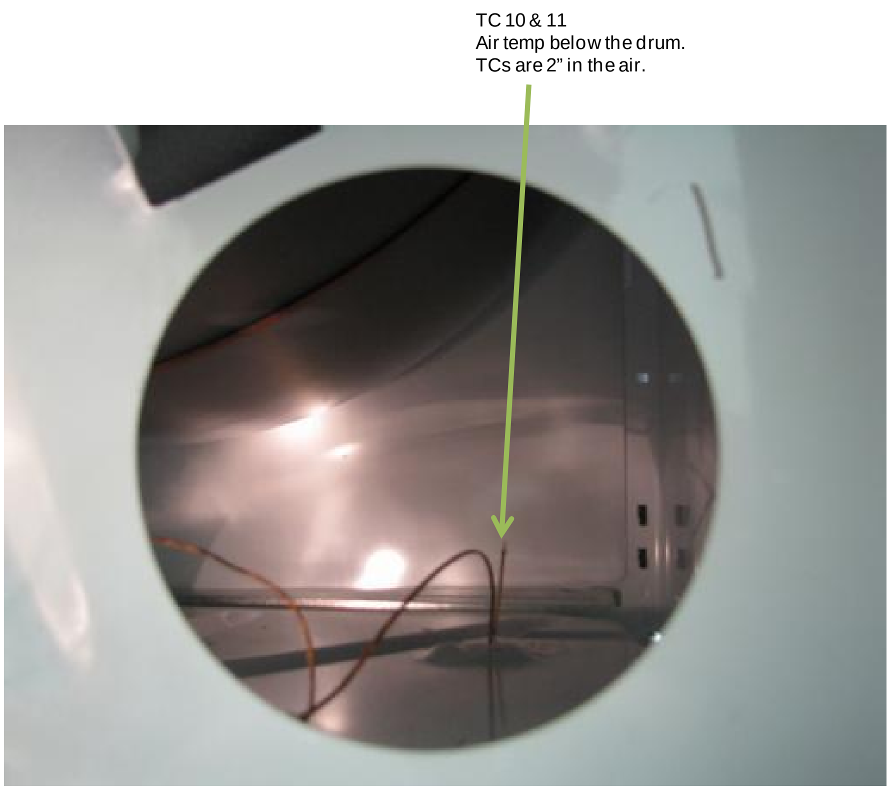


Figure A-7. Dryer 1: Location of TC 10 and 11.

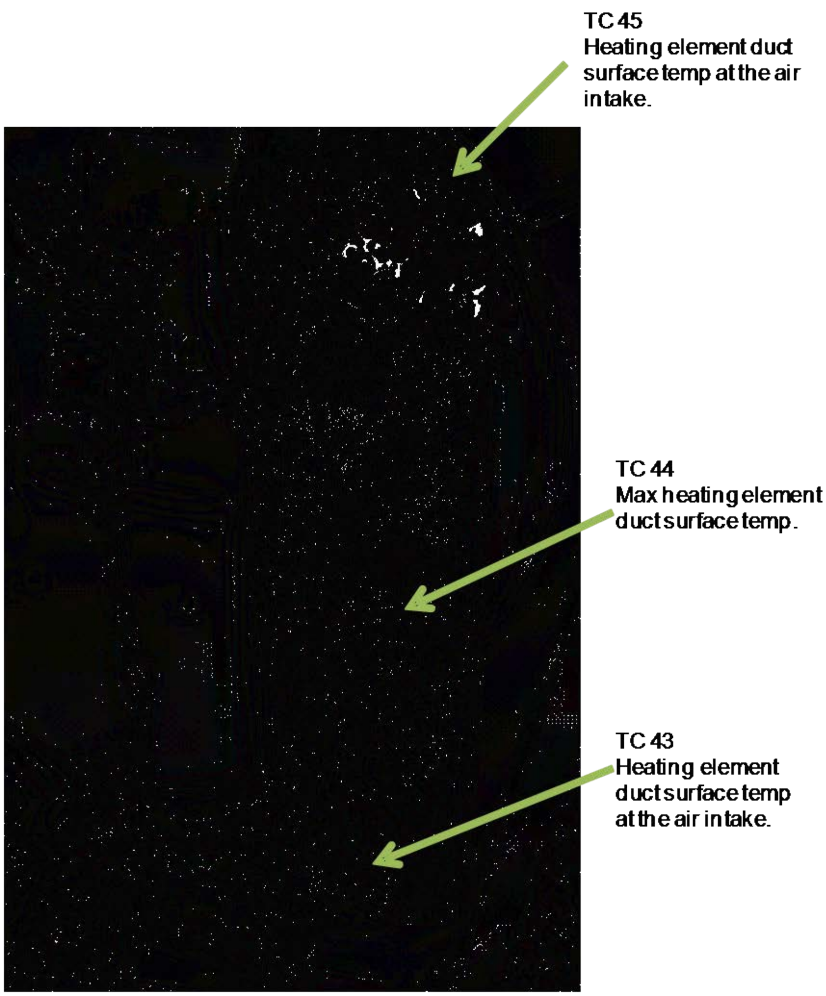


Figure A-8. Dryer 1: Location of TC 43, 44, and 45 after insulation.

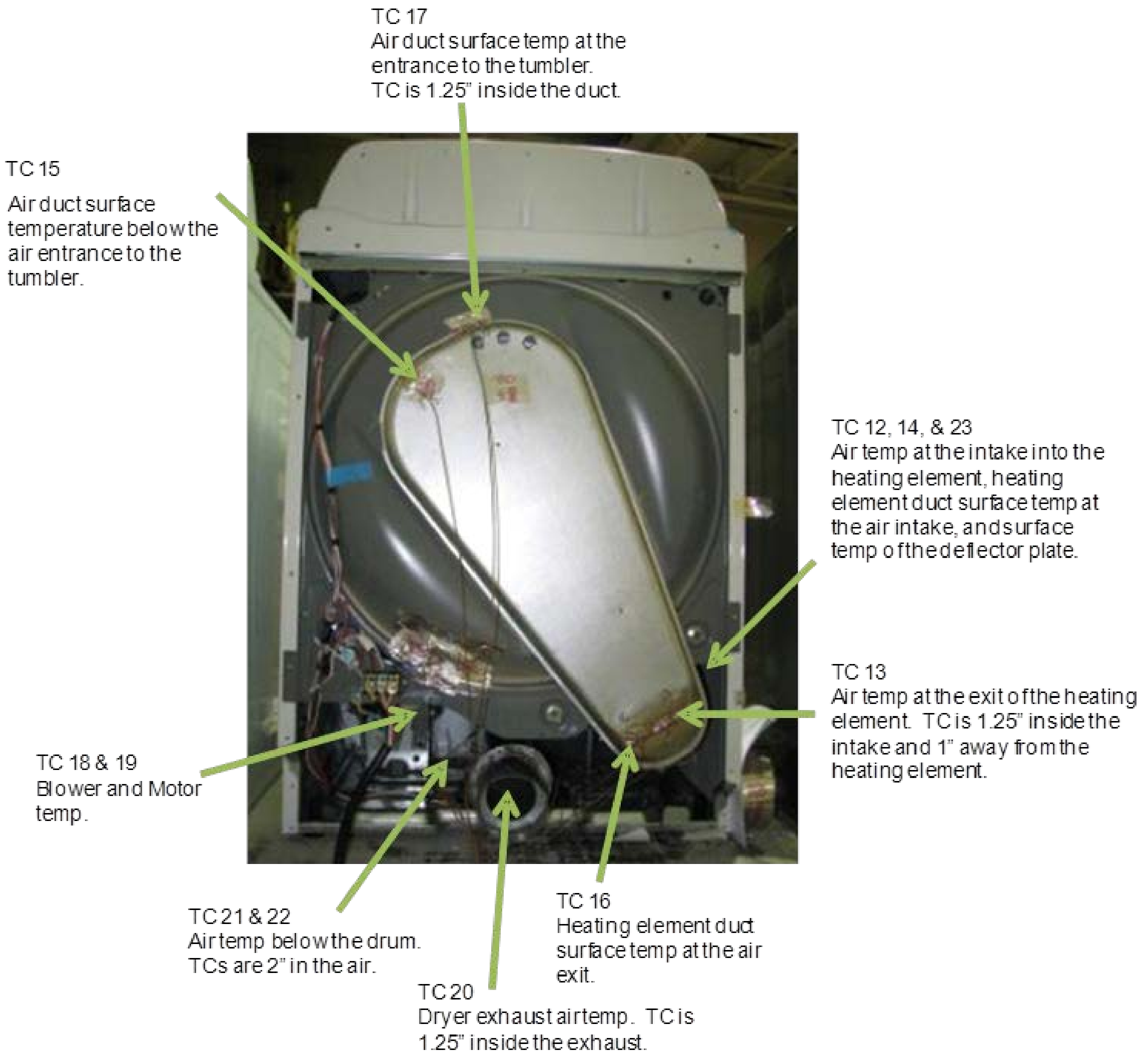


Figure A-9. Dryer 2: Thermocouple Locations

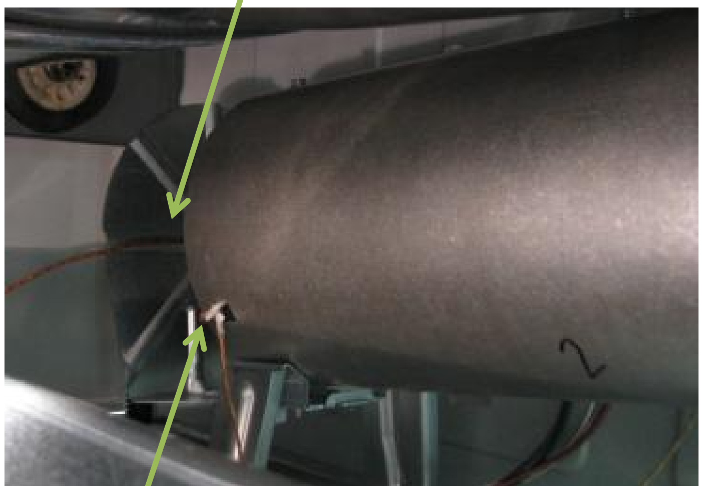


Figure A-10. Dryer 2: Location of TC 12 and 23.

Figure A-11. Dryer 2: Location of TC 14.

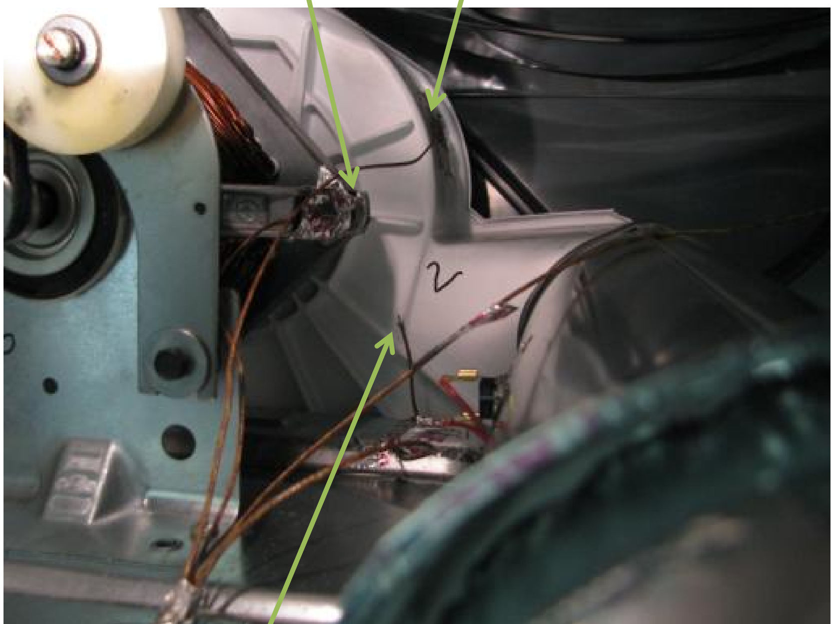


Figure A-12. Dryer 2: Location of TC 18, 19, 21, and 22.

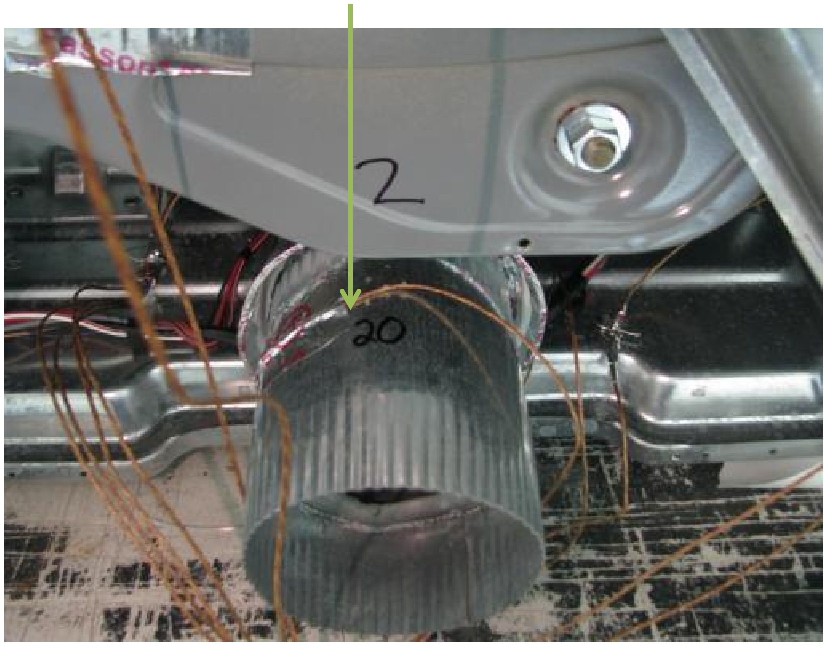


Figure A-13. Dryer 2: Location of TC 20.

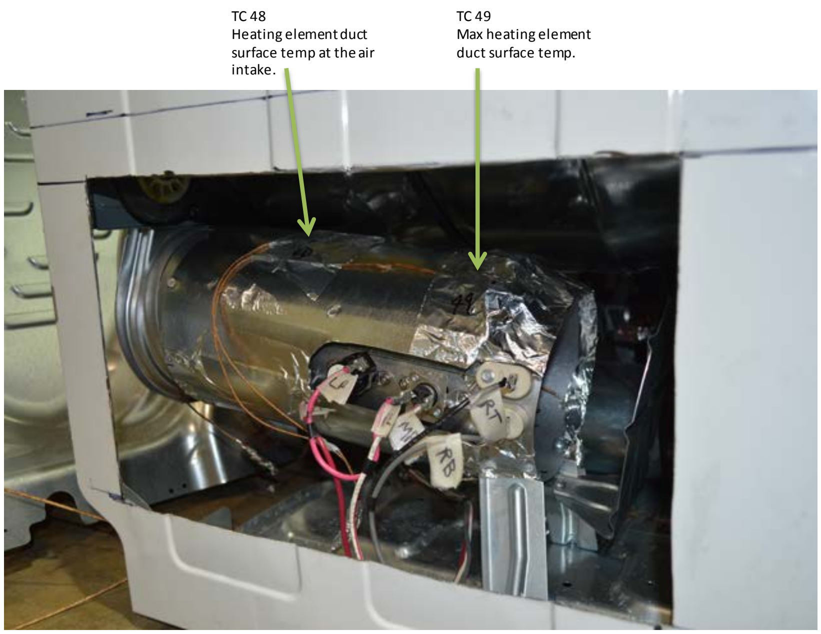


Figure A-14. Dryer 2: Location of TC 48 and 49 after insulation.

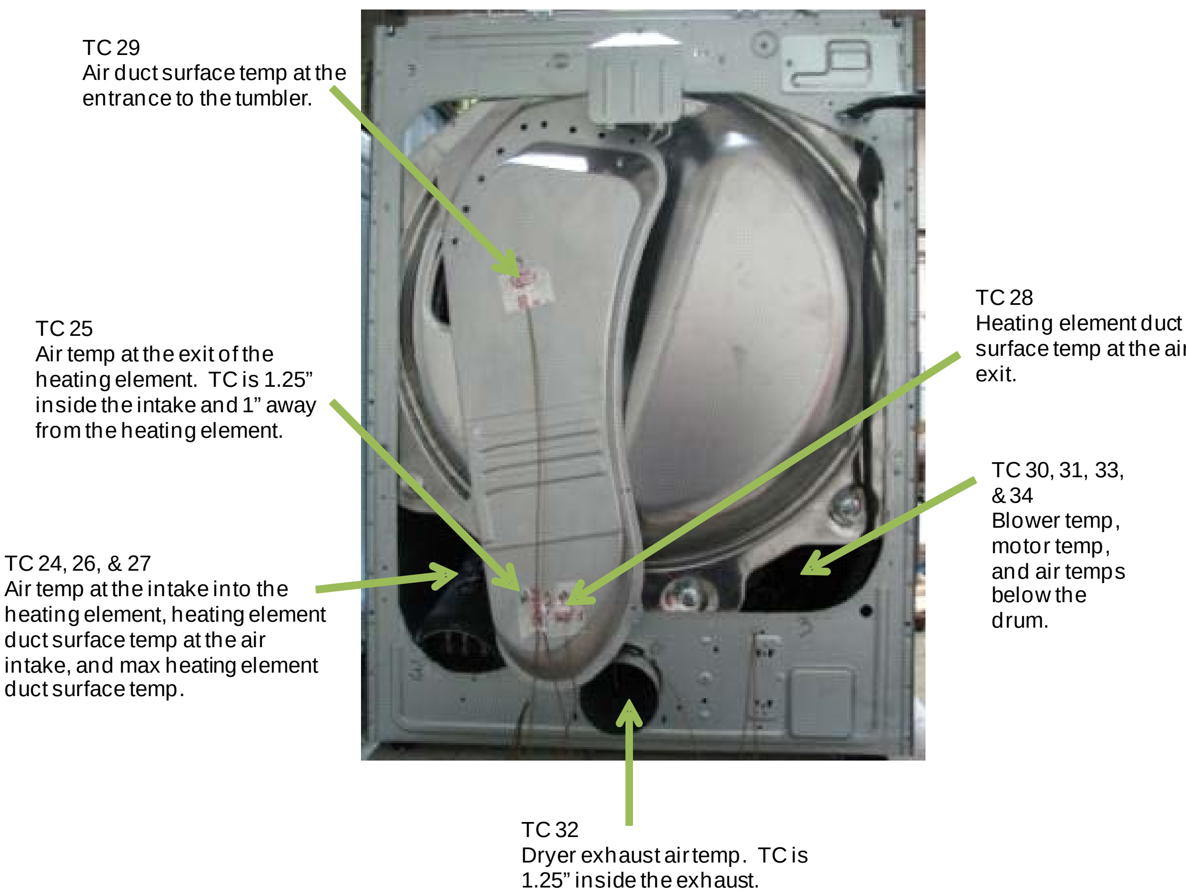


Figure A-15. Dryer 3: Thermocouple Locations

Figure A-16. Dryer 3: Locations of TC 24, 26, and 27.

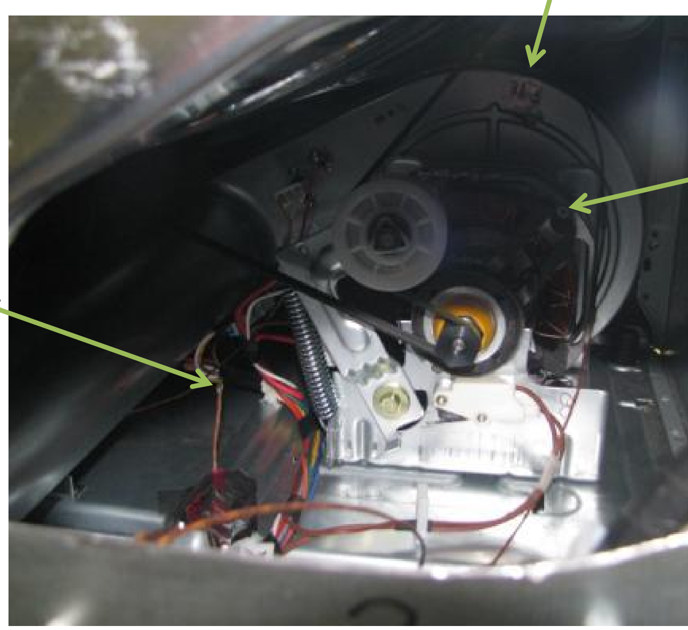


Figure A-17. Dryer 3: Locations of TC 30, 31, 33, and 34.

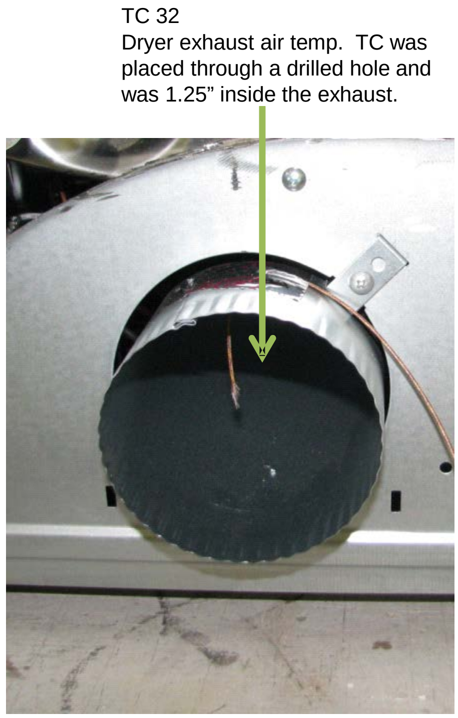


Figure A-18. Dryer 3: Location of TC 32.

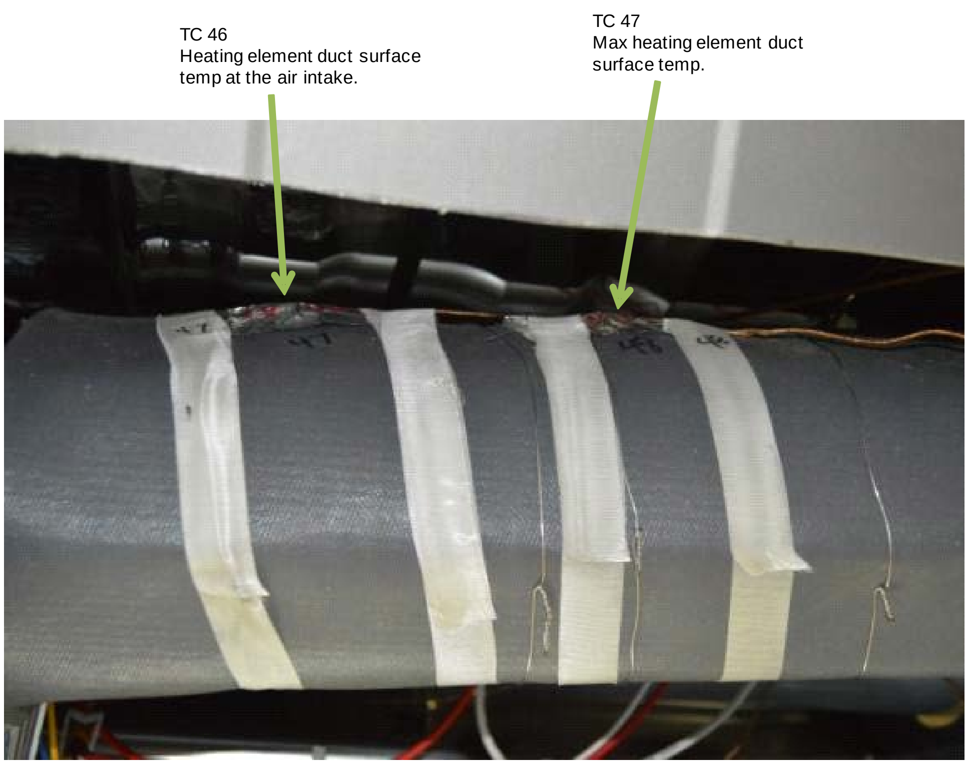


Figure A-19. Dryer 3: Location of TC 46 and 47 after insulation.

APPENDIX B

UNMODIFIED DRYER PERFORMANCE TESTS

GRAPHICAL DATA

(CONSISTING OF 12 PAGES)

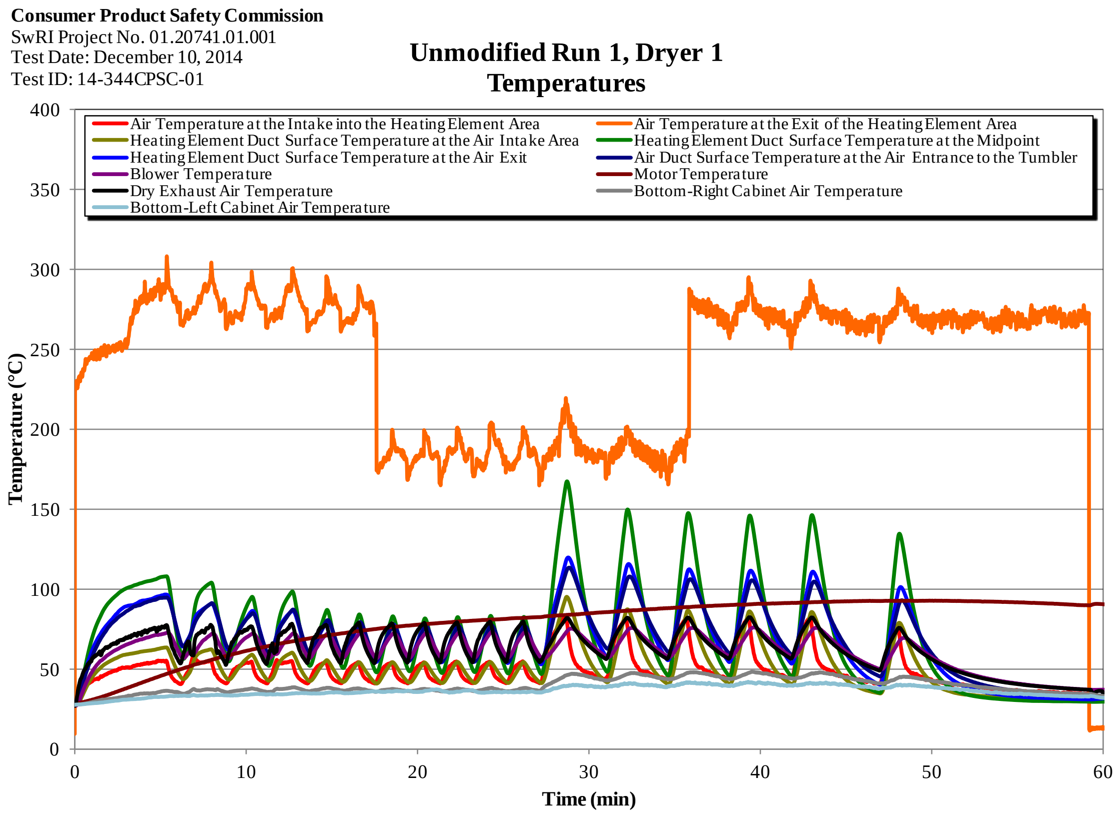


Figure B-1. Unmodified Run 1, Dryer 1 – Temperatures.

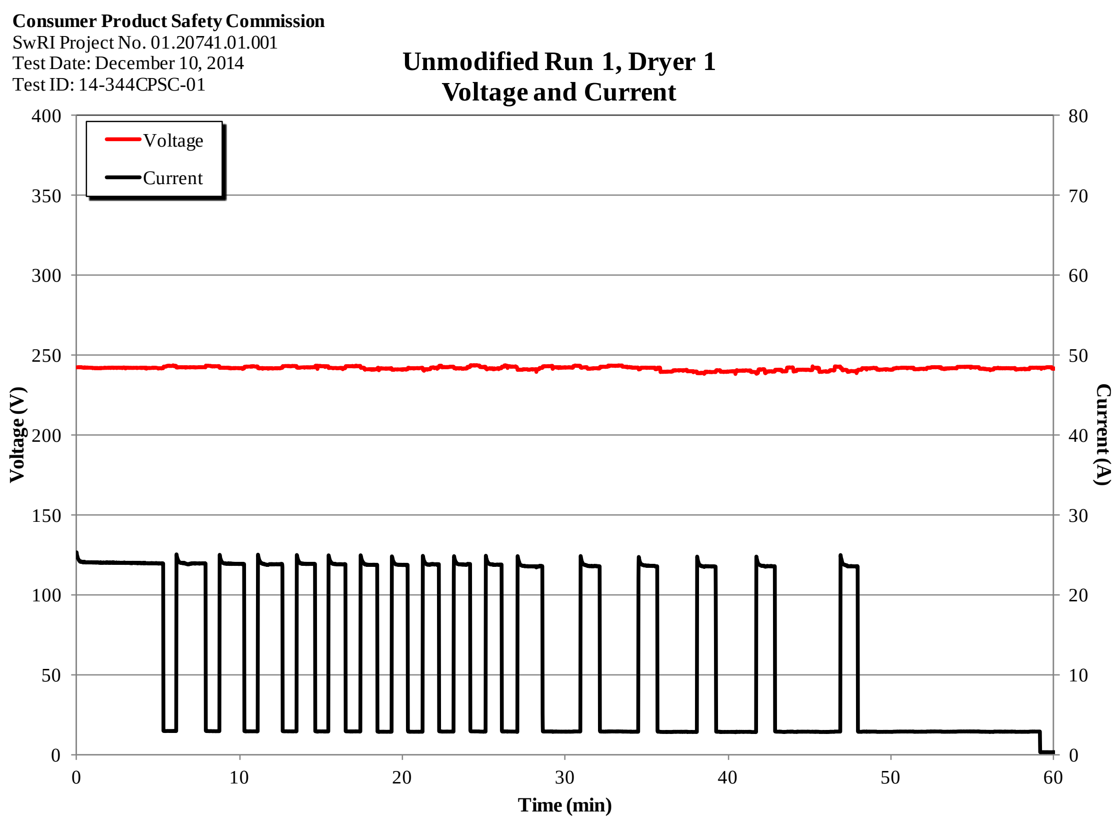


Figure B-2. Unmodified Run 1, Dryer 1 – Voltage and Current.

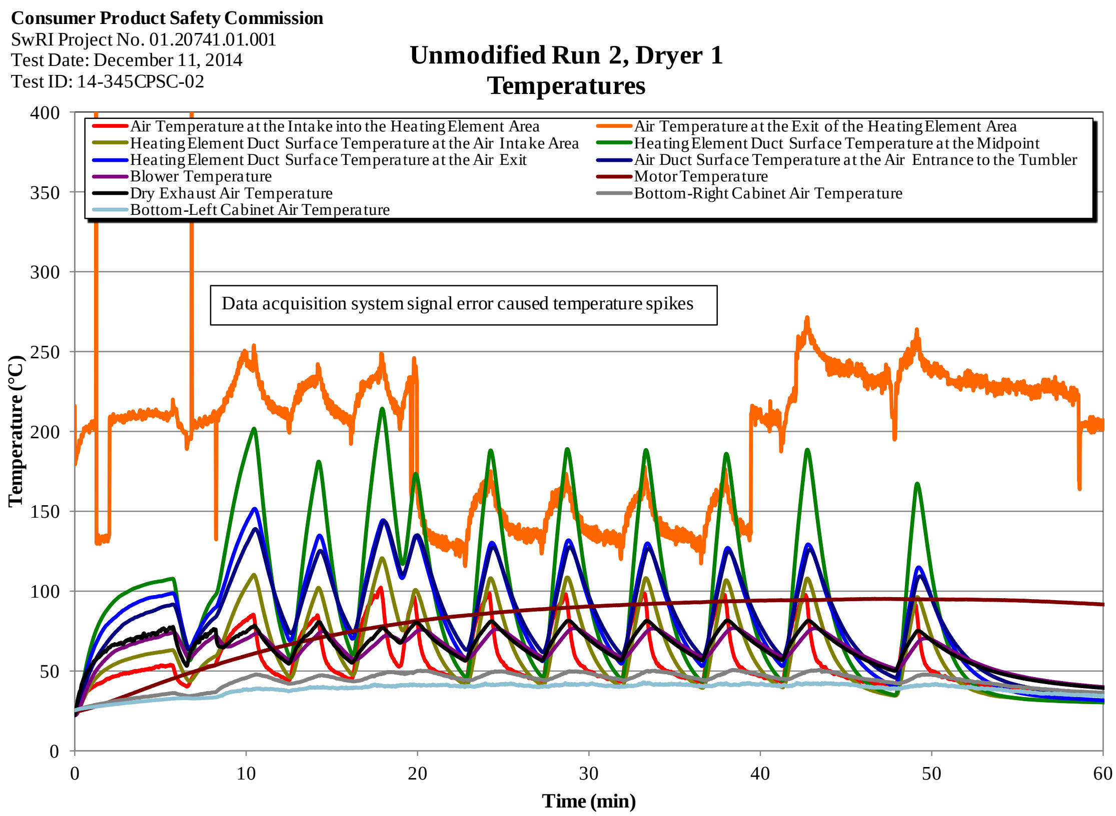


Figure B-3. Unmodified Run 2, Dryer 1 – Temperatures.

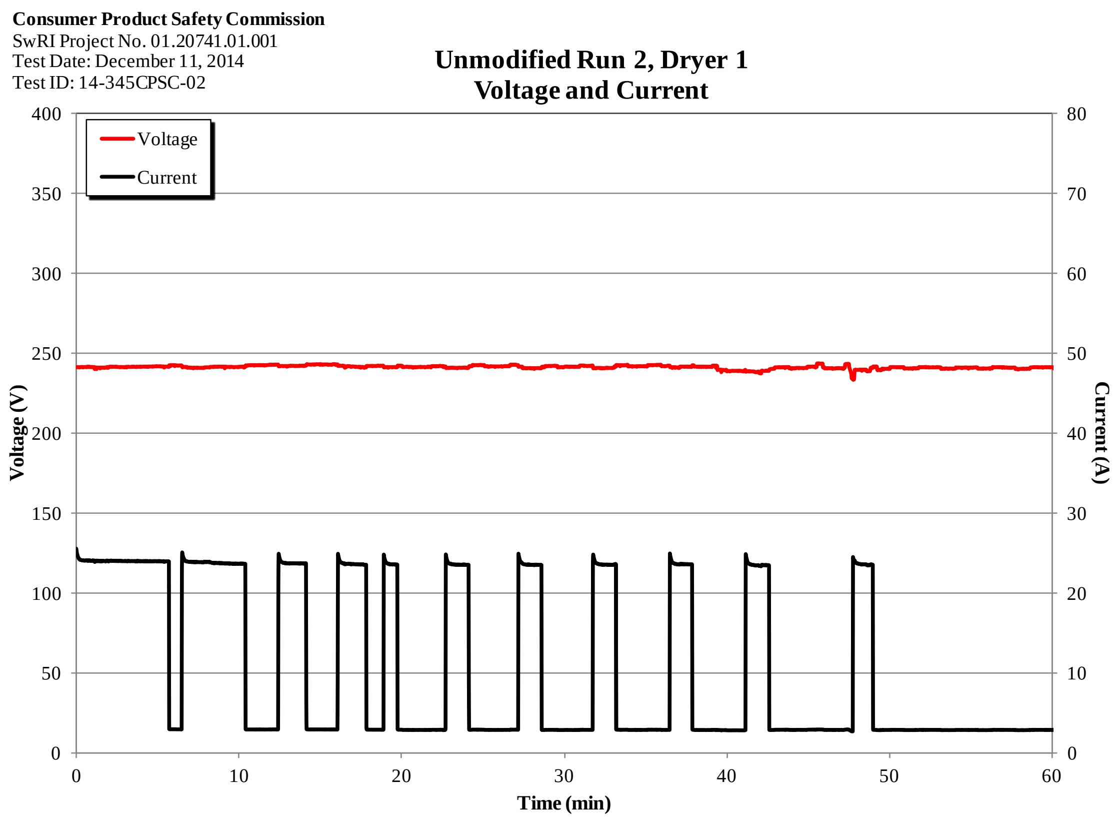


Figure B-4. Unmodified Run 2, Dryer 1 – Voltage and Current.

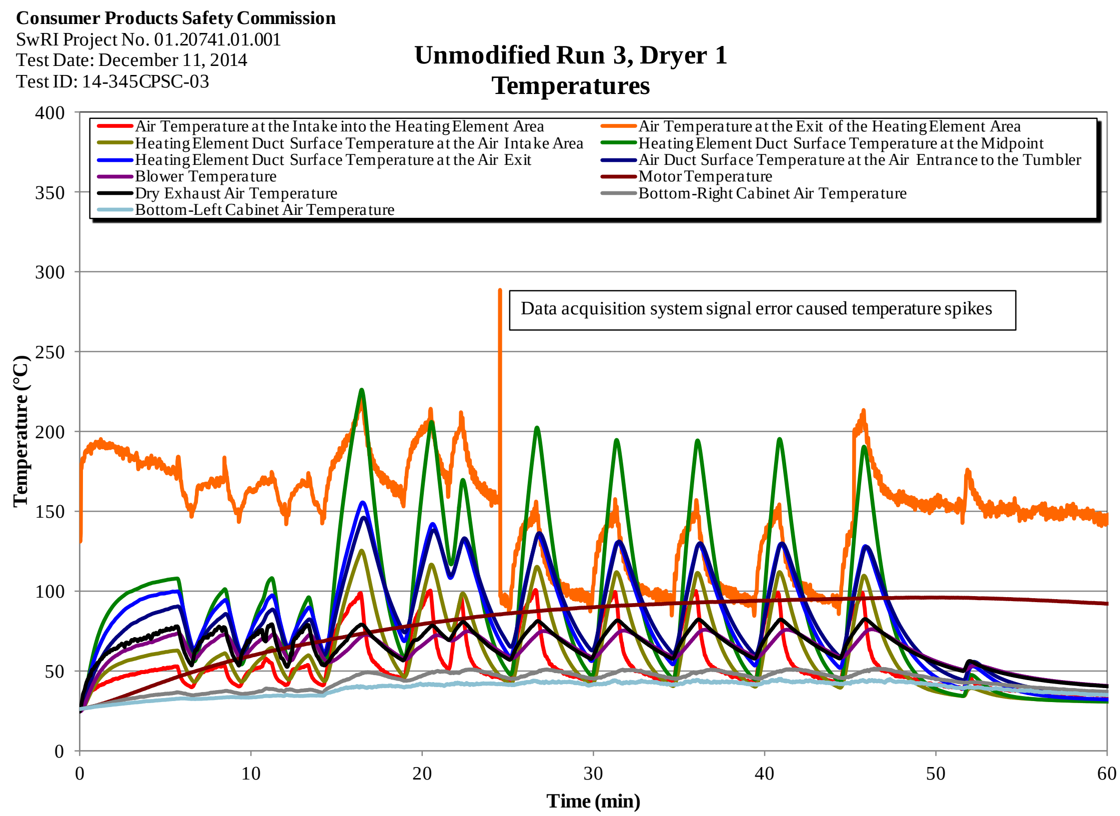


Figure B-5. Unmodified Run 3, Dryer 1 – Temperatures.

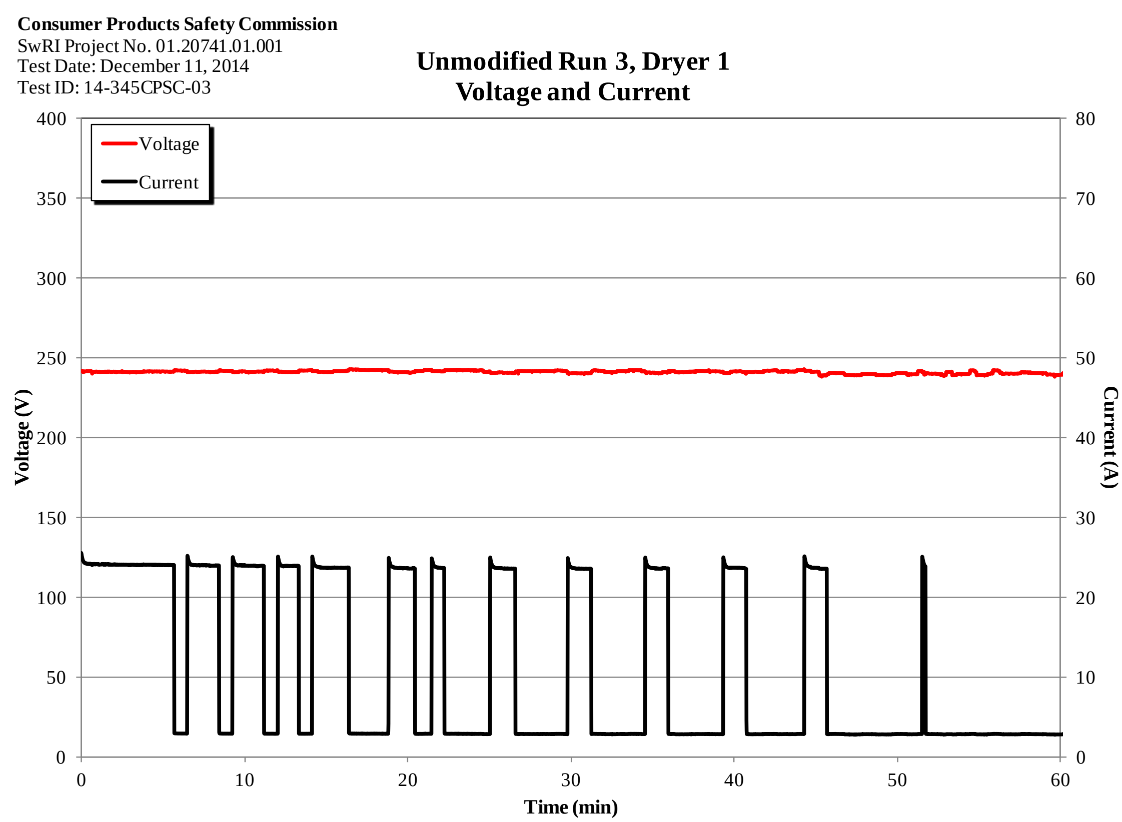


Figure B-6. Unmodified Run 3, Dryer 1 – Voltage and Current.

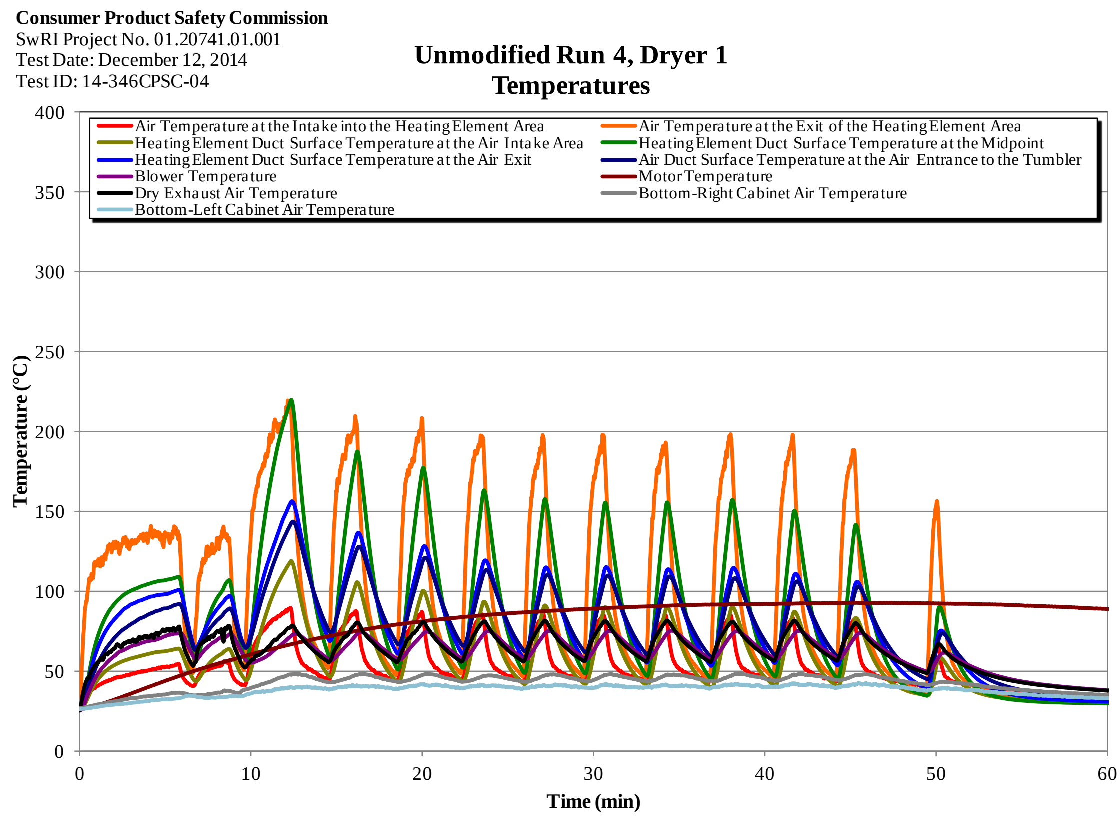


Figure B-7. Unmodified Run 4, Dryer 1 – Temperatures.

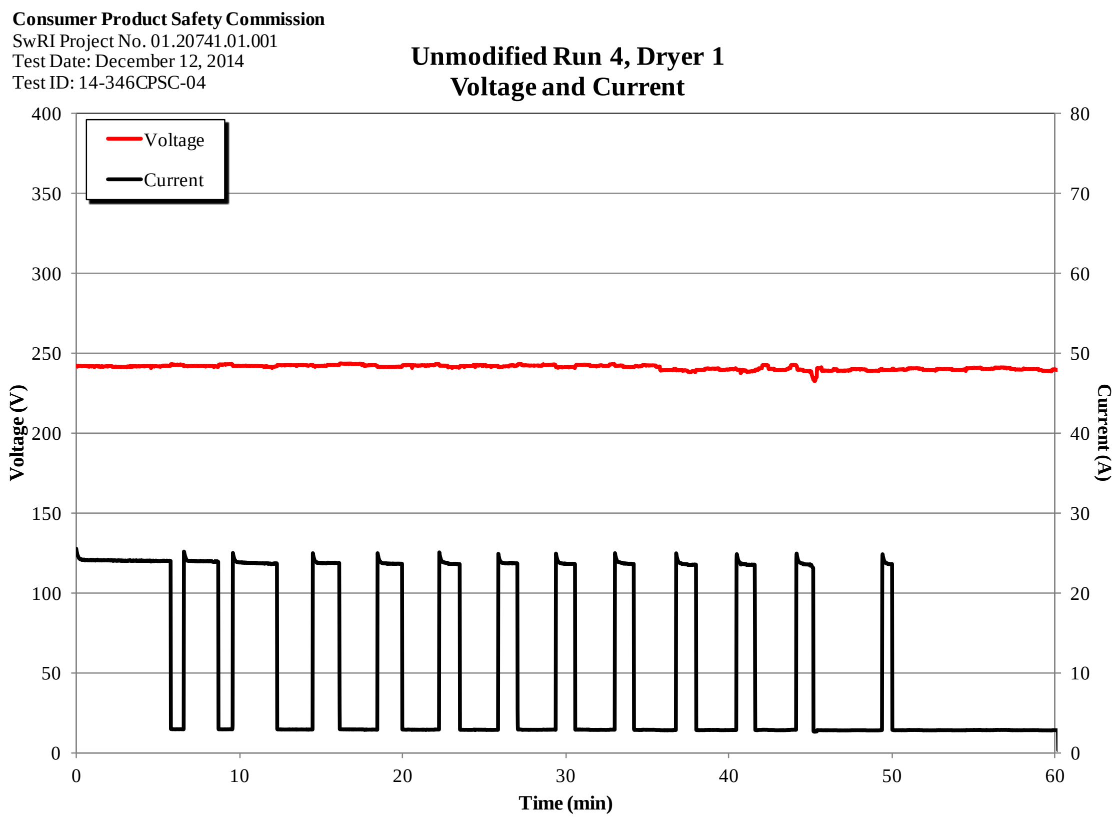


Figure B-8. Unmodified Run 4, Dryer 1 – Voltage and Current.

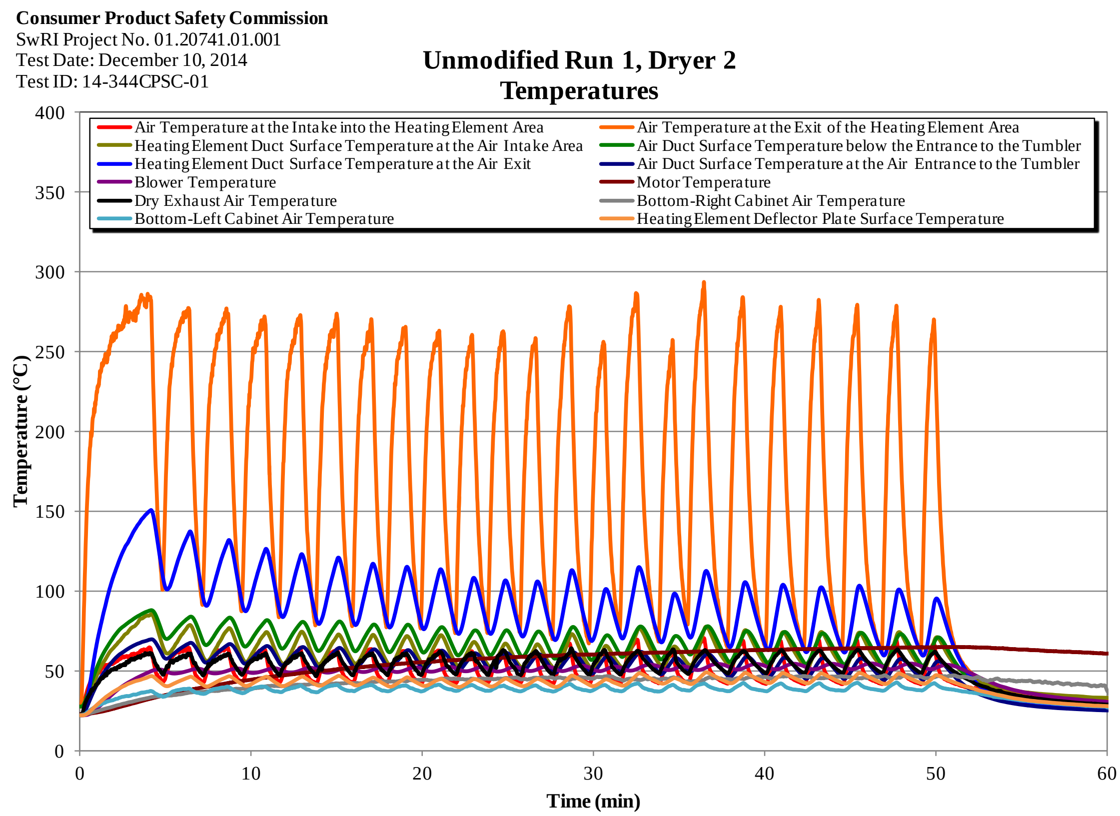


Figure B-9. Unmodified Run 1, Dryer 2 – Temperatures.

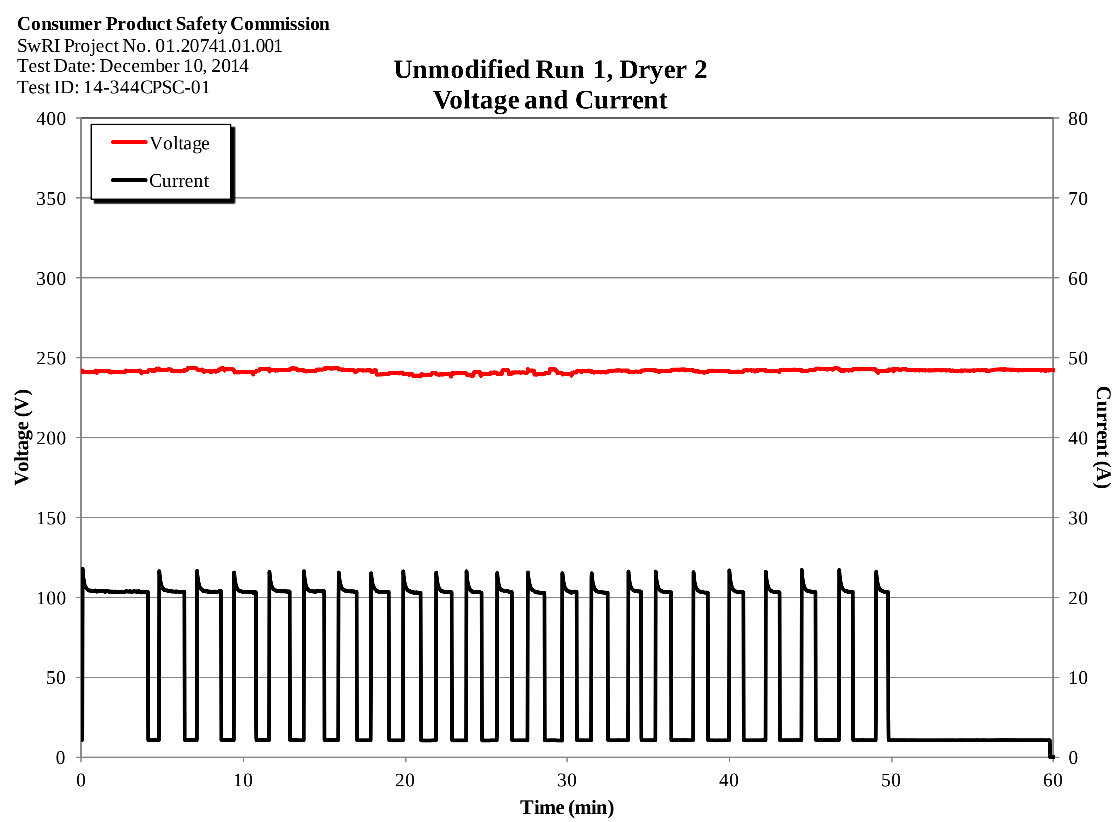


Figure B-10. Unmodified Run 1, Dryer 2 – Voltage and Current.

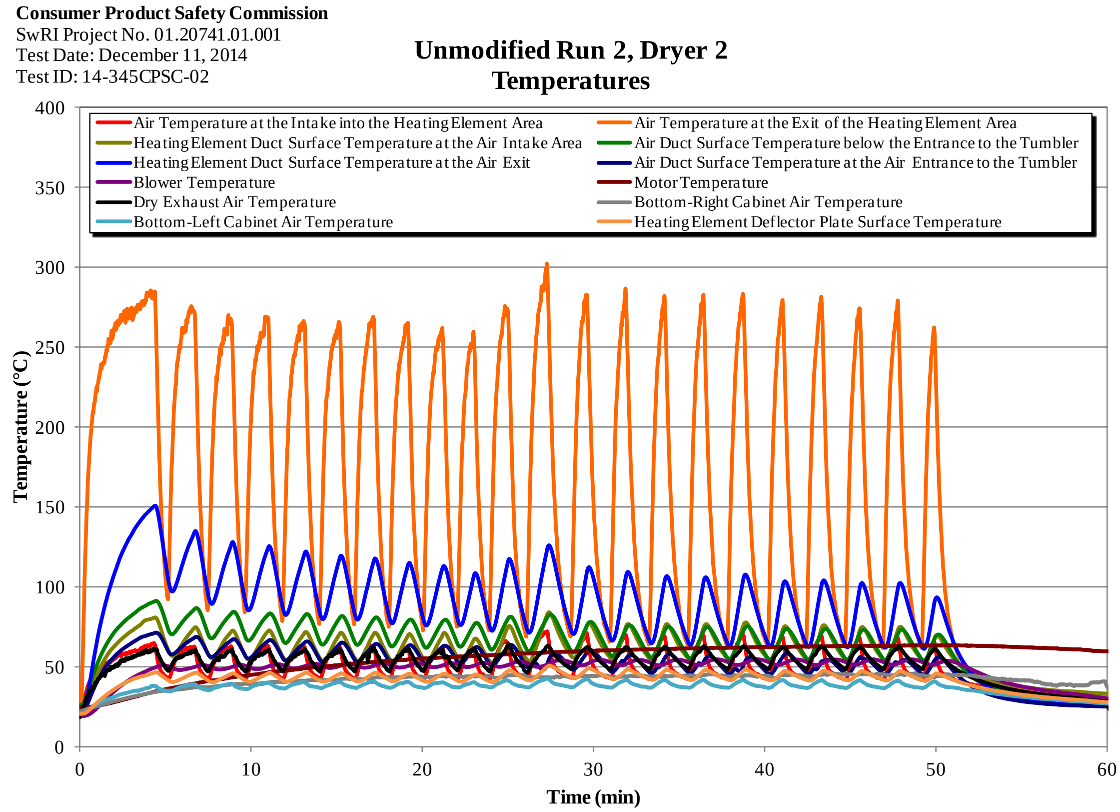


Figure B-11. Unmodified Run 2, Dryer 2 – Temperatures.

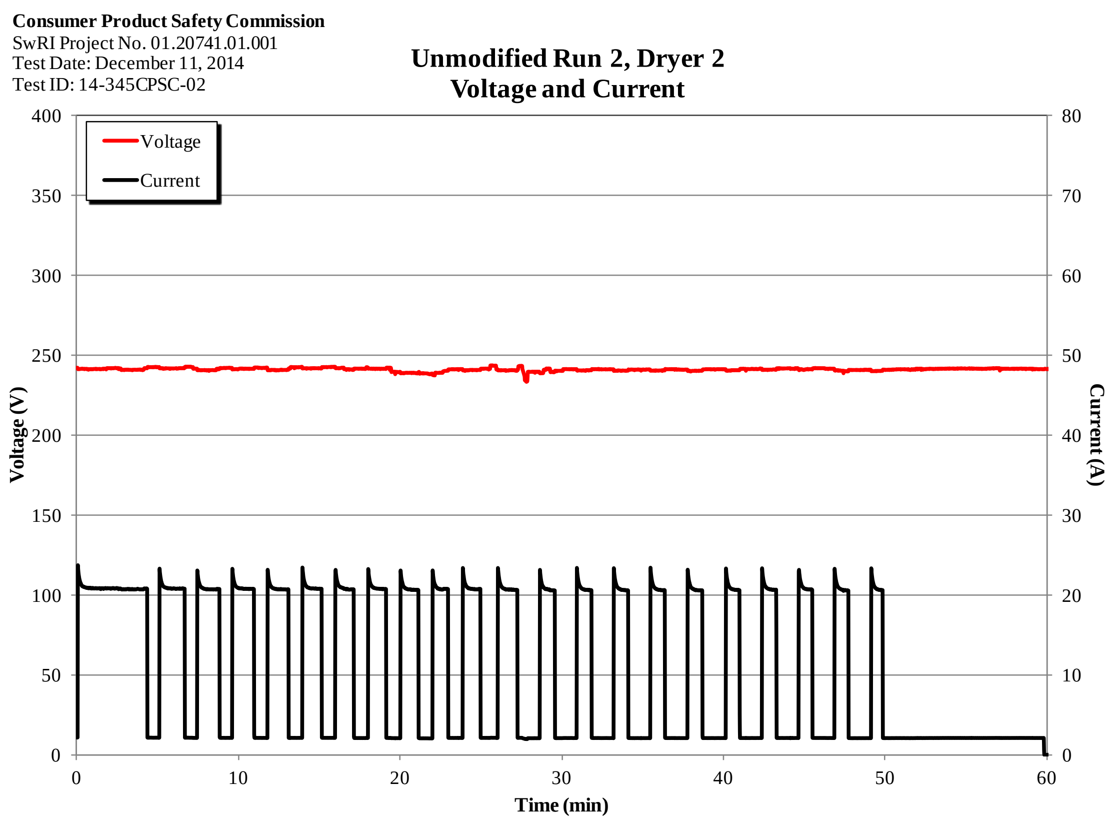


Figure B-12. Unmodified Run 2, Dryer 2 – Voltage and Current.

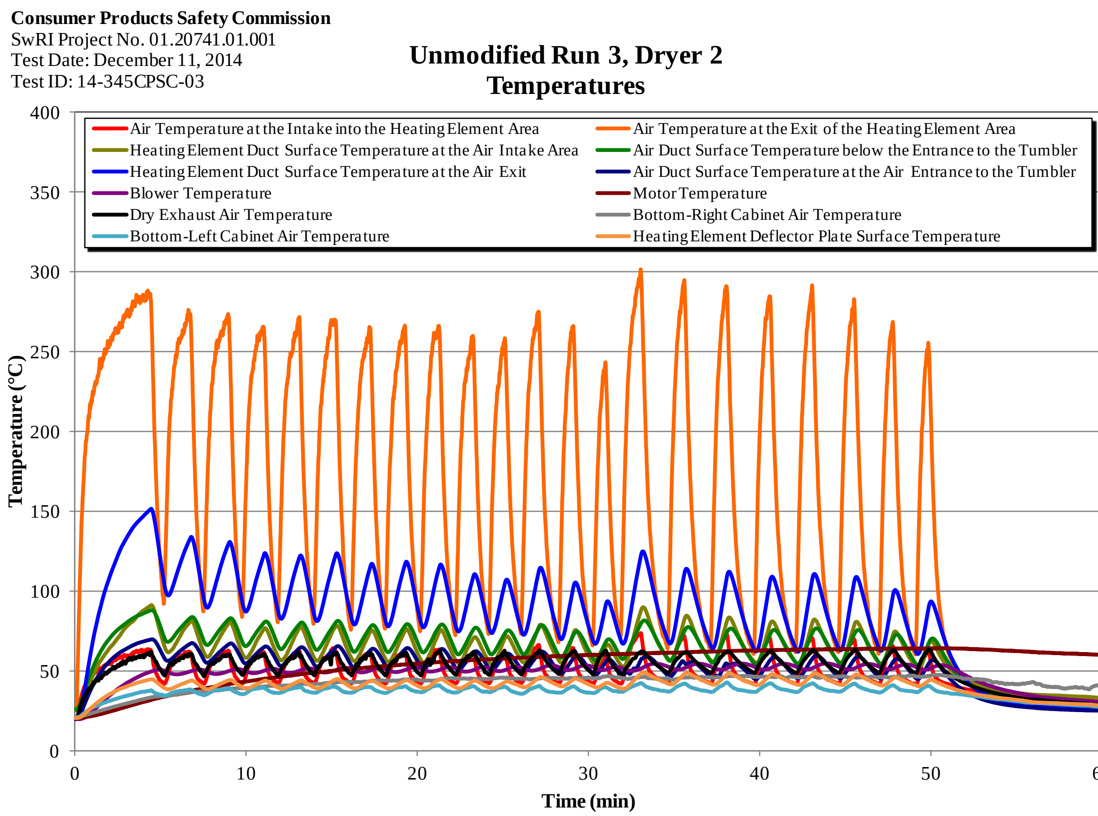


Figure B-13. Unmodified Run 3, Dryer 2 – Temperatures.

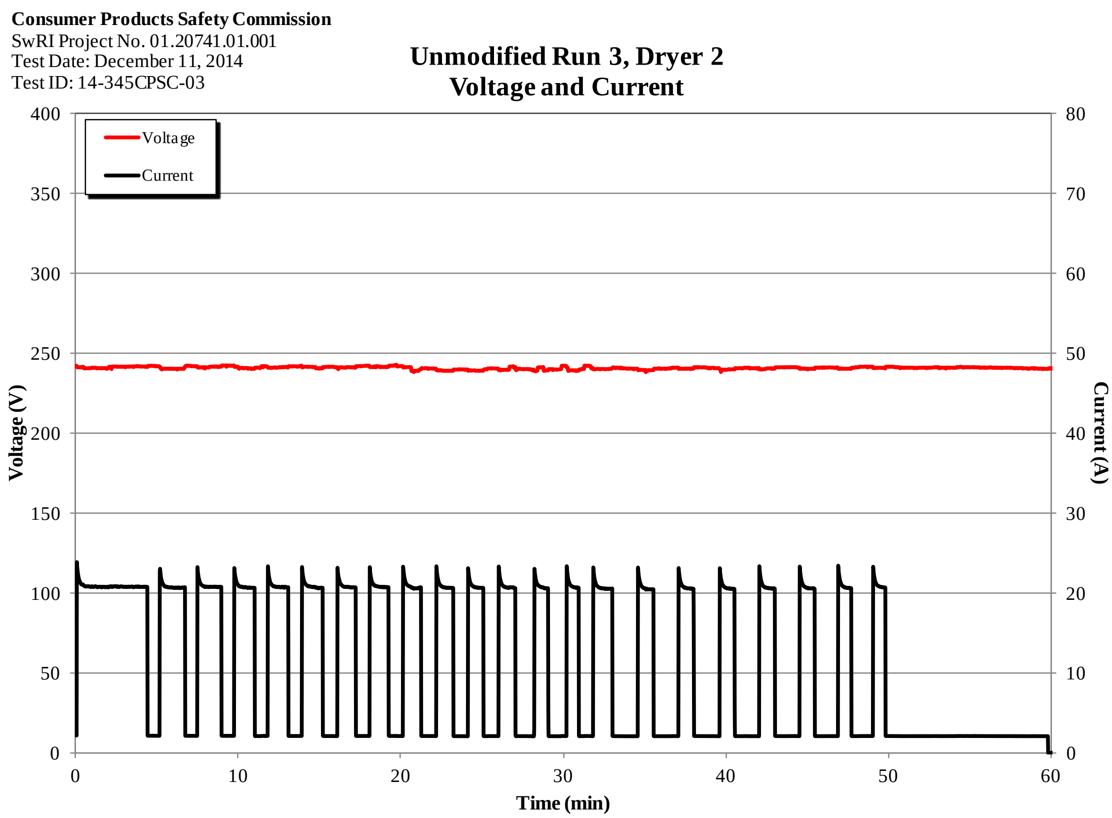


Figure B-14. Unmodified Run 3, Dryer 2 – Voltage and Current.

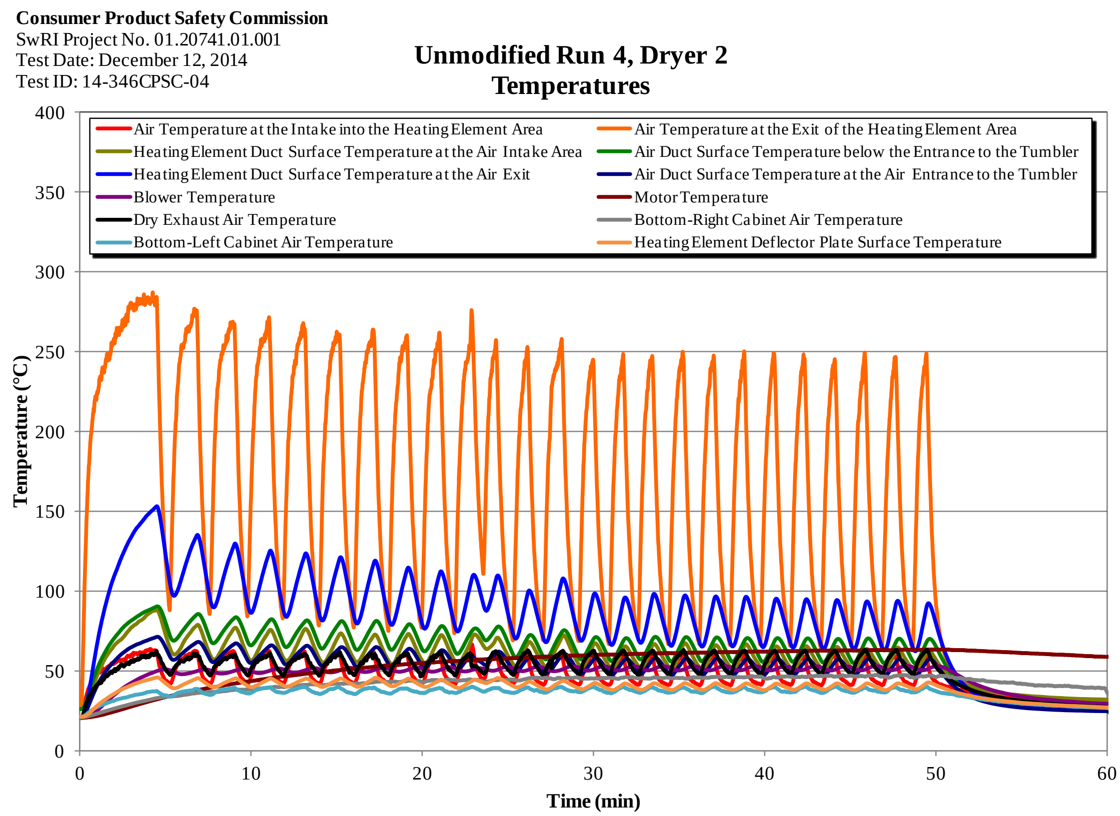


Figure B-15. Unmodified Run 4, Dryer 2 – Temperatures.

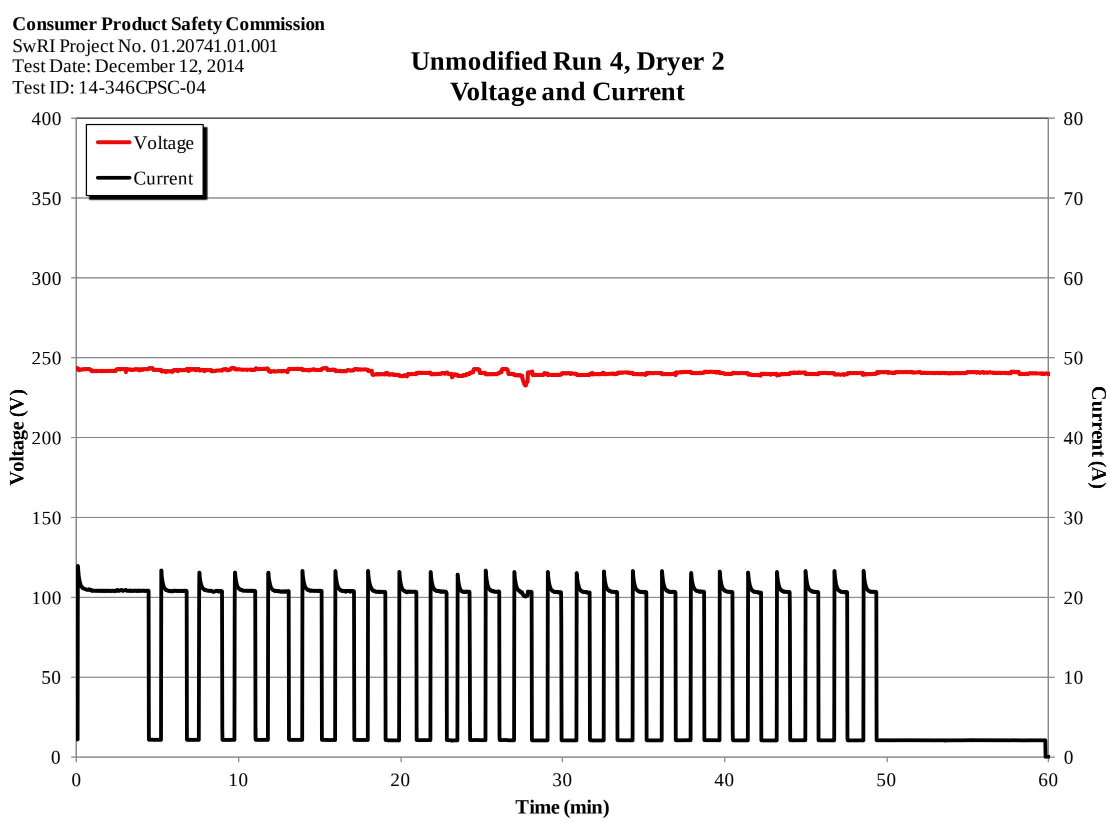


Figure B-16. Unmodified Run 4, Dryer 2 – Voltage and Current.

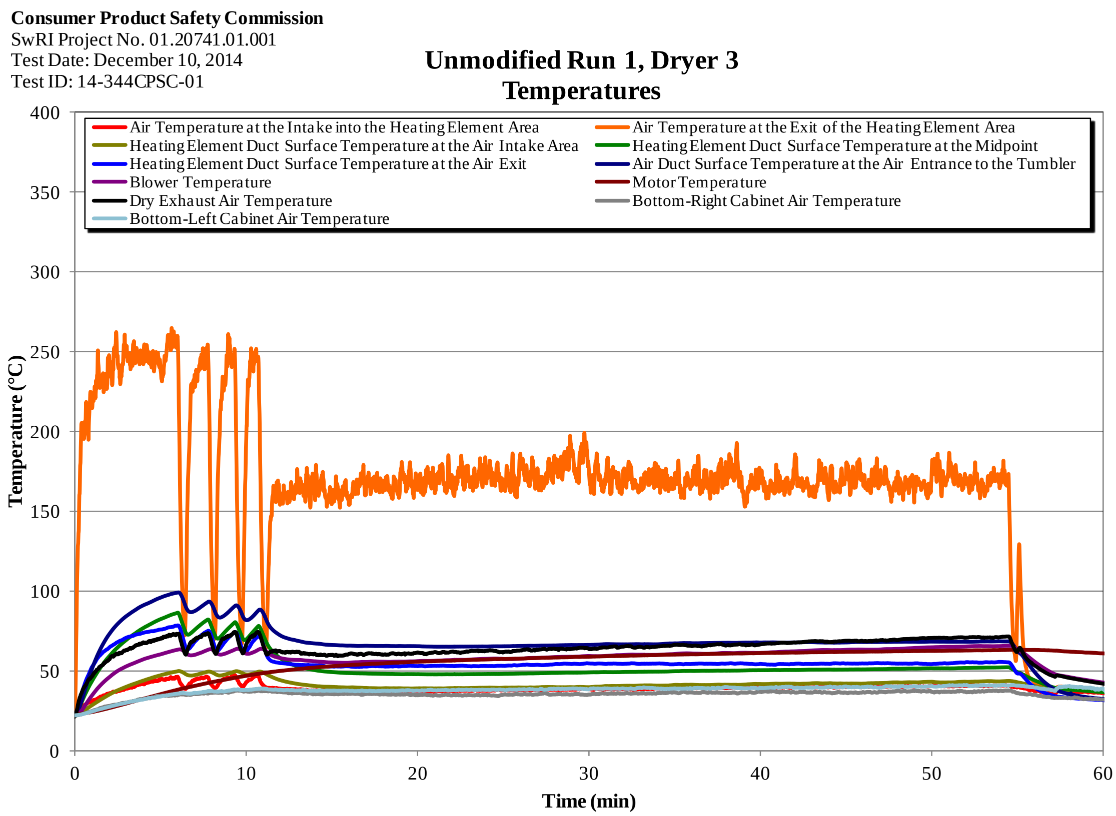


Figure B-17. Unmodified Run 1, Dryer 3 – Temperatures.

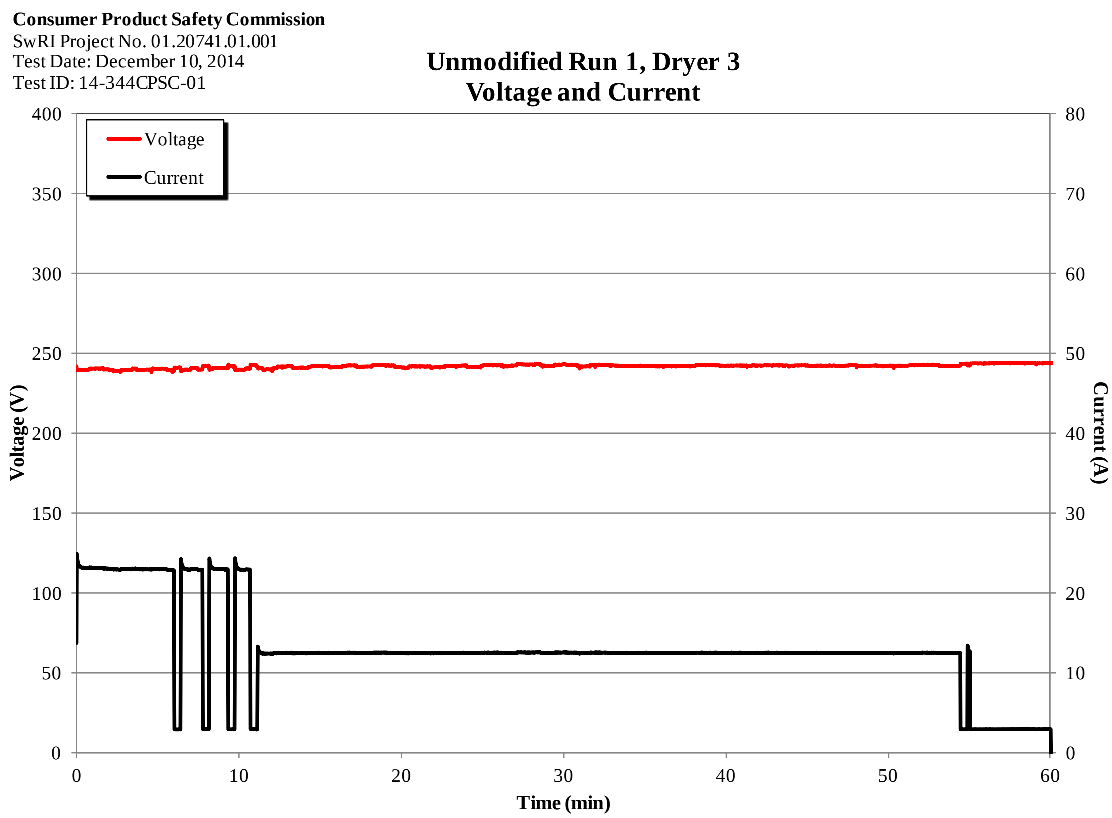


Figure B-18. Unmodified Run 1, Dryer 3 – Voltage and Current.

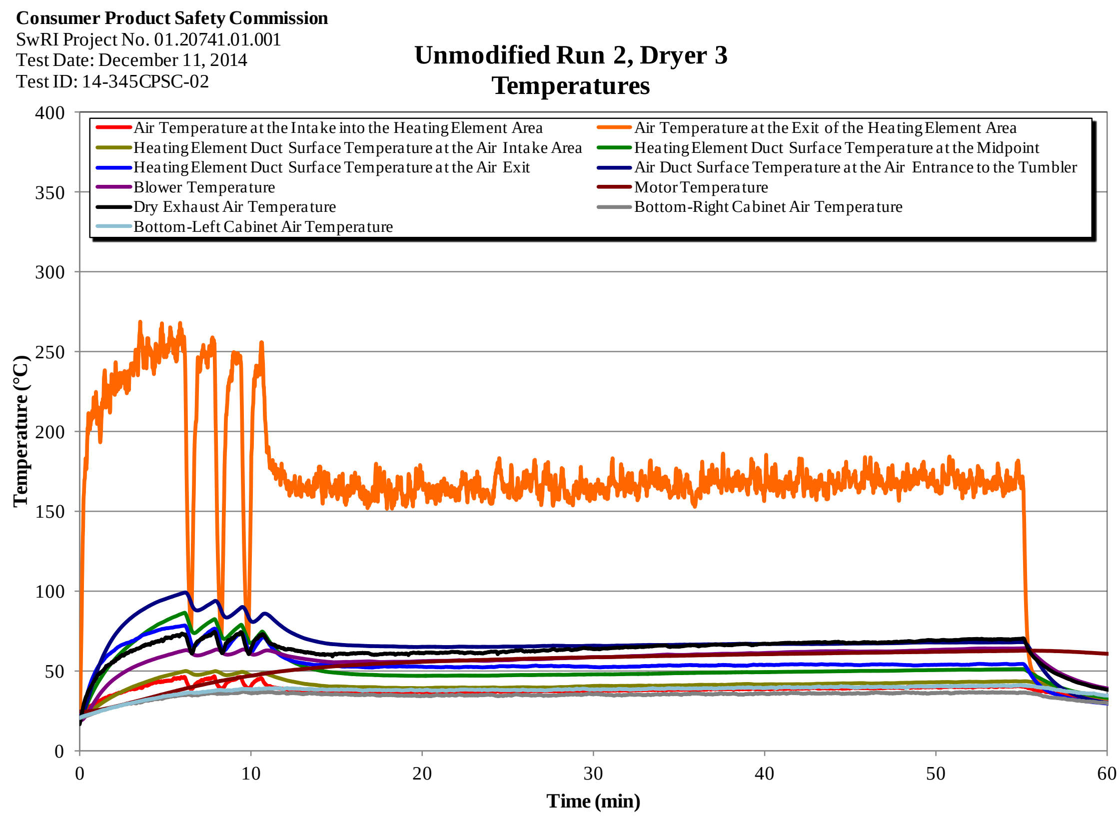


Figure B-19. Unmodified Run 2, Dryer 3 – Temperatures.

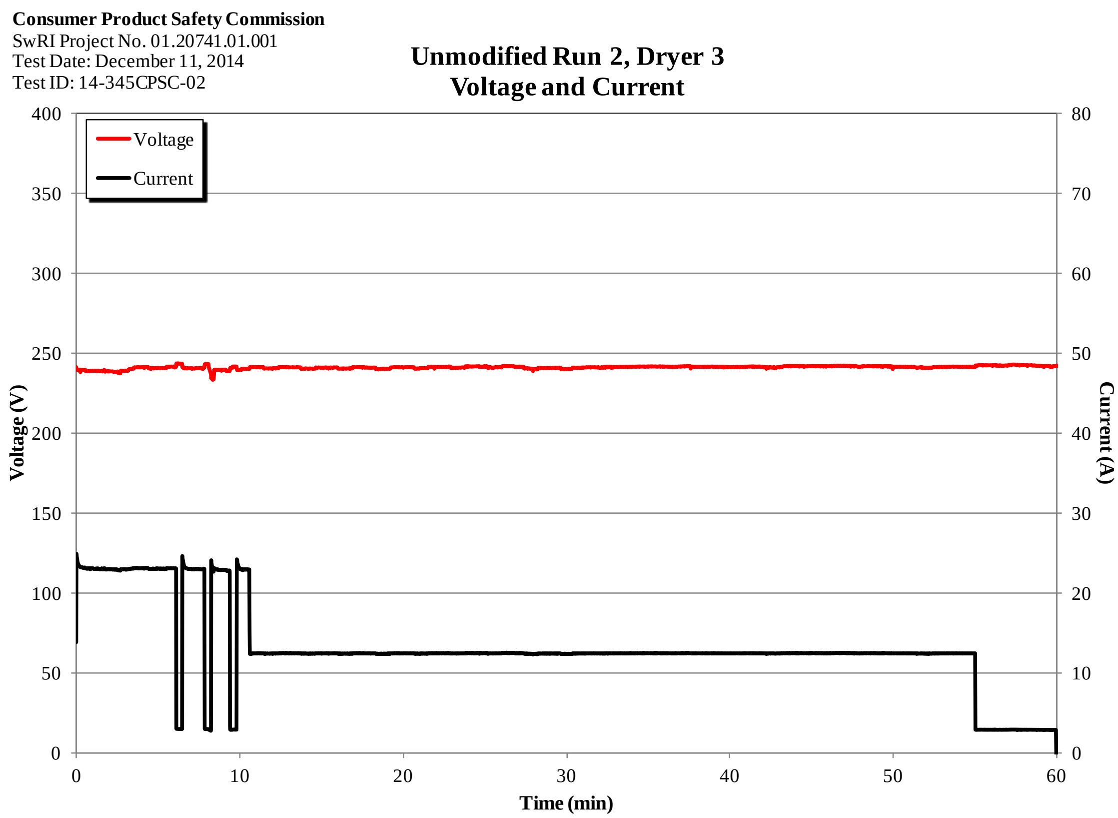


Figure B-20. Unmodified Run 2, Dryer 3 – Voltage and Current.

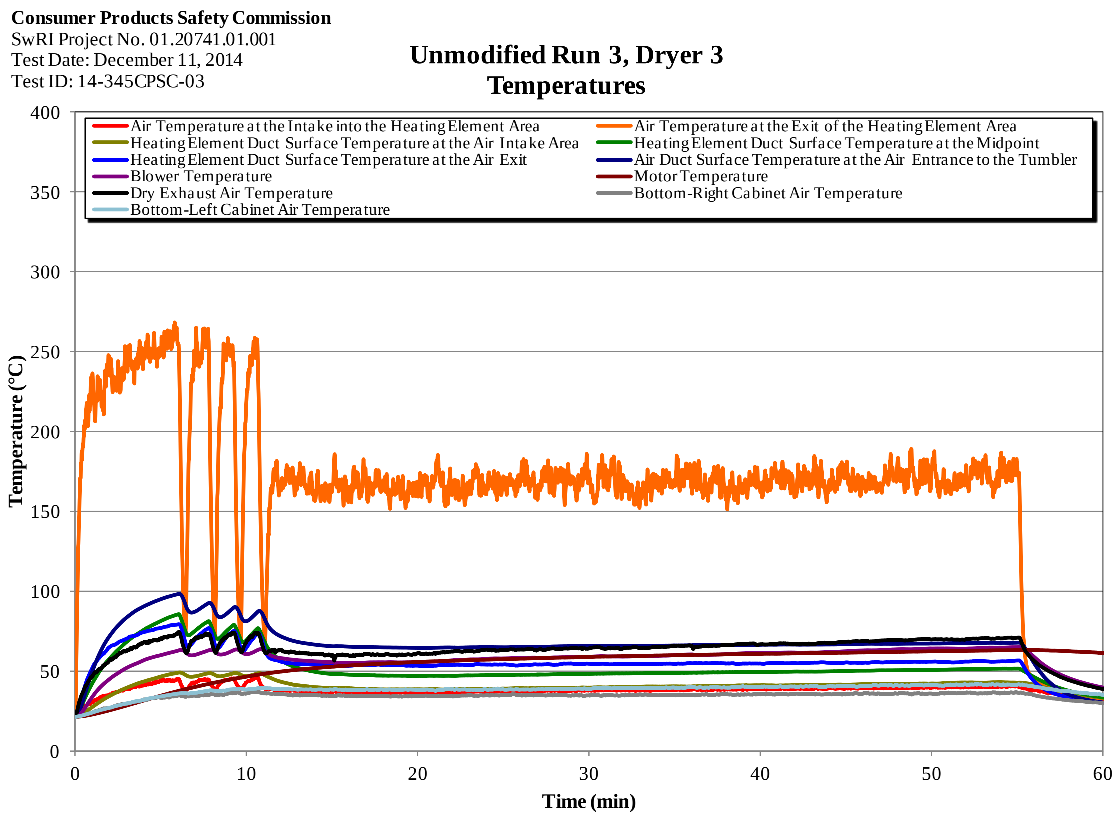


Figure B-21. Unmodified Run 3, Dryer 3 – Temperatures.

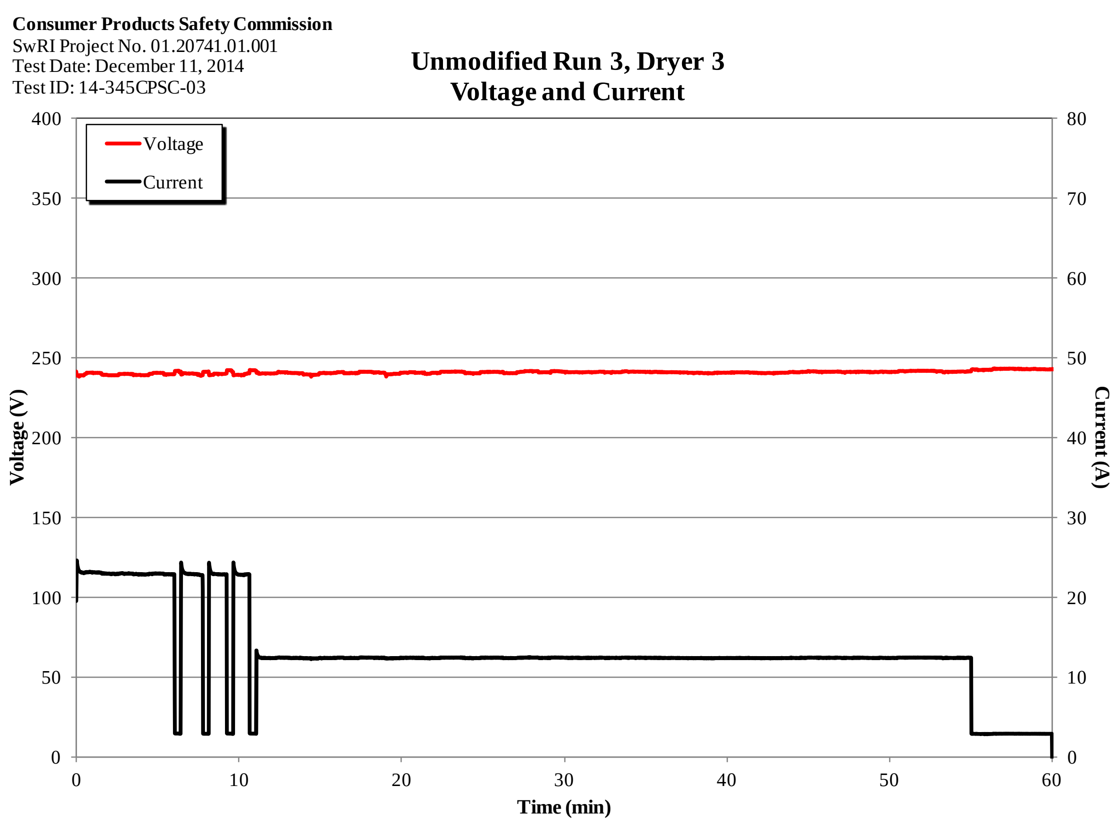


Figure B-22. Unmodified Run 3, Dryer 3 – Voltage and Current.

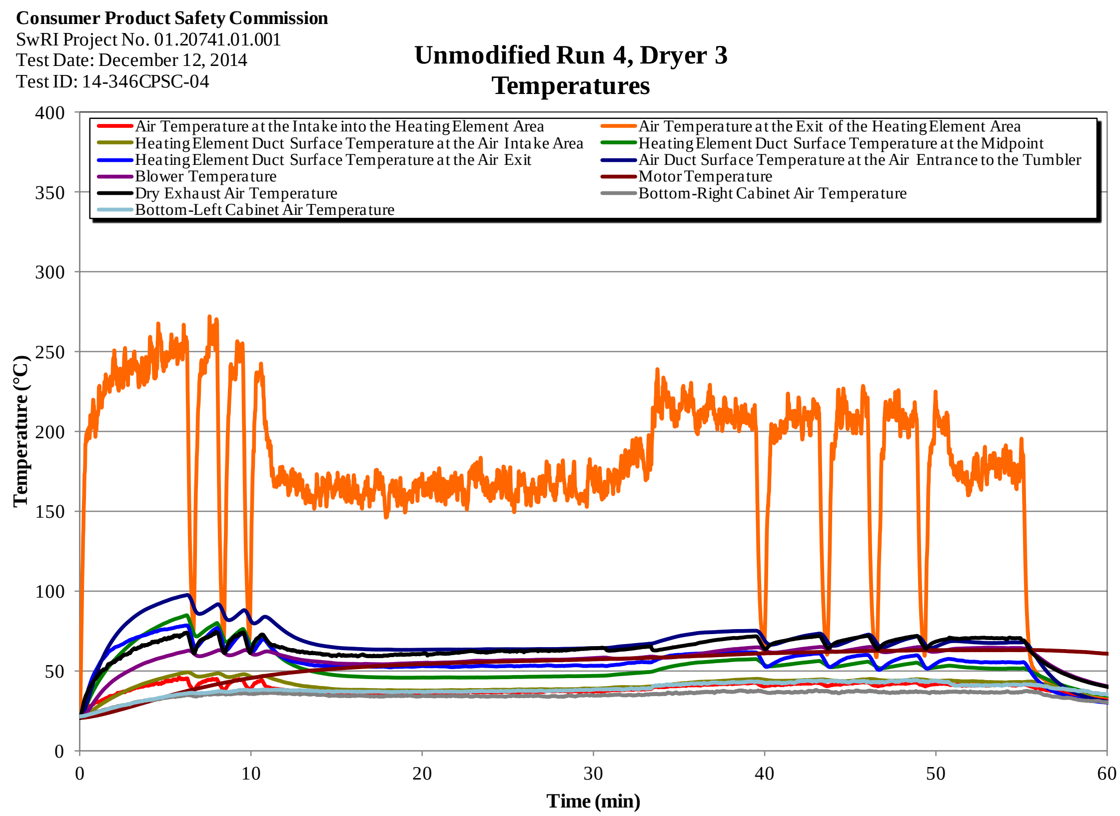


Figure B-23. Unmodified Run 4, Dryer 3 – Temperatures.

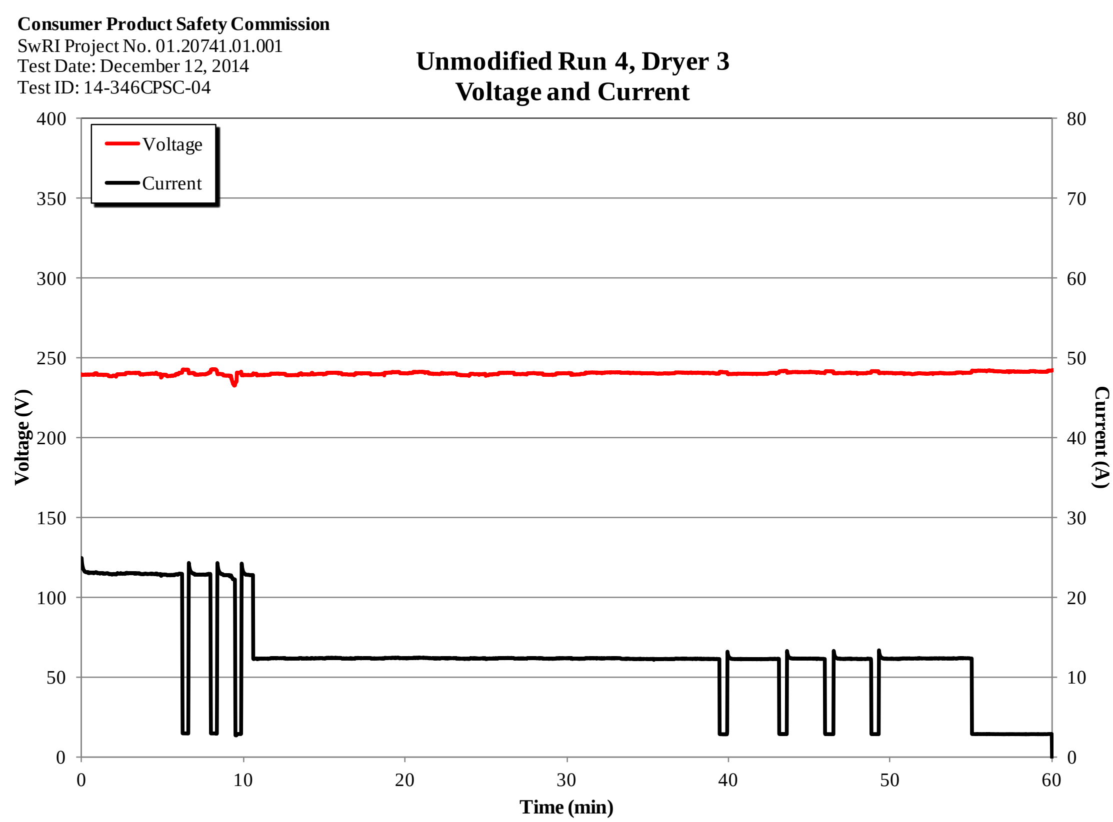


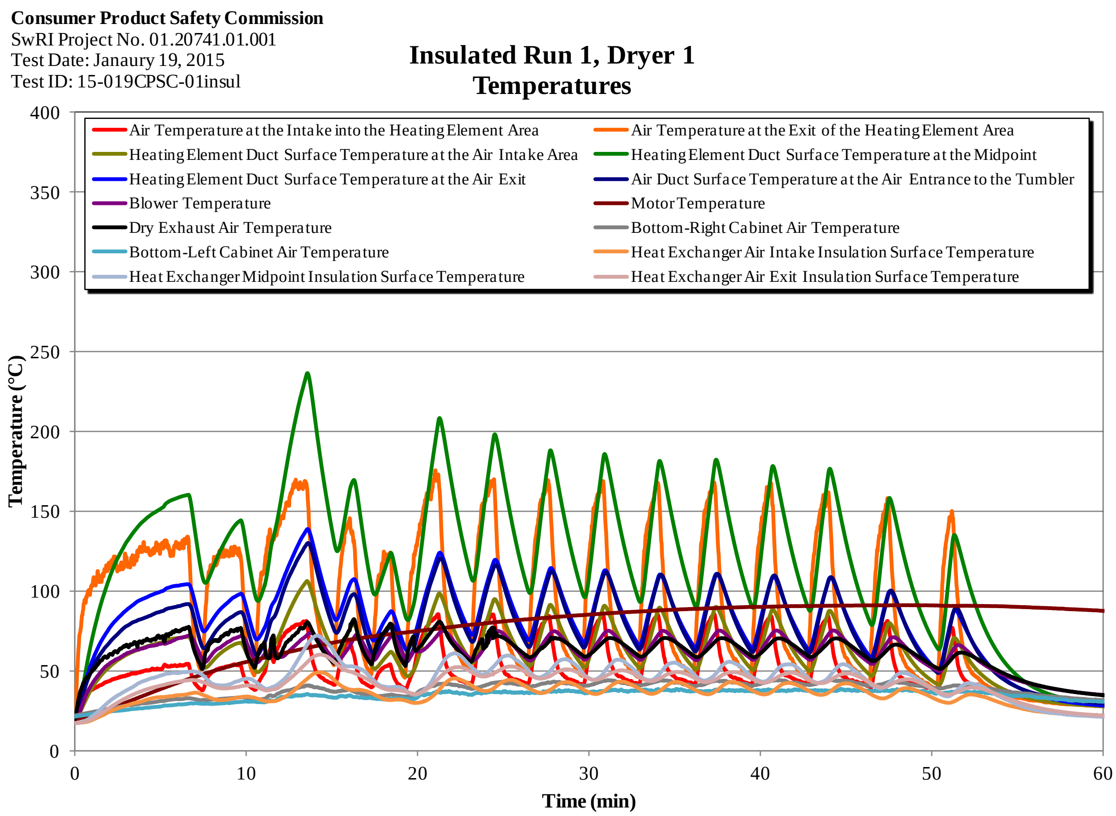
Figure B-24. Unmodified Run 4, Dryer 3 – Voltage and Current.

Appendix C

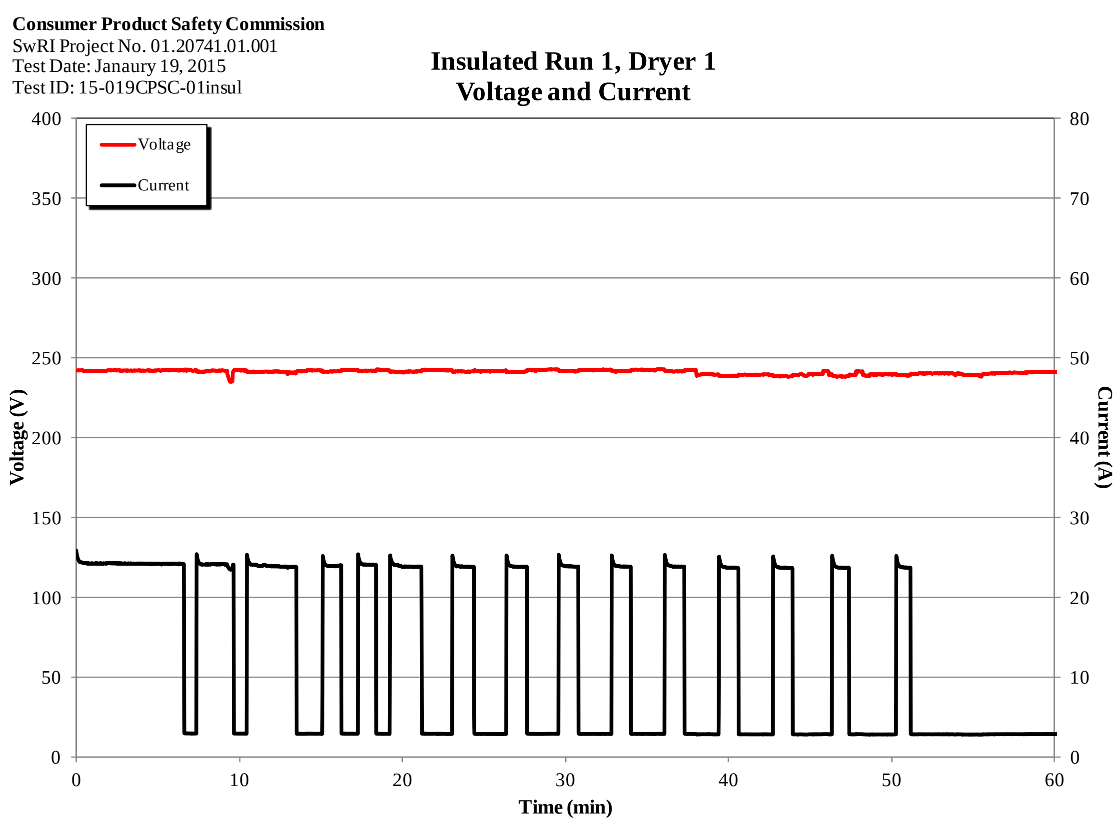
Insulated Dryer Performance Tests

Graphical Data

(Consisting of 12 Pages)



C-1. Insulated Run 1, Dryer 1 – Temperatures.



C-2. Insulated Run 1, Dryer 1 – Voltage and Current.

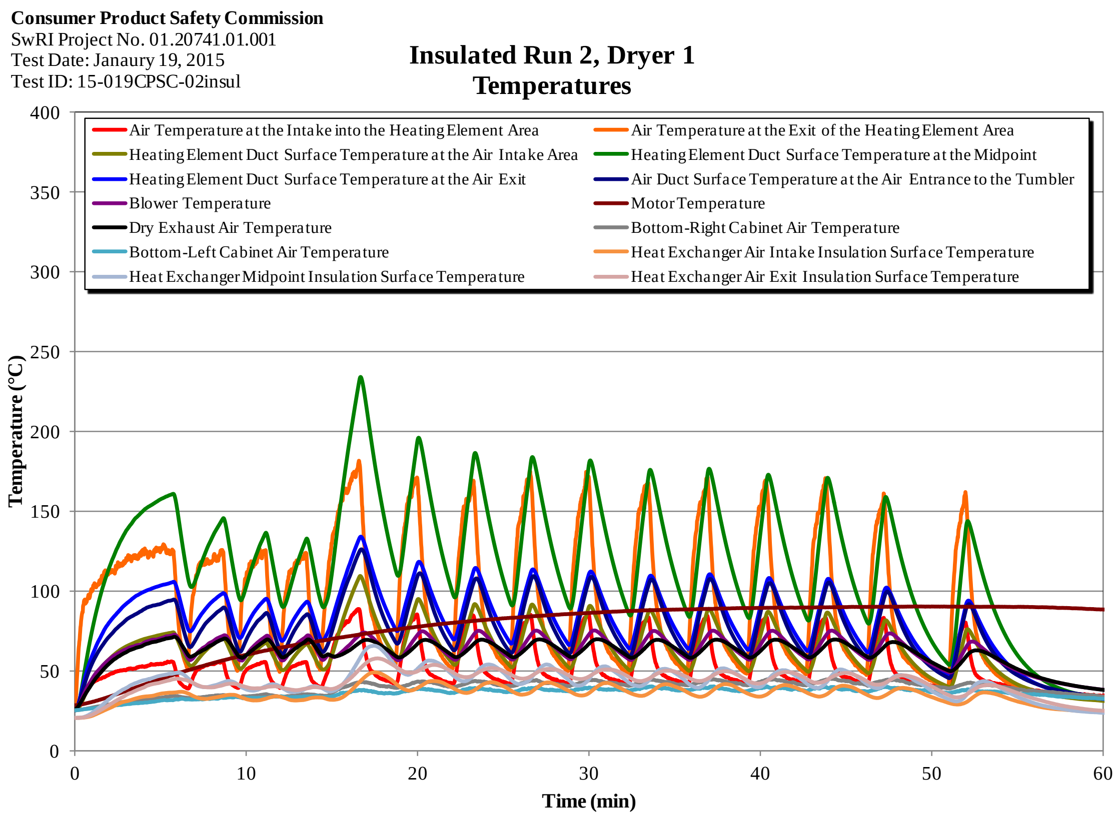


Figure C-3. Insulated Run 2, Dryer 1 – Temperatures.

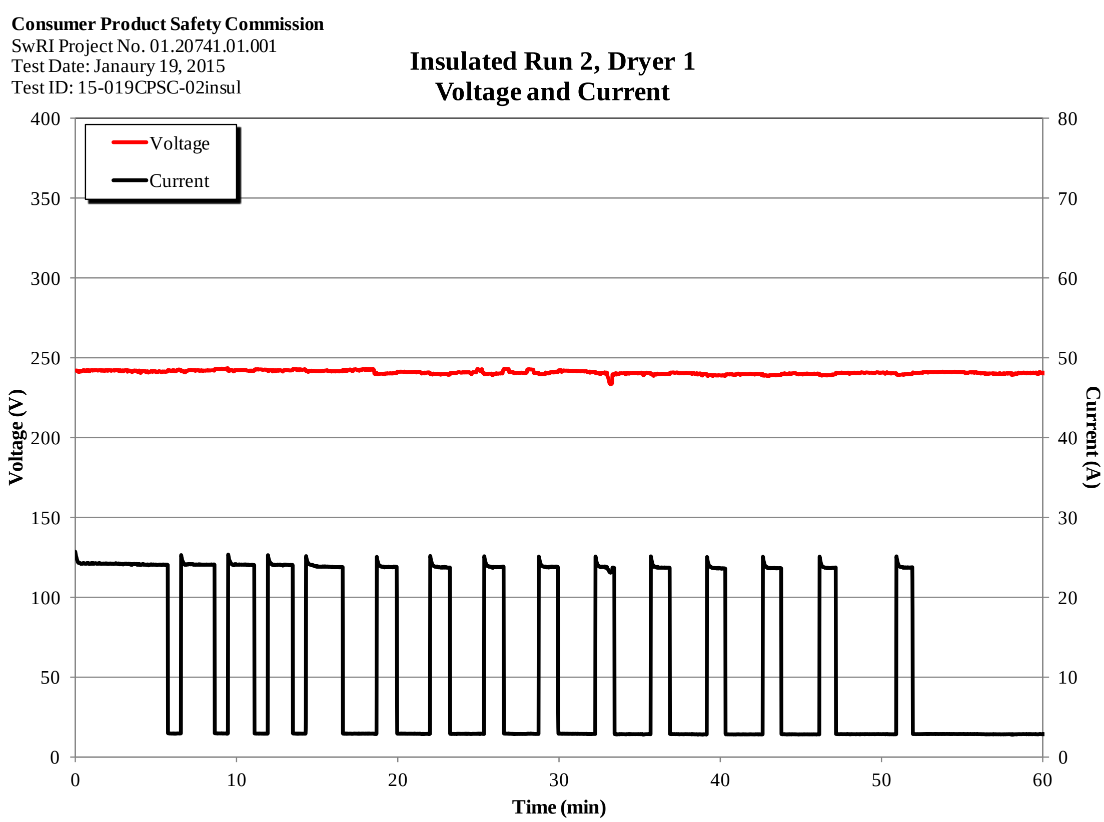


Figure C-4. Insulated Run 2, Dryer 1 – Voltage and Current.

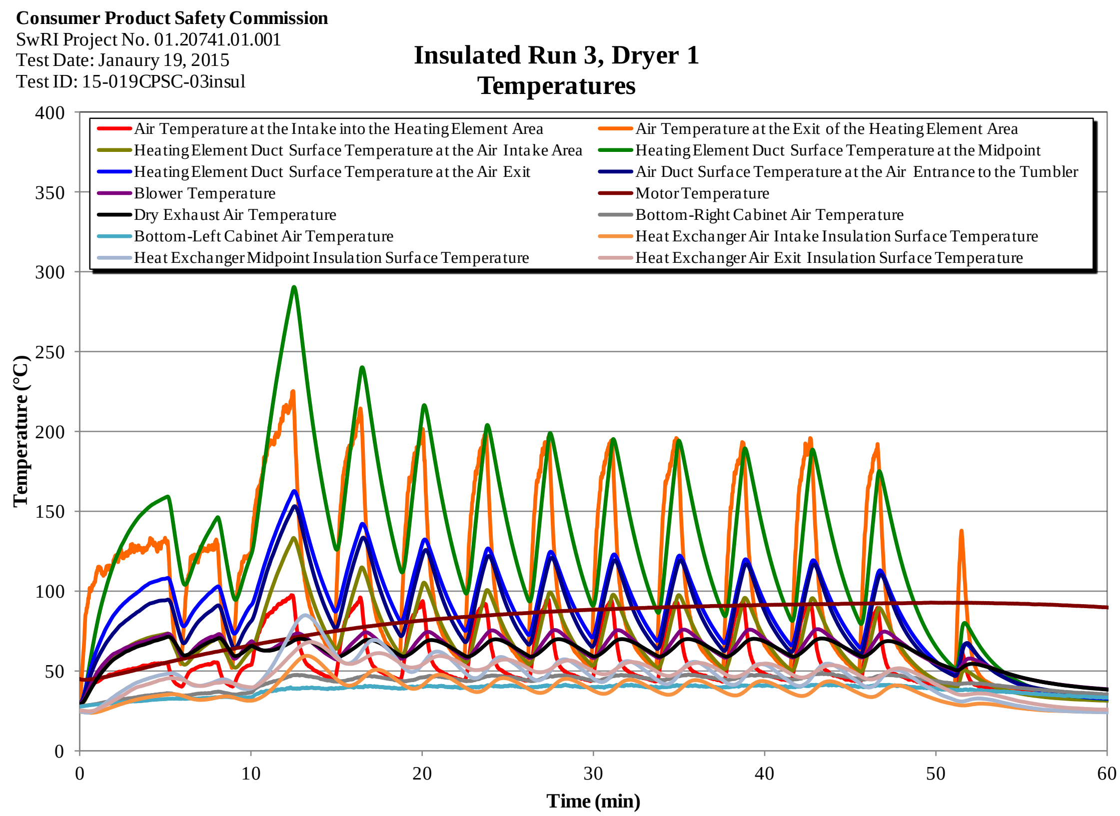


Figure C-5. Insulated Run 3, Dryer 1 – Temperatures.

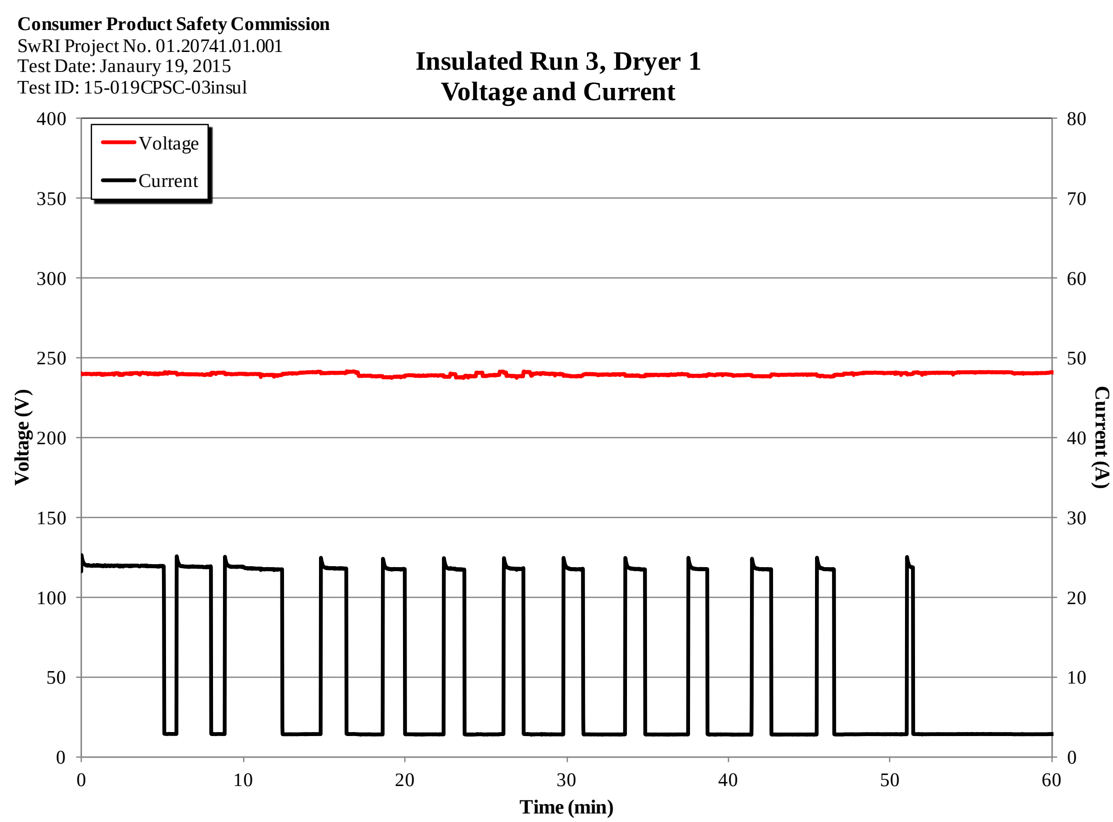


Figure C-6. Insulated Run 3, Dryer 1 – Voltage and Current.

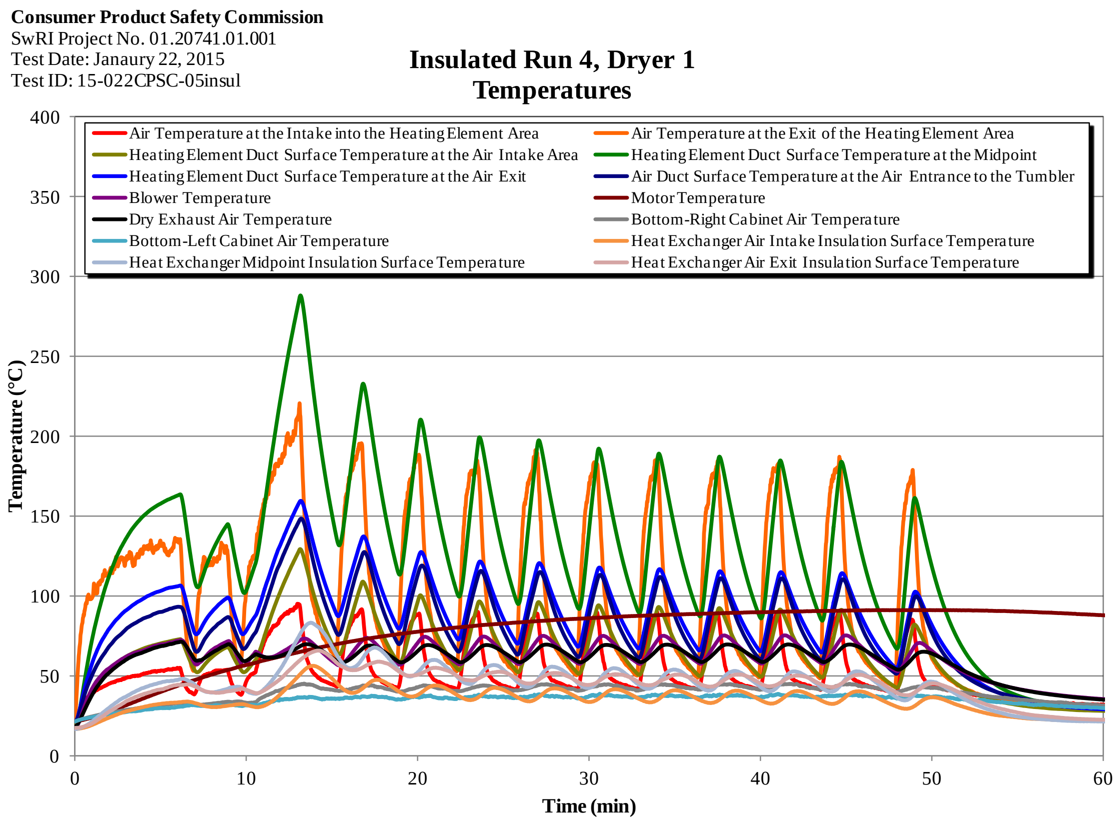


Figure C-7. Insulated Run 4, Dryer 1 – Temperatures.

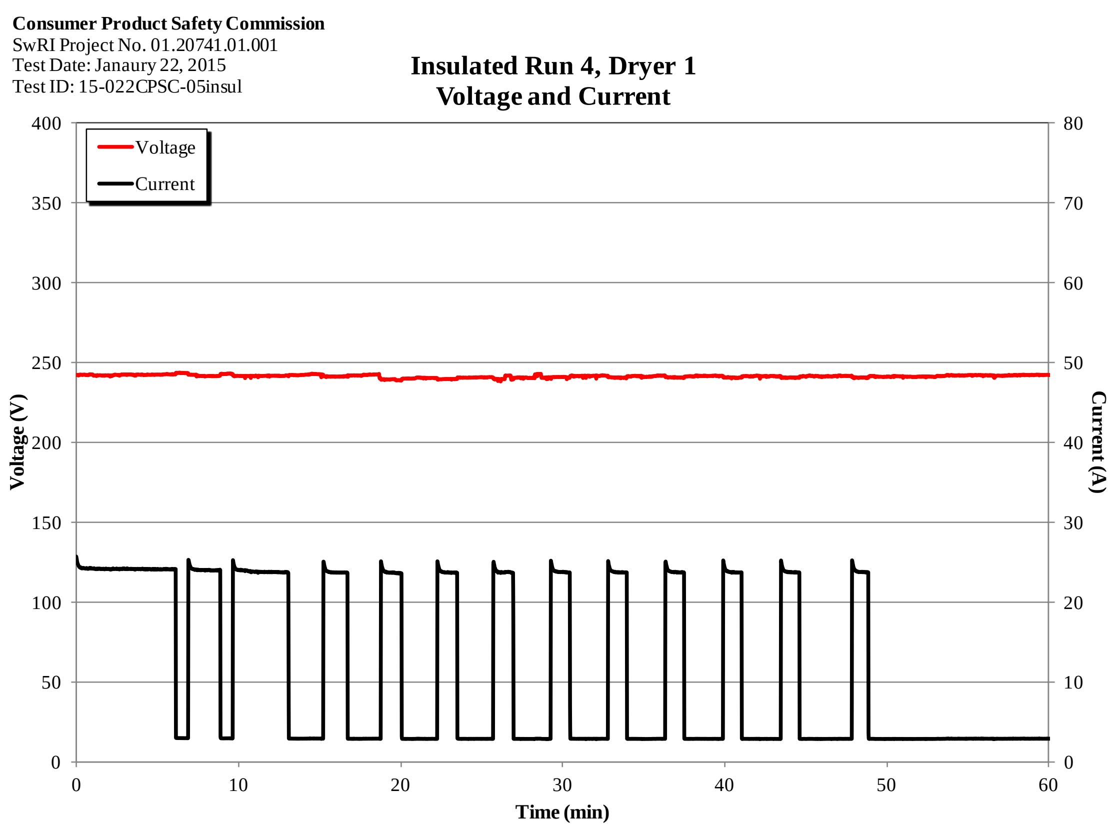


Figure C-8. Insulated Run 4, Dryer 1 – Voltage and Current.

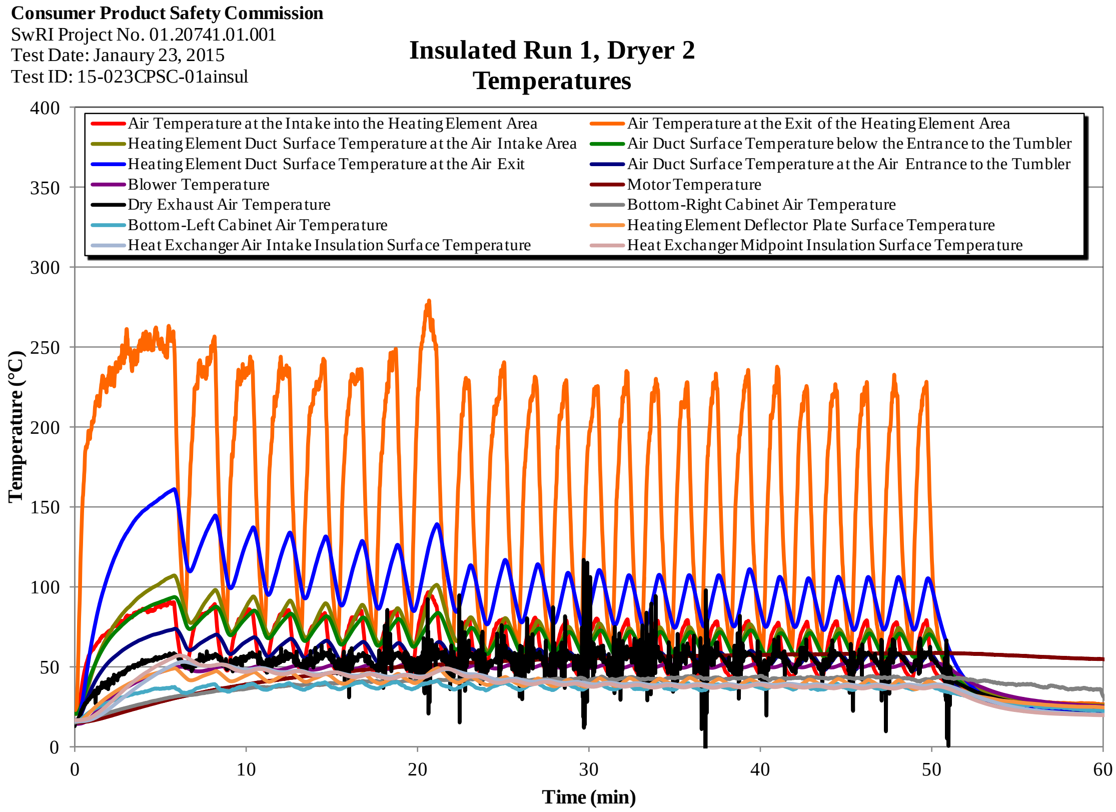


Figure C-9. Insulated Run 1, Dryer 2 – Temperatures.

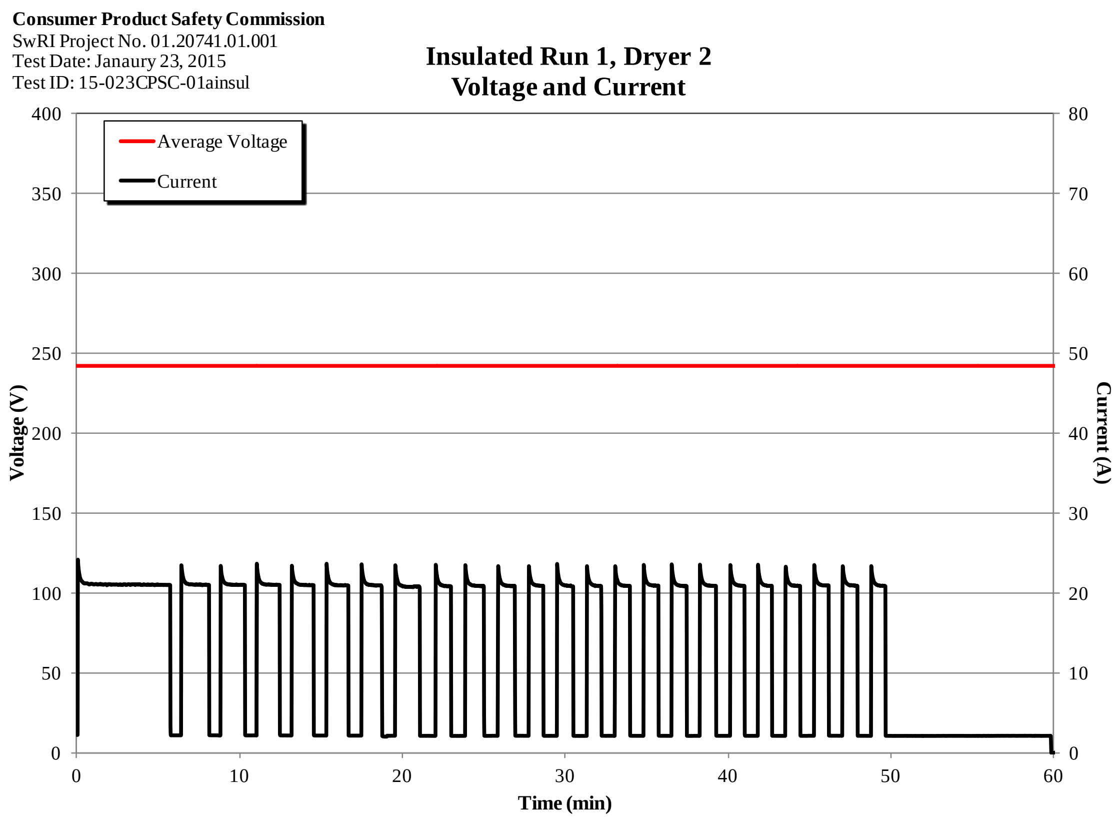


Figure C-10. Insulated Run 1, Dryer 2 – Voltage and Current.

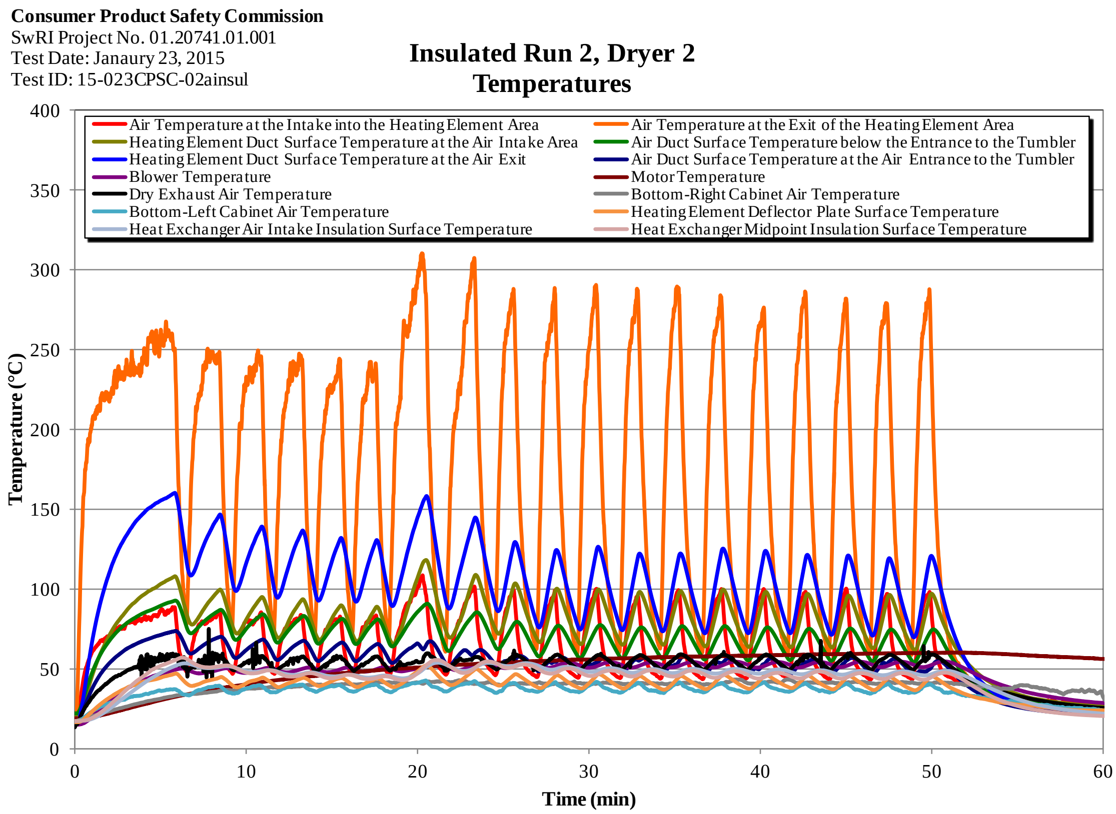


Figure C-11. Insulated Run 2, Dryer 2 – Temperatures.

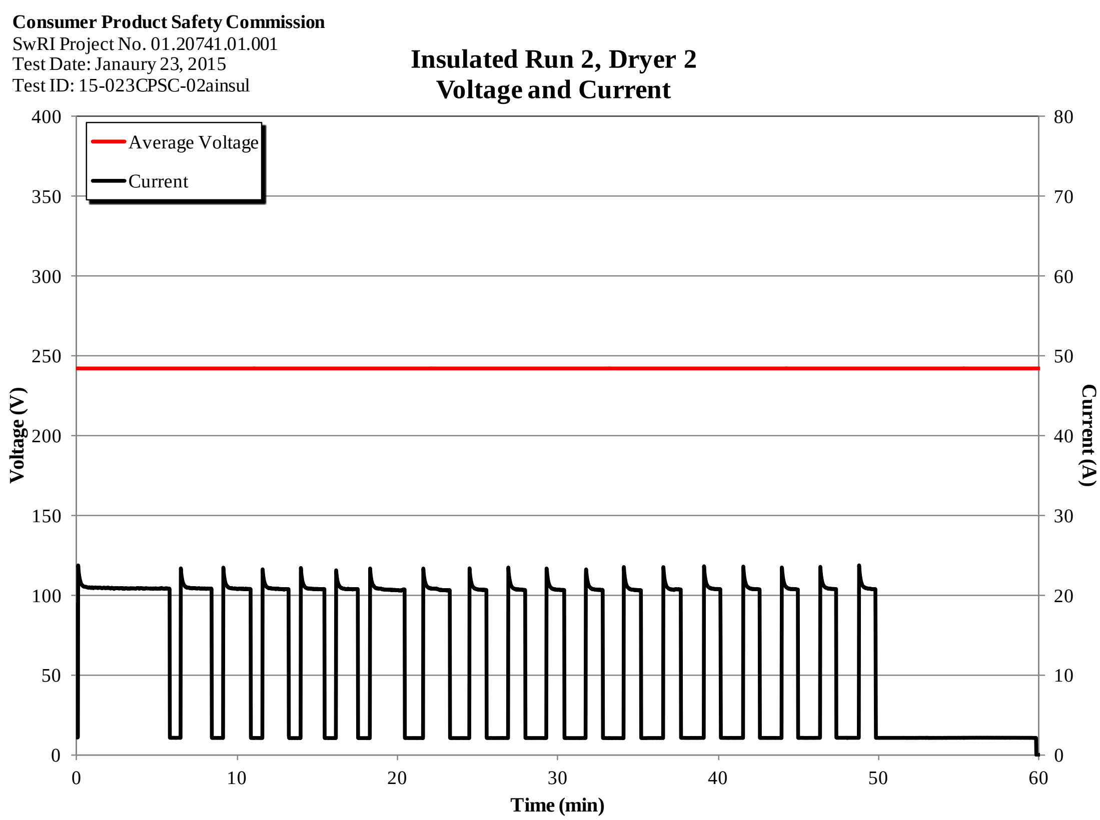


Figure C-12. Insulated Run 2, Dryer 2 – Voltage and Current.

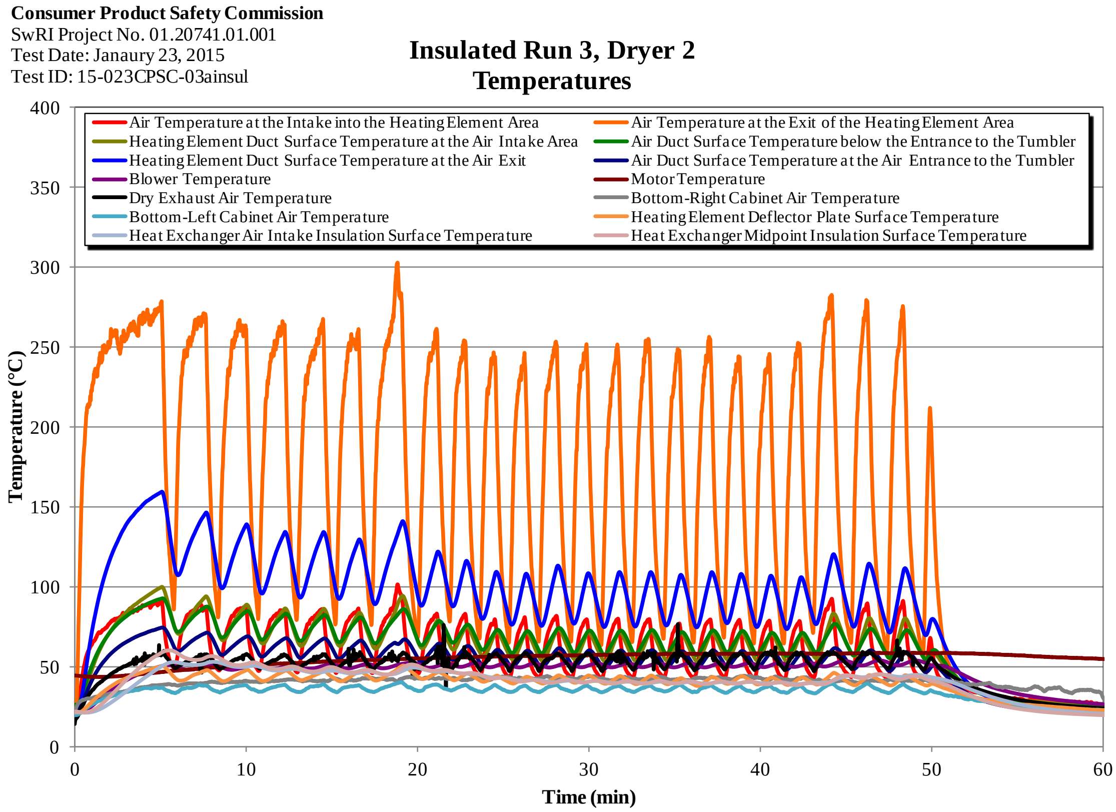


Figure C-13. Insulated Run 3, Dryer 2 – Temperatures.

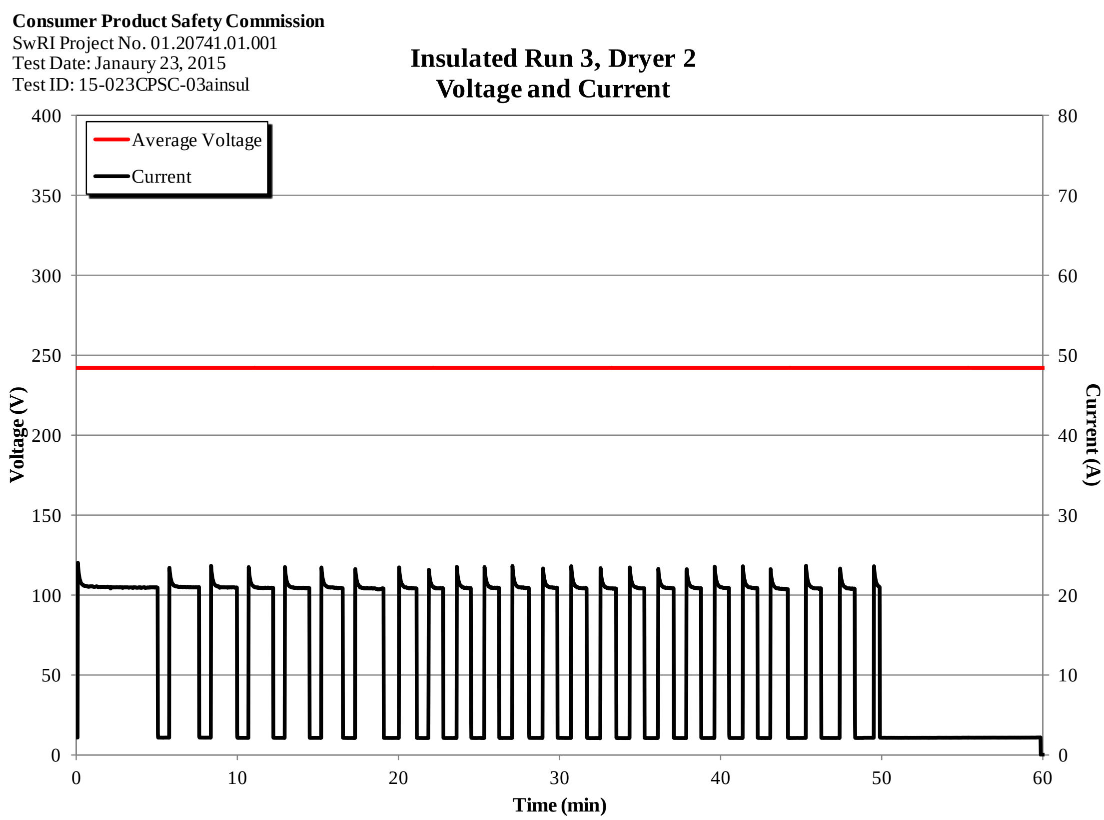


Figure C-14. Insulated Run 3, Dryer 2 – Voltage and Current.

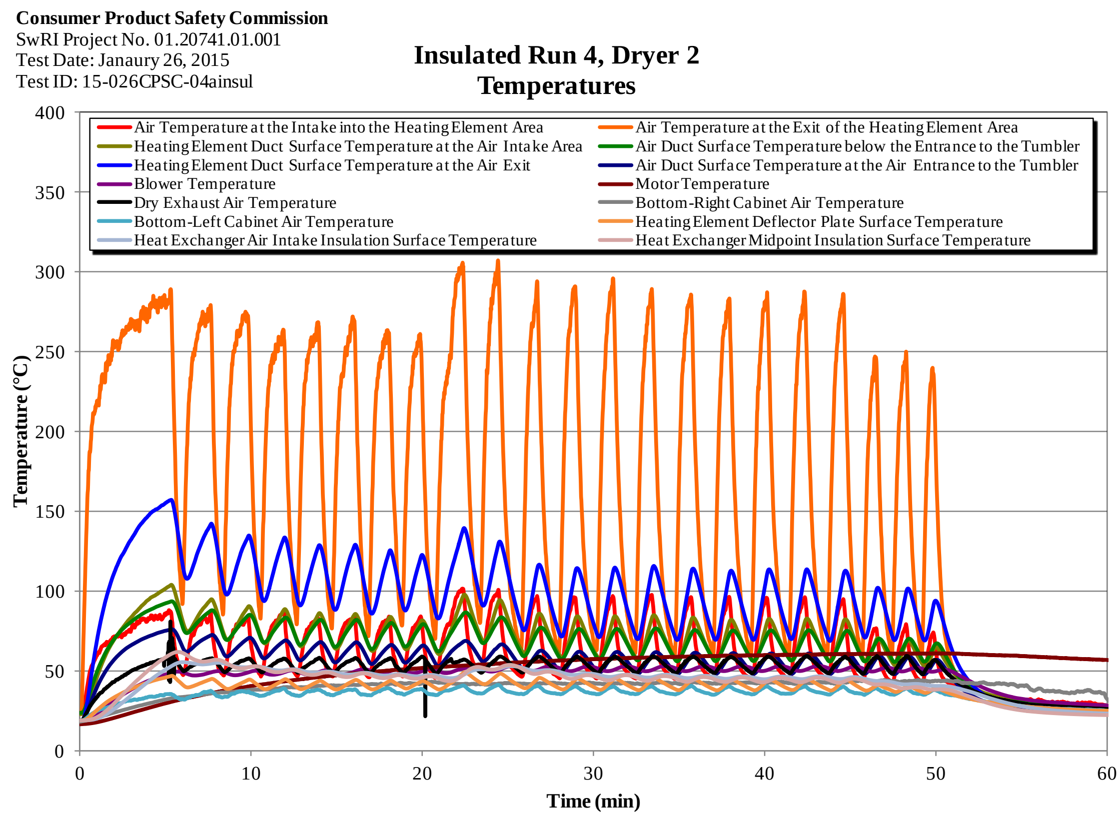


Figure C-15. Insulated Run 4, Dryer 2 – Temperatures.

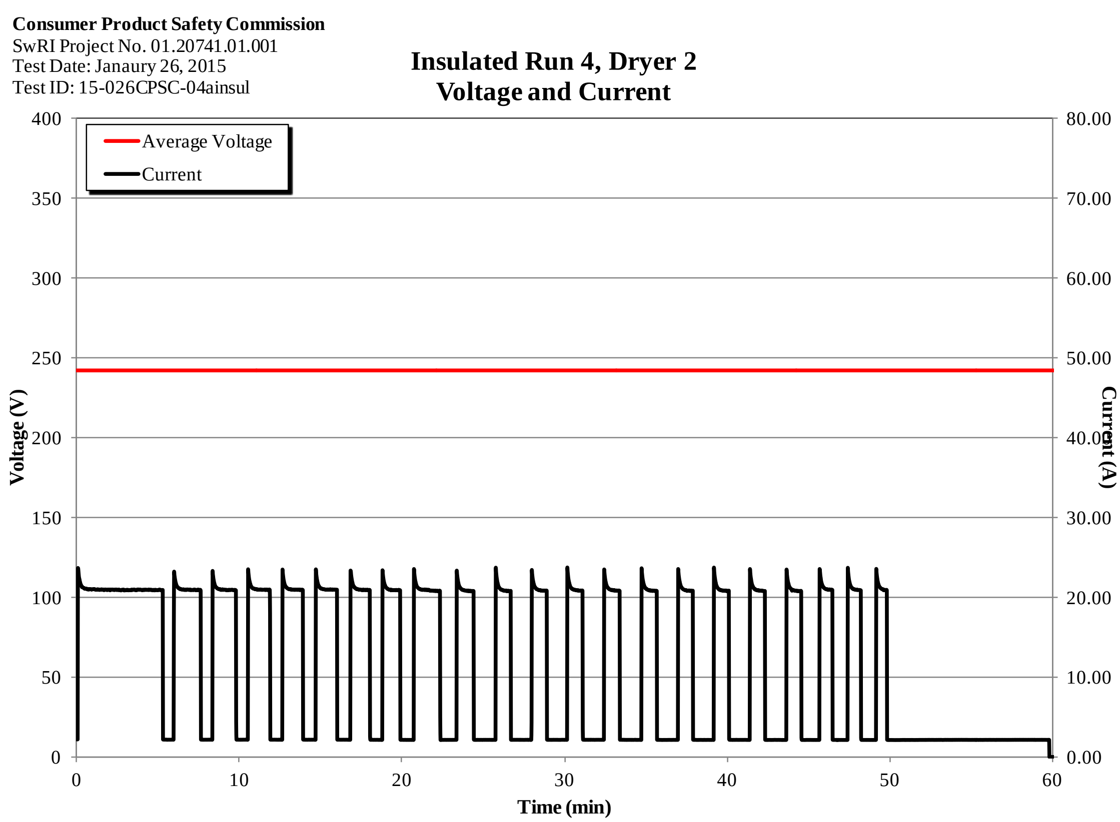


Figure C-16. Insulated Run 4, Dryer 2 – Voltage and Current.

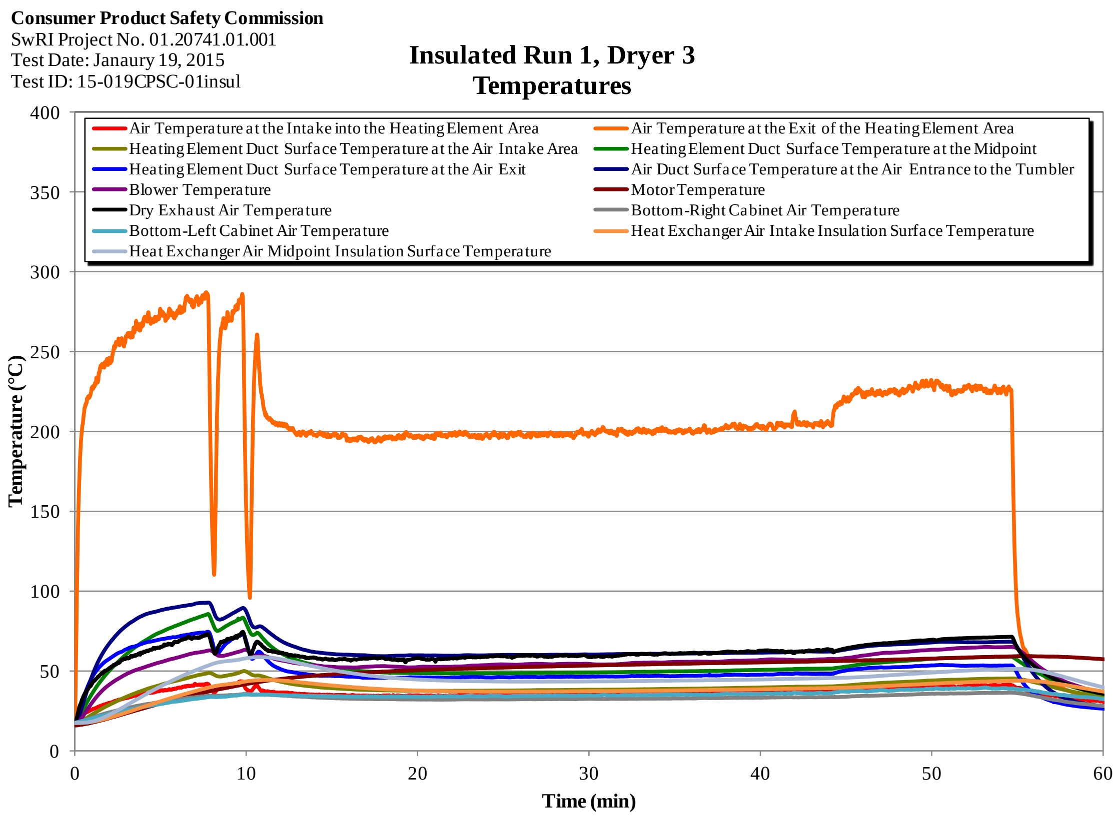


Figure C-17. Insulated Run 1, Dryer 3 – Temperatures.

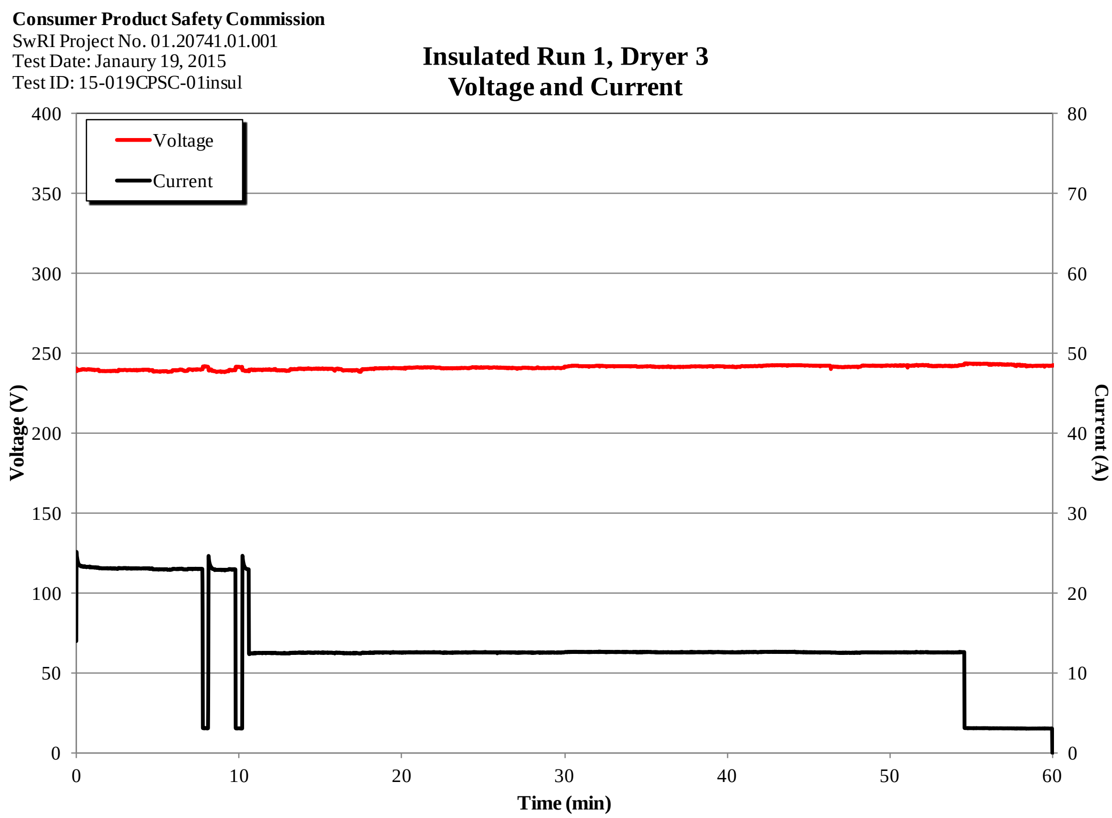


Figure C-18. Insulated Run 1, Dryer 3 – Voltage and Current.

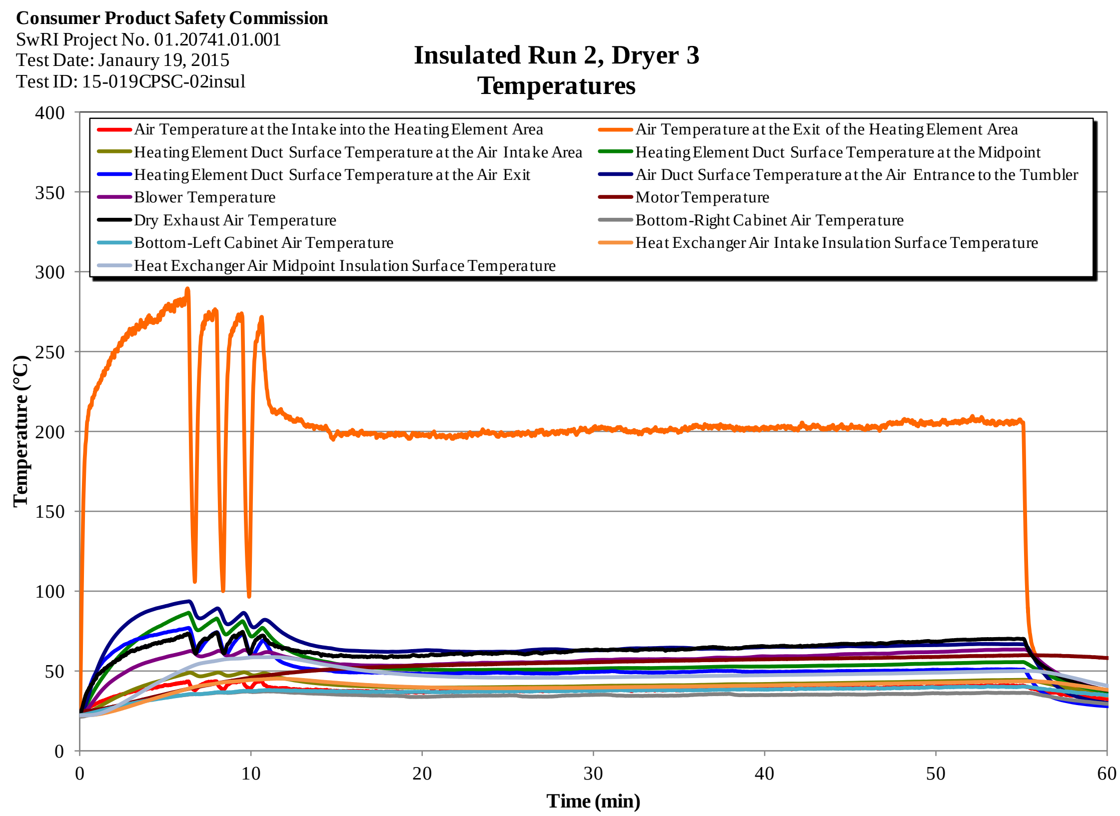


Figure C-19. Insulated Run 2, Dryer 3 – Temperatures.

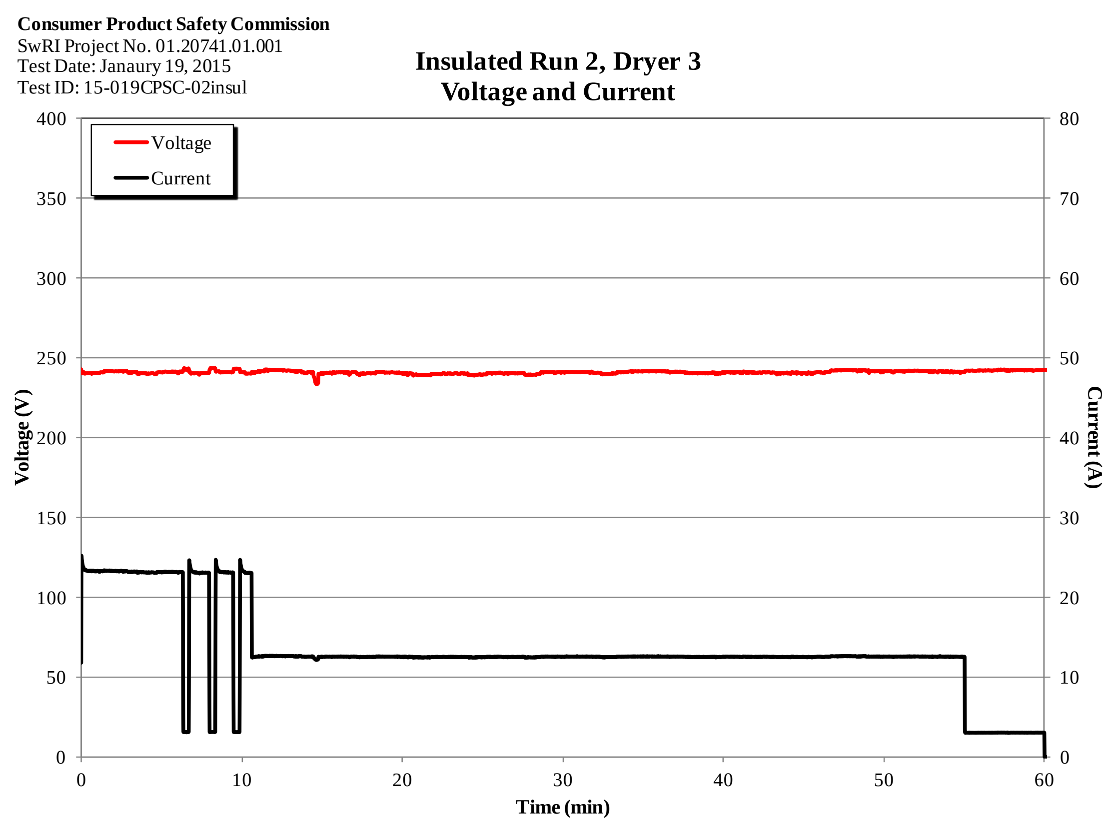


Figure C-20. Insulated Run 2, Dryer 3 – Voltage and Current.

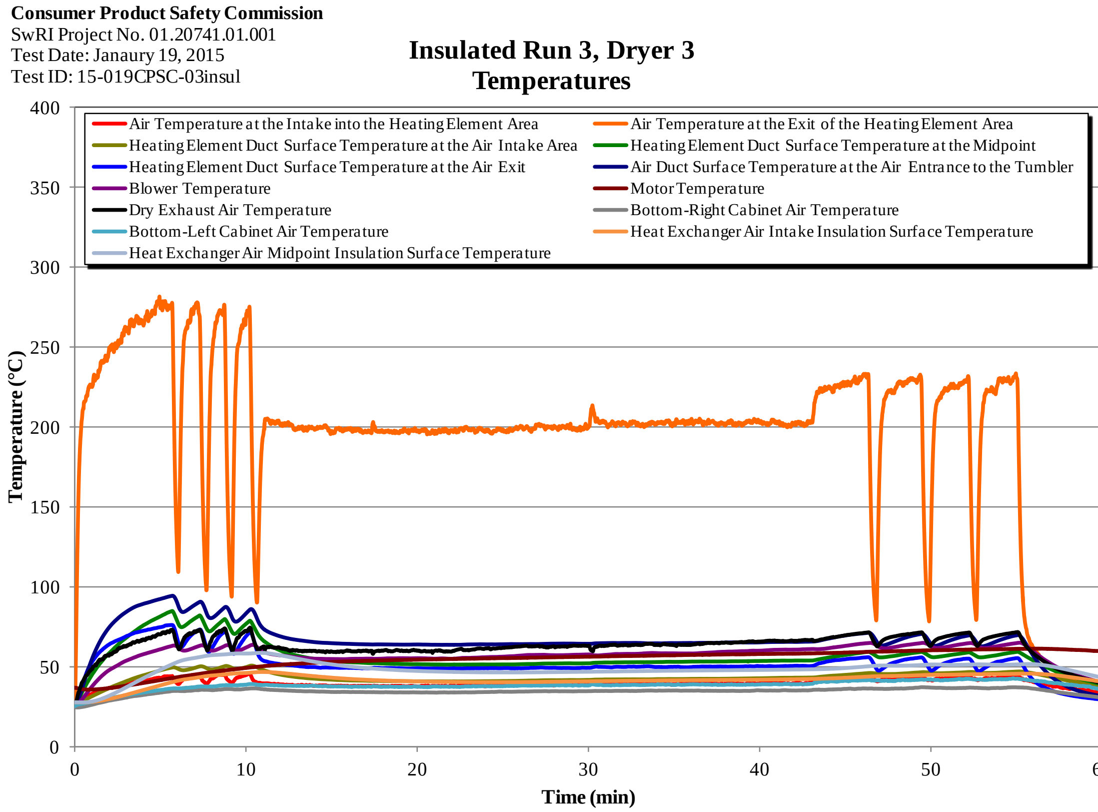


Figure C-21. Insulated Run 3, Dryer 3 – Temperatures.

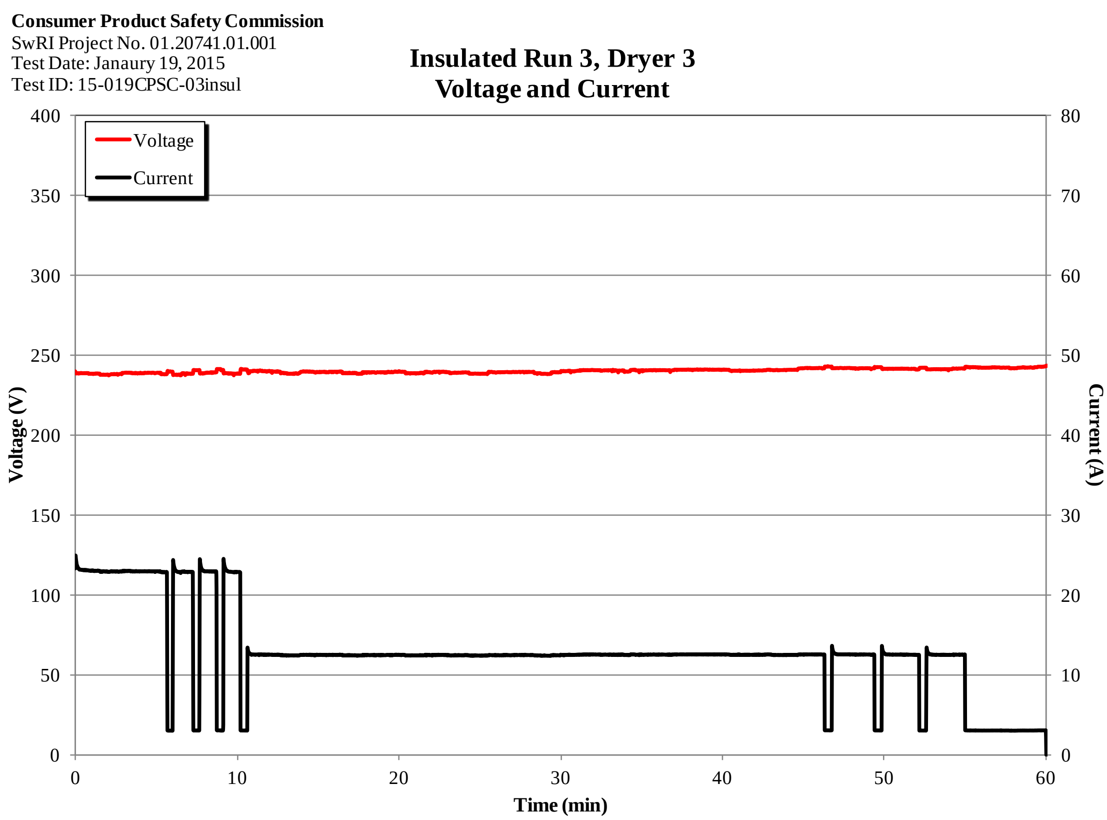


Figure C-22. Insulated Run 3, Dryer 3 – Voltage and Current.

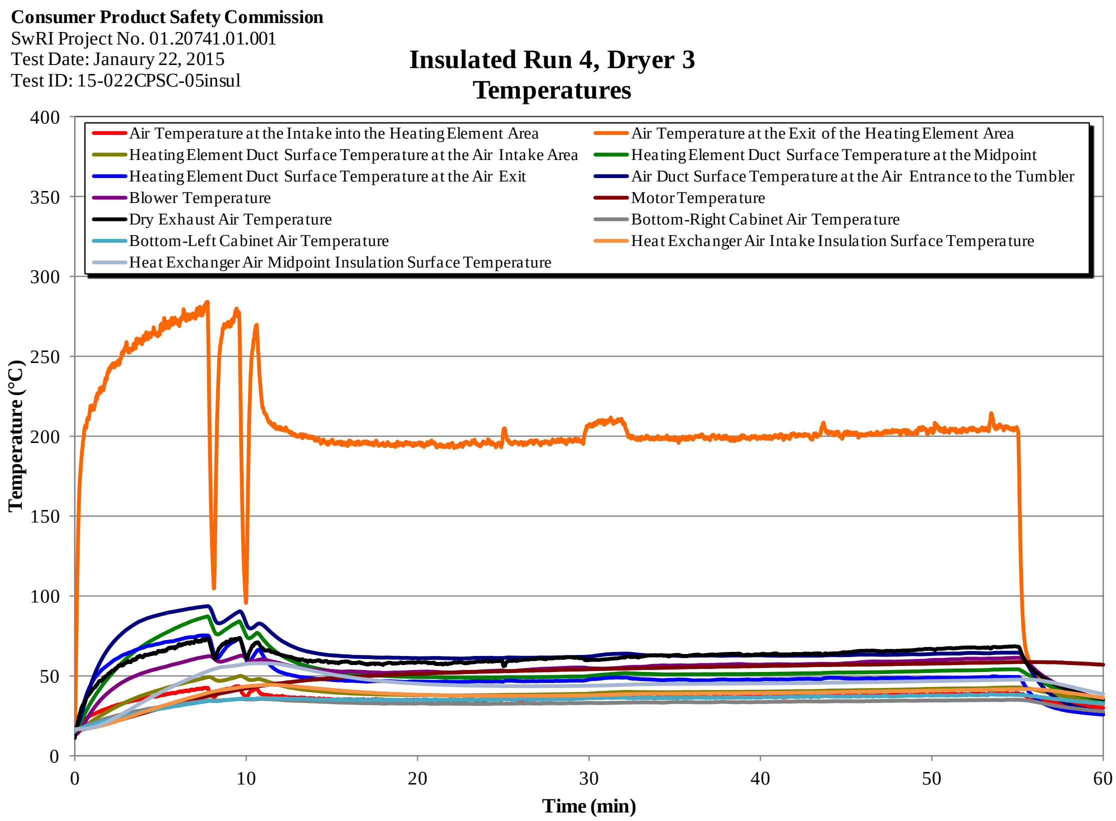


Figure C-23. Insulated Run 4, Dryer 3 – Temperatures.

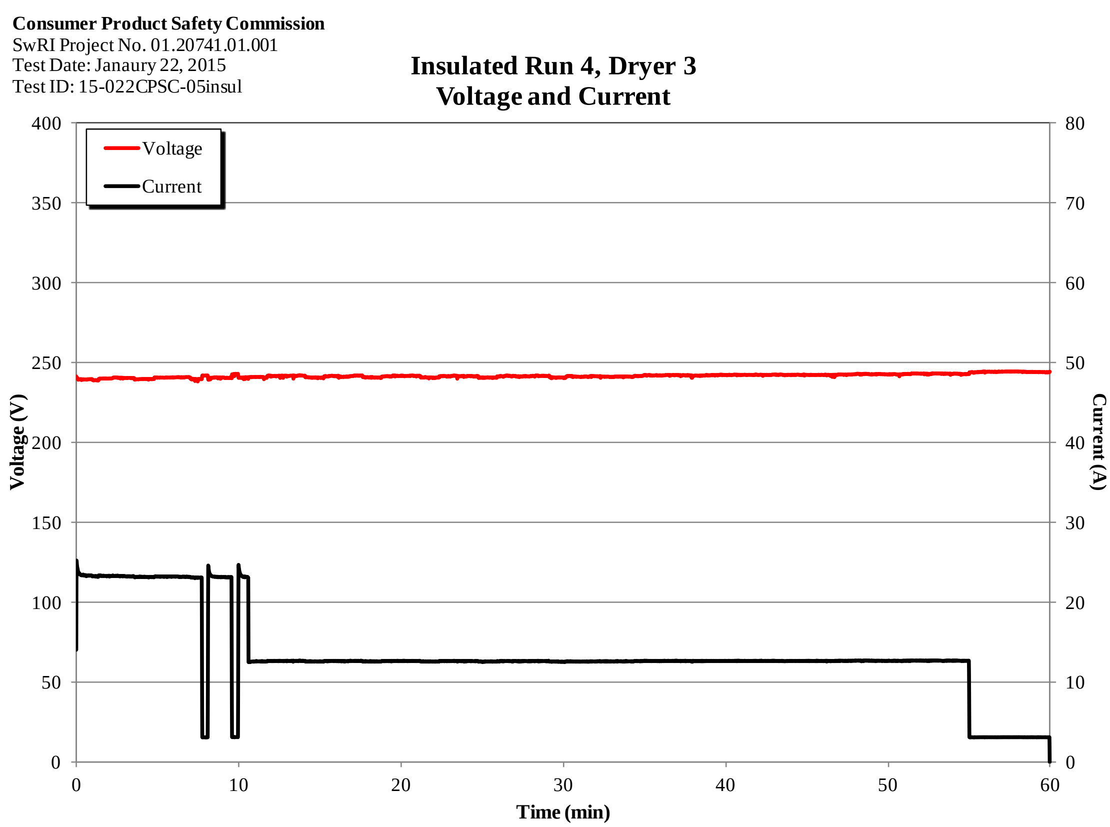


Figure C-24. Insulated Run 4, Dryer 3 – Voltage and Current.