Northeast Energy Efficiency Partnerships

Residential Electric Clothes Dryer Baseline Study

Brian McCowan, Kerri-Ann Richards, and Michael Wacker

Energy & Resource Solutions, March 2015

About NEEP & the Regional EM&V Forum

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency in the building sector through public policy, program strategies and education. Our vision is that the region will fully embrace energy efficiency as a cornerstone of sustainable energy policy to help achieve a cleaner environment and a more reliable and affordable energy system.

The Regional Evaluation, Measurement and Verification Forum (EM&V Forum or Forum) is a project facilitated by Northeast Energy Efficiency Partnerships, Inc. (NEEP). The Forum's purpose is to provide a framework for the development and use of common and/or consistent protocols to measure, verify, track, and report energy efficiency and other demand resource savings, costs, and emission impacts to support the role and credibility of these resources in current and emerging energy and environmental policies and markets in the Northeast, New York, and the Mid-Atlantic region.

Energy & Resource Solutions (ERS)

ERS was founded in 1995 to provide energy efficiency services and over the past 19 years has developed an exclusive consulting practice focused on energy efficiency, renewable energy and emerging technologies. With offices in Massachusetts, Maine, Connecticut, New York, Texas, California, and Oregon, our staff of more than eighty professionals includes professional engineers, certified energy managers, and LEED-accredited professionals. ERS is involved in many diverse activities, including engineering analysis and modeling of energy efficiency measures, program process and impact evaluation, and program planning and delivery.

Summary Report

Residential Electric Clothes Dryer Baseline Study

prepared for the

Regional Evaluation, Measurement, and Verification Forum; Northeast Energy Efficiency Partnerships

energy & resource solutions

Corporate Headquarters:
120 Water St., Suite 350
North Andover, Massachusetts 01845
(978) 521-2550
Fax: (978) 521-4588

February 2015

Contents

Contents

Brian McCowan of ERS managed the project and was assisted by ERS Engineers Kerri-Ann Richards and Michael Wacker. Elizabeth Titus of the Regional Evaluation, Measurement, and Verification Forum (EM&V Forum) coordinated the project with management assistance from Dave Lis of Northeast Energy Efficiency Partnerships, Inc. (NEEP) and Chris Neme of Energy Futures Group.

The primary research portion of this project would not have been possible without the cooperation and assistance of Chris Badger and Lara Bonn of Efficiency Vermont and the cooperation of the participating homeowners. The project team thanks them for their efforts.

The project team wishes to acknowledge the EM&V Forum project subcommittee, which provided valuable input, and content review, during the development of this project. We also would like to thank Eileen Eaton of the Consortium for Energy Efficiency (CEE) who provided details regarding ENERGY STAR dryer test procedures.

Regional Evaluation, Measurement, and Verification Forum

The EM&V Forum is a project facilitated by NEEP with the purpose of providing a framework for the development and use of common and/or consistent protocols to measure, verify, track, and report energy efficiency and other demand resource savings, costs, and emission impacts to support the role and credibility of these resources in current and emerging energy and environmental policies and markets in the Northeast, New York, and the Mid-Atlantic region. For more information, see www.neep.org/initiatives/emv-forum.

1 Executive Summary

This report presents the research results from a study to determine baseline assumptions and provide potential programmatic support for advanced clothes dryer technologies for the residential market. The research is part of a continued effort to assess several emerging technologies and innovative program approaches by the Regional EM&V Forum managed by NEEP.

The residential clothes dryer study metered 23 existing residential electric clothes dryers in single household homes in Vermont, New Hampshire, Maine, and Massachusetts. In addition, targeted secondary research of other studies that focused on the energy consumption and usage patterns of electric clothes dryers was performed.

A PowerPoint presentation of this study's findings can be accessed here (http://www.neep.org/sites/default/files/Microsoft%20PowerPoint%20-%20NEEP%20Dryer%20Presentation%20Final%2003-30-15.pdf).

Key Findings

The following are key findings from the metered data analysis and review of other dryer studies conducted in the United States:

- The average annual energy usage for this study's monitored sites is estimated to be 1,060 kWh per household, and the average household size observed in this study was 3 people. This average usage is extrapolated to a full year, but not normalized for household size.
- The average annual energy usage from this study, normalized for an average United States household size of 2.8 people is estimated to be 993 kWh ± 129 kWh[1]
- The daily load shape is relatively flat between 11 a.m. and 10 p.m. and differs from other reviewed studies that reported a significant midday peak.
- The highest average demand occurs during the weekend. The highest average weekday demand occurs during the evening hours.

---

[1] Applying a standard 90% confidence interval analysis results in ± 13%, although this statistical confidence analysis is not fully appropriate given the sample selection methodology, which was not fully random, and for results based partly on extrapolated data.

- There are seasonal variations, as the colder months require more energy for drying clothes because more and heavier clothing is worn during the winter months.
- Dryer standby energy usage is very small:
  - Dryers with electronic controls use about an additional 1 to 1.5 kWh per dryer per year for the controls (actual measured amperage is below logging meter accuracy range)
  - Dryers with electro-mechanical controls had no standby usage
- The average number of annual dryer loads varies but is estimated to be 439. Using the metered data, it is difficult to differentiate normal dryer loads from "touch-up" operation (when the user restarts the dryer with the same load in the drum). The project team combined short-cycle loads with the previous load to more accurately assess the number of loads, however it was not possible to identify all touch-up loads and the total load estimate of 439 is likely somewhat high.
- Dryer runtime varies widely, but is estimated to average 48 minutes per load. This average was also calculated using the approach that combined touch-up operation with normal dryer loads. Because total dryer runtime was recorded, the drying time per load will vary in direct correlation with the estimated number of loads.
- This and other studies are relatively consistent in estimating both the number of annual dryer loads, and the annual energy usage. In addition, the studies conclude that dryer usage is higher than estimated for the ENERGY STAR program, which assumes a smaller number of annual dryer loads. As such, both usage and savings are potentially higher than estimated by ENERGY STAR.
- Heating make-up air energy consumption varies and is estimated to be 120kWh, 2.3 gallons fuel oil, or 3.2 therms natural gas (NG) – or approximately 12% of the dryer energy usage for the average home with a dryer vented to the outdoors. The net energy effect will vary with the location of the dryer and weather-tightness of the home.
- Only one of 23 homes in our study was air conditioned. For New England, the make-up air energy usage is primarily associated with heating. In warmer climate zones, where air conditioning is more prevalent, dryer venting will result in additional cooling of make-up air.
- For New England, the most common dryer location is in a heated or semi-heated (thermally coupled) basement.
- All surveyed sites had proper venting to the outdoors.

1.1 Project Goals

The primary goals for this study are to establish a reasonable energy usage baseline and average load shape for residential electric clothes dryers. The results would inform the development of energy efficiency and/or demand reduction measures that promote advancing clothes dryer technologies. The goals established for the study are summarized as follows:

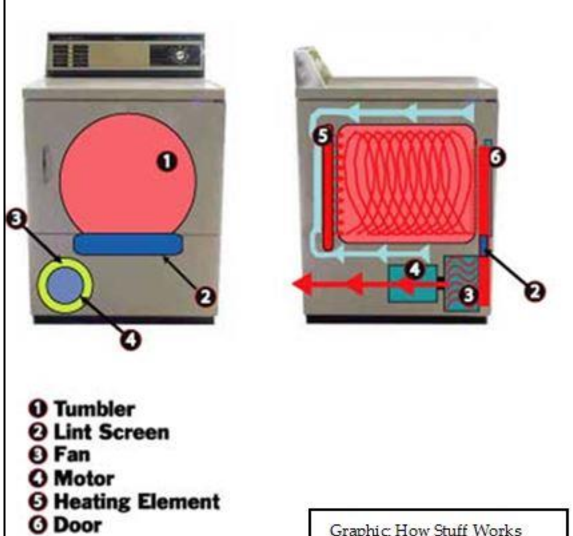
- Establish baseline assumptions for residential electric dryer efficiency measures.

- Monitor and report the average energy demand and usage.
- Determine the average load shape for peak and non-peak demand seasons.
- Measure and report the energy impact of venting dryer air to the outdoors.
- Develop assumptions for the existing dryers and associated washers (type, age, etc.).
- Characterize homeowner usage patterns.
- Characterize typical installations.

2 Electric Clothes Dryer Primer

Electric tumble clothes dryers were introduced in the United States in the late 1930s, and until recently have remained largely unchanged, with only small incremental improvements in operation. The basic operation of standard electric clothes dryers is outlined in Figure 2.1.

Figure 2.1. Basic Clothes Dryer Operation



Graphic: How Stuff Works

Electric Dryer Operation

- Motor and controls operate on 120 v.
- Resistance coils operate on 240 v.
- Coil(s) are cycled on/off depending on the temperature settings and sensors. Some dryers have two separately controlled coils.
- One motor drives the fan and the tumbler. The fan draws air across the heating coils and forces it through the tumbler drum.
- Older dryers with electro-mechanical controls have no standby energy usage.

2.1 Advanced Clothes Dryer Technologies

Advancements in electric clothes dryers range from simple control improvements to alternative methods for removing moisture.

- **Advanced controls** – In addition to timed drying, most dryers are now available with moisture sensors which signal controls to stop the drying process when the exhaust air reaches a low moisture content. In addition, more heat settings are often available to more closely control the dryer cycle.

- **Condensing dryers** – Condensing dryers are relatively new to the U.S. market and operate largely the same as standard clothes dryers. A major difference is that rather than exhausting moist warm air to the outdoors, they utilize a heat exchanger to condense the water vapor, draining the liquid, and exhausting the warm air to the interior space.
- **European heat pump clothes dryers -** Marketed in Europe and Asia for several years, clothes dryers that rely solely on heat pumps for heating the drying air are not currently available on the U.S. market. It is estimated that these European models use about 50% less energy than conventional electric clothes dryers. Drying times are also significantly longer for heat pump dryers.
- **Hybrid heat pump clothes dryers** –Clothes dryers that incorporate heat pump technology are currently being introduced in the U.S. in limited geographic markets. Although they are commonly referred to as heat pump clothes dryers they are actually termed hybrid heat pump dryers by their manufacturers. Hybrid heat pump dryers utilize both conventional resistance and heat pump technologies. Hybrid dryers are designed to have drying times closer to those of conventional electric dryers, while still providing significant energy savings. To date a typical configuration utilizes a heat pump to condense the water vapor and return the warm dried air to the tumbler. Both electric resistance coils and the heat pump are used to initially heat the drying air. A "mode" switch regulates the mix of electric resistance and heat pump usage to manage drying times and energy usage. Of the two hybrid dryers currently available in the U.S., one is ventless, and one vents to the outdoors. Additional models are anticipated to be introduced to U.S. markets during 2015.
- **Microwave clothes dryers** – Microwave clothes dryers are marketed in Asia, but have never been introduced in the U.S. due to concerns over electrical arcing associated with metal objects in the dryer. They utilize the same technology as microwave ovens to heat the air that is fan forced through the tumbler.

3 STUDY PARTICIPANT RECRUITING

Study recruitment began in late Fall 2013. The original intention was to recruit efficiency program participants with the assistance of the EM&V Forum member organizations. For many of these organizations, participant privacy considerations restricted the process. Efficiency Vermont assisted in recruiting participants. In addition, participants in southern Maine, southern New Hampshire, and central Massachusetts were recruited. In total, 23 study participants were recruited.

3.1 Clothes Dryer Baseline Considerations

During the planning process for this study, it was determined that the baseline should be associated with "time of natural replacement" purchases. As such, baseline energy usage is aligned with likely alternative purchases if incentives are not offered for advanced dryers. It is further assumed that existing dryers being replaced are at, or near, the end of useful life. The recruitment process targeted homes with recently purchased (within 5 years) dryers in order to align with conventional dryers currently available. The following factors contributed to establishing the study recruitment process:

- **Time of purchase** – Major appliances such as dryers are most often replaced at or near their end-of-life, or as first-time purchases.
- **Performance features** – The project team proposes that customers who are likely purchasers of advanced dryers, such as heat-pump dryers, when purchasing standard technology dryers, are most likely to purchase dryers with some advanced features, such as moisture and/or temperature sensing drying cycles, rather than the simplest, least expensive models.

Participant recruitment targeted single-household homes with the following attributes:

- Year-round occupancy and year-round electric clothes drying
- Two to four occupants
- Recent (less than 5 years old with random set of control features) electric dryer models[2]
- Washing machine population that included modern horizontal axis front-load machines[3]
- Variety of dryer installation locations

A summary of the participant sites is presented in Table 3.1.

Table 3.1. Participant Sites

ID	State	City	Dryer Make	Dryer Model #	Dryer Age	Washer Make	Washer Type	Washer Age	Dryer Location	Heated Space	Family Size	Heat Source	Cooling	# Floors	Square Footage
V1	VT	MIDDLEBURY	Kenmore	796.4117221	1	Kenmore	Front Load	1	Utility Room	Yes	2 Adults	40%/60% oil/wood	None	2	3,800
V2	VT	WALTHAM	Kenmore	110.6002201	3	Kenmore	Front Load	3	Utility Room	Yes	2 Adults	Passive solar/wood/electric backup	Ductless heatpump	2	2,100
V3	VT	CHARLOTTE	Whirlpool	WED70HEBWO	1	Whirlpool	Front Load	1	Utility Room	Yes	2 Adults, 2 Children	Propane/wood	None	2	2,200
V4	VT	BRANDON	Samsung	DV400EWHDR/AA	1	Samsung	Front Load	3	Utility Room	Yes	2 Adults, 2 Children	65%/35% oil/wood	3 Window units	2	2,100
V5	VT	UNDERHILL	NA	NA	1	NA	NA	1	Basement	Yes	2 Adults	50%/50% oil/wood	None	2	1,600
V6	VT	SHELBURNE	Sears	417.82042101	NA	Sears	Front Load	NA	Garage	Yes	2 Adults, 2 Children	100% NG furnance	None	2	2,800
V7	VT	SOUTH BURLINGTON	LG	DLE2516W	2	NA	Front Load	2	Basement	Yes	3 Adults	100% NG furnance	None	1	1,100
V8	VT	MIDDLEBURY	Maytag	MEDX500XW1	1	Maytag	Top Load	1	Basement	Yes	2 Adults	100% Propane	None	1	900
V9	VT	VERGENNES	GE	DWSR463EG6WW	6+	Frigidaire	Front Load	3	Utility Room	Yes	2 Adults, 2 Children	60%/40% oil/wood	None	2	2,200
V10	VT	VERGENNES	Whirlpool	WED8200YWO	5	Whirlpool	Front Load	5	Utility Room	Yes	2 Adults, 1 Child	50%/50% oil/wood	None	2	2,300
V11	VT	BRISTOL	Kenmore	NA	2	Kenmore	Front Load		Utility Room	Yes	2 Adults	80%/20% oil/wood	None	2	1,600
ME1	ME	YORK	NA	NA	1	NA	Top Load	1	Utility Room	Yes	1 Adult	Propane	None	1	900
ME2	ME	YORK	Maytag	MDE6800AYW	7	Whirlpool	Top Load	7	Basement	No	2 Adults	100% Oil	None	2	1,200
ME3	ME	YORK	Samsung	DV457EVGSGR/A1	1	Samsung	Front Load	1	Basement	No	2 Adults	100% Oil	None	2	1,400
ME4	ME	YORK	Kenmore	110.87561603	5	Kenmore	Front Load	5	Basement	No	3 Adults	100% Oil	None	2	1,638
ME5	ME	YORK	GE	DWSR405EB2WW	5+	GE	Top Load	10	First floor	No	2 Adults,2 Children	100% Oil	None	2	1,800
ME6	ME	YORK	Maytag	MDE5500AYQ	5	Whirlpool	Front Load	5	Basement	No	4 Adults	100% Oil	None	2	1,938
MA1	MA	LEOMINSTER	Kenmore	110.84821301	2	Kenmore	Front Load	2	Basement	Yes	3 Adults	100% Oil	None	2	1,500
MA2	MA	LUNENBURG	Whirlpool	LER5636EQ3	1	Whirlpool	Top Load	7	Basement	Yes	4 Adults	60%wood/40% Oil	None	2	1,600
MA3	MA	LEOMINSTER	Whirlpool	LE7685XPW0	5	Whirlpool	Top Load	10	Basement	No	3 Adults	100% Oil	None	1	1,300
MA4	MA	LEOMINSTER	Kenmore	110.668625	3	GE	Top Load	10	First floor	Yes	3 Adults, 1 Child	100% NG furnance	None	2	3,000
NH1	NH	BROOKLINE	Maytag	MEDC400VW0	4	Kenmore	Top Load	5	Second floor	Yes	2 Adults, 1 Child	80%/20% oil/wood	Central AC	2	2,600

NA = Not applicable

---

2 All dryers monitored had at least one sensor terminated cycle available.

3 The study did not seek a specific number or percentage of horizontal axis washing machines, however, the majority of participants owned horizontal axis. According to the E.P.A. ENERGY STAR program, the market penetration of horizontal axis machines was approximately 34% in 2014 and increasing. The same source also maintains that modern vertical axis machines are incorporating many of the water and energy saving features of horizontal axis machines.

4 CLOTHES DRYER MONITORING PROCESS

The following sections describe the methodology used for monitoring clothes dryer usage.

4.1 Monitoring Schedule

Because of the delays involved in the participant recruitment process, the project team was unable to begin monitoring sites until March of 2014. To meet the sponsor deadlines, the metering was initially scheduled to be completed in October 2014. To collect as much cold weather data as possible, the monitoring was extended into November for most sites; for three sites, we collected data in November and reinstalled the meters to collect data into January 2015.

4.2 Metering Protocols

ERS Safety Director Michael Wacker developed a monitoring procedure to ensure the safety of the metering equipment installer and the homeowner. Depending on the electrical panel configuration in the participant home, one of two procedures was used:

1. Recording data loggers (Onset UX120 4 channel loggers) and 50 amp current transformers (CTs) were installed inside the electrical panel, leaving no metering equipment exposed.
2. Non-conductive junction boxes housed the Onset loggers and CTs. This assembly was plugged into the dedicated dryer outlet and the dryer was plugged into the junction box. With both the CT and logger housed within the junction box no additional wiring was needed and no wiring was exposed.

Both legs of the 220-volt circuit were metered. This was done because one leg typically powers one-half of the resistance coils and the 110-volt fan/tumbler motor; the other leg powers the other half of the resistance coil and the 110-volt control panel.

The logging procedure collected the following data:

- ❑ Dryer run times
- ❑ Demand (kW)
- ❑ Energy usage (kWh) during the dryer operation
- ❑ Standby energy usage:
    - ➢ The large energy demand of the dryers requires the use of 50-amp CTs. The accuracy of CTs this large is insufficient for the recording of the extremely low standby usage of the dryer control panels. For this reason, ERS used Fluke series 3000 handheld meters to record the standby current, using the recorded standby times to calculate total standby usage.

4.2.1 Exhaust Air Monitoring Procedure

ERS investigated various methodologies for monitoring the volume of air exhausted from the dryers and uses the same methodology as that for measuring the velocity and volume of air moving through HVAC ductwork. An explanation of the procedure and the results is presented in Section 5.

4.3 Initial Site Visits

During the initial site visits, the dryer installation was inspected for safe metering, the metering method was selected, and the metering devices were installed and checked for proper data recording. The washer and dryer make and model numbers were collected, as were the location of the dryer and configuration of the venting. In addition, the general building configuration and heating/cooling system information was recorded.

Homeowner interviews were conducted regarding their laundry practices, including the estimated number of weekly loads, any outdoor hang-drying, and the selected cycles. If time allowed, the velocity of the air exhausted to the outdoors during the dryer operation was recorded to calculate its volume. Section 5 has additional information regarding the exhaust air.

4.3.1 Metering Verification

Approximately two months after the meters were installed, two of the sites were checked to ensure that the data was being properly logged. The monitoring at one site was terminated in summer 2014 because the homeowner was moving out of the region.

4.4 Second Interview and Monitoring Equipment Pickup

During the return visit to collect the monitoring equipment, we conducted a second homeowner interview focused on whether anything had changed since the first interview, such as the household size, new equipment, and decision to hang-dry the clothes outdoors.

For three sites, the data was downloaded and the monitoring equipment was reinstalled to continue collecting dryer usage data during the colder weather. Due to budget constraints, and project deadlines we were unable to extend this to more than three sites. Table 4.1 presents significant data collected during these interviews.

Table 4.1. Participant Survey Responses

Average # of loads per week	5.25
Average % of loads dried in electric dryer	79%
Average % of loads moisture or air temperature sensor terminated[1]	75%
Average % of loads timer terminated	25%
Average % of loads receiving extra or extended ("ultra") spin cycle	33%

[1]All dryers monitored had at least one sensor terminated cycle available.

5 Data Analysis

ERS developed a custom spreadsheet tool for the analysis of the recorded runtime, energy usage, and demand. The data collected provided approximately six million data points that were catalogued and analyzed. The procedure is described as follows:

1. The data was reviewed for consistency with typical dryer operation. One site generated data that was widely inconsistent and outside the bounds of normal dryer operation. Following a discussion with the participant, the data was removed from the set as we were unable to

determine the cause of the inconsistent data. One site had an interruption in logging; its monitoring equipment was reset in November to collect more data. All other data usable.

2. The data associated with dryer operation was segregated from the dryer standby data, in order to accurately calculate the standby energy usage.
3. A procedure was developed to differentiate the complete dryer cycles from the touch-up cycles. The identified touch-up cycles were associated with the preceding cycle to determine the number, and length, of dryer loads for each site.
4. Dryer runtimes were recorded for each site.
5. Dryer energy consumption while operating was recorded for each site.
6. The energy demand was mapped for each site to determine its load shape.

Table 5.1 presents the metered data collected at the participant sites.

Table 5.1. Site-Metered Data

ID	Date Start	Date End	Days Metered	Number of Loads	Average Load Time (mins)	Average Demand During Operation (kW)
V1	4/24/2014	11/3/2014	193	101	35	3.0
V2	4/23/2014	11/3/2014	194	178	63	2.4
V3	4/22/2014	11/3/2014	195	147	43	3.8
V4	4/24/2014	11/3/2014	193	337	67	2.5
V5	4/24/2014	11/4/2014	194	283	35	2.8
V6	4/22/2014	10/27/2014	188	228	26	2.7
V7	4/23/2014	11/3/2014	194	168	41	3.1
V8	4/23/2014	10/15/2014	175	128	25	3.8
V9	4/22/2014	11/3/2014	195	196	46	2.9
V10	4/23/2014	12/4/2014	225	218	64	3.1
V11[a]	N/A	N/A	N/A	N/A	N/A	N/A
ME1[b]	4/2/2014	8/12/2014	132	418	25	1.8
ME2[c]	5/18/2014	6/30/2014	43	35	40	4.0
ME3	5/18/2014	12/12/2014	208	262	39	3.1
ME4	3/31/2014	12/11/2014	255	132	96	2.3
ME5	5/19/2014	1/9/2015	235	312	34	3.1
ME6	3/25/2014	5/16/2014	52	35	51	3.4
ME6[d]	12/14/2014	1/11/2015	28	31	30	4.9
MA1	3/26/2014	11/7/2014	226	348	110	1.3
MA2	3/30/2014	12/14/2014	259	665	42	3.8
MA3	3/29/2014	11/6/2014	222	345	33	2.9
MA4	3/26/2014	11/3/2014	222	118	82	2.3
NH1	4/1/2014	1/15/2015	289	292	40	3.2
Average			**187**	**226**	**48**	**3.0**

[a]Data was corrupt.
[b]The customer moved in August.
[c]Logger failure
[d]Gap in metered data
N/A = Not applicable

5.1 Data Extrapolation from Partial to Full Month

The monitoring procedure included some partial-month data collection that was extrapolated to full-month data using a simple average daily usage methodology. Table 5.2 presents the extrapolated data.

Table 5.2. Metered Data Extrapolated to Full-Month Usage

Site ID	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan-15	Annual Standby kWh	Daily Average kWh
V1	NM	NM	NM	32	32	19	30	23	33	34	NM	NM	NM	1.1	1.0
V2	NM	NM	NM	27	31	33	20	31	34	165	131	NM	NM	1.1	1.9
V3	NM	NM	NM	56	62	65	51	80	54	65	142	NM	NM	1.1	2.4
V4	NM	NM	NM	190	262	117	47	68	185	199	256	NM	NM	1.1	5.4
V5	NM	NM	NM	85	93	80	64	61	62	67	92	NM	NM	1.1	2.5
V6	NM	NM	NM	57	58	28	41	38	38	52	NM	NM	NM	1.1	1.5
V7	NM	NM	NM	16	49	71	46	78	50	56	68	NM	NM	1.1	2.0
V8	NM	NM	NM	40	36	40	27	30	32	55	NM	NM	NM	1.0	1.2
V9	NM	NM	NM	118	87	52	51	59	56	76	149	NM	NM	1.1	2.7
V10	NM	NM	NM	74	118	91	82	92	88	104	108	NM	NM	1.3	3.1
ME1	NM	NM	NM	49	72	96	79	54	NM	NM	NM	NM	NM	0.7	2.3
ME3	NM	NM	NM	NM	104	102	90	74	69	56	56	106	NM	1.2	2.7
ME4	NM	NM	NM	76	49	63	46	55	47	54	71	72	NM	1.5	1.9
ME5	NM	NM	NM	NM	89	62	55	60	60	74	88	74	117	1.4	2.5
ME6	NM	NM	NM	75	50	NM	NM	NM	NM	NM	NM	88	65	1.0	2.3
MA1	NM	NM	NM	92	85	152	156	85	110	25	90	NM	NM	1.2	3.3
MA2	NM	NM	NM	101	222	217	199	217	183	244	248	252	NM	1.4	6.8
MA3	NM	NM	NM	72	96	68	67	73	72	68	90	NM	NM	1.3	2.5
MA4	NM	NM	NM	38	30	54	61	43	38	78	35	NM	NM	1.3	1.5
NH1	NM	NM	NM	64	65	82	69	59	59	82	59	61	53	1.7	2.1
Average														1.2	2.6

NM = Not metered

5.2 Extrapolation for Annual Usage

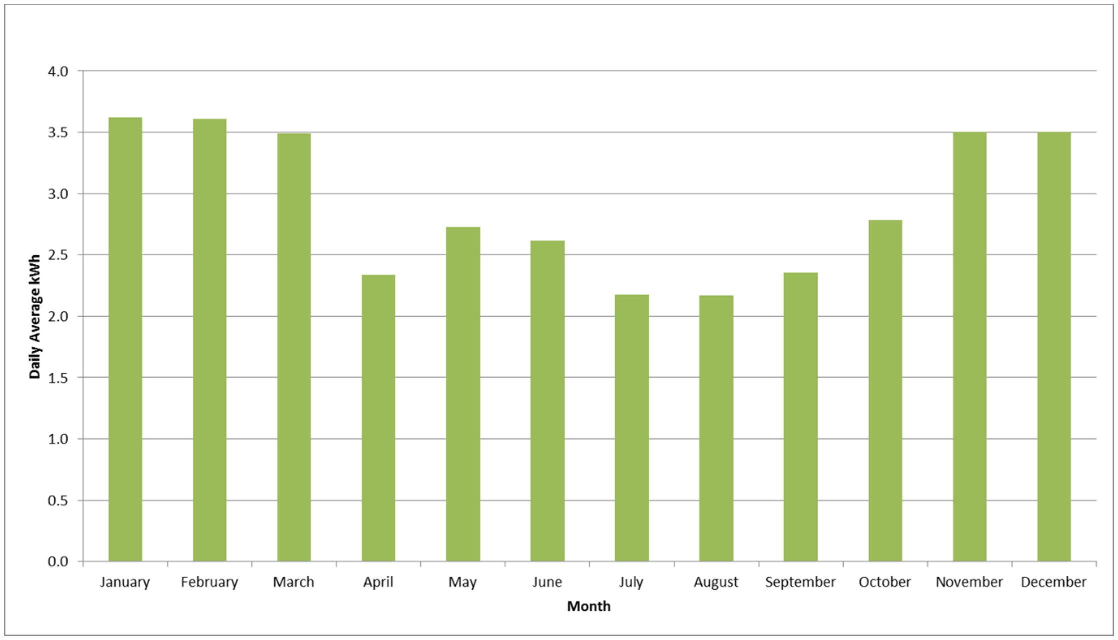
To estimate the annual usage, the metered data was extrapolated as follows:

- Partial-month metered data for each site was extrapolated to full-month usage.
- The January, February, and March data was extrapolated from the data metered during October, November, December, and early January 2015 (limited to three sites for 2 weeks).
- Limited data was collected for April and was extrapolated to a full month; however, the limited data showed low usage, and the resulting April extrapolation may be low. The low usage recorded for April may be due to a number of factors, such as school vacation periods, or may simply be associated with the timing of the limited metering. It was decided to utilize the metered April data, extrapolating to full month usage. If the April data was normalized to be more consistent with May and June data, overall estimated energy usage would increase by approximately 1.25%.

- The projected data was compared with metered monthly data reported in the Northwest Energy Efficiency Alliance (NEEA) dryer field study[4] performed by Ecotope for consistency with the usage changes associated with colder weather periods.

Figure 5.1 presents the extrapolated annual usage.

Figure 5.1. Data Extrapolated to Annual Usage



5.3 Normalized for Household Size

To develop baseline energy usage that is consistent with the average household sizes, we performed a normalization from a three-person to a 2.8-person household size. The following assumptions were developed using nationwide data from the 2010 United States Census:

- Sixty percent of homes are single-unit homes.
- The average household size for all housing types is 2.58 occupants.
- The average household size for single-unit homes is 2.81 occupants.
- The average household size for this study is 3.00 occupants.
- The average annual metered energy usage is 1,060 kWh.
- The average annual energy usage, normalized[5] to 2.8 occupants, is 993 kWh.

Table 5.3 presents the normalized data.

[4] NEEA Dryer Field Study, Ecotope. 2014.

[5] The household size normalization was performed as a simple linear extrapolation. Although there may be differences in usage based on occupant ages, no valid data was found to support such analysis.

Table 5.3. Data Normalized for 2.8-Person Household Occupancy

	kWh	
Month	Monthly Average, All Sites	Daily Average All Sites
January[a]	112	3.6
February[a]	101	3.6
March[a]	108	3.5
April	70	2.3
May	85	2.7
June	78	2.6
July	67	2.2
August	67	2.2
September	71	2.4
October	86	2.8
November	105	3.5
December	109	3.5
Total annual kWh; all sites	**1,060**	
Normalized for 2.8 occupants per household	**993**	

[a]January, February, and March data is fully extrapolated, April and December data is partially extrapolated.

5.4 Daily and Monthly Energy Usage

The data was analyzed for the daily and monthly energy usage, which was found to be highest on weekend days, consistent with the participant interviews. Figure 5.2 presents the average daily usage for the sites. Figure 5.3 presents the data for the monthly usage.

Figure 5.2. Average Daily Energy Usage, March through December

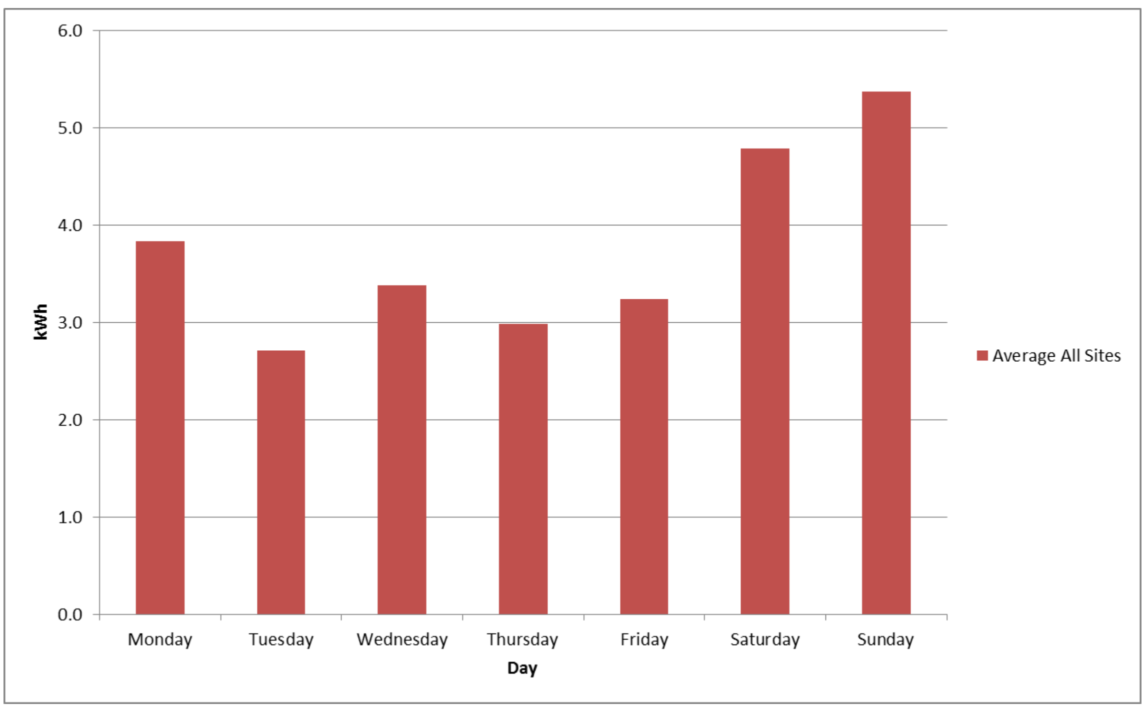
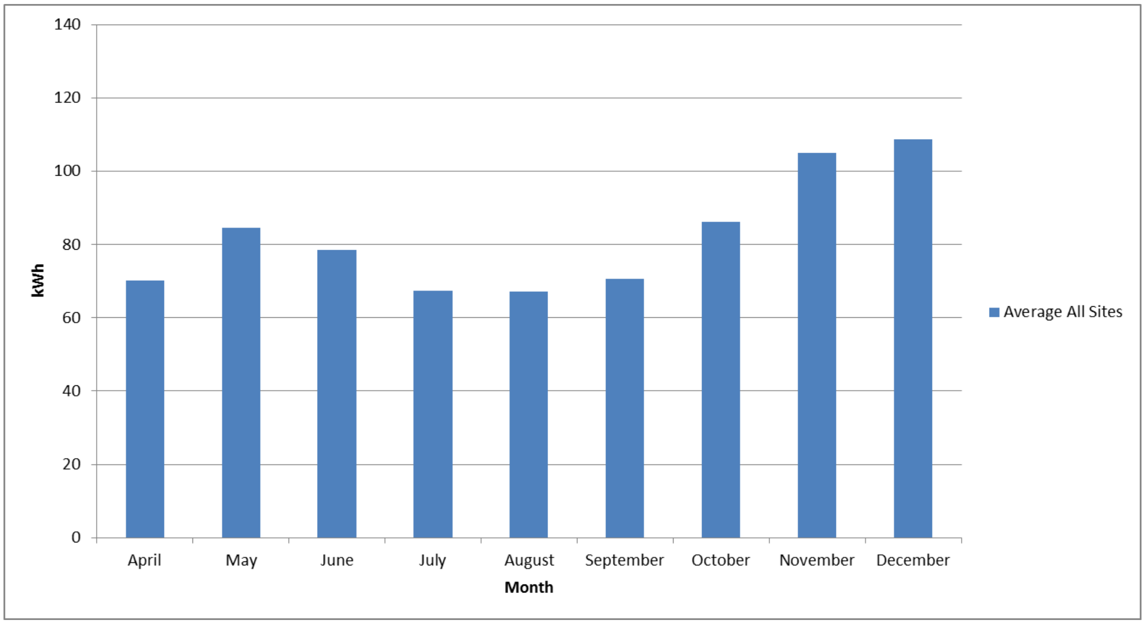


Figure 5.3. Average Monthly Energy Usage, April through December



5.5 Load Shape

The average load shape for the monitored sites was plotted for the metered period and the summer peak load periods as defined by the New England ISO. Figure 5.4 presents the load shape for the monitoring period. Figure 5.5 presents the peak period load shape.

Figure 5.4. Average Load Shape, April through December

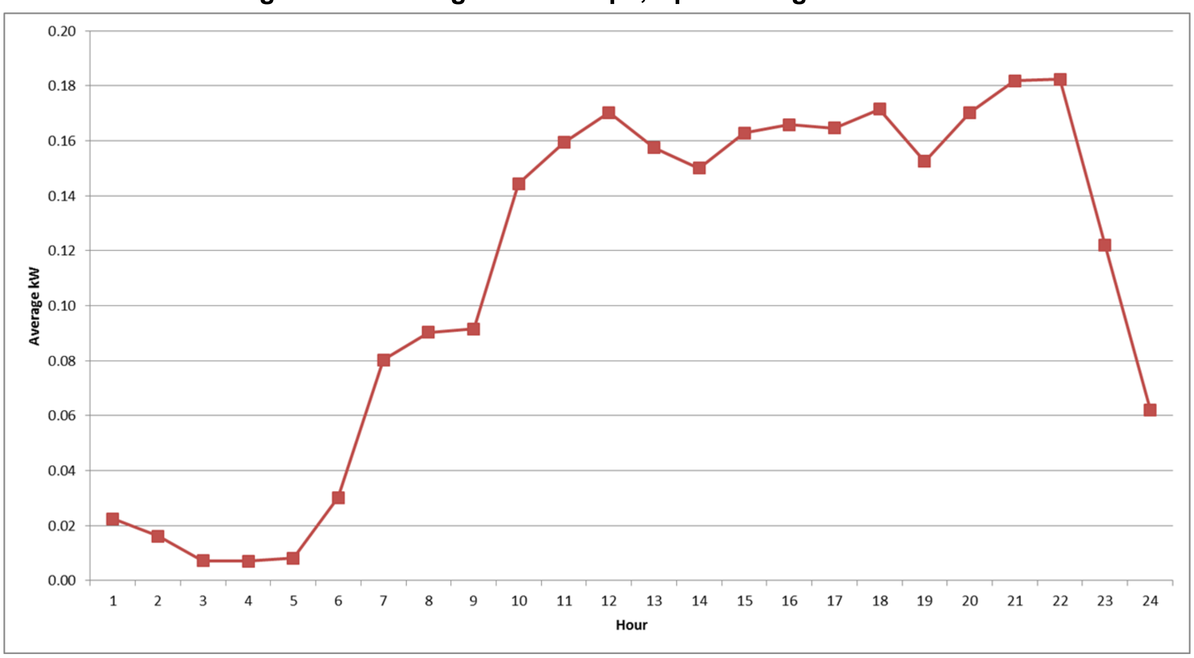
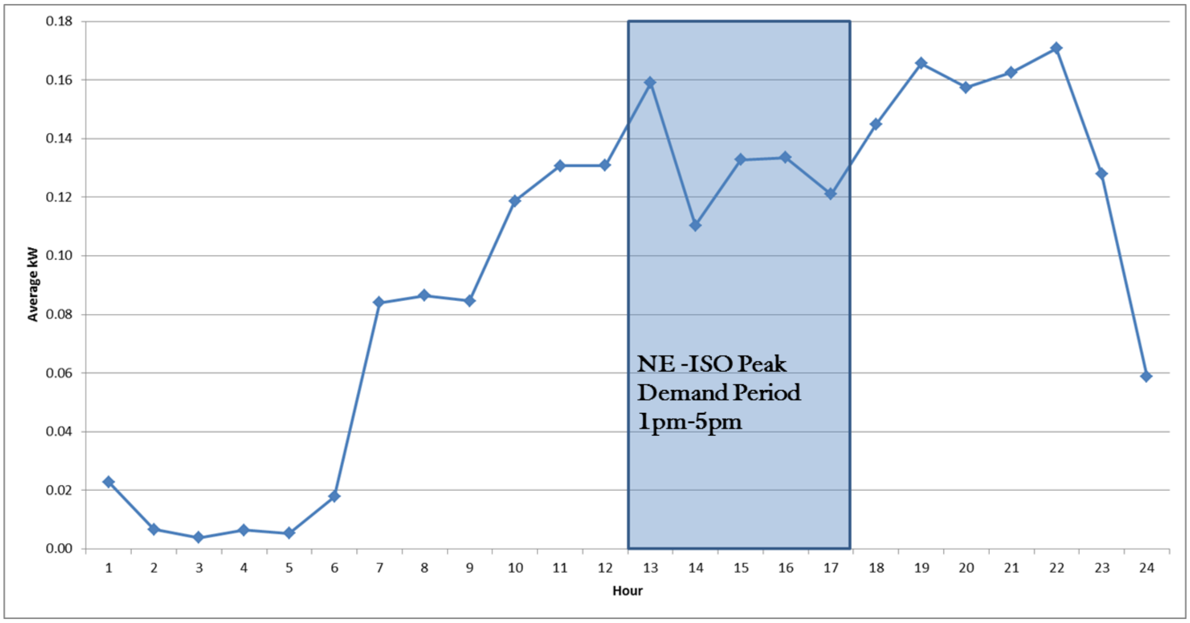


Figure 5.5. Average Load Shape – Weekdays, June, July and August



Average demand, NE-ISO Peak Period – 0.13 kW ± 0.014 kW (11%)
90% confidence level; ± 11% of metered average

5.5.1 Load Shape – Other Studies

The monitoring for this study resulted in load shapes that were significantly different than those that were reported in other studies. Most of the other studies reported that the peak weekday usage was during the late-morning hours. Our participant interviews were consistent, however, with peak weekday usage occurring during the evening hours. Made evident by the fact that we needed to install nearly all monitoring equipment during evening or weekend hours, our participants were rarely home during weekday hours, whereas the national average for dual income households is approximately 60%.

Figures 5.6 and 5.7 present the load shapes from other studies. Additional load shape comparisons are included in the companion presentation slides to this report.

Figure 5.6. NEEA/Ecotope Residential Baseline Stock Assessment of Ninety-Six Sites in Pacific Northwest

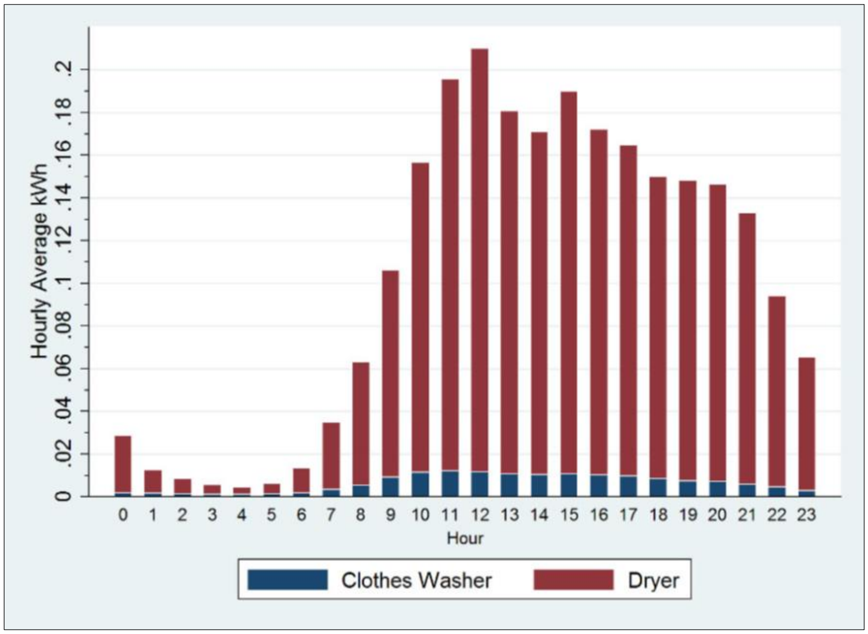
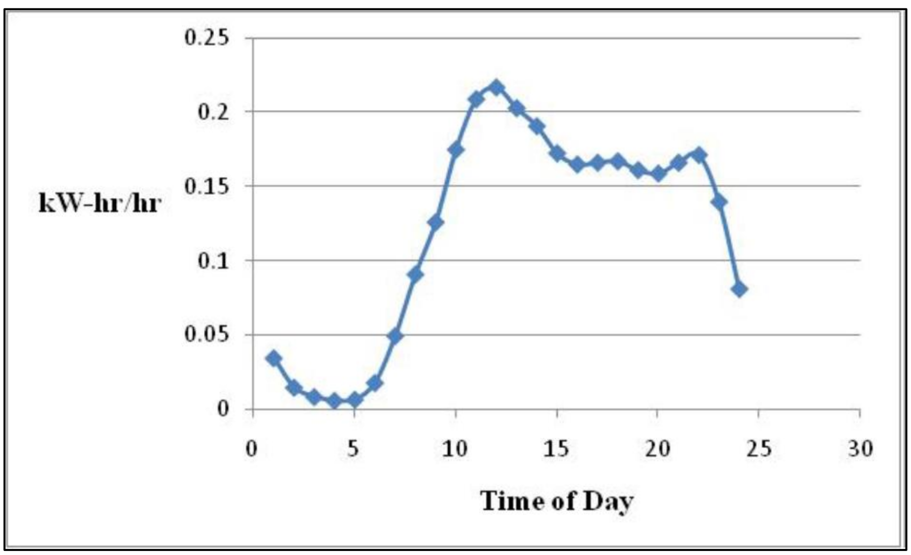


Fig 5.7. DOE End-Use Load and Consumer Assessment Program 1989; Average Daily Load Shape



6 Dryer Exhaust Air

The exhausted dryer air creates increased negative pressure in the space, increasing infiltration to replace the exhausted air. This make-up air must be conditioned, adding to the total heating and cooling load of the building. The total net effect is dependent on whether the space is cooled (only one of the homes in this study was cooled), the location of the dryer, and the tightness of the structure.

Some dryer manufacturers publish data on the amount of air exhausted, but this is typically reported as a range for various models and vent configurations. For example, Whirlpool reports that their dryers, including TurboVent™ commercial dryers, exhaust between 105 and 230 CFM with the dryer empty, filters clean, and operating on an "air only"cycle.[6] The lower figure is for standard residential dryers, and we recorded average CFM to be somewhat lower in the field under a variety of conditions including lint in the filters and various clothing loads. Another point of reference is the ENERGY STAR program which reports that the rated fan CFM for residential dryers ranges from 100-150 CFM.[7] For six of the participant homes, we were able to record the dryer exhaust while actual loads of clothes were being dried. To estimate the effect of the dryer exhaust, we used the following procedure:

- Exhausted dryer air was metered with a Dwyer 471 Thermo-Anemometer, which recorded the velocity.
  - The velocity was recorded at several spots across the face of the exhaust outlet.
  - The velocity was recorded at several different stages of the drying cycle.
- The velocity was converted to volume (cfm) and averaged using data collected when the dryer cycle was initiated, at mid cycle, and just prior to cycle termination.
- Typical meteorological year (TMY3) weather data for Burlington, Vermont; Pease Air Force Base, and Manchester, New Hampshire; and Worcester, Massachusetts, was used to calculate the make-up air heating and cooling.

The impact of the venting is illustrated in Table 6.1

Table 6.1. Annual Energy Impacts of Vented Dryer Air

Average Velocity (fps)	Average Flow (cfm)	Heating (Btu/hr)	Cooling (Btu/hr)	Oil Heating Penalty[1] (gallons)	NG Heating Penalty[2] (therms)	Electric Heating Penalty[3] (kWh)	Cooling Penatly[4] (kWh)
1,136	99	3,681	461	4.7	6.4	239.5	3.0

[1]#2 fuel oil = 138,500 Btu/gallon at 78% system efficiency
[2]Natural gas = 100,000 Btu/therm at 80% system efficiency
[3]Electric resistance heating at 100% system efficiency
[4]Only one of the homes was cooled; the cooling is estimated for air conditioning at SEER = 13.

The values presented in Table 6.1 above may be used to estimate the impact for tightly constructed homes with low infiltration rates and where the dryer is located in a conditioned space. Several studies have demonstrated – and it is now accepted engineering and building science practice – that the net effect of such venting is reduced for buildings constructed at

[6] Whirlpool dryer venting specifications. 2011.

[7] ENERGY STAR Market & Industry Scoping Report, Residential Clothes Dryers. November 2011.

average tightness levels. For average buildings of standard construction, it is estimated that the total net effect is approximately 50% of the energy needed to condition the calculated air volume.[8]

6.1 Hybrid Heat Pump Dryer Venting

As noted in section 2.1, of the two hybrid models currently marketed in the U.S., one is ventless and one vents to the outdoors. Ventless dryers that utilized heat pumps will return cooler air to the space in which they are installed. Although this does not alter the baseline, the effect will need to be considered to accurately calculate the net savings compared with conventional vented dryers.

7 DRYER STUDIES – OTHER JURISDICTIONS

The project team reviewed several other residential dryer studies that addressed baseline conditions to see what methodologies had been used and to compare the results of the data collected. We found that not all of the studies reported the metering process, but when the metering process was detailed, these field studies used the same basic metering approach that was used for this study. All of the field studies interviewed participants, with one study, performed by Ecova for the Northwest Energy Efficiency Alliance, also asking participants to weigh and record their dryer loads. No studies, other than this EM&V Forum study, measured the volume of dryer exhaust air. Table 7.1 compares the average annual energy usage estimated by the six studies most relevant to the EM&V Forum study. The results are remarkably consistent and support a baseline annual energy usage number in the 900–1,000 kWh range.[9]

Table 7.1. Comparison of Study Results; Annual Energy Usage

Study	Year Completed	Average Annual Energy Usage (kWh)	Notes
EM&V Forum Study	2015	993	
NEEA - Ecova Field Study	2014	915	Pacific Northwest
DOE - EIA Residential Energy Consumption Survey	2001	1070	
BPA/ELCAP - Exisiting Homes	1986	918	Pacific Northwest
BPA/ELCAP - New Homes	1986	987	Pacific Northwest
Progress Energy	1999	885	Florida
Multi-Housing Laundry Association	2002	993	Average for 3-bedroom home

The Progress Energy study was performed in a warm climate, and therefore likely associated with the drying of lighter clothing. The BPA studies, completed nearly thirty years ago, reported nearly identical usage compared with the NEEA and EM&V Forum studies. Although dryer and

[8] Francisco, P., and L. Palmiter. 1996. "Modeled and Measured Infiltration in Ten Single-Family Homes."

[9] The EM&V Forum study average annual kWh is normalized for 2.8 average household size. The average household size for the NEEA study was 2.8, and for the BPA study was 2.7. Average household size was not reported for the other studies.

washing machine efficiency has improved during the last decades, laundry habits, such as the prevalence of outdoor clothesline drying have also undoubtedly changed. In addition, the BPA studies included rental unit households, and compact dryers installed in manufactured housing units. The 2014 NEEA study provides for the best comparison with this EM&V Forum study, as it was recently completed, the metering procedures were nearly identical, and the climate includes both warm and cold weather periods. Several key factors are presented in Table 7.2.

Table 7.2. NEEA and NEEP EM&V Forum Study Key Findings

Key Finding or Factor	NEEA Study	NEEP Study
Average annual energy usage (kWh) per single family household of 2.8[a]	915	993[b]
Average # of dryer loads per year	311	439[b,c]
Average annual dryer runtime (hours)	307	351[b]
Average drying time per load (minutes)	56	48[c]
Reported percentage of washer loads dried in dryer (opposed to hang dry)	93.5%	79%
Increase in drying time for heavy fabrics	13%	N/A[d]
Percentage of medium and high temperature settings selection	50/50%	N/A
Cycle time variation for medium & high temperature settings selection	None	N/A
Average annual standby energy usage (kWh)	1.5	1.1
Energy savings associated with auto-termination vs. timed drying	None	N/A
Energy penalty associated with make-up air (kWh - electric resistance heat)	N/A	120
Percentage of horizontal axis (front load) washers in study	23%	62%

[a]NEEA study actual average household size was 2.8 – NEEP study normalized to 2.8 (*note: only annual energy usage is normalized for household size)*

[b]Extrapolated from partial-year metered data

[c]Difficult to differentiate distinct loads from touch-up loads

[d]Limited metered data demonstrates increased drying time during winter months

N/A = Not applicable

8 ENERGY STAR CERTIFICATION FOR ELECTRIC DRYERS

In June 2014, the first ENERGY STAR specification for residential clothes dryer was introduced. It officially went into effect on January 1, 2015. As of February 27, 2015, there are forty-seven products that are ENERGY STAR-certified electric dryers. Many of the forty-seven dryers have identical specifications and can be assumed to be functionally identical products with differing convenience or aesthetic features, and/or are marketed under different brand names, which is common in the appliance industry.

None of the dryers in our sample were ENERGY STAR-certified. Research into the certified dryers reveals that they are all new to the market and incorporate advanced features such as multiple moisture sensor based cycles. ENERGY STAR-certified dryers are estimated by the United States Environmental Protection Agency (EPA) to use approximately 20-30% less energy than their standard counterparts.

A simple method of calculating the energy savings associated with ENERGY STAR dryers would be to calculate the difference between the estimated usage according to the ENERGY STAR rating and the average usage for standard dryers estimated from the data collected in this study.

However, the current ENERGY STAR specification is based on a methodology that calculates the energy usage per dryer load weight in pounds. Test loads that were dried under specific conditions are used to calculate the energy usage per load, which is then multiplied by an estimated number of annual loads (283 loads [cycles] per year). This is termed the combined energy factor (CEF) and is defined by the United States' Department of Energy (DOE) as follows: "The clothes dryer test load weight in pounds divided by the sum of the per cycle standby and off mode energy consumption and either the total per-cycle electric dryer energy consumption or the total per-cycle gas dryer energy consumption expressed in kilowatt hours (kWh)."[10]

The test methodology of utilizing specific fabric type, weight, and cycle selection, provides consistency, allowing comparisons across many brands and models. However, it is very different than collecting field data, where operating conditions vary. According to the Consortium for Energy Efficiency (CEE), in addition to the number of cycles being lower, the test cloths used for ENERGY STAR ratings are small and uniform and not representative of real world clothing. Also the starting and ending moisture content values used for testing are likely to be different from actual field usage.[11]

Comparing ENERGY STAR test procedures and field collected dryer usage data leads to a conclusion that the average energy usage and associated potential savings associated with clothes dryers is higher than the ENERGY STAR reported figures. Nonetheless, by allowing for the difference in overall energy usage, the ENERGY STAR ratings and methodology can be used to estimate savings compared with the baseline values reported in this study.

Fourteen of the dryers encountered in this study are included in the DOE Compliance Certification Database. The CEF for the dryers ranged from 3.02 to 3.10, with 3.08 being the most common factor. ENERGY STAR estimates that standard dryers within this CEF range use approximately 769 kWh annually. A review of the standard models in the DOE database reveals that almost all of them fall within this range.

ENERGY STAR-certified dryers also have a narrow range of energy performance. The forty-four electric resistance heated certified models are rated at either 3.94 or 3.93 CEF and 607 to 608 annual kWh. The two dryers that incorporate heat pump technology are rated at 4.5 and 4.3 CEF and 531 to 556 annual kWh, respectively.

8.1 ENERGY STAR Baseline Adjustments

In order to utilize the ENERGY STAR rated energy usage with the baseline annual energy usage reported in this study, adjustments needs to be made to account for the differences in estimated annual dryer usage. The ENERGY STAR methodology concludes that electric resistance heated ENERGY STAR dryers use approximately 20% less energy than standard dryers and that hybrid heat-pump ENERGY STAR dryers use approximately 30% less energy than standard dryers.

[10] https://www.energystar.gov/index.cfm?c=clothesdry.pr_crit_clothes_dryers

[11] Email correspondence with Eileen Eaton, Program Manager, Consortium for Energy Efficiency. March 12-2015. www.cee1.org

A simple methodology for using the ENERGY STAR ratings is to apply the appropriate savings factor (20 or 30%) to the baseline energy usage of 993 kWh per year. The resulting annual savings for an ENERGY STAR electric resistance dryer would be approximately 199 kWh (993 x 20%). The resulting annual savings for an ENERGY STAR hybrid heat pump dryer would be approximately 298 kWh (993 x 30%).

For ventless dryers, the make-up air savings discussed in section 6 should be added to the total. For ventless hybrid heat pump dryers, the effect of the heat pump cooling the interior ambient air should also be considered.

Field studies of advanced dryer technologies, including heat-pump dryers, are underway. The results can be used to further refine savings estimates.

8.2 Developing Technical Resource Manual Documentation for ENERGY STAR Dryers

Studies are currently underway to assess the field performance of advanced dryers, including hybrid heat pump dryers. Those studies are recording total energy consumption and will provide for consistent comparison with the baseline consumption values reported in this study as well as findings from the NEEA and other studies.

As discussed, ENERGY STAR does not currently utilize field study data for rating dryers, but uses a CEF based on assumed averages for dryer load weights, load runtime, and annual number of loads. The CEF is the quotient of the test load size (8.45 lbs) divided by the sum of the machine electric energy use during standby and operational cycles. The ENERGY STAR published equation is shown here:

$$CEF = \frac{C(lbs)}{Eon + Estandby}$$

A standard formula for using CEF for calculating energy savings for ENERGY STAR dryers can be illustrated as:

$$Annual\ kWh\ savings = \left\lfloor \frac{1}{CEFstandard} - \frac{1}{CEFefficient} \right\rfloor x\ lb/load\ x\ \ Loads/year$$ [12]

It is important to note however, that the number of loads per year used by ENERGY STAR is significantly lower than the number of loads reported by this and other studies.

Using the methodology presented in section 8.1, the formula for calculating savings can be presented for ENERGY STAR conventional dryers, as:

$$Annual\ kWh\ savings\ = baseline\ annual\ kWh -\ baseline\ annual\ kWh\ x\ 0.8$$

And for ENERGY STAR hybrid heat pump dryers as:

$$Annual\ kWh\ savings\ = baseline\ annual\ kWh -\ baseline\ annual\ kWh\ x\ 0.7$$

[12] Tennessee Valley Authority, Technical Resources Manual. 2015

9 KEY FINDINGS

The key findings from this study allow program administrators to develop the baseline energy usage and load shapes for the residential electric dryers installed in single-household homes. The following is a list of these findings:

- The average annual energy usage for this study's monitored sites is estimated to be 1,060 kWh per household, and the average household size observed in this study was 3 people. This average usage is extrapolated to a full year, but not normalized for household size.
- The average annual energy usage from this study, normalized for an average United States household size of 2.8 people is estimated to be 993 kWh ± 129 kWh[13]
- The daily load shape is relatively flat between 11 a.m. and 10 p.m. and differs from other reviewed studies that reported a significant midday peak.
- The highest average demand occurs during the weekend. The highest average weekday demand occurs during the evening hours.
- There are seasonal variations, as the colder months require more energy for drying clothes because more and heavier clothing is worn during the winter months.
- Dryer standby energy usage is very small:
  - Dryers with electronic controls use about an additional 1 to 1.5 kWh per dryer per year for the controls (actual measured amperage is below logging meter accuracy range)
  - Dryers with electro-mechanical controls had no standby usage
- The average number of annual dryer loads varies but is estimated to be 439. This number is somewhat lower than the number of loads reported in the NEEA field study which asked participants to keep a log of dryer usage. Using the metered data, it is difficult to differentiate normal dryer loads from "touch-up" operation (when the user restarts the dryer with the same load in the drum). The project team combined short-cycle loads with the previous load to more accurately assess the number of loads, however it was not possible to identify all touch-up loads and the total load estimate of 439 is likely somewhat high.
- Dryer runtime varies widely, but is estimated to average 48 minutes per load. This average was also calculated using the approach that combined touch-up operation with normal dryer loads. Because total dryer runtime was recorded, the drying time per load will vary in direct correlation with the estimated number of loads.
- This and other studies are relatively consistent in estimating both the number of annual dryer loads, and the annual energy usage. In addition, the studies conclude that dryer usage is higher than estimated for the ENERGY STAR program, which assumes a smaller

[13] Applying a standard 90% confidence interval analysis results in ± 13%, although this statistical analysis is not fully appropriate for the sample, which was not fully randomly selected, and for extrapolated data based partly on engineering judgment.

number of annual dryer loads. As such, both usage and savings are potentially higher than estimated by ENERGY STAR.

- Heating make-up air energy consumption varies and is estimated to be 120kWh, 2.3 gallons fuel oil, or 3.2 therms natural gas (NG) – or approximately 12% of the dryer energy usage for the average home with a dryer vented to the outdoors. The net energy effect will vary with the location of the dryer and weather-tightness of the home.
- Only one of 23 homes in our study was air conditioned. For New England, the make-up air energy usage is primarily associated with heating. In warmer climate zones, where air conditioning is more prevalent, dryer venting will result in additional cooling of make-up air.
- For New England, the most common dryer location is in a heated or semi-heated (thermally coupled) basement.
- All surveyed sites had proper venting to the outdoors.

9.1 Recommendations

The following recommendations for the baseline development and further study have been developed from the key findings:

- **Baseline assumptions** – Dryers are typically replaced at or near the end of their useful life. It is recommended that baselines assume that the alternative to an ENERGY STAR dryer is a modern standard efficiency dryer, such as those encountered in this study. It is also assumed that many purchasers will be buying modern washing machines at the same time, or will have previously upgraded to modern washers. There is potential for developing incentives for ENERGY STAR washer/dryer combined installations.
- **Energy usage baseline** – With multiple studies concluding similar baseline usages, the program administrators should be confident in adopting a dryer baseline of 900 to 1,000 kWh annual energy usage for single-household homes.
- **Savings calculations for ENERGY STAR dryers** – Although current *in situ* studies of ENERGY STAR qualifying dryers, including ventless heat pump dryers, will provide additional valuable data, the baseline usage reported in this study can be used with ENERGY STAR data after making the adjustments to the total dryer usage.
- **Support ongoing efforts** – The Super Efficient Dryer Initiative (SEDI) is a multiple-organization effort, supported by NEEP and NEEP sponsors, that works with dryer manufacturers, government agencies, utilities, and appliance retailers in the United States and Canada to promote the introduction of advanced clothes dryers to the North American market. SEDI and its member organizations have ongoing research projects and will continue to provide valuable information regarding clothes dryer technologies and potential savings.
- **Further study** – Advanced dryer technologies can offer significant savings in multi-family settings, where one dryer may be installed per three or more households. Baseline studies are needed to determine the load shape and annual usage of this scenario.

- **Washer/dryer combined baseline** – Given that many purchasers buy washing machines and dryers at the same time, program administrators may want to conduct additional research (secondary or primary) to develop washer/dryer combined baseline estimates.

9.2 References

Ecotope. *Dryer Field Study*. Northwest Energy Efficiency Alliance (NEEA) 2014.

Meyers, Franco, Lekov, Thompson, and Sturges, Lawrence Berkeley National Laboratory. *Do Heat Pump Clothes Dryers Make Sense for the U.S. Market?* ACEEE Summer Study Proceedings. 2010.

Building Energy Codes Research Center. *Ventilation Requirements for Condensing Clothes Dryers* - http://www.energycodes.gov Accessed October, 2014.

CLASP Super Efficient Dryer Initiative. *Analysis of Potential Energy Savings from Heat Pump Clothes Dryers in North America.* 2013.

U.S. EPA. *ENERGY STAR Market & Industry Scoping Report Residential Clothes Dryers.* 2011.

U.S. EPA. *ENERGYSTAR Program Requirements Product Specification for Clothes Dryers*. 2015.

Karg. *Survey of Tightness Limits for Residential Buildings*. 2001.

Multi-Housing Laundry Association. *National Study of Water & Energy Consumption in Multifamily Housing.* 2002

U.S. Compliance Certification Database. http://www.regulations.doe.gov/certification-data/CCMS-4140264705.html Accessed October 2014.

U.S. EPA. ENERGY STAR Certified Residential Clothes Dryers. http://www.energystar.gov/productfinder/product/certified-clothes-dryers Accessed October 2014.

Progress Energy Florida. *Residential Energy Usage Study.* 1999.

U.S. Energy Information Administration. *Residential Energy Consumption Survey.* 2001.

Bonneville Power Authority. *End-Use Load and Consumer Assessment Program. 1986-1992.*

Francisco, P., and L. Palmiter. *Modeled and Measured Infiltration in Ten Single-Family Homes*. 1996.