END-USE DATA DEVELOPMENT FOR POWER SYSTEM LOAD MODEL IN NEW ENGLAND

End-Use Data Development for Power System Load Model in New England - Methodology and Results

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1 EXECUTIVE SUMMARY

End-Use Data Development for Power System Load Model in New England is a project sponsored by the U.S. Department of Energy with a goal of providing a representation of electrical loads to facilitate power system dynamic stability modelling. NERC Reliability Standard TPL-001-4 calls for the study of dynamic load performance per requirement R2.4 and associated sub-requirements. The work performed in this project resulted in a representation of electrical system load in New England by 1) summer peak and spring light load hour[1], 2) by seven geographic regions within New England, 3) by customer sector, 4) by electrical end-use categories specific to each customer sector, and 5) by load components identified as being inputs to dynamic stability modelling applications. The load representation developed in the project is in the framework of the Western Electricity Coordinating Council (WECC) composite load model which divides system load into fractional components accounting for the constant power loads (electronics and various motor applications), constant current loads, and constant impedance loads.

The estimated load representation produced in this project was developed using a "bottom-up" methodology which leverages the Energy Information Administration's residential, commercial buildings, and manufacturing energy consumption surveys as core data sources. DNV GL augmented this data with end-use consumption estimates from secondary sources. The end-use consumption estimates were calibrated to specific population metrics and weather data for the seven New England regions. The methodology first derived annual electricity consumption estimates by end-use category within sector and region and then adjusted the annual consumption to the load in the summer peak and light spring load hours using the DNV GL load shape library.

The ultimate representation of system load into the WECC composite load model component categories used rules of association for the proportional breakdown of load by end-use category (e.g. incandescent lighting) and sector class (e.g. lodging within the commercial sector). Some rules of association assign 100% of the end-use load for the sector class to a single load component (e.g. single-phase space cooling compressors are assigned to the 'Motor D' load component) while others decompose the end-use load to multiple components.

An important goal for the project was to not only develop the New England regional load decompositions but also to rigorously document the analysis approach and assess data gaps and the various data sources used in the analysis with respect to its application in this project, acknowledging that the data may have been originally collected for very different purposes. The rules of association were developed primarily from engineering judgment of the DNV GL and stakeholder project team rather than grounded on evaluation data (as we would vastly prefer), building on the foundation of the rules of association developed for the WECC composite load model.

Given that the estimation framework produced in this study leverages survey research data that has been collected on a regular periodic schedule, the estimates presented herein can be updated as new data releases are made. Additionally, the estimation framework can incorporate more regionally specific data which are not covered in this analysis to better represent load dynamics in specific locations. The estimation

[1] The summer peak was assumed to be the hour ending 3 pm on a July weekday with a temperature of 95 degrees Fahrenheit and 70 degree dew point. The spring light load hour was assumed to be the hour ending 9 am on a May weekend day with a temperature of 55 and dew point of 47.

framework can also be extended to other hours of the year besides the summer peak and light load hour which were the focus.

1.1 New England End-Use Load Summary

At the highest level, the results of this project suggest that there is low to moderate variation across the seven New England regions in terms of the proportional representation of the three customer sectors, end-uses across customer sectors, and load components across the end-uses categories. Several summary figures and tables of the findings of this study are presented in this section. A more complete set of summary figures can be found in Section 4.5.

Figure 1-1 and Figure 1-2 show the estimated system load breakdown in the two hours that were the focus of this study. In all regions the industrial sector had a reduced share of summer peak load in comparison with the light spring load hour. This is due to the industrial sector being the less weather sensitive than the residential or commercial buildings sectors.

Figure 1-1: Summer peak hour load breakdown by New England region and sector

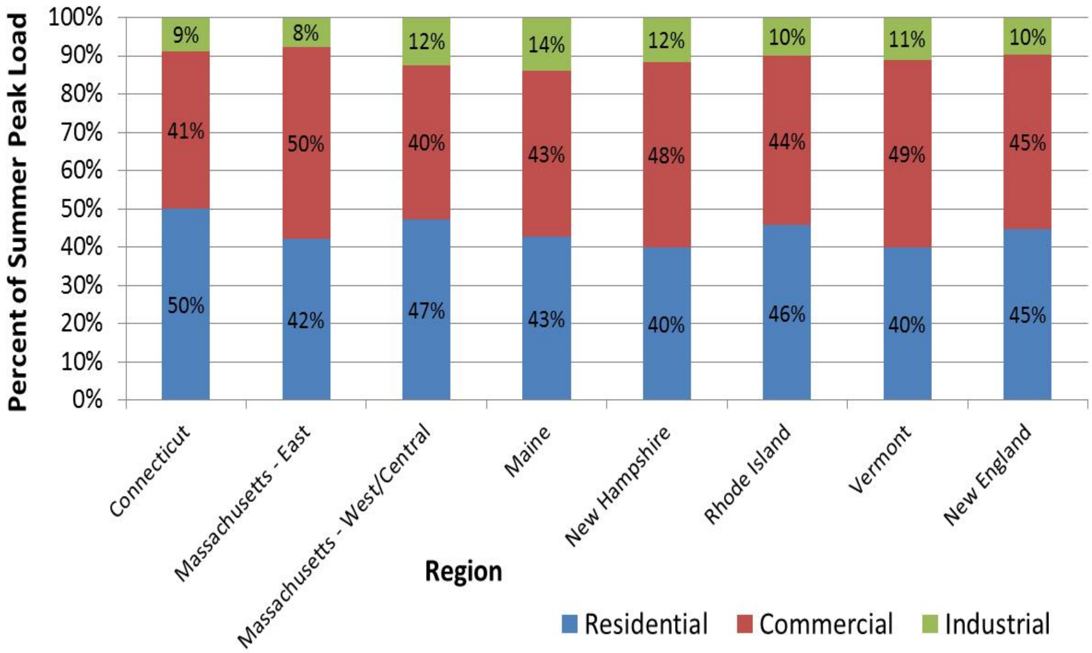
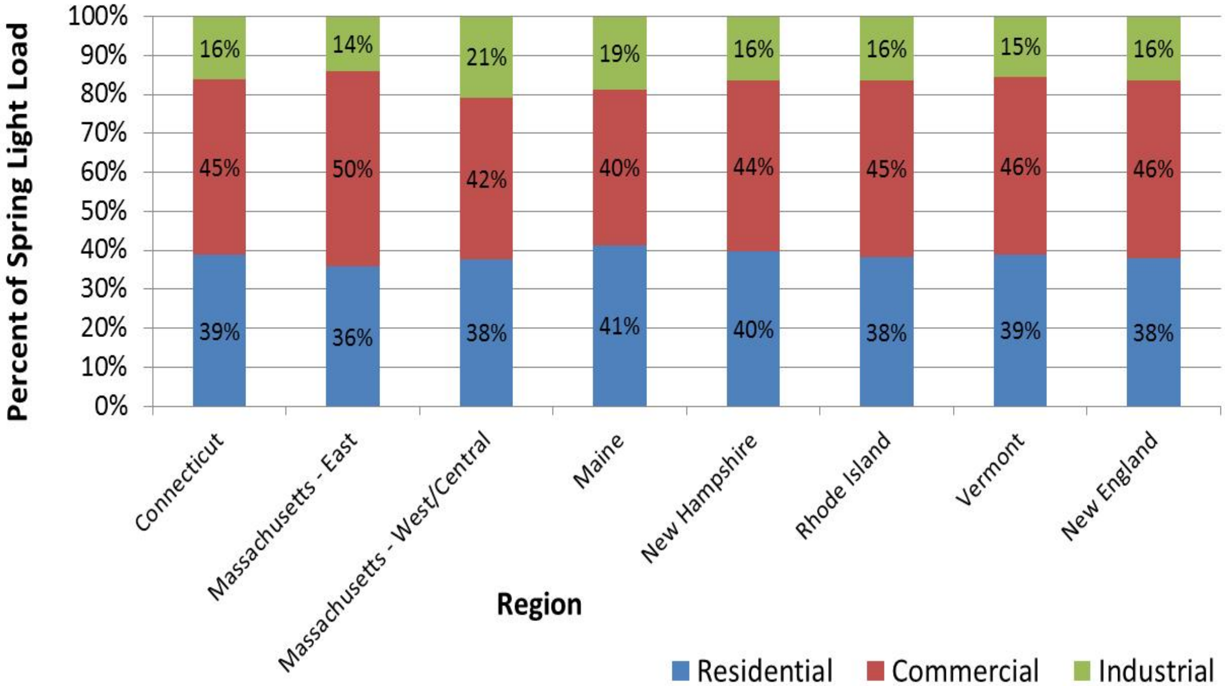


Figure 1-2: Spring light hour load breakdown by New England region and sector



Space cooling accounted for about 35% of system load in the summer peak hour as shown in the end-use breakdown in Table 1-1, with other weather sensitive loads such as ventilation and pool pumps also accounting for notable shares. The CFL/Linear Fluorescent lighting category also accounted for a large share of peak load, driven primarily from commercial buildings, and was the top end-use category in the spring light load hour, as shown in Table 1-2. This was followed by machine drives, which is the dominant end-use category of the industrial sector. We caution, however, that in specific localities where industrial activity is relatively low, and/or weekend operations are limited will have a reduced share for machine drives.

Table 1-1: Cross-sector end-use breakdown of summer peak hour system load (MW)

End-Use Category	Connecticut	Massachusetts East	Massachusetts West/ Central	Maine	New Hampshire	Rhode Island	Vermont	New England	New England Percent Share	Cumulative Share
Space Cooling - Split Phase	1,193	1,406	509	310	242	361	134	4,156	14.5%	14.5%
Lighting - CFL/Linear Fluorescent	912	1,112	298	327	309	228	171	3,357	11.7%	26.2%
Space Cooling - Three Phase	774	1,345	290	213	244	206	160	3,232	11.3%	37.4%
Space Cooling - Single Phase	768	858	251	169	162	209	106	2,522	8.8%	46.2%
Ventilation	369	553	153	164	156	114	84	1,595	5.6%	51.7%
All Other End Uses - COM	337	499	133	145	136	105	74	1,428	5.0%	56.7%
Machine Drive	295	328	181	221	126	87	73	1,309	4.6%	61.3%
Refrigeration	301	467	128	124	117	96	68	1,301	4.5%	65.8%
All Other End Uses - RES	282	339	116	125	102	84	55	1,104	3.8%	69.7%
Refrigerators/Freezers	256	331	111	125	106	78	56	1,062	3.7%	73.3%
Office Equipment	231	358	89	99	94	70	52	993	3.5%	76.8%
Pool Pumps	186	275	102	83	68	53	67	832	2.9%	79.7%
All Other Electronics	435	238	36	41	34	24	18	827	2.9%	82.6%
Lighting - Incandescent	171	216	72	91	75	52	41	717	2.5%	85.1%
Water Heating	147	179	56	89	71	46	39	626	2.2%	87.3%
Lighting - Other	112	141	45	59	51	33	27	469	1.6%	88.9%
Lighting - HID Interior	109	149	46	48	48	33	26	459	1.6%	90.5%
Clothes Dryers	92	111	39	60	49	27	26	404	1.4%	91.9%
Settop/cable box, digital, DVR	96	131	44	40	34	29	18	392	1.4%	93.3%
Process Heating	101	94	43	25	35	29	15	342	1.2%	94.5%
Process Cooling and Refrigeration	51	75	23	27	22	19	20	235	0.8%	95.3%
Electro-Chemical Processes	29	43	40	20	23	25	5	186	0.6%	95.9%
Ceiling Fans	39	44	15	17	14	12	7	147	0.5%	96.4%
Other TVs	35	44	15	13	10	10	6	133	0.5%	96.9%
Cooking	27	43	12	11	11	10	6	120	0.4%	97.3%
Air Compression	28	41	11	12	11	9	6	119	0.4%	97.7%
CRT TVs	25	31	10	12	10	8	5	101	0.4%	98.1%
Other Process Use	18	24	7	24	8	5	3	89	0.3%	98.4%
Well Pumps	19	13	5	14	11	5	6	75	0.3%	98.6%
Clothes Washers	17	21	8	10	8	5	4	72	0.3%	98.9%
Other Facility Support	19	21	7	6	8	5	4	70	0.2%	99.1%
Elevator drives and hydraulic pumps	15	23	6	7	6	5	3	66	0.2%	99.4%
Range/Oven	15	17	6	9	8	5	4	64	0.2%	99.6%
Dishwashers	8	11	4	4	3	2	2	33	0.1%	99.7%
Conventional Boiler Use	6	8	4	4	3	2	2	29	0.1%	99.8%
Agriculture	2	1	1	7	1	0	8	20	0.1%	99.9%
Mining	6	3	1	0	1	1	1	13	0.0%	99.9%
Other Nonprocess Use	2	4	1	1	1	1	1	11	0.0%	100.0%
Onsite Transportation	2	2	1	1	1	0	0	6	0.0%	100.0%
Space Heating	1	1	1	1	1	0	0	4	0.0%	100.0%
Construction	0	0	0	0	0	0	0	0	0.0%	100.0%
Grand Total	**7,531**	**9,598**	**2,918**	**2,758**	**2,418**	**2,091**	**1,404**	**28,719**	**100%**	**100.0%**

Table 1-2: Cross-sector end-use breakdown of spring light hour system load (MW)

End-Use Category	Connecticut	Massachusetts East	Massachusetts West/ Central	Maine	New Hampshire	Rhode Island	Vermont	New England	New England Percent Share	Cumulative Share
Lighting - CFL/Linear Fluorescent	408	625	172	189	175	128	98	1,795	12.1%	12.1%
Machine Drive	257	282	160	191	105	74	58	1,127	7.6%	19.6%
Refrigeration	251	390	107	103	98	80	57	1,086	7.3%	26.9%
All Other End Uses - RES	276	332	114	122	100	83	53	1,079	7.2%	34.2%
Ventilation	230	342	96	101	97	71	52	990	6.6%	40.8%
All Other End Uses - COM	233	345	92	100	94	72	51	987	6.6%	47.4%
Water Heating	219	253	81	135	106	68	57	920	6.2%	53.6%
Refrigerators/Freezers	204	262	88	99	84	62	44	843	5.7%	59.3%
Lighting - Incandescent	156	194	66	85	68	47	37	654	4.4%	63.7%
Space Cooling - Three Phase	176	231	60	47	55	47	33	649	4.4%	68.0%
Office Equipment	140	218	54	60	57	43	31	603	4.1%	72.1%
Space Heating	78	137	47	43	41	24	21	391	2.6%	74.7%
Clothes Dryers	88	106	37	58	46	26	25	387	2.6%	77.3%
Lighting - Other	92	111	37	50	42	27	23	382	2.6%	79.9%
Settop/cable box, digital, DVR	88	120	40	37	31	27	16	359	2.4%	82.3%
All Other Electronics	79	102	35	40	34	24	18	332	2.2%	84.5%
Lighting - HID Interior	72	105	29	28	30	20	16	301	2.0%	86.5%
Process Heating	90	82	38	21	31	26	12	300	2.0%	88.6%
Electro-Chemical Processes	28	42	39	20	22	25	5	182	1.2%	89.8%
Process Cooling and Refrigeration	40	58	18	20	17	14	14	182	1.2%	91.0%
Space Cooling - Split Phase	46	57	15	8	10	13	6	155	1.0%	92.0%
Range/Oven	37	41	14	23	19	11	10	155	1.0%	93.1%
Well Pumps	34	23	9	26	21	10	11	134	0.9%	94.0%
Space Cooling - Single Phase	42	48	12	6	9	10	6	133	0.9%	94.9%
Cooking	23	36	10	10	9	8	5	101	0.7%	95.6%
CRT TVs	24	31	10	11	10	8	5	99	0.7%	96.2%
Other TVs	24	30	11	9	7	7	4	92	0.6%	96.8%
Other Process Use	16	21	7	21	7	4	3	78	0.5%	97.4%
Clothes Washers	16	21	7	9	8	5	4	69	0.5%	97.8%
Air Compression	16	23	6	7	6	5	4	67	0.4%	98.3%
Elevator drives and hydraulic pumps	15	24	6	7	6	5	3	67	0.4%	98.7%
Dishwashers	15	20	7	7	6	4	3	63	0.4%	99.1%
Other Facility Support	16	18	6	5	6	4	3	59	0.4%	99.5%
Conventional Boiler Use	5	6	3	3	2	2	2	23	0.2%	99.7%
Agriculture	1	1	1	4	1	0	5	13	0.1%	99.8%
Mining	5	2	1	0	1	1	1	11	0.1%	99.9%
Other Nonprocess Use	2	3	1	1	1	1	0	9	0.1%	99.9%
Ceiling Fans	2	2	1	1	1	0	0	6	0.0%	100.0%
Onsite Transportation	1	1	1	1	0	0	0	5	0.0%	100.0%
Construction	0	0	0	0	0	0	0	0	0.0%	100.0%
Pool Pumps	-	-	-	-	-	-	-	-	0.0%	100.0%
Grand Total	**3,547**	**4,745**	**1,538**	**1,709**	**1,463**	**1,084**	**801**	**14,887**	**100%**	**100.0%**

The estimated load component breakdowns for New England system load during summer peak and spring light load hours are given in Figure 1-3 and Figure 1-4. The figures show low to moderate variation across the study regions in the load component percentage shares. The load component breakdowns are also similar from summer peak to spring light load hours with the exception of Motor D with significantly higher representation in the summer peak hour due to higher share of single phase compressor motors and constant impedance has a higher share in the light load hour due in large part to resistive lighting and water heating loads.

Figure 1-3: Cross-sector breakdown of New England summer peak load into WECC composite load model components

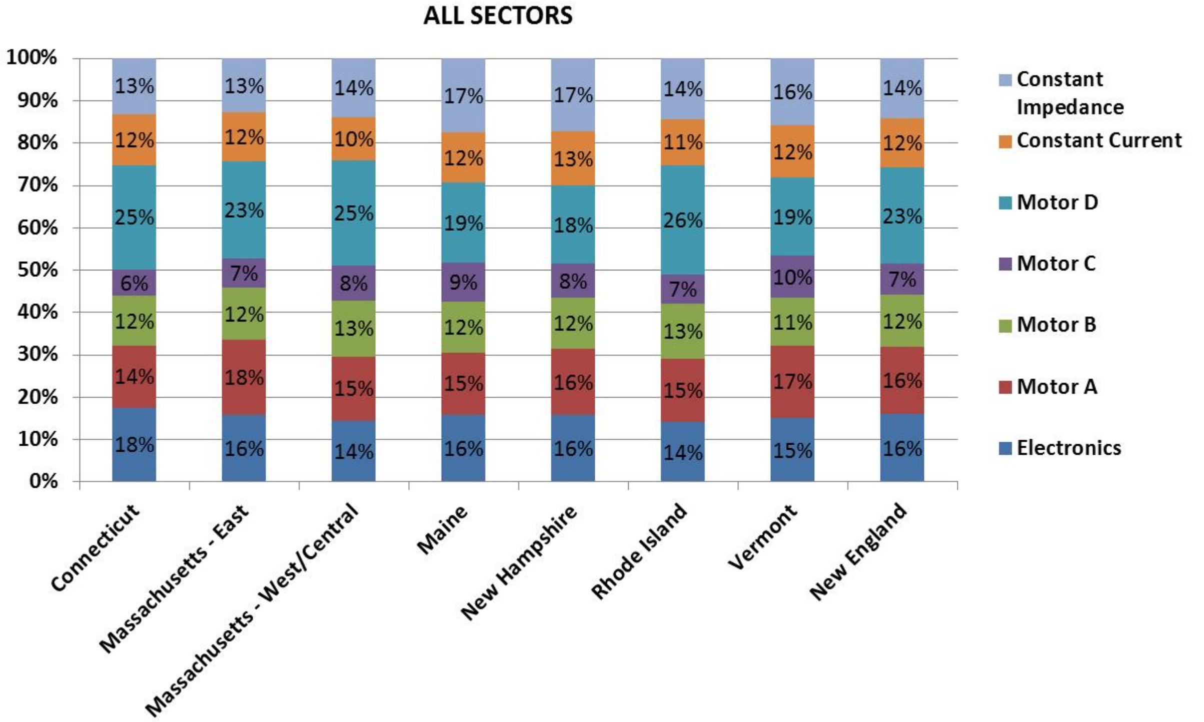
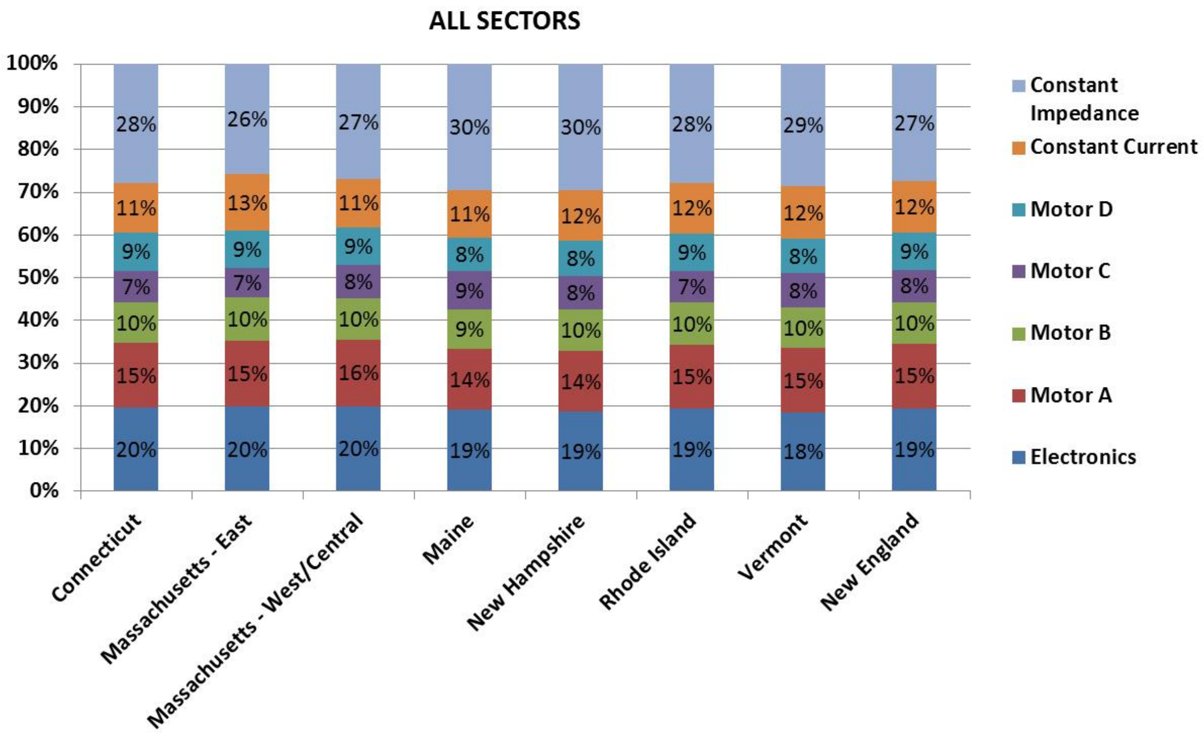


Figure 1-4: Cross-sector breakdown of New England spring light load into WECC composite load model components



While the regions appear to be fairly homogeneous in terms of the load component distributions, there is much more significant variation across the individual sectors and classes within sectors. At finer level geographic areas within these regions the load component distributions may be very different than those shown in these figures. The sector-level load component distributions by region are presented in Appendix C as well as instructions for producing customized overall cross-sector load distributions within a region if the percentages of system load for residential, commercial, and industrial are known for the peak or light load hours.

It should also be noted that data were not available to differentiate the load component distributions at the level of granularity of the end-use load distributions. The estimated load component distributions do not, for example, differentiate single-family homes from one region to another, beyond what was estimated for the end-use representation onto which the rules of association were applied.

1.2 Recommendations

DNV GL offers the following recommendations concerning future load model data development work in New England, and other regions where a similar load representation framework has been established.

1. Update the load representation estimates as new iterations of the key data sources are released. The Energy Information Administration is anticipating the release of their newest Commercial Buildings Energy Consumption Survey public use microdata in late 2015. These data will be a much needed update of the 2003 survey, which is currently the most recent iteration available and does not account for important developments in commercial buildings such as data centers and efficiency improvements by major end uses. The next iterations of the manufacturing and residential consumption surveys will be released in subsequent years.

2. Expand the load representation estimation framework to incorporate interval load data and other more granular data sources. The load representations presented in this study and the accompanying data tools are expected to be reasonably accurate for the seven New England regions that were the focus of this study. However, the estimates are expected to be less and less accurate in smaller geographic areas within each of the regions, due to electricity end-user populations being less diverse in specific areas. For example, certain localities will have high concentrations of industrial load, comprised of a small number of industry classes rather than with the diversity seen in the overall regions. The existing estimation framework could be modified to make use of consumption data from load serving entities.

3. Develop research plans for estimating load component rules of association based on recent data collected from key end-use categories. The rules of association developed for the WECC composite load model and expanded for this study provide a starting point based primarily on engineering judgment. Rules of association derived from the analysis of actual end-use data may improve the accuracy of the current rules, especially for the end-use categories which account for the largest shares of system load. This would include components of HVAC systems, lighting technologies, industrial machine drives, and other major end-use categories. Given that the cost of this research could be significant, we recommend that the data collection efforts should be conducted in conjunction with existing ongoing initiatives, such as end-use metering efforts supporting baseline and impact evaluation studies for energy efficiency program evaluations. Existing data facilitating

aspects of this analysis could be accessible through data sharing agreements with entities conducting this end-use load research.

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John Kueck – Independent Consultant

2 INTRODUCTION

2.1 Electricity Customer Classes Accounted for in this Study

The end-use load model produced in this study accounts for the following classes of electricity customers:

- **Residential customers**. This includes households occupying single-family, multi-family, and mobile homes.
- **Commercial customers**. This class includes buildings in which at least half of the floor space is used for a purpose that is not residential or industrial. The commercial sector coverage includes building types not always associated with the commercial activities, such as correctional institutions, buildings used for religious worship, and schools.
- **Industrial customers**. This includes customers who purchase offsite-produced electricity and can be classified, according to the North American Industrial Classification System (NAICS), in the manufacturing industries (NAICS 31-33), mining industries (NAICS 21), construction industries (NAICS 23), or the agricultural industries (NAICS 11, except for fishing and forestry establishments).

2.2 Electricity Customer Classes Not Accounted for in this Study

The end-use load model produced in this study does not account for the full universe of electricity customers in New England. The primary data sources are from end-user sample surveys administered by the U.S. Department of Energy's Energy Information Administration, which targets specific populations that together comprise the vast majority – but not all – of the energy consumed in the U.S. Unlike survey research conducted by or in partnership with electric utilities, the EIA end-user surveys select entities for their surveys from sample frames of households, buildings, and manufacturing establishments, which have been assembled without access to customer accounts.

While it is not practical to delineate the classes of electricity customers which are not covered by this end-use load model, this list does include the following groups:

- **Public sector utility services.** This includes waste water treatment plant activities, water pumping for potable water and irrigation for publicly owned land.
- **Outdoor lighting.** This includes lighting outside of residences, commercial buildings, and public spaces. Since the objective of the study is to produce end-use load breakdowns during time periods during daylight hours, the lack of coverage for this segment of end uses is minimal.
- **Commercial activity outside of permanent buildings.** This includes outdoor markets and other venues where purchased electricity is consumed outside of an enclosed building.
- **Fishing and forestry establishments.** The EIA estimate for energy consumed by the agricultural sector does not include electricity used for harvesting fish from a farm or their natural habitats or for harvesting timber.
- **Transportation.** The estimates in this study do not account for the purchased electricity used for rail or other forms of transportation.

The load accounted for these groups will vary from region to region. For example, transportation is expected to account for a larger portion of system load in East Massachusetts than West/Central Massachusetts.

The extent to which the non-coverage of the groups listed above will impact the load model will depend on the specific locality in which it is applied. For example, the impact would be high for a feeder that serves a waste water treatment plant. For the non-manufacturing industrial customer classes, the impact would be related to the level of accuracy of the assumed rules of association which are subsequently applied.

Additionally, while the model accounts for total purchased electricity consumed by agricultural, mining, and construction customers, it does not account for the electricity consumption usage by end-use categories. In absence of this level of information, we apply assumed rules of association to the total purchased electricity usage by these classes of customers directly.

A high level assessment of coverage of the end-use load model produced in this study was made by comparing the estimates for annual energy consumption to retail sales of annual energy. Table 2-1 shows the level of agreement between the two sets of estimates. Note that a ratio of one indicates perfect agreement. Overall, the bottom-up annual energy consumption estimate across all sectors produced in this study is 1.13 times the total retail sales for New England for 2012. The comparison ratios vary by state, as shown in Table 2-1, and by sector. Further comparisons by sector and state and analysis are presented in Section 6.1.

Table 2-1 Comparison of bottom-up estimates for annual energy produced in this study to annual retail sales of electricity.

State	Estimated Annual Electricity Consumption - New England End-Use Load Model (MWh)	2012 Electricity Retail Sales - EIA (MWh)	Ratio of Estimated Consumption to Sales (MWh)
CT	32,713,966	29,492,338	1.109
MA	57,958,352	55,313,324	1.048
ME	15,255,182	11,561,059	1.320
NH	13,083,379	10,870,261	1.204
RI	9,988,455	7,708,334	1.296
VT	7,175,133	5,510,764	1.302
NE Region	136,174,497	120,456,080	1.130

DNV GL recommends that the load model be calibrated to more granular data sources than are used in this study when applying the load model to finer levels of geography than the seven New England sub-regions and/or collections of distribution circuits. Further details on the recommended approach for incorporating load information from individually modelled bus-level customers can be found in Section 3.8.

3 END-USE LOAD ESTIMATION METHODOLOGY

The objective of the end-use load estimation analysis was to estimate the proportional shares of end-use loads at the summer peak load hour and during a spring light load hour for the residential, commercial, and industrial sectors comprising total load in each of the seven regions of New England which were the focus of this study:

1. Connecticut
2. Eastern Massachusetts
3. Western and Central Massachusetts
4. Maine
5. New Hampshire
6. Rhode Island
7. Vermont

The summer peak and spring light load hours were assumed to correspond with the following conditions given in Table 3-1 below.

Table 3-1 Definitions for summer peak and spring light load hours used in this analysis

Condition	Summer Peak Load Hour	Spring Light Load Hour
Month	July	May
Day Type	Tuesday - Thursday	Weekend
Time	Hour ending 15:00	Hour ending 09:00
Temperature (°F)	95	55
Dew Point (°F)	70	47

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The methodological approach for estimating the proportional shares of end-use loads in the seven regions varied by sector, due to different sets of source data linked to the analysis of each sector. The general approach did however follow a common framework which consisted of the following three steps:

1. Estimate the proportional end-use shares of annual energy consumption by sector.

   This step entails leveraging existing end-use breakdowns estimated through survey research and subsequent data modelling activities. The EIA administers consumption surveys covering the manufacturing, commercial buildings and residential buildings in the U.S. and by region, although not to the level of geographic detail desired in this project. Additionally, publicly available regional end-use studies were identified which offered estimates of some desired end-uses not covered by the EIA consumption surveys. DNV GL used data linkages to these secondary sources when this was deemed appropriate and sufficient value was added to the load model. We define linkages in this context to refer to the practice of assuming that when a population is covered in two different surveys, characteristic properties of that population derived from data collected on one survey can be assumed on the other survey, when population characteristics associated with those characteristic properties are reasonably controlled.

   For example, suppose one household survey in a state did not collect square footage, but another survey of the households in the state did. It would be more appropriate to link to the square footage from the other survey when controlling for population segments such as housing unit type and another measure of size such as the number of bedrooms than assuming the average square footage across all households in the first survey would apply ubiquitously for each household in the second survey.

2. Calibrate the regional end-use consumption shares to each of the seven regions.

   Calibration is a means of adjusting estimates derived from data collected in one survey to match a control total or characteristic from another data source. Calibration was used in this project to adjust EIA end-use shares from a broader population – New England, Northeast, or national level estimates to the seven regions of interest, using population characteristics collected in both the EIA data and other surveys at the state or county level. Additionally, calibration techniques were used to adjust the end-use consumption shares to account for regional differences in weather.

3. Adjust the annual consumption end-use shares to the summer peak and spring light load hours.

   While end-use shares of annual electricity consumption may be useful in some applications, this was not the principal objective of this project. To adjust the end-use shares to account for summer peak and spring light load hours, DNV GL used further calibration to load shapes specific to end-use categories within sector, which covered the target hours. The load shapes were not only specific to end-use category and sector, but in many cases were also available for segments within the sectors. For example, in the commercial sector analysis we used separate lighting load shapes to differentiate the usage at peak and light load for office buildings, hospitals, and other building types.

   DNV GL maintains a load shape library for many end uses by customer segment as well as total site-level load for certain classes of customers. For example, the library includes a shape for dishwashers in single-family homes. For industrial customers, only site-level load shapes are contained in the library, for energy-intensive industries such as food processing and paper.

   An important characteristic of the load shape library is that each load shape has been separated into four key component ratios, described below, which are initially developed from the original source data, but then can be adjusted to match differing conditions in the targeted sector, end use, segment, and, particularly, weather conditions. For the load shapes to be applicable to the target conditions, these component ratios that comprise the load shape description must therefore be "recalibrated" and then the resulting set of ratios applied to the annual consumption estimates for the target segment so that they are scaled properly for the new applications. This framework provides a means for developing load shapes in different regions, maintaining ratios from the original study population that apply, and modifying ratios that are more applicable to the target population.

   The load hour calibration process is based on four key sets of ratios:

   1. Proportion of annual consumption of a given end use for each month[2]
   2. Ratio of peak day to average weekday consumption for each month
   3. Ratio of weekend day to average weekday daily consumption for each month
   4. Proportion of daily consumption per given hour by day type (peak day, average weekday, average weekend day) by month.

[2] Space conditioning end uses used heating and cooling degree-days specific to the regions of this study to determine the monthly consumption ratios.

To illustrate the application of the load shape library ratios, suppose we know a customer has an end use that consumes 1,000 kWh of electricity on an annual basis, and we wish to estimate the hourly load at 3 p.m. on a peak July weekday, and suppose the four sets of ratios are as follows:

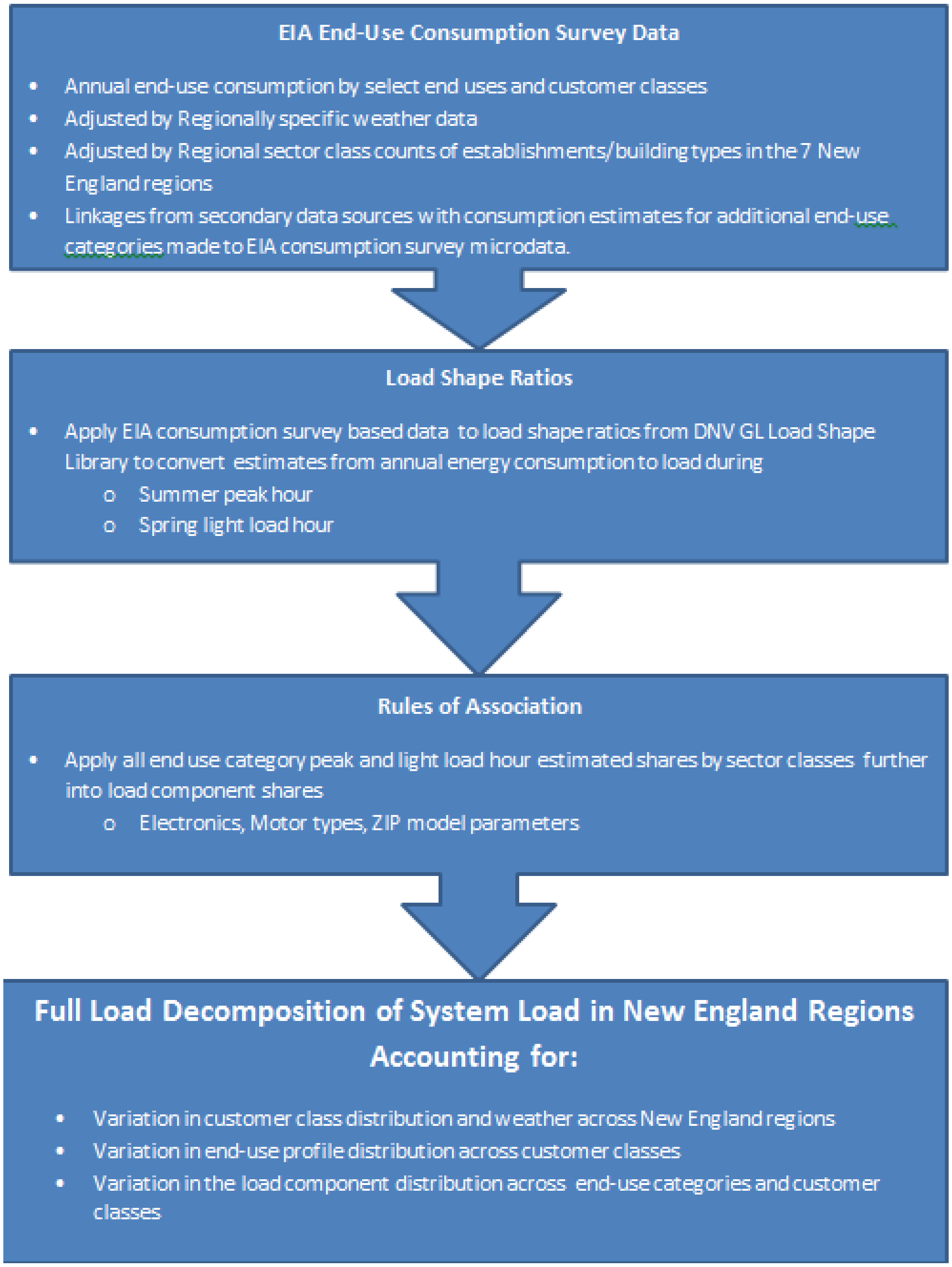
- Monthly ratio for July: 0.1, i.e. 10% of annual consumption occurs in July for this end use
- Peak day ratio: 1.4, i.e. on the peak weekday of July, consumption is 1.4 times that of an average weekday in July.
- Weekend to weekday ratio: 0.8, i.e. on average, consumption during July weekends is 80% of that on July weekdays.
- Ratio for 3 p.m. on a July peak weekday: 0.08, i.e. for this end use, 8% of the daily consumption occurs in the hour ending at 3 p.m.

The calculation is then as follows:

$$Expected\ kWh\ at\ 3\ p.m.\ on\ a\ July\ peak\ weekday =$$
$$1{,}000 kWh\ per\ year\ \times 0.1\ \frac{kWh\ July}{kWh\ per\ Year} \times \frac{1}{(31\ days\ (\frac{5}{7})+31\ days\left(\frac{2}{7}\right)(0.8)}\frac{kWh\ on\ ave.weekday}{kWh\ July} \times 1.4\ \frac{kWh\ on\ peak\ weekday}{kWh\ on\ average\ weekday} \times$$
$$.08\frac{kWh\ at\ 3PM}{kWh\ on\ peak\ weekday}$$

The following flow chart summarizes the analysis process that is common across the residential, commercial, and industrial sectors. Sections 3.1, 3.2, and 3.3 provide details of this process for the individual sector analyses.

Figure 3-1 Load Decomposition Analysis Process Used in this Study



The following sections describe the methodologies specific to the residential, commercial, and industrial sectors, including descriptions of the sector-specific data sources.

3.1 Residential End-Use Load Model

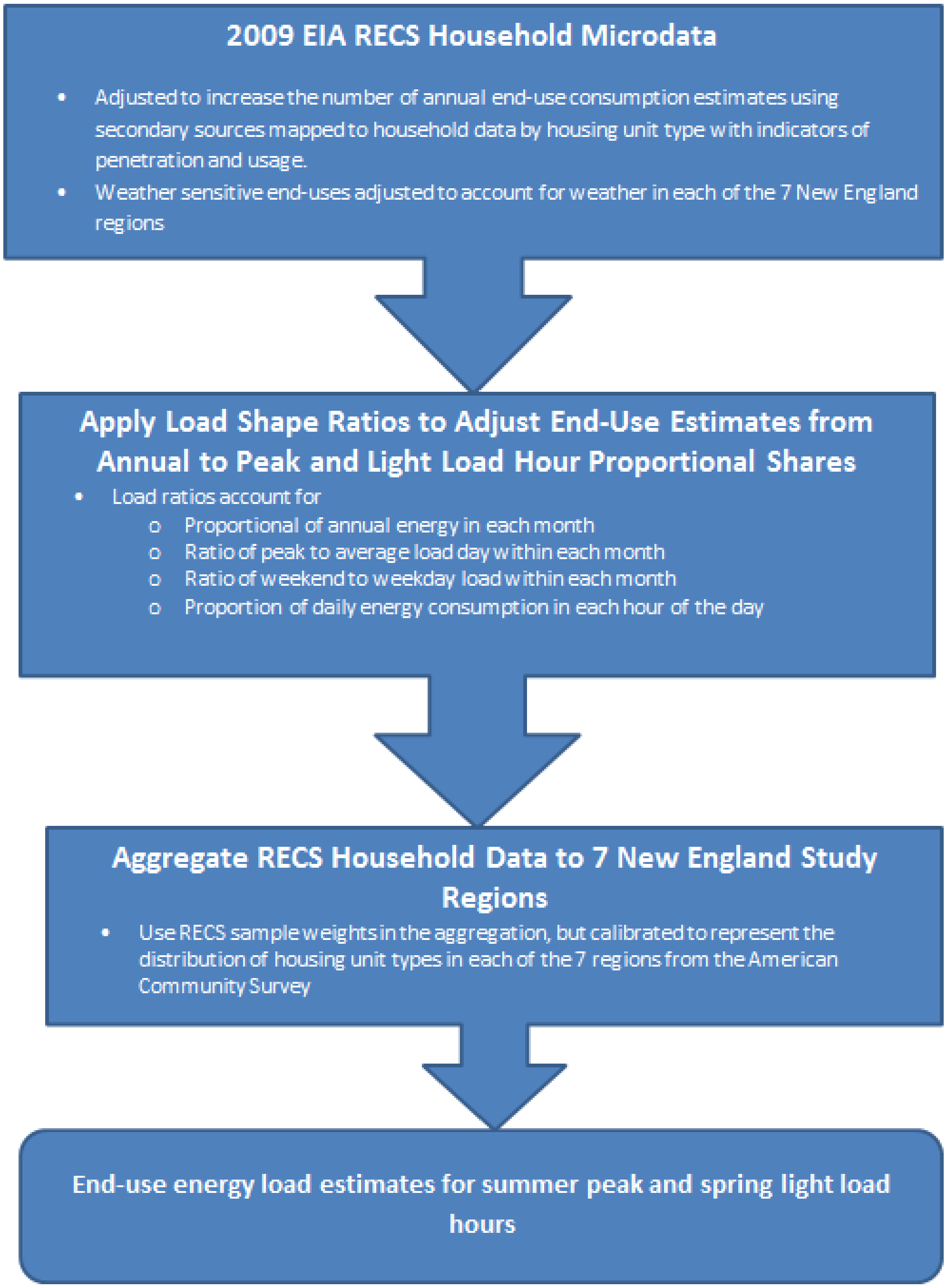
In this analysis, the residential sector consists of three segments: single-family homes, multi-family homes and mobile homes. The base penetrations of different electrical end uses found in residential homes in the seven regions come from EIA's Residential Energy Consumption Survey (RECS). The RECS accounts for primary residences and does not include secondary homes, vacant units, military barracks, or common areas in apartment buildings. This analysis does, however, account for vacant and seasonal use dwellings through its calibration of RECS-based end-use consumption estimates with American Community Survey - based housing unit count estimates specific to the seven New England sub-regions in this study.

The electrical end-use load categories that were accounted for in the residential sector analysis of this study were:

- Space heating
- Water heating
- Space cooling
  - Single phase
  - Split phase
  - Three phase
- Lighting
  - CFL/Linear Fluorescent
  - Lighting – Incandescent
  - Lighting – Other
- Televisions
  - CRT TVs
  - Other TVs
- Set-top/cable boxes/DVR
- All other electronics
- Refrigerators/Freezers
- Range/Oven
- Dishwashers
- Clothes Washers
- Clothes Dryers
- Ceiling Fans
- Pool Pumps
- Well Pumps
- All other residential end uses

The following flow chart depicts the analysis process used in the residential sector for producing the load decomposition by end-use category and region.

Figure 3-2 Flow chart of residential sector end-use load estimation process



3.1.1 Data Sources

Residential Energy Consumption Survey (RECS)

The RECS collects household characteristics and usage patterns from a nationally representative sample of housing units using specially trained interviewers.[3] This information is combined with data from energy

[3] RECS home page: http://www.eia.gov/consumption/residential/

suppliers to these homes to estimate energy costs and usage for heating, cooling, select appliances, and other end uses. The 2009 survey collected data from 12,083 households in housing units statistically selected to represent the 113.6 million U.S. housing units that are occupied as a primary residence, and includes reportable domains of Massachusetts and the group of remaining states in New England.

The 2009 RECS was the core data source for the residential end-use shares for annual electricity consumption.

Usage: The 2009 RECS microdata was the backbone of the residential end-use load model. Estimates from the 2009 RECS included annual consumption estimates for water heating and refrigeration, space heating per heating degree day estimates, space cooling per cooling degree day estimates, and penetration estimates for clothes dryers, clothes washers, dishwashers, freezers, well pumps, pool pumps, ceiling fans and various electronics.

2009 California Residential Appliance Saturation Study (CA RASS)

The California Energy Commission sponsored a Residential Appliance Saturation Study in 2009.[4] KEMA was the prime consultant. The study surveyed the following utilities: Pacific Gas and Electric Company, Southern California Edison, San Diego Gas and Electric Company, Southern California Gas Company, and Los Angeles Department of Water and Power. The survey collected data regarding the saturation and usage of appliances and electrical equipment and household energy consumption behaviors. The RASS data products include energy consumption estimates and saturation estimates by utility, climate zone, dwelling type, age group and income, as well as estimates of annual consumption for a limited number of electrical end-use categories.

Usage: This report's analysis incorporates the annual unit energy consumption estimates for clothes dryers, clothes washers, dishwashers, freezers and well pumps.

Efficiency Vermont 2013 Technical Reference User Manual (Vermont TRM)

In 2012 Efficiency Vermont published a Technical Reference User Manual, which documents the methods, formulas and default assumptions that Efficiency Vermont's energy efficiency programs uses in its impact estimates.[5] Data come from Vermont data when available; when not available, data come from nearby regions, such as New England or other states in the Northeast, or from engineering calculations.

Usage: The unit energy consumption estimates for pool pumps were used in this analysis, the data came from the Consortium for Energy Efficiency and Vermont level assumptions on average days of use per year. The Vermont TRM reported an average daily consumption of a single-speed pool pump, a two-speed pool pump, and a variable speed pool pump.

Assessment of Energy-Efficiency and Distributed Generation Baseline Opportunities

Efficiency Maine Trust contracted The Cadmus Group to assess the energy-efficiency and distributed generation resources for Maine's residential, commercial and industrial sectors for the 2012 to 2021 period.[6] Field visits collected data on building characteristics and electric equipment saturation to establish a baseline. Data collected from the surveys allowed adjustment of assessments to current market conditions, especially in terms of saturations of electric equipment, specifically energy-efficient equipment.

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4 Report location: http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF

5 Report location: http://www.greenmountainpower.com/upload/photos/371TRM_User_Manual_No_2013-82-5-protected.pdf

6 Report location: http://www.efficiencymaine.com/docs/Cadmus-Baseline-Opps.pdf

Usage: This report gave an estimate of 20% penetration of multi-speed pool pumps; this 20% estimate combined with the UECS from the Vermont TRM led to the average annual energy consumption of a single pool pump.

Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential

The Department of Energy contract TIAX to characterize residential Miscellaneous Electronic Loads including unit level, household level and annual level electricity consumption.[7] The study used mostly engineering estimates to come up with UECs and research to find residential saturation of these miscellaneous electric appliances.

Usage: This report's estimate on ceiling fan consumption in New England was used in the residential end-use analysis.

Energy Consumption of Consumer Electronics in U.S. Homes in 2010

Report prepared by Fraunhofer Center for Sustainable Energy Systems for the Consumer Electronics Association (CEA). This study was commissioned to determine the energy usage of mainstream consumer electronics in 2010. Unit electricity consumption (UEC) estimates were produced using the power draw of the electronic devices and the hours of annual use.

Usage: Hours of use in different operating modes (on, off, standby) were combined with load estimates at each setting in the production of the UECs. DNV GL's electronics' end-uses leverage UECs for the following household electronics: digital/analogue converter boxes, set top boxes, LED TVs, other TVs (used when TV type not identified), and other PCs and monitors.

Final Field Research Report

This report summarizes the field measurements of the energy consumption of consumer electronics in the state of California and was prepared by ECOS Consulting and RLW Analytics.[8] The study collected data of various plug loads in California households and analysed the results of the field data collection to provide annual energy use estimates for many common household electronics.

Usage: DNV GL's electronics end-use estimate leveraged UECs for the following household electronics from this report: cable boxes, satellite boxes, DVR, game consoles, combo DVD/VCR, DVD players, VCRs, home theatre/speakers/audio, CRT TVs, LCD TVs, plasma TVs, projection TVs, desktop PCs, laptop PCs, CRT computer monitors, LCD computer monitors, wireless routers, printers, fax machines, copiers, cordless phones, power tools and stereos.

Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates

This 2012 report was published by the Department of Energy and prepared by DNV KEMA Energy and Sustainability (now DNV GL).[9] The aim of the study was to estimate national and regional lighting usage measures and consumption within U.S. households. These estimates were built using a "bottom up" approach using hours of use, household categorical cross-classifications, and lamp level characteristics.

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[7] Report location: http://iepec.org/confdocs/evaluator_resources/TIAX_MiscElecLoadsReportToDOE.pdf

[8] Report location: http://www.efficientproducts.org/documents/Plug_Loads_CA_Field_Research_Report_Ecos_2006.pdf

[9] Residential lighting study home page: http://www1.eere.energy.gov/buildings/ssl/residential-lighting-study.html

Usage: DNV GL linked the annual lighting consumption estimates to the RECS respondents to account for lighting consumption by residential households.

3.1.2 End-Use Shares of Annual Energy Consumption

The DNV GL approach for producing estimated end-use shares of annual energy consumption for residential buildings was to leverage end-use consumption estimates from the RECS, and link RECS building-level characteristics and consumption data to secondary data sources containing unit energy consumption for end-use categories not covered by the RECS. Through the linkage process, the list of end-use consumption estimates linked to RECS buildings, either directly or indirectly, expanded towards the desired list of end uses to account for in the analysis. This linkage process has the effect of shrinking the share of the “All other” residential end uses, comprising the balance of annual consumption which the direct end-use estimates from RECS do not account for.

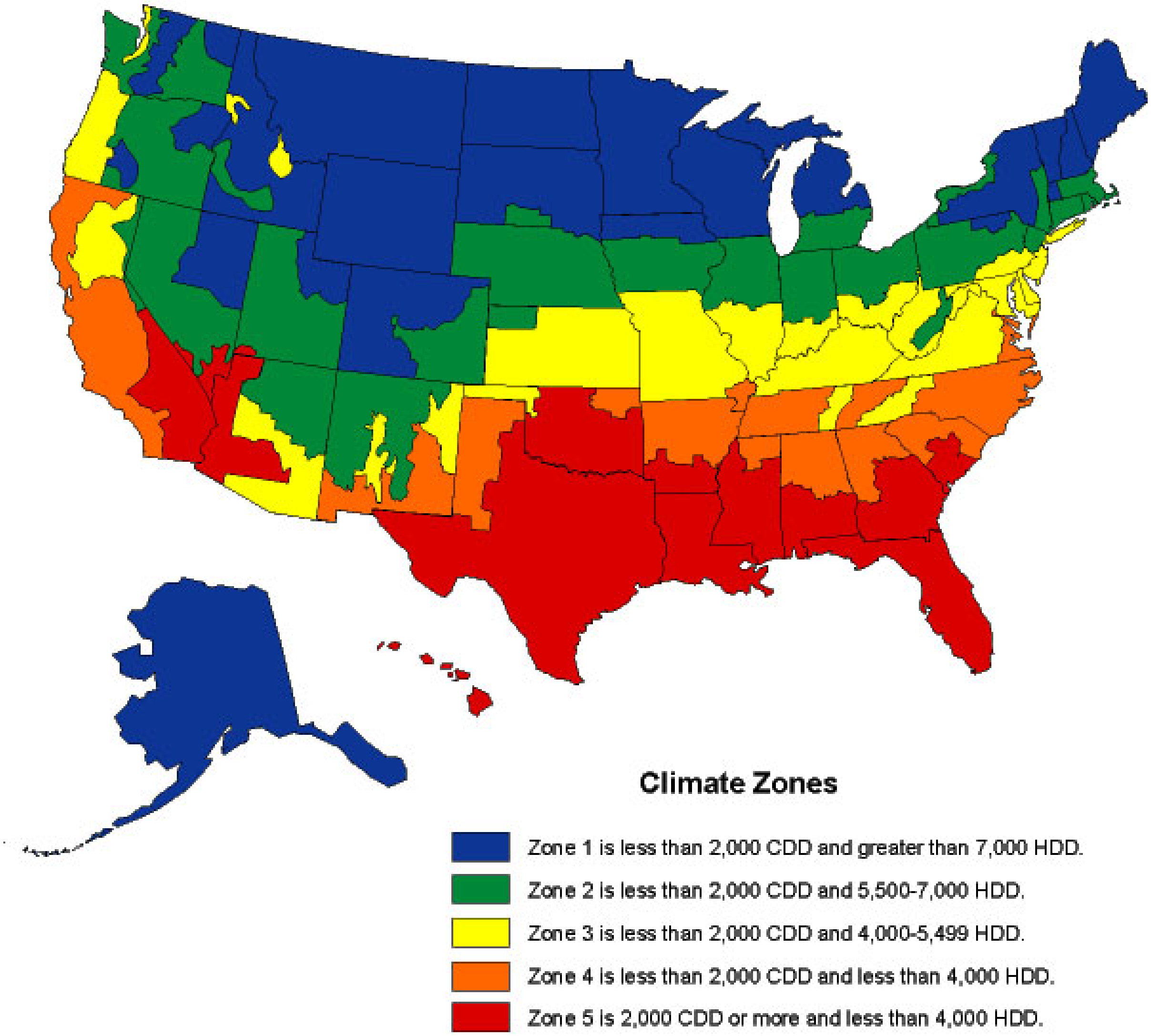
The 2009 RECS microdata file contains several identifiers related directly or indirectly to geography. The following survey variables were used in this analysis:

- Reportable domain
- AIA Climate zone

EIA developed five distinct climate zones for RECS based on seven climate categories previously defined by the American Institute of Architects (AIA) for DOE. The zones are based on the 30 year average of heating degree and cooling degree-days (base 65 degrees Fahrenheit).[10] Figure 3-3 below shows the AIA zonal boundaries, creating a partition of the U.S. Degree-day averages from 1980-2010 were used to create the zones.

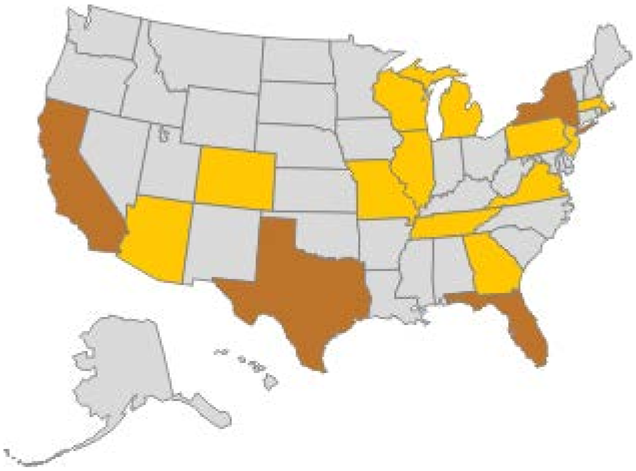
[10] AIA zone definition: http://www.eia.gov/consumption/residential/terminology.cfm#c

Figure 3-3 AIA climate zones for the RECS



The reportable domain variable is a subdivision of census divisions. New England is the census division that is most geographically specific to the seven regions of this study. The reportable domain variable divides the New England states into two sub-regions: Massachusetts and the other New England States (Connecticut, Maine, New Hampshire, Rhode Island and Vermont). The following figure indicates the 2009 RECS reportable domains consisting of individual states.

Figure 3-4 2009 RECS reportable domains consisting of individual states



This analysis further divided the latter reportable domain into two using AIA climate zones with the goal of using the finest level of geographic specificity in the RECS data to the seven regions of interest to this study. Climate zone 1 (Less than 2,000 CDD and greater than 7,000 HDD) was considered to be New Hampshire, Maine and Vermont, and climate zones 2 & 3 (Less than 2,000 CDD and 5,500 - 7,000 HDD; Less than 2,000 CDD and 4,000 - 5,499 HDD) were considered to be made up of Connecticut and Rhode Island. This interaction between reportable domain and climate zone was not applied to Massachusetts.

DNV GL aggregated the RECS building-level microdata with identifiers for the New England reportable domains crossed with climate zone so that the end-use shares reflected the RECS households as geographically specific to the seven regions of interest as possible.

The following end-use categories had direct estimates of annual consumption given in the 2009 RECS microdata:

- Space cooling
- Space heating
- Refrigeration
- Water heating
- All other residential end uses

For space cooling, the desired level of estimation was for the type of unit – three phase, split phase, or single phase, so the space cooling end-use category was subdivided by mapping cooling equipment types listed for each household respondent in the 2009 RECS to a specific phase classification. While the RECS survey collected several space cooling characteristics for each unit in the homes, phase type was not explicitly captured. We developed a classification system based on system type (Central, Window/Wall), building type (Apartment with five or more units) and whether the cooling system cools other homes, businesses or farms. If a central air conditioning system was in an apartment with five or more units and the central air conditioner cools other homes, businesses or farms then we considered it a 460 V/Three Phase system. If a central air conditioning system was not in an apartment with five or more units or it did not cool other homes, businesses or a farm then we assigned it 240 V/Split Phase. Finally, all window/wall unit systems were assigned 115-120 V/Single Phase.

Ten residential end-use categories were not available directly from the 2009 RECS, so DNV GL sought appropriate secondary sources for these end-use consumption estimates. The data sources and approaches were different for each of these end uses and are described below.

Six of the residential end-use category estimates leveraged unit energy consumption (UEC) estimates from the California RASS: electric clothes dryers, clothes washers, dishwashers, freezers, electric ranges/ovens, and well pumps. The California RASS provided UEC estimates for each of these by household type categories:[11]

- Single-family detached homes
- Single -family attached homes
- 2 to 4 unit apartments
- 5 or more unit apartments
- Mobile homes

For each of the six end-uses, RECS households that reported having that end-use were assigned the associated consumption estimate per housing unit type. For example, a single family household that reported having an electric range was assigned an annual energy consumption of 310 kWh per year for the electric range end-use.

Ceiling Fans

The approach for estimating ceiling fan electricity consumption used 2009 RECS household penetration of ceiling fans with a UEC estimate for ceiling fans of 20kWh/year from TIAX LLC (Residential Miscellaneous Electric Loads Study). So a household that used one ceiling fan would have an estimated annual consumption of 20 kWh for ceiling fans, while one using 5 fans would have an estimated annual consumption of 100 kWh.

Pool Pumps

The 2013 Vermont Technical Reference Manual provided three UEC estimates: one for single speed pumps (22.3 kWh per day), one for two speed pumps (6.9 kWh per day), and one for variable speed pumps (2.6 kWh per day). The report also provided an average regional use of 107 days per year. While RECS household characteristics survey data provided indicators whether a household had a pool, there was no indication to what speed the pool pump might be. Efficiency Trust Maine's "Assessment of Energy-Efficiency and Distributed Generation Baseline and Opportunities" estimated that 20% of households already have multi-speed pool pumps, which DNV GL assumed to be split equally between two-speed and variable speed pool pumps. Based on this estimate, an annual UEC for households with pools was developed: .8(22.3*107) + .1(6.9*107) + .1(2.6*107) = 2,010.5 kWh per pool per year. This estimate was applied uniformly to RECS single family homes which indicated that they owned an onsite pool with a filtration system.

Lighting

The lighting consumption estimates were derived from the DOE Residential End-Use Lighting Consumption Study, which provided annual energy consumption estimates for three lamp types: CFLs, Incandescents and other. Other lamp types are defined as any residential interior light that is not a CFL or incandescent, such as an LED lamp. The study's data tool provides estimates down to the reportable domain level and other

[11] For clothes washers, DNV GL decided to use the single-family detached UEC for all household types based on industry knowledge of the UECs.

factors. In this analysis, we assigned the lighting study estimate of annual kWh by reportable domain, lamp type, and housing unit type (single family, multi-family, mobile home) to the RECS households.

Electronics

The DNV GL strategy for estimating the annual electricity consumption of electronics was to use household-level equipment saturations from the household-level 2009 RECS microdata and multiply them by annual UEC estimates found in industry study reports. Unit energy consumption values for electronic devices were obtained from “Energy Consumption of Consumer Electronics in U.S. Homes in 2010” prepared for the Consumer Electronics Association and “Final Field Research Report” prepared by ECOS Consulting and RLW Analytics for the California Energy Commission (CEC) in 2006.

Televisions

RECS recorded the total number of televisions in the home along with the type of TV for the three most commonly used. TVs were classified as CRT, LCD, plasma, projection, or LED. The UEC values for TVs from the 2006 CEC report were used for TVs with a specific technology listed. For all TVs beyond the first three, for which the RECS did not list the specific technology, the UECs for the general TV category from the CEA report were used. DNV GL divided televisions into two end-uses: CRT TVs and all other TVs.

Personal Computers

The approach for televisions was applied for personal computers as well. The type of computer (desktop or laptop) was recorded by RECS for the first three computers, as were the monitor types. The monitors were classified as either CRT or LCD. For each computer and monitor in the first three, the UECs for the listed technology were applied from the 2006 CEC study report to the RECS saturation indicators. For PCs and monitors beyond the first three, the general-category UECs from the 2010 CEA study report was applied. Personal computers were incorporated into ‘other electronics’ as an end-use.

Other Electronics

Consumption values were found for all electronics recorded in the RECS with the exception of stand-alone answering machines. All unit energy consumption values came from the 2006 CEC report unless noted above. Several electronic items were recorded in the RECS, but not done in a manner which directly translated to household saturation. The count of power tools was determined in the RECS to be either 0,1-3,4-8, or 8+. The median of the ranged responses were used to calculate the saturation and a value of nine was used in the uncapped maximum category. The following items were recorded as either present or not present by the RECS, but the binary response did not give direct saturation: fax machines, copiers, cordless phones, and stereo systems. For these items, it was determined that the likelihood of a household having multiples of the same device were minimal. The binary yes/no categories from the RECS were used as saturation estimates. Consumption values for these end uses, like the others, were determined by combining the saturation values with the reported yearly UECs in the 2006 CEC Consulting report.

Table 3-2 below summarizes the unit energy consumption estimates used in the residential electronics analysis. The four categories (CRT TVs; all other TVs; Set top boxes, digital convertors, DVR; and all other electronics) show which electronic devices went into the four specific electronic-related end-uses.

Table 3-2 Electronics unit energy consumption estimates used in the residential end-use analysis

Electronic Device	Annual Unit Energy Consumption (UECs)	Source
CRT TVs		
CRT TV	123	Final Field Research Report
All Other TVs		
LCD TV	77	Final Field Research Report
LED TV	183	Energy Consumption of Consumer Electronics in U.S. Homes in 2010
Plasma TV	441	Final Field Research Report
Projection TV	447	Final Field Research Report
Other TV (Used when TV type unknown)	183	Energy Consumption of Consumer Electronics in U.S. Homes in 2010
Set top boxes, Digital converters, DVR		
Cable Box	239	Final Field Research Report
Digital/Analogue Converter Box	239	Energy Consumption of Consumer Electronics in U.S. Homes in 2010
DVR	363	Final Field Research Report
Satellite Box	124	Final Field Research Report
Set Top Box	239	Energy Consumption of Consumer Electronics in U.S. Homes in 2010
All Other Electronics		
Combo DVD/VCR	23	Final Field Research Report
DVD Player	13	Final Field Research Report
VCR	34	Final Field Research Report
Copier	11	Final Field Research Report
Cordless Phone	22	Final Field Research Report
Fax Machine	26	Final Field Research Report
Game Console	16	Final Field Research Report
Home theatre/speakers/audio	126	Final Field Research Report
Monitor - CRT Computer	82	Final Field Research Report
Monitor - LCD Computer	70	Final Field Research Report
PC – Desktop	225	Final Field Research Report
PC – Laptop	83	Final Field Research Report
PC and Monitor – Other (Used when computer and/or monitor type unknown)	131	Energy Consumption of Consumer Electronics in U.S. Homes in 2010
Power Tools	37	Final Field Research Report
Printer	15	Final Field Research Report
Stereo	58	Final Field Research Report
Wireless Router	48	Final Field Research Report

Reducing the ‘All Other’ Residential End Uses Category

Once the indirect estimates were calculated and added to the RECS household microdata, the “all other” end-use category from the RECS data file had to be reduced accordingly so that the total household consumption remained constant. For example, if a RECS single-family household had an electric range and a clothes washer, it would receive an estimate of 121 kWh for the clothes washer and 310 kWh for the range. Since these were previously accounted for in the ‘all other’ category, this would now need to be reduced by 431 kWh so that the total annual consumption at the household level would remain constant. Since it is possible that the sum of the secondary source end-use kWh estimates exceeds the 2009 RECS “All Other” kWh (since the secondary source estimates are for population averages rather than individual households), we use the following rule:

If $EU\ kWh_{secondary} > EU\ kWH_{Other}$

Then set:

$$EU\ kWh_{i,Calibrated} = EU\ kWh_i \times \frac{EU\ kWh_{Other}}{EU\ kWH_{Secondary}}$$

Otherwise

$$EU\ kWh_{i,Calibrated} = EU\ kWh_i$$

The following equation will then hold in all cases:

$$EU\ kWh_{Other} = EU\ kWh_{i,Calibrated} + EU\ kWh_{Balance}$$

After the calibration, the “all other residential end uses” still accounts for about 19% of the residential electric energy consumption annually. A report conducted for DOE, “Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential”, broke down the large energy consuming end uses accounted for in the “other” category.[12] Many of these high energy users, such as TVs and PCs have already been incorporated into the model in this analysis. However, other household appliances, such as kitchen appliances (microwave, coffee machine, toaster, etc.), bathroom appliances (hair dryers), and other miscellaneous items, such as aquariums, clothes irons, vacuum cleaners, and wine coolers are not accounted for in this study. This study also does not account for the recent rise in tablets and related plug-load devices, which were not addressed in the 2009 RECS. It should also be noted that the RECS end use estimates are based on a conditional demand analysis regression model, which has to date never been calibrated to end-use metering data – it is solely based on the statistical relationships between household characteristics, energy consumption from billing data, and weather data. DNV GL recommends that future RECS should include this calibration using onsite inventory and end-use metering data for a subsample of RECS households.

Overall annual consumption by end use

These data transformations resulted in estimates of annual energy consumption by household type and region. Table 3-3 below summarizes the average number of units per household and unit energy consumption estimates by region and housing unit type for all the non-space conditioning end uses. Note that through the reduction process for the “all other” category described above, some households will have reduced UEC values to prevent the “all other” category electricity consumption from being negative. Because of this, the UEC values below vary by customer group. For example, the starting UEC for ceiling fans is 20 kWh per unit per year but the final UEC for Connecticut and Rhode Island homes was either 18 or 19 kWh per unit per year, depending on dwelling type.

[12] http://iepec.org/conf-docs/evaluator_resources/TIAX_MiscElecLoadsReportToDOE.pdf

Table 3-3 Number of units per establishment and unit energy consumption by region, dwelling type and end use

Region	Dwelling Type	End Use	Number of Units per Household	Unit Energy Consumption (kWh/year)
Connecticut, Rhode Island	Multi-Family	All Other	1.00	948
Connecticut, Rhode Island	Mobile Home	All Other	1.00	1,286
Connecticut, Rhode Island	Single-Family	All Other	1.00	2,088
Connecticut, Rhode Island	Multi-Family	All Other Electronics	1.00	310
Connecticut, Rhode Island	Mobile Home	All Other Electronics	1.00	420
Connecticut, Rhode Island	Single-Family	All Other Electronics	1.00	584
Connecticut, Rhode Island	Multi-Family	Ceiling Fans	0.72	19
Connecticut, Rhode Island	Mobile Home	Ceiling Fans	0.95	19
Connecticut, Rhode Island	Single-Family	Ceiling Fans	2.12	18
Connecticut, Rhode Island	Multi-Family	CFLs	1.00	93
Connecticut, Rhode Island	Mobile Home	CFLs	1.00	98
Connecticut, Rhode Island	Single-Family	CFLs	1.00	192
Connecticut, Rhode Island	Multi-Family	Clothes Dryers	0.25	468
Connecticut, Rhode Island	Mobile Home	Clothes Dryers	0.81	476
Connecticut, Rhode Island	Single-Family	Clothes Dryers	0.83	643
Connecticut, Rhode Island	Multi-Family	Clothes Washers	0.33	113
Connecticut, Rhode Island	Mobile Home	Clothes Washers	1.00	110
Connecticut, Rhode Island	Single-Family	Clothes Washers	0.94	111
Connecticut, Rhode Island	Multi-Family	CRT TVs	1.26	112
Connecticut, Rhode Island	Mobile Home	CRT TVs	1.08	120
Connecticut, Rhode Island	Single-Family	CRT TVs	1.36	111
Connecticut, Rhode Island	Multi-Family	Dishwashers	0.31	51
Connecticut, Rhode Island	Mobile Home	Dishwashers	0.00	.
Connecticut, Rhode Island	Single-Family	Dishwashers	0.72	76
Connecticut, Rhode Island	Multi-Family	Incandescents	1.00	384

Region	Dwelling Type	End Use	Number of Units per Household	Unit Energy Consumption (kWh/year)
Connecticut, Rhode Island	Mobile Home	Incandescents	1.00	589
Connecticut, Rhode Island	Single-Family	Incandescents	1.00	1,053
Connecticut, Rhode Island	Multi-Family	Other Lighting	1.00	142
Connecticut, Rhode Island	Mobile Home	Other Lighting	1.00	515
Connecticut, Rhode Island	Single-Family	Other Lighting	1.00	544
Connecticut, Rhode Island	Multi-Family	Other TVs	0.68	120
Connecticut, Rhode Island	Mobile Home	Other TVs	0.99	125
Connecticut, Rhode Island	Single-Family	Other TVs	1.61	139
Connecticut, Rhode Island	Multi-Family	Pool Pumps	0.00	.
Connecticut, Rhode Island	Mobile Home	Pool Pumps	0.00	.
Connecticut, Rhode Island	Single-Family	Pool Pumps	0.10	1,978
Connecticut, Rhode Island	Multi-Family	Range/Oven	0.66	171
Connecticut, Rhode Island	Mobile Home	Range/Oven	1.00	205
Connecticut, Rhode Island	Single-Family	Range/Oven	0.70	272
Connecticut, Rhode Island	Multi-Family	Refrigerators/Freezers	1.08	840
Connecticut, Rhode Island	Mobile Home	Refrigerators/Freezers	1.27	671
Connecticut, Rhode Island	Single-Family	Refrigerators/Freezers	1.68	881
Connecticut, Rhode Island	Multi-Family	Settop/cable box, digital, DVR	0.80	480
Connecticut, Rhode Island	Mobile Home	Settop/cable box, digital, DVR	0.87	464
Connecticut, Rhode Island	Single-Family	Settop/cable box, digital, DVR	0.93	688
Connecticut, Rhode Island	Multi-Family	Water Heating	0.26	2,121
Connecticut, Rhode Island	Mobile Home	Water Heating	1.00	2,528
Connecticut, Rhode Island	Single-Family	Water Heating	0.27	2,424
Connecticut, Rhode Island	Multi-Family	Well Pumps	0.00	.
Connecticut, Rhode Island	Mobile Home	Well Pumps	0.14	447
Connecticut, Rhode Island	Single-Family	Well Pumps	0.35	514
Maine, New Hampshire, Vermont	Multi-Family	All Other	1.00	448
Maine, New Hampshire, Vermont	Mobile Home	All Other	1.00	934

Region	Dwelling Type	End Use	Number of Units per Household	Unit Energy Consumption (kWh/year)
Maine, New Hampshire, Vermont	Single-Family	All Other	1.00	1,886
Maine, New Hampshire, Vermont	Multi-Family	All Other Electronics	1.00	288
Maine, New Hampshire, Vermont	Mobile Home	All Other Electronics	1.00	368
Maine, New Hampshire, Vermont	Single-Family	All Other Electronics	1.00	587
Maine, New Hampshire, Vermont	Multi-Family	Ceiling Fans	0.21	20
Maine, New Hampshire, Vermont	Mobile Home	Ceiling Fans	0.65	20
Maine, New Hampshire, Vermont	Single-Family	Ceiling Fans	1.87	19
Maine, New Hampshire, Vermont	Multi-Family	CFLs	1.00	87
Maine, New Hampshire, Vermont	Mobile Home	CFLs	1.00	107
Maine, New Hampshire, Vermont	Single-Family	CFLs	1.00	194
Maine, New Hampshire, Vermont	Multi-Family	Clothes Dryers	0.27	459
Maine, New Hampshire, Vermont	Mobile Home	Clothes Dryers	1.00	489
Maine, New Hampshire, Vermont	Single-Family	Clothes Dryers	0.94	664
Maine, New Hampshire, Vermont	Multi-Family	Clothes Washers	0.30	111
Maine, New Hampshire, Vermont	Mobile Home	Clothes Washers	1.00	121
Maine, New Hampshire, Vermont	Single-Family	Clothes Washers	1.00	111
Maine, New Hampshire, Vermont	Multi-Family	CRT TVs	1.14	111
Maine, New Hampshire, Vermont	Mobile Home	CRT TVs	0.98	123
Maine, New Hampshire, Vermont	Single-Family	CRT TVs	1.32	114
Maine, New Hampshire, Vermont	Multi-Family	Dishwashers	0.17	50
Maine, New Hampshire, Vermont	Mobile Home	Dishwashers	0.00	.
Maine, New Hampshire, Vermont	Single-Family	Dishwashers	0.71	79
Maine, New Hampshire, Vermont	Multi-Family	Incandescents	1.00	361
Maine, New Hampshire, Vermont	Mobile Home	Incandescents	1.00	645
Maine, New Hampshire, Vermont	Single-Family	Incandescents	1.00	1,062
Maine, New Hampshire, Vermont	Multi-Family	Other Lighting	1.00	134
Maine, New Hampshire, Vermont	Mobile Home	Other Lighting	1.00	564
Maine, New Hampshire, Vermont	Single-Family	Other Lighting	1.00	549

Region	Dwelling Type	End Use	Number of Units per Household	Unit Energy Consumption (kWh/year)
Maine, New Hampshire, Vermont	Multi-Family	Other TVs	0.27	71
Maine, New Hampshire, Vermont	Mobile Home	Other TVs	0.67	77
Maine, New Hampshire, Vermont	Single-Family	Other TVs	1.27	146
Maine, New Hampshire, Vermont	Multi-Family	Pool Pumps	0.00	.
Maine, New Hampshire, Vermont	Mobile Home	Pool Pumps	0.00	.
Maine, New Hampshire, Vermont	Single-Family	Pool Pumps	0.09	1,884
Maine, New Hampshire, Vermont	Multi-Family	Range/Oven	0.93	164
Maine, New Hampshire, Vermont	Mobile Home	Range/Oven	0.33	224
Maine, New Hampshire, Vermont	Single-Family	Range/Oven	0.85	280
Maine, New Hampshire, Vermont	Multi-Family	Refrigerators/Freezers	1.09	782
Maine, New Hampshire, Vermont	Mobile Home	Refrigerators/Freezers	1.00	498
Maine, New Hampshire, Vermont	Single-Family	Refrigerators/Freezers	1.69	895
Maine, New Hampshire, Vermont	Multi-Family	Settop/cable box, digital, DVR	0.77	479
Maine, New Hampshire, Vermont	Mobile Home	Settop/cable box, digital, DVR	1.00	409
Maine, New Hampshire, Vermont	Single-Family	Settop/cable box, digital, DVR	0.93	540
Maine, New Hampshire, Vermont	Multi-Family	Water Heating	0.16	1,849
Maine, New Hampshire, Vermont	Mobile Home	Water Heating	1.00	2,292
Maine, New Hampshire, Vermont	Single-Family	Water Heating	0.32	2,437
Maine, New Hampshire, Vermont	Multi-Family	Well Pumps	0.00	.
Maine, New Hampshire, Vermont	Mobile Home	Well Pumps	0.33	447
Maine, New Hampshire, Vermont	Single-Family	Well Pumps	0.45	525
Massachusetts	Multi-Family	All Other	1.00	876
Massachusetts	Mobile Home	All Other	1.00	794
Massachusetts	Single-Family	All Other	1.00	1,886
Massachusetts	Multi-Family	All Other Electronics	1.00	295
Massachusetts	Mobile Home	All Other Electronics	1.00	310
Massachusetts	Single-Family	All Other Electronics	1.00	564
Massachusetts	Multi-Family	Ceiling Fans	0.87	18

Region	Dwelling Type	End Use	Number of Units per Household	Unit Energy Consumption (kWh/year)
Massachusetts	Mobile Home	Ceiling Fans	0.76	19
Massachusetts	Single-Family	Ceiling Fans	1.70	18
Massachusetts	Multi-Family	CFLs	1.00	68
Massachusetts	Mobile Home	CFLs	1.00	91
Massachusetts	Single-Family	CFLs	1.00	200
Massachusetts	Multi-Family	Clothes Dryers	0.34	449
Massachusetts	Mobile Home	Clothes Dryers	0.41	454
Massachusetts	Single-Family	Clothes Dryers	0.75	628
Massachusetts	Multi-Family	Clothes Washers	0.41	110
Massachusetts	Mobile Home	Clothes Washers	0.60	115
Massachusetts	Single-Family	Clothes Washers	0.97	109
Massachusetts	Multi-Family	CRT TVs	1.09	111
Massachusetts	Mobile Home	CRT TVs	0.95	111
Massachusetts	Single-Family	CRT TVs	1.31	111
Massachusetts	Multi-Family	Dishwashers	0.37	48
Massachusetts	Mobile Home	Dishwashers	0.42	48
Massachusetts	Single-Family	Dishwashers	0.73	76
Massachusetts	Multi-Family	Incandescents	1.00	350
Massachusetts	Mobile Home	Incandescents	1.00	523
Massachusetts	Single-Family	Incandescents	1.00	963
Massachusetts	Multi-Family	Other Lighting	1.00	49
Massachusetts	Mobile Home	Other Lighting	1.00	296
Massachusetts	Single-Family	Other Lighting	1.00	531
Massachusetts	Multi-Family	Other TVs	0.77	112
Massachusetts	Mobile Home	Other TVs	0.69	75
Massachusetts	Single-Family	Other TVs	1.60	139
Massachusetts	Multi-Family	Pool Pumps	0.00	.
Massachusetts	Mobile Home	Pool Pumps	0.00	.

Region	Dwelling Type	End Use	Number of Units per Household	Unit Energy Consumption (kWh/year)
Massachusetts	Single-Family	Pool Pumps	0.13	1,868
Massachusetts	Multi-Family	Range/Oven	0.50	163
Massachusetts	Mobile Home	Range/Oven	0.53	218
Massachusetts	Single-Family	Range/Oven	0.61	279
Massachusetts	Multi-Family	Refrigerators/Freezers	1.16	777
Massachusetts	Mobile Home	Refrigerators/Freezers	1.13	881
Massachusetts	Single-Family	Refrigerators/Freezers	1.55	897
Massachusetts	Multi-Family	Set-top/cable box, digital, DVR	0.78	542
Massachusetts	Mobile Home	Set-top/cable box, digital, DVR	1.00	387
Massachusetts	Single-Family	Set-top/cable box, digital, DVR	0.93	658
Massachusetts	Multi-Family	Water Heating	0.24	1,867
Massachusetts	Mobile Home	Water Heating	0.45	1,484
Massachusetts	Single-Family	Water Heating	0.20	2,632
Massachusetts	Multi-Family	Well Pumps	0.00	.
Massachusetts	Mobile Home	Well Pumps	0.24	434
Massachusetts	Single-Family	Well Pumps	0.18	546

Table 3-4 shows the proportion of households with electric space conditioning (space heating and space cooling) as well as the average kWh usage per degree day. Note that the region categories represent the finest level of geography that can be deduced from the 2009 RECS, not the regions under study for this evaluation.

Table 3-4 Space Conditioning – Usage per degree day and proportion of households with electric space conditioning by region, dwelling type and end use

Region	Dwelling Type	End Use	Proportion of Households with Electric Space Conditioning	Annual Consumption Per Degree Day (kWh)
Connecticut, Rhode Island	Multi-Family	Space Heating	0.30	0.26
Connecticut, Rhode Island	Multi-Family	Space Cooling - Single Phase	0.63	0.45
Connecticut, Rhode Island	Multi-Family	Space Cooling – Split Phase	0.10	0.47

Region	Dwelling Type	End Use	Proportion of Households with Electric Space Conditioning	Annual Consumption Per Degree Day (kWh)
Connecticut, Rhode Island	Multi-Family	Space Cooling - Triple Phase	0	.
Massachusetts	Multi-Family	Space Heating	0.35	0.27
Massachusetts	Multi-Family	Space Cooling - Single Phase	0.61	0.37
Massachusetts	Multi-Family	Space Cooling - Triple Phase	0.02	0.39
Massachusetts	Multi-Family	Space Cooling – Split Phase	0.12	0.61
Maine, New Hampshire, Vermont	Multi-Family	Space Heating	0.38	0.22
Maine, New Hampshire, Vermont	Multi-Family	Space Cooling - Triple Phase	0.04	0.26
Maine, New Hampshire, Vermont	Multi-Family	Space Cooling - Single Phase	0.45	0.41
Maine, New Hampshire, Vermont	Multi-Family	Space Cooling – Split Phase	0	.
Connecticut, Rhode Island	Mobile Home	Space Heating	0.32	0.11
Connecticut, Rhode Island	Mobile Home	Space Cooling - Single Phase	0.19	0.18
Connecticut, Rhode Island	Mobile Home	Space Cooling – Split Phase	0.67	0.46
Connecticut, Rhode Island	Mobile Home	Space Cooling - Triple Phase	0	.
Massachusetts	Mobile Home	Space Cooling – Split Phase	0.09	0.19
Massachusetts	Mobile Home	Space Heating	0.09	0.21
Massachusetts	Mobile Home	Space Cooling - Single Phase	0.69	0.73
Massachusetts	Mobile Home	Space Cooling - Triple Phase	0	.
Maine, New Hampshire, Vermont	Mobile Home	Space Heating	0.67	0.07
Maine, New Hampshire, Vermont	Mobile Home	Space Cooling - Single Phase	0.33	0.09
Maine, New Hampshire, Vermont	Mobile Home	Space Cooling – Split Phase	0	.
Maine, New Hampshire, Vermont	Mobile Home	Space Cooling - Triple Phase	0	.
Connecticut, Rhode Island	Single-Family	Space Heating	0.29	0.14
Connecticut, Rhode Island	Single-Family	Space Cooling - Single Phase	0.49	0.65
Connecticut, Rhode Island	Single-Family	Space Cooling – Split Phase	0.28	1.35
Connecticut, Rhode Island	Single-Family	Space Cooling - Triple Phase	0	.
Massachusetts	Single-Family	Space Heating	0.35	0.21
Massachusetts	Single-Family	Space Cooling - Single Phase	0.54	0.6

Region	Dwelling Type	End Use	Proportion of Households with Electric Space Conditioning	Annual Consumption Per Degree Day (kWh)
Massachusetts	Single-Family	Space Cooling – Split Phase	0.27	1.41
Massachusetts	Single-Family	Space Cooling - Triple Phase	0	.
Maine, New Hampshire, Vermont	Single-Family	Space Heating	0.25	0.16
Maine, New Hampshire, Vermont	Single-Family	Space Cooling - Single Phase	0.44	0.44
Maine, New Hampshire, Vermont	Single-Family	Space Cooling – Split Phase	0.03	1.3
Maine, New Hampshire, Vermont	Single-Family	Space Cooling - Triple Phase	0	.

3.1.3 Calibration to the Seven New England Regions

DNV GL used two regional calibration factors – regional degree-days and regional household counts by housing unit type – to account for sub-regional differences within New England.

Regional Weather Calibration

Regional weather calibration for annual energy consumption was used for the heating and cooling end-uses only as these are the most sensitive to changes in temperature. To regionalize the RECS data, the heating annual consumption estimates were divided by the average number of annual heating degree-days (base 65) and the annual space cooling consumption estimates were divided by the average number of annual cooling degree-days (base 65) to create consumption per degree-day estimates for each. We then multiplied the estimates by actual 2012 heating and cooling degree-days for each of the regions to come up with an annual regional estimate for each of the seven regions (Table 3-5). This approach leverages the well-established property[13] that energy consumption is approximately linear with respect to heating and cooling degree-days above corresponding reference temperatures.

Table 3-5 Heating and Cooling Degree Days by Region

Region	Heating Degree Days (base 65)	Cooling Degree Days (base 65)
Connecticut	4,986	953
Maine	6,146	474
Massachusetts - Central/West	5,644	655
Massachusetts - East	4,819	818
New Hampshire	6,235	566
Rhode Island	4,819	818
Vermont	6,163	724

Population and Housing Type Calibration

To account for differences in housing type and population across the seven New England analysis regions, DNV KEMA calibrated the RECS data using the Census Bureau American Community Survey estimates of housing unit counts of various housing unit types (single-family, multi-family, mobile home) as regional weights. Table 3-6 shows the counts of the number of households according to the ACS.

[13] For an example research publication where the linearity of consumption with respect to degree-days, see Statistical Analysis of Historical State-Level Residential Energy Consumption Trends (Belzer and Cort, PNNL)

Table 3-6 Number of Households by Region and Household Type from Census Bureau American Community Survey

Region	Household Type	Number of Households (ACS)
Connecticut	Multi-family	516,912
Connecticut	Mobile Home	10,796
Connecticut	Single-Family	960,209
Massachusetts - East	Multi-family	920,799
Massachusetts - East	Mobile Home	15,902
Massachusetts - East	Single-Family	1,159,918
Massachusetts – West/Central	Multi-family	246,476
Massachusetts – West/Central	Mobile Home	8,024
Massachusetts – West/Central	Single-Family	428,995
Maine	Multi-family	139,166
Maine	Mobile Home	65,559
Maine	Single-Family	519,309
New Hampshire	Multi-family	157,528
New Hampshire	Mobile Home	35,974
New Hampshire	Single-Family	423,481
Rhode Island	Multi-family	186,173
Rhode Island	Mobile Home	4,522
Rhode Island	Single-Family	271,774
Vermont	Multi-family	74,069
Vermont	Mobile Home	20,619
Vermont	Single-Family	229,184

The combined calibration approach resulted in regional differentiation in the estimated annual energy consumption for the various end uses reflecting the regional variation in the demand for space conditioning, and also reflected regional variation in housing stock. For example, we expected Eastern Massachusetts to have end-use consumption shares from multi-family housing units to be a greater component of the overall residential end-use shares than other regions since it contains the largest urban area of New England.

3.1.4 Calibration to summer peak and spring light load hours

In order to develop the hourly contribution of each annual end use share (by sector, end use and weather zone), a load shape library was developed, as described in section (3) of the Methodology. The load shape method enables a calculation, described in the methodology, to apply a load shape, defined by the four sets of ratios, to determine the value for any desired hour of the year. In this case, summer peak is defined as a July peak weekday (Tuesday-Thursday) at hour ending 15 on a hot day (95 degrees, Dew Point 70) and the light spring as a weekend day at hour ending 9 am.

A set of ratios to produce those specific hourly kW values from the annual kWh usage input for each sector, end use, and weather zone was produced from the full load shape for every distinct scenario.

The principal issue in developing customized ratios was the identification of the most applicable source and, if necessary, the requirement to adjust that source to reflect conditions that would be different from the New England conditions and customers that it would be applied to.

The issues involving sources fall into these categories:

- Daily Weather-sensitive end uses – This category encompasses cooling and heating end uses, including ventilation/fans. Unless data was collected for a source specific to the weather zone, adjustments would need to be made to reflect each of the weather zones. Section 3.4 of this report details the process used to compile applicable weather and generate the monthly usage and peak day factors for residential heating and cooling end uses. Specific sources for the weekend to weekday ratios and hourly per-unit ratios by day type and month were:
    - Cooling
        - LIPA Edge CAC from DLC baseline analysis – this was closest in region
        - PG&E Blue Canyon area for Multi-family for 3-phase units – this was from the Regional Technical Forum (RTF) website and closest to the same weather pattern as New England
        - PG&E Blue Canyon area for Room A/C units and ventilation – this was from the Regional Technical Forum (RTF) website and closest to the same weather pattern as New England
    - Heating
        - PG&E Blue Canyon area for Heating – this was from the Regional Technical Forum (RTF) website and closest to the same weather pattern as New England

  For each end use, a specific set of monthly and peak day factors were used, as described in Section 3.4, based on analysis of 10 years of weather from each of the 8 ISO-NE zones.

- Seasonal weather-sensitive end uses – This category encompasses end uses that are not daily weather-sensitive, but do vary by seasonal weather patterns based on indirect weather-sensitivity. These would include refrigeration, freezers, pool pumps and water heating. Data sources from local or regional studies would work best, followed by sources with the same general weather distribution across months. For these end uses, sources selected were:
    - Water Heating – A 1989 Massachusetts state-wide study (Joint Utility Monitoring Project/JUMP) was used for this end use
    - Refrigerators and Freezers – PG&E end use load study was used, from the Regional Technical Forum (RTF) website and considered close to the same weather pattern as New England
    - Pool Pumps – LIPA Pool Pump DLC baseline analysis – this was closest in region

- Seasonal non-weather-sensitive end uses – This category encompasses seasonal end uses that are not directly affected by weather but do exhibit seasonal tendencies due to other factors (e.g. sunrise/sunset and commuting patterns for lighting). This group includes lighting, cooking, and laundry. The sources for these were:
    - Lighting – Used a NEEP-sponsored study by NMR. This was also used for “other” end uses, reflecting the concept that they are largely occupancy-influenced, as is lighting, with some degree of 24/7 and security/overnight use, reflecting some “always-on/phantom” loads.

- o Washer and Dryer - A 1989 Massachusetts state-wide study (Joint Utility Monitoring Project/JUMP) for dryers was used for both washers and dryers
  - o Cooking (Electric Ranges) - A 1989 Massachusetts state-wide study (Joint Utility Monitoring Project/JUMP) for electric ranges was used for both washers and dryers

- Non-weather-sensitive end uses – This category covers all other end uses, including TVs, set-top boxes, and dishwashers.
  - o TVs – ELCAP/RTF study from late 1980's
  - o Set-top boxes – Uses flat daily usage with PG&E refrigeration hourly values from RTF database

For end uses other than cooling and heating, since sources were obtained that were regional for other weather-sensitive end uses, no adjustments to the monthly factors or other ratios were deemed necessary. Specific sources are noted in the appendix and supplemental documents provided.

3.2 Commercial End-Use Load Model

The commercial sector in this analysis is identical to the population covered by EIA's Commercial Building Energy Consumption Survey (CBECS): "all buildings in which at least half of the floor space is used for a purpose that is not residential, industrial, or agricultural". The definition includes building types not always associated with the commercial activities, such as correctional institutions, buildings used for religious worship, and schools.[14] The three eligibility criteria that CBECS utilized in determining whether a building was eligible were:

- Building definition: an enclosed structure that is intended for human access. This, therefore, excludes energy-using structures such as radio towers, lumber yards, pumping stations, etc. The one exception is when the entire first floor of a structure is full enclosed.
- Building Use: Building must be at least 50% used for commercial purpose. Nonresidential buildings not included:
  - o farm buildings, such as barns, (unless space is used for retail sales to the general public)
  - o industrial or manufacturing buildings that involve the processing or procurement of goods, merchandise, or food (again, unless space is used for retail sales to the general public)
  - o buildings on most military bases; buildings where access is restricted for national security reasons
  - o single-family detached dwellings that are primarily residential, even if the occupants use part of the dwelling for business purposes; and
  - o mobile homes that are not placed on a permanent foundation (even if the mobile home is used for nonresidential purposes).
- Building Size: must be at least 1,000 square feet to be in scope (excludes establishments within malls which had no minimum square footage

The CBECS building population accounts for the following types of non-residential activities:

- Health care
  - o Inpatient
  - o Outpatient
- Grocery
- Lodging

[14] CBECS home page: http://www.eia.gov/consumption/commercial/index.cfm

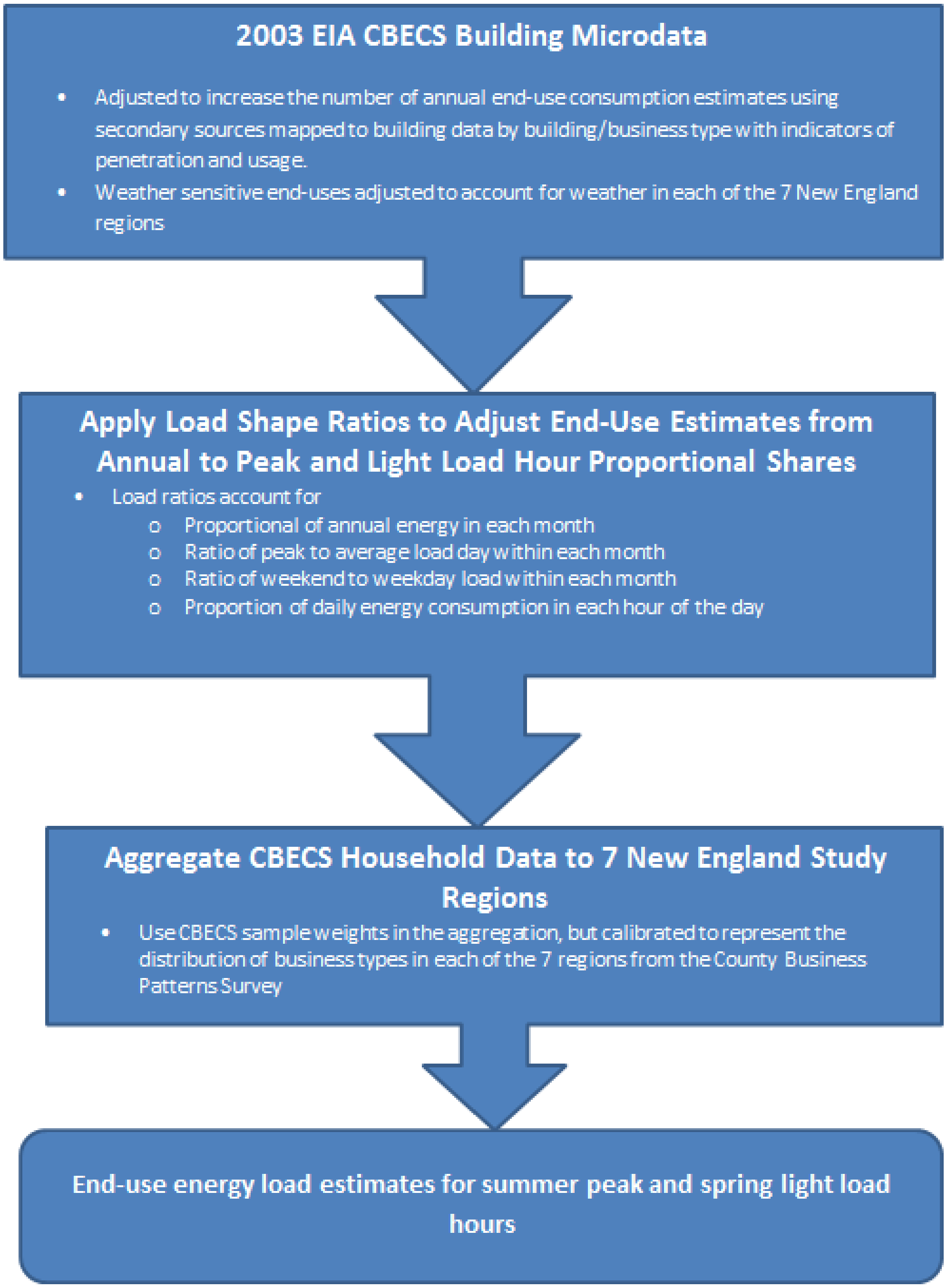
- School
- College
- Office
    - Large (>= 30,000 SQFT)
    - Small (< 30,000 SQFT)
- Public assembly
- Public order and safety
- Religious Worship
- Retail
- Warehouse
    - Non-refrigerated warehouse
    - Refrigerated warehouse
- Miscellaneous

The end-use categories that were accounted for in the commercial sector analysis were:

- Space heating
- Ventilation
- Space cooling:
    - Single phase
    - Split phase
    - Three phase
- Lighting:
    - CFL/linear fluorescent
    - Incandescent
    - High-intensity discharge
    - Other lamp types
- Air Compression
- Cooking
- Elevator Drives and Hydraulic Pumps
- Office Equipment
- Refrigeration
- Water Heating
- All Other Commercial End Uses

Figure 3-5 gives an overview of the commercial sector analysis process. For a description of any acronyms listed in this chart, refer to Appendices A and B

Figure 3-5 Flow chart of commercial sector analysis process



The following sections provide detail into how end-use share estimates were generated for these end uses at the summer peak and spring light load hour, starting with descriptions of publicly available data sources that were used in the analysis.

3.2.1 Data Sources

Commercial Buildings Energy Consumption Survey (CBECS)

The CBECS is a national sample survey that collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures.[15] Commercial buildings include all buildings in which at least half of the floor space is used for a purpose that is not residential, industrial, or agricultural, so they include building types that might not traditionally be considered "commercial," such as schools, correctional institutions, and buildings used for religious worship. CBECS data is available in summary tables, or through the use of the publicly available database of over 5,000 participating buildings in the 2003 sample. The microdata file contains estimates of annual energy consumption for several end-uses, heating and cooling degree-days, along with various building characteristics. The finest level of geography indicated on the CBECS data is Census Division. The New England states comprise one such division.

Usage: Like the RECS for the residential analysis, the CBECS is the backbone of the commercial sector end-use load model. DNV GL used the following annual consumption estimates by building type in this analysis: ventilation, water heating, refrigeration, office equipment, cooking, other, space heating (per heating degree day), and space cooling (per cooling degree day. DNV GL also used penetration estimates for air compression and elevators.

California Commercial End-Use Survey (CA CEUS)

The California Energy Commission contracted a team led by Itron to administer the CA CEUS.[16] The CA CEUS was conducted with a sample of 2,790 commercial facilities in the following service areas: Pacific Gas and Electric, San Diego Gas and Electric, Southern California Edison, Southern California Gas Company, and the Sacramento Municipal Utility District. Commercial buildings were selected based on SIC code provided by the utilities; the CA CEUS report defines the 'premise' sampling unit as "a collection of buildings and/or meters service a unique customer at a contiguous location". The sample was stratified by utility, CEC forecasting climate zone, building type, and annual energy consumption for 2000. The analysis year for this data was 2002. Using survey results, time-of-use data loggers, and billing analysis, the CEUS collected and reported estimates on building systems, electricity and gas consumption, equipment penetration, operating schedules, and other characteristics.

Usage: DNV GL used the CA CEUS UECs for air compressors.

County Business Patterns

The County Business Patterns (CBP) is an annual series published by the U.S. Census Bureau that provides subnational economic data by industry.[17] This series includes the number of establishments, employment during the week of March 12, first quarter payroll, and annual payroll. This data is useful for studying the economic activity of small areas; analyzing economic changes over time; and as a benchmark for other statistical series, surveys, and databases between economic censuses. Businesses use the data for analyzing market potential, measuring the effectiveness of sales and advertising programs, setting sales quotas, and developing budgets. Government agencies use the data for administration and planning.

Usage: The commercial analysis of this project utilized CBP counts of business establishments at the county level by NAICS industry code category group.   These counts were used to calibrate the end-use shares of commercial electricity consumption to reflect the economic activity specific to each of the seven regions.

[15] CBECS home page: http://www.eia.gov/consumption/commercial/index.cfm

[16] CEUS home page: http://www.energy.ca.gov/ceus/

[17] CBP home page: http://www.census.gov/econ/cbp/

Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030

TIAX LLC conducted a study of the electricity consumption of various commercial and residential end-uses.[18] The U.S. Department of Energy's EIA and the Decision Analysis Corporation commissioned this report. The study created consumption estimates for twenty-one commercial and residential electric loads for the years 2005 (base year), 2010, 2015, 2020 and 2030.

Usage: The annual consumption estimates for elevators in this project were derived from linkages to this report.

Commercial and Industrial Lighting Load Shape Project

KEMA (now DNV GL) produced a report in 2011 for Regional Evaluation, Measurement and Verification Forum, a project facilitated by the Northeast Energy Efficiency Partnerships (NEEP).[19] This report delivers weather normalized 8,760 lighting end-use load shapes for commercial lighting through a combination of short-term metering and external data sources.

Usage: The project's full load equivalent hours (FLEH) estimations were used in the calculation of the commercial lighting estimates in this analysis.

2010 DOE Lighting Market Characterization Study

In 2010 DOE's Solid State Lighting Program released a report containing measures of lighting usage in the United States.[20] Commercial, residential and industrial lighting estimates, including energy use, installed number of lights and average lumen were all aspects of this study. The specific light categories that had estimates were: incandescent, halogen, compact fluorescent, linear fluorescent, high intensity discharge (HID), and other.

Usage: While the CBECS provides lighting usage estimates, this analysis leveraged the Lighting Market Characterization Study for disaggregating lighting into more granular categories.

3.2.2 End-Use Shares of Annual Energy Consumption

The DNV GL approach for producing estimated end-use shares of annual energy consumption for commercial buildings was to leverage end-use consumption estimates from the CBECS, and link CBECS building-level survey data to secondary data sources containing unit energy consumption for end-use categories not covered by the CBECS. Through the linkage process, the list of end-use consumption estimates linked to CBECS buildings, either directly or indirectly, expands towards the desired list of end uses to account for in the analysis. This linkage process has the effect of shrinking the share of the "All other commercial end uses" balance of annual consumption which the direct end-use estimates from CBECS does not account for.

The CBECS microdata file has the following identifiers directly or indirectly related to geography:

- Climate zone
- Census region
- Census division

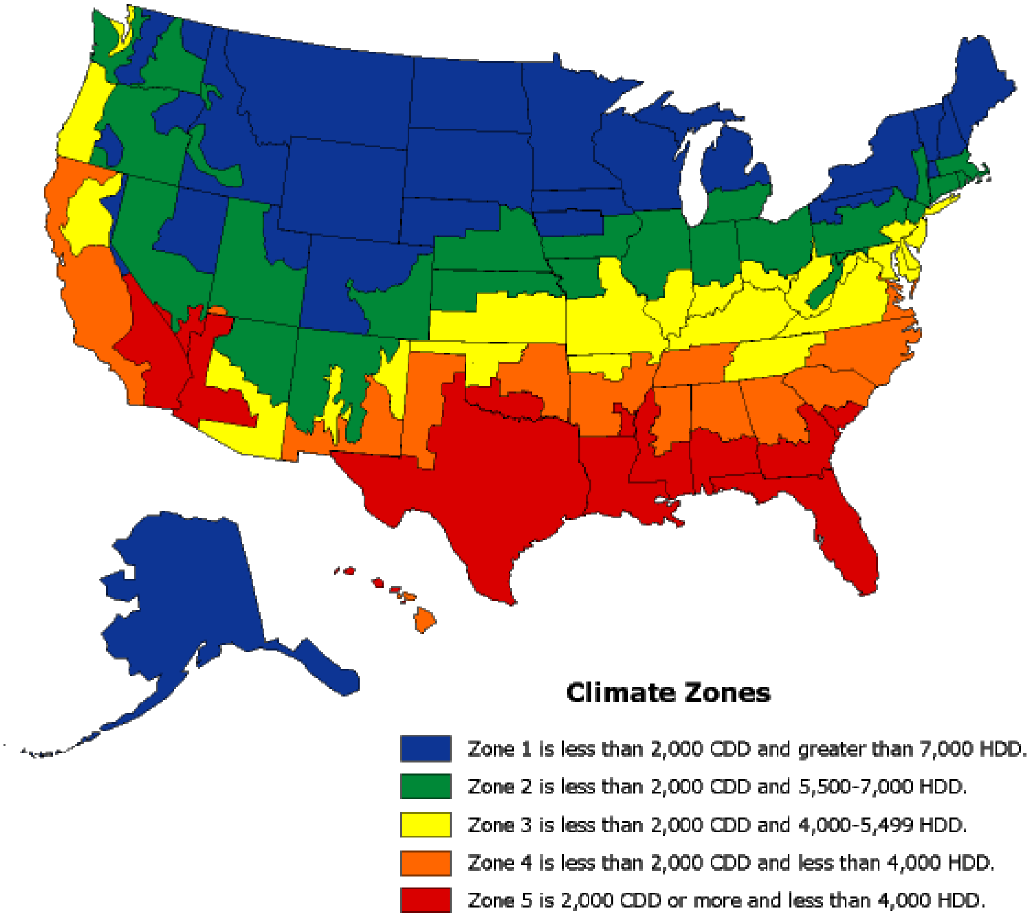
[18] Misc. Electricity Consumption Report location: http://iepec.org/conf-docs/evaluator_resources/TIAX_EIA_MiscElecReport.pdf

[19] C&I Lighting Load Shape Project Report location: http://www.rieermc.ri.gov/documents/evaluationstudies/2011/KEMA_2011_CILightingLoadShapeProject.pdf

[20] Lighting Market Characterization report location: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

CBECS defines climate zones as “long-term weather conditions which affect the heating and cooling loads in buildings”. There five climate zones in the CBECS are based on 30-year span of weather averaged from 1971-2000.[21] Figure 3-6 below displays the five CBECS climate zones based on ranges of heating and cooling degree-days.

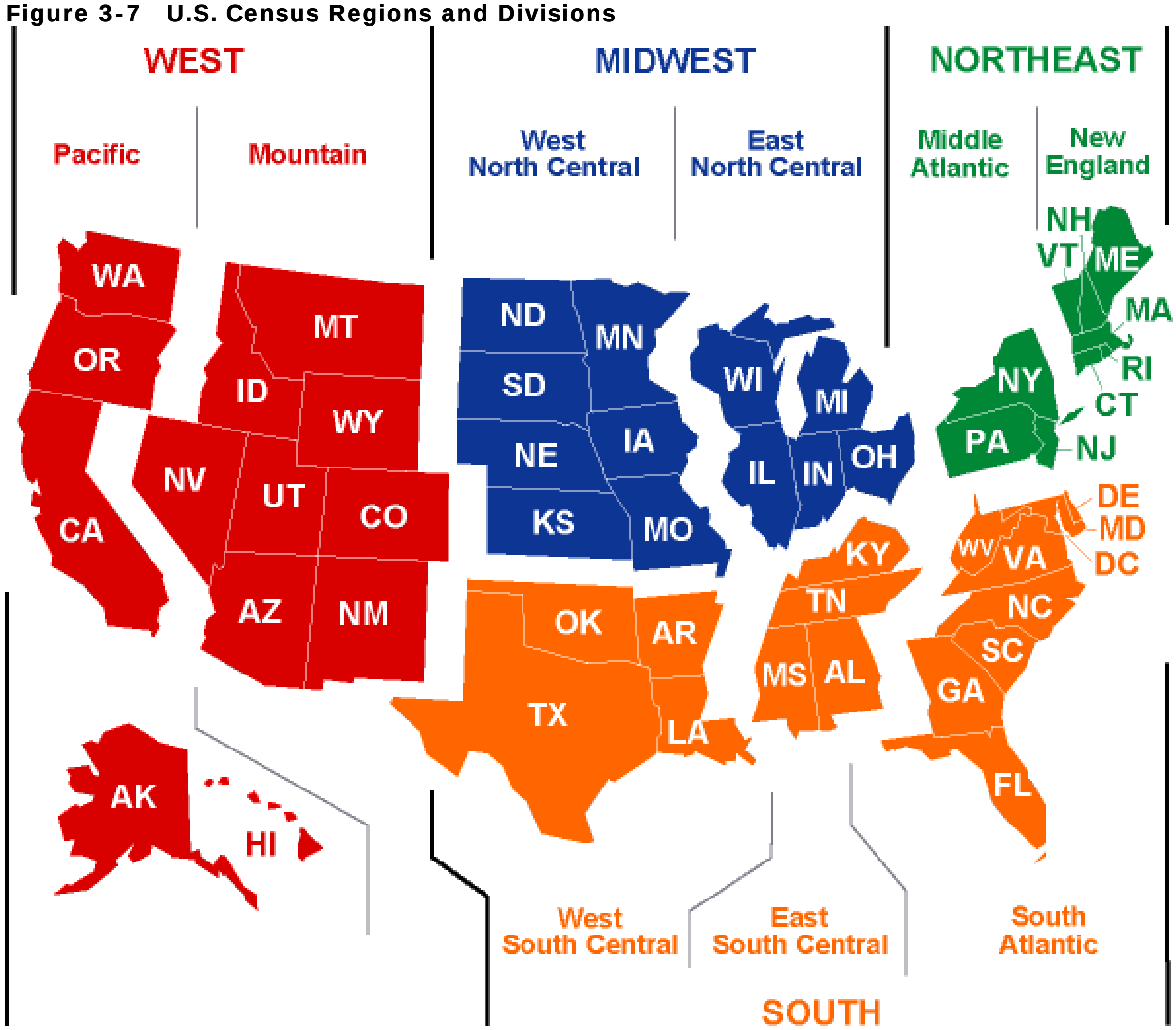
Figure 3-6 U.S. Climate Zones for the 2003 CBECS



The four census regions are the Northeast, Midwest, South and West. The census division is a further subset of that, with the two census divisions in the Northeast being New England (the six states that are the focus of this study) and the Middle Atlantic (New York, New Jersey, and Pennsylvania). Figure 3-7 below shows the partitions of the U.S. with census regions and divisions.

[21] http://www.eia.gov/consumption/commercial/terminology.cfm#H

Figure 3-7 U.S. Census Regions and Divisions



DNV GL aggregated the CBECS building-level microdata with identifiers for the New England census division so that the end-use shares reflected the buildings as geographically specific to the seven regions of interest as possible, with two exceptions. College and refrigerated warehouse building types were not adequately represented in the New England data to yield stable end-use shares representative of these building types.[22] The geographic range was expanded to include the Middle Atlantic in the production of end-use shares for colleges, and to climate zones I and II for refrigerated warehouses.

The following end-use categories had direct estimates of annual consumption given in the CBECS microdata:

- Space cooling
- Ventilation
- Refrigeration
- Office equipment
- Electric heating
- Cooking

[22] One college and zero refrigerated warehouses were accounted for in the 2003 CBECS New England respondents. The expansion to the Northeast census region and climate zones I and II increased the number of sample cases to 16 and 9, respectively.

- Water heating

For space cooling, the desired level of estimation was for the type of unit – three phase, split phase, or single phase, so the space cooling end-use category was subdivided according to the following steps:

1. Map cooling equipment types listed for each building respondent in the CBECS to a specific phase classification. While the CBECS survey collected several space cooling characteristics for each unit in the buildings, phase type was not explicitly captured. Table 3-7 shows the breakdown of how phase types were classified for this analysis.

Table 3-7 Re-categorizing Space Cooling Equipment Type into Phase Type

CBECS Equipment Type Categories	Phase Type
Individual room air conditioners, other than heat pumps	115-120 V / Single Phase
"Swamp" coolers or evaporative coolers	115-120 V / Single Phase
Heat pumps for cooling	240 V / Split Phase
Residential-type central air conditioners, other than heat pumps, that cool air directly and circulate it without using chilled water	240 V / Split Phase
District chilled water piped in from outside the building	460 V / Three Phase
Central chillers inside the building that chill water for air conditioning	460 V / Three Phase
Packaged air conditioning units, other than heat pumps	460 V / Three Phase
Other cooling equipment	460 V / Three Phase

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2. Create annual estimates for each phase by multiplying the total cooling usage estimate by the percent of conditioned floor space cooled by each phase type. For example, if an office building had district chilled water for 80% of the conditioned square footage and individual room air conditioners for the remaining 20%, 80% of the annual cooling consumption estimate would be considered 'three phase' and 20% would be considered 'single phase'.

Three commercial end-use categories – air compressors, elevators, and lighting – were not available directly from the CBECS or more reliable estimates were available, and so DNV GL sought appropriate secondary sources for these estimates. The data sources and approaches were different for each of these end uses and are described below.

Air Compressors

The air compressor estimate came from the California CEUS, which provided air compression estimates in kWh per square foot by building type. These estimates were merged with the CBECS data by linking the CEUS kWh per square foot estimates with CBECS data using the building types field. Air compressor estimates were the product of the kWh per square foot estimate from the CA CEUS and the square footage of the building from the CBECS data. This created more accurate regional estimates than taking the average kWh by building type from the CA CEUS study.

Elevators

A report to the EIA by TIAX, *Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to Y2030* provided an annual consumption estimate for elevators for 2010 and 2015. The average of these two estimates, 6,850 kWh/year, was used in the analysis as the 2012 kWh/year estimate. The annual elevator consumption per building estimate resulted from multiplying the number of elevators in each building from the CBECS data file by the annual elevator estimate.

Lighting

While CBECS provides consumption estimates for interior lighting for sample buildings, this analysis used a more robust calculation combining the Department of Energy's Lighting Market Characterization Study (LMC) and regional annual lighting hours of use by building type. In addition to using more recent data (LMC published in 2010), this approach provided data to break lighting usage into four categories: incandescent, fluorescent (including CFLs), High Intensity Discharge (HID) and all other lighting types. The LMC provided national estimates only, but a New England level estimate could be calculated by taking regional level full-load equivalent hours (FLEH) from a report published by KEMA, C&I Lighting Load Shape Project, and creating a ratio with the FLEH reported by the LMC. The following four steps map out the calculations to produce New England level estimates for each of the four interior lighting end-uses.

1. Take average daily hours per lighting type and convert to annual.

$$FLEH_{national} = Hours_{daily} * 365$$

2. Create New England level kWh estimate for all lighting types combined.

$$kWh_{region} = kWh_{national} * \frac{FLEH_{region}}{FLEH_{national}}$$

3. Create proportions to scale total lighting kWh to specific lighting type

$$Prop_I = \frac{P_I * W_I * HOU_I}{\sum P * W * HOU}$$

The numerator of the proportion incorporates three items: percent of lamps that make up a specific type to account for the saturation of the lamp type, the average watts to account for differences in power of the lamp type, and hours of use to account for differences in usage.

4. Create regional kWh estimates for each kWh lighting type

$$kWh_I = kWh_{region} * Prop_I$$

Where:

I = type of light – lighting types include incandescent, fluorescent, HID, and Other

P_I = Percent of all lamps that make up the specific lighting type

W_I = Average Watts per bulb

HOU_I = Average hours of use per bulb

$Prop_I$ = Proportion of national lighting that is from the specific lighting type

FLEH = Full Load Equivalent Hours

Reducing the 'All Other' Commercial End Uses Category

Once the indirect estimates were calculated and added to the CBECS building microdata, the "all other" end-use category from the CBECS data file had to be reduced accordingly so that the total building consumption remained constant. For example, if a CBECS commercial building had one elevator, an estimate of 6,850 kWh per year was used for the elevators end-use category. Since elevators were previously accounted for in the 'all other' category, this would now need to be reduced by 6,850 kWh. Since it is possible that the sum of the secondary source end-use kWh estimates exceeds the 2003 CBECS "All Other" kWh (since the secondary source estimates are for population averages rather than individual buildings), we use the same rule outlined in section 3.1.2 for Residential.

After the calibration procedure described above, the "all other commercial end-uses" still accounts for about 14% of the commercial sector's annual electric energy consumption. A report conducted for DOE, "Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type", explored the breakdown of the "other" category by building type. This study examined nine business types that line up similarly to the 14 building types/activities that DNV GL used in this analysis. These nine business types were office, retail/service: non-food, food sales, food service, education, warehouse, healthcare, public AO&R, lodging, and other building/non-building. Some notable end-uses that would fall into other in the office include kitchen appliances in the office staff lounge, non-refrigerated vending machines, and personal space heaters. For lodging, however, other might include ice machines, laundry, or even slot machines. In healthcare, all of the medical equipment would fall under the other category.

Overall annual consumption by end use

These data transformations resulted in estimates of annual energy consumption by building type. Table 3-8 below summarizes the average energy intensity (kWh per square foot per year) by building type for all the non-space conditioning end uses after the calibration of the other category.

Table 3-8 Energy intensity by building type and end use

Building Type	End Use	Energy Intensity (kWh/sqft/year)
College	Air Compression	0.14
College	CFL/Linear Fluorescent Lighting	0.428
College	Cooking	0.076
College	Elevator drives and hydraulic pumps	0.124
College	HID Interior Lighting	0.045
College	Incandescent Lighting	0.009
College	Office Equipment	2.373
College	Other Lighting	0.025
College	Other Uses	1.338
College	Refrigeration	1.013
College	Ventilation	6.028
College	Water Heating	0.027
Grocery	Air Compression	0.04
Grocery	CFL/Linear Fluorescent Lighting	9.074
Grocery	Cooking	0.478
Grocery	Elevator drives and hydraulic pumps	0
Grocery	HID Interior Lighting	0.401
Grocery	Incandescent Lighting	0.114
Grocery	Office Equipment	0.543
Grocery	Other Lighting	0.209
Grocery	Other Uses	1.921
Grocery	Refrigeration	36.916
Grocery	Ventilation	2.135
Grocery	Water Heating	0.214

Building Type	End Use	Energy Intensity (kWh/sqft/year)
Inpatient healthcare	Air Compression	0.22
Inpatient healthcare	CFL/Linear Fluorescent Lighting	1.495
Inpatient healthcare	Cooking	0.101
Inpatient healthcare	Elevator drives and hydraulic pumps	0.15
Inpatient healthcare	HID Interior Lighting	0.009
Inpatient healthcare	Incandescent Lighting	0.021
Inpatient healthcare	Office Equipment	0.78
Inpatient healthcare	Other Lighting	0.055
Inpatient healthcare	Other Uses	1.236
Inpatient healthcare	Refrigeration	0.245
Inpatient healthcare	Ventilation	3.877
Inpatient healthcare	Water Heating	0.233
Lodging	Air Compression	0.02
Lodging	CFL/Linear Fluorescent Lighting	3.13
Lodging	Cooking	0.109
Lodging	Elevator drives and hydraulic pumps	0.102
Lodging	HID Interior Lighting	0.025
Lodging	Incandescent Lighting	1.352
Lodging	Office Equipment	0.479
Lodging	Other Lighting	0.275
Lodging	Other Uses	0.899
Lodging	Refrigeration	0.77
Lodging	Ventilation	0.771
Lodging	Water Heating	0.912
Miscellaneous	Air Compression	0.193
Miscellaneous	CFL/Linear Fluorescent Lighting	2.838
Miscellaneous	Cooking	0.007
Miscellaneous	Elevator drives and hydraulic pumps	0.075
Miscellaneous	HID Interior Lighting	0.747
Miscellaneous	Incandescent Lighting	0.079
Miscellaneous	Office Equipment	1.245
Miscellaneous	Other Lighting	0.178
Miscellaneous	Other Uses	1.963
Miscellaneous	Refrigeration	2.765
Miscellaneous	Ventilation	1.705
Miscellaneous	Water Heating	0.128
Office	Air Compression	0.094
Office	CFL/Linear Fluorescent Lighting	3.999

Building Type	End Use	Energy Intensity (kWh/sqft/year)
Office	Cooking	0.008
Office	Elevator drives and hydraulic pumps	0.163
Office	HID Interior Lighting	0.053
Office	Incandescent Lighting	0.052
Office	Office Equipment	2.502
Office	Other Lighting	0.129
Office	Other Uses	2.01
Office	Refrigeration	1.185
Office	Ventilation	1.506
Office	Water Heating	0.193
Outpatient healthcare	Air Compression	0.22
Outpatient healthcare	CFL/Linear Fluorescent Lighting	2.351
Outpatient healthcare	Cooking	0.022
Outpatient healthcare	Elevator drives and hydraulic pumps	0.13
Outpatient healthcare	HID Interior Lighting	0.017
Outpatient healthcare	Incandescent Lighting	0.054
Outpatient healthcare	Office Equipment	1.07
Outpatient healthcare	Other Lighting	0.063
Outpatient healthcare	Other Uses	3.509
Outpatient healthcare	Refrigeration	0.644
Outpatient healthcare	Ventilation	2.492
Outpatient healthcare	Water Heating	0.097
Public assembly	Air Compression	0.263
Public assembly	CFL/Linear Fluorescent Lighting	3.283
Public assembly	Cooking	0.014
Public assembly	Elevator drives and hydraulic pumps	0.019
Public assembly	HID Interior Lighting	1.309
Public assembly	Incandescent Lighting	0.517
Public assembly	Office Equipment	0.047
Public assembly	Other Lighting	0.213
Public assembly	Other Uses	0.597
Public assembly	Refrigeration	0.42
Public assembly	Ventilation	1.88
Public assembly	Water Heating	0.003
Public order and safety	Air Compression	0.3
Public order and safety	CFL/Linear Fluorescent Lighting	3.386
Public order and safety	Cooking	0
Public order and safety	Elevator drives and hydraulic pumps	0.045

Building Type	End Use	Energy Intensity (kWh / sqft / year)
Public order and safety	HID Interior Lighting	0.365
Public order and safety	Incandescent Lighting	0.044
Public order and safety	Office Equipment	0.743
Public order and safety	Other Lighting	0.159
Public order and safety	Other Uses	1.487
Public order and safety	Refrigeration	0.966
Public order and safety	Ventilation	1.794
Public order and safety	Water Heating	0.318
Religious worship	Air Compression	0.169
Religious worship	CFL/Linear Fluorescent Lighting	1.777
Religious worship	Cooking	0.003
Religious worship	Elevator drives and hydraulic pumps	0.012
Religious worship	HID Interior Lighting	0.122
Religious worship	Incandescent Lighting	0.178
Religious worship	Office Equipment	0.009
Religious worship	Other Lighting	0.09
Religious worship	Other Uses	0.212
Religious worship	Refrigeration	0.07
Religious worship	Ventilation	0.181
Religious worship	Water Heating	0.011
Restaurant	Air Compression	0.02
Restaurant	CFL/Linear Fluorescent Lighting	4.707
Restaurant	Cooking	3.996
Restaurant	Elevator drives and hydraulic pumps	0
Restaurant	HID Interior Lighting	0.396
Restaurant	Incandescent Lighting	1.315
Restaurant	Office Equipment	0.271
Restaurant	Other Lighting	0.266
Restaurant	Other Uses	2.879
Restaurant	Refrigeration	7.608
Restaurant	Ventilation	4.207
Restaurant	Water Heating	0.04
Retail	Air Compression	0.089
Retail	CFL/Linear Fluorescent Lighting	4.722
Retail	Cooking	0.05
Retail	Elevator drives and hydraulic pumps	0.008
Retail	HID Interior Lighting	1.533
Retail	Incandescent Lighting	0.342

Building Type	End Use	Energy Intensity (kWh/sqft/year)
Retail	Office Equipment	0.406
Retail	Other Lighting	0.803
Retail	Other Uses	1.634
Retail	Refrigeration	0.769
Retail	Ventilation	1.5
Retail	Water Heating	0.948
School	Air Compression	0.009
School	CFL/Linear Fluorescent Lighting	1.059
School	Cooking	0.053
School	Elevator drives and hydraulic pumps	0.039
School	HID Interior Lighting	0.11
School	Incandescent Lighting	0.022
School	Office Equipment	0.468
School	Other Lighting	0.061
School	Other Uses	0.204
School	Refrigeration	0.46
School	Ventilation	1.633
School	Water Heating	0.131
Warehouse and Storage	Air Compression	0.136
Warehouse and Storage	CFL/Linear Fluorescent Lighting	2.1
Warehouse and Storage	Cooking	0
Warehouse and Storage	Elevator drives and hydraulic pumps	0.009
Warehouse and Storage	HID Interior Lighting	0.878
Warehouse and Storage	Incandescent Lighting	0.005
Warehouse and Storage	Office Equipment	0.035
Warehouse and Storage	Other Lighting	0.081
Warehouse and Storage	Other Uses	0.688
Warehouse and Storage	Refrigeration	4.384
Warehouse and Storage	Ventilation	0.403
Warehouse and Storage	Water Heating	0.005

Table 3-9 shows the proportion of buildings with electric space conditioning (space heating and space cooling) as well as the average kWh usage per degree day. Note that these tables represent averages for New England as a whole, which is the finest level of geography in the 2003 CBECS.

Table 3-9 Proportion of buildings with electric space conditioning and consumption per degree day by building type and end use

Building Type	End Use	Proportion of Buildings with Electric Space Conditioning	Consumption per Degree Day (kWh)
College	Electric Cooling - Single Phase	0.34	116.26
College	Electric Cooling - Split Phase	0.19	76.98
College	Electric Cooling - Three Phase	0.46	401.08
College	Electric Heating	0.30	52.34
Grocery	Electric Cooling - Single Phase	0.33	3.08
Grocery	Electric Cooling - Split Phase	-	.
Grocery	Electric Cooling - Three Phase	0.45	24.52
Grocery	Electric Heating	0.13	5.35
Inpatient healthcare	Electric Cooling - Single Phase	0.95	178.65
Inpatient healthcare	Electric Cooling - Split Phase	0.11	41.34
Inpatient healthcare	Electric Cooling - Three Phase	1.00	421.16
Inpatient healthcare	Electric Heating	0.11	35.14
Lodging	Electric Cooling - Single Phase	0.26	11.73
Lodging	Electric Cooling - Split Phase	0.09	68.88
Lodging	Electric Cooling - Three Phase	0.31	15.67
Lodging	Electric Heating	0.53	4.54
Miscellaneous	Electric Cooling - Single Phase	0.17	4.36
Miscellaneous	Electric Cooling - Split Phase	0.14	76.13
Miscellaneous	Electric Cooling - Three Phase	0.06	315.12
Miscellaneous	Electric Heating	0.19	7.36
Office	Electric Cooling - Single Phase	0.37	6.23
Office	Electric Cooling - Split Phase	0.35	11.73
Office	Electric Cooling - Three Phase	0.33	46.59
Office	Electric Heating	0.29	5.78
Outpatient healthcare	Electric Cooling - Single Phase	0.01	10.93
Outpatient healthcare	Electric Cooling - Split Phase	0.83	1.55
Outpatient healthcare	Electric Cooling - Three Phase	0.14	122.97
Outpatient healthcare	Electric Heating	0.00	18.14
Public assembly	Electric Cooling - Single Phase	0.20	2.07
Public assembly	Electric Cooling - Split Phase	0.01	12.02
Public assembly	Electric Cooling - Three Phase	0.11	22.09
Public assembly	Electric Heating	0.03	6.18
Public order and safety	Electric Cooling - Single Phase	0.74	2.87
Public order and safety	Electric Cooling - Split Phase	-	.
Public order and safety	Electric Cooling - Three Phase	0.26	28.70

Building Type	End Use	Proportion of Buildings with Electric Space Conditioning	Consumption per Degree Day (kWh)
Public order and safety	Electric Heating	-	.
Religious worship	Electric Cooling - Single Phase	0.08	0.53
Religious worship	Electric Cooling - Split Phase	0.04	1.24
Religious worship	Electric Cooling - Three Phase	-	.
Religious worship	Electric Heating	0.11	0.47
Restaurant	Electric Cooling - Single Phase	0.17	4.07
Restaurant	Electric Cooling - Split Phase	0.16	0.62
Restaurant	Electric Cooling - Three Phase	0.50	31.63
Restaurant	Electric Heating	0.17	6.80
Retail	Electric Cooling - Single Phase	0.30	1.72
Retail	Electric Cooling - Split Phase	0.06	1.97
Retail	Electric Cooling - Three Phase	0.44	63.80
Retail	Electric Heating	0.33	14.53
School	Electric Cooling - Single Phase	0.59	4.68
School	Electric Cooling - Split Phase	0.15	3.13
School	Electric Cooling - Three Phase	0.11	23.37
School	Electric Heating	0.01	14.56
Warehouse and Storage	Electric Cooling - Single Phase	0.08	10.11
Warehouse and Storage	Electric Cooling - Split Phase	0.16	3.88
Warehouse and Storage	Electric Cooling - Three Phase	0.11	8.60
Warehouse and Storage	Electric Heating	0.01	13.16

3.2.3 Calibration to the Seven New England Regions

DNV GL used two regional calibration factors – regional weather and regional business establishment counts – to account for sub-regional differences in New England.

Weather Calibration

The weather calibration was used for the heating and cooling end-uses only as these are the most susceptible to changes in temperature. To regionalize the CBECS data the building-level annual kWh estimates for space heating were divided by the number of heating degree-days given for the building in the CBECS microdata file, and the space cooling estimates were divided by the corresponding total cooling degree-days to create a consumption per degree-day estimate for space conditioning category. The estimates were then multiplied by actual 2012 degree-days specific to each of the seven regions to produce regional estimates for space heating and cooling for a 2012 basis year (see Table 3-5 for heating and cooling degree days by region).

Business Type Calibration

To account for business type facility differences across the seven New England analysis regions, business establishment counts by NAICS category from the Census Bureau County Business Patterns Survey data were mapped to CBECS microdata to act as regional weights. For example, if health care facilities are more prevalent in one sub region than others, the estimated end-use shares for this type of business would have a greater regional weight in the overall average than other types of businesses which may be less prevalent in the region.

As CBECS building categories and NAICS business categories do not map together perfectly, this analysis leveraged EIA's published crosswalk of CBECS "Primary Building Activities" to NAICS codes.[23] The Census Business Pattern Survey data does not include NAICS code 92, Public Administration. To make sure these building types were not excluded, the analysis developed an approach specifically for Public Administration. The two CBECS building types that fit Public Administration were "Government Offices" and "Public Order and Safety". The number of buildings in New England was assumed from the CBECS weighted number, which is meant to correspond to the actual number of buildings in that region.

The CBECS New England end-use consumption estimates for public administration were apportioned to the sub-regions according to the population of each of the regions. The rationale for this is that public administration energy consumptive activity in buildings is related to the size of the population it is serving.

Table 3-10 shows the number of buildings by region and building type/activity. Table 3-11 shows the average square footage by building type.

Table 3-10 Number of Buildings by Region and Building Type / Activity from the County Business Patterns Survey

Region	Building Type / Activity	Number of Buildings (CBP)[24]
Connecticut	College	29
Connecticut	Grocery	2,172
Connecticut	Inpatient healthcare	47
Connecticut	Lodging	1,606
Connecticut	Miscellaneous	8,273
Connecticut	Office	29,747
Connecticut	Outpatient healthcare	6,900
Connecticut	Public assembly	2,386
Connecticut	Public order and safety	1,825
Connecticut	Religious worship	3,476
Connecticut	Restaurant	7,589
Connecticut	Retail	9,154
Connecticut	School	1,288
Connecticut	Warehouse and Storage	3,966
Massachusetts – East	College	73
Massachusetts – East	Grocery	3,670

[23] See FAQ #8: http://www.eia.gov/consumption/commercial/faq.cfm#q8

[24] The number of buildings for Public Order and Safety and for Government Offices (part of offices) come from CBECS counts; the building counts were regionalized proportionally with respect to population by region.

Region	Building Type / Activity	Number of Buildings (CBP)[24]
Massachusetts – East	Inpatient healthcare	102
Massachusetts – East	Lodging	2,781
Massachusetts – East	Miscellaneous	12,489
Massachusetts – East	Office	47,327
Massachusetts - East	Outpatient healthcare	8,653
Massachusetts - East	Public assembly	3,712
Massachusetts - East	Public order and safety	2,573
Massachusetts - East	Religious worship	4,627
Massachusetts - East	Restaurant	12,064
Massachusetts - East	Retail	13,199
Massachusetts - East	School	2,022
Massachusetts - East	Warehouse and Storage	5,679
Massachusetts – West/Central	College	27
Massachusetts – West/Central	Grocery	1,099
Massachusetts – West/Central	Inpatient healthcare	34
Massachusetts – West/Central	Lodging	933
Massachusetts – West/Central	Miscellaneous	3,568
Massachusetts – West/Central	Office	10,845
Massachusetts – West/Central	Outpatient healthcare	2,448
Massachusetts – West/Central	Public assembly	934
Massachusetts – West/Central	Public order and safety	839
Massachusetts – West/Central	Religious worship	1,428
Massachusetts – West/Central	Restaurant	3,410
Massachusetts – West/Central	Retail	3,909
Massachusetts – West/Central	School	576
Massachusetts – West/Central	Warehouse and Storage	1,511
Maine	College	18
Maine	Grocery	775
Maine	Inpatient healthcare	49
Maine	Lodging	1,878
Maine	Miscellaneous	4,059
Maine	Office	11,987
Maine	Outpatient healthcare	2,437
Maine	Public assembly	1,177
Maine	Public order and safety	888
Maine	Religious worship	1,549
Maine	Restaurant	2,984
Maine	Retail	4,510
Maine	School	466

Region	Building Type / Activity	Number of Buildings (CBP)[24]
Maine	Warehouse and Storage	1,479
New Hampshire	College	27
New Hampshire	Grocery	696
New Hampshire	Inpatient healthcare	33
New Hampshire	Lodging	861
New Hampshire	Miscellaneous	3,612
New Hampshire	Office	11,765
New Hampshire	Outpatient healthcare	2,298
New Hampshire	Public assembly	1,005
New Hampshire	Public order and safety	757
New Hampshire	Religious worship	1,329
New Hampshire	Restaurant	3,019
New Hampshire	Retail	4,644
New Hampshire	School	574
New Hampshire	Warehouse and Storage	1,552
Rhode Island	College	12
Rhode Island	Grocery	686
Rhode Island	Inpatient healthcare	16
Rhode Island	Lodging	691
Rhode Island	Miscellaneous	2,665
Rhode Island	Office	8,756
Rhode Island	Outpatient healthcare	2,173
Rhode Island	Public assembly	766
Rhode Island	Public order and safety	567
Rhode Island	Religious worship	1,031
Rhode Island	Restaurant	2,756
Rhode Island	Retail	2,747
Rhode Island	School	391
Rhode Island	Warehouse and Storage	1,243
Vermont	College	21
Vermont	Grocery	556
Vermont	Inpatient healthcare	17
Vermont	Lodging	643
Vermont	Miscellaneous	1,996
Vermont	Office	6,451
Vermont	Outpatient healthcare	1,228
Vermont	Public assembly	649
Vermont	Public order and safety	397
Vermont	Religious worship	954

Region	Building Type / Activity	Number of Buildings (CBP)[24]
Vermont	Restaurant	1,440
Vermont	Retail	2,440
Vermont	School	351
Vermont	Warehouse and Storage	798

Table 3-11 Average square footage by building type

Building Type	Average Square Footage per Building
College	107,659
Grocery	6,033
Inpatient healthcare	480,160
Lodging	21,292
Miscellaneous	12,408
Office	12,285
Outpatient Healthcare	22,229
Public Assembly	8,309
Public Order and Safety	8,334
Religious worship	13,499
Restaurant	4,490
Retail	14,288
School	31,282
Warehouse and Storage	23,229

3.2.4 Calibration to summer peak and spring light load hours

As with the residential sector, hourly contribution of each annual end use share (by end use and weather zone) were calculated via development of a load shape library, as described in section (3) of the Methodology. For Commercial end uses, an additional significant factor was added, business type, which has a substantial effect on load patterns, especially for weekend to weekday patterns and hourly per-unit ratios by day type, since those are heavily affected by operating hours.

A set of ratios to produce those specific hourly kW values from the annual kWh usage input for each sector, end use, business type, and weather zone was produced from the full load shape for every distinct scenario.

The principal issue in developing customized ratios again was identification of the most applicable source and, if necessary, the requirement to adjust that source to reflect conditions that would be different from the New England conditions and customers that it would be applied to.

As with the residential load shapes, the issues involving sources fall into these categories:

- Daily Weather-sensitive end uses –For cooling and heating end uses, including ventilation/fans, unless data was collected for a source specific to the weather zone, adjustments would need to be made to reflect each of the weather zones. Section 3.4 of this report details the process used to compile applicable weather (heating degree days using HDD65 and cooling degree days using CDD55) and generate the monthly usage and peak day factors for residential heating and cooling end uses. Specific sources for the weekend to weekday ratios and hourly per-unit ratios by day type and month were:

  - Cooling
    - NEEP Unitary HVAC Load Shape Project – this was within the region and produced cooling load shapes by business types used for all three size categories (single-phase, split-phase and 3-phase)
  - Heating
    - Commercial Heating from Regional Technical Forum (RTF) website and adjusted for each set of ISO-NE weather zones for monthly and peak day factors, as described in Section 3.4, based on analysis of 10 years of weather from each of the 8 ISO-NE zones. Separate load shapes by business type were not available and not considered critical.

- Seasonal weather-sensitive end uses – This category encompasses end uses that are not daily weather-sensitive, but do vary by seasonal weather patterns based on indirect weather-sensitivity. These would include refrigeration, freezers, and ventilation. Data sources were taken from RTF for the "all other "commercial end-use category.

- Seasonal non-weather-sensitive end uses – This category encompasses seasonal end uses that are not directly affected by weather but do exhibit seasonal tendencies due to other factors (e.g. sunrise/sunset and operating hours for different business types). This group includes lighting, air compressors and cooking. The sources for these were:
  - Lighting – Used a NEEP-sponsored lighting study. This was also used for "all other" end uses
  - Range, air compressors – Used RTF Commercial source

- Non-weather-sensitive end uses – This category covers all other end uses, including Office equipment, pumps, motors - Used RTF Commercial source.

Specific sources are noted in the appendix and supplemental documents provided.

3.3 Industrial End-Use Load Model

The industrial sector in this analysis accounts for purchased electricity from manufacturing industries (NAICS 31-33), mining industries (NAICS 21), construction industries (NAICS 23), and agricultural industries (NAICS 11). Each of these industry groups is comprised of many sub-industry classifications which give more detailed descriptions of the corresponding industrial activities for establishments in the various classes.

The electrical end-use load categories that were accounted for in the industrial sector analysis were:

- Conventional boiler Use
- Electro-chemical processes
- Lighting
  - CFL/Linear Fluorescent
  - HID Interior
- Machine drives

- Onsite transportation
- Process cooling and refrigeration
- Process heating
- Space cooling
- Ventilation
- Other facility support
- Other process support
- Other non-process support

Additionally, shares of non-manufacturing industries – agriculture, mining, and construction – are presented as end-use load categories. Publicly available sources for electrical end-use load shares in these industry classes were not identified in this project.

Special issues for the industrial analysis that distinguish it from the residential and commercial sector analyses include:

- The MECS does not publish manufacturing establishment-level microdata of survey responses.
    - End-use consumption estimates are for NAICS industries at a national level rather than for New England or other finer level of granularity.

- The MECS does not cover the entire industrial sector as the RECS survey covers the residential sector, or CBECS covers the commercial sector.
    - Estimates of the purchased electricity used by nonmanufacturing industries are available in the EIA's AEO by year, but only at a national level, and not by segments within each of the three non-manufacturing sectors.

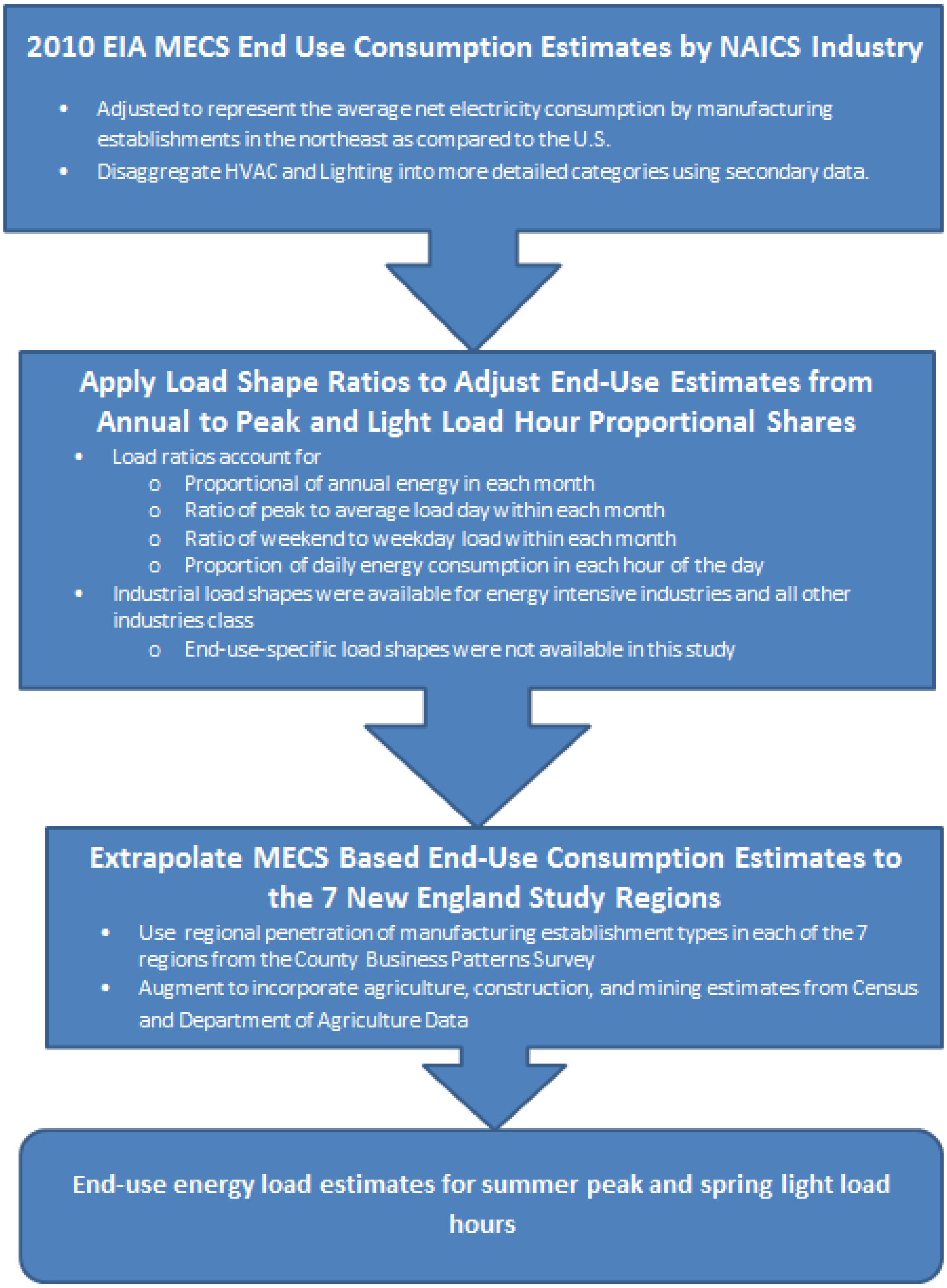
- It cannot be assumed that electricity consumed at industrial establishments was purchased from a load serving entity in all cases.
    - Onsite generation of electricity is prevalent in the industrial sector, especially in energy-intensive manufacturing industries.
    - In some manufacturing industries net purchased electricity can be negative, indicating electricity sold to the grid or transferred to another establishment.

The list of end-use consumption categories included in the MECS was relatively complete for the purposes of this study. HVAC and Lighting, however, needed to be disaggregated into components.

- HVAC needed to be split into space conditioning and ventilation.
- Lighting needed to be broken out into lamp technology categories.

The following flow chart depicts the analysis process used for the industrial sector end-use load estimation. Detail on acronym definitions and terminology in the flow chart can be found in appendices A and B.

Figure 3-8 Flow chart of the industrial sector analysis process



3.3.1 Data Sources

Manufacturing Energy Consumption Survey (MECS)

The MECS is a national sample survey that collects information on the stock of U.S. manufacturing establishments, their energy-related operational characteristics, and their energy consumption and expenditures. While microdata are not available from the MECS, data tables of consumption of net electricity by end-use category and region and consumption of offsite-produced electricity by NAICS industry and region are publicly available. The MECS finest level of geography is census region, which for the New England states also includes New York, New Jersey, and Pennsylvania.

Usage: The 2010 MECS estimates are the backbone of the industrial sector. The annual electricity consumption estimates by NAICS and end-use categories were leveraged in this analysis. These end-use estimates are at the national level, so they were calibrated to Northeast estimates of purchased electricity by NAICS industry.

County Business Patterns

The County Business Patterns (CBP) is an annual series published by the U.S. Census Bureau that provides subnational economic data by industry.[25] This series includes the number of establishments, employment during the week of March 12, first quarter payroll, and annual payroll. This data is useful for studying the economic activity of small areas; analyzing economic changes over time; and as a benchmark for other statistical series, surveys, and databases between economic censuses. Businesses use the data for analyzing market potential, measuring the effectiveness of sales and advertising programs, setting sales quotas, and developing budgets. Government agencies use the data for administration and planning.

Usage: The industrial analysis of this project utilized manufacturing establishment counts at the county level by NAICS industry. These counts were used to calibrate the MECS end-use shares to reflect the manufacturing activity specific to each of the seven regions.

Economic Census

The Economic Census is the U.S. Government's official five-year measure of American business and the economy.[26] It is conducted by the U.S. Census Bureau, and response is required by law. The Economic Census provides state-level estimates of numerous measures of economic activity by NAICS industry code, including the cost and quantity of purchased electricity and dollars of value added.

Usage: These measures are used in this project to account for the regional differentiation in the shares of purchased electricity by the mining and construction industries, neither of which is covered by the MECS sample frame. The most recent Economic Census with data published is for 2007.

Annual Energy Outlook

The Annual Energy Outlook is a product of the U.S. Department of Energy’s Energy Information Administration (EIA).[27] The AEO contains retrospective and prospective estimates of energy production, sales, and consumption by fuel, market sector, and other categories.

Usage: The industrial sector analysis uses the AEO estimates of the quantity of purchased electricity by the industrial sector (manufacturing, mining, construction, and agriculture) by year for the U.S.

Farm Service Agency Crop Acreage Data

This dataset is released monthly and contains mandatory self-reported cropland acreage data at a national, state, and county level.[28] It includes data for planted cropland by type of crop, field state, and number of farms. At the time of this report the December 2013 monthly release was the most recent dataset.

[25] CBP home page: http://www.census.gov/econ/cbp/

[26] Economic Census home page: http://www.census.gov/econ/census/

[27] AEO home page: http://www.eia.gov/forecasts/aeo/er/index.cfm

[28] FSA Crop Acreage Data home page: http://www.fsa.usda.gov/FSA/webapp?area=newsroom&subject=landing&topic=foi-er-fri-cad

Usage: DNV GL utilized the planted acreage by county in the industrial analysis, as fallow fields were determined to have minimal electrical impact. Since the planted acreage data is available at the county level, it could be used to apportion the state of Massachusetts into the appropriate regions.

2010 DOE Lighting Market Characterization Study

In 2010 DOE's Solid State Lighting Program released a study report prepared by Navigant Consulting containing measures of lighting usage in the United States.[29] Commercial, residential and industrial lighting estimates, including energy use, installed number of lights and average lumen were all aspects of this study. The specific lamp categories that had LMC estimates were: incandescent, halogen, compact fluorescent, linear fluorescent, high intensity discharge (HID), and other.

Usage: Estimated shares of energy consumption for lamp technologies in the industrial sector were used in this analysis to apportion lighting consumption from the MECS data into lamp type categories.

3.3.2 End-Use Shares of Annual Energy Consumption

The DNV GL approach for producing estimated end-use shares of annual energy consumption for industrial establishments was to utilize the MECS estimates of end-use consumption by fuel and manufacturing sub-industry. Unlike the analyses of other sectors, data linkages to secondary data sources were not used in the manufacturing analysis. The main analysis activities were decomposing HVAC and lighting consumption into a finer level of detail, and preparing a transformation of the MECS data so that it could be merged with regionally specific establishment counts by NAICS industry.

Industrial HVAC Decomposition

A publicly available source for decomposing industrial HVAC electricity usage into space heating, space cooling, and ventilation was not identified. DNV sought a proxy building type from the commercial sector which would have exhaust hoods for specific applications along with general circulation of air in buildings as would commonly be the case in a manufacturing setting. It was decided that the HVAC component shares for commercial lodging buildings fit this criteria since ventilation would be necessary not only in common spaces occupied by customers and staff, but also through more intensive exhaust hoods for cooking applications in adjoined restaurants.

Since the principal objective of this analysis was to produce end-use load shares at summer peak and spring light load hours, we decided that manufacturing electricity consumption for HVAC decomposition should not include space heating, since space heating would be expected to be an extremely small share of load at these hours. Additionally, it was assumed that manufacturers would likely utilize another fuel than electricity for space heating applications in nearly all cases.

The share of ventilation among ventilation and space cooling for commercial lodging buildings in New England was 40% according to the 2003 CBECS, so MECS HVAC estimates were decomposed, with 40% of the HVAC share going to ventilation and 40% going to three phase space cooling.

Industrial Lighting Decomposition

The MECS estimate for electricity consumption for facility lighting was decomposed into categories associated with lamp technologies using the 2010 DOE Lighting Market Characterization Study. LMC Table 4-8 contains shares of industrial lighting for several lamp types. The study found that 40% of annual industrial lighting energy consumption went to linear fluorescent lamps and 60% to high-intensity discharge

[29] Lighting Market Characterization report location: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

lamps. Both of these estimates were rounded up – there was representation of other lamp types, but the shares were so small that they were not broken out in this analysis.

The MECS published two tables of end-use consumption estimates for the manufacturing sector that were considered in this analysis. Table 5.1 gives national level end-use shares of net electricity consumption by NAICS industry code. Table 5.5 gives New England level end-use shares of net electricity for the entire manufacturing sector, rather than by NAICS industry code. While the regional end-use breakdown had obvious advantages for this project, it was decided that capturing the diversity in load share distributions by NAICS industry was more critical. The primary reason was that this was the only path for arriving at a representatively weighted end-use breakdown reflecting the regional differences in the types of manufacturing establishments.

Transformation of the MECS Data

MECS table 5.5 gives end-use shares for net electricity consumption for each three-digit NAICS industry code, and for select four to six digit NAICS codes (the more digits, the more detailed the industry class definition). The first three digits in a four to six digit NAICS code will be the higher level industry class the finer level class is grouped into.

For example, NAICS 311 is the food industry. NAICS 3112 is the class for grain and oilseed milling, which is a more detailed sub-class of the food industry. NAICS 311221 is an even finer level subclass of food, and it is also a subclass of the grain and oilseed milling industry, since the first four digits is 3112.

Since there are hundreds if not thousands of different NAICS codes of various numbers of digits, it would be impractical for the MECS to collect information from enough manufacturing establishments to produce end-use shares for all of these industry classes with sufficient statistical precision. The MECS selects four to six digit NAICS industry classes to account for in its estimates according to their energy intensity as well as other programmatic reasons.

While the MECS estimates form a partition of the manufacturing sector in terms of the three-digit NAICS industry classes, the same cannot be said about the four to six digit NAICS industry class levels. Since the goal of the manufacturing analysis was to merge the end-use consumption shares with establishment counts within the seven New England regions, at a finer level than three-digit NAICS when possible, DNV GL had to produce balance groups at the four to six digit NAICS industry class levels within each main three-digit NAICS class. The end-use shares for the three-digit NAICS level would be used to represent the more granular NAICS balance group. Table 3-12 contains the NAICS industry codes presented in the MECS tables at selected sub-industry class detail, including balance groups defined by DNV GL in this analysis.

Table 3-12 NAICS Industry Class Partition of the Manufacturing Sector Used in the Industrial Analysis

NAICS	Subsector and Industry
311	Food
3112	Grain and Oilseed Milling
3114	Fruit and Vegetable Preserving and Specialty Foods
3115	Dairy Products
3116	Animal Slaughtering and Processing
3110	All other 4-digit NAICS Food Industries
312	Beverage and Tobacco Products

NAICS	Subsector and Industry
3121	Beverages
3122	Tobacco
313	Textile Mills
314	Textile Product Mills
315	Apparel
316	Leather and Allied Products
321	Wood Products
321113	Sawmills
321219	Reconstituted Wood Products
321000	All other 6-digit NAICS Wood Products Industries
322	Paper
322110	Pulp Mills
322121	Paper Mills, except Newsprint
322130	Paperboard Mills
322000	All other 6-digit NAICS Paper Products Industries
324	Petroleum and Coal Products
324110	Petroleum Refineries
324121	Asphalt Paving Mixture and Block
324199	Other Petroleum and Coal Products
324000	All other 6-digit NAICS Petroleum Coal Products Industries
325	Chemicals
325110	Petrochemicals
325120	Industrial Gases
325181	Alkalies and Chlorine
325182	Carbon Black
325188	Other Basic Inorganic Chemicals
325192	Cyclic Crudes and Intermediates
325193	Ethyl Alcohol
325199	Other Basic Organic Chemicals
325211	Plastics Materials and Resins
325212	Synthetic Rubber
325222	Noncellulosic Organic Fibers
325311	Nitrogenous Fertilizers
325312	Phosphatic Fertilizers
325412	Pharmaceutical Preparation
325992	Photographic Film, Paper, Plate, and Chemicals
325000	All other 6-digit NAICS Chemicals Industries
326	Plastics and Rubber Products
327	Nonmetallic Mineral Products
327121	Brick and Structural Clay Tile
327211	Flat Glass
327212	Other Pressed and Blown Glass and Glassware
327213	Glass Containers

NAICS	Subsector and Industry
327215	Glass Products from Purchased Glass
327310	Cements
327410	Lime
327420	Gypsum
327993	Mineral Wool
327000	All other 6-digit NAICS Nonmetalic Mineral Products Industries
331	Primary Metals
331111	Iron and Steel Mills
331112	Electrometallurgical Ferroalloy Products
331314	Secondary Smelting and Alloying of Aluminum
331315	Aluminum Sheet, Plate and Foils
331316	Aluminum Extruded Products
331419	Primary Smelting and Refining of Nonferrous Metals, except Copper and Aluminum
331511	Iron Foundries
331521	Aluminum Die-Casting Foundries
331524	Aluminum Foundries, except Die-Casting
331000	All other 6-digit NAICS Primary Metals Industries
332	Fabricated Metal Products
333	Machinery
334	Computer and Electronic Products
334413	Semiconductors and Related Devices
334000	All other 6-digit NAICS Computer and Electronic Products Industries
335	Electrical Equip., Appliances, and Components
336	Transportation Equipment
336111	Automobiles
336112	Light Trucks and Utility Vehicles
336411	Aircraft
336000	All other 6-digit NAICS Transportation Equipment Industries
337	Furniture and Related Products
339	Miscellaneous

Table 3-13 below presents the estimated manufacturing establishment counts by region and NAICS Industry code (3-digit). This data was tabulated from Census Bureau County Business Pattern Survey data.

Table 3-13 Establishment counts by NAICS industry group and region

NAICS Code	Manufacturing Industry	Establishment Counts							
		Connecticut	Maine	Massachusetts - East	Massachusetts - West/Central	New Hampshire	Rhode Island	Vermont	New England
311	Food	282	184	492	119	104	139	157	1,477
312	Beverage and Tobacco Products	48	37	47	22	21	13	28	216
313	Textile Mills	32	22	54	25	19	48	6	206
314	Textile Product Mills	84	73	98	26	39	43	13	376
315	Apparel	21	5	77	15	19	8	14	159
316	Leather and Allied Products	5	25	26	5	14	8	5	88
321	Wood Products	104	179	103	73	119	32	106	716
322	Paper	59	22	56	73	25	25	6	266
323	Printing and Related Support	374	134	498	171	154	118	70	1,519
324	Petroleum and Coal Products	35	21	31	21	20	2	9	139
325	Chemicals	160	52	247	80	62	60	32	693
326	Plastics and Rubber Products	168	54	167	123	89	53	27	681
327	Nonmetallic Mineral Products	144	67	158	82	80	47	97	675
331	Primary Metals	65	9	55	35	29	45	3	241
332	Fabricated Metal Products	1,175	244	832	453	390	288	108	3,490
333	Machinery	452	81	318	215	154	114	61	1,395
334	Computer and Electronic Products	285	53	567	91	203	45	38	1,282
335	Electrical Equip., Appliances, and Components	149	11	151	51	54	28	22	466
336	Transportation Equipment	186	103	113	26	33	44	14	519
337	Furniture and Related Products	222	102	212	91	72	59	75	833
339	Miscellaneous	338	156	528	155	148	294	95	1,714

NAICS Code	Manufacturing Industry	Establishment Counts							
		Connecticut	Maine	Massachusetts - East	Massachusetts - West/Central	New Hampshire	Rhode Island	Vermont	New England
Manufacturing Total		4,388	1,634	4,830	1,952	1,848	1,513	986	17,151

Census Bureau County Business Patterns Survey

The following table presents the average annual energy consumption and summer peak and light spring load estimates per manufacturing establishment. While the industrial analysis uses NAICS Industry specific annual energy consumption per establishment estimates, they have been aggregated across the industry types in this table as the expanded list would nearly double the length of this report.

Table 3-14 Average Industrial Unit Energy Consumption Estimate by End-Use Category Across All Manufacturing Industries

Industrial End-Use Category	Annual Energy – Average Consumption per Establishment (MWh)	Summer Peak Load Hour - Average Load per Establishment (MW)	Spring Light Load Hour – Average Load per Establishment (MW)
Machine Drive	29,343	3.77	3.25
Process Heating	7,561	0.98	0.86
Process Cooling and Refrigeration	4,969	0.68	0.52
Electro-Chemical Processes	4,664	0.54	0.52
Space Cooling - Three Phase	4,571	0.61	0.52
Ventilation	3,047	0.41	0.35
Lighting - HID Interior	2,997	0.24	0.23
Lighting - CFL/Linear Fluorescent	1,998	0.16	0.16
Other Process Use	1,947	0.26	0.23
Other Facility Support	1,508	0.20	0.17
Conventional Boiler Use	625	0.08	0.07
Other Nonprocess Use	235	0.03	0.03
Onsite Transportation	127	0.02	0.01

3.3.3 Calibration to the Seven New England Regions

Manufacturing

The end-use shares of electricity consumption were calibrated to the seven New England regions by first converting MECS estimates to a per-establishment basis, and then weighting the per-establishment end-use consumption share estimates using region-specific estimated counts of establishments by NAICS industry. The Census Bureau's County Business Patterns Survey includes establishment counts by NAICS industry at the national, state, and county level.

DNV GL aggregated the establishment counts to the Northeast census region level and was paired with the Northeast census region MECS estimates of purchased electricity by NAICS code to get MECS consumption estimates on a per-establishment basis in the census region that includes New England.

The remaining analysis step started with aggregating the CBP establishment counts by NAICS industry up to the 7 regions of this study. These establishment counts per NAICS industry in each region were then used as poststratification weights in the averaging of the end-use consumption estimates across the NAICS industries in each region. The product of this calibration was a set of regional end-use shares which reflected the region-specific distribution of manufacturing industries.

Agriculture

DNV GL used data from the December 2013 Farm Service Agency Planted Cropland report at the state level to determine an estimate of planted acres in the United States and in the New England area. The ratio of cropland in New England to the total cropland in the United States was multiplied by the nationwide purchased electricity total for the agricultural sector from the 2012 AEO, which was used as an estimate of purchased electricity for the agricultural sector in New England.

This regional estimate was then subdivided into state-level estimates by using the ratio of cropland in each state compared to the total cropland in New England. To split the state-level estimate for Massachusetts into the West/Central and Eastern regions, county level data from the December 2013 FSA Planted Cropland report was used in a similar manner to estimate the ratio of the planted cropland in each portion of the state. The state-level estimate for Massachusetts was then divided in accordance with the calculated ratios. This process resulted in the regionally-specific estimates of purchased electricity consumption for the seven New England regions.

Mining

The DNV GL approach for the mining industry electricity consumption estimates for the seven regions was to apportion the national-level AEO estimate of purchased electricity consumed by the mining industry to the seven regions using state-level estimates of an appropriate economic measure correlated with purchased electricity. Purchased electricity happened to be one of the economic measures in the state-level mining data, so we first attempted to make use of that directly. Unfortunately, several states had estimates withheld due to either risk of disclosure or insufficient statistical precision.

To find a backup economic measure for apportioning national purchased electricity for the industry, DNV GL computed the sum of the squared differences in the regional shares for the New England states without purchased electricity suppressed and the corresponding shares for other candidate economic measures. Value added had the lowest sum of squares, so it was used to apportion purchased electricity down to the state level. Massachusetts was further subdivided using the corresponding division ratio from the manufacturing sector as a proxy.

Construction

DNV GL used a very similar approach in the construction industry as was taken for mining. Again, the 2012 AEO national estimate of energy consumption of purchased electricity for the mining industry needed to be apportioned to the New England states using an appropriate economic measure that was thought to be highly correlated with energy consumption of purchased electricity. Purchased electricity in dollars was available for the construction industry state-level data, but for three states the dollar values were withheld. DNV GL first estimated the purchased electricity for these three states using value added state-level shares, then the purchased electricity cost value was used to apportion the national estimate from the AEO to the seven regions, and Massachusetts was divided into east and west/central using the corresponding ratio for the manufacturing industry total.

3.3.4 Calibration to summer peak and spring light load hours

For Industrial end uses, the principal driver of load variation is the industry, noted by Standard Industrial Classification (SIC) or North American Industrial Classification System (NAICS) code. As with the residential and commercial sector, hourly contribution of each annual end-use share were calculated via the development of a load shape library, as described in section (3) of the Methodology. Unlike the residential and commercial sector analyses, however, end-use specific load shapes were not available by industry segment, but rather only at the whole-site level. This implies that the end-use load share fractions within each industry group is constant, but the load magnitudes vary by time and season in accordance with the load seasonality at the whole-site level.

Typically, the bulk of the loads are for industry-specific processes with load factors that are typically very high, which means that end-use specific load shape time series are less critical to this study for the industrial sector than for the residential and commercial sectors. The operating hours typically only vary by number of shifts (2 or 3) and whether or not it is a 5, 6 or 7 day per week operation. Some industries are also seasonal to some degree, not dependent on weather but rather on the nature and availability of the product raw materials and output delivery. Industry-specific load shapes are clearly the best source, although since load factors are so high, assumed values for two or three shifts and 5, 6 or 7 day operation, with flat load shapes during those operating times can provide a reasonable approximation.

Weather-sensitivity is not a major consideration since any heating or cooling is nearly insignificant compared to process loads. However, DNV GL adjusted the load ratios for space cooling to reflect region-specific cooling degree-days in a similar approach to that was used in the commercial and industrial sector. Therefore the end-use shares were not static since space cooling shares accounted for differences along the time series, albeit slight differences.

For the industries selected for inclusion, data from the RTF database was available for the following SIC groupings, from which applicable load shapes were drawn. For other industries, either the “Other” or “Total Industrial” load shape was an option.

IND_SIC 20 - Food and Kindred Products

IND_SIC 24 - Lumber and Wood Products, Except Furniture

IND_SIC 26 - Paper and Allied Products

IND_SIC 28 - Chemicals and Allied Products

IND_SIC 29 - Petroleum Refining and Related Industries

IND_SIC 33 - Primary Metal Industries

IND_SIC 37 - Transportation Equipment

For the agricultural sector, DNV GL used the load shape associated with irrigation as this most closely approximated the seasonality of agricultural electricity consumption. For construction and mining the load shape for the “All Other” SIC industries was used in the analysis.

A set of ratios to produce those specific hourly kW values from the annual kWh usage input for each industry was produced from the full load shape. Each SIC code was converted to NAICS to facilitate matching to the regional end-use share estimation framework.[30]

Specific sources are noted in the appendix and supplemental documents provided.

3.4 Data Sources for Load Ratios Used in this Study

For the Residential load shapes, the primary sources for the load shape factors were Massachusetts, Long Island, NEEP, and PG&E load shapes from end use studies obtained from the Northwest Power Council Regional Technical Forum (RTF). DNV GL staff member Joseph Lopes was the consultant on the Joint Utility Monitoring Project (JUMP), worked directly with LILCO on developing the LILCO Pool Pump load shapes and completed a project in early 2013 that involved compiling and formatting over 250 load shapes used in the RTF member utilities and organizations, from which many of the non-weather-sensitive end use load shapes were obtained. This enabled a full appreciation of the quality of the data and a good sense of the applicability and required adjustments (specifically weather) required to make them appropriate for use in this project.

For the Commercial load shapes, the primary sources were NEEP Unitary A/C studies performed by KEMA (now DNV GL) in 2011, with ISO-NE regional weather adjustments; NEEP Lighting Load Shape Project performed by KEMA (now DNV GL) in 2011; RTF for most other non-lighting/non-weather-sensitive loads; and an international end use study for elevators. Detailed sources and assumptions, with links, where available, are provided in the following tables.

For Industrial load shapes, the primary source was the RTF Load Shape archive for those SICs available. No weather adjustments were considered necessary since process loads are the dominant component.

[30] NAICS to SIC conversion was done using an online tool: http://www.naics.com/search.htm

Table 3-15 Residential Load Shape Source documentation

Residential End-Use Category	Data Source	Methodology Notes	URL (where applicable)
Room A/C	PG&E Blue Canyon from Northwest Regional Council / Regional Technical Forum (RTF) Archives	Blue Canyon has similar Annual CDD to New England. Weather adjustment from 10-year ISO-NE weather archives analysis	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
CAC/HP	LIPA Edge Hourly Loads with New England Regional Weather	Weather adjustment from 10-year ISO-NE weather archives analysis	
3-phase A/C	PG&E large multi-family, weather adjusted by ISO-NE Zones	Weather adjustment from 10-year ISO-NE weather archives analysis; used large Multi-family to reflect larger MF units	RTF load shapes.xlsx; ELCAP Res load shapes 8760.xls
Ventilation/fans	PG&E Blue Canyon from Northwest Regional Council / Regional Technical Forum (RTF) Archives	Used Room A/C load shape and weather adjustment	RTF load shapes.xlsx; ELCAP Res load shapes 8760.xls
Refrigerator/Freezer	PG&E, from Regional Technical Forum (RTF) Archives	No peak day adjustment	RTF load shapes.xlsx; ELCAP Res load shapes 8760.xls
Elec-TVs	PG&E, from Regional Technical Forum (RTF) Archives (ELCAP)		RTF load shapes.xlsx; ELCAP Res load shapes 8760.xls
Elec-settop boxes	PG&E, from Regional Technical Forum (RTF) Archives Refrigerator load shape	Removed monthly seasonality (same use/day)	RTF load shapes.xlsx; ELCAP Res load shapes 8760.xls
Lighting – CFL and Incandescent	Extract of 2009 NEEP/NMR Res Lighting Markdown Eval		http://www.env.state.ma.us/dpu/docs/electric/09-64/12409nstrd2ae.pdf
Elec - Other	Same as Lighting Load Shape (2009 NEEP/NMR Res Lighting Markdown Eval)	Assumed same shape as Res lighting	
Electric Heating	PG&E Blue Canyon from Northwest Regional Council / Regional Technical Forum (RTF) Archives	Blue Canyon has similar Annual HDD to New England. Weather adjustment from 10-year ISO-NE weather archives analysis	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Electric Range	Massachusetts Joint Utility Monitoring Project (JUMP)		1989-1991 end use load study
Dishwasher	PG&E, from Regional Technical Forum (RTF) Archives	No peak day adjustment	RTF load shapes.xlsx; ELCAP Res load shapes 8760.xls
Clothes Dryer	Massachusetts Joint Utility Monitoring Project (JUMP)	No peak day adjustment	1989-1991 end use load study
Washing Machine	Same as Dryer (JUMP)		

Residential End-Use Category	Data Source	Methodology Notes	URL (where applicable)
Swimming Pool Pump	LILCO Pool Pump DLC Evaluation (1991) with Vermont TRM monthly allocation	LILCO monthly use allocation revised to use Vermont TRM monthly allocation	
CRT TV's	Same as Lighting Load Shape (2009 NMR Res Lighting Markdown Eval)	Assumed same shape as Res lighting	
Water Heaters	Massachusetts Joint Utility Monitoring Project (JUMP)	No peak day adjustment	
Sump, Well, & Water Pressure Pumps	Massachusetts Joint Utility Monitoring Project (JUMP)	Same as Water Heaters	
Other Residential End Uses	Same as Lighting Load Shape (2009 NMR Res Lighting Markdown Eval)	Assumed same shape as Res lighting	

Table 3-16 Commercial Load Shape Source documentation

Commercial End-Use Category	Data Source	Methodology Notes	URL (where applicable)
Central A/C (3-phase, split and single-phase)	NEEP C&I Unitary HVAC Load Shape Project (2011)	Separate load shapes by Business Types (all except Warehouse, Lodging, Large Office, Religious and Assembly), and by ISO-NE Region (used 10-year weather database for monthly allocation and peak day adjustment)	NEEP EM&V Forum Load Shape Studies Databases (Unitary HVAC Load Shape Tool) http://neep.org/emv-forum/forum-products-and-guidelines/index#loadshape
Central A/C (3-phase, split and single-phase)	RTF Commercial Cooling Database	Separate load shapes by Business Types (for Warehouse, Lodging, and Large Office), and by ISO-NE Region (used 10-year weather database for monthly allocation and peak day adjustment)	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Central A/C (3-phase, split and single-phase)	Rochester Gas & Electric 1991 Commercial end use load study modeling	Separate load shapes for Public Assembly (also used for Religious), and by ISO-NE Region (used 10-year weather database for monthly allocation and peak day adjustment)	
Ventilation/Fans	RTF Commercial Ventilation	Load shape not considered sufficiently different by business type, high load factor, insufficient source data for further segmentation	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Refrigeration	RTF Commercial Refrigeration	Load shape not considered sufficiently different by business type, high load factor, insufficient source data for further segmentation	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls

Commercial End-Use Category	Data Source	Methodology Notes	URL (where applicable)
Electronics Loads	RTF Office Equipment	Load shape not considered sufficiently different by business type, high load factor, insufficient source data for further segmentation	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Interior Lighting (also Fluorescent/CFL and incandescent)	NEEP Lighting Load Shape Project (KEMA 2011)	Separate load shapes by Business Types (Office, Warehouse, Grocery, Medical, University/College, Education, Lodging, Retail, Restaurant, Religious, Public Assembly, Service, Other)	NEEP EM&V Forum Load Shape Studies Databases (Commercial Lighting Load Shape Tool) http://neep.org/emv-forum/forum-products-and-guidelines/index#loadshape
Electric Heating	RTF Commercial Heating Database	Separate load shapes by ISO-NE Region (used 10-year weather database for monthly allocation and peak day adjustment). Differences by business type were not available and not considered significant enough at the targeted hours (Summer peak and Spring/Fall low load time) to warrant additional detail.	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Electric Range	RTF Commercial Cooking	Differences by business type were not available and not considered significant enough at the targeted hours to warrant additional detail.	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Air Compression	RTF Commercial Air Compressors	Differences by business type were not available and not considered significant enough at the targeted hours to warrant additional detail.	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Elevator Drives, Lifts, and Hydraulic Pumps	Finnish/Portuguese study of Large Office traffic	Large Offices are the dominant load for this end use	load data from 2006 study "Elevator planning with stochastic multicriteria acceptability analysis" by Tommi Tervonena, Henri Hakonen, Risto Lahdelmab (Finland, Portugal) (published on-line 2009) - http://www.lgi.ecp.fr/~mousseau/Cours/MCDA/pmwiki/uploads/Main/article2009-5.pdf
Water Heating	RTF Commercial Water Heating	Differences by business type were not available and not considered significant enough at the targeted hours to warrant additional detail.	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls
Other	RTF Commercial Misc.	Differences by business type were not available and not considered significant enough at the targeted hours to warrant additional detail.	http://www.nwcouncil.org/ RTF load shapes.xlsx; ELCAP (late 1980's) Res load shapes 8760.xls

3.5 Aggregating Weather Data

In order to generate the weather-related ratios specific to the seven New England regions, hourly weather data for each of the zones was obtained from the ISO-NE web site, at their directions.[31] These data files contained hourly dry bulb temperature and dew point (the two variables used by ISO-NE to define peak conditions), with each year's data contained in a separate Excel file going back to 2003. As of the date of the analysis, data through October 2013 had been compiled. From these files, daily statistics were developed, calculating maximum, minimum and average dry bulb temperature, heating degree days (65 degree F base) and cooling degrees (55, 60 and 65 F bases) and dew point for afternoon (Hour ending 16). To produce a sufficient basis for calculating averages and variation of period of exactly ten years was used, ending the latest month of data, i.e., November 2003 through October 2013. Given recent warming trends, 10 years was considered the best option, although another data source would have been used for additional years.

For weather-sensitivity analysis, both a 65 degree and 55 degree base was calculated for cooling degree days because, based on prior extensive experience with cooling loads by sector, residential cooling matched well to cooling degree days using a 65 degree base but commercial loads matched much better to a 55 degree base. This is largely attributable to heat gain in commercial buildings, which causes cooling requirements even when outdoor temperatures are below 65 degrees.

This weather data was then used in the calculation of the key weather-sensitive ratios, namely monthly usage allocation and peak day adjustment factor. The other two load shape ratios used in the load shape library method – weekend to weekday ratio and daily percent by hour by day type - typically do not vary by any predictable weather statistic:

- Residential weekend to weekday ratios are typically close to 1, although the distribution of usage across hours does vary, reflected in different weekend day to weekday hourly factors (e.g. later start on weekends).

- Commercial weekend to weekday factors for cooling and heating are driven by the business type, reflecting the operating hours of those businesses, rather than weather. This is especially true of cooling, which is more discretionary, and is often shut down when the businesses are not operating. For heating, setbacks are often employed during non-operational hours. For 24-hour business types, like Health and Hotel, the weekend to weekday factors are typically higher than for businesses that operate more limited hours, such as small offices and educational facilities, reflected in the differences in weekend to weekday ratios for all end uses, including cooling and heating.

- For per-unit day-type load shapes, daily load shapes for weather-sensitive end uses are primarily a function of dwelling type for residential and business type for commercial, with operating hours a major factor. Per-unit end use load shapes, when consolidated by business, would not vary significantly given similar weather conditions. Where borrowed hourly load shapes do not have the same seasonality, monthly day type load shapes could be matched to similar climate months from the borrowed load shape area. For example, the daily weather in a moderate climate in July may be comparable to the weather in a hot climate in May, so the heating and cooling per-unit load shapes

[31] Hourly Zonal Data Files by year:
http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html

for the hot climate in May could be used for the moderate climate for July. Within-day weather variation must be accounted for, since this could vary significantly.

For monthly usage allocation for heating and cooling, the heating and cooling degree days for each of the 8 load zones, corresponding to 7 weather zones (RI and SEMASS use the same weather station) were calculated from the 10 years of weather data (November 2003 – October2013). Average degree days for heating (65 degree base = HDD65) and cooling (both 55 degree base = CDD55 for commercial and 65 degree base for residential = CDD65) were calculated by month to determine average monthly heating and cooling factors. The variation across the 8 zones was analyzed for each of the degree day stats to determine where significant differences existed, with the following results:

- HDD65 – The pattern is very consistent for percent of annual across all 8 zones, so a single set of 12 monthly values was used. Levels did vary, reflecting the climate, as would be expected, but the ratios were consistent.

- CDD65 – The pattern shows 4 distinct groupings:
  - ME – the most concentrated in the peak month
  - NH,WCMASS
  - VT,RI,SEMASS
  - CT,NEMASSBOST – the least concentrated in the peak month

- CDD55 - The pattern shows 3 distinct groupings:
  - ME – The most concentrated in the peak month
  - NH,VT,WCMASS
  - CT, RI,SEMASS,NEMASSBOST – the least concentrated in the peak month

For Peak Day Adjustment, specific factors for each weather zone were computed. Based on the peak definition provided by LBNL (95 degrees, 70 degree dew point In July), which represents an approximately 1 in 10 probability of occurrence by year (1 in 10 years), the ratio of weather sensitivity for that type day vs. an average day in July and August was calculated for each month and year. The pattern shows 3 distinct groupings:

  - NH,VT,WCMASS – the highest peaking factor
  - ME
  - CT, RI,SEMASS,NEMASSBOST – the lowest peaking factor

As a result, a complete custom set of monthly factors and peak day factors for each weather zone and weather statistic (HDD65 for heating, CDD65 for residential cooling, CDD55 for commercial cooling) was developed and applied to each of the applicable residential and commercial heating and cooling load shape factors.

3.5.1 Calibration of weather sensitive load ratios to Regions within New England

The objective of the peak load analysis was to estimate the contribution of load components under ISO-NE- “peak” conditions, which were defined as 95 degrees and 70 degree dew point for the overall ISO-NE region, which was considered a 1 in 10 year probability of occurrence. In reviewing the weather data over the 10 year period of weather data studied, there was indeed only one occurrence of the combination of 95 degrees and 70 degree dew point. This occurred on August 2, 2006, with a high of 95 degrees and 73 dew point.

In order to calculate the 1 in 10 year occurrence by each of the 8 regions (7 distinct weather zones), the ratio of peak to average weekday (PDAF) for each year was calculated. Rather than use the actual 1 in 10 occurrence for each region, which could be quite volatile, a statistical method was used instead, using the standard deviation of the PDAFs, assuming a normal distribution, and building a 90% confidence interval, equivalent to a 1 in 10 year occurrence pattern. The resulting calculation, when applied to the weather-sensitive loads for July (cooling, ventilation and pool pumps), produced total weather-sensitive load built from the bottom-up by end uses that was significantly less than the ISO-NE top-down estimate for a 1 in 10 year weather-sensitive load and, instead, comparable to a 1 in 2 year weather-sensitive load estimate.

Given that, the distribution of actual occurrences of 95 degrees and 70 degree dew point were reviewed for each region, with the following result:

Table 3-17 Distribution of Weather by ISO-NE Region

Region	Days at/over 95° and dew point at/over 70°	Conditions on 8/2/06 (Max Temperature/dew point)
ISO-NE Total	1 (8/2/06)	95/73
ME	1	93/74
NH	2	96/70
VT	2	92/74
CT	7	99/72
RI	4	100/73
SEMASS	4	100/73
WCMASS	0	93/72
NEMASSBOST	3	98/73
Total of Regions	23	
Average of Regions	2.875	

As indicated, the number of occurrences by region varied between 0 (WCMASS) and 7 (CT), with a total of 23 occurrences in the 8 regions. Some regions experienced more extreme conditions than the "95/70" and some less to enable the overall ISO-NE conditions to average "95/70". When analyzing the ratios by region, therefore, the occurrences of 95/70 were about 2.9 per 10 years, on average, for the "95/70" conditions, rather than each individual 1 in 10 probability. The diversity of weather across the regions caused the 1 in 10 year occurrence overall, despite occurring more often in most of the regions, more extreme conditions on the overall 95/70 day and even different days, in some cases. In order to produce the 1 in 10 conditions for the overall ISO-NE service area, therefore, a more stringent condition than 1 in 10 by region is required. Higher confidence levels were considered, with the objective of producing a higher set of PDAFs by region, scaled proportionately, that would produce a total bottom-up weather-sensitive load that better matched the ISO-NE top-down weather-sensitive load.

To the base PDAF factors for the 90% confidence level, we applied the adjustment factors for 99% confidence levels, which were 1.1 for base-65 degree cooling degree-days (residential) and 1.05 for base-55 cooling degree-days (commercial). The resulting total weather-sensitive load for the ISO-NE System, which applies to cooling, pool pumps and ventilation, was then compared to ISO-NE's own estimates of top-down weather-sensitive load to calibrate the PDAFs further.

In comparing regions, the pattern of peak to average day ratios showed 3 distinct groupings:

- New Hampshire, Vermont, West/Central Massachusetts – the highest peaking factor
- Maine – medium peaking factor
- Connecticut, Rhode Island, Southeast Massachusetts, Northeast Massachusetts/Boston – the lowest peaking factor

As a result, a complete custom set of monthly factors and peak day factors for each weather zone and weather statistic (HDD65 for heating, CDD65 for residential cooling, CDD55 for commercial cooling) was developed and applied to each of the applicable residential and commercial heating and cooling load shape factors.

3.6 Combining Estimates to Represent Total Load

The DNV GL team combined the estimated energy consumption of the end-use categories produced for each sector in the summer peak and spring light load hours to represent total system load. This was done by summing the estimated consumption for each end-use category across the residential, commercial, and industrial sectors. Certain end-use categories, such as machine drives, are only represented in one sector. Other categories, such as three phase space cooling, are represented in multiple sectors. For end-use categories like three phase space cooling, the corresponding estimate of summer peak hour energy in the final cross-sector end-use load model is equal to the sum of the peak hour energy estimates for three phase space cooling in the residential, commercial, and industrial sectors. The end-use categories are aggregated in this manner as a precursor to applying the rules of association for the end use load categories. The same rules of association will apply for three phase space cooling, for example, whether it is space cooling in the residential, commercial, or industrial sector.

The fractional end-use shares for each region are computed after aggregating the end-use energy consumption shares, i.e. when the fractional shares are summed, “one hundred percent” corresponds with the full system load that is accounted for in this analysis.

3.7 Reconciliation of Estimates Produced in this Study with More Granular Data Sources

The ultimate purpose for the analysis estimates produced in this study will be applying the models to finer level geographic areas corresponding to segments of the ISO-NE grid specific to individual transmission owners. This is inevitably problematic since the end-use estimates for the seven regions of this study are at a higher geographic level with broader customer class diversity than should be expected for grid segments such as individual feeders.

DNV GL recommends some of or all of the following regional calibration approaches for reconciling the estimates with specific areas of application:

- **Calibrate peak and light load hour adjustment ratios to local weather data**: If the end-use load model is applied to a region where weather differences from the broader region are expected to be influential, the load ratios used to derive estimates for the peak and light load hours should be adjusted to reflect the local weather conditions. This step will be most important for microclimates, such as mountainous or coastal areas, where electricity demand from HVAC systems in the two load hours will differ from the region overall. Calibration of the load ratios consists of the following steps. Detailed information on the load ratios can be found in Section 3. Load ratios are specific to end-use categories for customer segments within sectors, e.g. space cooling for single-family homes.

- Monthly adjustment factor: If there is a significantly different fraction of annual cooling degree-days for the year for July or May for the locality as compared with the estimate for the region overall, this should be adjusted up or down to reflect the difference.
- Peak day adjustment factor: The peak day adjustment factor should reflect the increase in load on a peak day within the month with respect to an average day. Should the locality have a higher or lower expected peak day adjustment factor than the estimate for the region overall, it should be adjusted to reflect the expected difference.
- Hour of day adjustment factor: If the HVAC load is expected to differ for a locality at peak or light load hour than the estimated ratio for the region overall for an end-use within a customer segment, this may be adjusted to account for the applicable ratio.

- **Calibrate weekend to weekday ratio:** If the weekend to weekday ratio differs from the estimate for the region for a customer segment, this should be adjusted up or down to account for the difference. This is most relevant for the industrial sector, where customer demand is related to operating schedules which can vary significantly from establishment to establishment. For example, if a transmission owner knows an industrial customer on a feeder to have weekend load to be on average 80% of that on weekdays, the weekend ratio should be 0.8 for that industrial class.

- **Calibrate estimates to more granular estimates for customer class penetration:** The most important calibration step to specific localities is to utilize the most accurate estimates for customer penetration by sector (e.g. residential customers) or class (e.g. the count of healthcare facilities in the commercial sector). Customer billing data that can be mapped to residential, commercial and industrial sectors, as roughly defined by this study, is a good source for calibrating to proportional representation at the level of application of the end-use load model. For example, suppose the end-use load model assumes 40% residential load in the summer peak load hour for a particular region, but it is known that the load on a particular feeder is 80% residential. In this circumstance we would recommend utilizing the end-use proportional shares within each sector from this study, but re-weight them by the localized representation.

  To further improve the accuracy of the load model in localized applications, DNV GL recommends mapping the localized region to counties, and re-weighting the class-level penetration estimates according to representation of customer classes by county, using estimates from the Census Bureau's American Community Survey (ACS) and County Business Patterns Survey (CBP). The ACS, for example, can provide resolution into the number of food processing industrial establishments there are in a county.

Beyond these steps and other analysis providing deeper resolution to the load activities in specific localities, DNV GL recommends that the proportional shares for the sectors and end-use categories be applied to total system load. For example, if the system load for a transmission region is 2 gi, the transmission owner could assume that this load divides into sectors and end-use categories within sectors at the same proportions given for the one region of the seven used in this study that the transmission region is best aligned.

It should also be noted that the estimates in this study should be considered to be at the level of customer premises, so line losses should be taken into account when making comparisons to measurements taken upstream in transmission and distribution systems.

3.8 Calibration of regional end-use estimates using load information from bus-level customers

Throughout New England there is approximately 680 MW of directly modelled load. This section describes two recommended approaches for adjusting the end-use load model for the seven regions of this study to account for these loads, effectively removing the large modelled loads that are already modelled by system planners.

Less Intensive Approach

This approach utilizes the companion spreadsheet "Composite Load Model Input Tool.xlsx". If this spreadsheet is unavailable to a reader of this report, instructions for replicating the approach are contained in Appendix C.

Step 1: Open the companion workbook to this report, "Composite Load Model Input Tool.xlsx".

Summer Peak Hour Load		
Connecticut	(green)	User inputs for customized load breakdowns
24,000	(yellow)	Generated Load Component Breakdowns specific to the inputs in the green cells
40%	(no color)	No color: default load breakdowns by region if no information is entered
40%		
20%		

	Percentage Shares							Load Breakdown (MW)						
Custom	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Overall	18%	24%	10%	10%	13%	11%	14%	4,383.56	5,833.12	2,501.32	2,298.08	3,024.14	2,630.50	3,329.27
Commercial	17%	28%	11%	4%	8%	23%	10%	1,668.36	2,707.42	1,020.35	344.94	748.26	2,161.57	949.09
Industrial	20%	33%	9%	17%	3%	2%	17%	1,877.96	3,125.69	845.75	1,631.94	240.15	217.36	1,661.13
Residential	17%	0%	13%	7%	42%	5%	15%	837.24	-	635.22	321.20	2,035.73	251.57	719.05

Step 2: Compute the system load percentage breakdown between residential, commercial, and industrial, after subtracting the industrial load that is individually modelled and accounted for separately.

Step 3: Enter the new values into the green shaded cells in either the summer peak or spring light tab of the spreadsheet.

For example, suppose it was known that some portion of Connecticut had total system load at summer peak of 5,000 MW with breakdown 40% residential, 40% commercial, 20% industrial, and that there was a large industrial customer accounting for 500 MW of the 1,000 MW of industrial load which was modelled separately. The new system load value that would be entered into the spreadsheet would be 4,500 MW and the percentage breakdowns would be 44.44% for both residential and commercial, and 11.11% for industrial:

Adjusted residential and commercial percentage = 2,000 MW/4,500 MW = .4444

Adjusted industrial percentage = 500 MW/4,500 MW = .1111

The less intensive approach has the advantage of being quite simple to implement but does not account for the revised load component distribution for the remaining industrial load. In deciding whether to use this simplified approach, we recommend comparing the load component distribution pie chart for the NAICS industrial class associated with the large individually modelled load to the default industrial load component distribution listed in the spreadsheet for the region. If the distribution is very similar, this less intensive approach may be appropriate.

More Intensive Approach

Step 1: Collect NAICS industrial classification for the individual load.

Step 2: Locate the NAICS code and corresponding New England region in the manufacturing tab of the Sector class end-use and load component shares workbook, e.g. Plastics Materials and Resins Manufacturers (NAICS 325211) in Rhode Island.

	A	B	C	D	E	F	G
	Region	Sector	NAICS Code	NAICS Code Definition	3-Digit NAICS Code	3-Digit NAICS Code Definitio	Number of Establishments
6	Rhode Island	Industrial	325211	Plastics Materials and Resins	325	Chemicals	12
3	Rhode Island	Industrial	325211	Plastics Materials and Resins	325	Chemicals	12
30	Rhode Island	Industrial	325211	Plastics Materials and Resins	325	Chemicals	12
27	Rhode Island	Industrial	325211	Plastics Materials and Resins	325	Chemicals	12
74	Rhode Island	Industrial	325211	Plastics Materials and Resins	325	Chemicals	12

Step 3: Locate the establishment count column for the industry/region. For example, there are 12 Plastics Materials and Resins manufacturing establishments in Rhode Island.

Step 4: Compute the per establishment estimated average load for the industry and region. For this example, the peak GWh for this industry across the 12 establishments in Rhode Island is 0.00629 (6.29 MW), so the average is around 524 kW per establishment.

	A	B	C	D	L	M	N	O	P
1	Region	Sector	NAICS Code	NAICS Code Definition	ROA Component	ROA Estimate	ROA Component Annual mkWh	ROA Component Summer Peak mkwh	ROA Component Spring Light Load mkwh
39674	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor C	0.05	0.105112966	1.13506E-05	1.15061E-05
40021	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor D	0.05	0.105112966	1.13506E-05	1.15061E-05
40368	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Ip	0	0	0	0
40715	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Iq	0	0	0	0
41062	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Pp	0	0	0	0
41409	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Pq	0	0	0	0
41756	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Zp	0.8	1.681807461	0.00018161	0.000184098
42103	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Zq	0	0	0	0
42450	Rhode Island	Industrial	325211	Plastics Materials and Resins	Electronics	0.1	0.1567736	1.69292E-05	1.71611E-05
42797	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor A	0.9	1.410962403	0.000152363	0.00015445
43144	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor B	0	0	0	0
43491	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor C	0	0	0	0
43838	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor D	0	0	0	0
44185	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Ip	0	0	0	0
44532	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Iq	0	0	0	0
44879	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Pp	0	0	0	0
45226	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Pq	0	0	0	0
45573	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Zp	0	0	0	0
45920	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Zq	0	0	0	0
46267	Rhode Island	Industrial	325211	Plastics Materials and Resins	Electronics	0.3	0.313547201	3.38584E-05	3.43222E-05
46614	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor A	0	0	0	0
46961	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor B	0.7	0.731610135	7.90028E-05	8.00851E-05
47308	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor C	0	0	0	0
47655	Rhode Island	Industrial	325211	Plastics Materials and Resins	Motor D	0	0	0	0
48002	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Ip	0	0	0	0
48349	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Iq	0	0	0	0
48696	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Pp	0	0	0	0
49043	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Pq	0	0	0	0
49390	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Zp	0	0	0	0
49737	Rhode Island	Industrial	325211	Plastics Materials and Resins	ZIP-Zq	0	0	0	0
49854									

Manufacturing / NAICS Industries / Manufacturing-SpringLight / Manufacturing - Spring ROA / Manufacturing-SummerPeak / Manufacturing - Summer ROA / Agriculture / Mining / Construction / Comm NAIC

Ready 143 of 49852 records found Average: 4.39855E-05 Count: 144 Sum: 0.006289924

Step 5: Set the establishment count to be one less for the type of load you wish to subtract. In this example, we would set the number of NAICS 325211 establishments to be 11 instead of 12.

Step 6: Re-compute the NAICS industry group/region total load or consumption as the product of the new number of establishments count and the per establishment load estimate.

Step 7: Re-compute the total load estimate for the region with the reduced load estimate for the selected industry group.

Given that the industrial end-use analysis is the least regionally specific of all of the sectors in this study (because of the limited data available), we recommend the following additional steps:

- For industrial establishments that are individually modelled, compare the known annual energy consumption for that site vs. the per-site estimated value given in the intermediate analysis workbook that was derived from EIA data.
- If there are other establishments of that type in the region, and the annual energy consumption in the workbook for that type of establishment appears to be erroneous not only for the modelled site, but also for other sites of that type in the region, we recommend replacing the per-establishment annual consumption estimate with this new one.

If the distribution of residential and/or commercial customers by sector class (e.g. schools) is known, we recommend updating the number of households or building type counts in the corresponding residential and commercial tabs of the intermediate analysis workbook and re-computing the weighted average across sector classes in a similar approach as described above. The updated customer counts could be taken from customer billing information, county level census data, or another source.

4 RULES OF ASSOCIATION FOR END-USE LOADS

While the end-use load disaggregation estimation framework was a significant task in this study, it is effectively an intermediate analysis activity since the ultimate objective was to further decompose system load into load components which are used in the composite load model developed for the Western Electricity Coordinating Council (WECC). The load component categories defined for this reliability modelling framework are as follows:

- Constant power electronics loads
- Constant power motor loads
  - Motor A: Constant load torque, e.g. three-phase condenser motor
  - Motor B: Load torque proportional to speed squared with high inertia, e.g. a fan
  - Motor C: Load torque proportional to speed squared with low inertia, e.g. a pump
  - Motor D: Single-phase air conditioners
- Constant current loads
- Constant impedance loads

To facilitate the decomposition of system load into these load components in the WECC region, David Chassin (Pacific Northwest National Laboratory) and Dmitri Kosterev (Bonneville Power Authority) developed so-called rules of association for disaggregating end-use load into load categories. The rules of association were set up as the lynchpin between two separate problems with separate research objectives which, when connected by the rules of association, combine to address the primary research question of this study. Estimated disaggregations of system and sector level power consumption and load has been researched since at least the 1970's for load forecasting, demand-side management (DSM), and other applications. Load dynamics with respect to voltage has been researched for power system reliability applications, although with insufficient coverage of end-use loads used in various customer classes.

The rules of association developed for the WECC system were preliminary assignments based primarily on intuition from knowledge and experience researching end-use loads, rather than through rigorous research studies. Rules of association were developed only for single-family and multi-family residential customers and for several commercial customer classes.

This section of the report presents the rules of association used in this study, which used the WECC rules as a starting point and were modified based on data sources identified and engineering judgment.

4.1 Rules of Association for WECC Composite Load Model

The starting point for the rules of association used in this study was the set of rules for the WECC Composite Load Model, which is presented in Table 4-1. The WECC rules cover several end-use categories within customer classes, all of which are accounted for in the estimation framework developed in this study, but several of the customer classes and end-use categories of this study are not accounted for in the WECC rules of association. Because of this, it was necessary to expand the rules from the table presented below.

The nomenclature of the WECC load components references ZIP model parameters (e.g. ZIP Ip), which we decided to avoid using, for reasons discussed in Section 4.2.1. For some end-use categories the WECC rules of association include estimates associated with reactive power. Since this study only focused on active power, we do not present component estimates for reactive power, which have column headings ending in "q" (e.g. ZIP Iq).

Table 4-1 WECC Load Component Rules of Association

Building Type	End Use	Electronic	Motor-A	Motor-B	Motor-C	Motor-D	ZIP Ip	ZIP Iq	ZIP Zp (G)	ZIP Zq (B)
Grocery	Heating		0.70			0.20			0.10	0.02
	Cooling		1.00			0.00				
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.10	0.80			0.10				
	Exterior Lighting						1.00	-0.36		0.06
	Interior Lighting						1.00	-0.36		0.06
	Office Equipment	1.00								
	Miscellaneous			0.50	0.50					
	Process			0.50	0.50					
	Motors		0.30	0.40	0.30					
	Air Compression		1.00							
Health	Heating		0.75			0.15			0.10	0.02
	Cooling		1.00							
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.20	0.70			0.10				
	Exterior Lighting						1.00	-1.20		0.20
	Interior Lighting						1.00	-1.20		0.20
	Office Equipment	1.00								
	Miscellaneous								1.00	
	Process			0.50	0.50					
	Motors			0.50	0.50					
	Air Compression		1.00							

Building Type	End Use	Electronic	Motor-A	Motor-B	Motor-C	Motor-D	ZIP Ip	ZIP Iq	ZIP Zp (G)	ZIP Zq (B)
Large office	Heating		0.70			0.20			0.10	0.02
	Cooling		1.00			0.00				
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.10	0.80			0.10				
	Exterior Lighting						1.00	-0.36		0.06
	Interior Lighting						1.00	-0.36		0.06
	Office Equipment	1.00								
	Miscellaneous			0.50	0.50					
	Process	0.50		0.25	0.25					
	Motors		0.30	0.40	0.30					
	Air Compression		1.00							
Lodging	Heating		0.70			0.20			0.10	0.02
	Cooling		0.50			0.50				
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.10	0.40			0.50				
	Exterior Lighting						1.00	-0.36		0.06
	Interior Lighting						1.00	-0.36		0.06
	Office Equipment	1.00								
	Miscellaneous			0.50	0.50					
	Process			0.50	0.50					
	Motors		0.30	0.40	0.30					
	Air Compression		1.00							
Multi-family	Cooking	0.40							0.60	

Building Type	End Use	Electronic	Motor-A	Motor-B	Motor-C	Motor-D	ZIP Ip	ZIP Iq	ZIP Zp (G)	ZIP Zq (B)
loads	Water Heating								1.00	
	Lighting						0.10	-0.02	0.90	
	Plugs	0.90							0.10	
	Washing				0.70				0.30	
	Heating			0.05		0.15			0.80	
	Cooling			0.10		0.90				
	Refrigeration	0.10				0.90				
Restaurant	Heating		0.70			0.20			0.10	0.02
	Cooling		1.00			0.00				
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.10	0.80			0.10				
	Exterior Lighting						1.00	-0.36		0.06
	Interior Lighting						1.00	-0.36		0.06
	Office Equipment	1.00								
	Miscellaneous			0.50	0.50					
	Process			0.50	0.50					
	Motors		0.30	0.40	0.30					
	Air Compression		1.00							
Retail	Heating		0.70			0.20			0.10	0.02
	Cooling		1.00			0.00				
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.10	0.80			0.10				
	Exterior Lighting						1.00	-0.36		0.06

Building Type	End Use	Electronic	Motor-A	Motor-B	Motor-C	Motor-D	ZIP Ip	ZIP Iq	ZIP Zp (G)	ZIP Zq (B)
	Interior Lighting						1.00	-0.36		0.06
	Office Equipment	1.00								
	Miscellaneous			0.50	0.50					
	Process			0.50	0.50					
	Motors		0.30	0.40	0.30					
	Air Compression		1.00							
School	Heating		0.70			0.20			0.10	0.02
	Cooling		1.00			0.00				
	Vent	0.30		0.70						
	Water Heating								1.00	0.15
	Cooking	0.20		0.20					0.60	
	Refrigeration	0.10	0.80			0.10				
	Exterior Lighting						1.00	-0.36		0.06
	Interior Lighting						1.00	-0.36		0.06
	Office Equipment	1.00								
	Miscellaneous			0.50	0.50					
	Process			0.50	0.50					
	Motors		0.30	0.40	0.30					
	Air Compression		1.00							
Single-family loads	Cooking	0.30							0.70	
	Water Heating								1.00	
	Lighting						0.10	-0.02	0.90	
	Plugs	1.00								
	Washing				0.50				0.50	
	Heating					0.30			0.70	
	Cooling					1.00				
	Refrigeration					1.00				

Building Type	End Use	Electronic	Motor-A	Motor-B	Motor-C	Motor-D	ZIP Ip	ZIP Iq	ZIP Zp (G)	ZIP Zq (B)
Small office	Heating		0.30						0.70	
	Cooling	0.15	0.70		0.15					
	Vent			1.00						
	Water Heating								1.00	
	Cooking								1.00	
	Refrigeration		0.85			0.15				
	Exterior Lighting						1.00			
	Interior Lighting						1.00			
	Office Equipment	1.00								
	Miscellaneous								1.00	
	Process	0.30		0.20	0.40				0.10	
	Motors					1.00				
	Air Compression					1.00				

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4.2 Development of Rules of Association for this Study

Besides the aforementioned rules of association from WECC provided for this study, DNV GL searched research publications which could be used to expand, modify, or validate the WECC rules of association for various end-use categories.

4.2.1 Connection with ZIP Model Parameter Estimates

The initial search for data sources focused on research papers where estimated ZIP model parameters were presented for the following reasons:

- ZIP models describe the relationship between active and reactive power and changes in voltage –
  - I_p: Active power load that changes linearly with voltage
  - Z_p: Active power load that changes quadratically with changes in voltage
  - P_p: Active power load that is invariant with voltage (constant power)

  The interpretations for these parameters are very similar to those of the composite load model, with Z_p relating to constant impedance, I_p relating to constant current, and P_p relating to the motor and power electronics portion of the load.

- ZIP models have the property that the active power components sum to one.
  This was a common property with the WECC rules of association for the load components.

Despite these commonalities, we ultimately decided to not use ZIP model parameter estimates in the rules of association since they could be and often were estimated to be negative. Since there was not a discernible method for translating negative ZIP model components into positive proportions, we developed the rules of association by expanding on those rules already being used in WECC.

4.2.2 Industrial Sector Rules of Association

The largest gap in the WECC rules of association that needed to be addressed was on the industrial end-use categories. The WECC industrial rules of association currently exist only at the whole site rather than end-use level, and for a select number of industrial customer classes. Since the industrial rules needed to be developed from the ground up, our goal was to develop a single rule of association for each end-use category without any variation by manufacturing industry.

The *machine drives* end-use category is the dominant industrial end use in terms of electricity consumption. Therefore, much of our search for data sources concerned this end-use category. Robert Adler and Thomas Lorenz of the EIA provided a reference to Manufacturing and Energy Carbon Footprints, produced by Energetics Inc. for the U.S. DOE Advanced Manufacturing Office.[32] The footprints include a breakdown of machine drive consumption into the following motor categories:

- Pumps
- Fans
- Compressed Air
- Materials Handling
- Materials Processing
- Other Systems

[32] http://energy.gov/sites/prod/files/2014/02/f7/2014_all_manufacturing_energy_carbon_footprint.pdf

While this decomposition did not match directly to the load components, this provided an improved basis for producing a rule of association for machine drives. Sabine Brueske and Ridah Sabouni of Energetics provided a reference to a 2010 report on the adoption of high efficiency motors and drives.[33] The motor category descriptions in this report suggested that the majority of the use by compressors and fans may be part of other MECS end-use categories besides machine drives, so we modified the percentage allocations to align with the MECS definition. The remaining machine drive load was determined to be 40% pump applications, which would be associated with the Motor C component and 60% constant torque motor applications. Examples of assumed constant torque motor applications include lathes, extruders, mixers, drill presses, boring machines, wheel grinders, positive displacement pumps, reciprocating air compressors, hoists, conveyors.

Another considerable issue was the proportion of motors controlled with a variable frequency drives (VFD)[34] since motors controlled with VFDs behave more like constant power electronics than motors.[35] VFDs are used to more precisely control motor speed and offer both energy efficiency improvements as well as reduced motor wear. The report referenced above by Lowe, et al. indicates that approximately 20% of motors were operating using VFDs as of 2010. We estimate that this has likely increased to approximately 30% due to the higher proportion of newer motor applications going into service which have VFDs.[36] This estimate is unfortunately based on judgment rather than supported by recent data sources.

4.3 Estimated Rules of Association Data Tables

The ideal scenario for this project would be to apply a specific rule of association at each of the most granular levels that end-use load was estimated: for the mix of end-uses within a specific category (e.g. ventilation), within a sector class (e.g. restaurants) within a specific region (e.g. New Hampshire). The WECC rules of association, however, allowed for only limited differentiation by customer classes, so in many cases the rule of association for a given end-use was the same for all customer classes.

Given the lack of data to support an expansion to new customer class categories, our approach was to not expand by customer classes within sectors from what was in place from WECC, but to expand to cover new end-use categories within sectors, and then to modify them as DNV GL and project stakeholders deemed appropriate. Each modification was coupled with a brief statement of rationale that is documented in Table 4-3. Note that the nomenclature in Table 4-2 differs from that of Table 4-1 for the constant current and impedance components, as discussed above in Section 4.2.1.

[33] U.S. Adoption of High Efficiency Motors and Drives: Lessons Learned, February 25, 2010, Marcy Lowe, Ruggero Golini, and Gary Gereffi; http://www.cggc.duke.edu/pdfs/CGGC-Motor_and_Drives_Report_Feb_25_2010.pdf

[34] Variable frequency drives are synonymous with adjustable speed drives (ASDs) and variable speed drives (VSDs).

[35] Chassin notes that some VFDs will not behave like constant power electronics under fault voltage conditions since the power may trip off below a certain threshold of voltage.

[36] John Kueck, an electrical engineer with expertise in motor applications, was contacted by the project team to comment on the estimated penetration of VFDs. He confirmed the general lack of data on this subject but suspected the motor load associated with VFDs was likely less than 50%, which we initially estimated was associated with 20% - 30% of industrial motors operating with VFDs.

Table 4-2 Load Component Rules of Association Used in this Study

Sector	End Use	Sector Class	Electronics	Motor-A	Motor-B	Motor-C	Motor-D	Constant Current	Constant Impedance
Residential	All Other Electronics	Multi-family	0.9						0.1
		Single-family/ Mobile Home	1						
	All Other End Uses - RES	Multi-family	0.3		0.1	0.1			0.5
		Single-family/ Mobile Home	0.3		0.1	0.1			0.5
	Ceiling Fans	Multi-family			1				
		Single-family/ Mobile Home			1				
	Clothes Dryers	Multi-family			0.2				0.8
		Single-family/ Mobile Home			0.2				0.8
	Clothes Washers	Multi-family				0.85			0.15
		Single-family/ Mobile Home				0.85			0.15
	CRT TVs	Multi-family	1						
		Single-family/ Mobile Home	1						
	Dishwashers	Multi-family				0.3			0.7
		Single-family/ Mobile Home				0.3			0.7
	Lighting - CFL/Linear Fluorescent	Multi-family						1	
		Single-family/ Mobile Home						1	
	Lighting - Incandescent	Multi-family							1
		Single-family/ Mobile Home							1
	Lighting - Other	Multi-family							1
		Single-family/ Mobile Home							1
	Other TVs	Multi-family	1						
		Single-family/ Mobile Home	1						
	Pool Pumps	Multi-family				1			
		Single-family/ Mobile Home				1			
	Range/Oven	Multi-family			0.1				0.9

Sector	End Use	Sector Class	Electronics	Motor-A	Motor-B	Motor-C	Motor-D	Constant Current	Constant Impedance
		Single-family/ Mobile Home			0.1				0.9
	Refrigerators/Freezers	Multi-family			0.1		0.9		
		Single-family/ Mobile Home			0.1		0.9		
	Settop/cable box, digital, DVR	Multi-family	0.9						0.1
		Single-family/ Mobile Home	0.9						0.1
	Space Cooling - Single Phase	Multi-family			0.1		0.9		
		Single-family/ Mobile Home			0.1		0.9		
	Space Cooling - Split Phase	Multi-family			0.3		0.7		
		Single-family/ Mobile Home			0.3		0.7		
	Space Cooling - Three Phase	Multi-family	0.15	0.5	0.25	0.1			
		Single-family/ Mobile Home	0.15	0.5	0.25	0.1			
	Space Heating	Multi-family			0.05		0.15		0.8
		Single-family/ Mobile Home					0.3		0.7
	Water Heating	Multi-family							1
		Single-family/ Mobile Home							1
	Well Pumps	Multi-family				1			
		Single-family/ Mobile Home				1			
Commercial	Air Compression	All commercial classes		1					
	All Other End Uses - COM	Healthcare	0.2						0.8
		All other commercial classes	0.2		0.4	0.4			
	Cooking	All commercial classes	0.1		0.05				0.85
	Elevator drives and hydraulic pumps	All commercial classes				1			
	Lighting - CFL/Linear Fluorescent	All commercial classes						1	
	Lighting - HID Interior	All commercial classes							1
	Lighting - Incandescent	All commercial classes							1

Sector	End Use	Sector Class	Electronics	Motor-A	Motor-B	Motor-C	Motor-D	Constant Current	Constant Impedance
	Lighting - Other	All commercial classes							
	Office Equipment	All commercial classes	1						
	Refrigeration	Lodging	0.1	0.4			0.5		
		Healthcare	0.2	0.7			0.1		
		All other commercial classes	0.1	0.8			0.1		
	Space Cooling - Single Phase	All commercial classes					1		
	Space Cooling - Split Phase	All commercial classes					1		
	Space Cooling - Three Phase	All commercial classes	0.15	0.85					
	Space Heating	Healthcare		0.75			0.15		0.1
		All other commercial classes		0.7			0.2		0.1
	Ventilation	All commercial classes	0.3		0.7				
	Water Heating	All commercial classes							1
Industrial	Agriculture	All industrial Classes	0.1	0.2	0.25	0.35			0.1
	Construction	All industrial Classes	0.15		0.4	0.15	0.15		0.15
	Conventional Boiler Use	All industrial Classes							1
	Electro-Chemical Processes	All industrial Classes	0.15	0.15	0.25	0.15	0.15		0.15
	Lighting - CFL/Linear Fluorescent	All industrial Classes						1	
	Lighting - HID Interior	All industrial Classes							1
	Machine Drive	All industrial Classes	0.3	0.42		0.28			
	Mining	All industrial Classes	0.05	0.2	0.35	0.35			0.05
	Onsite Transportation	All industrial Classes	1						
	Other Facility Support	All industrial Classes	0.5		0.25	0.25			
	Other Nonprocess Use	All industrial Classes	0.5		0.25	0.25			
	Other Process Use	All industrial Classes	0.1	0.15	0.25	0.25	0.25		
	Process Cooling and Refrigeration	All industrial Classes	0.1	0.55	0.15	0.15	0.05		

Sector	End Use	Sector Class	Electronics	Motor-A	Motor-B	Motor-C	Motor-D	Constant Current	Constant Impedance
	Process Heating	All industrial Classes		0.05	0.05	0.05	0.05		0.8
	Space Cooling - Three Phase	All industrial Classes	0.1	0.9					
	Ventilation	All industrial Classes	0.3		0.7				

4.4 Rules of association notes

The rules of association, as noted above, were developed from the judgment of individuals with industry knowledge in absence of a rigorous study. The following notes are related to the rationale, assumptions, or issues related to the rules of association presented in Table 4-1 above, along for the source for the assignment.

Table 4-3 Sources for Rules of Association Assignments

Sector	End Use	Source
Residential	All Other Electronics	Chassin, Plugs - Multi-family
Residential	All Other Electronics	Chassin, Plugs - Single-family
Residential	All Other End Uses - RES	DNV GL and Kosterev, assuming primarily resistive and electronics load with some small appliance motor load as well
Residential	Ceiling Fans	DNV GL, fans are motor B
Residential	Clothes Dryers	DNV GL and Dean Latulipe, NGRID. Bulk of the load with dryers is the heating element
Residential	Clothes Washers	DNV GL, assuming most of water heating is not from a heating element in the clothes washer
Residential	CRT TVs	Chassin, Plugs - Multi-family
Residential	CRT TVs	Chassin, Plugs - Single-family
Residential	Dishwashers	DNV GL, most of the load will be for the heating element
Residential	Lighting - CFL/Linear Fluorescent	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Residential	Lighting - Incandescent	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Residential	Lighting - Other	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Residential	Other TVs	Chassin and Kosterev, Plugs - Multi-family
Residential	Pool Pumps	DNV GL, pumps are motor C
Residential	Range/Oven	DNV GL, Chassin, Latulipe, Kosterev - most of range/oven load is constant impedance for heating element, with some share for convection ovens, and some fan motor load
Residential	Refrigerators/Freezers	Chassin, Refrigeration - Multi-family loads
Residential	Refrigerators/Freezers	Chassin, Refrigeration - Single-family loads
Residential	Settop/cable box, digital, DVR	Kosterev, assumes some resistive load
Residential	Space Cooling - Single Phase	DNV GL, assuming window/wall units have 10% Motor B for ventilation
Residential	Space Cooling - Split Phase	DNV GL, assuming split phase AC units have 30% Motor B for ventilation

Sector	End Use	Source
Residential	Space Cooling - Three Phase	DNV GL, assuming three phase systems have about half load to compressor, a quarter to ventilation, with 15% electronics and 10% pump motor load
Residential	Space Heating	Chassin, Heating - Multi-family. Assumes mostly resistive with some heat pumps and circulating pumps
Residential	Space Heating	Chassin, Heating - Single-family. Assumes 70% resistive with 30% heat pump
Residential	Water Heating	Chassin, all resistive now but need to track penetration of heat pump water heaters
Residential	Well Pumps	DNV GL, pumps are motor C
Commercial	Air Compression	Chassin, AirComp - Large Office (same for all commercial classes except small office)
Commercial	All Other End Uses - COM	DNV GL - adjusted from Chassin's 50/50 Motors B and C used for Misc in non-Health buildings to include 20% electronic load
Commercial	All Other End Uses - COM	DNV GL - adjusted from Chassin's 100% Zp used for Misc in Health buildings to include 20% electronic load
Commercial	Cooking	Kosterev, modified from WECC rule to have higher resistive load share
Commercial	Elevator drives and hydraulic pumps	DNV GL, assuming 100% motor C since this is pump motor load
Commercial	Lighting - CFL/Linear Fluorescent	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Commercial	Lighting - HID Interior	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Commercial	Lighting - Incandescent	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Commercial	Lighting - Other	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Commercial	Office Equipment	Chassin, OfficeEquip - All building types
Commercial	Refrigeration	Chassin, Refrig - School
Commercial	Refrigeration	Chassin, Refrig - Grocery
Commercial	Refrigeration	Chassin, Refrig - Health
Commercial	Refrigeration	Chassin, Refrig - Lodging
Commercial	Refrigeration	Chassin, Refrig - Large Office
Commercial	Space Cooling - Single Phase	DNV GL, space cooling is separate from ventilation in comm and ind so no Motor B
Commercial	Space Cooling - Split Phase	DNV GL, space cooling is separate from ventilation in comm and ind so no Motor B
Commercial	Space Cooling - Three Phase	DNV GL, space cooling is separate from ventilation in comm and ind so no Motor B

Sector	End Use	Source
Commercial	Space Cooling - Three Phase	DNV GL, space cooling is separate from ventilation in comm and ind so no Motor B. Assuming 15% share of constant power electronics for VFDs
Commercial	Space Heating	Chassin, Heating - School
Commercial	Space Heating	Chassin, Heating - Grocery
Commercial	Space Heating	Chassin, Heating - Healthcare
Commercial	Space Heating	Chassin, Heating - Lodging
Commercial	Space Heating	Chassin, Heating - Large Office
Commercial	Space Heating	Chassin, Heating - Restaurant
Commercial	Space Heating	Chassin, Heating - Retail
Commercial	Ventilation	Chassin, Vent - All Commercial Buildings. Assuming 30% share for VFDs
Commercial	Water Heating	Chassin, Water Heating - All Commercial Buildings
Industrial	Agriculture	DNV GL, Assuming broad mix of end uses with biggest share to pumping for irrigation
Industrial	Construction	DNV GL, Assuming broad mix of end uses with biggest share to fans
Industrial	Conventional Boiler Use	DNV GL, assuming all resistive
Industrial	Electro-Chemical Processes	DNV GL, assuming broad mix of end uses.
Industrial	Lighting - CFL/Linear Fluorescent	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Industrial	Lighting - HID Interior	DNV GL, assuming CFL/FL is constant current, other lighting is constant impedance
Industrial	Machine Drive	DNV GL, using industrial motor breakdown in http://www.cggc.duke.edu/pdfs/CGGC-Motor_and_Drives_Report_Feb_25_2010.pdf. Most machine drive motors will have constant torque or will be pump applications. Assuming about 30% of load is associated with VFDs
Industrial	Mining	Kosterev, WECC Industrial Load Composition
Industrial	Onsite Transportation	DNV GL, assuming all plugload
Industrial	Other Facility Support	DNV GL, assuming about half electronics, other half misc. fans and pumps
Industrial	Other Nonprocess Use	DNV GL, assuming about half electronics, other half misc. fans and pumps
Industrial	Other Process Use	DNV GL, assuming broad mix of motors and electronics
Industrial	Process Cooling and Refrigeration	DNV GL, assuming mostly constant torque compressor with some fans pumps and electronics
Industrial	Process Heating	DNV GL, assuming mostly resistive load heating

Sector	End Use	Source
Industrial	Space Cooling - Three Phase	DNV GL, assuming all three phase space cooling in industrial. Ventilation is separate. Assuming 10% of load through VFDs.
Industrial	Ventilation	Chassin, Vent - All Commercial Buildings with 30% VFD load

4.5 Application of the Rules of Association

This section describes how the end-use load disaggregation documented in Section 3 was combined with the rules of association presented in Section 4. As noted in these sections, both data sets are presented at the end-use category level within sector classes (e.g. multi-family residential households or retail commercial buildings).

The end-use load disaggregations were merged with the rules of association by sector, end use, and sector class, but not by region since rules of association are not defined at that level of granularity. An example of these data being merged together for residential clothes dryers is shown below. In Figure 4-1 below the annual kWh for residential dwelling types (SF=single family, MF=multi-family, MH=mobile homes) is given by region (state codes and CW_MA=West/Central Massachusetts, E_MA=East Massachusetts). The summer peak and spring light load are not shown in this example but the merging and expansion process would work in the same way as for annual consumption.

Figure 4-1: Example load disaggregation for an end-use category within a sector class

sector	region	enduse	dwelling	hhlds	aec_kwh
Residential	CT	Clothes Dryers	MF	516912	117.85042546
Residential	CT	Clothes Dryers	MH	10796	384.91937829
Residential	CT	Clothes Dryers	SF	960209	531.29051203
Residential	CW_MA	Clothes Dryers	MF	246476	150.62748051
Residential	CW_MA	Clothes Dryers	MH	8024	184.87178788
Residential	CW_MA	Clothes Dryers	SF	428995	473.83822659
Residential	E_MA	Clothes Dryers	MF	920799	150.62748051
Residential	E_MA	Clothes Dryers	MH	15902	184.87178788
Residential	E_MA	Clothes Dryers	SF	1159918	473.83822659
Residential	ME	Clothes Dryers	MF	139166	122.13251533
Residential	ME	Clothes Dryers	MH	65559	489
Residential	ME	Clothes Dryers	SF	519309	626.64471882
Residential	NH	Clothes Dryers	MF	157528	122.13251533
Residential	NH	Clothes Dryers	MH	35974	489
Residential	NH	Clothes Dryers	SF	423481	626.64471882
Residential	RI	Clothes Dryers	MF	186173	117.85042546
Residential	RI	Clothes Dryers	MH	4522	384.91937829
Residential	RI	Clothes Dryers	SF	271774	531.29051203
Residential	VT	Clothes Dryers	MF	74069	122.13251533
Residential	VT	Clothes Dryers	MH	20619	489
Residential	VT	Clothes Dryers	SF	229184	626.64471882

Figure 4-2 below shows a snapshot of the rule of association for clothes dryers in multi-family dwellings, where 80% of the load is assumed to be for constant impedance from the heating element and 20% Motor B.

Figure 4-2: Rule of association for clothes dryers for multi-family residential dwellings.

sector	region	dwelling	enduse	load_component	roa_estimate
Residential	CT	MF	Clothes Dryers	Electronics	.
Residential	CT	MF	Clothes Dryers	Motor A	.
Residential	CT	MF	Clothes Dryers	Motor B	0.2
Residential	CT	MF	Clothes Dryers	Motor C	.
Residential	CT	MF	Clothes Dryers	Motor D	.
Residential	CT	MF	Clothes Dryers	Constant Current	.
Residential	CT	MF	Clothes Dryers	Constant Impedance	0.8

These two data sets are then merged by the factors listed above into a single data set which expands the rules of association data since it has more several rows for each combination of residential, CT, MF, endues, for the load components. The annual kWh is added to each row in this data set. Figure 4-3 shows the merged data set for the first row in Figure 4-1, expanded to the load component level.

Figure 4-3: Combined annual consumption broken into load components through the rule of association.

region	sector	dwelling	enduse	load_component	roa_estimate	hhlds	aec_kwh	aec_kwh_ROA
CT	Residential	MF	Clothes Dryers	Electronics	0	516912	117.85042546	0
CT	Residential	MF	Clothes Dryers	Motor A	0	516912	117.85042546	0
CT	Residential	MF	Clothes Dryers	Motor B	0.2	516912	117.85042546	23.570085091
CT	Residential	MF	Clothes Dryers	Motor C	0	516912	117.85042546	0
CT	Residential	MF	Clothes Dryers	Motor D	0	516912	117.85042546	0
CT	Residential	MF	Clothes Dryers	Constant Current	0	516912	117.85042546	0
CT	Residential	MF	Clothes Dryers	Constant Impedance	0.8	516912	117.85042546	94.280340364

Once the full set of end-use disaggregation estimates have been merged in with the load component rules of association in this manner, the data can be tabulated according to multiple factors. One such factorization is to sum by load component rather than by end use to arrive at the ultimate load component level desired for this project (shown in Appendix C).

It should be noted that the rules of association can be collapsed into three categories to align with the ZIP model representation by summing the load for the four motor types and electronics as a single *constant power* category.

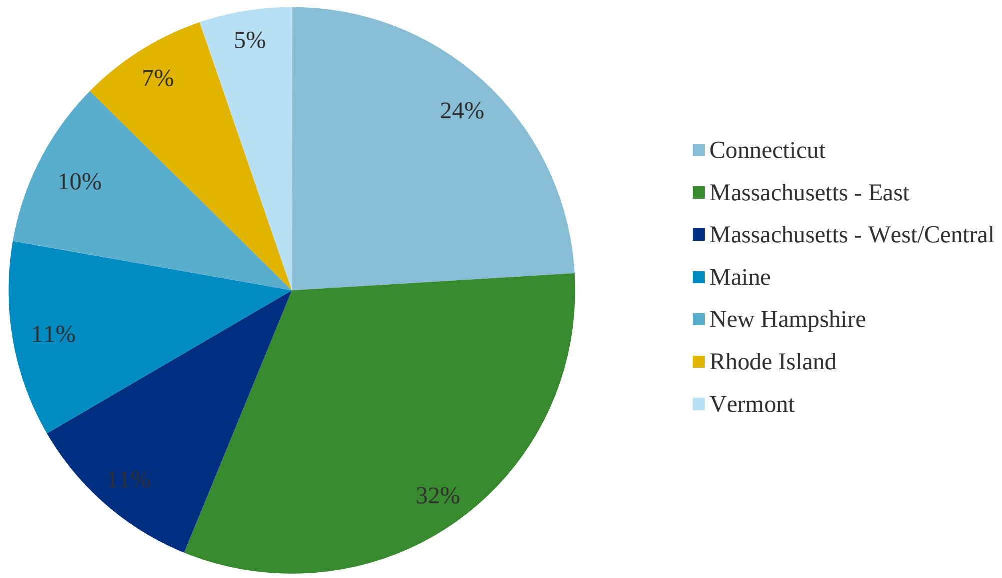
5 FINDINGS OF THIS STUDY

This section presents a summary of the results of the analyses described in this report. For a more complete set of results, the companion “cross-sector end-use shares with pivot.xlsx” and “sector class end-use and load component shares.xlsx” workbooks to this report contain interactive table and figure generation tools.

5.1 Distribution of energy and load by customer sector and region

Figure 5-1 displays the proportional shares of New England annual energy consumption by region. Eastern Massachusetts and Connecticut account for over half the annual energy consumption in the region. The proportional shares for peak load hour and spring light load hour are not shown as the breakdowns are very similar.

Figure 5-1 New England Annual Energy Consumption Proportional Shares by Region



5.2 Energy consumption and load by customer sector and region

Figure 5-2 shows the annual energy consumption breakdown between the residential, commercial, and industrial sectors across each of the seven regions. In all regions, the commercial sector is the largest, followed by the residential, then industrial.

Figure 5-2 Distribution of annual energy consumption by sector

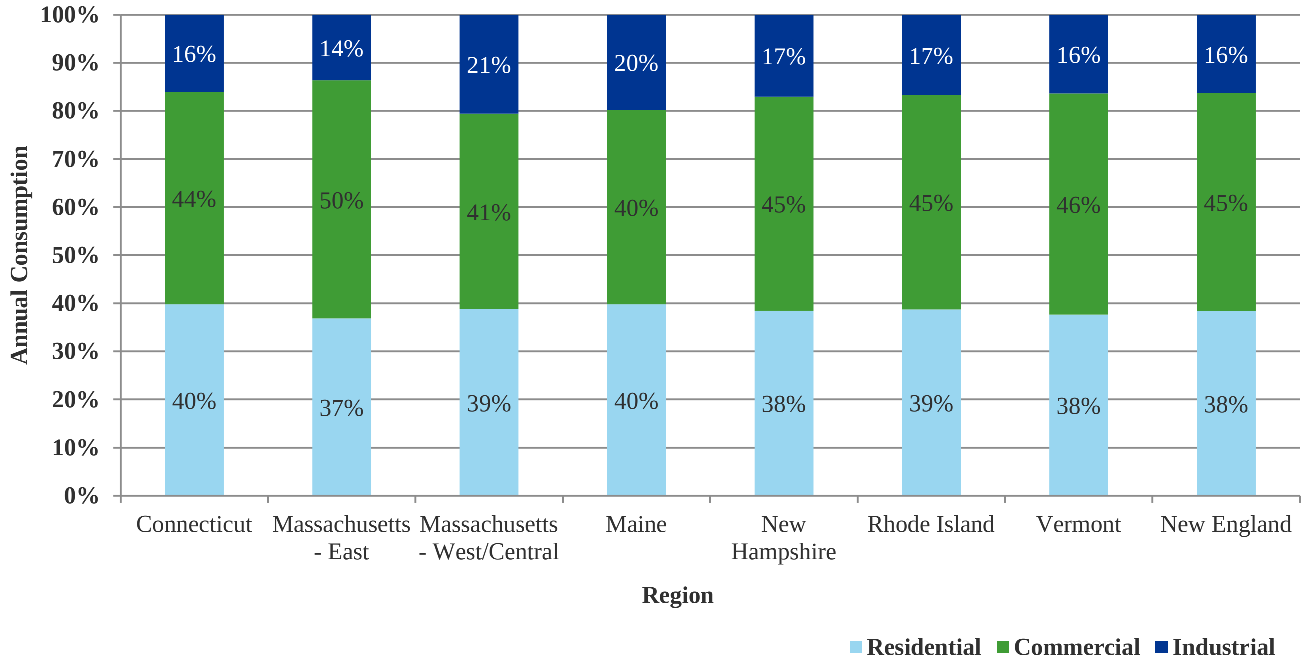


Figure 5-3 shows the proportional breakdown of the estimated summer peak hour system load into the residential, commercial, and industrial sectors. Unlike in the annual consumption, the residential share is higher in some regions than commercial (Connecticut, Massachusetts – West/Central, and Rhode Island). The industrial sector represents a reduced share as compared with the annual energy consumption breakdown above since manufacturing loads tend to be less weather sensitive than the other sectors.

Figure 5-3 Distribution of summer peak hour load by sector

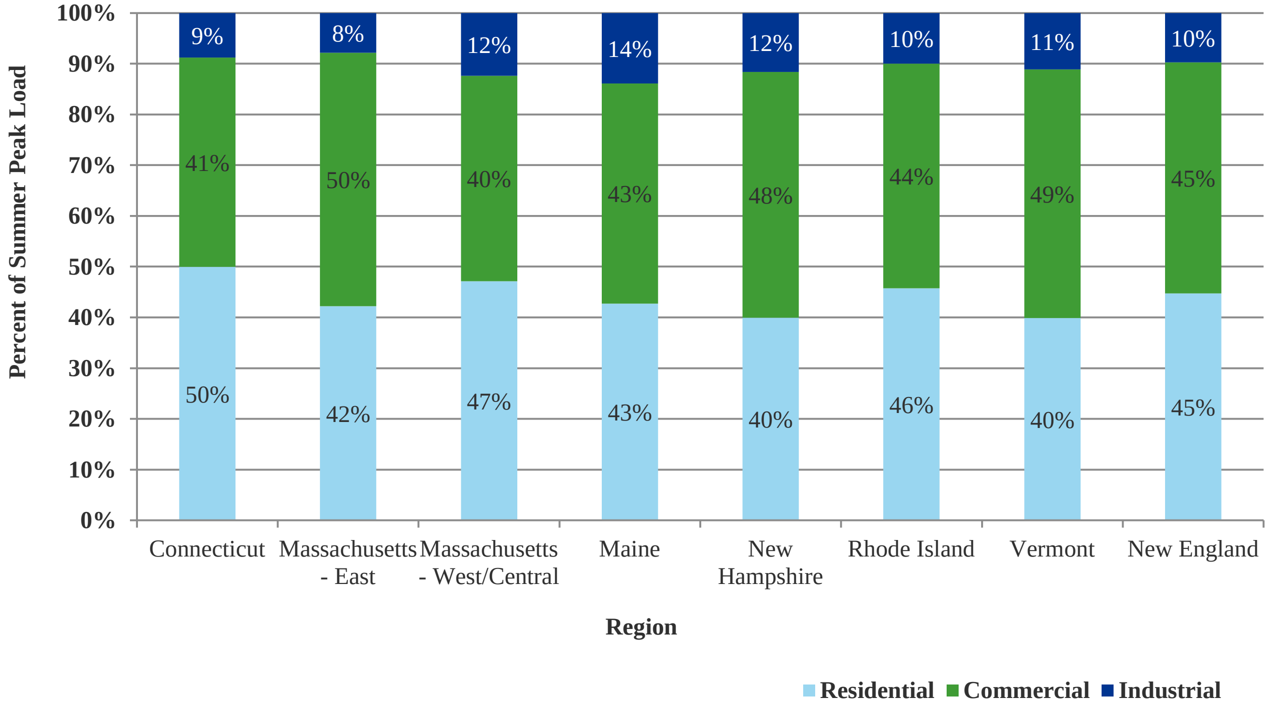
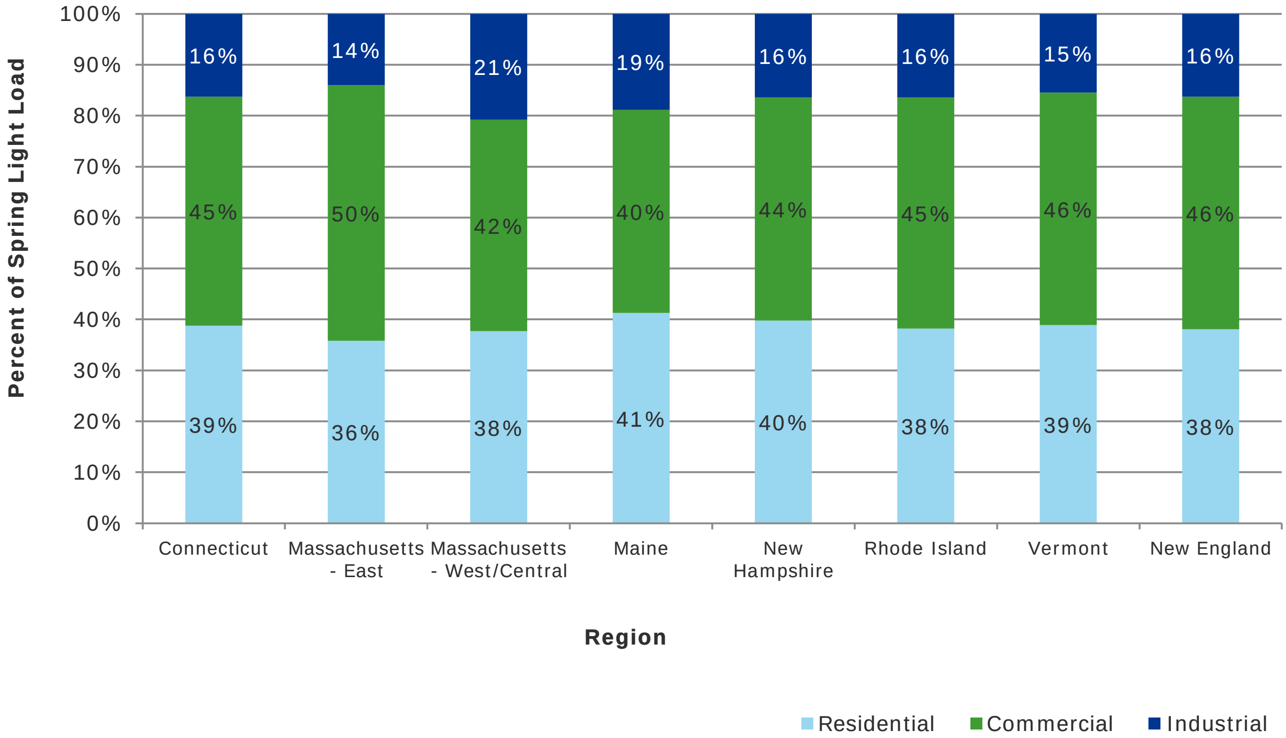


Figure 5-4 shows the corresponding sector-level breakdown during the spring light load hour. The distribution is similar to that of annual consumption.

Figure 5-4 Distribution of spring light hour load by sector



5.3 Proportional representation of customer classes by sector

The figures in this section show the representation of customer classes within sector for New England, at both the summer peak and light load hours. Since there are far too many industrial classes to show in these figures, Figure 5-5 and Figure 5-6 contain only the top 10 industrial class groups and an “all other” category for the load from the remaining classes.

Industrial load, as noted elsewhere in this report, is not particularly weather sensitive so the peak and light load hour breakdowns are nearly identical. The breakdowns by class are fairly static in residential and commercial as well, suggesting that most of these classes have similar increases in demand during peak conditions due primarily to space cooling loads.

Figure 5-5 New England industrial sector summer peak load by customer class

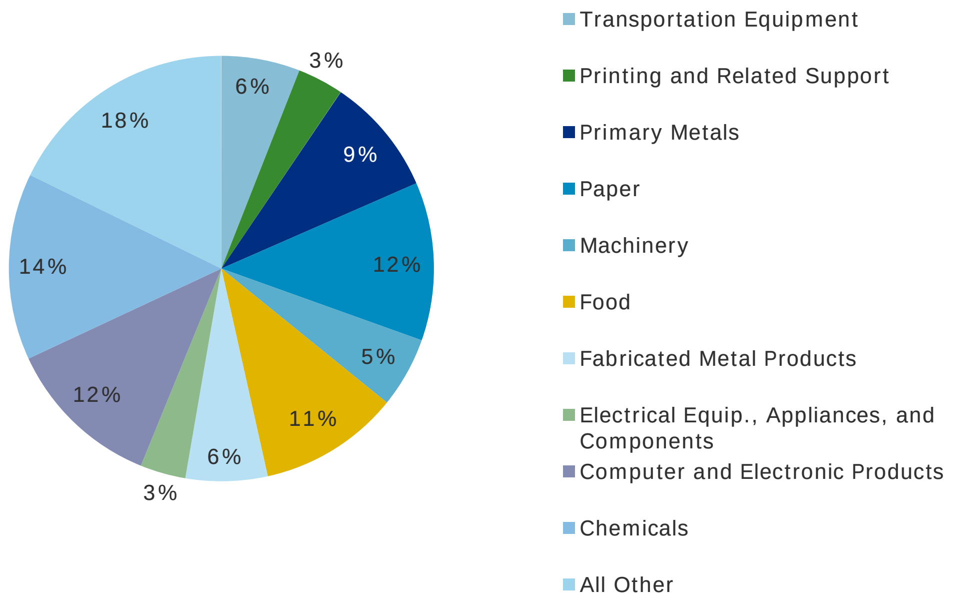


Figure 5-6 New England industrial sector spring light load by customer class

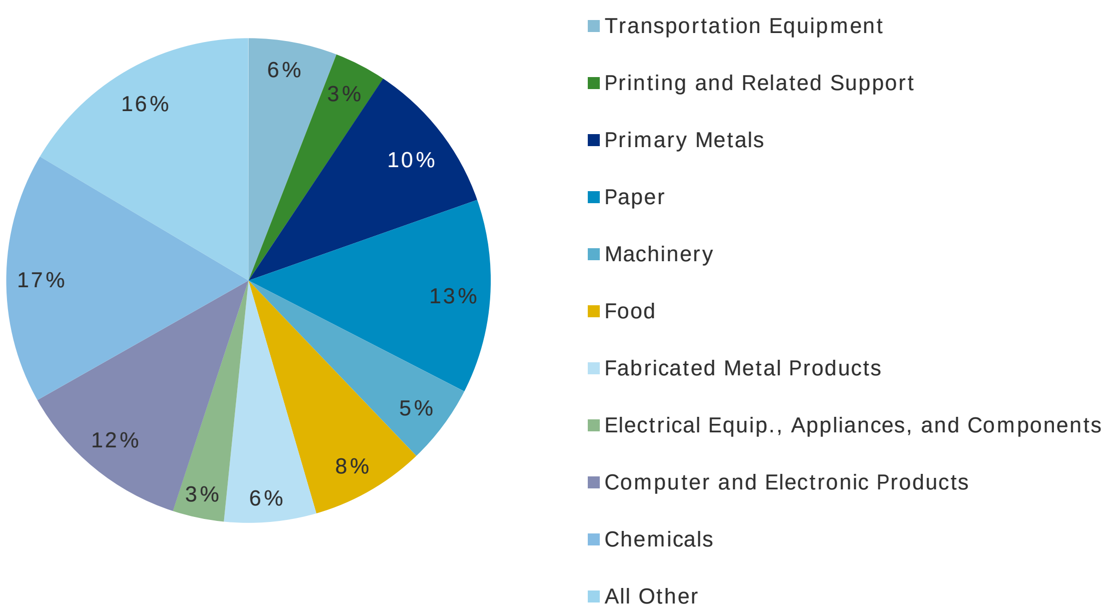


Figure 5-7 New England residential sector summer peak load by customer class

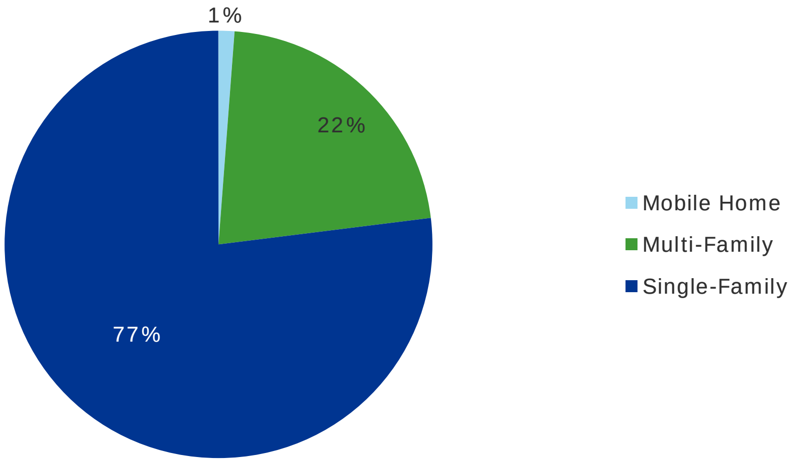


Figure 5-8 New England residential sector spring light load by customer class

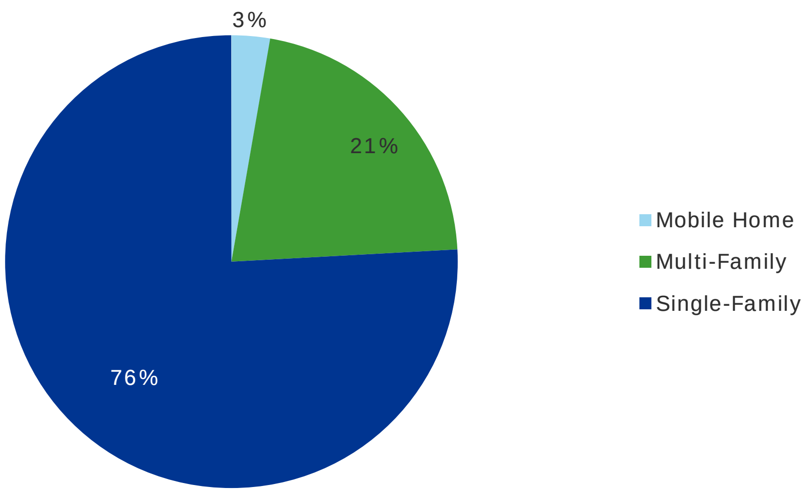


Figure 5-9 New England commercial sector summer peak load by customer class

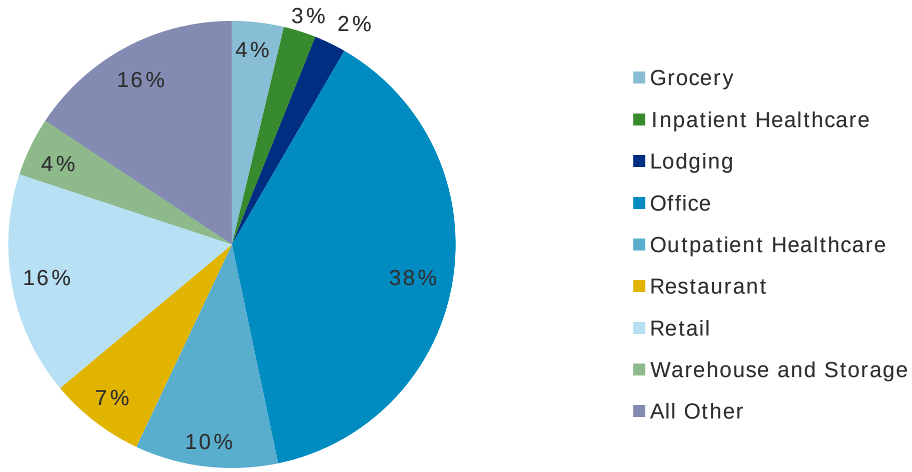
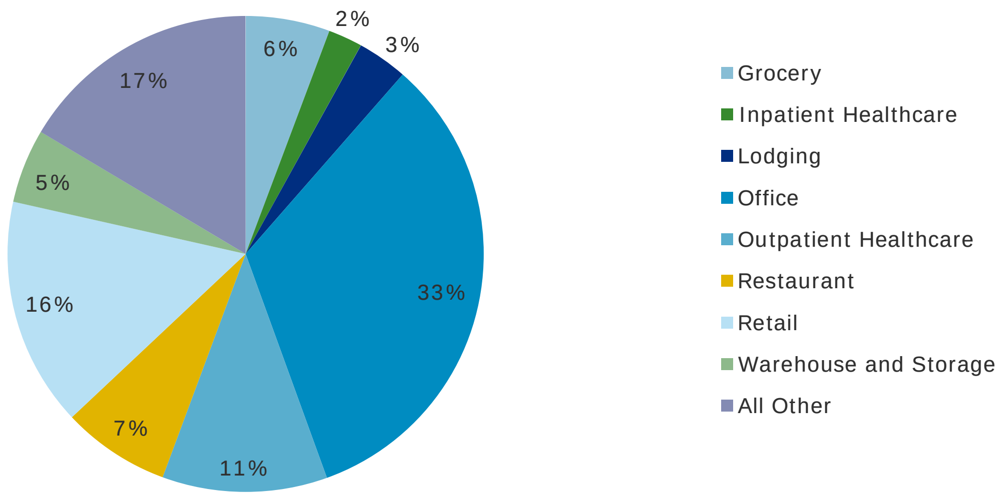


Figure 5-10 New England commercial sector spring light load by customer class



5.4 Summer peak load by customer sector and end use

Figure 5-11 through Figure 5-13 show the breakdown of the different customer sectors by end-use during the summer peak hour. Space cooling and ventilation are weather sensitive loads and are the dominant end-use categories during summer peak in the residential and commercial sectors.

Industrial sector load is less weather sensitive and more process driven than the other sectors. Machine drives and process heating, neither of which is weather sensitive, make up the bulk of the peak load in the industrial sector.

The “all other” residual end use categories make up roughly 10% of the summer peak hour load in the residential and commercial sectors.

Figure 5-11 End-use proportional breakdown of residential summer peak hour load for New England

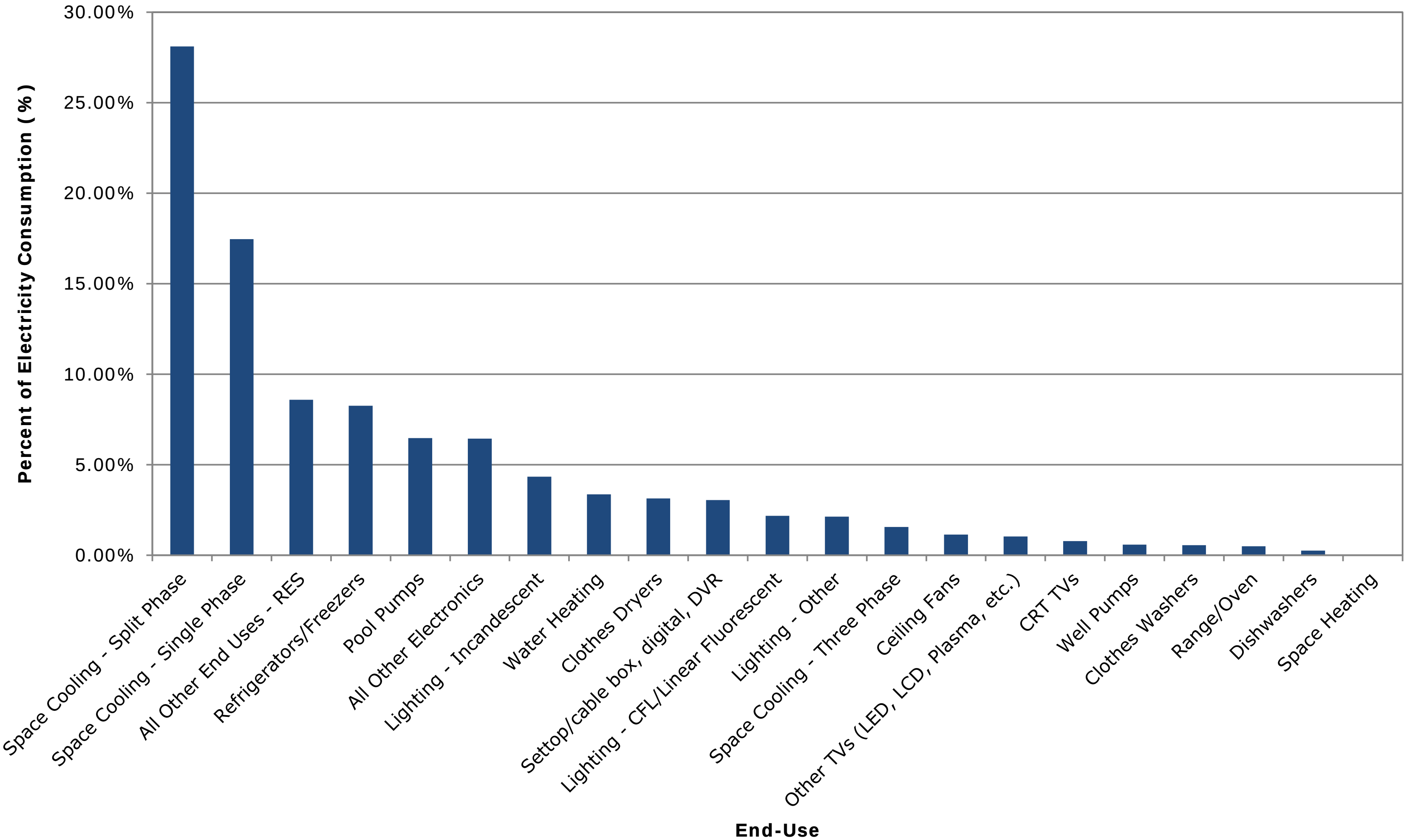


Figure 5-12 End-use proportional breakdown of commercial sector summer peak hour load for New England

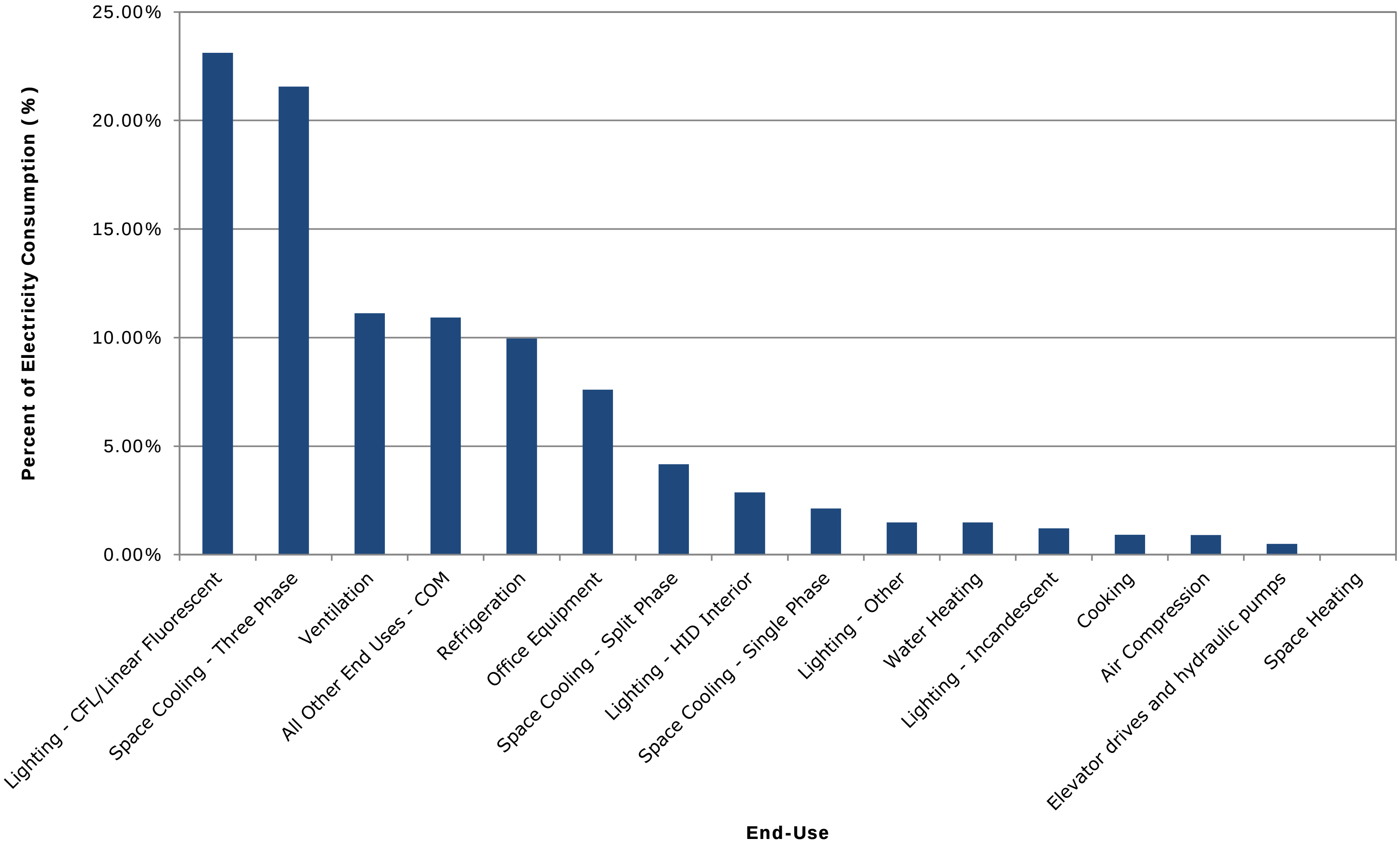
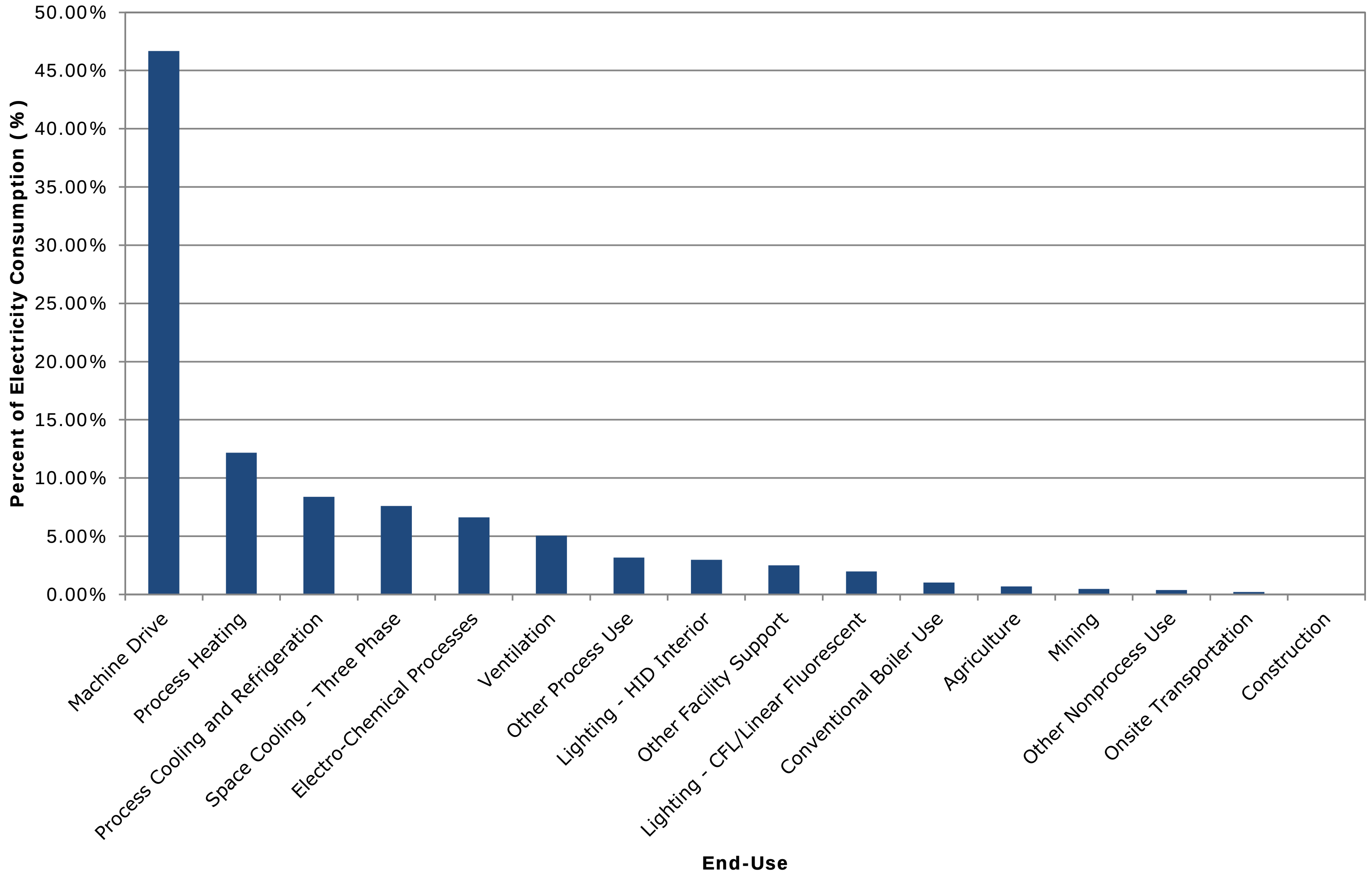


Figure 5-13 End-use proportional breakdown of industrial sector summer peak hour load for New England



5.5 Spring light load by customer sector and end use

Figure 5-14 through

Figure 5-16 show the end-use breakdowns of the spring light load hour by sector. The dominant share end-use categories are a major shift from the corresponding peak load hour breakdowns given above, for the residential and commercial sectors. Lighting and refrigeration, along with the "all other" residual end-use category account for large shares, with weather sensitive loads having significantly lower representative shares. The industrial sector light load hour end-use breakdown is very similar to its peak load hour counterpart because of the relative lack of weather sensitive loads.

Figure 5-14 End-use proportional breakdown of residential spring light hour load for New England

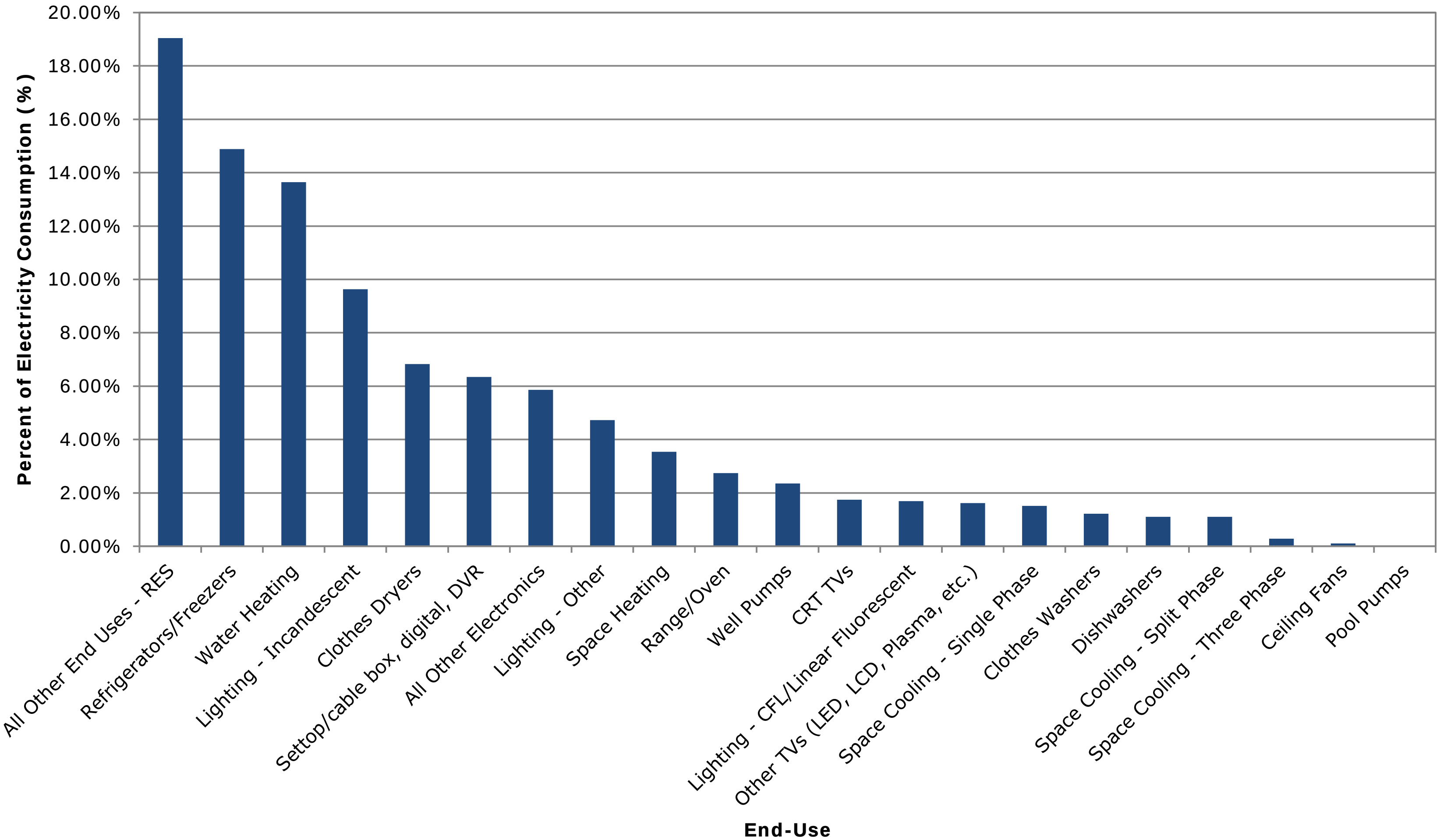


Figure 5-15 End-use proportional breakdown of commercial sector spring light hour load for New England

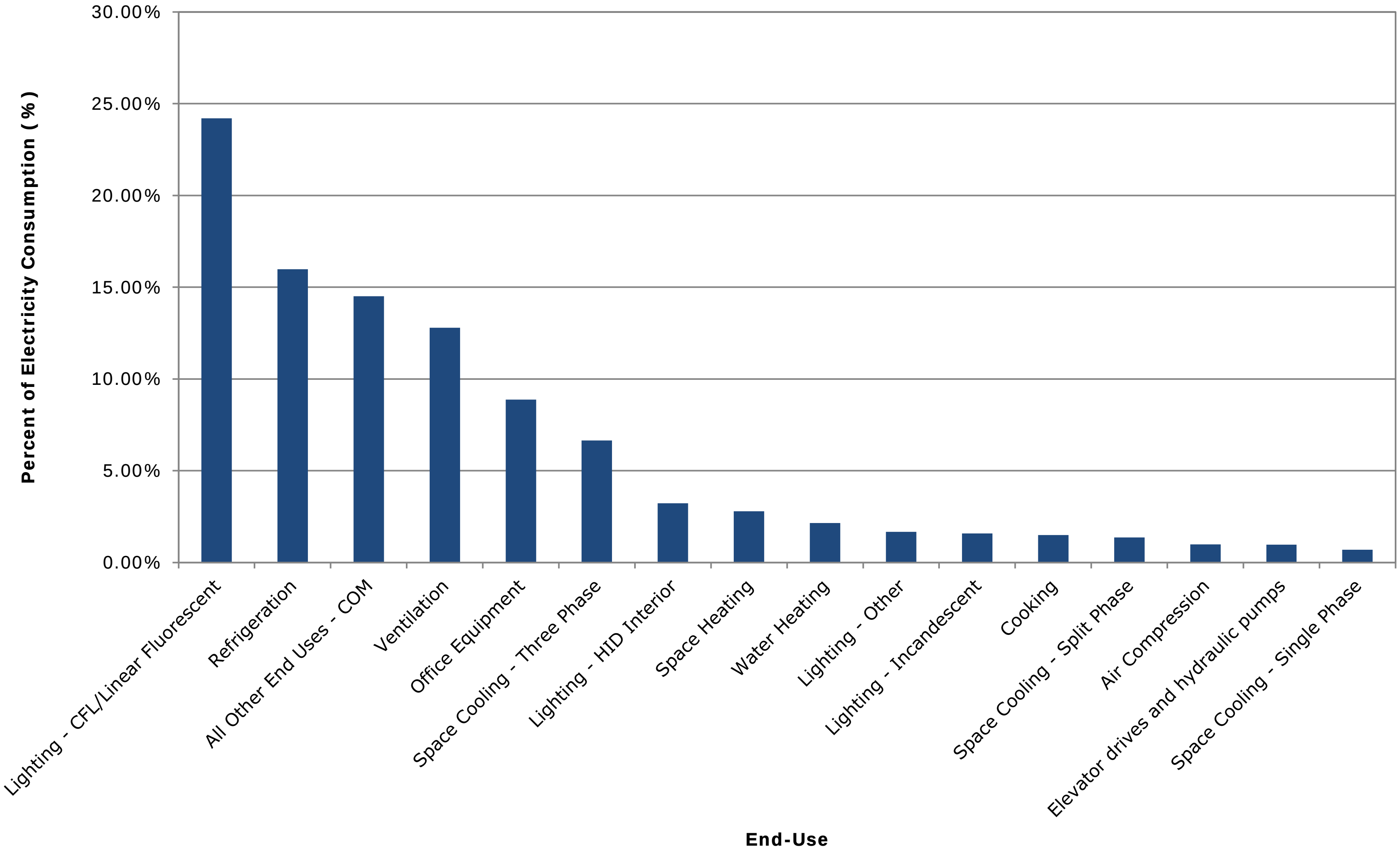
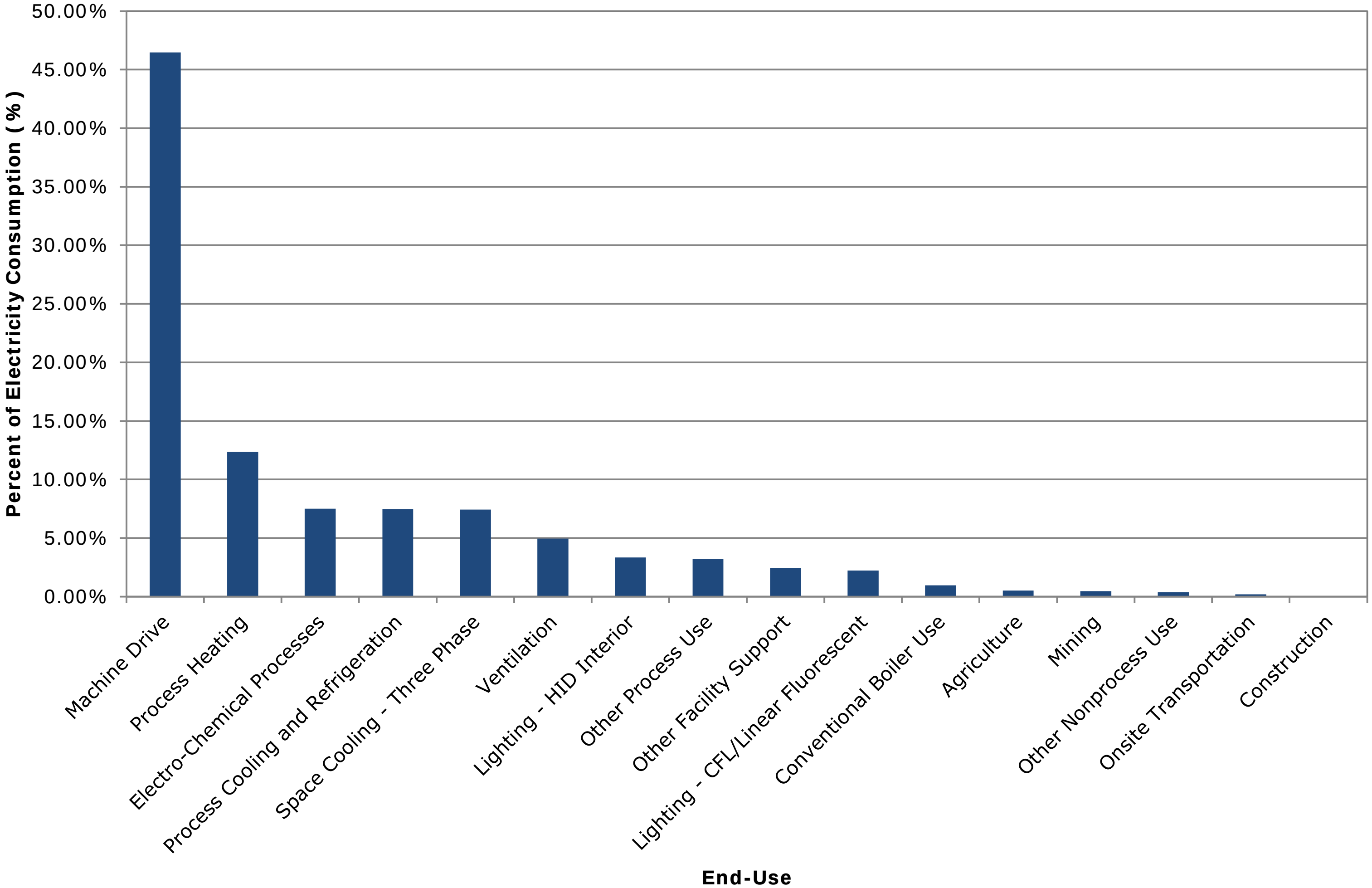


Figure 5-16 End-use proportional breakdown of industrial sector spring light hour load for New England



5.6 End Use Consumption by Region

Figure 5-17 and

Figure 5-18 show the breakdown of the top ten end-uses by region across all sectors. The other end uses were all combined into the “all other” category. While there is a moderate level of variation in the summer peak load hour proportional shares from region-to-region, the spring light load hour estimates are relatively static across the regions.

Figure 5-17 Region-by-region cross-sector summary of the proportional shares of the top ten end-use loads in the summer peak load hour

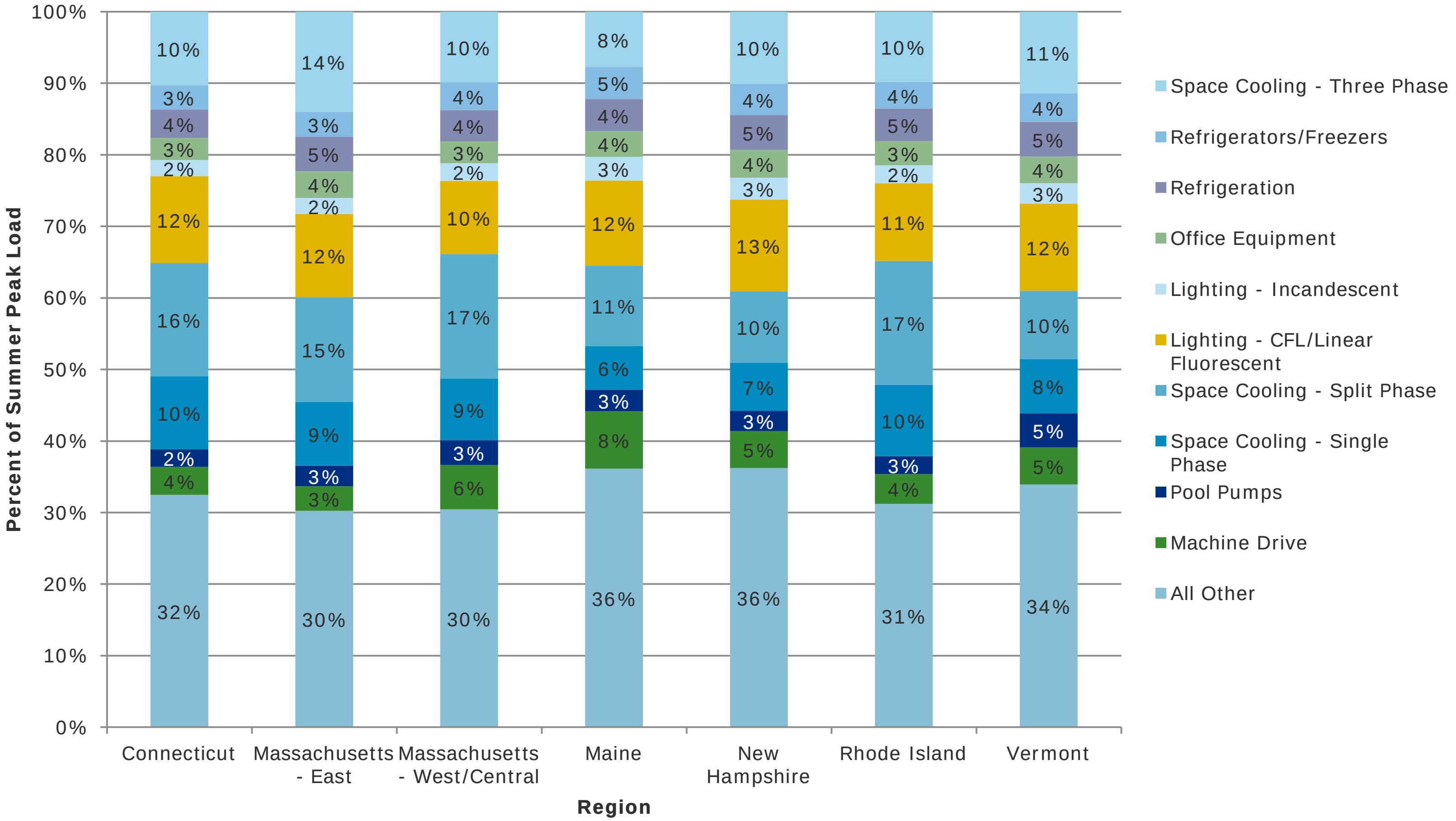
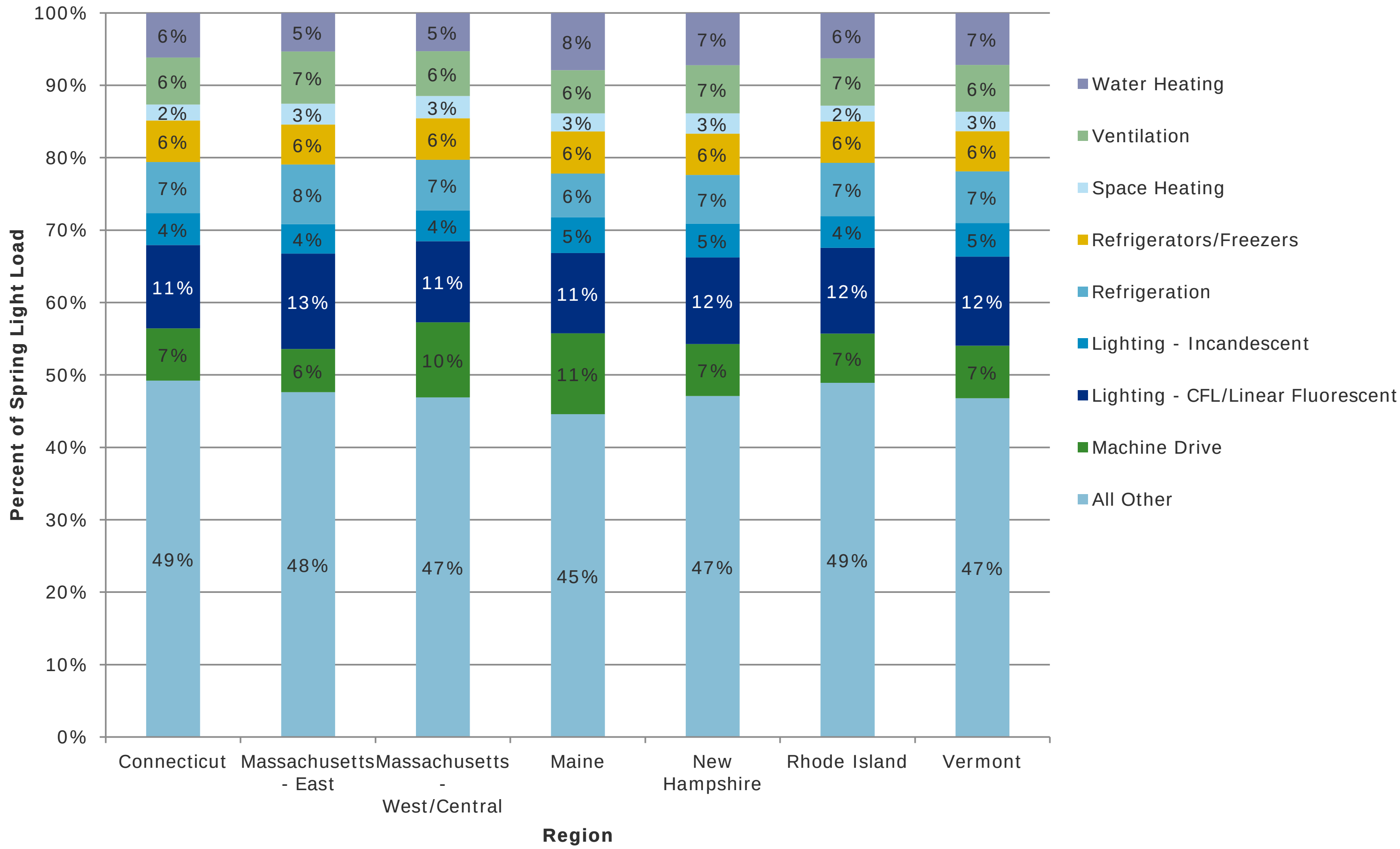


Figure 5-18 Region-by-region cross-sector summary of the proportional shares of the top ten end-use loads in the spring light load hour



5.7 Rules of Association Load Component Breakdowns

Figure 5-19 and

Figure 5-20 show the region-to-region variation in the load component shares across all sectors during the summer peak and spring light load hours. Motor types “A” and “D” make up larger shares at peak since these are the classifications for single phase and three phase air compressors. However, they still have a presence in the spring light load hour due to single phase refrigerator motors (Motor D) and constant torque industrial motor load (Motor A). The constant impedance load component has increased an increased proportional share in the spring light load hour due to the increased end-use share of lighting.

Figure 5-19 Region-to-region cross-sector distribution of load component shares during the summer peak load hour

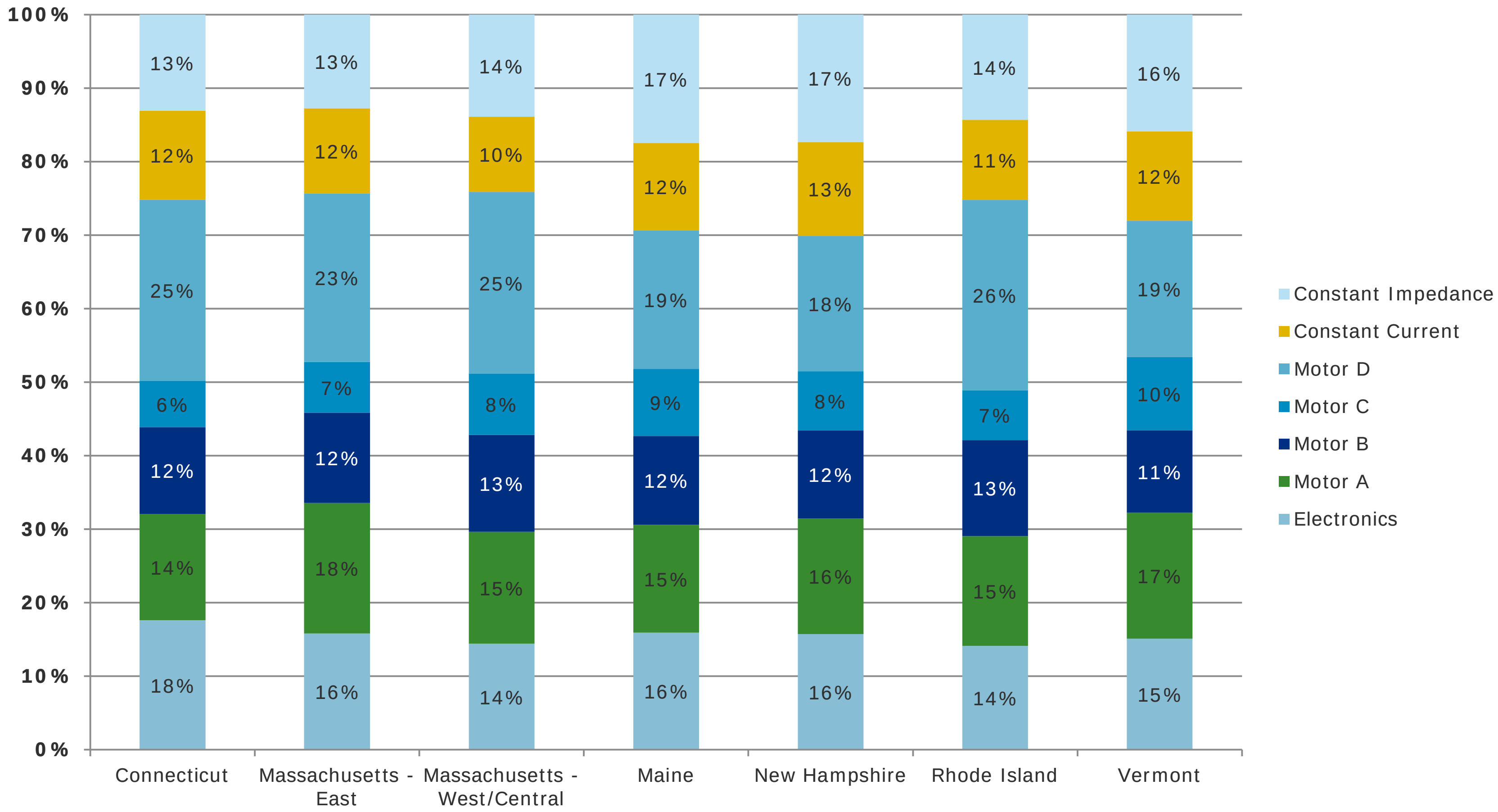
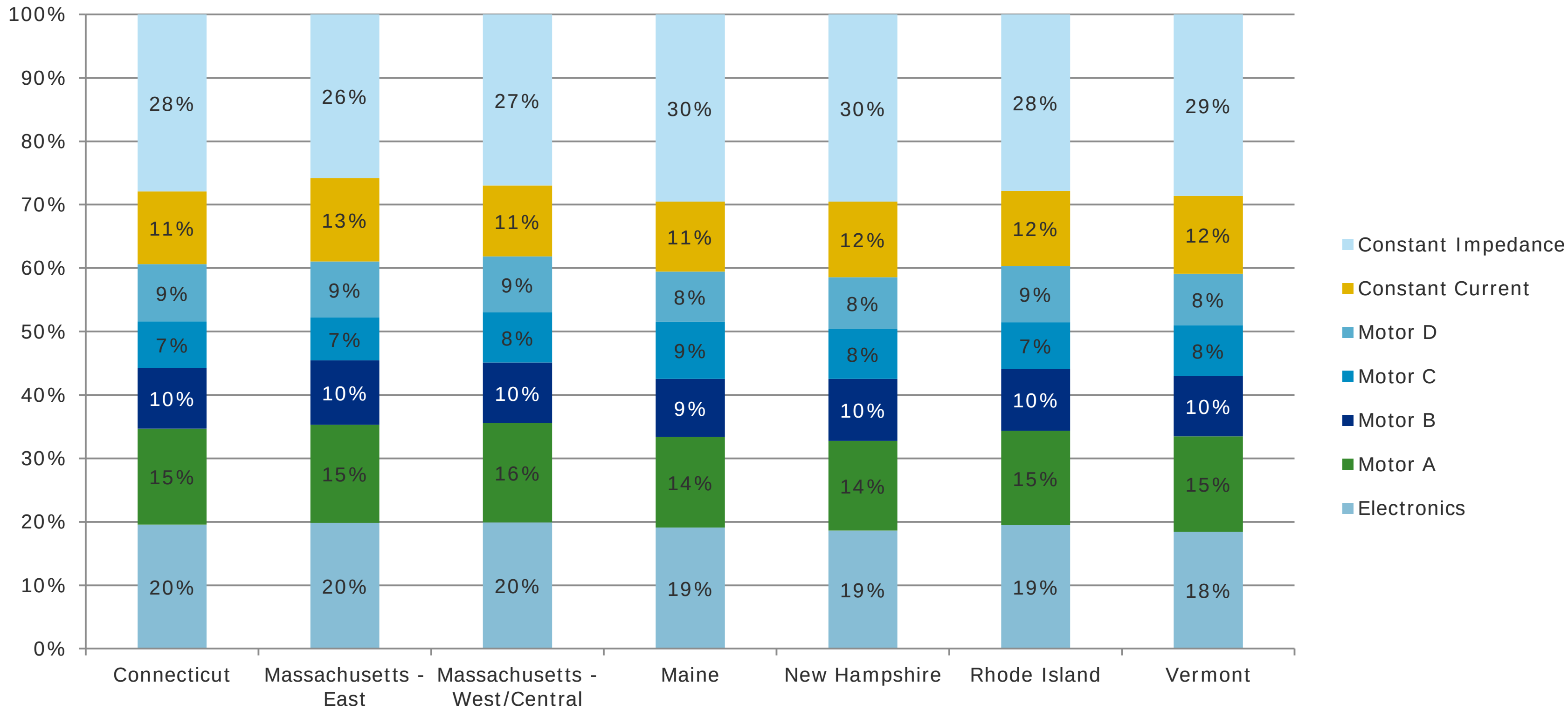


Figure 5-20 Region-to-region cross-sector distribution of load component shares during the spring light load hour



6 ASSESSMENTS OF QUALITY OF ESTIMATES AND RECOMMENDATIONS

6.1 Coverage Assessment by Sector and Region

DNV GL compared the bottom-up estimates for total annual consumption built up from the end-use level produced in this study as an intermediate analysis step to top-down retail electricity sales data from EIA to derive a rough estimate of the portion of system load which is not covered in this study.

Table 6-1 presents a comparison of the estimates produced in this study to 2012 retail electricity sales from the EIA-861[37]. The ratio column of the table gives the level of agreement between the estimates in this study and the retail sales for 2012 – the closer the ratio is to one, the higher the level of agreement between the two.

Table 6-1 Comparison of annual electricity consumption from this study to retail sales by state and sector

Sector	State	Estimated Annual Electricity Consumption - New England End-Use Load Model (MWh)	2012 Electricity Retail Sales - EIA (MWh)	Ratio of Estimated Consumption to Sales (MWh)
Residential	**CT**	13,007,941	12,757,633	1.020
	MA	21,616,891	20,313,469	1.064
	ME	6,062,796	4,480,736	1.353
	NH	5,026,618	4,439,208	1.132
	RI	3,867,664	3,121,367	1.239
	VT	2,702,162	2,095,283	1.290
	NE Region	52,284,246	47,207,696	1.108
Commercial	**CT**	14,459,806	12,976,050	1.114
	MA	27,457,316	17,722,811	1.549
	ME	6,170,339	4,053,188	1.522
	NH	5,824,561	4,478,420	1.301
	RI	4,450,038	3,639,866	1.223
	VT	3,295,910	1,993,892	1.653
	NE Region	61,657,969	44,864,227	1.374
Industrial	**CT**	5,246,075	3,565,944	1.471
	MA	8,884,145	16,927,205	0.525
	ME	3,022,047	3,027,135	0.998
	NH	2,232,200	1,952,633	1.143
	RI	1,670,753	923,478	1.809
	VT	1,177,061	1,421,589	0.828
	NE Region	22,232,282	27,817,984	0.799
Total	**CT**	32,713,966	29,492,338	1.109

[37] http://www.eia.gov/electricity/data/eia861/

Sector	State	Estimated Annual Electricity Consumption - New England End-Use Load Model (MWh)	2012 Electricity Retail Sales - EIA (MWh)	Ratio of Estimated Consumption to Sales (MWh)
	MA	57,958,352	55,313,324	1.048
	ME	15,255,182	11,561,059	1.320
	NH	13,083,379	10,870,261	1.204
	RI	9,988,455	7,708,334	1.296
	VT	7,175,133	5,510,764	1.302
	NE Region	136,174,497	120,456,080	1.130

Overall, the estimates in this study for New England had a discrepancy of about 13 percent with retail sales. There were larger discrepancies for certain regions and sectors. The largest discrepancies were seen for the commercial and industrial sectors. DNV GL expects that the large discrepancies are primarily due to differences in classification and coverage deficiencies for certain classes of loads identified in Section 2.2. In this study the classification rules are tied to end-user surveys which have very detailed eligibility criteria. It is expected that the classifications derived for retail sales may be based on billing rate codes, which are far less detailed. For example, in most cases a utility will not know what kind of business or industrial activity their customers are engaged in, except for the very large customers which may have account representatives.

Other likely sources for discrepancies include economic effects impacting total consumption between the base years of the different sources and changes in the technology base and efficiency of the end-use equipment stock.

6.2 Assessment of Data Sources for Use in this Study

In this section DNV GL ranked the end-use estimates and rules of association according to the following criteria:

- **Was the estimate derived from a rigorous research study**? Was statistical sampling used for selecting the study sites? Were device inventories or audits taken by a trained engineering field technician onsite?
- **How relevant to the seven New England regions are the estimates?** Were the estimates based on data collected in all of the seven regions? If not, were they derived from data collected from some of the regions or nearby geographic areas which are relevant? Or, is the end-use such that geography is not a critical factor for its relevance?
- **How relevant are the estimates today?** Were the estimates based on a recent study? Is this an end-use category with a significant shift in the equipment stock that is currently in service in customer sites?
- **How relevant are the end-use load shapes that were used to transform annual energy to spring light load and summer peak load hours?**

6.2.1 Assessment of Residential Data Sources

Table 6-2 below contains scores (high, medium, or low) for the quality criteria given above for the assessment. Assessments have only been made for end-use categories accounting for the top 90% of summer peak load.

Table 6-2: Assessment of Residential End-Use Estimates

Proportion of Summer Peak Load	End-Use Category	Source Quality	Regional Specificity	Age of Data Source	Notes
28.1%	Space cooling – split phase	High	High	Medium	Residential space cooling estimates are linked to a rigorous sample design through the RECS and load shapes that are relevant to New England. The annual consumption estimates are derived from the RECS end-use modelling process which is assumed to be accurate but has not been validated using estimates derived from AC metering data. The age of the data is likely not a big issue for space cooling, but the estimates will not reflect efficiency improvements since 2009.
17.5%	Space cooling – single phase	High	High	Medium	
8.6%	All other residential end uses	Medium	High	Medium	The RECS residual component is very large. We reduced this significantly through linkages to secondary sources, but it is still a large end-use category, and the end uses making up this category has likely shifted somewhat since 2009.
8.3%	Refrigerators/Freezers	High	High	Medium	These end-use categories are difficult to derive estimates for through conditional demand analysis models, so some question about the accuracy of annual energy consumption estimates but likely in range of reasonableness.
6.5%	Pool Pumps	Medium	Medium	Medium	The pool pump estimate in this study is highly dependent on the accuracy of the secondary sources. There is likely an increased share for variable speed pumps that the data could not have reflected due to the age.
6.4%	All other electronics	Medium	Low	Low	The equipment stock for electronics changes rapidly, making penetration and consumption estimates quickly obsolete. Likely accounts for some of the residual category
4.4%	Lighting – Incandescent	High	High	Low	Installed lamp type distribution has likely shifted in the past 4-5 years since this the data these estimates are based on was collected.
3.4%	Water heating	Medium	High	Medium	Water heating consumption can be difficult to model with a conditional demand analysis, as is done with the RECS, but is probably fairly stable. This will change when penetration of heat pump water heaters increases.
3.2%	Clothes dryers	Medium	Low	Medium	Estimate is derived from a California end-use study but likely is applicable
3.1%	Set-top/cable box, digital, DVR	Medium	Low	Low	The equipment stock for electronics changes rapidly, making penetration and consumption estimates quickly obsolete.
2.2%	Lighting – CFL/Linear Fluorescent	High	High	Low	Installed lamp type distribution has likely shifted in the past 4-5 years since this the data these estimates are based on was collected.
2.1%	Lighting - Other				Low priority – Bottom 10%
1.6%	Space cooling – three phase				Low priority – Bottom 10%
1.2%	Ceiling Fans				Low priority – Bottom 10%
1.0%	Other TVs				Low priority – Bottom 10%
0.8%	CRT TVs				Low priority – Bottom 10%
0.6%	Clothes				Low priority – Bottom 10%

Proportion of Summer Peak Load	End-Use Category	Source Quality	Regional Specificity	Age of Data Source	Notes
	Washers				
0.5%	Range/Oven				Low priority – Bottom 10%
0.3%	Dishwashers				Low priority – Bottom 10%
<0.1%	Space Heating				Low priority – Bottom 10%

The following sections provide brief assessments of the primary residential data sources.

2009 RECS: The rigorous sample design of the RECS makes it an indispensable data source for this study. The quality of the end-use estimates has not been validated with a rigorous end-use metering study, but the estimates nonetheless are thought to be quite reliable. The number of published end-use estimates, however, is very limited. The face-to-face householder interviews prevent accurate lamp counts and nameplate collection from major appliances, so reliance on secondary sources for end-use consumption is necessary to get a complete picture of the residential end-use consumption breakdown without having an extremely large residual category.

The geographic specificity of the RECS microdata allowed for grouping the New England regions into two groups directly (Massachusetts and the other New England states) and another split indirectly through mapping the climate zone variable to the state boundaries. Although not perfect for this study, it allowed for straightforward calibration to the seven New England regions using the American Community Survey data.

Load Ratios: The load ratios were generally expected to be appropriate for use in this study, since they were tied to regionally specific and fairly recent annual energy consumption estimates, and for lighting and HVAC the load ratios are current and regionally specific, due to measurement and verification studies for demand side resource programs in New England. The age of the load shape studies from which the electronics load shapes were derived is a concern, but less so that it would be if electronics represented a greater proportion of peak load. It is, however, likely that electronics accounts for a significant portion of the “all other” category, which is a big portion of peak residential load. DNV GL recommends that the electronics and “all other” residual category be revisited as studies become available which shed light on this issue.

American Community Survey (ACS): The ACS is an excellent data source for this analysis since it provides recent housing unit counts by type at an even more granular geographic area (county level) than was required for this study. For application of the load model to specific feeders or groups of feeders, the county level housing type distribution estimates would facilitate a valuable calibration.

6.2.2 Assessment of Commercial Data Sources

Table 6-3 provides quality ratings of the commercial sector estimates according to the criteria described above in this section. Assessments have only been made for end-use categories accounting for the top 90% of summer peak load.

Table 6-3: Assessment of Commercial Sector End-Use Data Sources for Use in This Study

Proportion of New England Summer Peak Load	End-Use Category	Source Quality	Regional Specificity	Age of Data Source	Notes
23.12%	Lighting - CFL/Linear Fluorescent	High	High	Medium	The installed stock of lamp technology has shifted in commercial buildings since the 2003 CBECS which may have an effect on the proportional end-use share, but CFL/Linear fluorescent share estimate was derived from a fairly recent secondary source. Regionally specific and recent load shapes were used to produce the load ratios for this study.
21.56%	Space Cooling - Three Phase	High	High	Low	Age is the primary concern, along with accounting for new technologies that are in stock since the 2003 CBECS
11.12%	Ventilation	High	High	Low	Age is the primary concern, along with accounting for new technologies that are in stock since the 2003 CBECS
10.93%	All Other End Uses - COM	Medium	Medium	Low	There is a significant share of all other end uses in the CBECS, unfortunately. Unfortunately, the distribution of end uses making up this category is regionally dependent.
9.96%	Refrigeration	High	High	Low	Age is the primary concern, along with accounting for new technologies that are in stock since the 2003 CBECS
7.60%	Office Equipment	High	High	Low	Installed stock of office equipment technology is dramatically different than it was in 2003.
4.16%	Space Cooling - Split Phase	High	Medium	Low	This category is most closely tied with small businesses, which will have the most regional dependency for air conditioning of the commercial building types.
2.88%	Lighting - HID Interior	High	High	Medium	Age of CBECS lighting estimates is the primary concern. Like with fluorescents, the 2010 Lighting Market Characterization Study was used to apportion lighting to this category and others.
2.14%	Space Cooling - Single Phase				Low priority - Bottom 10%
1.49%	Lighting – Other				Low priority - Bottom 10%
1.49%	Water Heating				Low priority - Bottom 10%
1.22%	Lighting - Incandescent				Low priority - Bottom 10%
0.91%	Cooking				Low priority - Bottom 10%
0.91%	Air Compression				Low priority - Bottom 10%
0.50%	Elevator drives and hydraulic pumps				Low priority - Bottom 10%
0.02%	Space Heating				Low priority - Bottom 10%

The following sections provide brief assessments of the primary commercial data sources.

2009 CBECS: The assessment of the CBECS can be summed up very succinctly: it is an excellent resource for this study but the data are too old to be reliable consistently across the end-use categories. Fortunately, the 2012 CBECS estimates are expected to be publicly available in 2015.

Like the RECS, the rigorous sample design of the CBECS makes it an indispensable data source for this study. The quality of the end-use estimates has not been validated with a rigorous end-use metering study, but the estimates nonetheless are thought to be quite reliable and based on statistically-adjusted engineering models grounded on end-use metering data. The number of published end-use estimates, however, is very limited. The face-to-face interviews prevent accurate end-use equipment counts, so reliance on secondary sources for end-use consumption is necessary to get a complete picture of the commercial end use consumption breakdown without having an extremely large residual category.

The geographic specificity of the CBECS is less than the 2009 RECS, as the finest level of geography with direct identifiers in the microdata is New England.

Load Ratios: See load ratios assessment for the residential estimates.

County Business Patterns Survey (CBP): The CBP Survey is an excellent data source for this analysis since it provides business establishment counts by type at an even more granular geographic area (county level) than was required for this study. Unfortunately, there is not a perfect translation from building type (from the CBECS) to NAICS business category.

6.2.3 Assessment of Industrial Data Sources

Machine drives account for almost half of the purchased electricity used in the manufacturing sector, with process heating, electro-chemicals processing, process cooling and refrigeration, HVAC, lighting, and other process use comprising the top 90% of annual consumption.

The following assessments apply to all end-use categories in the industrial sector.

2010 MECS: The MECS has some excellent qualities for use in this study:

- Rigorous statistical sample design with deep coverage of the manufacturing sector
- End-use categories with annual consumption estimates are closely aligned with the goals of this study and in some cases more detailed.

Unfortunately there are some aspects of the MECS which makes it less desirable than the RECS or CBECS:

- Due to protections in place to prevent disclosures of operational data from manufacturing establishments, the MECS published estimates are not presented in microdata form with sample weights to facilitate customized cross-tabulation of the response data.
- MECS end-use consumption estimates are self-reported. This is an issue to the extent which there is a bias in the assumed distribution of energy consumption by end-use category exhibited by MECS respondents.
- The end-use estimates are not regionally specific. Rather, they correspond with the whole U.S. level of geography. For this study, we had to assume that the proportional end-use shares at the national level held for the Northeast, which was the finest and closest region in which purchased electricity for consumption was reported. Our analysis also had to assume that the northeast (which includes

New England, New York, and New Jersey) end-use estimates applied in the seven New England sub-regions.

- The MECS does not account for the industrial sector as a whole. The consumption and load estimates for the non-manufacturing portion of the industrial sector therefore have no end-use detail. Consequently the importance of the rules of association for those customer classes is very high. Fortunately agriculture, construction, and mining did not have significant shares of total system load in this analysis. For certain regions, however, electric rail transportation and/or utility services loads are expected to be large and are not accounted for in this study.

Despite its shortcomings as it relates to this study, the MECS is by far the best option to serve as the backbone of the industrial sector end-use decomposition analysis.

Load Ratios: The load ratios for the industrial sector that were available for this study were at the whole facility level, rather than the end-use level, and for only the most energy intensive industries. While this on the surface may seem problematic, it is less of an issue in this study for the following reasons:

- Compared to other sectors, the load factor for industrial establishments is relatively high so the load is more stable throughout the day.
- Industrial end uses are less weather-sensitive than estimates for other sectors.

One major weakness of relying on industrial load shapes for this study instead of actual interval consumption data for industrial sites is that the spring light load hour plant operation may be very site-specific, or be dependent on characteristics of the larger economy which are not accounted for in the assumed load shapes.

6.2.4 Assessment of Rules of Association Used in this Study

The rules of association used in this study are a starting point, and only in select cases were they grounded in either fairly deterministic assignment due to engineering principles or on data from studies grounded to a rigorous statistically designed sample. DNV GL recommends the following next steps:

- For the end-use categories comprising at least the top 50% of the load in the summer peak or spring light load hour (or other time), develop ranges for the rules of association which represent high and low cases for each component.
- Conduct a sensitivity analysis to the high and low points of the range to see the impact on the ultimate load component distribution. It may be possible to design an analysis to optimize the rules of association to match the observed load behavior.
- For at least the most critical end-uses, conduct a rigorous research study to develop rules of association based on measurements from a sample with an appropriate level of diversity in the end use load type.

For those end uses which are both important contributors to peak load and have been researched with end-use metering studies for demand side management applications, statistically designed samples of equipment with end-use metering data already exist and may provide benefit for relatively low cost. Permissions from data owners would need to be sought and confirmation would be needed on the usefulness of the data.

A related option could be partnering with a metering study prior to it being launched.

APPENDIX A – ACRONYMS LISTED IN THIS REPORT

AEC	annual energy consumption
AEO	Annual Energy Outlook
AIA	American Institute of Architects
CBECS	Commercial Buildings Energy Consumption Survey
CEC	California Energy Commission
CDD	cooling degree-day
CEA	Consumer Electronics Association
CEUS	(California) Commercial End-Use Survey
CFL	Compact Fluorescent Lighting
CRT	cathode ray tube
CT	Connecticut
DOE	U. S. Department of Energy
EIA	Energy Information Administration
HDD	heating degree-day
HID	high Intensity Discharge
HVAC	heating, ventilation, and air-conditioning
MA	Massachusetts
MA-E	Massachusetts – East
MA-WC	Massachusetts – West/Central
MECS	Manufacturing Energy Consumption Survey
MH	mobile home
MF	Multi-family
NEEP	Northeast Energy Efficiency Partnership
NAICS	North American Industrial Classification System
NH	New Hampshire
NOAA	National Oceanic and Atmospheric Administration
PDAF	Peak Day Adjustment Factor
RECS	Residential Energy Consumption Survey
RI	Rhode Island
SF	single family
TRM	technical reference manual
UEC	unit energy consumption
VT	Vermont

APPENDIX B – GLOSSARY OF TERMS

A-

Agricultural Industries: Organizations and infrastructure involved with production, processing, sale, marketing, storage or protection of agricultural products, such as crops and livestock (source: Census)

Air Compression: Commercial and industrial end-use comprised of systems that generate, store, and distribute energy in the form of compressed air

Annual Energy Consumption (AEC): The average yearly energy usage for a given system or end-use

B-

Building Type: Characterization of a commercial unit defined by its primary use or the function of the company occupying the most floor space of the unit (source: EIA)

C-

Calibration: Analysis technique that transforms data based on regional characteristics such as climate and weather

Ceiling Fan: A fan installed on the ceiling of a room used for ventilation purposes (source: EIA)

Census Division: A subset of states located in the same geographic area used for regional analysis; New England is the census division applicable to this study (source: EIA)

Climate Zone: Regions within or across states that are as climactically homogeneous as possible and can be placed into one of five zones based on its 30 year average heating degree-days and cooling-degree days (source: EIA)

Clothes Dryer: An appliance in a residential unit that dries laundry using heat and rapid air movement (source: EIA)

Clothes Washer: An appliance with an agitator used to wash and clean laundry with water (source: EIA)

Commercial Sector: Economic grouping of organizations and businesses that are for-profit, non-governmental or vendors of goods and services (source: Census)

Construction Industries: Organizations and infrastructure engaged in the construction of buildings or engineering projects (source: Census)

Conventional Boiler Use: Industrial end-use of generating steam for power, processing, or heating purposes using a boiler vessel (source: EIA)

Cooking: An end-use that uses energy for commercial or institutional food preparation (does not include residential food preparation) (source: EIA)

Cooling Degree-Day: A measure representative of the demand for energy needed to cool a building to a standardized base temperature of 65 degrees Fahrenheit (source: EIA)

D-

Dry Bulb Temperature: Air temperature that is not affected by humidity or moisture (source: NOAA)

Dishwasher: An electrical device used to automatically clean dishware and utensils (source: EIA)

E-

Eastern Massachusetts: The eastern part of the state of Massachusetts comprising of Essex, Middlesex, Suffolk, Norfolk, Plymouth, Bristol, Barnstable, Nantucket, and Dukes Counties

Elevator Drives: Electric powered equipment that moves people or goods vertically between levels of a building or structure

End-use: A device, function, or process that consumes energy (source: EIA)

Electro-chemical Processes: Industrial end use processes commonly used in the aluminum industry, and in the alkaline and chlorine industry in which electricity causes chemical transformations that reduce and separate substances (source: EIA)

Electronics: Static constant power plug loads (source: Kosterev et al)

F-

Feeder: A medium-voltage power line transferring power from a distribution substation to the distribution transformers

G-

H-

Heating Degree-Day: A measure representative of the demand for energy needed to heat a building to a standardized base temperature of 65 degrees Fahrenheit (source: EIA)

Household: A family, an individual, or a group of up to nine unrelated people, occupying the same housing unit (source: EIA)

Housing Unit: A residential dwelling defined characterized as a mobile home, single family unit, or multi-family unit (source: EIA)

Hydraulic Pump: A pump powered by energy generated from moving water

I-

Industrial Sector: Economic group of organizations or businesses that construct and manufacture products (source: Census)

J-

K-

L-

Lighting: An end-use that uses electricity to illuminate both the interior and exterior of a dwelling in residential analysis and the interior of a building in commercial analysis (source: EIA)

Lighting – CFL/Linear Fluorescent: A subset of the lighting end-use, which includes CFLs and Linear Fluorescent lighting in the Residential, Commercial and Industrial sectors

Lighting – HID Interior: A subset of the lighting end-use, which includes High-Intensity Discharge lighting in the Commercial and Industrial sectors

Lighting – Other: A subset of the lighting end-use, which includes the categories not explicitly modeled. For residential, this excludes CFLs and Incandescents. For commercial this excludes CFL/Linear Fluorescents, Incadescents and HID interior lighting. For industrial this excludes CFL/Linear Fluorescent and HID Interior.

Linkage: Analysis technique that assumes that when a population is covered in two different surveys, characteristic properties of the population derived from data collected on one survey can be assumed on the other survey, when population characteristics associated with those

Load Component Categories: End-use load types Motor A (constant load torque e.g. three-phase air conditioner), Motor B (load torque proportional to speed squared with high inertia e.g. a fan), Motor C (load torque proportional to speed squared with low inertia e.g. a pump), and Motor D (single-phase air conditioners) (source: Kosterev et al)

Load Shape: A linear model that plots electrical load versus time for a customer class, system, building or end-use and varies according to temperature or season

M-

Machine Drive: Industrial end use of motors found in almost every process in manufacturing where thermal or electric energy is converted into mechanical energy (source: EIA)

Manufacturing Industries: Commercial or industrial organizations that involve labor and machine processes to produce merchandise

Microdata: Non-aggregated data from the units within a study

Mining Industries: Organizations and infrastructure involved in extracting naturally occurring mineral solids, liquid minerals, and gases; the non-manufacturing economic sector broadly includes quarrying, well operations, beneficiating, and other preparation performed as a part of mining activity (source: Census)

Mobile homes: A manufactured residential unit that was originally constructed on a movable chassis to be transported to a site (source: EIA)

Monthly Usage Allocation: Percentage that represents the annual usage of a particular end use assigned to each month; the monthly breakdown values are unique for each climate zone and are influenced by weather on a seasonal basis

Motor A: Constant load torque, e.g. three-phase condenser motor (source: Kosterev et al)

Motor B: Load torque proportional to speed squared with high inertia, e.g. a fan (source: Kosterev et al)

Motor C: Load torque proportional to speed squared with low inertia, e.g. a pump (source: Kosterev et al)

Motor D: Single-phase air conditioners (source: Kosterev et al)

Multi-family: A residential structure that is divided into living quarters for two to four families or households (source: EIA)

N-

Non-Manufacturing Industries: Commercial or industrial organizations that do not produce merchandise; includes service industries such as medical care and teaching (source: Census)

North American Industrial Classification System (NAICS): A North American standard system used in grouping and classifying establishments into industries based on the similarity of their production processes (source: Census)

O-

Office Equipment : A class of energy-using equipment including computers, servers, copiers, FAX machines, cash registers, mainframe computer systems, and other miscellaneous office equipment (source: EIA)

Other Commercial End-uses: End-uses that comprise of residual total load for commercial sector after accounting for: space heating, ventilation, space cooling, lighting, air compression, cooking, elevator drives and hydraulic pumps, office equipment, refrigeration, and water heating. Remaining items in the other category vary by the building type. Some notable end-uses that would fall into other in the office include kitchen appliances in the office staff lounge, non-refrigerated vending machines, and personal space heaters. For lodging, however, other might include ice machines, laundry, or even slot machines. In healthcare, all of the medical equipment would fall under the other category

Other Electronics: End-use category consisting of residential consumer electronics not in either the television, office equipment, or set top/cable box, digital, DVR categories; the other electronics end use category is not included in the Other Residential End-uses categories (source: EIA)

Other Facility Support: Non-process end uses at manufacturing sites that include energy used in diverse applications that are associated with building operations or activities such as cooking in cafeterias, operating office equipment, or operating elevators

Other Non-Process Support: End uses in operations and maintenance at manufacturing sites other than heating, ventilation, air conditioning (HVAC), facility lighting, facility support, onsite transportation, conventional electricity generation (source: EIA)

Other Process Support: End uses involved in manufacturing processes other than process heating, process cooling and refrigeration, machine drive, and electrochemical processes (source: EIA)

Other Residential End-uses: End-uses that comprise of residual total load for residential sector after accounting for: space heating, water heating, space cooling, lighting, televisions, set-top/cable boxes/DVR, all other electronics, refrigerators/freezers, range/oven, dishwashers, clothes washers, clothes dryers, ceiling fans, pool pumps, and well pumps. Remaining items in the other category include kitchen appliances (microwave, coffee machine, etc), general household appliances (hair dryers, clothes irons, vacuum cleaners), and other miscellaneous items, such as aquariums and wine coolers.

Onsite-Transportation: Industrial end use that includes energy used in vehicles and transportation equipment within the boundaries of a manufacturing facility (source: EIA)

P-

Penetration: The count of a particular end-use type found in a residential housing unit

Peak Day Adjustment Factor: Ratio used in the load hour calibration process that represents the daily usage for a peak day vs. that of a typical weekday (by season or month); the value of the ratio is impacted primarily by differences in daily weather sensitivity of the peak day vs. the typical day and can be based on some pre-defined probability, such as a one-in-one-year peak day scenario vs. a one-in-ten year peak day scenario

Per-Unit Day-Type Load Shapes: The actual hourly load shape represented in per-unit of daily maximum for each type of day (peak day, weekday, and weekend day); the number of per-unit load shapes used to represent any hour of the year varies according to the required precision and variation of the loads over different day types and seasons

Pool Pump: An electric pump used in residential pool applications to circulate water and move it through the filtering and heating systems (source: EIA)

Process Cooling and Refrigeration: Industrial end use that utilizes energy to lower the temperature of substances involved in the manufacturing process (source: EIA)

Process Heating: Industrial end use that utilizes energy to increase the temperature of substances involved in the manufacturing process (source: EIA)

Q-

R-

Range/Oven: End-use category consisting of enclosed ovens as well as stove top burners (source: EIA)

Reportable Domain: Sub-division of a census division into one or more states; the New England census division is comprised of two domains: Massachusetts and other New England States

Residential Sector: Economic grouping of dwellings units consisting of single-family homes, multi-family homes, or mobile homes that provide living, cooking, sleeping, and sanitation facilities (source: EIA)

Rules of Association: Static proportional representation of an end-use load in terms of the six ZIP model parameters or the load component categories

Refrigerators/Freezers: End-use category for devices designed for cooling food a temperatures above 32 degrees Fahrenheit and freezing food at temperatures of 8 degrees Fahrenheit and below (source: EIA)

S-

Sample frame: The sources from which a statistical sample is drawn for analysis

Saturation: The proportion of households in a group having a particular end-use type

Single-family: A residential unit that provides living space for one household or family (source: EIA)

Set top/cable box, digital, DVR: End-use that includes devices that connects to televisions, containing inputs and displaying outputs from an external source of signal that provides content that can then be displayed on a television screen (source: EIA)

Single-phase Air Conditioner: Cooling devices, such as individual air room air conditioners and evaporative coolers, powered by the Motor D load component category; they are commonly found in residential units

Space Heating: An energy end-use that involves the use of mechanical equipment to heat all or part of the ambient air in a residence or building (source: EIA)

Space Cooling: An energy end-use that involves the use of mechanical equipment to cool all or part of the ambient air in a residence or building (source: EIA)

Split Phase Air Conditioner: Cooling devices commonly found in residential units, such as heat pumps for cooling and central air conditioners that are powered by the Motor D load component category

Spring light load hour: An hourly scenario occurring in May at the hour ending 09:00, where conditions are a temperature of 55 degrees Fahrenheit with a dew point of 47

Summer peak load hour: An hourly scenario occurring mid-week (Tuesday, Wednesday, or Thursday) in July at the hour ending 15:00, where conditions are a temperature of 95 degrees Fahrenheit with a dew point of 70

T-

Televisions: End-use category consisting of televisions (telecommunicating devices that transmit and receive moving images), such as cathode ray tube (CRT), plasma, projection, LED, and others (source: EIA)

Televisions – CRT: A subset of the television end-use category consisting of cathode ray tube televisions

Televisions – Other: A subset of the television end-use category containing, plasma, projection, LED, and others. It does not include CRT TVs

Three-phase Air Conditioner: Cooling devices commonly found in commercial buildings, such as commercial chillers and packaged air conditioning units, that are powered by the Motor A load component category

U-

Unit Energy Consumption (UEC): The average yearly energy usage for an individual unit of a particular end-use

V-

Ventilation: Electrical processes used for the circulation of air through a building to provide fresh air to occupants and to deliver heating and cooling to occupied spaces (source: EIA)

W-

Water Heating: End use category that involves using a thermally insulated, automatically controlled device to heat and store water at temperatures less than 180 degrees Fahrenheit (source: EIA)

West/Central Massachusetts: The western/central part of the state of Massachusetts comprising of Berkshire, Franklin, Hampden, Hampshire, and Worcester Counties

Weekend to Weekday Ratio: Load hour calibration process ratio defined as the ratio of a typical weekend day usage to a typical weekday usage (by season or month); the value of the ratio is subject to variation across sectors, as some commercial buildings have more weekend activity than others, while residential end uses generally have less variation between weekdays and weekend days

Well Pump: A pump that draws water from a well below ground level up into the water pipes that circulate through a residential unit (source: EIA)

X-

Y-

Z-

ZIP coefficient load model: Model used to represent power consumed by a load as a function of voltage; end use load types comprise of constant impedance Z, constant current I, P constant Power, and Q reactive power (source: Bokhari et al)

ZIP-I_p: The change in the ratio of active power to rated active power which increases linearly with a unit increase to the ratio of voltage to rated voltage (source: Bokhari et al)

ZIP-I_q: The change in the ratio of active power to rated active power which increases linearly with a unit increase to the ratio of voltage to rated voltage (source: Bokhari et al)

ZIP-P_p: the change in the ratio of active power to rated active power which is invariant with voltage

ZIP-P_q: The change in the ratio of reactive power to rated reactive power which is invariant with voltage

ZIP-Z_p: The change in the ratio of reactive power to rated reactive power which increases linearly with a unit increase in the squared ratio of voltage to rated voltage (source: Bokhari et al)

ZIP-Z_q: The change in the ratio of reactive power to rated reactive power which increases linearly with a unit increase in the squared ratio of voltage to rated voltage (source: Bokhari et al)

APPENDIX C: RULES OF ASSOCIATION BY SECTOR AND REGION

The tables contained in this appendix were produced by applying the rules of association presented in section 4 to the end-use load distribution described in section 3. These tables may be used to generate customized load component breakdown within a region, using known MW of system load and known percentages of system load attributed to the residential, commercial, and industrial sector. The following steps should be used to produce a customized load component breakdown:

1. Select either the summer peak hour or spring light hour estimated load component distribution tables below, depending on which set is relevant for the application.

2. Identify the region of interest from the rows in the table.

3. Multiply the system load by each load component percentage in the relevant row of each of the residential, commercial, and industrial tables. This will give a preliminary MW value for each load component type for each sector.

4. Multiply the sector percentages of system load by each of the corresponding preliminary MW values computed in step 3. For example, if the industrial sector accounts for 20% of system load at summer peak, you would multiply 0.2 by the preliminary MW value for industrial electronics, industrial motor A, etc…

5. Sum up the load components from step 4 across the sectors. So the MW for electronics overall would be the MW for industrial electronics from step 4 plus the MW for commercial electronics from step 4 plus the MW for residential electronics from step 4. This summation would be carried out for each load component across the 3 sectors.

Table 6-1: Estimated Residential Peak Hour Load Component Distribution

New England Region	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Connecticut	17%	0%	13%	7%	42%	5%	15%
Massachusetts - East	13%	2%	15%	9%	44%	1%	16%
Massachusetts - West/Central	10%	1%	16%	9%	46%	1%	16%
Maine	12%	1%	13%	10%	37%	1%	26%
New Hampshire	12%	1%	13%	10%	38%	1%	25%
Rhode Island	10%	0%	16%	8%	49%	1%	17%
Vermont	11%	1%	12%	15%	37%	1%	23%
New England	**14%**	**1%**	**14%**	**9%**	**43%**	**2%**	**18%**

Table 1-2: Estimated Commercial Peak Hour Load Component Distribution

New England Region	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Connecticut	17%	28%	11%	4%	8%	23%	10%
Massachusetts - East	17%	29%	11%	4%	8%	22%	9%

Massachusetts - West/Central	17%	26%	12%	4%	7%	24%	11%
Maine	18%	22%	12%	4%	6%	26%	12%
New Hampshire	18%	24%	12%	4%	6%	25%	11%
Rhode Island	18%	27%	11%	4%	7%	23%	11%
Vermont	17%	27%	11%	4%	7%	23%	10%
New England	**17%**	**27%**	**11%**	**4%**	**7%**	**23%**	**10%**

Table 1-3: Estimated Industrial Peak Hour Load Component Distribution

New England Region	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Connecticut	20%	33%	9%	17%	3%	2%	17%
Massachusetts - East	20%	34%	10%	17%	3%	2%	15%
Massachusetts - West/Central	21%	33%	8%	18%	3%	2%	15%
Maine	22%	35%	8%	21%	3%	2%	9%
New Hampshire	20%	33%	9%	17%	3%	2%	15%
Rhode Island	19%	32%	10%	17%	3%	2%	17%
Vermont	20%	35%	9%	19%	2%	2%	13%
New England	**20%**	**33%**	**9%**	**18%**	**3%**	**2%**	**15%**

Table 1-4: Estimated Residential Light Hour Load Component Distribution

New England Region	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Connecticut	21%	0%	6%	6%	17%	1%	49%
Massachusetts - East	22%	0%	6%	5%	17%	2%	48%
Massachusetts - West/Central	22%	0%	6%	5%	17%	2%	48%
Maine	18%	0%	5%	7%	14%	2%	54%
New Hampshire	18%	0%	6%	7%	15%	2%	52%
Rhode Island	21%	0%	6%	6%	16%	2%	49%
Vermont	18%	0%	6%	7%	15%	2%	52%
New England	**21%**	**0%**	**6%**	**6%**	**16%**	**2%**	**50%**

Table 1-5: Estimated Commercial Light Hour Load Component Distribution

New England Region	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Connecticut	18%	22%	13%	5%	5%	24%	13%
Massachusetts - East	19%	21%	13%	5%	4%	24%	13%
Massachusetts - West/Central	18%	21%	13%	5%	4%	24%	14%

Maine	18%	19%	14%	5%	4%	25%	15%
New Hampshire	18%	20%	14%	5%	4%	25%	14%
Rhode Island	18%	21%	13%	5%	4%	24%	14%
Vermont	18%	21%	13%	5%	4%	25%	13%
New England	**18%**	**21%**	**13%**	**5%**	**4%**	**24%**	**13%**

Table 1-6: Estimated Industrial Light Hour Load Component Distribution

New England Region	Electronics	Motor A	Motor B	Motor C	Motor D	Constant Current	Constant Impedance
Connecticut	19%	32%	9%	17%	3%	3%	18%
Massachusetts - East	19%	33%	9%	16%	3%	3%	16%
Massachusetts - West/Central	21%	32%	8%	19%	3%	2%	15%
Maine	23%	35%	8%	21%	3%	1%	9%
New Hampshire	20%	33%	10%	17%	3%	2%	16%
Rhode Island	19%	31%	10%	17%	4%	2%	17%
Vermont	20%	34%	9%	19%	2%	2%	13%
New England	**20%**	**33%**	**9%**	**18%**	**3%**	**2%**	**15%**

APPENDIX D: TRANSMISSION OPERATOR FEEDBACK AND DNV GL RESPONSES

New England Transmission Owners (TOs) received a draft version of this report at a March 14, 2014 meeting hosted by ISO-NE. TOs had the opportunity to review the draft and provide comments to DNV GL. This Appendix provides the comments from National Grid, Northeast Utilities and NSTAR as well as the responses to the comments from DNV GL.

Comments from National Grid

Please provide (some) more background information regarding modeling and classification of Variable Speed Drives (VSD) during determination of the Rules of Association. Is any distinction made between different sizes of motors with VSD?

> **DNV GL Response:** Data was very limited for use in developing rules of association, but significant discussion between project stakeholders and outside experts took place regarding the representation of VSDs. The following source indicated that VSDs account for about 20% of motor load in the industrial sector as of 2010. John Kueck suspected that the distribution of VSDs on motors was not necessarily skewed towards larger size motors. We are assuming about 15% of the three phase AC compressor load is associated with VSDs. David Chassin noted that not all of the VSD motor load would behave as constant power electronics during voltage fault conditions since some classes would trip off completely below a certain threshold.

Suggest to provide an introduction to polynomial curve fitting with an example or reference to used methods. The demo on polynomial curve fitting among the Matlab demo examples on Programmatic Fitting could provide some guidance and examples. This suggestion is related to use of the ZIP model reference in IEEE Trans Power Systems 2013 (Section 4.1).

> **DNV GL Response:** Since the draft that was reviewed by TOs, we decided to avoid using ZIP model parameters since they do not translate directly to the rules of association framework. Also, the ZIP models would only apply in a narrow voltage range, and not necessarily around fault conditions. Instead, we are using primarily engineering judgment for developing assumed proportional shares into load components.

The updated Rules of Associations tables (spreadsheet received March 19) do no longer include reference to Dmitry Kosterev. Has a comparison been performed between the updated Rules of Associations spreadsheet with what is used by WECC in their dynamic load model?

> **DNV GL Response:** The final rules of association tables have more complete references and notes regarding the judgment or justification, including references to Dmitry and others.

Comments from Northeast Utilities

It is not apparent from the report the end product expected from the load survey and load characterization. We are, therefore, suggesting that the introductory sections of this report should briefly introduce the user to the ultimate end product of the effort; the workbooks and the load parameters contained in these workbooks. How will these workbooks assist the user in modeling the appropriate composition of load in an area?

DNV GL response: The final workbook will include an instructions tab with an example. We will add some description in the intro sections of the report as well.

We recommend that some public sector utility services, such as water treatment and pumping stations and waste water treatment plants be also included in the load models. For some areas these establishments may be the dominant load and consequently the voltage profiles and the dynamics of the electric system in these areas depend on the dynamics of these loads. Moreover, these public sector utilities operate continuously irrespective of the climatic season and the time of the day.

We also recommend that public transportation load be included in the load models since the heavy use periods of these loads coincide with the peak load period in New England. For southwest Connecticut in the corridor of New Haven, Bridgeport and Stamford to New York this load is very dominant and therefore its dynamics on the system should not be ignored.

DNV GL response: We understand and agree with this concern. For this project the basis for the analysis was end-use consumption survey data which unfortunately does not account for these customer classes. We recommend accounting for these classes by aggregating individual customer consumption data specific to geographic areas which are more specific than the 7 regions of this study. The steps for this would be:

1. Compute summer peak and spring light hour load for the additional classes
2. Develop rules of association for the new customer classes
3. Disaggregate the new load classes according to the rules of association
4. Add the new classes to the load models and recomputed the proportional shares by sector, end-use category, and load components

It is not apparent from the report whether each of the seven load regions formulated for New England could further be sub-divided (most probably along the lines of the PSS/E zones) to fit the actual load profile of the sub area. We are concerned that representing an area like Connecticut with one load profile will not reveal the true dynamic behavior of the electric system in this area. For Connecticut the composition of the different loads in Southwest Connecticut is vastly different from that of Eastern Connecticut and also from northwest Connecticut. Central Connecticut or the Hartford area has a concentration of commercial loads greater than the east and northwest. The ability should be built into the workbooks to accurately capture these differences.

DNV GL Response: The workbook will allow for user input to different proportional representation by sector from the default load disaggregation. For example, if a certain zone had 50% of system load from industrial customers, adjustments could be made to account for this.

We agree that for peak load periods, ending at 3:00 pm, outdoor lighting could be ignored in the load model, however, that will not be true for light load periods, the period ending at 09:00 am. Therefore, we recommend that outdoor lighting should be considered in the light load models to reflect the true nature of the load. In New England it has been determined that the dynamics of the electric system are well noticeable during light load conditions and including outdoor lighting will help capture the extent to which they affect the dynamics of the system.

DNV GL Response: We are unfortunately not in a position to account for outdoor lighting at this late stage. It is something that could be done in a follow-up effort.

We would like to know whether station service loads are accounted for in the modeling and how are these loads they classified?

Will the survey data be updated to reflect newly planned or built data centers? We are concerned that since these data centers consume huge amounts of electrical energy and have electronic load characteristics an entire area's load dynamics may change due to their presence. Failure to update the survey data will not reveal the true nature of the dynamic behavior of the area.

> **DNV GL Response:** We agree. Unfortunately the current source for commercial sites is the 2003 EIA commercial buildings survey, which is outdated with many respects especially for data centers. A new survey is being completed by EIA and the data could be incorporated into the analysis shortly after its release.

Comments from NSTAR

As was observed during the Load Model Workshop, the Load Component Breakdown is fairly uniform across all of New England.

One would expect to have a different load model for a area like Boston versus rural Vermont or other rural areas. In the past we have been concerned with a possible voltage collapse scenario for the Boston area during peak load conditions and limited in-city generation. Therefore, I would ask that consideration be given to a load model for the Boston area as a separate load zone.

> **DNV GL Response:** The final report will contain an assessment of the variation by region and comments regarding potential inaccuracies due to data limitations.

It looks like outdoor lighting and transportation was not included in the model. Please consider how to include this load component for the Boston load area, since it may be a relatively significant load component?

> **DNV GL Response:** Outdoor lighting was not included in the model due to the reference hours for the two slices of time being during the day (acknowledging that some outdoor lighting load is still out there during the day). transportation could be included but we would need to work with data provided by utilities to account for this in a bottom-up style methodology consistent with the rest of the analysis.

There is only one peak - which is the summer peak. However, for light load it is possible that the new dynamic load models for the October / November or January / February times will be more limiting for stability simulations. Therefore, it may be worthwhile to develop Load Component Breakdowns for other light load times and compare visually or by stability simulations.

> **DNV GL Response:** This is something we would be able to add in a follow-up effort.

The IEEE paper on the ZIP model states that the model was developed for steady state analysis, therefore we may want to reconsider if this model is applicable for the dynamic load model effort.

> **DNV GL Response:** Agreed. Following the great discussion during the meeting Friday we are going back to a load component breakdown framework where all of the components are positive, since static ZIP models do not fit with the purpose of this study. On this point, I would suggest that the WECC rules of association avoid using ZIP model parameter nomenclature to avoid others thinking they may be appropriate in this application.

How individual TO load composition data may be used should also be clearly described and perhaps even used to compare to the approach used in the study. I know that energy consumption data is fairly readily available for our company based on Residential, Commercial and Industrial load components. Unless there is clear direction / procedure on how this information can be easily used then once the model is finalized we will not be able to replace or update based on TO load composition data in the future.

DNV GL Response: We will be editing the report to improve the instruction for making use of the information.

It would be useful to compare the load component data presented in the Task 2 - Estimated Load Component Breakdowns - Summer ... (and Spring) of the Presentation Slides, with dynamic models used in other regions of the US that have somewhat similar climate and region - who may have experience with dynamic load models.

DNV GL Response: We agree. At minimum it would be good to compare with some results from WECC. We are not sure what other regions have a parallel effort underway. We would certainly be interested in developing a similar model for other regions.

Figure 2 describes a flow chart of the load model development methodology. However, it is not clear to me how the methodology was actually used. It may be helpful to have an example to accompany the flow chart that can help to clarify the process. Especially for future reference.

DNV GL Response: We will revisit this in production of the final report.

The dynamic load model used in the stability simulations will have significant financial impact on the design of the transmission system and the generator interconnection. Therefore it is worth the effort that is being given to develop the new model which will be used for years to come.

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