DNV·GL

FINAL REPORT

National Grid Rhode Island Gas Load Shapes Study

Date: January 25, 2021

Table of contents

List of figures

List of tables

List of acronyms used in this report

DR – Demand Response - Actions taken by utilities to modify customer demand for short-term specific time periods (curtailment events) via automated or remote communications

DSM – Demand-Side Management – Actions taken by utilities to modify the customer demand that would not otherwise have occurred

EE – Energy Efficiency

ECM – energy conservation measure, also known as DSM measure

ELCAP - End Use Load and Consumer Assessment Program (ELCAP) - End use metered load study program undertaken by the Bonneville Power Administration from 1986 through 1989 in an effort to obtain hourly and sub-hourly electricity demand information from a variety of residential and commercial end-uses. Now administered by the Regional Technical Forum (RTF)

GLS – General Load Shape – Refers to the condensed load shape ratio format developed by DNV GL staff and used for this project.

HDD – Heating Degree Days: Calculated as difference between average daily temperature and base temperature (e.g. 60° or 65°)

MCF – Thousands of cubic feet (unit of gas measurement)

NAICS - The North American Industry Classification System - the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.

PDAF – Peak Day Adjustment Factor – Defined as the ratio of peak day usage to average weekday usage for a given month.

RTF – Regional Technical Forum, a technical advisory committee to the Northwest Power and Conservation Council established in 1999 to develop standards to verify and evaluate energy efficiency savings.

SIC – Standard Industrial Classification Code – represents building/business type; four-digit numerical codes assigned by the U.S. government to business establishments to identify the primary business of the establishment.

1 EXECUTIVE SUMMARY

1.1 Study purpose, objectives, and research questions

DNV GL carried out the Gas Load Shapes Study for Rhode Island National Grid from September 2020 to January 2021. The study's overall purpose was to develop a load shape library corresponding to Natural Gas DSM measures by commercial customer segment. Its objectives are as follows:

1. Identify load shapes for DSM measures applicable to natural gas customers in the National Grid Rhode Island service area.
2. Develop load shapes by key customer segments. At a minimum:
   - Commercial gas heating and non-heating end uses for up to 12 business types (e.g., Office, Retail, Health, Restaurant, Warehouse, School, Grocery, and Lodging), with key subsets by size or other key factors.
   - Industrial types with significant contribution to total loads in the service area.
3. Develop an end use load shape library sufficient to support National Grid's tracking of peak gas demand usage and savings, including user-defined peak definitions (e.g. coldest or design day at 8 am) and segmentation by end use measures identified in various planning applications, including:
   a. Natural Gas DSM Potential Studies – Forecast of how much efficiency programs will reduce usage and peak demand over time
   b. Gas DSM Evaluation Studies – For DSM programs implemented, independent evaluations are typically required by regulators to determine how much savings in usage and peak have actually been achieved.
4. Develop capability to produce hourly and/or daily peak impacts corresponding to DSM impacts by segment and measure, with peak definition user-definable by National Grid, which could include average year, one in "X" years, or a design temperature/weather level.

The study was designed to answer the following research questions:

1. What are the peak demand to annual usage ratios associated with the EE or DR measures previously identified for the Gas Potential for National Grid – Rhode Island?
2. What are the 8,760-hourly and 365-day load shape savings ratios to apply to each end use component and DSM potential measure?

1.2 Key findings and results

1.2.1 Definition of "load shape library"

The term "load shape" in the context of this report refers to the pattern of usage within a year, reflecting how loads vary by month, day type, hour and the factors that affect it, most notably weather and operating hours. Load shapes can be defined in terms of these six aspects:

1. Fuel – Electric or gas

2. Sector – Residential, commercial, industrial or institutional
3. Customer segment – Building and/or business type
4. Resolution – Time interval associated with measurement or estimation. Options typically include monthly, daily, hourly, or sub-hourly (e.g., 5 minutes, 15 minutes).
5. Level – Specifically at the building/premise level or the end use level (typically appliances or applications).
6. Applicability - Load shapes can be defined in terms of being:
    a. "Base" load shapes, defined as existing load patterns or what would occur without intervention;
    b. "DSM" or "measure" load shapes, defined as the result of intervention via utility efficiency or other programs intended to "improve" usage or load shape; and
    c. "Impact" or "Savings" load shapes, defined as the difference between "Base" and "DSM" measure load shapes.

In terms of this study, the fuel is Natural Gas, the sector is primarily Commercial[1], the resolution is both hourly and daily, and the level is end use. Applicability is primarily base or impact since research did not support different load shapes for "Measure" shapes different from base, except for load levels where efficiency was improved, usage was reduced but load patterns were not changed. For demand response programs, intervention is customized to address targeted reductions during peak hours, which can be modeled by adjustment to the baseline load shapes. Hourly load estimates are often referred to as "8,760 load shapes," referring to the number of hours in a typical year.

1.2.2 Commercial gas hourly end use load studies are uncommon, so other sources must be leveraged to produce good estimates

As expected, end use load studies were found to be rare, especially ones involving gas customers for hourly load patterns. Commercial end use load studies are especially rare given the wide variation in business types, which have a major influence on load shape patterns – especially on an hourly basis – due to differences in operating hours.

Most hourly load studies are conducted on a class level for support of rate studies (primarily on the electric side) and do not involve end uses. In addition, gas load studies are more often based on daily loads, since the nature of natural gas production and delivery is more conducive to storage and varying pressure, which limits the criticality of hourly load variations, so planning is often based on daily rather than hourly peaks.

Given this constraint, the methods used to develop end use load shapes most often leverage customer-level load shapes to derive the end uses, as was the case for this study. Most significantly for gas load shapes, heating loads can be isolated from total customer loads by modeling the weather-sensitivity of customer loads to determine the heating components for each distinct segment (e.g. office, retail, etc.). The high

[1] Industrial load shapes are dominated by process loads involved in the production or manufacturing aspect of the customer load. These processes are very industry-specific and, because these are typically larger customers, often already have interval metering or can justify additional metering costs to develop interval load patterns, where needed.

correlation of gas heating to weather factors was a principal element in the gas heating load shape development, as described later.

As a result, the method used to develop hourly commercial gas end use load shapes for this study is designed to optimize the data sources from electric load studies, whole-premise gas studies (including the availability of 628 interval load-metered Rhode Island Gas customers), and borrowed load shapes, all customized to the weather of Rhode Island.

The ratio load shape method described in this report is especially useful for this purpose, since it breaks down a load shape into distinct sets of ratios that break down annual loads into monthly, daily (by day type), and hourly patterns.

1.3 Relevance

The relevance of load shapes is in their ability to break loads into time-differentiated periods and facilitate analysis of peak effects on the distribution network and system. When planning for optimizing the gas distribution system capital needs, the peak effect is critical, and a peak load forecast essential.

1.4 Conclusions, recommendations, and future research

1.4.1 Conclusions

- The load shape library developed for this study provides a solid basis for National Grid – Rhode Island to use in tracking peak gas demand and savings.
- The methods and formats of load shapes developed for the study can be easily applied to upgrade the end use load shapes as additional sources are identified, including any future load studies conducted by National Grid for Rhode Island or any of its regional service areas.
- Other uses for this load shape library include:
  - Conversion of DSM Potential and other annual end use estimates for baseline and energy savings to any peak definition
  - Provide a baseline on which to project, estimate and evaluate demand response programs targeted at specific appliances.
  - Use of 8,760 end use load shapes for production cost model inputs to calculate system or distribution model effects
- Industrial load shapes were not developed for process loads (production or manufacturing application) since these are very industry-specific and subject to operating hours for specific industrial facilities and such data was not readily available for National Grid – Rhode Island customers. The portion of industry customer loads for heating and non-process loads for water heating, cooking, laundry and dishwashing can be taken from the warehouse segment end uses, which are considered applicable, given no other specific data sources.

1.4.2 Recommendations

- National Grid should consider additional studies of existing interval load data, such as the 628 interval load data points used in this study, as well as take advantage of forthcoming interval data made possible from electric and gas Automated Metering Infrastructure (AMI) data, as those systems are expanded within the regional service areas of National Grid.

- National Grid should consider investing in some additional end use load studies, including both electric and gas end uses (where the same technology but a different fuel is used). Given the importance and dominance of heating end uses in the service area and its key role in the peak, heating should be the primary target of end use load studies. Other end uses, especially water heating, dryers and cooking, could also be "borrowed" from electric studies of their end use counterparts, given the similar operating hours, and would be more cost-effectively metered.

1.4.3 Future research

Given the importance of peak impacts to National Grid, it should be a priority to develop some end use load studies that would improve confidence in the load shape library components, including additional segmentation (e.g., by size), end uses, and technologies, especially newer gas technologies that emerge and could be significant contributors in the future. Due to the lack of end use metered load studies for different end use technologies, especially those that may affect the pattern of loads, not just the levels of load, more study of these different types of technologies would enhance the accuracy and add load shapes.

Of particular note is the increased adoption of WiFi thermostats for small commercial customers, advanced building control systems and other components of "smart" buildings. These technologies typically enable the collection of runtime data, specifically duty cycles (percent of time HVAC is running), thermostat setpoints, and indoor temperature. This data could facilitate development of end use load shapes for use in load shape libraries that can help in studies on DSM potential, demand response impacts, DSM evaluation, load forecasting, rate studies, and technology assessment. Access to this data may require a combination of customer permission and pre-arranged cooperation by the thermostat manufacturers who collect and store the data for customer use. Agreement on privacy issues concerning use of the data is often a constraint.

Additional study of load shapes from the 628 customers with interval data could certainly be conducted, including daily weather-load relationships and hourly weather-sensitive and non-weather-sensitive load patterns that would add to the analysis already done on those customers whose business type was confirmable (only 251 of the 628 were identified by business type and size). Additional data on these customers, such as end use inventory, equipment type and operating hours, could further refine the segments. Such a study would add considerable understanding of the differences in load patterns by business type, size, and other factors, given such a robust sample. Analysis of non-heat season loads would provide an improved estimate of monthly weekend/weekday ratio and hourly per-unit load shape by day type, especially if coupled with end use equipment inventory.

1.5 Methodology overview

Based on inputs from National Grid and stakeholders and feedback on the work plan, DNV GL incorporated National Grid and external data sources to identify the customer segments, end uses, and DSM measures for which load shapes were developed.

DNV GL included in its research and assumptions the following potential sources, documented in Section 3.3

- Data developed for previous National Grid studies for Upstate New York (Gas and Electric), Downstate New York (Gas), Massachusetts, Connecticut, and other Rhode Island-specific parameters

- Baseline and savings assumptions, equipment, and other measure parameters for which primary information is not available from National Grid – Rhode Island-specific sources
- External and regional sources, such as interval load shape data and models from electric and gas load studies, gas program evaluations by National Grid, and available comparable studies

The result was a complete end use load shape library for all targeted segments, end uses, and end use measures customized for Rhode Island.

Given the importance of weather-sensitive heating load in the end uses targeted, DNV GL reviewed weather factors, including analysis of historical weather data and design-day conditions provided by National Grid for a designated weather station (e.g., Providence), to confirm and update weather-sensitive load patterns and ratios within the load shape library.

Monthly billing records and demand factors (demand as a function of energy and weather) were reviewed and analyzed, as available, for the designated non-residential sectors. To the extent that National Grid had established load shape ratios (e.g., ratio of daily peak to annual energy), DNV GL sought to review them so as to be consistent. DNV GL also reviewed monthly and seasonal factors from class billing histories provided by National Grid.

Customer-level interval data on a set of over 628 commercial gas customers from National Grid - Rhode Island was provided by National Grid, cross-checked against business type codes from billing records and analyzed to provide some of the load shape ratio parameters used in the development of the gas load shape library.

1.5.1 Constraints

As noted earlier, end use load shapes for commercial gas customers are a very rare data source – even more so for a specific jurisdiction. The study was able to develop end use gas load shape components from primarily a combination of customer-level interval gas load shapes, electric end use load shapes and weather modeling, sufficient to be reasonable start in calculating peak gas demand savings. However, precision could not be calculated nor could more technology-specific load shapes be derived.

2 INTRODUCTION

2.1 Study purpose, objectives, and research questions

DNV GL conducted the Gas Load Shapes Study for Rhode Island National Grid from September 2020 to January 2021. The study's overall purpose was to develop a load shape library corresponding to Natural Gas DSM measures by commercial customer segment, consistent with prior Natural Gas DSM potential studies performed for National Grid service areas.

Its objectives are as follows:

1. Identify DSM measures applicable to natural gas customers in the National Grid Rhode Island service area, as identified by National Grid
2. Develop load shapes by key customer segment. At a minimum:
   - Commercial gas heating and non-gas heating by up to 12 business types (e.g., Office, Retail, Health, Restaurant, Warehouse, School, Grocery, and Lodging), with key subsets by size or other key factors.
   - Industrial types with significant contribution to total loads in the service area
3. Develop an end use load shape library sufficient to support National Grid's tracking of peak gas demand usage and savings, including user-defined peak definitions (e.g. coldest or design day at 8 am) and segmentation by end use measures identified in various planning applications, including:
   a. Natural Gas DSM Potential Studies – Utilities periodically forecast how much their energy efficiency programs will reduce usage and peak demand over time in order to adjust future load forecasts and plan future DSM Programs. This typically starts with a potential study to forecast what the maximum amount of cost-effective savings could be achieved, both in terms of annual usage and peak demand. DSM Programs typically consist of one or more energy efficiency (EE) Conservation Measures (ECMs), such as more efficient equipment (e.g. high-efficiency boilers and water heaters), or demand response (DR) or control strategies (e.g. remote thermostat setpoint curtailments).
   b. Gas DSM Evaluation Studies – Once DSM programs are implemented, independent evaluations are typically required by regulators to determine how much usage and peak demand savings have actually been achieved, based on interventions by the utility programs over and above what would have occurred without them.
4. Develop capability to produce hourly and/or daily peak impacts corresponding to annual DSM energy impacts by segment and measure, with peak definition user-definable by National Grid, which could include average year, one in "X" years, or a design temperature/weather level.

The study was designed to answer the following research questions:

1. What are the peak to annual ratios associated with the annual usage impact measure components previously identified for the Gas Potential for National Grid – Rhode Island?
2. What are the 8,760-hour and 365-day load shape ratios to apply to each end use component and DSM potential measure?

2.2 Organization of report

The remainder of this report is organized as follows:

- Section 3: Methodology and approach
- Section 4: Development of load shape library
- Section 5: Analysis and results
- Section 6: Conclusions, recommendations, and considerations

3 METHODOLOGY AND APPROACH

3.1 Segmentation and development of load shapes

Based on inputs from National Grid and stakeholders and feedback on the work plan, DNV GL incorporated National Grid and external data sources to identify the customer segments, end uses, and DSM measures for which load shapes were developed. DNV GL also reviewed savings assumptions and performance parameters from National Grid studies and potential studies to ensure consistency and relevance.

DNV GL included in its research and assumptions primarily the data developed for previous National Grid studies for Upstate New York (Gas and Electric), Downstate New York (Gas), Massachusetts, Connecticut, and other Rhode Island-specific parameters, as far as baseline and savings assumptions, equipment, and other measure parameters, and other parameters for which primary information was not available from National Grid – Rhode Island-specific sources.

Table 3-1: List of commercial end uses for inclusion in load shape library

End Use lIst										
	Sizing Categories			End Uses						
C&I Biz Type				Heating	Water Heat	Cooking	Clothes Washer	Dishwasher	Dryer	Industrial
Office	Large	Small/SBDI		X	X	L		L		
Retail	Large	Small/SBDI		X	X	X				
Grocery	Large	Small/SBDI		X	X	X				
Warehouse				X						X
Education	Elem.	Secondary	College	X	X	X	SC	SC	SC	
Health	Large	Small		X	X	X	X		X	
Lodging	Large	Small		X	X	X	X		X	
Restaurant	Large	Small/SBDI		X	X	X	X			
Commercial-other	Large	Small/SBDI		X	X					
Industrial	Large	Medium	Small	X						X
		(SBDI = <100 kW) for Office, retail, Grocery, restaurant, other								

Note: “L” refers to large customers only; S refers to Secondary Education and |C” to College-level customers

A related DSM measure list was also developed, based on the measures and technologies typically included in the end uses associated with DSM programs and DSM potential studies, as follows:

Table 3-2: List of commercial DSM measures for inclusion in load shape library

Measure List		Base Shape	DSM Shape	Impact Shape
Heating	Base Gas-Fired Boiler	X		
	Combustion Controls w/Base Boiler	X	X	X
	Outdoor Temperature Boiler Reset w/Base Boiler	X	X	X
	Wi-fi Thermostats w/Base Boiler	X	X	X
	Base Furnace	X		
	EMS w/Base Furnace	X	X	X
	Custom Measure w/Base Furnace	X		
Water Heat	Base Water Heater	X		
	High Efficiency Water Heater	X		
	Tankless Water Heater	X	X	X
	Low Flow showerheads	X		
	Kitchen Faucet Aerators	X		
	Bathroom Faucet Aerators	X		
Cooking	Base Oven	X		
	ENERGY STAR Oven	X		
	Base Range	X		
	ENERGY STAR Range	X		
	Base Commercial Dishwasher	X		
	ENERGY STAR Dishwasher	X		
Clothes Washer	Base Clothes Washing Machine	X		
	High Efficiency Clothes Washing Machine	X		
Dryer	Base Clothes Dryer	X		
	High Efficiency Clothes Dryer	X		

Where possible, when a DSM measure could change the shape, both a baseline load shape and a DSM shape was to be developed. Unfortunately, separate end use load studies were not available for the measures identified in the above table. Additional data collection via end use load studies on specific end use technology equipment would be needed to provide that type of information.

3.2 Load shape ratio method

An efficient and universally applicable load shape library must meet certain criteria. Specifically:

- Each load shape must be applicable to a specific customer segment and end use, since patterns of load vary primarily by those two factors.
- Load shapes must be scalable for different usage levels rather than for a specific size end use or customer.
- Load shapes must be applicable to any target year so they do not require updating each year as the calendars change.[2]

To address those requirements in this study, DNV GL used a load shape ratio method that the project lead has used in many projects over the past 30+ years for interval load analytics for both electric and gas customers, although most for electric. This satisfies both criteria and comes with a pre-defined list of day

2 There are 14 different calendars possible, each with a unique start day of week (7: Sunday through Saturday), holidays, and number of days (365, except 366 for leap years)

type assignments for weekdays, weekend days, holidays, and a range of weekdays representing peak to low days, primarily for weather-sensitive end uses.

The load shape ratio method differs from traditional load shape interval storage methods and has been developed to address the increasing need and use of "8,760" data – hourly data by year – made increasingly available by the adoption of automated metering infrastructure (AMI) with interval data, particularly in the electric utility sector, where adoption has reached about 50% of all U.S electric meters by 2018. Other sources of interval data include special metering, mostly on large customers and special equipment; class load studies, which still mainly rely on samples, and runtime data, as new "smart" thermostats can produce hourly runtime data and indoor temperatures. DSM potential studies and evaluation studies are increasingly moving away from just coincident peak impacts and toward 8,760 impacts for improved planning detail.

Given more interval data availability, sufficient samples of commercial data by business type segments (office, retail, restaurant, health, churches, schools, etc.), customer size (e.g., large and small), and specialized subsets (e.g., fast-food vs. full-serve restaurants) could be developed, each characterized by a unique load pattern. Customers can be stratified by size across all sectors, which is useful because large customers often have different load patterns than small ones (e.g. offices). Load shapes can also enable new rate options to be tested against a wide range of customer types and load patterns, such as voluntary/targeted vs. mandatory time-differentiated rates.

Additional characteristics from third-party data sources include more demographic data available to link load data, and more detailed and accurate business types, such as SIC and NAICS codes.

The load shape ratio method stores 8,760 data in an optimal way to facilitate adjustments (such as weather), to enable projections to any calendar year, to scale the loads to any annual usage, and to facilitate the comparison of load shapes for different segments to identify consistent versus differing load pattern elements.

The load shape ratio method uses ratios derived from load shapes to identify the following patterns of load:

1. Proportion of annual consumption per month
2. Ratio of weekend to weekday consumption by month
3. Ratio of peak to average weekday energy consumption by month
4. Proportion of daily load in each hour of the day by day type (peak, weekday, weekend day) by month

Appendix B provides a more comprehensive description of the load shape ratio system.

Each of these ratios can be adjusted to customize the load shape and facilitate calibration to other known statistics.

While ratios by month can be used, minor differences within seasons are often insignificant enough to justify using seasonal averages for winter, summer and Spring/Fall. These are identified in the load shape names by the trailing two letters, as follows:

1st character (for Peak Day Adjustment factor): A for Annual average, S for Seasonal Average, M for monthly and F for "Fixed" – Fixed is used when the ratio is assumed fixed (typically =1.0) for end uses that are not daily weather-sensitive, such as water heating.

2nd character (for Weekend/Weekday ratio factor): A for Annual average, S for Seasonal Average, M for monthly.

For example, "FS" refers to Fixed Peak Day Adjustment Factor and Seasonal Weekend/Weekday factor.

1. Proportion of annual consumption per month

The monthly usage allocation for commercial segments accounts for the fact that commercial business types vary considerably, and their cooling and heating types also vary by seasonal and daily weather factors. Sources for the monthly usage allocation are the actual total monthly consumption data, segmented by heating and fuel type, identified heating and cooling degree days (weather-sensitive loads) for the source data, and other sources that demonstrate consistency and similar weather patterns. For this study, weather, in terms of heating degree days, was used for the monthly usage allocation for heating load shapes, while the source data for cooking was based on an electric load shape data source.

In the example below (Figs. 3-1 and 3-2), the contrast in monthly allocation is attributable to weather effects of the end use, with office gas heating contrasted with full-service restaurant cooking evident in Figure 3-1 and Figure 3-2. The y-axis in the figures is monthly energy usage based on an assumed total annual usage of 1000 units. The January usage of 215.9 is equal to 21.6% (215.9/1,000) based on annual consumption of 1,000.

Figure 3-1: Small office gas heat

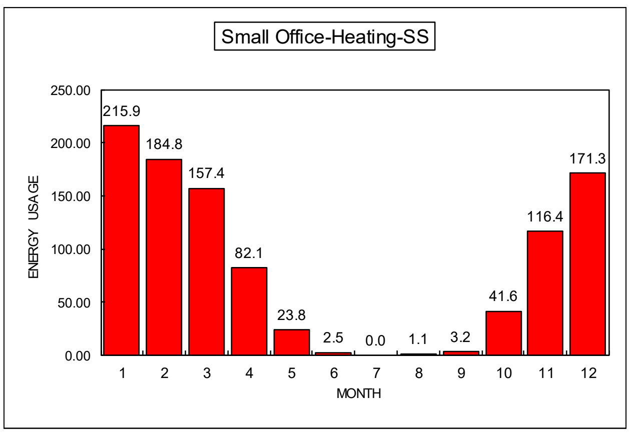
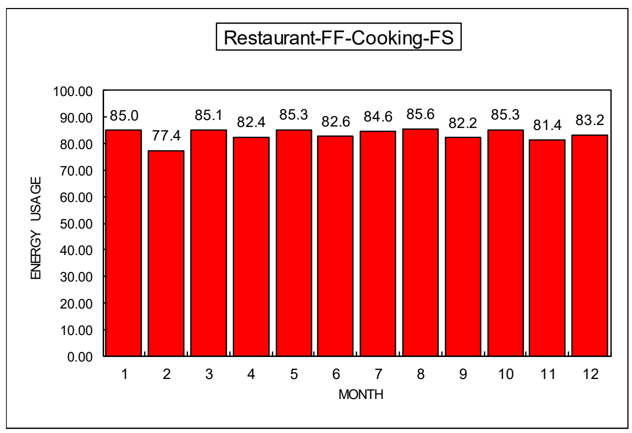


Figure 3-2: Restaurant Cooking



2. Ratio of weekend to weekday consumption by month

In Figs. 3-3 and 3-4, the weekend-to-weekday ratio for customer segments is the ratio of daily usage for weekend days to daily usage for weekdays by month. Non-heating end uses for commercial business types are very distinctive, most with a ratio less than 1, reflecting lower weekend operations. Health, Grocery, Lodging and Restaurant type facilities have higher ratios, often close to (or greater than) 1.0. Schools have varying ratios from 0.5 to 0.9 (i.e. weekdays are 50% - 90% of weekday usage), with universities having higher ratios, reflecting different types of 6-7 day operations such as dorms, cafeterias and recreation venues.

In the example below, a High School weekend/weekday ratio (Figure 3-3) for water heating is significantly lower (0.566) than for a University (Figure 3-4), at 0.849. As noted, the code "FS" for both denotes that a fixed peak day adjustment factor and a seasonal weekend/weekday factor are used for the water heater load shapes. For this study, each business type weekend/weekday ratio was based on the May 2019 interval data for that business type customers within the 628 total sites, which would exclude any heating, and considered typical of other months.

Figure 3-3: High School weekend/weekday ratio

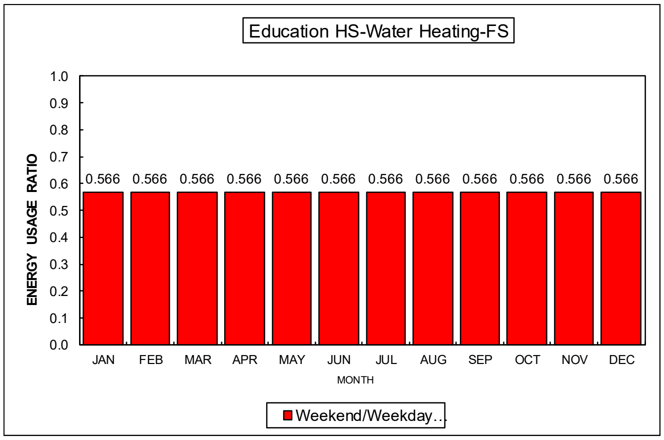
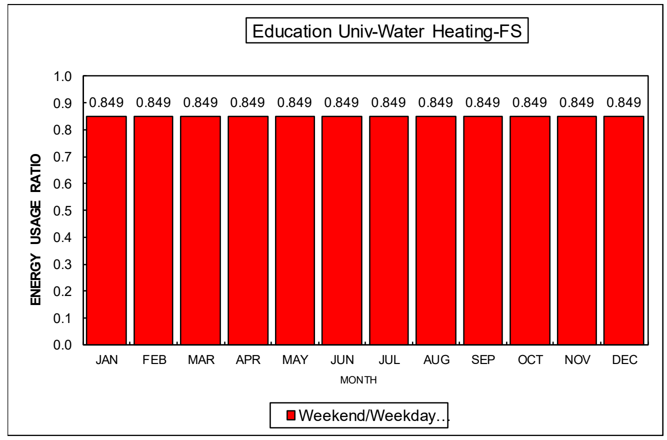


Figure 3-4: University weekend/weekday ratio



3. Ratio of peak to average weekday energy consumption by month

The peak day to weekday ratio, or peak day adjustment factor (PDAF), is driven by weather-sensitive loads (i.e., heating for gas usage). This can be adjusted to reflect a normal (average) year, a test year, or a design condition, with corresponding peak and seasonal characteristics. Some end uses have variation in loads and a "peak" day, with a peak day adjustment factor of greater than one but minimal predictability (such as water heating and refrigeration), so their peak day adjustment factor can be assumed to be 1.0, unlike heating, for example, which can be predicted from weather variation.

In the example below, a small office with gas heat has a fairly high PDAF of 1.569 in the winter vs. a Commercial restaurant cooking pattern, which has no significant variation due to weather, so is assumed to have a PDAF =1.0. Seasonal values tend to be consistent so are usually averaged, as they were for this study. Also notable is that PDAF ratios in Spring/Fall tend to be higher than for winter because "peak" days are typically isolated in Spring/Fall so the ratio of those few peak days to the average day is higher, compared to peak winter months, where most days are cold and the peak day is not as different (higher) than an average day in those months.

For heating end uses for this study, the peak day adjustment factors were based on the historical ratios of weather (heating degree days) for the local weather station, as described in report section 4.1 – Weather Data Analysis.

Figure 3-5: Small office heating PDAF

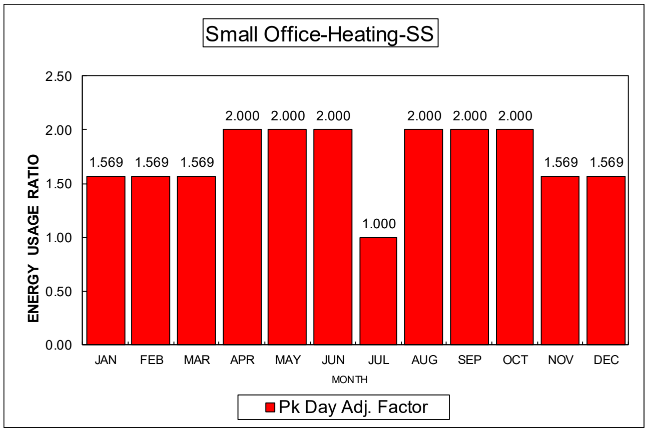
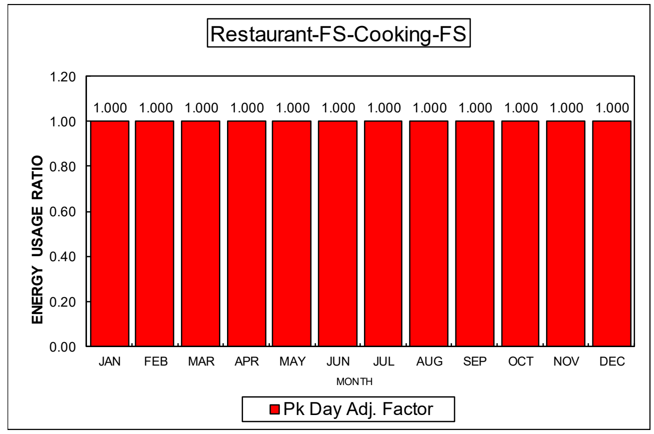


Figure 3-6: Restaurant cooking PDAF



4. Proportion of daily load in each hour of the day by day type (peak, weekday, weekend day) by month

Per-unit day type load shapes can be segmented by peak day, average weekday, and average weekend day per month, yielding 36 shapes per year. Each day type has a distinctive pattern, as do each weather level and each commercial business type. Demand response changes the daily pattern, causing reduction followed by recovery. Additional ratios can be used to consolidate certain hours and create additional key metrics, such as the ratio of a key time period (midnight-4am, 9am-3pm, 6pm-9pm) average weekday load to average weekday daily loads.

The examples below show (left) a large office with gas heat for January by day type vs. Commercial restaurant Water Heating by day type (peak day, weekday and weekend day), which shows little variation except slightly higher use during dinner hours. For this study, almost all hourly ratios used the "RTF" source (primarily from ELCAP and PG&E), as noted in Table 4-1.

Figure 3-7: Large office heating by day type

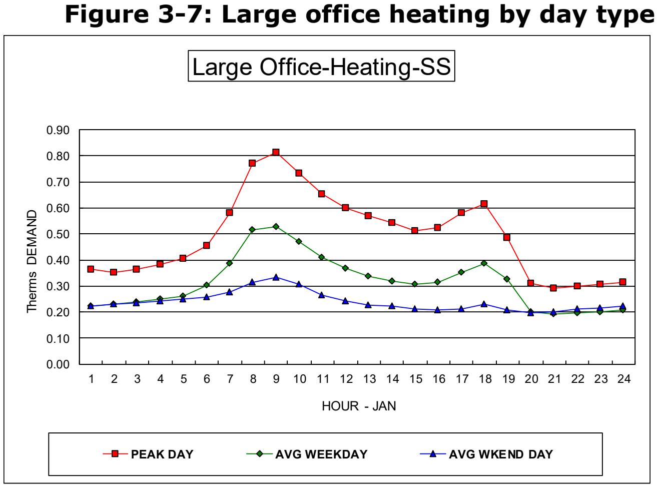
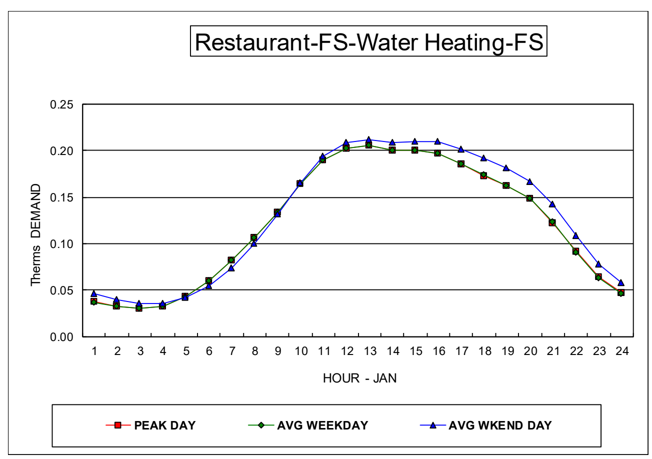


Figure 3-8: Restaurant cooking by day type



Most models only look at peak and average days. The load shape ratio method can produce three day-type load shapes: peak day, average weekday, and average weekend day for each month. The peak day can be defined any way that the user decides, but typically it is the highest value for a normal weather year. Which is how the load shape library base values are defined for this study. Alternative peak definitions can include the highest in 10 years or a design condition, such as a zero-degree average day (i.e., 65 HDD on a 65° base)

Load Shape Ratio Calculation Process

To use 8,760 load shapes in ratio format, the user selects annual usage (all hours are then scaled to sum target annual usage), the calendar/year (of 14 possible), and the output format of 8,760-column, 365x24, or others that can be customized (e.g. EEI format).

Load shape ratios can be used to store load shape patterns for use in scaling and conversion of annual energy to peak definitions, in the customization and transferability by weather factors, and to validate load shapes against other data sources. Modeling load shapes by customer segment and/or end use to "build" aggregated segments allows for segmentation by any characteristics available from population data (e.g., business type, size, seasonality, climate zone); distribution networks, including other energy technologies (e.g., DERS (solar, wind, storage)); and microgrids, with combinations of sectors (residential, commercial, industrial) and customer types (business types), scaled for size (annual usage). This model allows us to build load shapes for input to system and distribution models.

Once the load shape ratio format is developed, the user can calculate any hour or days' load value or defined peak value from the annual usage, using these steps:

Load shape patterns can be used to estimate demand at any hour, given known annual energy. The process is as follows (using Large Office Heating as the example, with yellow highlighting noting the example-specific values):

- Input target annual energy, peak month and hour (e.g. 1000 therms, January peak month and hour 8 as peak hour)
- Input target year for report or output (e.g. 2019)
- Multiply annual energy by monthly usage allocation for target month (e.g., January = 21.59%; 1000 annual Therms x 21.59% = 215.9 Therms for January)
- Use weekend to weekday ratio (WEWD) in the formula to produce average weekday daily usage (e.g., WEWD=0.763 for Large Office Heating):
  - Average weekday = 1 / (Days in month x 5/7 + days in month x 2/7 * WEWD) = 1 / (31 x 5/7 + 31 x 2/7 x 0.763) = 1 / 28.666 = 7.5321 Therms
- Use peak day adjustment factor (PDAF) to adjust average weekday for peak day (e.g., PDAF = 1.569)
  - Peak Day = PDAF x Weekday = 1.569 x 7.5321 = 11.818 Therms
- Compute Peak Hour value = Peak Hour Per-unit Max at Target hour / Sum of per-unit hourly values for Target load shape (Peak Day), e.g., 0.9483 at 8 am vs. sum of daily per-units of 14.525
  - Peak Hour = 0.9483 / 14.525 x Peak Day = 0.0653 * 11.818 = 0.7716 Therms

One statistic that can be calculated from this is peak day as a percent of annual. For this example, peak day = 11.818 / annual use = 1000 therms = 1.18%

If an alternate peak definition is used, the PDAF will be different.

- For a "1 in 9 year" peak, the PDAF would be 2.02, representing 58.5 HDD60 (from weather analysis in Appendix A). In that case the peak day would be 2.02 x 7.532 = 15.21 Therms, which is 1.52% of annual usage.

- For a 0° Average Design Day peak definition, the PDAF would be 2.07, representing 60 HDD60 (from weather analysis in Appendix A). In that case the peak day would be 2.07 x 7.532 = 15.59 Therms, or 1.56% of annual usage.

3.3 Data sources for load shape ratio factors

For the commercial load shapes, the primary sources of information and data for development of base end use load shapes were the following. Table 4-1: Commercial load shape source documentation notes the source for each of the load shape ratio components for each end use and segment.

- Whole building load studies, from which heating and other end uses could be modeled/derived:
  - Rhode Island Interval Data (628 sites), which were cross-linked to billing records to identify business type and usage levels. – Used for Weekend/Weekday ratios for heating and non-heating end uses and used laundromats for all full load shapes for laundry end uses.
  - MA DOER Load Study of College campus in MA (4 buildings) – used for some load shape components for University
- National Grid Billing/Account records (26,000 accounts), with 15 monthly billing records, NAICS (business type) and TRW (building type) – used for identifying business type, end use and usage levels for the 628 interval load metered sites
- Massachusetts P25 Impact Evaluation of 2011 Prescriptive Gas Measures[3] - used to identify technologies, measures and peak/usage savings levels for identifying potential end use load shape options
- Massachusetts Project 15 Prescriptive Gas Program Evaluation[4] - used to identify technologies, measures and peak/usage savings levels for identifying potential end use load shape options
- Fraunhofer – Commercial and Industrial Sector Natural Gas Demand Response - Final Report (December 2019) to Massachusetts Dept. of Energy Resources (DOER)
- RI Market Characterization Data Collection Study Final Report (DNV GL)[5]
- Projects where base end uses were modified for weather:
  - 2014 LBNL Study for ISO-NE by DNV GL (including for Rhode Island)[6] – Also used many of the same load shape ratio components and methods used in this study
- Borrowed End use load studies, which include:
  - The End Use Load and Consumer Assessment Program (ELCAP)[7] end use load studies were conducted in the late 1980's and early 1990's and covered residential and non-residential loads for several residential building types (single-family, multifamily) and by commercial business type. Special metering equipment was installed on a sample of customers and

[3] http://rieermc.ri.gov/wp-content/uploads/2018/03/kema_2013_prescriptive_gas.pdf
[4] http://rieermc.ri.gov/wp-content/uploads/2018/03/study-24_ma-lciec-15-prescriptive-gas-impact-evaluation.pdf
[5] http://rieermc.ri.gov/wp-content/uploads/2020/09/ri-market-characterization-data-collection-study_final-report.pdf
[6] https://certs.lbl.gov/sites/all/files/data-development-for-ne-end-use-load-modeling.pdf
[7] https://rtf.nwcouncil.org/elcap

databases built, which are now owned and maintained by the Regional Technical Forum and are public. A subsequent DNV GL project involved conversion of these load shapes to the Ratio Load Shape Format, with modules for conversion, modification, reporting and export. These were also used for the National Grid Downstate NY DSM Potential Study, adjusted for weather factors.

  - Many of the hourly components of the load shapes used in this study were taken from those in this load shape library

- CPUC Database for Energy Efficiency Resources (DEER)[8], which contains electric end use load shapes, primarily from engineering models, and recently the subject of a DNV GL project to convert all load shapes to the Ratio Load Shape Format used in this project

  - The load shape ratio methodology used in this study was also used for the CPUC DEER load shape conversion project and adopted for future versions of the DEER load shapes system.

8 http://www.deeresources.com/index.php/16-front-page

4 DEVELOPMENT OF LOAD SHAPE LIBRARY

DNV GL used existing interval load shape data and models from load studies, and consulted evaluations by National Grid, and available comparable studies to construct a complete load shape library for all segments, end uses, and end use measures for Rhode Island. Using a combination of available base end use load shapes and local Rhode Island weather, DNV GL developed end use load shapes for all end uses, covering primary DSM measures.

4.1 Weather data analysis

DNV GL reviewed weather factors, including analysis of historical weather data for the weather station closest to Providence, which was the Warwick, Rhode Island station located by Providence airport. Data for 2011-2020 and design-day conditions provided by National Grid were used to model weather-sensitive load patterns and ratios for the load shape library. DNV GL requested any existing weather-sensitivity studies or data available from National Grid or other sources to ensure consistency with any existing internal studies or established assumptions already used by National Grid, but there were no significant data sources available. Monthly billing records were reviewed and analyzed but not used as primary sources, except to identify which of the 628 Rhode Island Commercial interval metered customers could be assigned to business types DNV GL also confirmed the consistency of the load shapes developed from the load shape library to previously established ratios used by National Grid (including Downstate NY).

For weather-sensitivity analysis, a 60-degree base was calculated for heating degree days based on prior extensive experience with heating loads by sector, which showed commercial loads matched well to a 60-degree base instead of a 65-degree base because of heat gain in commercial buildings, which results in reduced heating requirements when outdoor temperatures are below 65 degrees.

This weather data was then used in the calculation of the key weather-sensitive ratios for heating end uses, 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:

- Commercial weekend to weekday factors for heating are driven by the business type, reflecting the operating hours of those businesses, rather than weather. This is especially true of heating, which is typically reduced using thermostat setbacks when the businesses are not operating. 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. This is reflected in the differences in weekend to weekday ratios for all end uses, including heating and water heating.
- For Peak Day Adjustment, specific factors for the local weather station were computed. Based on the three different peak definitions – historical average over nine years, most extreme day in nine years, and a defined design day of 0°F – the ratio of weather sensitivity for that type day vs. an average winter day was calculated for each month and year.
- For per-unit day-type load shapes, daily load shapes for weather-sensitive end uses are primarily a function of 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.

As a result, a complete custom set of monthly factors and peak day factors for the local weather station was developed and applied to each of the applicable commercial heating load shape factors.

4.2 Load shape library results

The load shape library results are presented in terms of the source and assumptions made for each end use and business type, as listed in the Table 4.1:

The main sources and results of note are:

For monthly breakdown:

- Monthly weather factors, specifically historical (normal) HDD60, for nearly all segments of heating, as noted in the table below:

Figure 4-1: Monthly Breakdown for Heating (60° Base)

Heating	Mo. Brkdown
JAN	21.59%
FEB	18.48%
MAR	15.74%
APR	8.21%
MAY	2.38%
JUN	0.25%
JUL	0.00%
AUG	0.11%
SEP	0.32%
OCT	4.16%
NOV	11.64%
DEC	17.13%
	100.00%

- For University Heating, the load-weather model for the three UMASS sites was used to calculate the monthly breakdown, applying normal monthly weather (HDD65).

Figure 4-2: Monthly Breakdown for Heating (65° Base)

Heating	Mo. Brkdown
HDD65	
JAN	19.66%
FEB	16.96%
MAR	15.08%
APR	9.05%
MAY	3.74%
JUN	0.77%
JUL	0.02%
AUG	0.12%
SEP	1.08%
OCT	5.56%
NOV	11.79%
DEC	16.19%
	100.00%

- For Water Heating, Cooking and Dishwashing, the monthly breakdown from the RTF Load Shape Library (from ELCAP load studies) was used.
- For laundry (washers and dryers), analysis of the two laundromats (without gas heat) included in the 628 Rhode Island sites with interval data was used to develop the monthly breakdown. The monthly pattern was very consistent with other end use studies of dryers and washers from the RTF source so were considered sufficient for use in this study.

Figure 4-3: Monthly Breakdown for Laundry

2301	Laundry
	Mo. Brkdown
JAN	10.84%
FEB	9.47%
MAR	10.22%
APR	8.58%
MAY	7.99%
JUN	6.89%
JUL	6.41%
AUG	6.58%
SEP	6.99%
OCT	8.06%
NOV	8.81%
DEC	9.16%
	100.00%

<u>For weekend/weekday:</u>

- The ratio of weekend to weekday for the heating end use for the business types was developed from the analysis of January 2019 data from the 628 Rhode Island interval data sites, as shown below for each business type and then broken down into further segmentation for restaurants (full-service vs. fast-food), office (large and small) and Education levels.

Figure 4-4: Heating Weekend/weekday by business type segment from NG RI interval data

National Grid - Rhode Island Interval Data					Jan-19	Jan-19	Jan-19	Jan-19
	count	days	MCF	Accounts	Peak MCF	Wkday MCF	Wkend MCF	Wkend/wkday
Office	14	775	13,370	25	27.41	10.53	8.34	0.793
Retail	14	496	24,335	16	71.30	33.67	22.72	0.675
Grocery	5	155	1,706	5	5.10	2.31	2.26	0.978
Warehouse	14	434	22,944	14	80.00	33.45	23.32	0.697
Education	67	2,728	129,567	88	312.54	145.72	127.74	0.877
Health	20	744	103,475	24	281.10	127.24	112.23	0.882
Lodging	23	744	23,622	24	57.90	28.63	28.59	0.999
Apartments	38	2,294	113,373	74	224.15	41.62	39.91	0.959
Restaurant	52	1,798	17,694	58	100.51	21.28	19.53	0.918
Commercial-other	4	186	4,307	6	9.60	4.25	2.60	0.612
Totals	251		454,392	334				

For this and all the other following tables, the count refers to the number of sites, days is the total number of days of data, MCF, is the thousand cubic feet (usage) pre-customer totals from the records, Accounts is the number of metering points, peak MCF is the highest monthly value, Wkday MCF is the average MCF for all January weekdays, Wkend MCF is the average MCF for January weekend days, and Wkend/Wkday is the ratio of average weekend daily usage (MCF) to average weekday daily usage (MCF).

Figure 4-5: Heating Weekend/weekday by business type subsegment from NG RI interval data

		count	days	MCF	Accounts	Peak MCF	Wkday MCF	Wkend MCF	Wkend/wday
Fast Food	**Restaurant**	7	217	1,199	7	4.10	1.58	1.70	1.072
Full Service	**Restaurant**	45	1,581	16,495	51	96.41	19.70	17.83	0.905
Elementary	**Education**	12	837	21,944	27	42.60	18.91	17.16	0.907
High School	**Education**	13	403	20,465	13	65.32	28.97	23.29	0.804
University	**Education**	34	1,116	69,069	36	158.12	75.96	67.78	0.892
Other/unknown	**Education**	8	372	18,089	12	46.50	21.88	19.51	0.892
Large	**Office**	5	341	9,544	11	19.50	7.40	5.64	0.763
Small	**Office**	9	434	3,826	14	7.91	3.13	2.70	0.862

- For Water Heating, Cooking and Dishwashing, the weekend/weekday analysis of the 628 interval data sites for May was used, segmented by business type, as shown below. The fast-food restaurant subsegment value (1.063) was also used for full-serve restaurants because the full-service subsegment value was inexplicably low (0.357), possibly indicating data problems. The Commercial – Other segment was not used since it only had 4 sites (6 accounts), which produced inconsistent results, was also considered too small a sample, and so the Warehouse value (0.519) was considered a better estimate, with 14 sample points.

Figure 4-6: Non-Heat Weekend/weekday by business type segment from NG RI interval data

National Grid - Rhode Island Interval Data					May-19	May-19	May-19	May-19
	count	days	MCF	Accounts	Peak MCF	Wkday MCF	Wkend MCF	Wkend/wkday
Office	14	775	4,358	25	14.23	3.34	2.87	0.860
Retail	14	496	14,044	16	62.90	21.54	10.55	0.490
Grocery	4	124	711	4	2.80	0.94	1.00	1.066
Warehouse	14	434	12,151	14	57.80	18.78	9.75	0.519
Education	67	2,728	40,812	88	201.67	47.16	39.58	0.839
Health	20	744	118,574	24	271.20	148.71	152.22	1.024
Lodging	23	744	10,949	24	34.35	13.49	13.86	1.027
Apartments	38	2,263	39,383	73	125.00	15.33	14.52	0.947
Restaurant	52	1,798	22,546	58	230.64	34.99	13.18	~~0.377~~
Commercial-other	4	186	1,580	6	6.00	1.63	0.43	~~0.262~~
Totals	250		265,109	332				

For the non-heat end uses, an analysis of May 2019 was used to calculate weekend/weekday factors.

Figure 4-7: Non-Heat Weekend/weekday by business type subsegment from NG RI interval data

		count	days	MCF	Accounts	Peak MCF	Wkday MCF	Wkend MCF	Wkend/wday
Fast Food	**Restaurant**	7	217	756	7	3.00	1.00	1.06	1.063
Full Service	**Restaurant**	45	1,581	21,790	51	227.64	33.99	12.12	~~0.357~~
Elementary	**Education**	12	837	4,334	27	27.89	4.18	3.31	0.790
High School	**Education**	13	403	2,410	13	44.45	3.67	2.08	0.566
University	**Education**	34	1,116	29,093	36	101.73	32.98	27.99	0.849
Other/unknown	**Education**	8	372	4,976	12	27.60	6.33	6.21	0.980
Large	**Office**	5	341	2,885	11	10.20	2.07	1.79	0.863
Small	**Office**	9	434	1,473	14	4.03	1.26	1.08	0.855

- For laundry (washers and dryers), analysis of the two laundromats included in the 628 sites of interval data was used to develop the weekend/weekday factor

<u>For Peak Day Adjustment Factor (PDAF):</u>

- Peak day factors are generally only applicable for daily weather-sensitive end uses, since it is designed to reflect variation of daily usage by weather factors within each month
- Monthly peak day factors from historical average HDD60, for nearly all segments of heating.

Figure 4-8: Peak Day Adjustment Factor for 60° Base

HDD60	PDAF
JAN	1.569
FEB	1.569
MAR	1.569
APR	2.000
MAY	2.000
JUN	2.000
JUL	1.000
AUG	2.000
SEP	2.000
OCT	2.000
NOV	1.569
DEC	1.569

- For University Heating, the load-weather model for the three college campuses in MA sites was used to calculate the peak day adjustment factor.

Figure 4-9: Peak Day Adjustment Factor for University Weather Model (65° Base)

2008	University
HDD65	PDAF
JAN	1.470
FEB	1.470
MAR	1.470
APR	2.000
MAY	2.000
JUN	2.000
JUL	2.000
AUG	2.000
SEP	2.000
OCT	2.000
NOV	1.470
DEC	1.470

- For Water Heating, Cooking, Dishwashing and laundry (washers and dryers), the peak day adjustment factors were assumed to be 1.0 since, while metered data may show some very minor variations, there is no weather-predictable "peak" effect from those end uses.

For hourly per-unit load shapes (peak day, weekday, and weekend) each month:

- For nearly all end uses and segments, the hourly factors from the RTF Load Shape Library (from ELCAP load studies) were used.
- For laundry (washers and dryers), analysis of the two laundromats included in the 628 sites of interval data was used to develop the hourly factors.

- For the non-heating load shapes (water heating, dishwashing, cooking and laundry), the peak day factors were all assumed to be equal to be 1.0 since experience in analysis of end uses has shown that any differences in weekday usage for those end uses were random and not dependent on daily weather and could not be predicted based on weather. Differences in daily weather are the determining factor in how much higher peak days are from average weekdays for gas heating, but not for non-heating end uses.

Table 4-1: Commercial load shape source documentation

Load Shape #	Description / Segment	Monthly Breakdown	Weekend / Weekday Ratio	Peak Day Factor	Hourly Profile
2001	Space Heating – Large Office	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF87 – Large Office Heating
2002	Space Heating – Small Office	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF165 – Small Office Heating
2003	Space Heating – Retail	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF139 – Retail Heating
2004	Space Heating – Grocery	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF49 – Grocery Heating
2005	Space Heating – Warehouse	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF113 – Warehouse Heating
2006	Space Heating – Elementary Education	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF152 – School Heating
2007	Space Heating – Secondary Education	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF152 – School Heating
2008	Space Heating – University Education	9-year average monthly HDD65 applied to UMass weather model	NG RI Jan Interval Data	9-year average monthly HDD65 applied to UMass weather model	RTF152 – School Heating
2009	Space Heating – Health	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF62 – Healthcare Heating
2010	Space Heating – Lodging	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF75 – Lodging Heating
2011	Space Heating – Full-Serve Restaurant	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF126 – Restaurant Heating
2012	Space Heating - Fast-food Restaurant	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF126 – Restaurant Heating
2013	Space Heating – Commercial Other	9-year average monthly HDD60	NG RI Jan Interval Data	9-year Seasonal average HDD	RTF100 – Misc. Comm Heating
2101	Water Heating – Large Office	RTF88 – Large Office Hot Water	NG RI May Interval Data	1.0 Assumed	RTF88 – Large Office Hot Water
2102	Water Heating – Small Office	RTF166 – Small Office Hot Water	NG RI May Interval Data	1.0 Assumed	RTF166 – Small Office Hot Water
2103	Water Heating – Retail	RTF140 – Retail Hot Water	NG RI May Interval Data	1.0 Assumed	RTF140 – Retail Hot Water
2104	Water Heating – Grocery	RTF50 – Grocery Hot Water	NG RI May Interval Data	1.0 Assumed	RTF50 – Grocery Hot Water
2105	Water Heating – Warehouse	RTF114 – Ware-house Hot Water	NG RI May Interval Data	1.0 Assumed	RTF114 – Ware-house Hot Water
2106	Water Heating – Elementary Education	RTF153 – School Hot Water	NG RI May Interval Data	1.0 Assumed	RTF153 – School Hot Water

Load Shape #	Description / Segment	Monthly Breakdown	Weekend / Weekday Ratio	Peak Day Factor	Hourly Profile
2107	Water Heating – Secondary Education	RTF153 – School Hot Water	NG RI May Interval Data	1.0 Assumed	RTF153 – School Hot Water
2108	Water Heating – University Education	RTF37 – College Hot Water	NG RI May Interval Data	1.0 Assumed	RTF37 – College Hot Water
2109	Water Heating – Health	RTF68 – Healthcare Hot Water	NG RI May Interval Data	1.0 Assumed	RTF68 – Healthcare Hot Water
2110	Water Heating – Lodging	RTF76 – Lodging Hot Water	NG RI May Interval Data	1.0 Assumed	RTF76 – Lodging Hot Water
111	Water Heating – Full-Serve Restaurant	RTF127 – Restaurant Hot Water	NG RI May Interval Data	1.0 Assumed	RTF127 – Restaurant Hot Water
2112	Water Heating - Fast-food Restaurant	RTF127 – Restaurant Hot Water	NG RI May Interval Data	1.0 Assumed	RTF127 – Restaurant Hot Water
2113	Water Heating – Commercial Other	RTF101 – Misc. Comm. Hot Water	NG RI May Interval Data - Warehouse	1.0 Assumed	RTF101 – Misc. Comm. Hot Water
2201	Cooking – Large Office	RTF84 – Large Office Cooking	NG RI May Interval Data	1.0 Assumed	RTF84 – Large Office Cooking
2202	Cooking – Small Office	RTF162 – Small Office Cooking	NG RI May Interval Data	1.0 Assumed	RTF162 – Small Office Cooking
2203	Cooking – Retail	RTF136 – Retail Cooking	NG RI May Interval Data	1.0 Assumed	RTF136 – Retail Cooking
2204	Cooking – Grocery	RTF46 – Grocery Cooking	NG RI May Interval Data	1.0 Assumed	RTF46 – Grocery Cooking
2205	Cooking – Warehouse	RTF110 – Ware-house Cooking	NG RI May Interval Data	1.0 Assumed	RTF110 – Warehouse Cooking
2206	Cooking – Elementary Education	RTF149 – School Cooking	NG RI May Interval Data	1.0 Assumed	RTF149 – School Cooking
2207	Cooking – Secondary Education	RTF149 – School Cooking	NG RI May Interval Data	1.0 Assumed	RTF149 – School Cooking
2208	Cooking – University Education	RTF33 – College Cooking	NG RI May Interval Data	1.0 Assumed	RTF33 – College Cooking
2209	Cooking – Health	RTF59 – Healthcare Cooking	NG RI May Interval Data	1.0 Assumed	RTF59 – Healthcare Cooking
2210	Cooking – Lodging	RTF72 – Lodging Cooking	NG RI May Interval Data	1.0 Assumed	RTF72 – Lodging Cooking
2211	Cooking – Full-Serve Restaurant	RTF123 – Restaurant Cooking	NG RI May Interval Data	1.0 Assumed	RTF123 – Restaurant Cooking

Load Shape #	Description / Segment	Monthly Breakdown	Weekend / Weekday Ratio	Peak Day Factor	Hourly Profile
2212	Cooking - Fast-food Restaurant	RTF123 – Restaurant Cooking	NG RI May Interval Data	1.0 Assumed	RTF123 – Restaurant Cooking
2213	Cooking – Commercial Other	RTF97 – Misc. Comm. Cooking	NG RI May Interval Data - Warehouse	1.0 Assumed	RTF97 – Misc. Comm. Cooking
2301	Clothes Washer – All Commercial	NG RI Load Data Laundromat (2)	NG RI Laundromat	1.0 Assumed	NG RI Laundromat (2)
2301	Dryer – All Commercial	NG RI Load Data Laundromat (2)	NG RI May Interval Data	1.0 Assumed	NG RI Load Data Laundromat (2)
2401	Dishwasher – Large Office	RTF84 – Large Office Cooking	NG RI May Interval Data	1.0 Assumed	RTF84 + 2 hrs – Large Office Cooking
2402	Dishwasher – Small Office	RTF162 – Small Office Cooking	NG RI May Interval Data	1.0 Assumed	RTF162 + 2 hrs Small Office Cooking
2403	Dishwasher – Retail	RTF136 – Retail Cooking	NG RI May Interval Data	1.0 Assumed	RTF136 + 2 hrs Retail Cooking
2404	Dishwasher – Grocery	RTF46 – Grocery Cooking	NG RI May Interval Data	1.0 Assumed	RTF46 + 2 hrs Grocery Cooking
2405	Dishwasher – Warehouse	RTF110 – Ware-house Cooking	NG RI May Interval Data	1.0 Assumed	RTF110 + 2 hrs Warehouse Cooking
2406	Dishwasher – Elementary Education	RTF149 – School Cooking	NG RI May Interval Data	1.0 Assumed	RTF149 + 2 hrs School Cooking
2407	Dishwasher – Secondary Education	RTF149 – School Cooking	NG RI May Interval Data	1.0 Assumed	RTF149 + 2 hrs School Cooking
2408	Dishwasher – University Education	RTF33 – College Cooking	RTF 152 College Heating	1.0 Assumed	RTF33 + 2 hrs College Cooking
2409	Dishwasher – Health	RTF59 – Healthcare Cooking	NG RI May Interval Data	1.0 Assumed	RTF59 + 2 hrs Healthcare Cooking
2410	Dishwasher – Lodging	RTF72 – Lodging Cooking	NG RI May Interval Data	1.0 Assumed	RTF72 + 2 hrs Lodging Cooking
2411	Dishwasher – Full-Serve Restaurant	RTF123 – Restaurant Cooking	NG RI May Interval Data	1.0 Assumed	RTF123 + 2 hrs Restaurant Cooking
2412	Dishwasher - Fast-food Restaurant	RTF123 – Restaurant Cooking	NG RI May Interval Data	1.0 Assumed	RTF123 + 2 hrs Restaurant Cooking
2413	Dishwasher – Commercial Other	RTF97 – Misc. Comm. Cooking	NG RI May Interval Data - Warehouse	1.0 Assumed	RTF97 + 2 hrs Misc. Comm Cooking

5 ANALYSIS AND RESULTS

The resulting load shape library is summarized below for each of the main end use segments.

The data fields are:

- Index – sequential list of all 53 end use load shapes
- Segment – Business type
- End Use – End use and seasonal (S) or fixed (F) monthly aggregations used
- Load Shape Name – Denotes Sector and End Use
- Source – Primary source of load shape (most are RTF reference number)
- Row in GLSShapes – Row where the data starts in GLSShapes tab
- Load Shape Number – Code number for load shape
- NCP Peak Hours Use Value – "Hours Use" for load shape peak (annual / non-coincident peak hour) and non-coincident peak day
- Peak Hour Day Adj Factors – PDAF for the peak day (same for peak day and peak hour)
- Hours Use Factor (Ann Pk2) – User-selected coincident hourly peak "Hours Use" (ratio of annual use to peak hour and peak day)
- Avg. Peak / Annual % - Percent of annual use for the peak day

Figure 5-1: Heating end use load shape library entries

National Grid - Rhode Island Load Shape Library							NCP Peak Hours Use Values		Peak Hour Day Adj Factors		Hours Use Factors (Ann/Pk)		
Index	Segment	End Use	Source	Load Shape Name	Row in GLSShapes	Load Shape Number	For Peak 1 (Hourly)	For Peak 2 (Daily)	For Peak 1	For Peak 2	Peak1 (Hour 8)	Peak2 (Daily)	Avg. Peak / Annual %
1	Large Office	Heating-SS	RTF87	Large Office-Heating-SS	1	2001	2,050.41	133.87	1.569	1.569	1,306.73	85.31	1.17%
2	Small Office	Heating-SS	RTF165	Small Office-Heating-SS	41	2002	1,228.97	137.92	1.569	1.569	783.22	87.90	1.14%
3	Retail	Heating-SS	RTF139	Retail-Heating-SS	81	2003	1,321.31	130.24	1.569	1.569	842.07	83.00	1.20%
4	Grocery	Heating-SS	RTF49	Grocery-Heating-SS	121	2004	1,981.68	142.70	1.569	1.569	1,262.93	90.94	1.10%
5	Warehouse	Heating-SS	RTF113	Warehouse-Heating-SS	161	2005	1,759.18	131.15	1.569	1.569	1,121.13	83.58	1.20%
6	Education Elem	Heating-SS	RTF152	Education Elem-Heating-SS	201	2006	1,240.36	139.78	1.569	1.569	790.48	89.08	1.12%
7	Education HS	Heating-SS	RTF152	Education HS-Heating-SS	241	2007	1,202.64	135.53	1.569	1.569	766.45	86.38	1.16%
8	Education Univ	Heating-SS	RTF152	Education Univ-Heating-SS	281	2008	1,356.32	152.85	1.470	1.470	922.43	103.95	0.96%
9	Health	Heating-SS	RTF62	Health-Heating-SS	321	2009	2,289.26	138.74	1.569	1.569	1,458.95	88.42	1.13%
10	Lodging	Heating-SS	RTF75	Lodging-Heating-SS	361	2010	2,203.82	143.52	1.569	1.569	1,404.50	91.47	1.09%
11	Restaurant-FS	Heating-SS	RTF126	Restaurant-FS-Heating-SS	401	2011	1,770.11	139.69	1.569	1.569	1,128.09	89.02	1.12%
12	Restaurant-FF	Heating-SS	RTF126	Restaurant-FF-Heating-SS	441	2012	1,856.94	146.54	1.569	1.569	1,183.43	93.39	1.07%
13	Commercial-other	Heating-SS	RTF100	Commercial-other-Heating-SS	481	2013	1,593.09	127.68	1.569	1.569	1,015.28	81.37	1.23%

Figure 5-2: Water heating end use load shape library entries

Index	Segment	End Use	Source	Load Shape Name	Row in GLSShapes	Load Shape Number	For Peak 1 (Hourly)	For Peak 2 (Daily)
14	Large Office	Water Heating	RTF88	Large Office-Water Heating-FS	521	2101	5,923.28	323.63
15	Small Office	Water Heating	RTF166	Small Office-Water Heating-FS	561	2102	5,751.56	319.71
16	Retail	Water Heating	RTF140	Retail-Water Heating-FS	601	2103	4,448.64	284.29
17	Grocery	Water Heating	RTF50	Grocery-Water Heating-FS	641	2104	6,161.10	342.60
18	Warehouse	Water Heating	RTF114	Warehouse-Water Heating-FS	681	2105	5,187.61	286.25
19	Education Elem	Water Heating	RTF153	Education Elem-Water Heating-	721	2106	3,256.40	311.62
20	Education HS	Water Heating	RTF153	Education HS-Water Heating-FS	761	2107	3,034.07	290.35
21	Education Univ	Water Heating	RTF37	Education Univ-Water Heating-	801	2108	5,195.22	317.15
22	Health	Water Heating	RTF63	Health-Water Heating-FS	841	2109	6,051.08	332.87
23	Lodging	Water Heating	RTF76	Lodging-Water Heating-FS	881	2110	5,845.79	349.60
24	Restaurant-FS	Water Heating	RTF127	Restaurant-FS-Water Heating-F	921	2111	5,129.43	342.63
25	Restaurant-FF	Water Heating	RTF127	Restaurant-FF-Water Heating-F	961	2112	5,129.43	342.63
26	Commercial-other	Water Heating	RTF101	Commercial-other-Water Heati	1001	2113	4,923.50	284.90

Figure 5-3: Cooking and laundry load shape library entries

National Grid - Rhode Island Load Shape Library							NCP Peak Hours Use Values	
Index	Segment	End Use	Source	Load Shape Name	Row in GLSShapes	Load Shape Number	For Peak 1 (Hourly)	For Peak 2 (Daily)
27	Large Office	Cooking-FS	RTF84	Large Office-Cooking-FS	1041	2201	4,244.34	356.59
28	Small Office	Cooking-FS	RTF162	Small Office-Cooking-FS	1081	2202	3,638.58	359.35
29	Retail	Cooking-FS	RTF136	Retail-Cooking-FS	1121	2203	4,327.20	314.12
30	Grocery	Cooking-FS	RTF46	Grocery-Cooking-FS	1161	2204	5,994.02	372.30
31	Warehouse	Cooking-FS	RTF110	Warehouse-Cooking-FS	1201	2205	4,206.50	325.14
32	Education Elem	Cooking-FS	RTF149	Education Elem-Cooking-FS	1241	2206	2,968.79	327.36
33	Education HS	Cooking-FS	RTF149	Education HS-Cooking-FS	1281	2207	2,766.10	305.01
34	Education Univ	Cooking-FS	RTF33	Education Univ-Cooking-FS	1321	2208	5,498.80	333.17
35	Health	Cooking-FS	RTF59	Health-Cooking-FS	1361	2209	5,516.25	368.79
36	Lodging	Cooking-FS	RTF72	Lodging-Cooking-FS	1401	2210	5,954.61	373.63
37	Restaurant-FS	Cooking-FS	RTF123	Restaurant-FS-Cooking-FS	1441	2211	5,828.54	371.36
38	Restaurant-FF	Cooking-FS	RTF123	Restaurant-FF-Cooking-FS	1481	2212	5,828.54	371.36
39	Commercial-other	Cooking-FS	RTF97	Commercial-other-Cooking-FS	1521	2213	5,019.07	313.73
40	Commercial-Other	Laundry-FS	NG-RI	Commercial-Other-Laundry-FS	1561	2301	3,555.19	309.01

Figure 5-4: Dishwashing load shape library entries

National Grid - Rhode Island Load Shape Library							NCP Peak Hours Use Values	
Index	Segment	End Use	Source	Load Shape Name	Row in GLSShapes	Load Shape Number	For Peak 1 (Hourly)	For Peak 2 (Daily)
41	Large Office	Cook/Dishwas	RTF84+2 h	Large Office-Cook/Dishwash-FS	1601	2401	4,244.34	356.59
42	Small Office	Cook/Dishwas	RTF162+2	Small Office-Cook/Dishwash-FS	1641	2402	3,638.58	359.35
43	Retail	Cook/Dishwas	RTF136+2	Retail-Cook/Dishwash-FS	1681	2403	4,327.20	314.12
44	Grocery	Cook/Dishwas	RTF46+2 h	Grocery-Cook/Dishwash-FS	1721	2404	5,994.02	372.30
45	Warehouse	Cook/Dishwas	RTF110+2	Warehouse-Cook/Dishwash-FS	1761	2405	4,206.50	325.14
46	Education Elem	Cook/Dishwas	RTF149+2	Education Elem-Cook/Dishwash	1801	2406	2,968.79	327.36
47	Education HS	Cook/Dishwas	RTF149+2	Education HS-Cook/Dishwash-F	1841	2407	2,766.10	305.01
48	Education Univ	Cook/Dishwas	RTF33+2 h	Education Univ-Cook/Dishwash	1881	2408	5,498.80	333.17
49	Health	Cook/Dishwas	RTF59+2 h	Health-Cook/Dishwash-FS	1921	2409	5,516.25	368.79
50	Lodging	Cook/Dishwas	RTF72+2 h	Lodging-Cook/Dishwash-FS	1961	2410	5,954.61	373.63
51	Restaurant-FS	Cook/Dishwas	RTF123+2	Restaurant-FS-Cook/Dishwash-	2001	2411	5,828.54	371.36
52	Restaurant-FF	Cook/Dishwas	RTF123+2	Restaurant-FF-Cook/Dishwash-	2041	2412	5,828.54	371.36
53	Commercial-other	Cook/Dishwas	RTF97+2 h	Commercial-other-Cook/Dishw	2081	2413	5,019.07	313.73

Figure 5-5: Cross-reference table for identifying load shape library index and load shape number

National Grid Rhode Island - Load Shape lookups

Commercial End Use	Large Office	Small Office	Retail	Grocery	Warehouse	Education - Elementary	Education - High School	Education - University	Health	Lodging	Full-Serve Restaurant	Fast-Food Restaurant	Commercial-other
Space Heating	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Water Heating	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113
Cooking	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213
Clothes Washer	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301
Dryer	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301	2301
Dishwasher	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413

Index #'s

National Grid Rhode Island - Load Shape lookups

Commercial End Use	Large Office	Small Office	Retail	Grocery	Warehouse	Education - Elementary	Education - High School	Education - University	Health	Lodging	Full-Serve Restaurant	Fast-Food Restaurant	Commercial-other
Space Heating	1	2	3	4	5	6	7	8	9	10	11	12	13
Water Heating	14	15	16	17	18	19	20	21	22	23	24	25	26
Cooking	27	28	29	30	31	32	33	34	35	36	37	38	39
Clothes Washer	40	40	40	40	40	40	40	40	40	40	40	40	40
Dryer	40	40	40	40	40	40	40	40	40	40	40	40	40
Dishwasher	41	42	43	44	45	46	47	48	49	50	51	52	53

6 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE RESEARCH

6.1 Conclusions

- The load shape library developed for this study provides a solid basis for National Grid – Rhode Island to use in tracking peak gas and demand savings, specifically the relationship between annual usage and various peak definitions and hourly loads overall.
- The methods and formats of load shapes developed for the study can be easily applied to upgrade the end use load shapes as additional sources are identified or additional analysis is done, including any future load studies conducted by National Grid for Rhode Island or any of its regional service areas.
- Use of historical weather (most recent 9 years) provided a means to establish weather-dependent components of heating loads, specifically monthly breakdowns and peak day adjustment factors, that also enabled different normalized peak definitions (annual average, 1 in 9 or 10 years, design day.
- The load shape ratio method used to build the load shape library provided a good structure for incorporating weather and several load sources to optimize the development of end use load shape patterns in the absence of actual end use load metered data.
- The load shape ratio method and the way in which the load shapes were stored will facilitate flexibility in application of the load shapes to cover scaling of usage levels, application to any calendar year, and outputs in several formats (e.g. 8760 1-column, 365x24 or EEI/2 lines per day).
- The load shape library module and linked LOADLIB reporting/output module will facilitate access to the load shapes and easy generation of load patterns for various applications, including:
    - DSM Potential studies – Most potential study models produce annual usage savings, which can now be converted to peak impact for any peak definition with a few simple inputs
    - DSM Evaluation – Most evaluations focus on annual usage savings, which can now be converted to any peak impact definition with the load shape library
    - Load Forecasting – With the load shape library, end use load forecasting annual usages can be converted to any peak definition for peak load forecasts. When/if the peak hour/day shifts, or weather trends change, the load shape library can facilitate those adjustments.
    - Demand Response – The end use load shape library provides a baseline load shape to which an estimate of impacts can be applied before actual event data is collected. Metered demand response data can itself be a source of end use load shapes, either via runtime or engineering units.
- Industrial load shapes were not developed for process loads (production or manufacturing application) since these are very industry-specific and subject to operating hours for specific industrial facilities and such data was not readily available for National Grid – Rhode Island customers. The portion of industry customer loads for heating and non-process loads for water heating, cooking, laundry and dishwashing can be taken from the warehouse segment end uses, which are considered applicable, given no other specific data sources.

- As better sources of metered or modeled end use data are developed, the load shape library can be easily updated, either for specific components of the four ratios or in total.

6.2 Recommendations

- National Grid should commission additional studies of existing interval load data, such as the 628 interval load data points used in this study, as well as take advantage of forthcoming interval data made possible from electric and gas Automated Metering Infrastructure (AMI) data, as those systems are expanded within the regional service areas of National Grid.
- National Grid should consider investing in some additional gas end use load studies, particularly for heating and water heating, by commercial business types for a sufficient sample of sites. Given the importance and dominance of heating end uses in the service area and its key role in the peak, heating should be the primary target of some end use load studies. Other end uses, especially water heating, dryers and cooking, could also be "borrowed" from electric studies of their end use counterparts, given the similar operating hours, and would be more cost-effectively metered, as well.
- As a combination utility, National Grid should coordinate with any electric end use load studies for end uses that also have gas fuel options (especially heating and water heating, but also dryers), which can provide load patterns that would apply equally to both electric and gas end uses. Electric end use load metering is often more practical and cost-effective than gas end use load metering but operating patterns are likely the same for both fuels.

6.3 Future research

Given the importance of peak impacts to National Grid, it should be a priority to develop some end use load studies that would improve confidence in the load shape library components, including additional segmentation (e.g., by size), end uses, and technologies, especially newer gas technologies that emerge and could be significant contributors in the future. Due to the lack of end use metered load studies for different end use technologies, especially those that may affect the pattern of loads, not just the levels of load, more study of these different types of technologies would enhance the accuracy and add load shapes.

Of particular note is the increased adoption of WiFi thermostats for small commercial customers, and advanced building control systems and other components of "smart" buildings for larger customers. These technologies typically enable the collection of runtime data, specifically duty cycles (percent of time HVAC is running), thermostat setpoints, and indoor temperature. This data will facilitate development of end use load shapes for use in load shape libraries that can help in studies on DSM potential, demand response impacts, DSM evaluation, load forecasting, rate studies, and technology assessment. One caveat is that access to this data may require a combination of customer permission and pre-arranged cooperation by the thermostat manufacturers who collect and store the data for customer use. Agreement on privacy issues concerning use of the data is often a constraint.

Additional study of load shapes from the 628 customers with interval data could certainly be conducted, including daily weather-load relationships and hourly weather-sensitive and non-weather-sensitive load patterns that would add to the analysis already done on those customers whose business type was confirmable (only 251 of the 628 were identified by business type and size). Additional data on these customers, such as end use inventory, equipment type and operating hours, could further refine the segments. A fuller identification of business types and end use inventories could be done, since for this study only 250 of the 628 were readily assignable to business types and sizes and no inventories were available. Such a study would add considerable understanding of the differences in load patterns by business type, size, end use ownership and other factors, given such a robust sample. Analysis of 12 months of loads would also provide an improved estimate of non-heating end use monthly breakdowns, monthly weekend/weekday ratios and hourly per-unit load shapes by day type, especially if coupled with end use equipment inventory.

APPENDIX A. WEATHER ANALYSIS

Weather analysis was conducted of the Warwick, RI weather station (KPVD) for 2011 through 2020, covering nine winters, to determine the monthly breakdown and peak day factors at three design day definitions: 1) average annual, 2) 1 in 9 year maximum, and 3) 0° average daily temperature.

Figure 6-1: Average Monthly Weather Statistics (HDD) for Warwick, RI - 60° Base

Month	KPVD Average Month HDD60	Max Month HDD60	Peak Day factor HDD60	Monthly HDD60 breakdown
1	29.14	45.44	1.56	21.6%
2	27.61	40.88	1.48	18.5%
3	21.24	33.96	1.60	15.7%
4	11.45	21.78	1.90	8.2%
5	3.21	12.52	3.90	2.4%
6	0.35	0.59	1.69	0.3%
7	-	-	-	0.0%
8	0.15	0.15	1.00	0.1%
9	0.45	1.67	3.70	0.3%
10	5.61	16.05	2.86	4.2%
11	16.23	28.09	1.73	11.6%
12	23.11	35.76	1.55	17.1%
Annual	4,183	45.44	Max	100.0%

For Design Day of 1 in 9 years (58.5 HDD60), the January Peak Day factor would be 2.02.

For Design Day of 0° Daily Average (60 HDD60), the January Peak Day factor would be 2.07.

Figure 6-2: Average Monthly Weather Statistics (HDD) for Warwick, RI - 65° Base

Month	KPVD Average Month HDD65	Max Month HDD65	Peak Day factor HDD65	Monthly HDD65 breakdown
1	34.14	50.44	1.48	19.7%
2	32.61	45.88	1.41	17.0%
3	26.19	38.96	1.49	15.1%
4	16.23	26.78	1.65	9.0%
5	6.49	17.52	2.70	3.7%
6	1.38	7.37	5.35	0.8%
7	0.04	0.04	1.13	0.0%
8	0.21	0.23	1.12	0.1%
9	1.94	8.07	4.17	1.1%
10	9.65	21.05	2.18	5.6%
11	21.15	33.09	1.56	11.8%
12	28.11	40.76	1.45	16.2%
Annual	5,383	50.44	Max	100.0%

Figure 6-3: Historical weather (HDD) for KPVD (Warwick, RI) weather station (60° Base)

Days	Month	Monthly HDD60 breakdown										
		2011	**2,012**	**2,013**	**2,014**	**2,015**	**2,016**	**2,017**	**2,018**	**2,019**	**2,020**	**>0**	**years**
31	1		821	912	1,033	1,049	856	783	953	957	764	903	9
28	2		684	827	891	1,172	756	681	577	770	663	773	9
31	3		444	674	806	839	501	776	664	721	501	658	9
30	4		280	332	352	337	370	265	427	294	436	343	9
31	5		65	99	82	51	113	136	71	181		100	8
30	6		17	4	-	29	1	17	12	5		11	8
31	7		-	-	-	-	-	-	-	-		-	8
31	8		-	-	-	20	-	-	-	17		5	8
30	9	13	18	32	20	5	11	7	12	7		14	9
31	10	186	147	180	185	212	172	61	264	161		174	9
30	11	349	539	548	540	373	403	485	562	584		487	9
31	12	644	668	826	683	431	775	897	750	777		716	9
	Annual	**NA**	**3,681**	**4,432**	**4,591**	**4,515**	**3,955**	**4,105**	**4,290**	**4,472**	**NA**	**4,183**	
	Count	4	12	12	12	12	12	12	12	12	4	12	

APPENDIX B. LOAD SHAPE RATIO SYSTEM

To facilitate load shape development, storage, calibration and transferability, DNV GL has developed a system of load shape pattern format storage, consisting of four types of load shape statistics. These four key parameters can be adjusted independently to describe a load shape for any class or end use. The four load shape parameters[9] are:

1. Monthly usage allocation: Percentage of annual usage assigned to each month. The sum of the 12 monthly values must sum to 100%. For heating in particular, and other end uses to a lesser extent (e.g. water heat), there is a direct correlation between weather and usage distribution over months and seasons. Without climate zone-specific end use load data, this set of factors can be estimated by weather parameters, especially with heating degree days. Other end uses, including cooking, washers, and dryers, are seasonal but not affected directly by weather, but by seasonal factors such as amount of clothing worn (and therefore washed/drier), type of meals prepared (hotter meals during cold weather than hot weather), and recreational activities (more outdoor activities in warm weather than cold weather). For the commercial sector, some business types have specific seasonality patterns not directly affected by weather, such as schools (reduced activity during summer), lodging (tourist seasons, which depend on location and influx of tourists), retail (more activity during pre-school, holiday shopping), restaurant (like residential, type of meals), and religious (holidays). All these monthly allocation factors can be established by end use and, to some degree, by commercial business type.
2. Weekend to weekday ratio: Defined as the ratio of a typical weekend day usage to a typical weekday usage (by season, month, or annual). A value of 1.0 means that weekend day and weekday usage are assumed to be equal. This is particularly subject to variation by commercial business types and building sizes, since some businesses have more weekend activity than others, and large businesses tend to have more weekend activity than smaller businesses. For example, large retail stores typically operate seven days per week, with possibly only slightly later openings and earlier closings on Sundays. Large offices typically have more activity on weekends, including data centers. Most elementary and secondary schools are closed on weekend days, but universities usually have more activity, especially where on-campus dorms exist.
3. Peak day adjustment factor (PDAF): Represents the ratio of the daily usage for a peak day vs. that of a typical weekday (by season or month). For example, a value of 1.5 means that peak day consumption is 50% higher than for a typical weekday for the same period. These factors are primarily driven by daily weather sensitivity, reflecting variation in weather across months or seasons. While there is some variation in other end uses, such as water heating, these are not predictably daily weather sensitive. Development of these factors can also be based on typical weather variations, reflecting some pre-defined probability, such as one-in-one-year vs. one-in-ten-year.
4. 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, weekend day). The number of per-unit load shapes used to represent any hour of the year varies depending on the required precision and the variation in the loads over different day types and seasons. At a minimum, the following eight load shapes can be used for a seasonal summary:
    - Peak for (1) summer and (2) winter

[9] This method of defining load shapes has been used in dozens of utility load studies by the author, involving DSM potential, end use load forecasting, demand response and energy efficiency program evaluation, as well as basic load research studies.

- Typical weekday for (3) summer, (4) spring/fall, and (5) winter
- Typical weekend day for (6) summer, (7) spring/fall, and (8) winter

To provide a fuller range of variations when sufficient data are available to support it, an annual summary, with 36 load shapes, would be used, as they have for this study: The load shapes would represent peak day, weekday, and weekend day for each of 12 months.

The advantage of creating a summarized version of hourly load shapes is that it facilitates the ability to adjust, scale, and otherwise transfer each of the four load shape parameters independently to match that of the target customer or end use group more closely, but it can also capture sufficient variation in loads, specifically by the use of the peak day adjustment factor, which the load shape ratio system uses to generate a range of daily usages for weekdays from peak to average to low, matching variation in weather. Knowing these parameters and any one hourly demand value or annual usage value enables the development of all the other hourly load values for the year.

6.4 Hourly demand estimation

Load shape patterns can be used to estimate demand at any hour, given known annual energy. The process is as follows:

- Known annual energy (input), with target demand month, day type and whether peak or average (e.g., 1000 Therms, with Peak January day at 5 pm).
- Multiply annual energy by monthly usage allocation for target month (e.g., January = 10%; 1000 annual Therms x 10% = 100 Therms for January)
- Use weekend to weekday ratio (WEWD) in the formula to produce average weekday daily usage (e.g., WEWD=0.8):
    - Average weekday = 1 / (Days in month x 5/7 + days in month x 2/7 * WEWD) = 1 / (31 x 5/7 + 31 x 2/7 x 0.8) = 1 / 29.228 = 0.03421; x 100 Therms = 3.421
- Use peak day adjustment factor (PDAF) to adjust average weekday for peak day (e.g., PDAF = 1.4)
    - Peak Day = PDAF x Weekday = 1.4 x 3.421 = 4.790 Therms
- Compute Peak Hour value = Peak Hour Per-unit Max at Target hour / Sum of per-unit hourly values for Target load shape (Peak Day), e.g., 0.8 at 5 pm vs. sum of daily per-units of 13.552
    - Peak Hour = 0.8 / 13.552 x Peak Day = 0.0590 * 4.790 = 0.28275 Therms
- The ratio of annual energy to defined peak demand is defined as the "Hours Use" ratio, which simplifies the conversion of energy to demand for a specific scenario. For example, net Hours Use value (annual Therms / Peak hour) = 1000 / 0.28275 = 3,537. In short, when we know the annual kWh, we just divide by 3,537 to get demand at system peak.

6.5 Modules for LOADLIB and GLS (General Load Shape) format

Conversion and reporting modules used in this study are as follows:

- GLS Load Shape Library: Stored versions of all the commercial business type, measure and end use load shapes.
- LOADLIBA-8760: This template inputs GLS format load shapes and provides tabular and graphic output reports, conversions to 365x24 and 8,760 formats for any year. A perpetual calendar is built in to enable any year's output.

- Convert8760toGLS365v#: Template module to convert 8760 load shapes to 365x24 and GLS format
- GLS-QuickMoEdit: Template for quick review and editing of monthly factors and hourly load shapes in GLS format. Inputs and outputs are GLS format.

6.5.1 Load Shape Format:

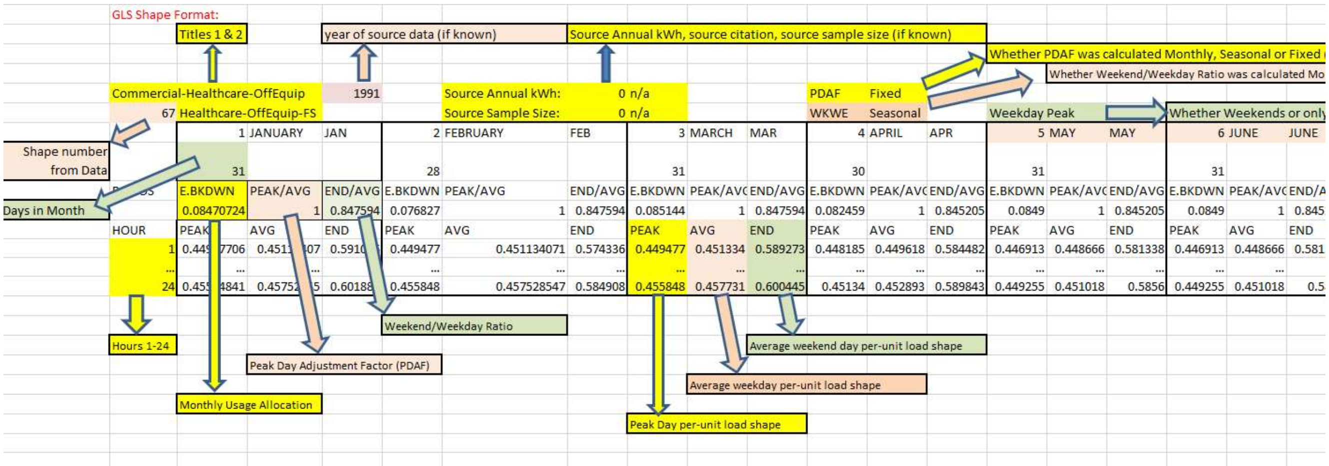
- Three monthly factors each month (Monthly Breakdown, Peak Day Factor (PDAF), and Wkend/Wkday Factor)
- Three per-unit load shape types per month (Peak Day, Weekday, Weekend)

Figure 6-4: Ratio Load Shape (GLS) Format excerpt

Large Office		KPVD-HDD60	RTF87			Source Annual Usage		n/a			PDAF	Seasonal	
	2001	Large Office-Heating-SS				Source Sample Size:		n/a			WEWD	Seasonal	
		1	JANUARY	JAN	2	FEBRUARY	FEB	3	MARCH	MAR	4	APRIL	APR
		31			28			31			30		
RATIOS		E.BKDWN	PEAK/AVG	END/AVG	E.BKDWN	PEAK/AVG	END/AVG	E.BKDWN	PEAK/AVG	END/AVG	E.BKDWN	PEAK/AVG	END/AVG
		0.215908405	1.569114195	0.763264442	0.184820724	1.569114195	0.763264442	0.157366932	1.569114195	0.763264442	0.082083123	2	0.763264442
HOUR		PEAK	AVG	END	PEAK	AVG	END	PEAK	AVG	END	PEAK	AVG	END
	1	0.446765155	0.425408223	0.673835257	0.423970322	0.405101664	0.647453989	0.388480583	0.40536543	0.650068185	0.396547221	0.39154135	0.62258958
	2	0.433693851	0.438697986	0.69356728	0.441077798	0.420862696	0.652702196	0.401255397	0.41802538	0.674207095	0.393051015	0.40291276	0.641719303
	3	0.445836056	0.451348339	0.708799295	0.448410104	0.436637846	0.681433164	0.419333895	0.433033625	0.698950494	0.412636135	0.423227334	0.664260648
	4	0.469052941	0.472861044	0.730250207	0.479588415	0.462399496	0.720775098	0.443361868	0.455456443	0.72780685	0.428300619	0.443008303	0.701389443
	5	0.496736613	0.493765502	0.753818939	0.497989295	0.480429944	0.740005132	0.463405355	0.474995977	0.757451757	0.445895369	0.534525433	0.743479348
	6	0.561585989	0.574074739	0.770279592	0.585826369	0.570433113	0.789669766	0.551280837	0.571432911	0.797936516	0.539540428	0.720669483	0.800027859
	7	0.713161532	0.733859065	0.836355852	0.770345255	0.750027734	0.858962909	0.764563809	0.766945209	0.851831085	0.688226862	0.922219381	0.8452815
	8	0.9483334	0.981564616	0.944289369	0.972390399	0.978307154	0.928390064	0.979033582	0.959250614	0.889125656	0.91196345	1	1
	9	1	1	1	1	1	1	1	1	1	1	0.932927128	0.970368836
	10	0.898725291	0.893297993	0.92072257	0.918084683	0.885640949	0.914602957	0.889882892	0.865094646	0.909514061	0.874958469	0.814608116	0.850697189
	11	0.801617121	0.780761425	0.79951939	0.835434723	0.783878594	0.805032338	0.815124478	0.755113429	0.811793467	0.743112739	0.71932112	0.775802077
	12	0.738940268	0.700565435	0.726269343	0.763396116	0.697531175	0.73784177	0.721706966	0.674409941	0.745383699	0.668751556	0.644110206	0.696112344
	13	0.698015361	0.640585718	0.685850669	0.699826136	0.632862839	0.690575555	0.664343642	0.599305974	0.690698831	0.625544705	0.585951269	0.65606442
	14	0.665643035	0.603888246	0.670620817	0.661011576	0.583790742	0.677149834	0.61246341	0.552487269	0.67686262	0.591140778	0.553422557	0.592565443
	15	0.630413581	0.584863724	0.638973554	0.650661125	0.565020622	0.626200559	0.59359076	0.540773256	0.626808124	0.587957211	0.552339253	0.588396818
	16	0.643504545	0.599240049	0.621587435	0.676706873	0.580410857	0.635578959	0.604853349	0.553832856	0.608684954	0.611722493	0.577105795	0.555041768
	17	0.712157824	0.670954292	0.639363721	0.73446833	0.625100183	0.612009337	0.654456914	0.59525568	0.596306808	0.659717401	0.624467142	0.577470346
	18	0.754400412	0.737774594	0.698307534	0.786568364	0.710980312	0.686066273	0.760255621	0.67988388	0.647032119	0.726742633	0.574749049	0.536382227
	19	0.595006711	0.620773425	0.620726863	0.667599732	0.618757563	0.620670122	0.659752236	0.605163772	0.609178738	0.649952746	0.39856842	0.474835553
	20	0.381475918	0.380775861	0.593357162	0.401193479	0.372870944	0.555581945	0.385609408	0.364337681	0.545959575	0.37841669	0.356657488	0.506549595
	21	0.358444139	0.369965451	0.605304767	0.391910029	0.3705941	0.542644081	0.367614711	0.362409491	0.565412686	0.369802607	0.355225597	0.524509983
	22	0.366397596	0.371730935	0.637145153	0.379105854	0.366706958	0.562010201	0.381046052	0.360476605	0.591333502	0.369828904	0.357345692	0.539089133
	23	0.376887762	0.379697718	0.653324011	0.396709692	0.369998104	0.588509964	0.378956526	0.365988213	0.597243301	0.368950902	0.370399705	0.560650764
	24	0.38850638	0.396693679	0.669828961	0.422015982	0.3868044	0.610739342	0.39422234	0.383688741	0.645639273	0.382728333	0.382245889	0.606953104

A diagram is provided in the "Notes" Tab of the Load Shape Library Module identifying what each component of this format represents.

Figure 6-5: Diagram of Load Shape Ratio (GLS) format components



6.5.2 Load Shape Library Module

The Load Shape Library module stores the General Load Shape Ratio (GLS) load shapes.

Module Tabs

- GLSShapes – This Tab contains the actual load General Load Shape Ratio (GLS) load shapes, which are a compressed format description of a full annual load shape and can be expanded to produce 8,760 load shapes. Load Shapes are stored every 40 rows, starting at row 1, 41, 81, etc.
- Notes – This Tab contains an annotated GLS format load shape layout, with notes describing what each element of the load shape is.
- Glossary – This Tab has descriptions of the four load shape ratio components and a description of the steps involved in the calculation of a typical hourly value based on the ratios in the GLS Load Shapes.
- Index – This Tab contains an index to each of the load shapes stored in the GLSShapes Tab, with column descriptions from Chapter 5:
  - Index – sequential list of all 53 end use load shapes
  - Segment – Business/building type
  - End Use – End use and seasonal (S) or fixed (F) monthly aggregations used
  - Load Shape Name – Denotes Sector and End Use
  - Source – Primary source of load shape (most are RTF reference number)
  - Row in GLSShapes – Row where the data starts in GLSShapes tab
  - Load Shape Number – Code number for load shape
  - NCP Peak Hours Use Value – "Hours Use" for load shape peak (annual / non-coincident peak hour) and non-coincident peak day

- Peak Hour Day Adj Factors – PDAF for the peak day (same for peak day and peak hour)
- Hours Use Factor (Ann Pk2) – User-selected coincident hourly peak "Hours Use" (ratio of annual use to peak hour and peak day)
    - Avg. Peak / Annual % - Percent of annual use for the peak day

- Search – This Tab contains the user-selected load shape. Cell A1 is the selection, using the Index from the Index Tab and Cell A2 is the Index number from the LOADLIB module selection. Setting Cell A1 as "=A2" will automatically choose the LOADLIB-selected load shape, or you can enter an indexed load shape in Cell A1 to browse the load shapes.
- Cross-Ref – This Tab identifies the Index number and Load Shape Number for each of the Load Shapes by business type and end use assigned by DNV GL for this study.

6.5.3 LOADLIB Reporting Module

The LOADLIB Module is an Excel workbook that inputs load shape parameters, provides tables and graphs displaying analysis of the load shape characteristics, and outputs 8,760-hour load shapes in either 365x24 or 8,760 1-column formats for use in other applications,

When linked to the Load Shape Library, LOADLIB automatically pulls in the selected load shape, based on the index in the Load Shape Library.

- Inputs
  - Target Year (e.g. 2019)
  - Annual Usage Target (or 1 for per-unit)
  - Load Shape Index Number (from Load Shape Library Lookup Table
  - Peak and Off-Peak Month & Hour
- Outputs:
  - Monthly Usage
  - Peak, Weekday and Weekend Usage/day
  - Non-Coin and Coin Peak
  - Annual Statistics

The LOADLIB module consists of the following Tabs

- LOADS – This Tab provides report tables and graphs on the selected load shape (see next pages)
- 365x24 – This Tab is the 365 day x 24 hour load shape output in engineering units based on the usage input by the user.
- 8760 – This Tab is the 8,760 hour one-column load shape output in engineering units based on the usage input by the user. Cell E2 allows the user to input a multiplier.
- Calendar – This Tab represents a perpetual calendar, enabling the user to output loads accurately for any year,
- Input Instructions – This Tab provides a means for the user to input target year, units, peak and off-peak season month and hour, and peak period definition

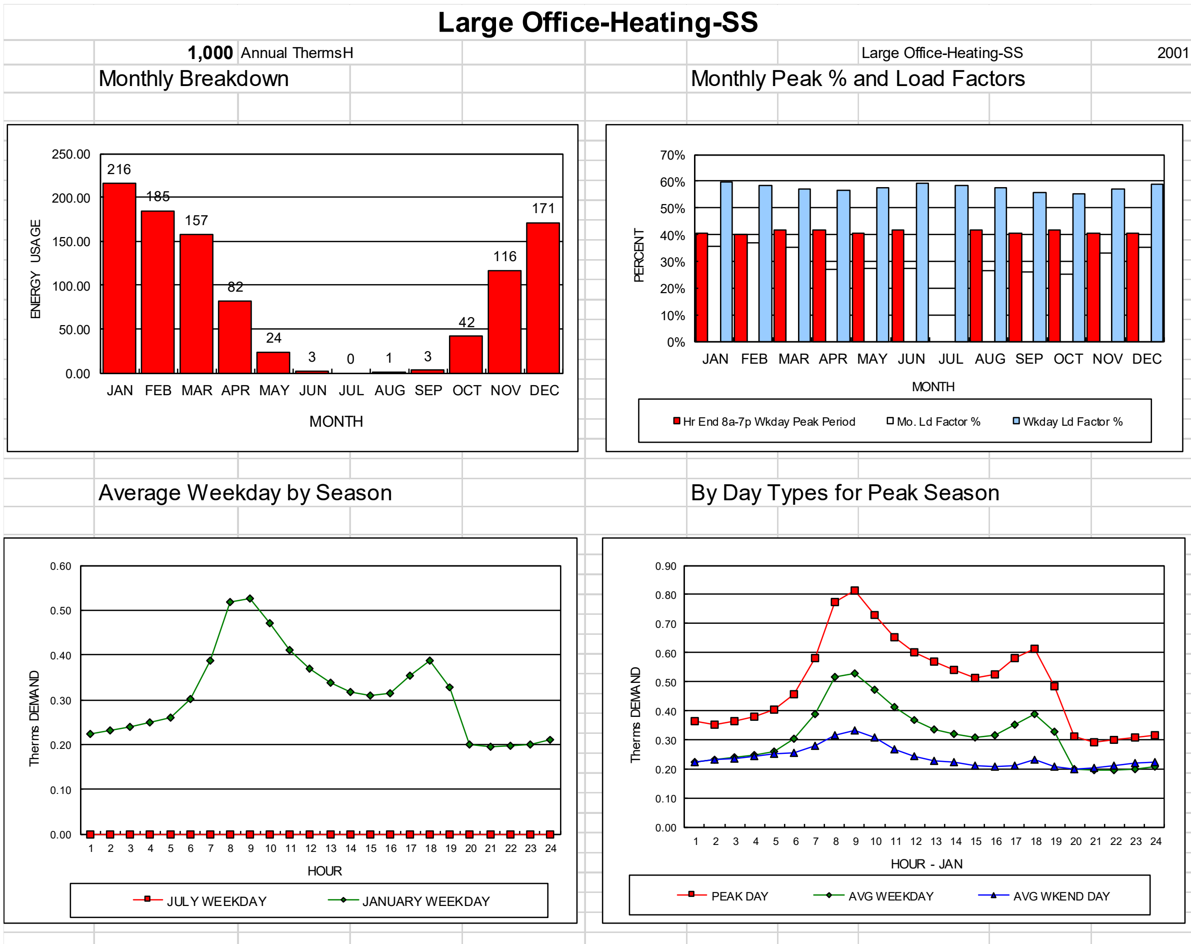
Figure 6-6: LOADLIB Module Summary Reporting Table

	Large Office-Heating-SS				**KPVD-HDD60**		
ENERGY PROFILE SUMMARY:		3	2019	*Large Office-I*	Peak Season	Off-Pk Season	2001
2001	ANNUAL USE:	**1000**	ThermsH	PEAK HR(s)	9	19	
Index	Calculated	998.1177497		PK MONTH(s)	1	12	
1		1000	**AVERAGE**	**AVERAGE**	**NON-COIN**	**COIN**	
	MONTHLY	**PEAK DAY**	**WEEKDAY**	**WEEKEND**	**PEAK**	**PEAK**	
also 16	**USAGE**	**USAGE**	**USAGE**	**USAGE**	**DEMAND**	**DEMAND**	SEAS
JAN	215.91	11.8182	7.5317	5.7487	0.81363	0.81363	P
FEB	184.82	11.2104	7.1444	5.4531	0.74714	0.77178	P
MAR	157.37	8.5432	5.4446	4.1557	0.59765	0.58816	P
APR	82.08	5.8692	2.9346	2.2399	0.42452	0.23926	O
MAY	23.78	1.6594	0.8297	0.6333	0.11751	0.06764	O
JUN	2.51	0.1795	0.0897	0.0685	0.01268	0.00732	O
JUL	0.00	0.0000	0.0000	0.0000	0.00000	0.00000	O
AUG	1.09	0.0755	0.0377	0.0288	0.00553	0.00308	O
SEP	3.23	0.2327	0.1164	0.0888	0.01732	0.00949	O
OCT	41.59	2.8781	1.4390	1.0984	0.22234	0.11732	O
NOV	116.36	6.5832	4.1955	3.2023	0.49070	0.45322	P
DEC	171.26	9.3741	5.9741	4.5599	0.65489	0.64537	P
	Large Office-Heating-SS						
	ANNUAL STATISTICS:						
	AVERAGE DEMAND			**0.1142**	Therms DEMAND		
	PEAK DEMAND			0.8136	Therms	0.814	Therms
	NON-COIN LOAD FACTOR			14.03%			
	NON-COIN PEAK HOURS USE			1229		1229	hrs/yr
						3.37	hrs/day
	COINCIDENT PEAK STATISTICS:					Demand Factor	100.0%
	Peak Season Coincident Peak			**0.8136**	Therms		
	9	AM in JAN					
	ANNUAL COINCIDENCE FACTOR			100.00%		**Peak Day % Annual**	
	PEAK DAY COINCIDENCE FACTOR			100.00%		**1.18%**	
	COIN PEAK LOAD FACTOR			14.03%		**Peak Hour % of Annual**	
	COIN PEAK HOURS USE			**1229**		**0.0814%**	
	Off-Pk Season Coincident Peak			**0.6454**	Therms		
	7	PM in DEC					
	COIN PEAK HOURS USE			**1550**			

Output Graphs:

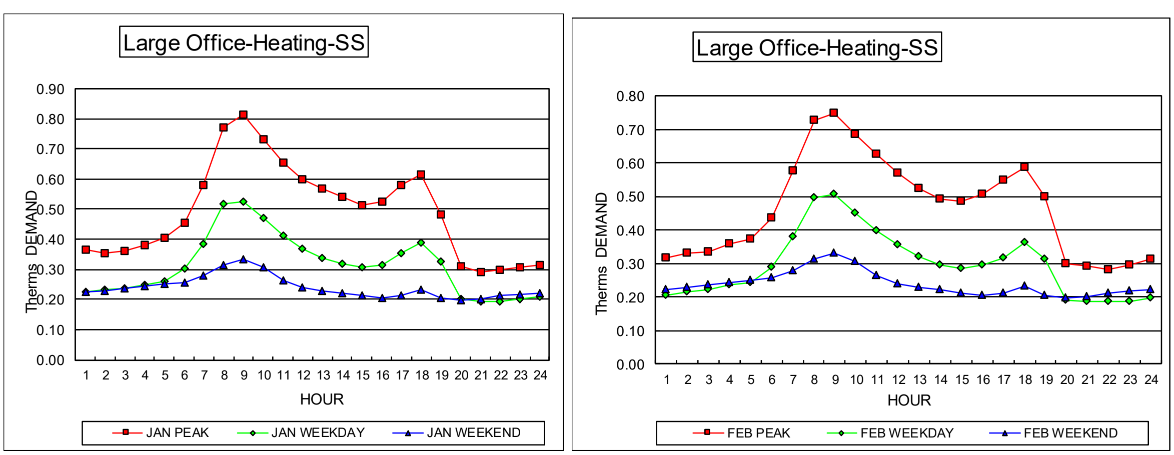
- Monthly Breakdown
- Peak and Load factors/month
- Peak Month/Season Hourly Load Shapes
- Peak, Weekday, and Weekend

Figure 6-7: LOADLIB Module Summary Graphic Outputs



Also: Peak, weekday, and weekend day by month

Monthly peak day, weekday and weekend day



LOADLIB Load Shape Output Generator

Figure 6-8: LOADLIB Module 365x24 Output format

Year	2019		sum	998.11775		1		2001	Large Office-Heating-S		Large Office-Heating-S	
Calendar #	3	1=pk,2=wk,3=wkend, 4=low Day										
Date	Month	DayType	1	2	3	4	5	6	7	8	9	10
1-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
2-Jan-19	1	7	0.309003	0.318656	0.327845	0.343471	0.358656	0.416990	0.533052	0.712978	0.726368	0.648864
3-Jan-19	1	7	0.309003	0.318656	0.327845	0.343471	0.358656	0.416990	0.533052	0.712978	0.726368	0.648864
4-Jan-19	1	6	0.181515	0.187186	0.192583	0.201763	0.210682	0.244949	0.313126	0.418819	0.426685	0.381157
5-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
6-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
7-Jan-19	1	8	0.266507	0.274833	0.282758	0.296235	0.309331	0.359643	0.459744	0.614925	0.626474	0.559628
8-Jan-19	1	1	0.363500	0.352865	0.362744	0.381634	0.404158	0.456921	0.580247	0.771589	0.813626	0.731226
9-Jan-19	1	8	0.266507	0.274833	0.282758	0.296235	0.309331	0.359643	0.459744	0.614925	0.626474	0.559628
10-Jan-19	1	2	0.224011	0.231009	0.237671	0.248999	0.260007	0.302296	0.386435	0.516872	0.526579	0.470392
11-Jan-19	1	8	0.266507	0.274833	0.282758	0.296235	0.309331	0.359643	0.459744	0.614925	0.626474	0.559628
12-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
13-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
14-Jan-19	1	2	0.224011	0.231009	0.237671	0.248999	0.260007	0.302296	0.386435	0.516872	0.526579	0.470392
15-Jan-19	1	2	0.224011	0.231009	0.237671	0.248999	0.260007	0.302296	0.386435	0.516872	0.526579	0.470392
16-Jan-19	1	4	0.096523	0.099539	0.102409	0.107290	0.112033	0.130255	0.166509	0.222713	0.226896	0.202685
17-Jan-19	1	5	0.139019	0.143362	0.147496	0.154526	0.161358	0.187602	0.239818	0.320766	0.326790	0.291921
18-Jan-19	1	2	0.224011	0.231009	0.237671	0.248999	0.260007	0.302296	0.386435	0.516872	0.526579	0.470392
19-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
20-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
21-Jan-19	1	3	0.224015	0.230575	0.235638	0.242770	0.250605	0.256077	0.278044	0.313926	0.332447	0.306092
22-Jan-19	1	6	0.181515	0.187186	0.192583	0.201763	0.210682	0.244949	0.313126	0.418819	0.426685	0.381157
23-Jan-19	1	5	0.139019	0.143362	0.147496	0.154526	0.161358	0.187602	0.239818	0.320766	0.326790	0.291921
24-Jan-19	1	2	0.224011	0.231009	0.237671	0.248999	0.260007	0.302296	0.386435	0.516872	0.526579	0.470392

……

Figure 6-9: LOADLIB Module 8760 1-col. Output format

		Col. Sum	998.11775	998.1177497	
			multiply by:	1	
	2019			Large Office	
Row	Date	Hour		Large Office-Heating-SS-2019	
				Large Office-Heating-SS	
1	1/1/2019	1	0.2240147	0.224014694	
1	1/1/2019	2	0.2305746	0.230574551	
1	1/1/2019	3	0.2356384	0.235638392	
1	1/1/2019	4	0.2427697	0.24276969	
1	1/1/2019	5	0.2506051	0.25060505	
1	1/1/2019	6	0.2560773	0.25607735	
1	1/1/2019	7	0.2780442	0.278044222	
1	1/1/2019	8	0.3139264	0.313926425	
1	1/1/2019	9	0.3324473	0.332447273	
1	1/1/2019	10	0.3060917	0.306091707	
1	1/1/2019	11	0.265798	0.265798041	
1	1/1/2019	12	0.2414463	0.241446262	
1	1/1/2019	13	0.2280092	0.228009184	
1	1/1/2019	14	0.2229461	0.222946062	
1	1/1/2019	15	0.212425	0.212425015	
1	1/1/2019	16	0.206645	0.206645048	
1	1/1/2019	17	0.2125547	0.212554725	
1	1/1/2019	18	0.2321504	0.232150435	
1	1/1/2019	19	0.206359	0.206358953	
1	1/1/2019	20	0.19726	0.19725997	
1	1/1/2019	21	0.2012319	0.201231919	
1	1/1/2019	22	0.2118172	0.211817168	
1	1/1/2019	23	0.2171958	0.217195786	
1	1/1/2019	24	0.2226828	0.222682811	
2	1/2/2019	1	0.3090031	0.309003126	
2	1/2/2019	2	0.3186564	0.318656391	
2	1/2/2019	3	0.3278452	0.327845209	

6.5.4 Operating the LOADLIB Module

The two main modules of the Load Shape Library System consist of linked Excel workbooks that enable the user to perform the following functions:

1. Identify and select the desired load shape
2. Load the selected load shape into the LOADLIB reporting module (LOADS: A5 – red text/yellow highlighted)
3. Choose inputs from the LOADLIB Module / “Input Instructions” Tab (values in Red)
4. Review the tables and graphs (LOADS Tab)
5. Choose the output file format – either 365x24 (365x24 Tab) or 8,760 (8760 Tab, with instructions in red)
6. Output the 8,760 or 365x24 file (copy/paste values)

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter, and greener.