Industrial Load Shape Research

January 29, 2021

Prepared for:

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Executive Summary

Energy Trust of Oregon (Energy Trust) contracted with Cadmus to perform research on options to develop improved estimates of coincident load factors for custom industrial measures without significant additional cost. Currently, Energy Trust estimates peak load impacts using relatively basic standard industrial load shapes provided by the Regional Technical Forum (RTF). The accuracy of these standard load shapes has become an increasingly important issue since load capacity value and its estimation is becoming more relevant in today's electricity marketplace.

Cadmus reviewed documentation supplied by Energy Trust to determine how the organization identifies targets for metering and assigns standard load shapes to prospective measures. This information provided context for comparison between actual and reported load shapes.

Cadmus developed measure-specific load shapes through power metering data from a subset of projects in the 2018-2019 Production Efficiency (PE) impact evaluation sample. We compared each measure-specific metered load shape to the standard RTF load shape assigned to it by Energy Trust. We then developed savings-weighted composite load shapes from all measures associated with each standard load shape. Cadmus also conducted statistical analyses on the error rate between the standard and metered load shapes.

Findings and Recommendations

Cadmus developed the following findings and recommendations through the process of developing load shapes from power metering data and the subsequent data review. We note there are additional areas that may warrant more analysis and additional conclusions beyond those observed in this report.

Load Shape Applicability

Based on the results for the 3-shift and flat load shapes, we consider it reasonable to assume that most non-HVAC measures with annual operating hours in the range of 8,500 to 8,760 would correspond to the flat load shape. The metered data for the measures in the analysis sample showed that they generally operated consistently and continuously throughout the day with little variation. Therefore, operating hour estimates in that range should be sufficient to use the standard flat load shape to estimate peak coincident demand savings without the need to develop and review the metered load shape. The sample did not include a sufficient number of 1-shift or 2-shift measures to determine whether the standard load shapes for those hourly shift profiles should be used going forward.

Cadmus confirmed that data collected by the PE program for custom projects can be used to develop reliable load shapes and savings load shapes when sufficient data are collected. The datasets we reviewed varied from three to 34 days of measurement. We consider two weeks to be the minimum reasonable amount of metering to accurately characterize a system's operation, although we made allowances for measures with only 13 days of metered data.

Cadmus believes that the data collected by the PE program should also be sufficient to develop a reliable peak savings estimate. PDCs conducted metering at various points throughout the year that frequently did not align with peak demand periods. However, most of the measures that we analyzed involved consistent, continuous operation throughout the year. Therefore, we consider it reasonable to assume that the metered load shapes can be used to represent a reasonable estimate of coincident demand savings load factor.

In addition, the load shapes and peak savings estimates can be further improved at relatively little cost by collecting metered data through TAS, verification, and evaluation stages of projects. This should be particularly applicable to 1-shift, 2-shift, and 3-shift load shape types, for which the available datasets for analysis were limited. The two 1-shift load shapes clearly provided data that can be used to better characterize that load shape compared with the original profile through the RTF.

Recommendations:

- Cadmus recommends a minimum metering period of two weeks. Two weeks is typically enough to capture a full production cycle but is again dependent on the type of equipment, production schedule, seasonality, weather, and other factors. For example, HVAC systems may require months of data at longer intervals or multiple metering periods to characterize operation in the shoulder months. PDCs should take these dependencies into consideration whenever metering.
- Cadmus recommends that Energy Trust assign the flat load shape to non-HVAC measures that operate in the range of 8,500 to 8,760 hours per year.
- Cadmus recommends that Energy Trust consider providing further guidance to PDCs on setting load shapes based on ranges of hourly operation, similar to those for the streamlined industrial and lighting tracks. These hourly operating ranges should be specific to the equipment associated with the energy efficiency measure, which may vary from the shifts worked at the facility. Cadmus determined the two 1-shift measures in the analysis sample had annual operating hours that aligned better with the range listed for the lighting track. However, the lighting track suggests 8,000 hours of operation to assign the 3-shift profile, which seems too high based on the analysis data. While we have limited data from which to work, Cadmus recommends that the 3-shift profile would be more appropriate for operating hours in the range of 7,000 hours (roughly 80% of the year). We recommend that equipment operating for 8,000 hours per year be assigned the flat load profile.
- Cadmus also recommends further investigation into the appropriate range of operating hours for assigning hourly shift profiles using metering data collected through previous program years. Further clarity from additional analysis should improve future assignments of hourly shift profiles for custom measures.
- We recommend that Energy Trust conduct additional research on existing and future data to refine composite load shapes for 1-shift, 2-shift, and 3-shift measures. Energy Trust has already obtained substantial data through previous PE program years and projects not included in the 2018-2019 PE impact evaluation sample that could be analyzed. Energy Trust can also obtain an increasingly larger catalog of datasets through future data already required by the program with minimal additional calculation effort. The additional data can then be used to refine the composite load shapes.

Accuracy in Hourly Shift Profiles

The data are currently too limited to determine whether the metered load shapes and peak savings estimates are an improvement over the Energy Trust's previous methods to estimate peak load impacts. The two 1-shift metered load shapes indicated variance from the RTF's 1-shift load shape that should result in improved peak load impact estimation if supported by further metering data. However, the 2-shift and 3-shift load shapes did not align with the streamlined or lighting tracks' recommended annual operating hour ranges, as shown in Table 1 and Table 2. Instead, the nine measures assigned to these load shape types reported operating hours ranging from 8,423 to 8,760, with an average of 8,648. The metering data for all of these measures showed continuous operation of the measure, with occasional variance in demand. The data did not align with the 2-shift and 3-shift load shapes and were actually a better fit for the flat load shape.

Recommendation:

- Energy Trust should consider working with the PDCs to obtain better information about the hourly shift profile for a particular measure to more accurately assign the load shape type. Since peak demand estimates are an increasingly important value, it might be useful for the program to add a field to program documentation that clearly identifies the operating hours expected for the measure. Energy Trust should consider assigning the load shapes based on annual operating hours in a manner that is more consistent with the guidelines for the streamlined or lighting tracks until these hourly shift ranges are approved or updated.

Measurement Guidelines

After reviewing Energy Trust's metering and load shape guidelines, Cadmus found various areas of ambiguity. We recommend enhancing the guidelines to ensure more consistent, high-quality measurement data that can also be used to support load shape development and analysis.

Recommendations:

- Cadmus recommends that Energy Trust update the general guidelines to require a maximum interval length of one minute, although shorter intervals may be appropriate for some systems. We found that the metering data provided in TAS and verification analyses had inconsistent metering intervals. This length is dependent of the equipment being metered. Some equipment may need up to one-second intervals to capture variability. For example, some process motors may only run for 15 seconds at a time and will not be accurately characterized through a one-minute interval.
- When applicable to the project, we also recommend that baseline and verification period metered data should be collected at the same level of detail. Standardizing a methodology that informs PDCs to apply the same metering guidelines for both baseline and verification metering will improve data quality for load shape development. This is particularly important when control strategies are complex and the equipment can be metered in both cases.

HVAC Systems and 8760 Model Data

As noted, we believe the current process is effective for estimating peak coincident demand savings for non-HVAC measures with consistent annual demand and operating hours in the range of 8,400 to 8,760. HVAC-related measures introduce issues with estimating the load shape and peak coincident demand savings if the metering period does not overlap with each utility's peak demand period. It is unlikely that HVAC metering will occur in time periods that will allow Energy Trust to develop load shapes that accurately characterize summer and winter peak savings. However, the PDCs have developed 8,760 models using spot measurements and trend data to characterize the annual operation of industrial HVAC measures.

Recommendation:

- Cadmus recommends that Energy Trust consider the use of 8,760 model data (when supported by spot measurements, power metering, and/or trend data) to inform the load shapes for industrial HVAC measures during the peak demand periods. While these data may not be as accurate as metered data during peak demand periods, it might form the most economically feasible alternative for measures with seasonal variation in load.

Memo

Energy Trust of Oregon

To: Board of Directors

From: Erika Kociolek, Evaluation Sr. Project Manager
Eric Braddock, Sr. Technical Manager – Industry and Agriculture

Date: January 29, 2021

Re: Staff Response to Industrial Load Shape Research

Understanding *when* measures save energy (i.e., estimating peak demand savings) is becoming increasingly important to Energy Trust, particularly for targeted load management (TLM) projects. Currently, Energy Trust does not store peak demand savings in its Project Tracking (PT) system, and only calculates peak demand savings on an ad hoc basis. The Regional Technical Forum (RTF) has standard savings shapes that are assigned to all measures in PT; these can be used to calculate peak demand savings. However, there is uncertainty about their accuracy, particularly for custom measures, which can be highly influential in TLM projects.

This research focused on generating savings shapes for custom measures sampled for the 2018-2019 Production Efficiency impact evaluation, using pre- and post-metering data collected by the program. The savings shapes generated using this data were then compared to the RTF standard savings shapes assigned to those measures. Of the 70 custom measures in the 2018-2019 Production Efficiency impact evaluation, 33 had pre- and post-metering data. Of those, 24 measures had sufficient metering data – i.e., at least 13 days of data in both the pre- and post-metering periods. Most of the 24 measures were assigned the flat (n=13) or 3-shift (n=8) RTF standard savings shapes; only a handful were assigned the 2-shift (n=1) or 1-shift (n=2) RTF standard savings shapes.

The evaluator found that Energy Trust's metering and savings shape guidelines for the custom track could be enhanced to ensure more consistent, high-quality metering data is obtained. The evaluator specifically recommended that Energy Trust provide guidelines to its program delivery contractors (PDCs) regarding metering periods and interval lengths, and instruct the PDCs to assign the flat RTF standard savings shape to non-HVAC measures with annual operating hours of 8,500 to 8,760. The evaluator also concluded that given the extremely small number of measures that were assigned the 2-shift and 1-shift RTF standard savings shapes, more research is needed to assess the extent to which the pre- and post-metering data for these measures agrees with the 2-shift and 1-shift RTF savings shapes. The evaluator noted that the PDCs developed 8,760 models (supported by spot measurements, metering, and/or trend data) to characterize the operation of HVAC measures. This research excluded these measures, but the evaluator recommended using these models to generate load shapes for HVAC measures in the future.

The program is planning to enhance the guidelines provided to its PDCs regarding assigning the RTF standard savings shapes based on hours of operation, which will be informed by the recommendations of this research. The program will also direct its PDCs to install metering for customers with variable or unknown operations, rather than those with consistent operations, to keep verification costs low. Energy Trust evaluation and program staff will revisit replicating this research for a broader set of measures (in particular, those assigned the 2-shift and 1-shift RTF standard savings shapes) in 2022. Currently, there are few custom measures assigned 2-shift or 1-shift profiles, but these may be more common for smaller customers, a group the program anticipates serving in greater numbers in the future.

Background

Energy Trust requested research into better options to estimate kilowatt (demand) impacts of custom industrial measures. Currently, Energy Trust estimates peak load impacts through standard industrial load shapes provided by the RTF. These industrial load shapes are relatively basic. For most manufacturing loads, they assume a relatively flat load shape dependent on the number of shifts assumed for a manufacturing facility. The accuracy of these load shapes has become an increasingly important issue since load capacity value and its estimation is becoming more relevant in today's electricity marketplace. Energy Trust contracted with Cadmus to perform research to determine if alternative methods might provide improved estimates of coincident load factors economically. At the same time as this study, Cadmus was performing Energy Trust's 2018-2019 PE impact evaluation, and was therefore familiar with Energy Trust's data and program implementation processes, as well as load shapes, savings shapes, and peak savings.

Production Efficiency Program

The PE program provides incentives for agricultural and industrial energy efficiency measures using the following tracks:

- Custom
- Streamlined
- Strategic Energy Management (SEM)

The industrial load shape research focused on whether there are better methods to estimate demand impacts (in kilowatts) of custom industrial measures. As noted, the current method of estimating peak load impacts relies on the industrial load shapes provided by the RTF.

Research Objectives

For this task, the research objectives were to determine whether:

- Data currently collected by the PE program for custom projects is sufficient to:
  - Develop reliable load shapes for a site and/or end use
  - Develop reliable savings shapes for measures at a site and/or end use
  - Develop a reliable peak savings estimate (coincident savings load factor)
- The load shapes, savings shapes, and peak savings estimates could economically be improved with the collection of additional data during the technical analysis study (TAS), verification, and/or evaluation phases of projects
- If the load shapes, savings shapes, and peak savings estimates are a significant improvement over the methods currently employed to estimate peak load impacts

Research Tasks

Cadmus completed the following tasks to meet the research objectives:

- Gathered and reviewed existing industrial load shapes currently used by Energy Trust
- Reviewed existing PE program implementation processes, as they pertained to custom measures that required metering and/or a TAS
- Reviewed custom projects completed in 2018 and 2019 associated with a TAS, with a focus on categorizing end uses (e.g., compressed air, process pump) and summarizing data commonly collected as part of the TAS and verification phases (e.g., hours of operation, metered data)
- Selected a representative sample of projects based on common end uses, where the project was deemed to have sufficient metering data to construct an end use-level load shape
- Generated load shapes and savings load shapes for the sample of projects
- Contrasted and compared the load shapes of the sample with the load shapes currently used by Energy Trust
- Developed a statistical analysis to compare the error rate between composite metered load shapes and the standard load shape types used by Energy Trust
- Determined if site-level qualitative data such as operation schedules may also be used as a proxy to estimate peak load impacts
- Made recommendations on the viability of estimating peak impacts and what, if any, changes could be made to the TAS or project verification processes that could potentially lead to improving the peak savings estimates

More specific detail on the methods and findings from these tasks can be found in the following sections.

Metering and Load Shape Implementation Review

Cadmus reviewed documentation supplied by Energy Trust to determine how the organization identifies targets for metering, develops load shapes, and assigns standard load shapes to prospective measures. This documentation included the following resources:

- *Guide to Load Profiles in Custom Workbook*
- *PE Program Custom Project Baseline Energy Guideline*
- *Load Profiles Lookup List*[1]

Measurement Methodology

Energy Trust developed the *PE Program Custom Project Baseline Energy Guideline* in part to determine if metering was necessary based on variations in baseline type and the project type. The baseline variations were retrofit, new construction, incremental change, equipment end of life, and unavailable systems (i.e., irrigation during off-season). Energy Trust further categorized projects as either simple or complex. They recommended measurement for baselines for the following systems:

- Complex projects with many variables
- Savings greater than 250,000 kWh
- Incentives greater than $20,000

Energy Trust also noted that inputs should include electrical power in kilowatts and that additional inputs should be measured whenever possible. Cadmus was unable to find specific details in the guideline as to what the measured methodology determined was sufficient for characterizing energy consumption. It appeared the term *measured* could describe spot measurements, power metering, and any other data monitored over time (i.e., production data). The guidance also did not provide recommendations on the measurement period of duration or metering interval.

Load Shape Assignment

Energy Trust provided further guidance in the *Guide to Load Profiles in Custom Workbook*. If annual hours of operation did not align with any hourly profile but the measure was related to production, the guide instructed users to select “facility type profile” or “flat” if no match existed. For weather dependent measures that were not related to production, the guide instructed users to select the appropriate non-refrigerated “warehouse profile” or “flat” if no match existed.

The *Guide to Load Profiles in Custom Workbook* did not provide a breakdown of the annual hours of operation for assigning the hourly shift profiles on custom measures. Energy Trust instructed PDCs to assign profiles based on the shift delineation, as shown in Table 1.

1 Included in email from Kirsten Svaren to Eric Braddock on September 24, 2020.

Table 1. Load Profile Assignments for Custom Track

Load Profile	Load Profile Description
1-shift industrial	1 shift operation
2-shift industrial	2 shift operation
3-shift industrial	3 shift operation: holidays/weekends off
Flat	24/7 operation

Energy Trust did provide a *Load Profiles Lookup List* that outlined how load shapes should be selected for the streamlined industrial and lighting tracks based on the annual hours, facility type, and dependency on weather or production. Table 2 and Table 3 show the breakdown of load profiles based on annual hours for the streamlined industrial and lighting tracks, respectively.

Table 2. Load Profile Assignments for Streamlined Industrial Track

Hours	Load Profile	Load Profile Description
0	1-shift industrial	1 shift operation
1,500	1-shift industrial	1 shift operation
4,160	2-shift industrial	2 shift operation
6,240	3-shift industrial	3 shift operation: holidays/weekends off
8,760	Flat	Continual electric operation: 24 hours/day, 365 days/year
8,760	Ag-Irrigation	Irrigation
	Flat	Flat gas operation

Table 3. Load Profile Assignments for Lighting Track

Hours	Load Profile	Load Profile Description
<3,500	1-shift industrial	1 shift operation
<5,500	2-shift industrial	2 shift operation
<8,000	3-shift industrial	3 shift operation: holidays/weekends off
8,760	Flat	Continual electric operation: 24 hours/day, 365 days/year

Load Shape Analysis

Cadmus performed Energy Trust's 2018-2019 PE impact evaluation. As part of that effort, we had access to the metering data used to develop the reported baseline and retrofit savings estimates for the projects and measures sampled for the impact evaluation. We reviewed the available data to generate measure-specific load shapes where sufficient data were available.

Sampling

Energy Trust's current method of estimating peak load impacts relies on the standard industrial load shapes provided by the RTF. Energy Trust assigned these load shapes to each project and provided them to Cadmus. The load shapes consisted of four primary profiles: 1-shift, 2-shift, 3-shift, and flat.

Cadmus reviewed custom measures included in the 2018-2019 PE impact evaluation to determine if the PDC provided sufficient metering data to generate a reasonable load shape. Table 4 provides more detail on the data availability for the measures we reviewed.

Table 4. Data Availability for Custom Measures in 2018-2019 PE Impact Evaluation

Data Availability	Number of measures
Custom measures evaluated for 2018-2019 PE impact evaluation	70
Custom measures with power metering data	33
Custom measures with at least 13 days of data	**24**
Custom measures with modeled 8760 data	9

In general, we considered 14 days of data to be sufficient, although we made exceptions for several projects with only 13 days of data. The measures involved a variety of industrial process applications, such as compressed air, process heating, pumps, and fans. Twenty-four measures of that set had at least 13 days' worth of data, so we developed load shapes for them. However, PDCs and contractors conducted metering over various time periods, so the data did not necessarily coincide with the dates of peak demand.

We also found that the PDCs had developed annual modeled consumption estimates of power consumption (8,760 models) for a subset of measures without power metering. These measures generally involved weather-dependent systems, such as process cooling and HVAC. The 8,760 model data occasionally relied on spot measurements or trend data from energy management systems to establish operational parameters. While not as accurate as power metering data, this type of information might be useful in future load shape analyses. Cadmus did not further investigate at this time since the study focused on load shapes generated from power metering data.

Load Shape Development

Cadmus developed load shapes for each of the 24 measures that had 13 or more days of data. Of the 24 measures, two were 1-shift, one was 2-shift, eight were 3-shift, and 13 were flat profiles. Some measures had metering data in the baseline and retrofit periods. In the cases where data were missing in one period, we modeled the missing data by creating a new dataset (pre or post) based on the evaluated energy savings calculation methodology.

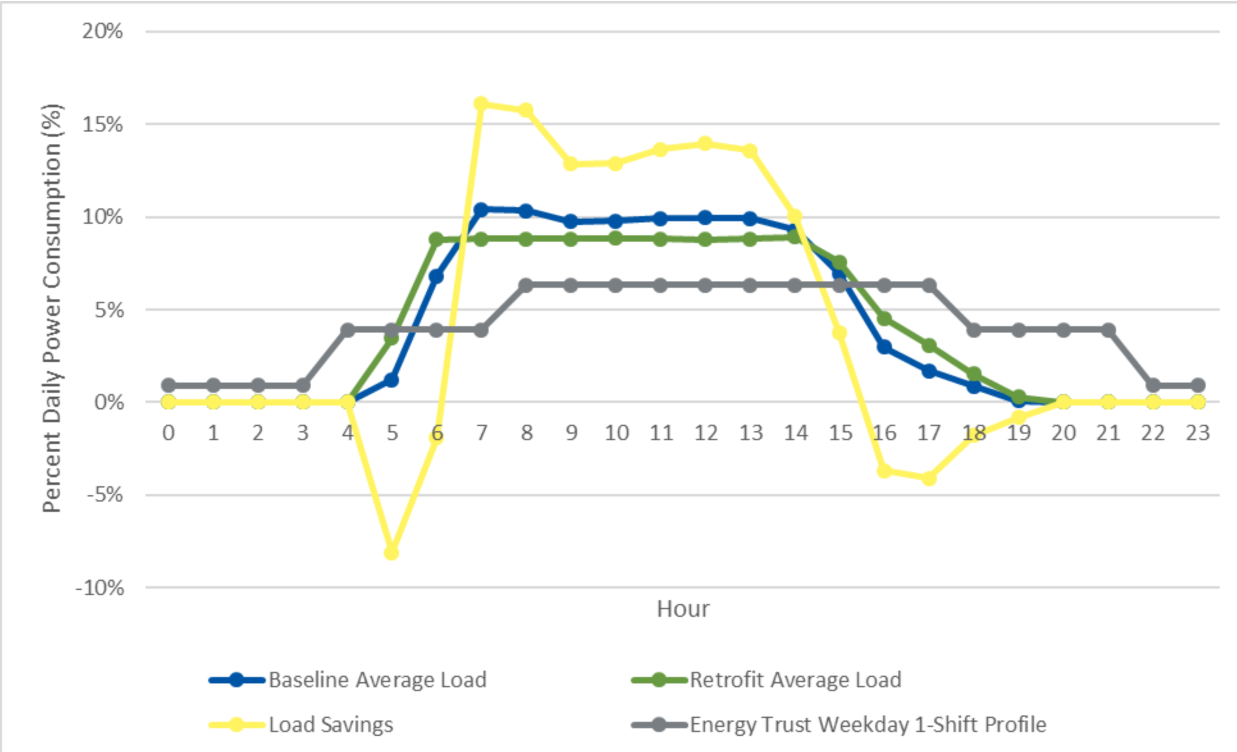
The metering and modeled data used to inform the load shapes for each measure ranged from minute-level to hour-level increments. Regardless of the metering interval, Cadmus aggregated these data to hourly increments to develop load shapes. We calculated and categorized the average load for each hour of the day in the baseline period and the retrofit period. We then represented the data as a percentage of the total daily load at each hour, where the daily load was calculated as the sum of the average load at each hour. We represented savings similarly, where we calculated the average load savings as the difference between the baseline and retrofit average load at each hour, and then represented them as a percentage of total daily savings at each hour.

The following sections provide comparisons between metered and standard load shapes. For each standard load shape, we selected one or more projects to display the complexity and diversity of measures and highlight differences with metered data.

1-Shift Load Shape

Figure 1 displays an example of the 1-shift load shape. It shows the load shapes for comparison between the 1-shift load shape assigned by Energy Trust and the baseline, retrofit, and savings load shapes based on metered data for measure ID 5319345. This measure involved the installation of VFDs on a curing oven fan and additional burner controls. The measure reported 2,914 annual hours of operation, equal to 33% of the annual operating hours possible. Those operating hours are reasonable for assigning the 1-shift hourly profile.

Figure 1. Measure ID 5319345 Load Shapes (1-Shift)



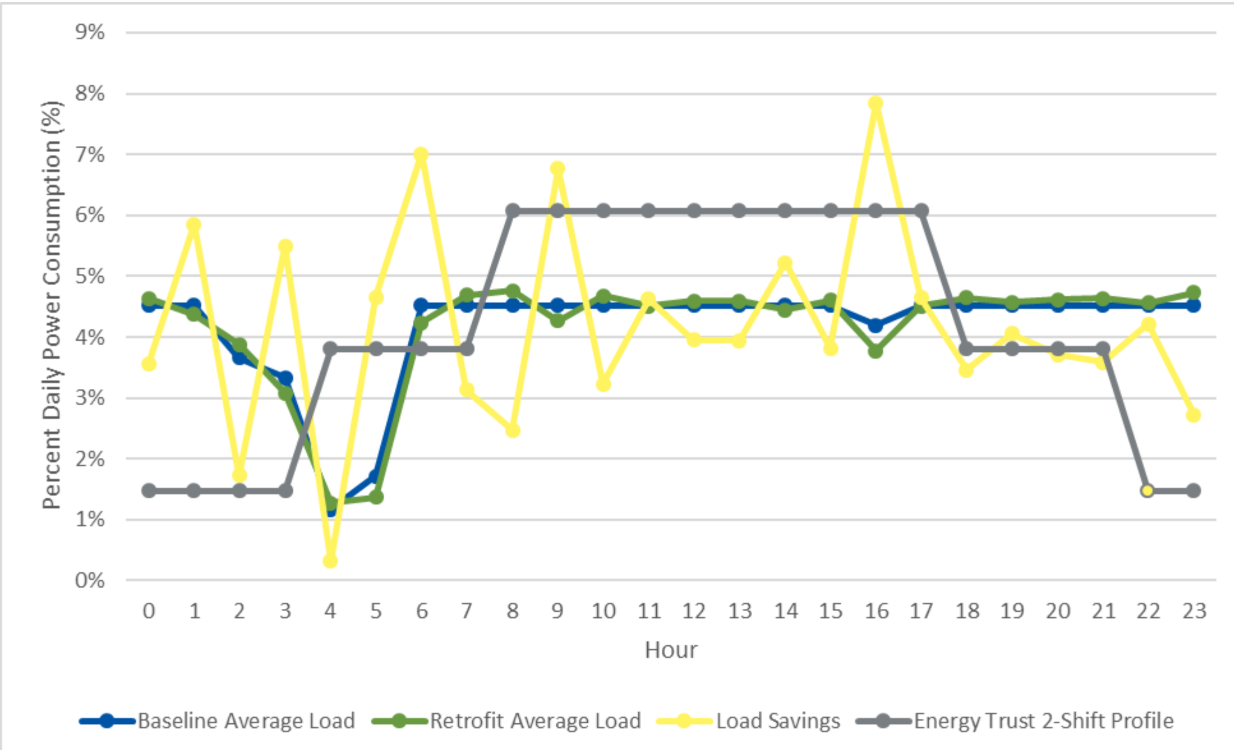
The PDC conducted 14 days of data power metering on this measure in both the baseline and retrofit periods. The hours of operation for the measure aligned somewhat with the highest peak of the Energy Trust load shape. However, the metered data showed the measure started and ended operation earlier and at consistently higher load than the standard 1-shift load shape.

For this particular measure, the participant adjusted the schedule for when the load occurred. The metered data showed a sustained maximum load from approximately 6:00 am to 2:30 pm each day, roughly equivalent to an eight-hour shift. The baseline operation started later and ramped down sooner than the retrofit case, which resulted in negative demand savings (i.e., increased power demand) during those times. This had a large effect on the composite 1-shift load shape shown in Figure 6 due to the low sample of 1-shift measures for this study. Despite that variation in schedule, the baseline and retrofit load shapes are well aligned. The measure achieved demand savings during the period of time in which the baseline and retrofit operation overlapped.

2-Shift Load Shape

The single 2-shift measure in the sample, measure ID 4775125, reported 8,423 annual hours of operation for lathe line upgrades to a diverter. Cadmus would expect a typical 2-shift measure to report annual operating hours in the range of 5,840, far less than this measure. Indeed the metered data for this measure showed some power draw for each hour of the day due to a constant load even during periods when the equipment was idle, shown in Figure 2. The constant load meant that the measure's load shapes did not align well with the reported 2-shift load shape. The energy efficiency measure resulted in a reduction in energy consumption, but the baseline and retrofit load shapes aligned closely. The savings load shape appeared highly variable because it represented minor increases and decreases in demand over the course of the 24-hour operating cycle. Due to the low sample of 2-shift measures, the composite 2-shift load shape consisted of just measure ID 4775125.

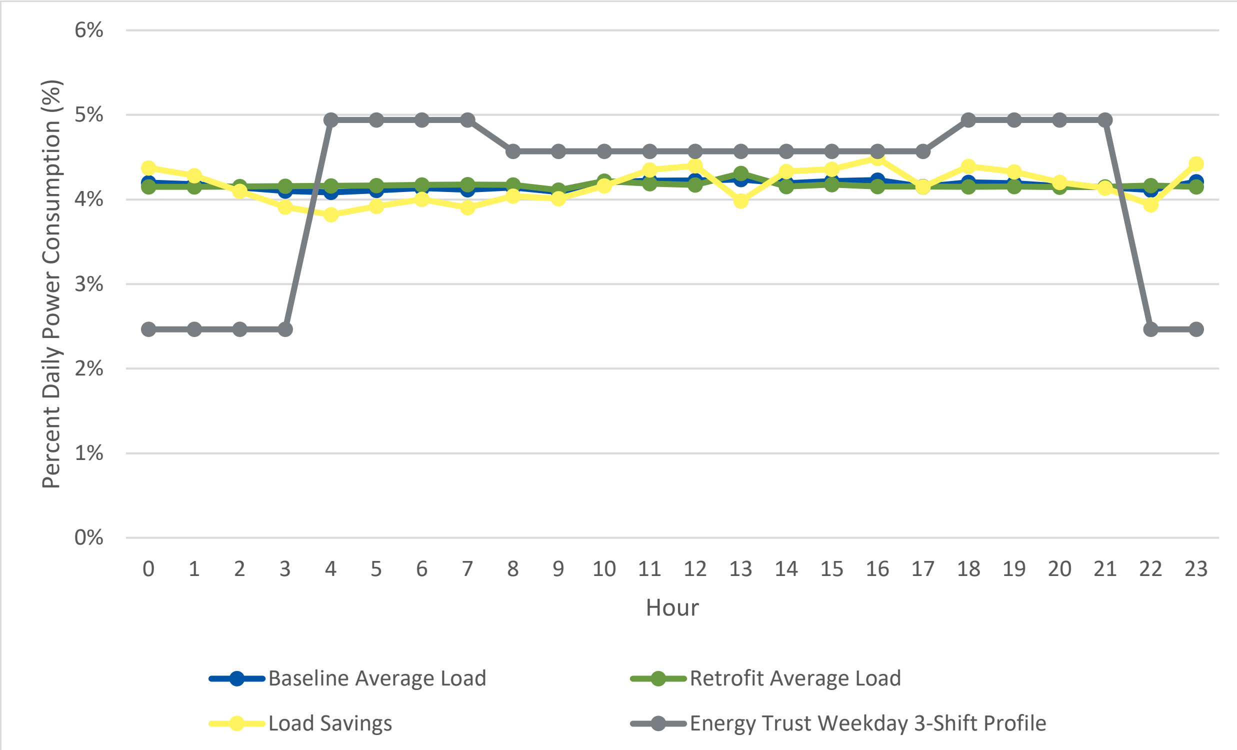
Figure 2. Measure ID 4775125 Load Shapes (2-Shift)



3-Shift Load Shape

Cadmus would expect a typical 3-shift measure to report annual operating hours in the range of 6,000 to 8,000 hours. The average annual operating hours for the eight 3-shift custom measures with metered data was 8,676, which is in the range expected for the flat standard load shape. Indeed, the load shapes for most of the 3-shift measures resembled a flat load shape with continuous operation, such as measure ID 5364146 in Figure 3. As a result, the composite 3-shift load shape Cadmus developed resembled the flat profile as well, as shown in Figure 7.

Figure 3. Measure ID 5364146 Load Shapes (3-Shift)



Flat Load Shape

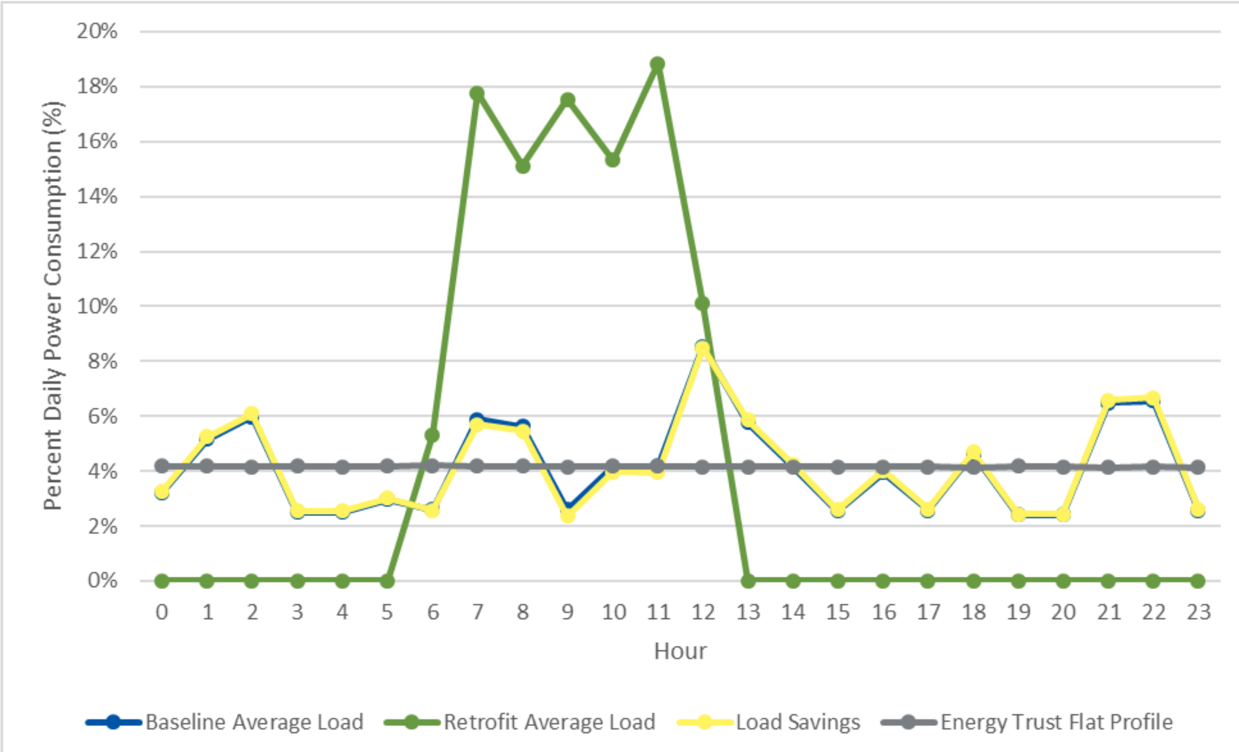
Measures assigned with a flat load shape had various profiles depending on the end use and measure. The average annual operating hours for the 13 measures assigned a flat load shape was 8,700, only slightly different from the 3-shift average annual hours.

Figure 4 displays the shape for measure ID 5280233, a desiccant dryer with demand-based controls measure that operates 24 hours per day, 7 days per week, and 12 months per year with a 15-day maintenance period where it is shut off. The metering data resembles a flat shape as expected for equipment that runs continuously.

Figure 4. Measure ID 5280233 Load Shapes (Flat)

However, measure ID 4327153, a shut-down timer measure for an air compressor, was also assigned the flat profile. The metering data showed the measure resulted in a retrofit load shape that more closely resembles a 1-shift load shape. Despite this, the baseline operated continuously, so the savings load shape would still be appropriate for the flat load shape. Note that the measure reduced demand by 98%, which is the reason the savings load shape so closely aligns with the baseline load shape.

Figure 5. Measure ID 4327153 Load Shapes (Flat)



Composite Load Shapes

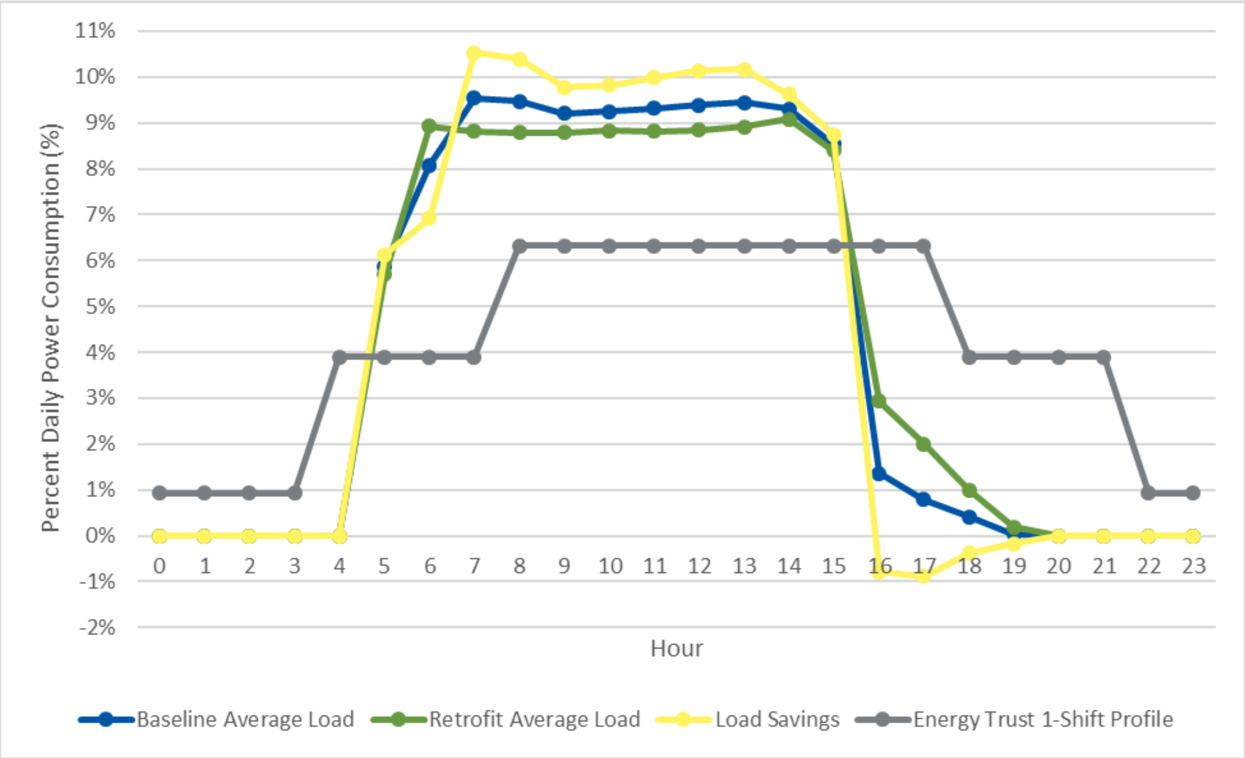
While the individual project results provided interesting detail for analysis, Cadmus and Energy Trust determined that a composite load shape would provide better detail for comparability. For each of the four standard load shapes, Cadmus also developed a savings-weighted composite load shape. To calculate these load shapes, we first summed the total power demand by hour for the retrofit, baseline, and savings for all measures sharing the same standard load shape reported by Energy Trust. We then divided the demand for each hour by the total demand over the full 24-hour period to calculate the portion of daily consumption by hour. This enabled us to generate the savings-weighted composite load shape.

1-Shift Composite Load Profile

The sample only included two 1-shift measures, so the load profile is not truly representative. The two measures reported annual operating hours of 2,914 and 3,854. As noted previously, measure ID 5319345 showed increased demand at the beginning and end of each shift (Figure 1.). This had a large effect on the composite 1-shift load shape shown in Figure 6 due to the low sample of 1-shift measures for this study.

It is not reasonable to draw meaningful results from a sample of only two measures. However, the results indicate the standard 1-shift load shape generally overlapped with the highest portion of load in the metered data, although not during the later peak demand times after 4:00 pm. In contrast to the standard load shape, the metered load shape showed zero load outside the regular operating hours and a higher peak during operation. Additional metering data from past and/or future measures assigned to the 1-shift load shape or with a similar range of operating hours could provide further clarity on the appropriate load profile.

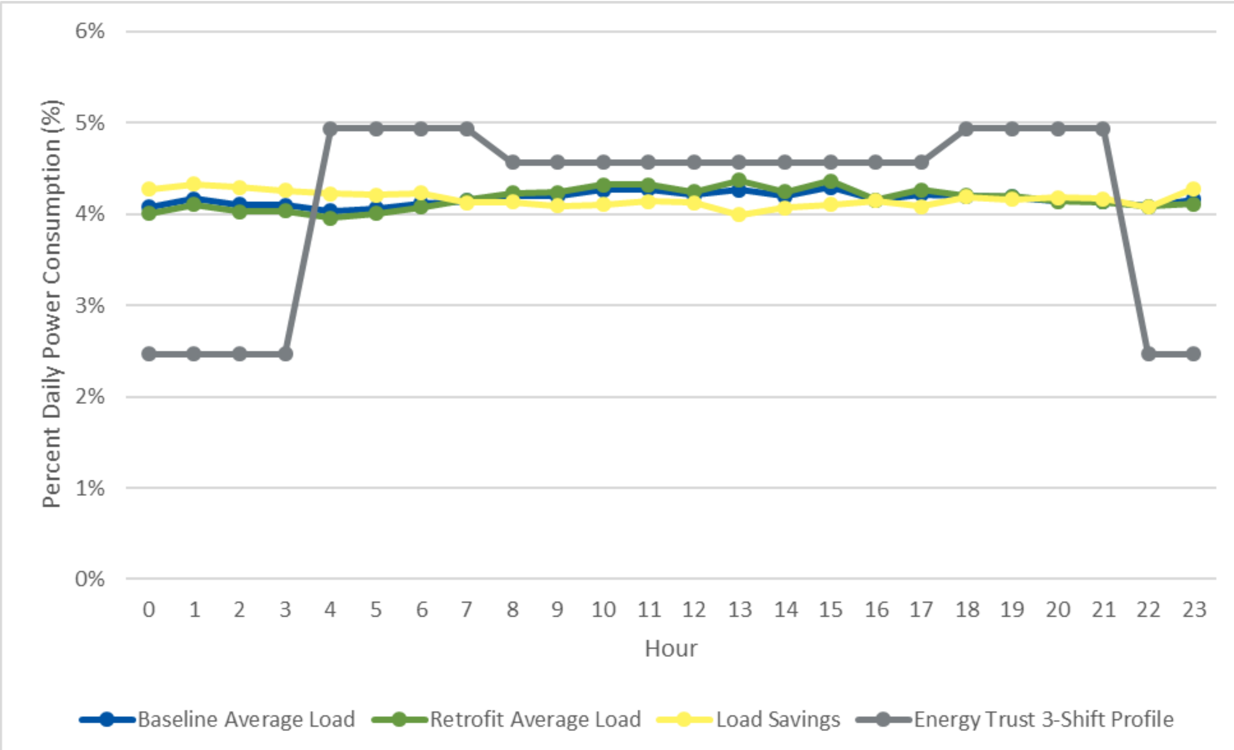
Figure 6. Composite 1-Shift Load Shape



3-Shift Composite Load Profile

Energy Trust assigned eight of the 24 measures as 3-shift load shapes. However, these measures reported average operating hours of 8,676, indicating nearly continuous operation. The metered data supported that assumption, with a nearly flat profile for the baseline, retrofit, and savings load shapes of most measures. As a result, the composite load shapes were nearly flat, as shown in Figure 7. Based on the average operating hours, it is likely these measures should have been originally assigned to the flat load shape. As with the 1-shift composite load shape, additional metering data from past and/or future measures assigned to the 3-shift load shape or with operating hours in the range of 6,000 to 8,000 could provide further clarity on the appropriate load profile.

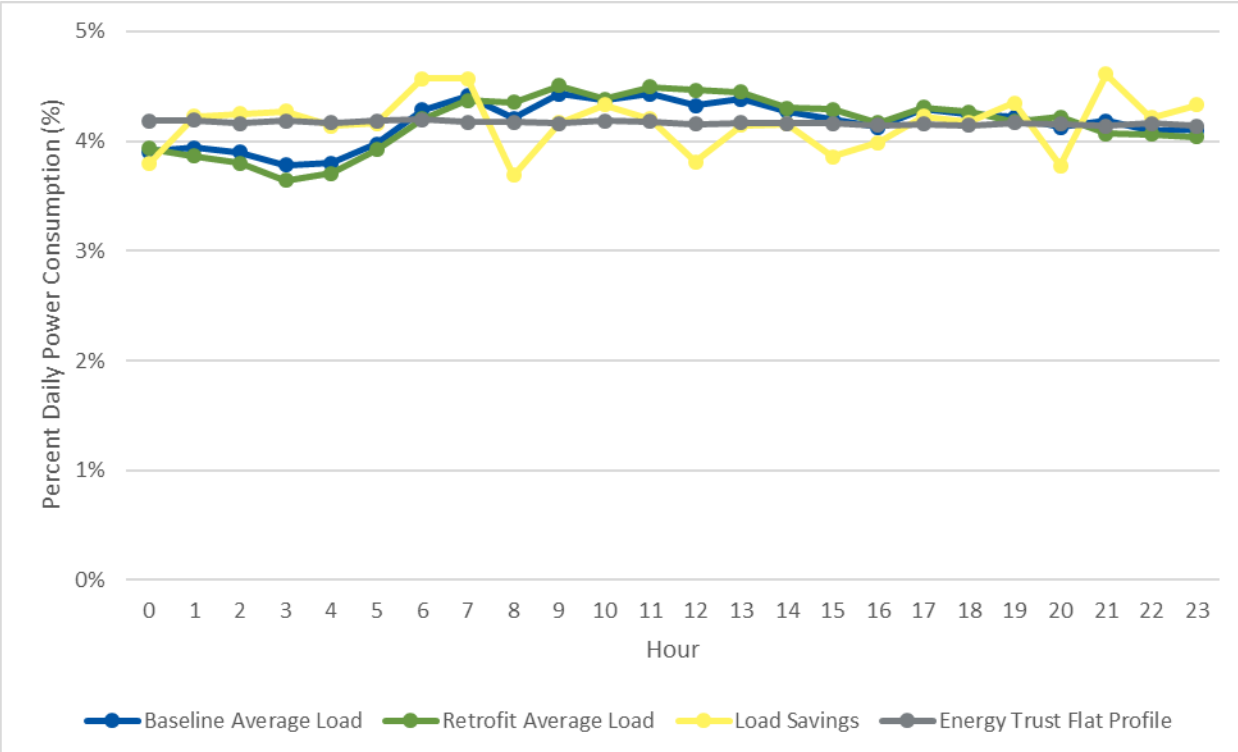
Figure 7. Composite 3-Shift Load Shape



Flat Composite Load Profile

Energy Trust assigned 13 of the 24 measures analyzed the flat load shape. These measures reported average operating hours of 8,700, implying nearly continuous operation. Two projects changed load shape to one that more closely resembled a 1-shift load shape in the retrofit case, but the savings-weighted composite for retrofit and savings were still nearly flat. As a result of measures with some variance, Cadmus' composite load shape for the flat profile varied slightly from Energy Trust's flat profile (shown in Figure 8).

Figure 8. Composite Flat Load Shape

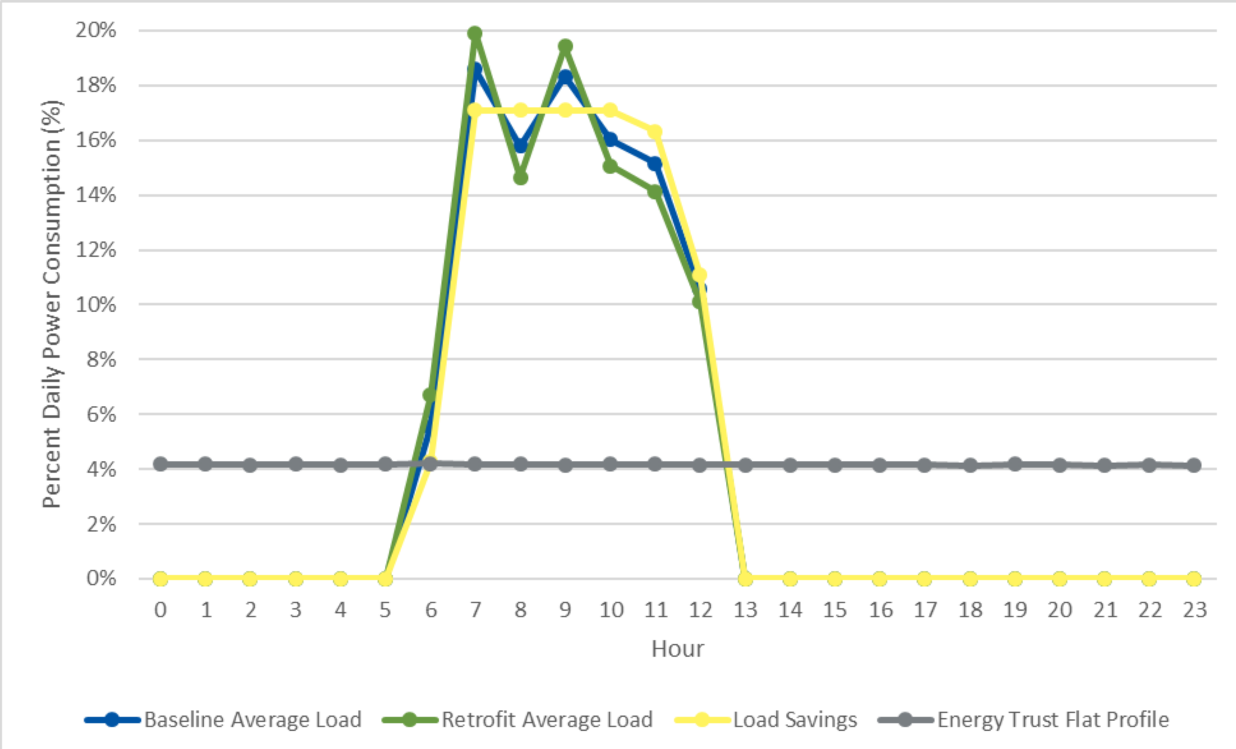


Operating Hour Analysis

Cadmus reviewed each measure's reported annual hours of operation and its relation to the reported load profile. Between the 3-shift and flat profile measures, Cadmus found two 3-shift measures and four flat profile measures that reported less than 8,700 annual hours of operation. These measures varied in load shapes, such as measure ID 4327153 shown in Figure 5, which reported 8,592 annual hours of operation. The retrofit period is shown as having no power draw between 1:00 pm and 5:00 am, as this measure was a shut-down timer installation. However, the baseline and savings load shape for this measure have a continuous power draw throughout the day and a flat load shape may have been the best fit as demonstrated by the savings load shape.

Only one of the six measures with annual operating hours less than 8,700 showed a baseline without continuous operation. That measure, 4327157, was installed on the same compressed air system as the one mentioned previously, 4327153. The retrofit load profile from 4327153 (Figure 5) represented the baseline for 4327157 (Figure 9). This more closely resembles the 1-shift load shape. However, it would not have been reasonable for Energy Trust to assign a 1-shift load shape based on the reported continuous air compressor operation as the system baseline.

Figure 9. Measure ID 4327157 Load Shapes (Flat)



Measure ID 4327157 was the only anomaly of this type among the measures with the standard flat load shape. The other five measures showed continuous operation sufficient to support the assignment of the flat load shape.

Statistical Analysis

Cadmus conducted a statistical analysis comparing the actual composite load shape values (we refer to these as actual or metered load shapes) for each type against the four standardized load shape profiles reported by Energy Trust.

For each of the four load shape types, Cadmus analyzed the statistical differences for the following three metered profiles:

- Baseline (pre-period consumption)
- Retrofit (post-period consumption)
- Savings (pre-post difference)

To characterize the alignment between the metered and reported load shapes, Cadmus first calculated the error in each hour as the Energy Trust reported consumption value minus the metered consumption value.[2] Then, we calculated three summary metrics to characterize the hourly errors:

- Mean absolute error (MAE)
- Root mean square error (RMSE)
- Median error

MAE and RMSE are measures of prediction accuracy, with a smaller value indicating that the prediction errors are smaller in magnitude. RMSE correlates closely with MAE, but it penalizes larger errors more heavily than MAE.

Median error is a measure of prediction bias, indicating whether the Energy Trust load shapes tend to overpredict or underpredict over the course of the day. A positive value indicates that overpredictions occur in a majority of hours, while a negative value indicates underpredictions in a majority of hours.

Table 3 shows the results for each of the 12 comparisons by each of these metrics.

2 All hourly consumption values normalized to percentage of daily consumption.

Table 5. Statistical Comparison Metrics*

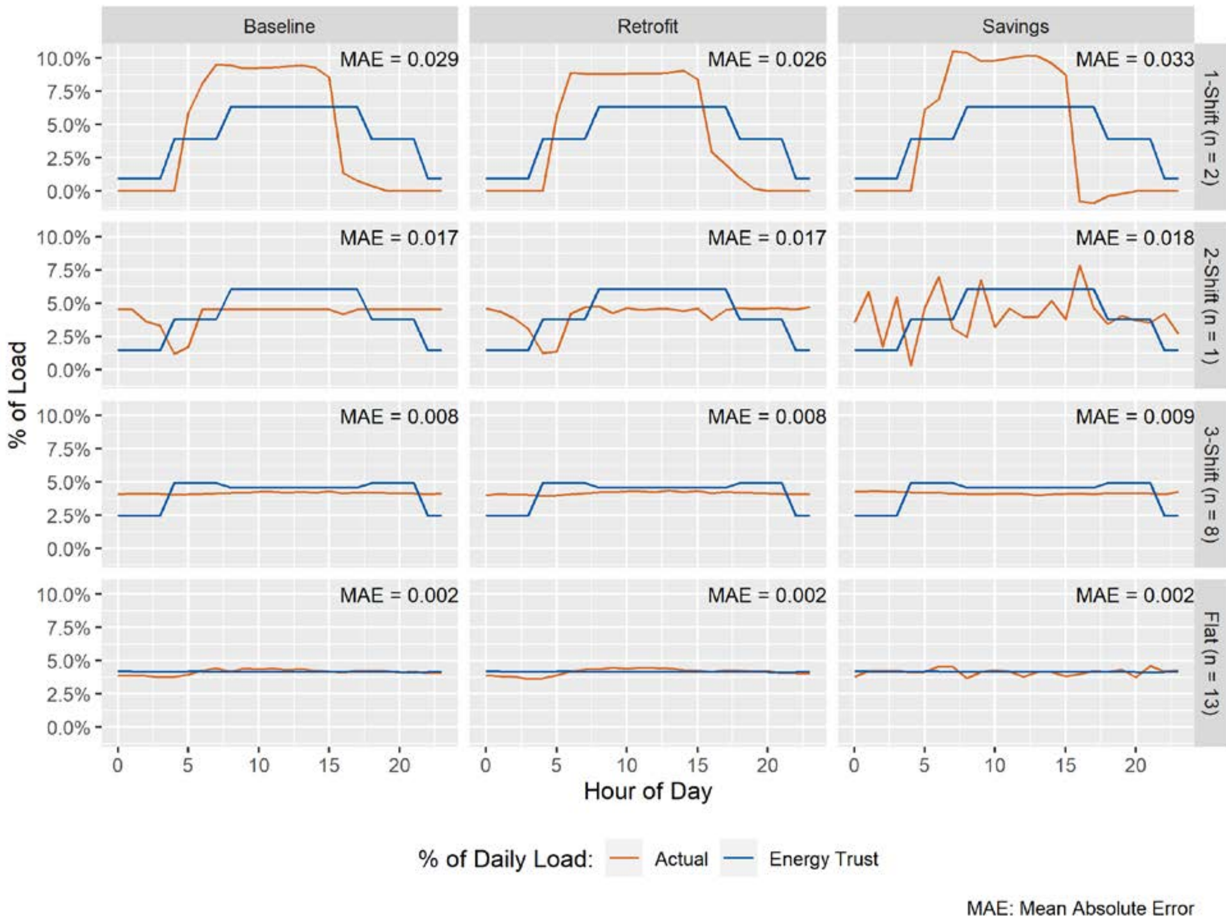
Load Shape Type	Metered Shape Type	Number of Projects	MAE	RMSE	Median Error
1-Shift	Baseline	2	0.029	0.160	5.354
1-Shift	Retrofit	2	0.026	0.143	1.651
1-Shift	Savings	2	0.033	0.186	-0.355
2-Shift	Baseline	1	0.017	0.092	0.092
2-Shift	Retrofit	1	0.017	0.094	0.087
2-Shift	Savings	1	0.018	0.108	0.044
3-Shift	Baseline	8	0.008	0.048	0.085
3-Shift	Retrofit	8	0.008	0.047	0.076
3-Shift	Savings	8	0.009	0.051	0.114
Flat	Baseline	13	0.002	0.010	-0.010
Flat	Retrofit	13	0.002	0.012	-0.010
Flat	Savings	13	0.002	0.012	-0.006

*For MAE and RMSE, smaller values are better. For median error, positive values indicate that overpredictions occur in a majority of hours, while negative values indicate underpredictions in a majority of hours – closer to zero is better.

We recommend using MAE as the primary metric for evaluating load shape alignment because it is a somewhat more intuitive measure than RMSE and, in the analysis sample, the two values were very highly correlated (r = 0.999). Generally, the Energy Trust flat load shapes aligned well with the metered shapes. The error metrics indicate progressively worse alignment for the 3-shift, 2-shift and 1-shift load shapes, respectively. However, due the small sample size in the 1-shift and 2-shift types, the results are inconclusive.

Figure 10 depicts the metered and Energy Trust load shapes for each of the 12 comparisons and the associated MAEs.

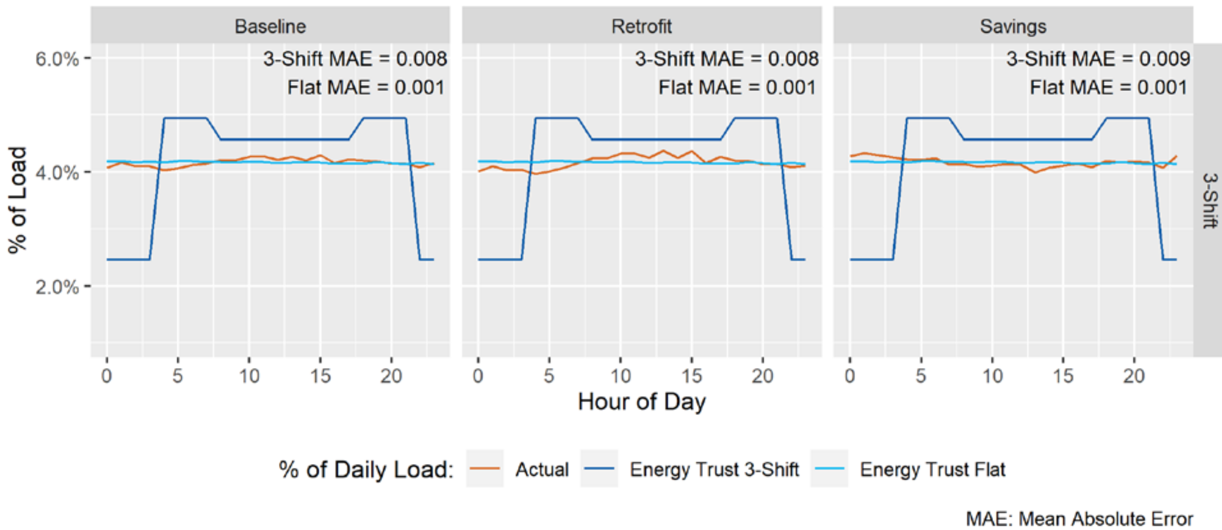
Figure 10. Actual Load vs. Energy Trust Profile



As noted above, the statistical analyses for the 1-shift and 2-shift composite metered load shapes indicate a relatively high level of error compared with the 3-shift and flat load shapes. These composite metered load shapes are based on small samples (two and one measure, respectively). Therefore, we do not consider the results meaningful for those two load shapes until a larger sample size can be analyzed.

Due the apparent flatness of the metered 3-shift load shape, Cadmus further investigated the similarities between the actual results from the 3-shift composite metered load shape and Energy Trust's flat load shape. Figure 11 shows the results of this comparison.

Figure 11. 3-Shift Load Comparison



The MAE estimates between the metered shape and the flat Energy Trust shape are meaningfully smaller than the MAE between metered shape and the 3-shift Energy Trust shape. The statistical analysis shows that the 3-shift composite metered load shape more closely aligns with Energy Trust's flat load shape than the 3-shift Energy Trust load shape.

Findings and Recommendations

Cadmus developed the following findings and recommendations through the process of developing load shapes from power metering data and the subsequent data review. We note there are additional areas that may warrant more analysis and additional conclusions beyond those observed in this report.

Load Shape Applicability

Based on the results for the 3-shift and flat load shapes, we consider it reasonable to assume that most non-HVAC measures with annual operating hours in the range of 8,500 to 8,760 would correspond to the flat load shape. The metered data for the measures in the analysis sample showed that they generally operated consistently and continuously throughout the day with little variation. Therefore, operating hour estimates in that range should be sufficient to use the standard flat load shape to estimate peak coincident demand savings without the need to develop and review the metered load shape. The sample did not include a sufficient number of 1-shift or 2-shift measures to determine whether the standard load shapes for those hourly shift profiles should be used going forward.

Cadmus confirmed that data collected by the PE program for custom projects can be used to develop reliable load shapes and savings load shapes when sufficient data are collected. The datasets we reviewed varied from three to 34 days of measurement. We consider two weeks to be the minimum reasonable amount of metering to accurately characterize a system's operation, although we made allowances for measures with only 13 days of metered data.

Cadmus believes that the data collected by the PE program should also be sufficient to develop a reliable peak savings estimate. PDCs conducted metering at various points throughout the year that frequently did not align with peak demand periods. However, most of the measures that we analyzed involved consistent, continuous operation throughout the year. Therefore, we consider it reasonable to assume that the metered load shapes can be used to represent a reasonable estimate of coincident demand savings load factor.

In addition, the load shapes and peak savings estimates can be further improved at relatively little cost by collecting metered data through TAS, verification, and evaluation stages of projects. This should be particularly applicable to 1-shift, 2-shift, and 3-shift load shape types, for which the available datasets for analysis were limited. The two 1-shift load shapes clearly provided data that can be used to better characterize that load shape compared with the original profile through the RTF.

Recommendations:

- Cadmus recommends a minimum metering period of two weeks. Two weeks is typically enough to capture a full production cycle but is again dependent on the type of equipment, production schedule, seasonality, weather, and other factors. For example, HVAC systems may require months of data at longer intervals or multiple metering periods to characterize operation in the shoulder months. PDCs should take these dependencies into consideration whenever metering.
- Cadmus recommends that Energy Trust assign the flat load shape to non-HVAC measures that operate in the range of 8,500 to 8,760 hours per year.

- Cadmus recommends that Energy Trust consider providing further guidance to PDCs on setting load shapes based on ranges of hourly operation, similar to those for the streamlined industrial and lighting tracks. These hourly operating ranges should be specific to the equipment associated with the energy efficiency measure, which may vary from the shifts worked at the facility. Cadmus determined the two 1-shift measures in the analysis sample had annual operating hours that aligned better with the range listed for the lighting track. However, the lighting track suggests 8,000 hours of operation to assign the 3-shift profile, which seems too high based on the analysis data. While we have limited data from which to work, we recommend that the 3-shift profile would be more appropriate for operating hours in the range of 7,000 hours (roughly 80% of the year). We recommend that equipment operating for 8,000 hours per year be assigned the flat load profile.
- Cadmus also recommends further investigation into the appropriate range of operating hours for assigning hourly shift profiles using metering data collected through previous program years. Further clarity from additional analysis should improve future assignments of hourly shift profiles for custom measures.
- We recommend that Energy Trust conduct additional research on existing and future data to refine composite load shapes for 1-shift, 2-shift, and 3-shift measures. Energy Trust has already obtained substantial data through previous PE program years and projects not included in the 2018-2019 PE impact evaluation sample that could be analyzed. Energy Trust can also obtain an increasingly larger catalog of datasets through future data already required by the program with minimal additional calculation effort. The additional data can then be used to refine the composite load shapes.

Accuracy in Hourly Shift Profiles

The data are currently too limited to determine whether the metered load shapes and peak savings estimates are an improvement over the Energy Trust's previous methods to estimate peak load impacts. The two 1-shift metered load shapes indicated variance from the RTF's 1-shift load shape that should result in improved peak load impact estimation if supported by further metering data. However, the 2-shift and 3-shift load shapes did not align with the streamlined or lighting tracks' recommended annual operating hour ranges, as shown in Table 1 and Table 2. Instead, the nine measures assigned to these load shape types reported operating hours ranging from 8,423 to 8,760, with an average of 8,648. The metering data for all of these measures showed continuous operation of the measure, with occasional variance in demand. The data did not align with the 2-shift and 3-shift load shapes and were actually a better fit for the flat load shape.

Recommendation:

- Energy Trust should consider working with the PDCs to obtain better information about the hourly shift profile for a particular measure to more accurately assign the load shape type. Since peak demand estimates are an increasingly important value, it might be useful for the program to add a field to program documentation that clearly identifies the operating hours expected for the measure. Energy Trust should consider assigning the load shapes based on annual operating hours in a manner that is more consistent with the guidelines for the streamlined or lighting tracks until these hourly shift ranges are approved or updated.

Measurement Guidelines

After reviewing Energy Trust's metering and load shape guidelines, Cadmus found various areas of ambiguity. We recommend enhancing the guidelines to ensure more consistent, high-quality measurement data that can also be used to support load shape development and analysis.

Recommendations:

- Cadmus recommends that Energy Trust update the general guidelines to require a maximum interval length of one minute, although shorter intervals may be appropriate for some systems. We found that the metering data provided in TAS and verification analyses had inconsistent metering intervals. This length is dependent of the equipment being metered. Some equipment may need up to one-second intervals to capture variability. For example, some process motors may only run for 15 seconds at a time and will not be accurately characterized through a one-minute interval.
- When applicable to the project, we also recommend that baseline and verification period metered data should be collected at the same level of detail. Standardizing a methodology that informs PDCs to apply the same metering guidelines for both baseline and verification metering will improve data quality for load shape development. This is particularly important when control strategies are complex and the equipment can be metered in both cases.

HVAC Systems and 8760 Model Data

As noted, we believe the current process is effective for estimating peak coincident demand savings for non-HVAC measures with consistent annual demand and operating hours in the range of 8,400 to 8,760. HVAC-related measures introduce issues with estimating the load shape and peak coincident demand savings if the metering period does not overlap with each utility's peak demand period. It is unlikely that HVAC metering will occur in time periods that will allow Energy Trust to develop load shapes that accurately characterize summer and winter peak savings. However, the PDCs have developed 8,760 models using spot measurements and trend data to characterize the annual operation of industrial HVAC measures.

Recommendation:

- Cadmus recommends that Energy Trust consider the use of 8,760 model data (when supported by spot measurements, power metering, and/or trend data) to inform the load shapes for industrial HVAC measures during the peak demand periods. While these data may not be as accurate as metered data during peak demand periods, it might form the most economically feasible alternative for measures with seasonal variation in load.