Ontario Energy Board | Commission de l'énergie de l'Ontario

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Appendix A to Staff Report to the Board

Staff Analysis of Hourly Residential and General Service Customer Data

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Structure of this Appendix

The purpose of this appendix is to, in combination with Appendix B, describe the analysis that staff, or consultants working on behalf of staff, have undertaken to better understand the alternative distribution rate designs that have been proposed in the Staff Report to the Board on Rate Design for Commercial and Industrial Electricity Customers. This appendix has been structured into the following sections:

> Section A provides an overview of the residential and general service consumption data that was collected as part of this project.
>
> Section B provides details on an analysis staff performed to generalize over 100,000 GS < 50 kW consumers average daily load profiles using a statistical clustering algorithm.
>
> Section C investigates how sample GS < 10 kW and GS 10 to 50 kW consumers will be impacted by OEB staff's recommended rate designs, and examines the consumption and load characteristics of negatively impacted customers in both groups.
>
> Section D provides details on an additional bill impact analysis performed by staff, in order to determine whether certain types of businesses might be impacted more than others under the proposed rate designs.

A – Summary of the Data

Tables 1 through 5 contain summary information on the hourly residential and commercial customer data that was collected as part of the rate design project. Each table is broken down by customer class and each row within a table reports the number of customers, average monthly consumption in kWh, average monthly peak demand in kW, and time period for each distributor sample.

Hourly consumption information on close to 109,000 general service customers was collected, for the purposes of calculating bill impacts. This sample of customers represents approximately 22% of the total general service customer population[1].

[1] Based on the OEB's 2017 Yearbook of Electricity Distributors

Table 1: Residential summary information

Distributor	Number of Customers	Average Monthly Consumption in kWh	Average Maximum Demand in kW	Data Year
Hydro One Brampton	125,215	758	5.1	2015-2016
Hydro One	261,660	1,014	6	2015-2016
PowerStream	311,865	798	5.1	2015-2016
Toronto Hydro	1,500	642	4.3	2012
Veridian	92,366	750	5	2015
Total	791,194			

Table 2: General Service Less Than 10 kW summary information

Distributor	Number of Customers	Average Monthly Consumption in kWh	Average Maximum Demand in kW
Entegrus	2,675	942	4.1
Hydro One	61,118	896	3.7
PowerStream	12,122	1,142	4.6
Orangeville	722	1,107	4.5
Toronto Hydro	1,136	1,058	4.4
Total	77,773		

Table 3: General Service 10 to 50 kW summary information

Distributor	Number of Customers	Average Monthly Consumption in kWh	Average Maximum Demand in kW
Entegrus	1,126	5,937	19.7
Hydro One	18,468	5,290	18
PowerStream	5,305	5,573	19.8
Orangeville	278	9,121	26.1
Toronto Hydro	278	4,622	14.9
Total	25,455		

Table 4: General Service Less Than 50 kW summary information

Distributor	Number of Customers	Average Monthly Consumption in kWh	Average Maximum Demand in kW	Data Year
Entegrus	3,802	2,415	8.7	2015
Hydro One	79,586	1,902	7	2014
PowerStream	17,427	2,491	9.2	2014
Orangeville	1,000	3,958	10.4	2015
Toronto Hydro	1,414	1,759	6.4	2012
Total	103,125			

Table 5: General Service Greater Than 50 kW summary information

Distributor	Number of Customers	Average Monthly Consumption in kWh	Average Maximum Demand in kW	Data Year
Entegrus	332	76,453	211	2015
Enersource	432	406,119	819	2014
Hydro One	691	93,795	199	2014
PowerStream	650	262,228	577	2014
Toronto Hydro	3,971	189,901	417	2012
Total	6,140			

B – Cluster Analysis of GS < 50 kW Average Daily Load Profiles

In order to better understand the varying daily consumption patterns that occur within the GS < 50 kW class at the individual level, staff use a statistical algorithm, to group customers into more generalizable daily load shapes.[i]

Results of Cluster Analysis

The range of assessed values for k (from 2 to 6) support the identification of four general types of GS <50 kW customer:

Type 1: Generally Flat load

Regardless of the level of k, a large proportion of sample GS < 50 kW customers, roughly between 55% to 67%, fall under cluster A which is a fairly flat average load profile, that increases, and eventually reaches its peak sometime between 5 pm and 10 pm.

Types 2 and 3: Strong and Weak Daily Peaking

Across a range of k values, another discernible subgroup consists of customers with daily peaks. Cluster B (when k = 2 or 6), C (if k = 4 or 5), and D (if k = 6) contain groups of customers that gradually increase their electricity consumption early in the day, between 5 am and 6 am, and peak sometime in the early afternoon. Depending on the grouping these customers either begin to decrease usage (C) or continue to use the same amount of electricity for several hours and then decrease usage (B when k = 6). Roughly 22% to 27% fall within cluster B and 9% and 11% of customers fall within cluster C.

Type 4: Evening/Nocturnal Activity

A fourth type of customer captures GS < 50 kW customers that operate at night rather than during the day (Cluster C (if k = 3), D (k = 4 or 5), and E (k = 6)). These customers, on average, appear to increase electricity usage around 4 pm, peaking sometime between 9pm and 10pm. Cluster D for k = 4 or 5 appears bi-modal, electricity consumption gradually begins to increase at between 7 am and 8 am, peaking once at noon and then again between 4 and 5 pm and begins to decrease thereafter. Roughly 5.5% to 6.5% of customers fall within this cluster.

Only .07% of customers fall into cluster E (when k = 5) or F (if k = 6). These customers use a majority of their electricity between 4 pm and 12 am and peak sometime between 8 pm and 10 pm

Figure 1 presents the main results of this analysis for a value of k = 4.

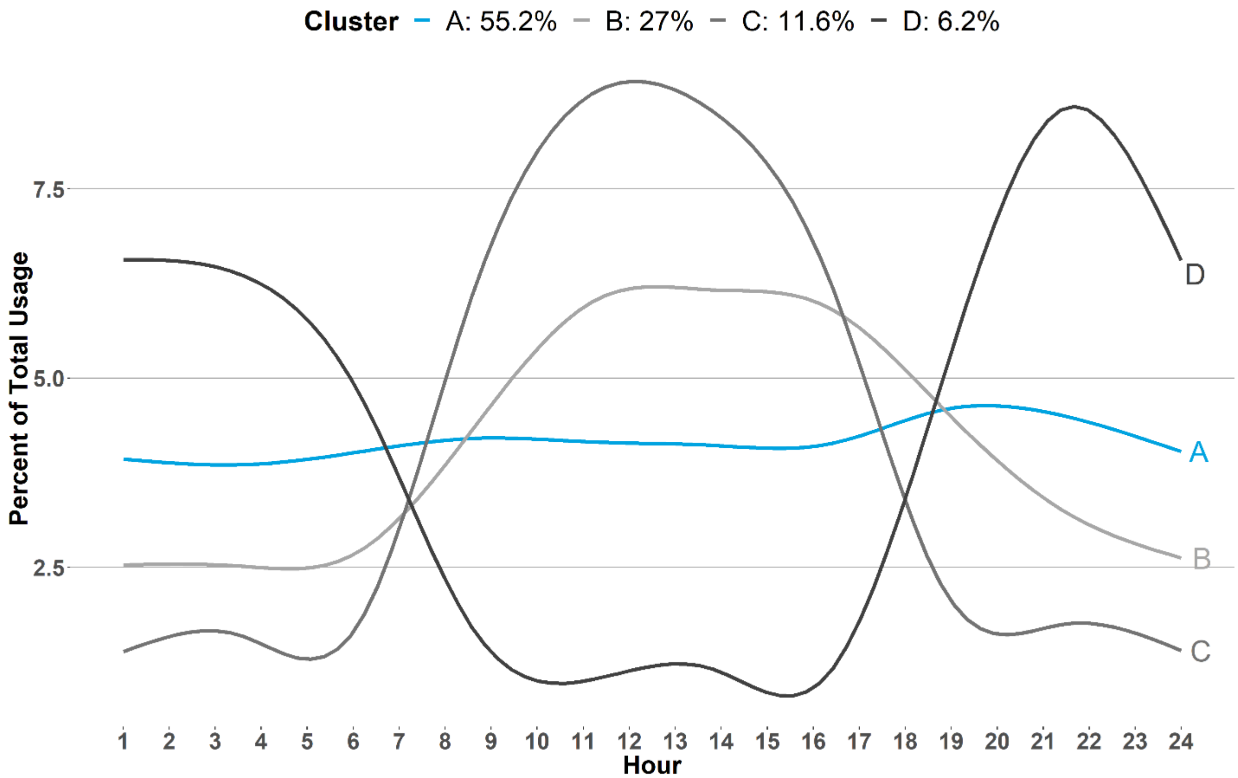

Figure 1 Generalized average daily load patters of GA<50 consumers for k=4

Table 6: Average monthly consumption and peak demand for k = 4

Cluster	Average Monthly Consumption in kWh	Average Monthly Peak Demand in kW
A	2,139	7.4
B	2,340	9.2
C	1,273	7.6
D	1,115	8.2

Figures 2 through 5 present values of k = 2, 3, 5, and 6. Figures 2, 3, and 1 (in that order) show the addition of each of the various types discussed previously, in particular the size, as a percent of total customers, for each of these groups is quite larger, greater than 5%. Figures 4 and 5 present groupings of generalizable load curves for k = 5 and 6. At this level an unusual grouping presents itself that is also a small as a percent of total customers, only .07%. It appears that increasing from k = 4 to k = 5 does not produce any substantial new groupings; however, increasing from k = 5 to k = 6 does, the new D cluster.

Average monthly consumption and peak demand values are calculated in Tables 6 through 10 for each of the generalized load profiles. Clusters A and B appear to consume almost twice as much as other cluster groupings. Average monthly consumption for cluster groupings E and F is remarkably low, compared to the other cluster groupings that are identified.

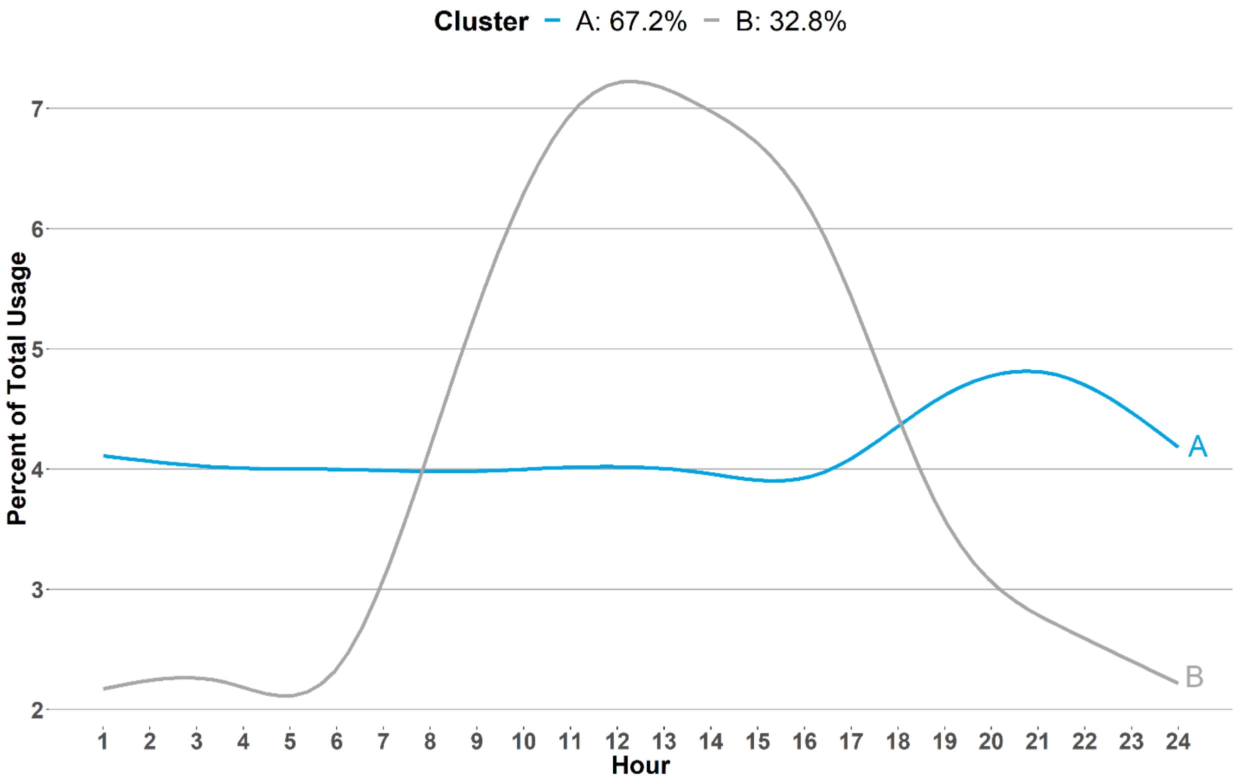

Figure 2: Generalized average daily load paters of GS<50 kW consumers for k=2

Table 7: Average monthly consumption and peak demand for k = 2

Cluster	Average Monthly Consumption in kWh	Average Monthly Peak Demand in kW
A	2,095	7.7
B	1,964	8.7

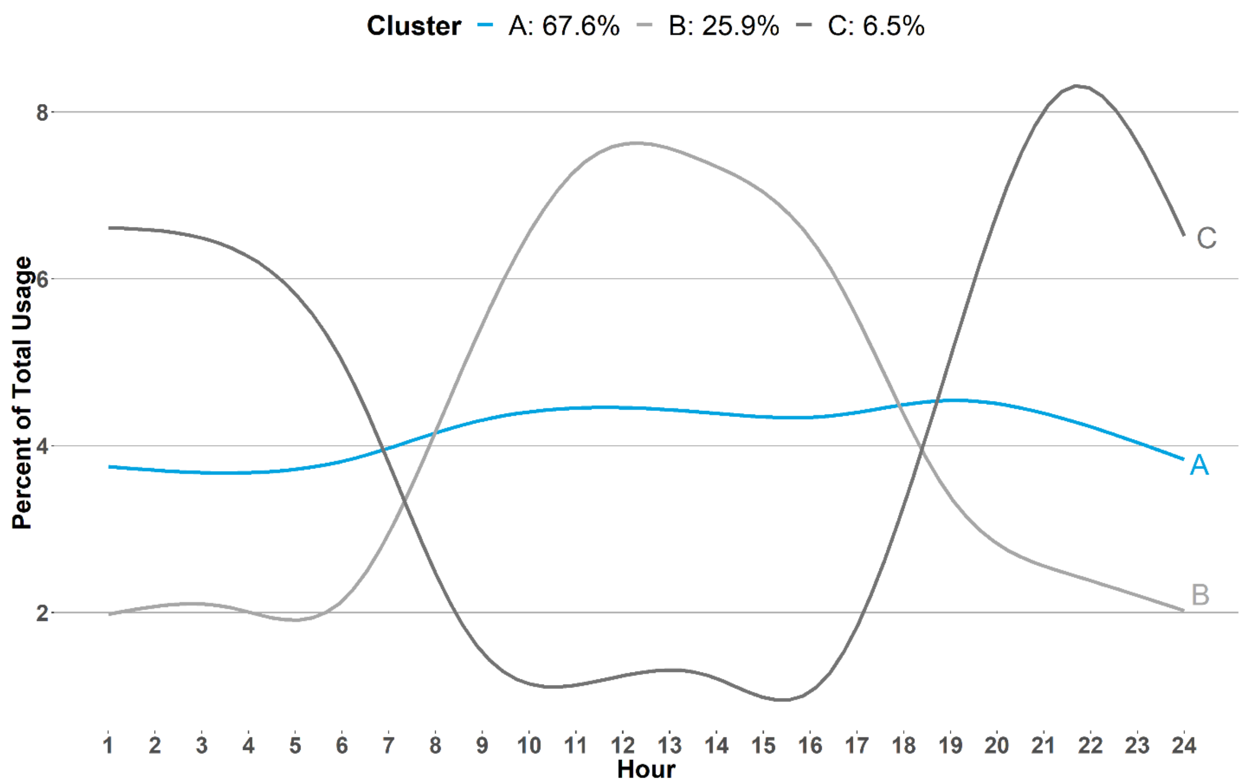

Figure 3: Generalized average daily load patters of GS < 50 kW consumers for k = 3

Table 8: Average monthly consumption and peak demand for k = 3

Cluster	Average Monthly Consumption in kWh	Average Monthly Peak Demand in kW
A	2,232	7.8
B	1,818	8.5
C	1,113	7.9

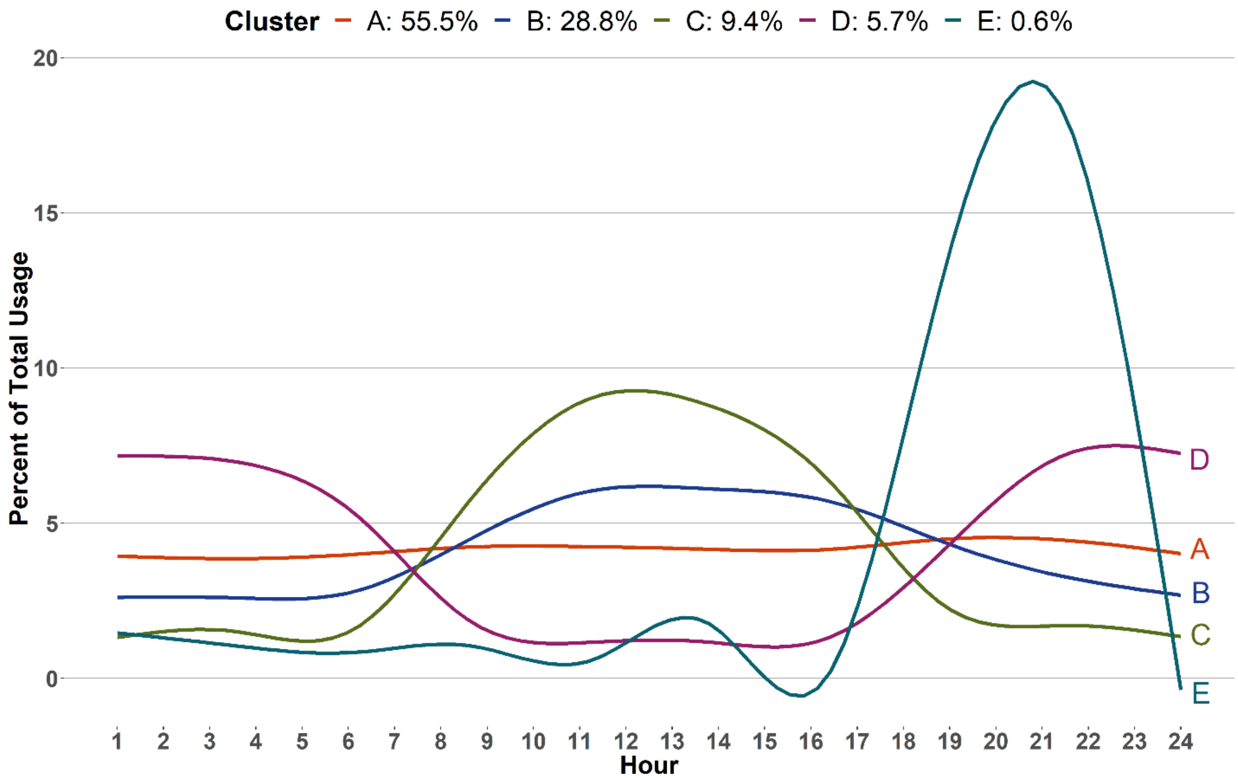

Figure 4: Generalized average daily load patterns of GS < 50 kW consumers for k = 5

Table 9: Average monthly consumption and peak demand for k = 5

Cluster	Average Monthly Consumption in kWh	Average Monthly Peak Demand in kW
A	2,145	7.5
B	2,336	9.2
C	1,268	7.6
D	1,186	7.9
E	362	8.6

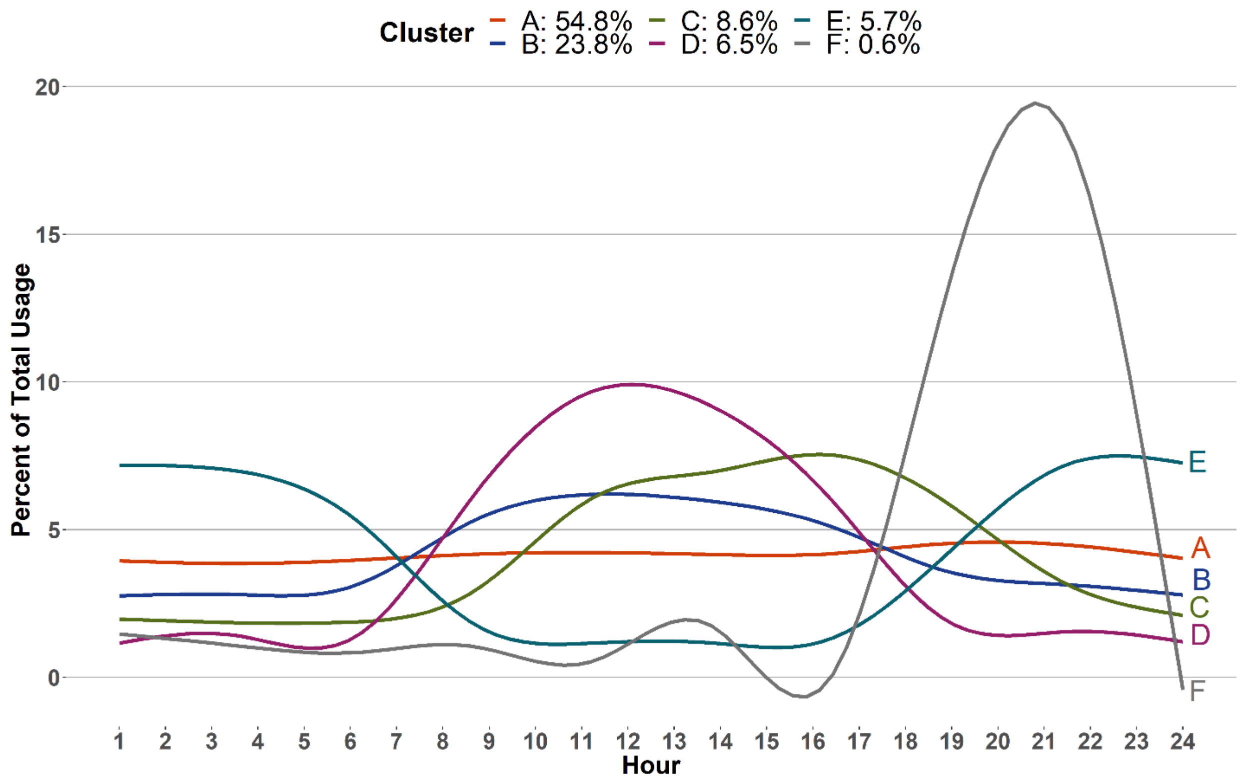

Figure 5: Generalized average daily load patterns of GS < 50 kW consumers for k = 6

Table 10: Average monthly consumption and peak demand for k = 6

Cluster	Average Monthly Consumption in kWh	Average Monthly Peak Demand in kW
A	2,158	7.5
B	2,346	9.3
C	1,936	8.5
D	1,127	7.1
E	1,183	7.9
F	367	8.8

C – Bill Impact Analysis

This section examines bill impacts across the entire GS < 10 kW and GS 10 – 50 kW sample. This analysis characterizes the impacted GS < 10 kW and GS 10 – 50 kW groups by their average daily load shapes and various mean statistics. A comparison is made between those characteristics and the information produced in the previous section. An additional analysis is performed on the GS 10 – 50 kW customer group, to better understand consumers who experience the top 1% of total bill increases, defined in both dollar and percent terms.

C.1 - General Service Less than 10 kW

The top right, and bottom left and right panels in Figure 6 present the impacts of implementing a fully-fixed rate design on the GS < 10 kW customer sample. Under the proposed design 60% of sample customers experience a total monthly bill increase, and 40% experience a total bill decrease; 49% experience a change in total bill between -20% and 20%; and 23% of GS < 10 kW sample customers experience a total bill increase between 0% and 20%. As expected, customers with low monthly kWh volumes experience larger total bill increases, in percentage terms, than those with higher monthly kWh volumes. Customers with particularly large monthly kWh volumes experience a total bill decrease.

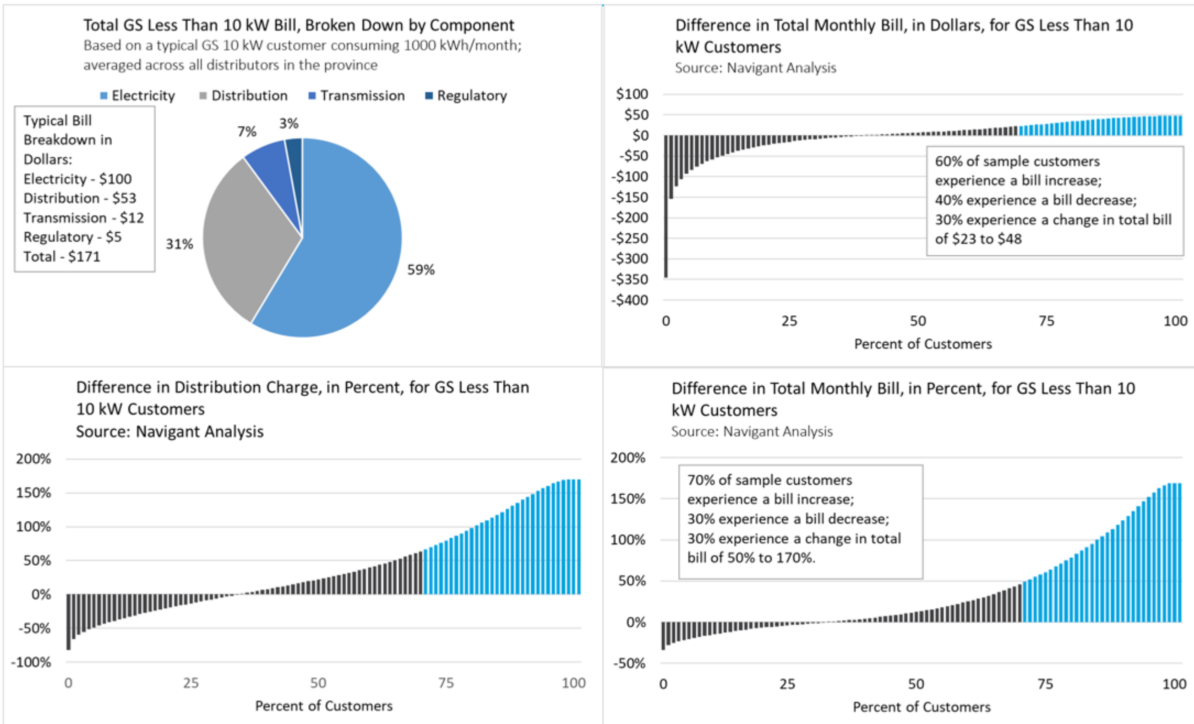

Figure 6: Analysis of customer impacts for the GS < 10 kW group.

Table 11 presents average monthly consumption and peak demand statistics broken down by distributor and whether a customer experienced a bill decrease, bill increase between 0% and 20%, or bill increase greater than 20%. As expected, the analysis shows that GS < 10 kW customers that experience a bill increase consume less than those that experience a bill decrease.

Table 11: Summary statistics for three GS < 10 kW groups experiencing: a total bill decrease; a total bill increase between 0% and 20%; and a total bill increase greater than 20%

Distributor	Average Peak Demand in kW			Average Monthly Consumption in kWh		
Bill impact type	bill decrease	< 20% bill increase	> 20% bill increase	bill decrease	< 20% bill increase	> 20% bill increase
Entegrus	6.4	3	0.8	1,753	543	53
Hydro One	6.5	4.1	1.7	1,901	832	270
PowerStream	6.7	3.9	1.3	1,990	786	219
Orangeville	6.9	3.7	1	2,020	709	71
Toronto Hydro	6.6	4.2	2.1	1,997	793	271

Figure 7 compares the status quo and fixed distribution charges and identifies the monthly consumption break-even point where a Toronto Hydro customer will pay more or less under the proposed GS < 10 kW rate design. For all consumption values where the black line is below the dotted blue line a customer will pay more, otherwise the customer will pay less. The red dotted line represents the cumulative percent of total Toronto Hydro population that have an average monthly consumption at or below the level defined on the horizontal axis.

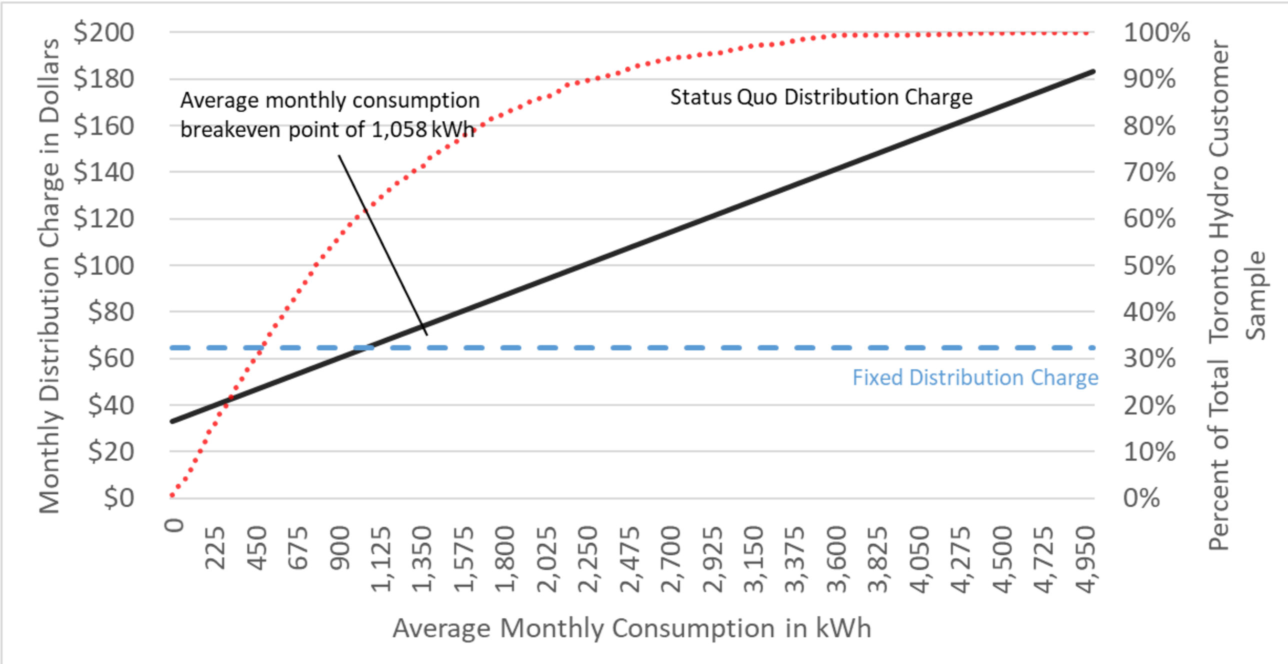

Figure 7: A comparison of Toronto Hydro status quo (2017 rates) and fixed distribution charge rates across various average monthly consumption values.

C.2 - General Service 10 – 50 kW

This sub-section identifies the range of total bill impacts GS 10 – 50 kW customers might experience, if the snapshot[2] variable distribution rate were changed from a monthly kWh to peak kW rate. Under the proposed design, 48% of customers are expected to see a total bill decrease, and 52% of customers are expected to see a total bill increase. The majority of customers (82%) experience a less than a 20% change in total bill, either increase or decrease. Most of these customers with a smaller bill change have a bill decrease (43% of the total customer group).

The mean statistics produced in Table 12 suggest that customers that experience bill increases (either small or larger) consume substantially less electricity, on a monthly basis, than customers who experience a bill decrease. Therefore peaky, low consuming individuals will be most impacted by the proposed rate design and customers with more consistent loading will see bill decreases.

[2] Analysis was done using 2016 tariffs.

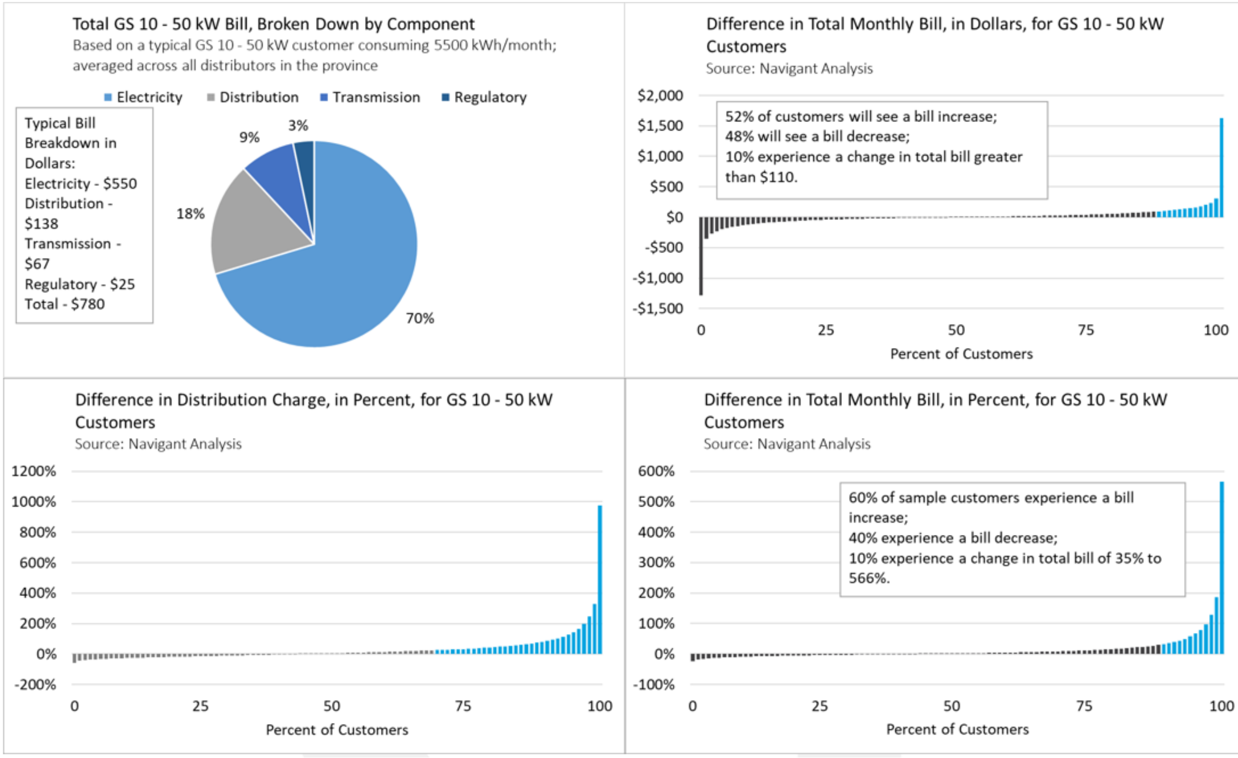

Figure 8: Analysis of customer impacts for the GS 10 - 50 kW group

Table 12: Summary statistics for three GS 10 - 50 kW groups experiencing: a total bill decrease; a total bill increase between 0% and 20%; and a total bill increase greater than 20%

Distributor	Average Peak Demand in kW			Average Monthly Consumption in kWh		
Bill impact type	bill decrease	< 20% bill increase	> 20% bill increase	bill decrease	< 20% bill increase	> 20% bill increase
Entegrus	21.2	19.8	18.5	8,098	4,126	1,031
Hydro One	20	17.5	17.6	7,909	4,473	2,298
PowerStream	21.1	18.4	27.3	7,559	3,926	1,926
Orangeville	25.2	22.2	22.2	10,960	6,231	1,434
Toronto Hydro	16	14.4	13.7	6,155	3,609	1,359

D - Analysis of U.S Department of Energy Business Type Data

This section contains an additional bill impact analysis using standardized building type data staff acquired from the U.S. Department of Energy (DOE) Commercial Reference Building database. Based on the results of the previous section, staff sought to determine whether certain customers identified by building type are more likely to be negatively impacted than others under the proposed rate design.

The DOE database contains roughly 20 gigabytes of simulated hourly consumption information for 16 building types across 936 Typical Meteorological Year (TMY3) locations. The DOE states that the business types in this dataset characterize approximately 70% of commercial building stock in the U.S.[3]. Staff calculated average peak demand across all building types and found that only 3 of the 16 building types contained within the DOE database had an average monthly maximum demand between 10 and 50 kW. Staff also selected states that are as close geographically to Ontario as possible[4]. Table 13 provides a list of building types that exist in the DOE database.

Those that were identified by staff as having an average peak demand between 10 – 50 kW are bolded. The DOE database is located at the following link.

Table 13: U.S. DOE commercial property building types; floor area; and number of floors

Building Type	Floor Area (FT^2)	Number of Floors
Large Office	498,588	12
Medium Office	53,628	3
Small Office	**5,500**	**1**
Warehouse	52,045	1
Stand-alone Retail	24,962	1
Strip Mall	22,500	1
Primary School	73,960	1
Secondary School	210,887	2
Supermarket	45,000	1
Quick Service Restaurant	**2,500**	**1**
Full Service Restaurant	5,500	1
Hospital	241,351	5
Outpatient Health Care	40,946	3
Small Hotel	43,200	4
Large Hotel	122,120	6
Midrise Apartment	**33,740**	**4**

[3] https://www.energy.gov/eere/buildings/commercial-reference-buildings

[4] Specifically: New York, Pennsylvania, Michigan, Ohio, Vermont, Maine, Massachusetts, Connecticut, Rhode Island, and New Jersey.

D.1 - Summary of DOE Data

This subsection presents a brief summary of each of the bolded DOE property types in Table 13. Mean statistics are provided in Table 14. Each building type section presents daily average load profiles, by year as well as by season and month.

Table 14: Summary statistics for U.S. DOE commercial property types (n = 244)

Customer type	Average Hourly Demand in kW	Average Monthly Consumption in kWh	Average Monthly Peak Demand in kW
Small Office	7.3	5,341	14.9
Quick-Service Restaurant	21.5	15,738	31.5
Mid-Rise Apartment	25.9	18,911	48.8

D.1.1 - Small Office

Figures 9 and 10 present average daily load profiles for the DOE small office building type. Average energy demand increases and eventually peaks during typical office hours 8 am – 2 pm and decreases as the work day winds down and into the night from 3 pm – 12 am. Seasonal variations appear to exist: higher peak demand in summer vs. winter; and delayed peak in fall and winter months.

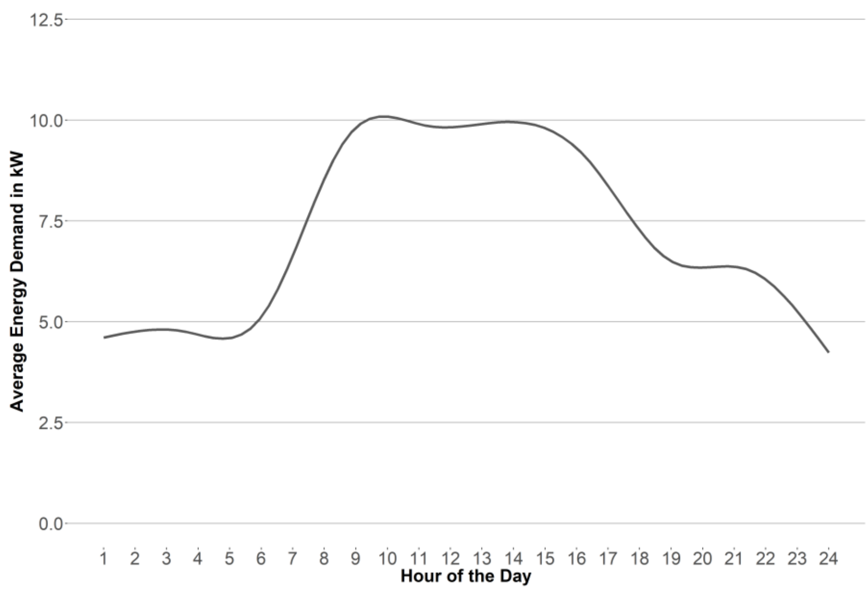

Figure 9: Average daily load profile of a sample of simulated small offices from the DOE dataset

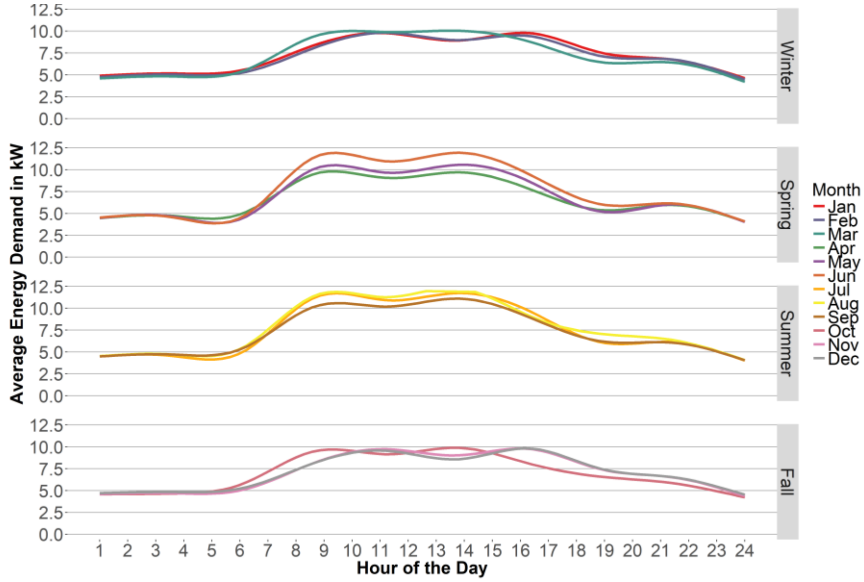

Figure 10: Average daily profiles from a sample of simulated small office properties from the DOE dataset, broken down by month

D.1.2 - Mid-Rise Apartment

Figures 11 and 12 present average daily load profiles for the DOE mid-rise apartment building type. Average energy demand decreases briefly from 1 am to 3 am and then increases, eventually peaking between 7 am and 8 am and decreases until 1 pm at which point there is an increase in hourly energy demand between 7 pm and 8 pm. Average demand decreases thereafter. No seasonal variation appears to exist, based on visual inspection.

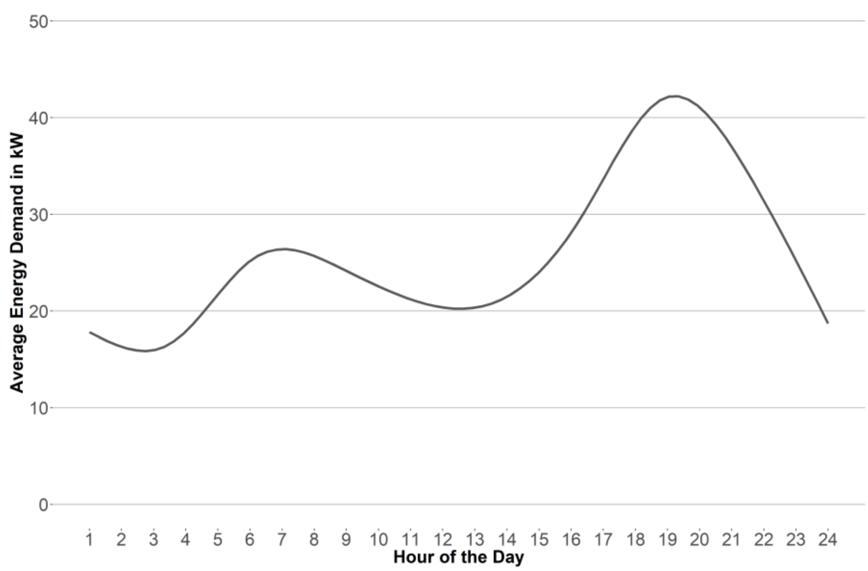

Figure 11: Average daily load profile for a sample of simulated mid-rise apartment customers from the DOE dataset

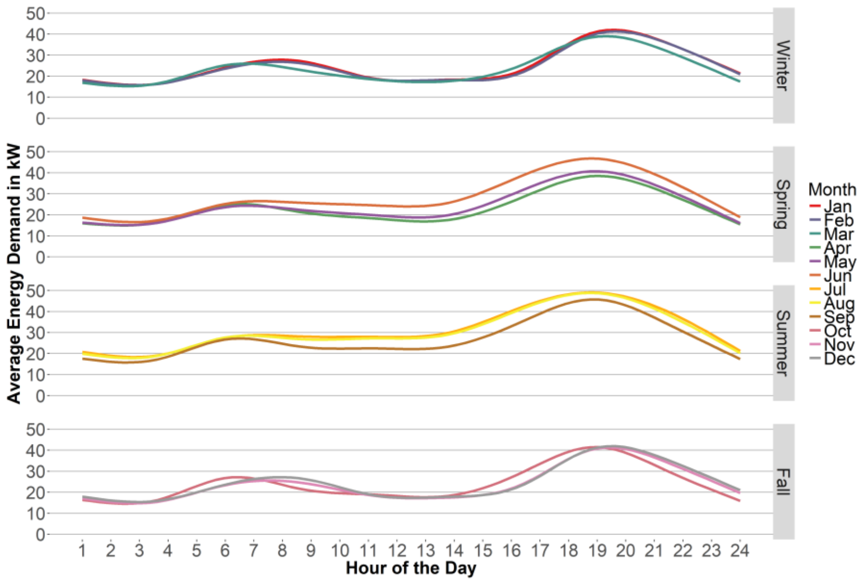

Figure 12: Average daily profiles from a sample of simulated mid-rise apartment properties from the DOE dataset, broken down by month

D.1.3 - Quick-Service Restaurant

Figures 13 and 14 present average daily load profiles for the DOE quick-service restaurant building type. Energy demand decreases from 1 am to 3 am and eventually increases and peaks between 6 am and 7 am, decreases between 7 am and 9 am and begins to increase and eventually peak again between 11 am and 12 pm, proceeds to decrease between 1 pm and 4 pm and then increase and eventually peak again between 6 pm and 8 pm and decreases thereafter. Seasonal variation is visible as well: winter months appear to have a third peak, at night. Demand peaks appear to flatten during some winter months (December through February) and a more pronounced demand occurs between 7 pm and 8 pm.

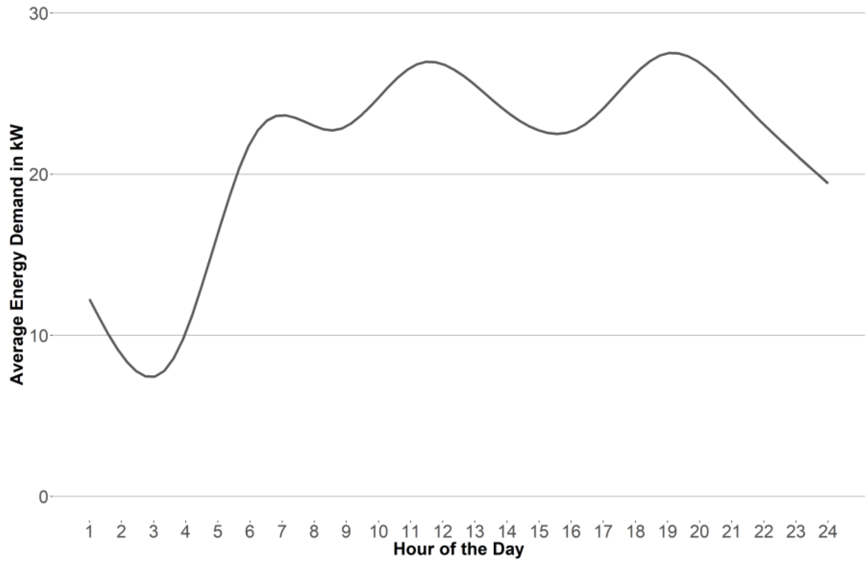

Figure 13: Average daily load profile for a sample of quick-service restaurant customers from the DOE dataset

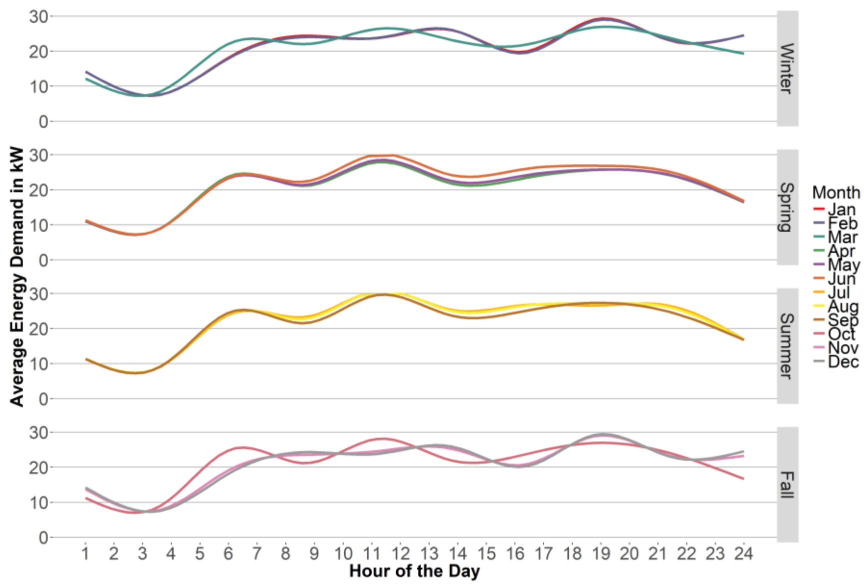

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Figure 14: Average daily profiles from a sample of simulated quick-service restaurant properties from the DOE dataset, broken down by month

D.2 - Bill Impacts

Total bill impacts were calculated and averaged for each of the three property types in the DOE dataset, using distribution rate data from each of the distributors that participated in the Commercial and Industrial rate design process. All three of these business types experience total bill decreases when applying staff's proposed tariffs. In general, OEB staff determined that the bill decreases are due to each of the simulated property types having a higher energy intensity[5] than the average distribution customers these rates were based on. That is, these business types have higher energy intensity than average customers. The only instance of a bill increase pertains to summertime cost for a small office customer when the tariff and proposed rates for Orangeville Hydro are applied[6].

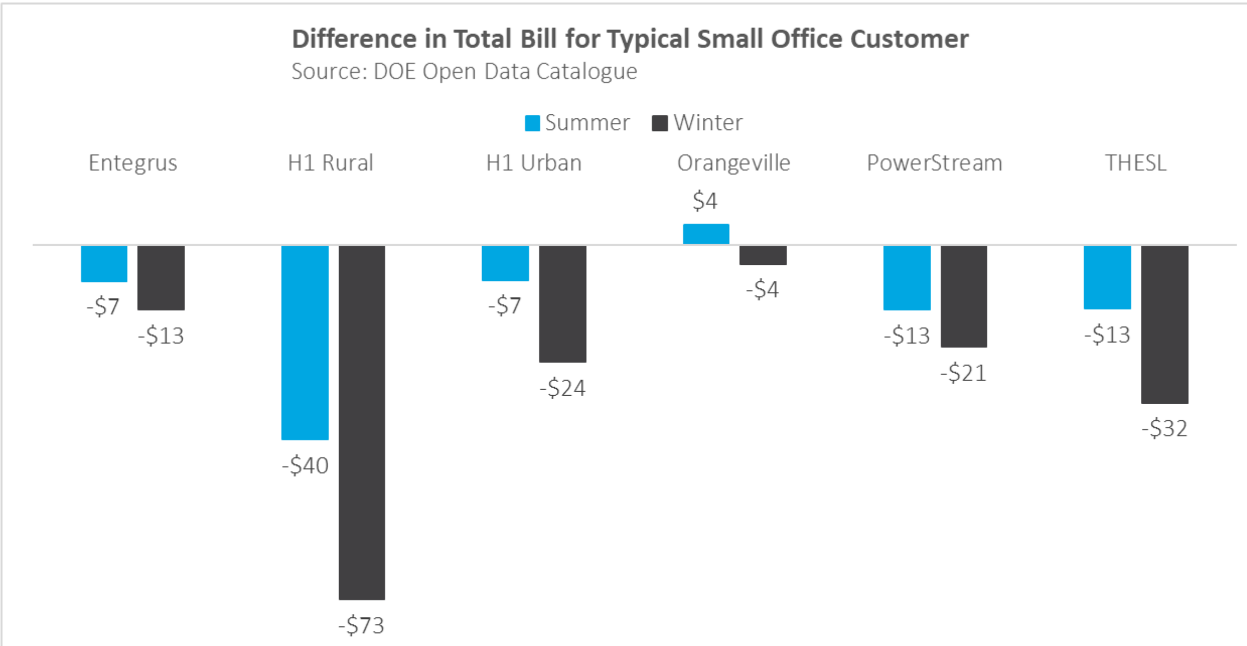

Figure 15: Difference in total bill (new – status quo) averaged across small office customers

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[5] We define energy intensity as the ratio of average monthly consumption to average monthly peak demand.

[6] Based on the definition of RPP summer and winter seasons.

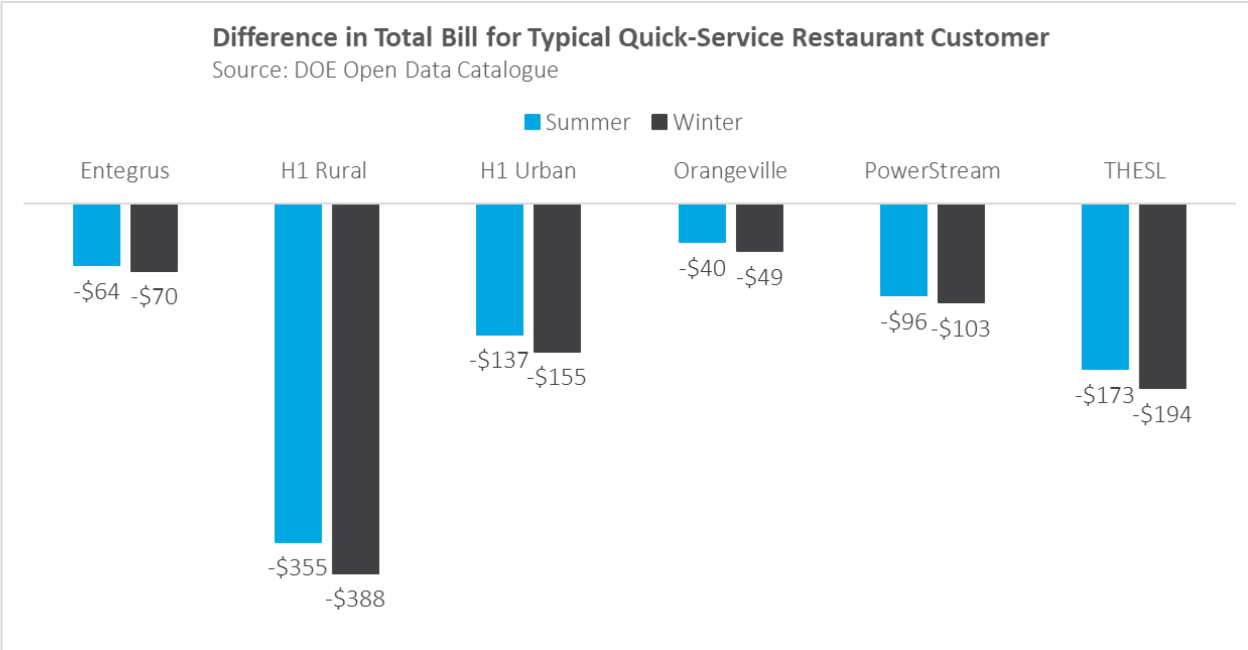

Figure 16: Difference in total bill (new – status quo) averaged across quick-service restaurant customers

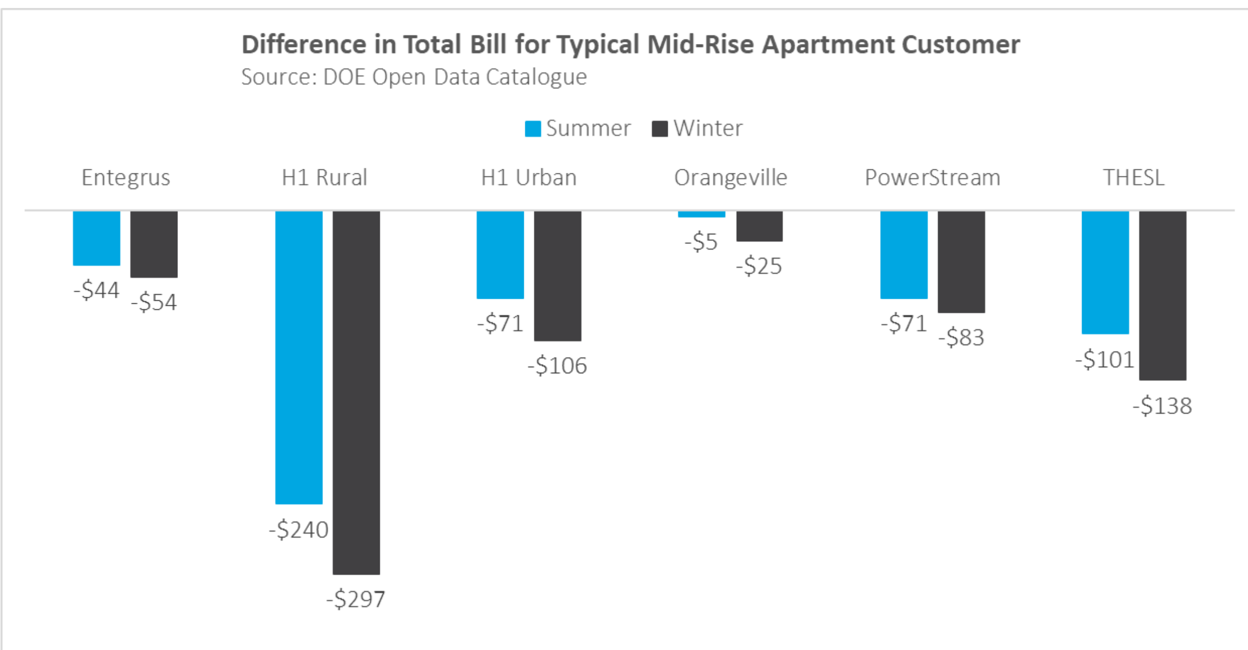

Figure 17: Difference in total bill (new – status quo) averaged across mid-rise apartment customers

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[i] All the analysis presented in Section B was developed with the R programming language. [R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.] All analyses were performed with the kml library in R. [Chistophe Genolini, Xavier Alacoque, Marianne Sentenac, Catherine Arnaud (2015). kml and kml3d: R Package to Cluster Longitudinal Data. Journal of Statistical Software, 65(4), 1-34.

A k-means algorithm typically operates in the following sequence of steps:

1. Initial mean centroids are randomly generated within the dataset;
2. Clusters are created, each data point is associated with a centroid based on a distance measure, in this case Euclidean distance was used;
3. The mean of the clusters becomes the new centroid;
4. Steps 2 and 3 are repeated until data points no longer change cluster assignment or the algorithm has reached a certain number of iterations; this is sometimes predefined.

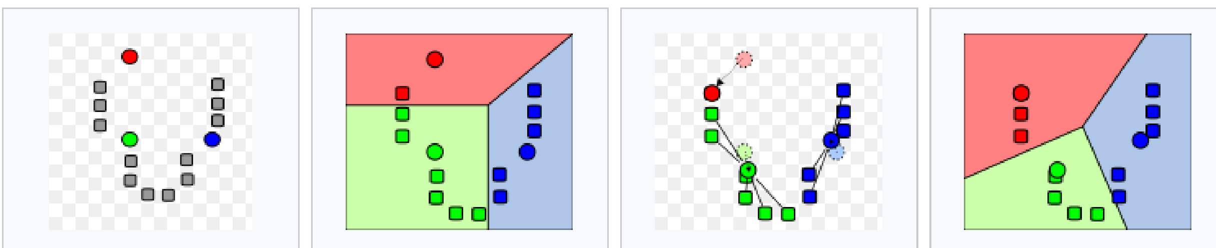

*Figure E1-**Error! Main Document Only.**: An example of a k-means clustering algorithm iterating through one sequence of steps*[i]

The challenge with implementing any k-means clustering algorithm is choosing the value of k. This is typically not determined by the algorithm and must be selected by the researcher. In order to assist in the decision making process the kml package reports on a variety of criteria that score each value of k based on how close load profiles are within a cluster, and how well separated load profile cluster groupings are from one another.

Figure E1-2 presents the outputs for each of the 5 criteria produced by the kml package. The horizontal axis in Figure E1-2 corresponds to the varying values of k that the kml algorithm churns through. Calsinki-Harabatz metrics classify an ideal cluster based on the value of k that is maximized; Davies-Bouldin and Ray-Turin classify an ideal cluster based on the value of k that is minimized. Each criteria measures how well each value of k is capable of: combining load curves into a similar grouping; and ensuring that each grouping is well separated from all other groupings. No value of k prevails based on the criteria presented in Figure E1-2, therefore, staff have decided to provide outputs for all values of k from 2 through 6. For the purposes of the Staff Report to the Board, staff present a value of k = 4 as it scores reasonably well for 3 of the 5 criteria provided. It is staff's view that for the values of k tested in this section there is diminishing marginal insights for values of k greater than 4.

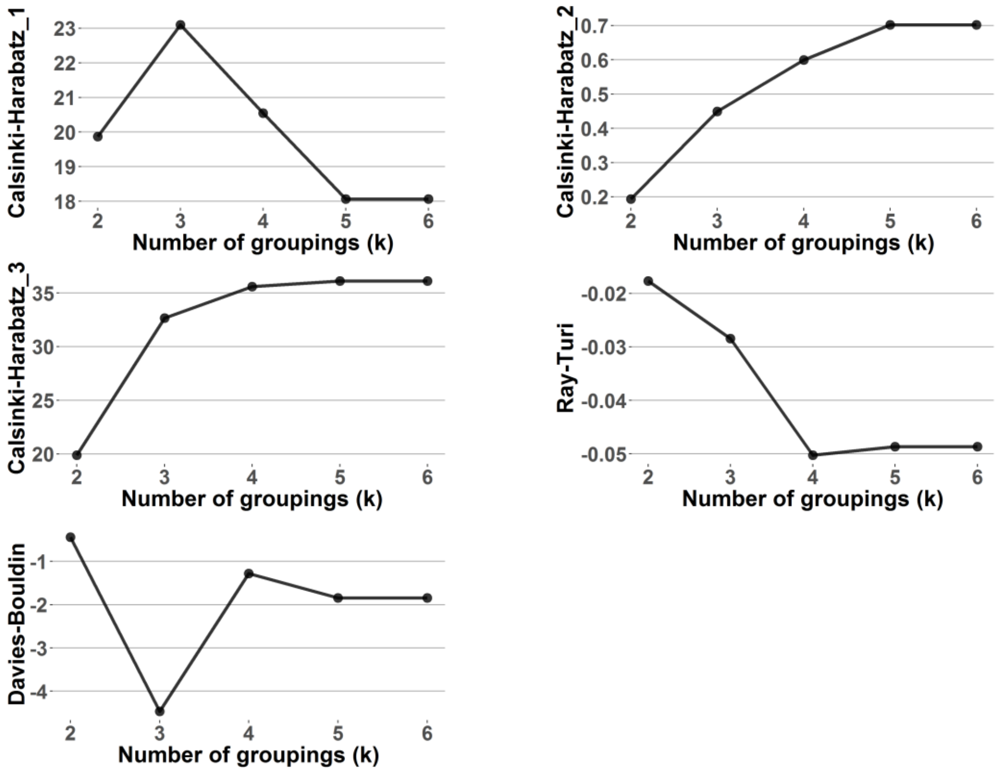

*Figure E1-**Error! Main Document Only.**: Various cluster criteria that aid in selecting a value of k*