MANCHESTER 1824

The University of Manchester

Preliminary Analysis of High Resolution Domestic Load Data

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Executive summary

This project is a part of the Supergen Flexnet project sponsored by the UK's Engineering and Physical Sciences Research Council carried out in the School of Electrical & Electronic Engineering at The University of Manchester. The present report carries out the preliminary analysis of domestic load data obtained in the project.

This report presents a preliminary analysis of measurements of domestic loads recorded in 22 households with a resolution of one minute over an 18-month period. MATLAB 7.6.0 is employed as an analysis tool.

In addition to presenting the data graphically in several ways that highlight the characteristics of these load profiles, this report also analyses the cross-correlations between these time series. It also discusses the characteristics of the load duration curves that can be deduced from this data.

From this preliminary analysis, some initial observations can be made:

- The typical pattern of individual domestic loads is very different from the pattern of aggregated loads on system wide.
- Domestic load exhibits small regular fluctuations, temporary drift, distinct big magnitude sharp jump and a low constant base load.
- The load duration curve of individual domestic consumer exhibits three main areas:
    - Long duration of low loads
    - Very short duration of very high loads
    - An intermediate region of high loads
- Domestic daily load usually has a morning peak, or an evening peak or both.
- The available data is not sufficient to identify seasonal patterns in the load profiles.
- There is not much positive cross correlation between the load time series of the different consumers included in the data.

Acknowledgement

The data used for this project was kindly provided by E.ON Engineering.

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1. Introduction

The ongoing smart grid revolution brings greater changes in power systems than ever before. Smart grid is recognized as electricity networks that can intelligently integrate the behavior and actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver a sustainable, economic and secure electricity supply. In the background of this ongoing smart grid revolution, flexibility is needed to facilitate renewable generation and to contribute to the economic and reliable supply of electrical energy to consumers. In the light of this vision, it is worth considering the potential flexibility contribution of the demand side to the power system.

Domestic electricity consumption is a significant player in smart grids as it accounts for approximately 36% of the total UK electricity supply. If domestic loads can be controlled in near real-time, then in principle, flexibility contributions can be made towards the whole system. Domestic appliances represent a large unutilized potential for “virtual” energy storage (e.g. thermal processes for refrigeration, air conditioning and heating). This potential could help maintain the power balance in the power system. Such virtual demand-side storage cannot feed energy back into the grid, but they can store the energy needed by the end-user process so that the timing of energy consumption becomes more flexible. This could, in theory, significantly ease the requirement to use primary generating plant to balance the system and facilitate the integration of intermittent renewable energy sources.

In this report, preliminary analyses of domestic load are carried out using records from field measurements of domestic loads obtained at a high time resolution. Analyzing this data and identifying patterns of consumption will serve as a basis for a more in-depth analysis in future work. The final aim of this project is to make contributions to control strategies and the design of distribution networks that provide flexibility, the market and investment mechanisms that promote its efficient uptake and the understanding of the role that public attitudes towards energy and energy technology have in shaping a flexible network.

This report is structured as follows. Section 2 provides an overview of the data and introduces the analysis tools. Section 3 presents all the preliminary analysis of domestic load, including load time series analysis, typical daily load profile analysis, cross correlations analysis and load duration curve analysis. Preliminary conclusions are presented in Section 4.

2. Data overall view and analysis tools.

2.1. Data overall view

The domestic load analysis in this report involves 22 UK households electricity consumption from December 2007 to June 2009. This load data was collected from field measurements of each household's whole electricity load on a one-minute basis. Table 2.1 shows the consumers' ID in the the following analysis.

TABLE 2.1 CONSUMERS' ID LIST

Ordinal number	ID	Ordinal number	ID
1	K07W514801	12	K07W514903
2	K07W514802	13	K07W514904
3	K07W514803	14	K07W514905
4	K07W514804	15	K07W514906
5	K07W514805	16	K07W514907
6	K07W514806	17	K07W514908
7	K07W514807	18	K07W514909
8	K07W514808	19	K07W514910
9	K07W514810	20	K07W514994
10	K07W514901	21	K07W514997
11	K07W514902	22	K07W515000

The domestic load data is recorded and transmitted weekly or monthly. There are always unavoidable failures in recording and transmission procedure that result in bad data, i.e. missing data, redundancies and magnitude errors. These bad data are identified in the data availability analysis, which is shown in Figure 2.1. In this figure, the horizontal axis is the time dimension and consumers are listed along the vertical axis. Red pixels mean that the data is available while white mean that it is not available. Load data is thus available for most household through January 2008 to June 2009 except for K07W514802 and K07W514907, which will not be considered in details in the following analysis. However, different amounts of data are missing for every household.

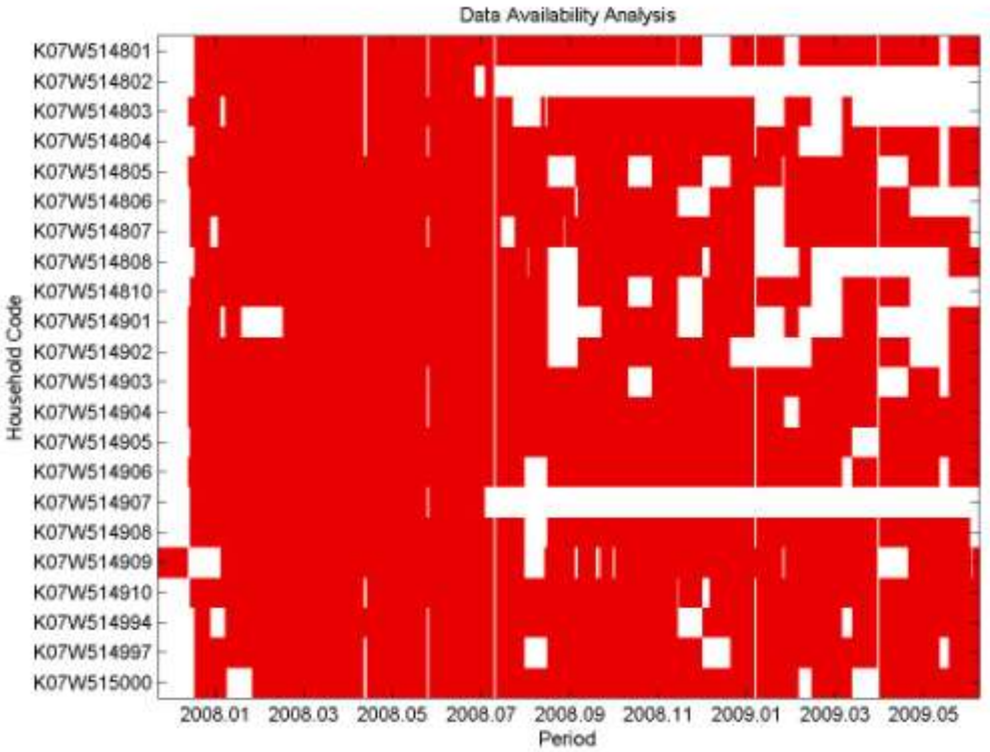


Figure 2.1 Data availability analysis of domestic load

2.2. Analysis tools

In this report, MATLAB 7.6.0 is employed as an analysis tool. Concerning the huge amount of data to be treated, all the available load time series are extracted from the original form of Excel files and saved in .mat format, which is easily processed using MATLAB. The intermediate and final results of the analysis are also saved in .mat format. Figures are plotted using MATLAB commands.

To improve the readability of the report, only typical figures are included in the main text of the report. Additional figures for each type of analysis are provided in the appendix.

3. Preliminary analysis of domestic load

3.1. Graphical analysis of load time series

In order to have a direct view of the domestic load pattern, load time series of each household are plotted graphically on minute-by-minute basis. The plot of consumer K07W514801 is shown in Figure 3.1. In this figure, the vertical axis represents the time of day while the horizontal axis represents the days for which data was collected as part of these field tests. The legend on the right side relates colors to the magnitude of electricity loads measured in kW. The color map is normalized on the basis of the highest load over the entire recorded data for each consumer: Red pixels represent high loads while blue pixels represent low loads. It can be seen from the figure that we can hardly distinguish red pixels in the figure, which is mostly blue. The figures for other households are similar (See appendix). This shows that high loads happen on extremely rare occasions. The dark blue columns correspond to periods of missing data.

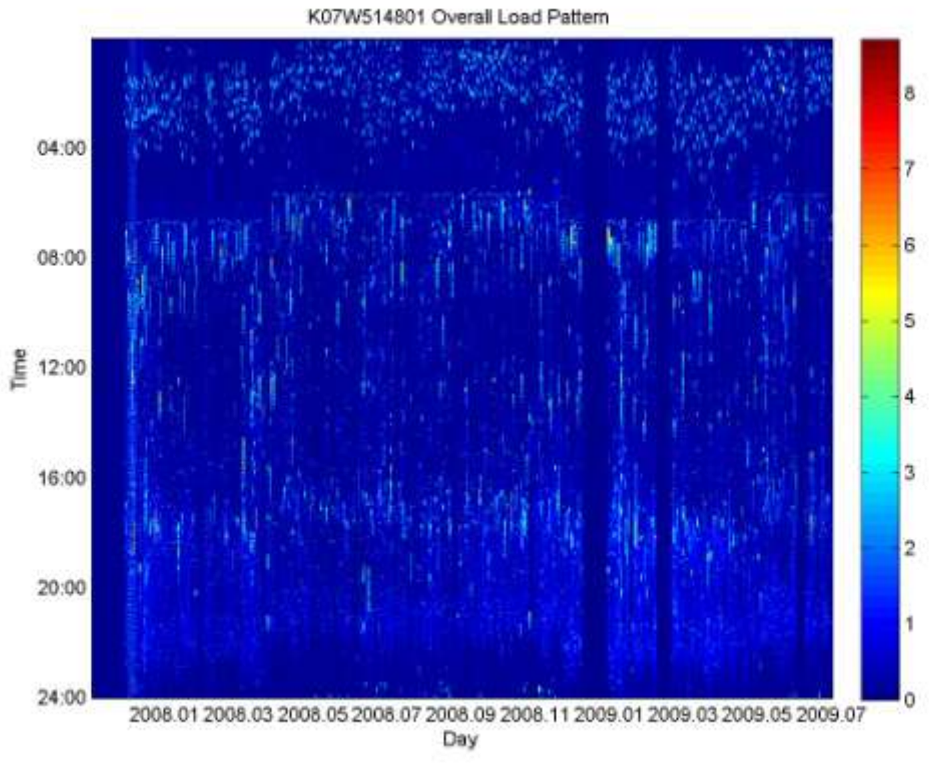


Figure 3.1 Overall load pattern for household K07W514801

It is clear that not much insight can be gained from the presentation of the data shown in Figure 3.1 because too large a proportion of the load is below 10% of the peak demand. A much better resolution can be obtained if the whole color resolution was used over the range from 0% to 10% of peak load in each household. Figure 3.2 shows the measured load for the same consumer as in Figure 3.1 but with the scaling shown in Figure 3.3. This new way of displaying the data shows patterns of use much more clearly.

Figure 3.4 plots the data for three other households which have typical load patterns. Once again blue columns in the figures are caused by missing data. Figures for data from other households can be found in appendix.

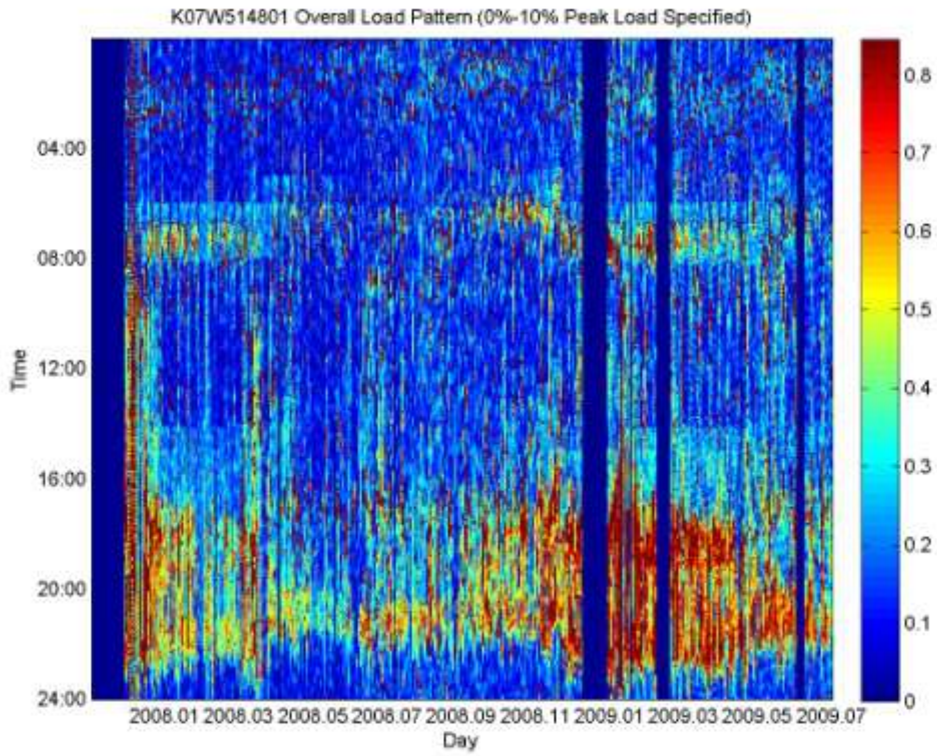


Figure 3.2 Overall load pattern of K07W514801 (0%-10% peak load specified)

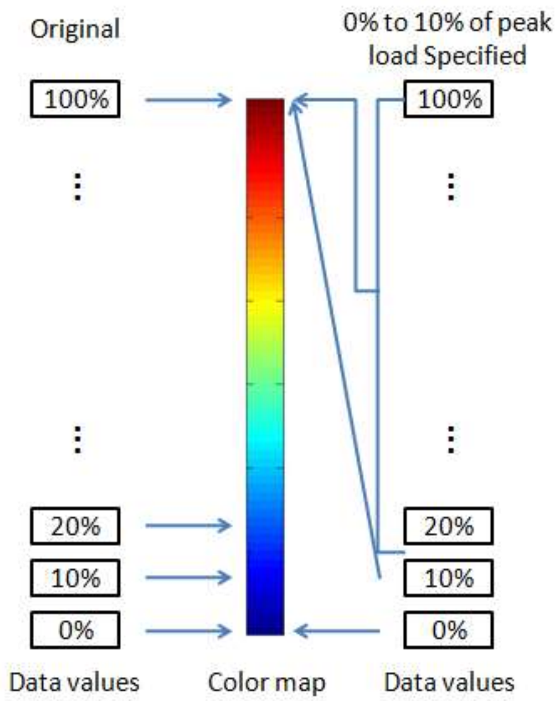


Figure 3.3 Colour scaling based on 0%-10% of peak load

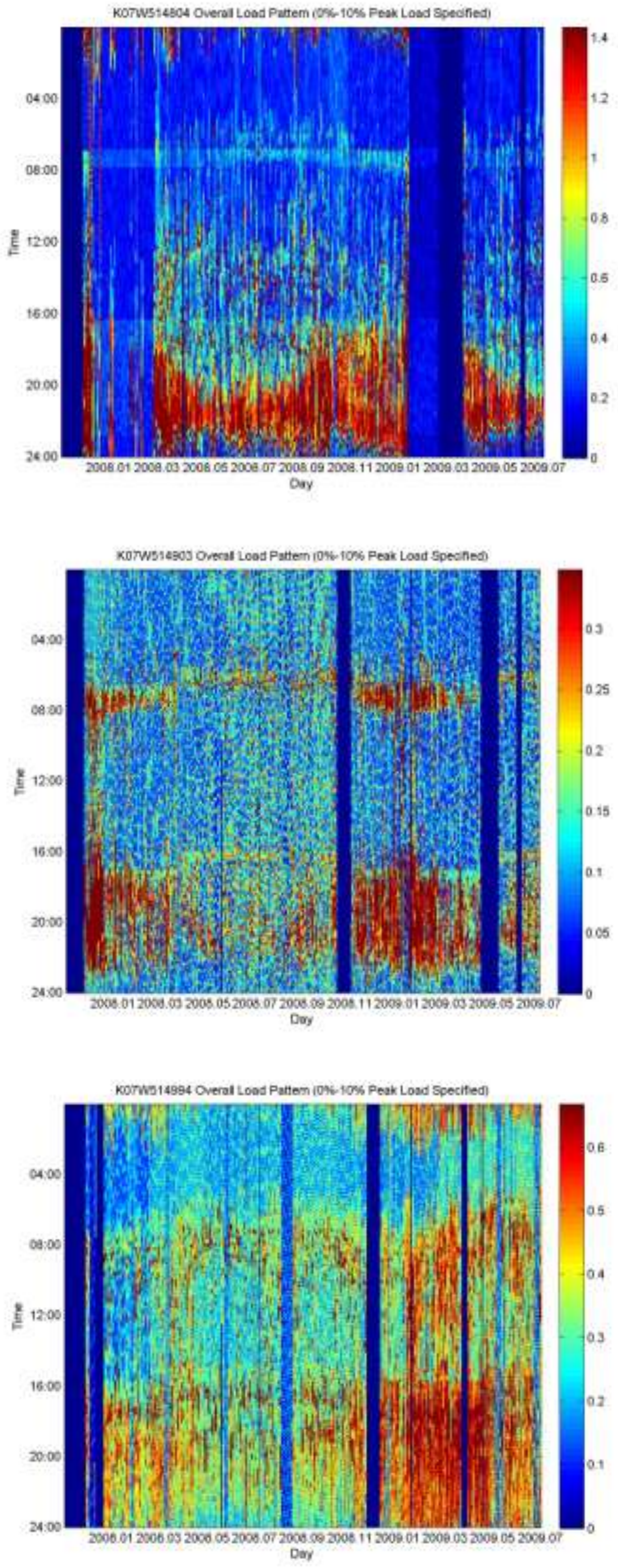


Figure 3.4 Load patterns (0%-10% peak load specified) for consumers K07W514804, K07W514994, K07W514994.

Although the typical load patterns shown above are different in magnitude and profile, they have some aspect in common:

1. Daily profile

Daily load curves for each household are similar over time, which indicates that households keep a relatively stable occupancy pattern along the research period. On the other hand, the daily load profiles for the various households are quite varied. This suggests different occupancy behavior.

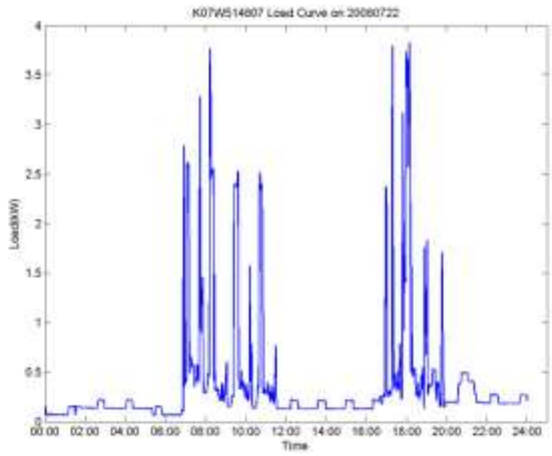
Most households have clear evening peaks, perhaps for cooking, heating and entertaining. Some households also have morning peaks and noon peaks.

2. Seasonal rhythm

Seasonal rhythm can also be detected from the images. Most households use more electric power in winter than in summer, i.e. typically longer and higher evening peak. While this matches common sense, there is not enough data to quantify this effect.

3.2. Typical daily load profile analysis

Daily load profile are examined and analyzed in detail in this section. Following the basic analysis presented in the previous section, several typical daily load curves have been selected for a more detailed analysis. These curves are shown in Figure 3.5. Other daily load curves have similar characteristics but different phases and magnitude. A typical aggregate UK electricity demand profile of 2009 (source: http://www.nationalgrid.com/uk/) is shown in Figure 3.6 in order to provide a contrast with the typical domestic load.



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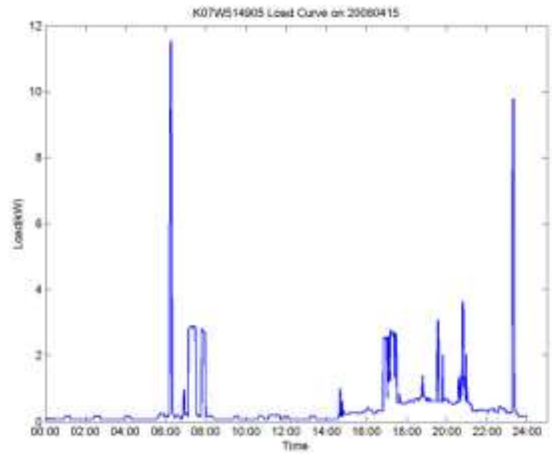

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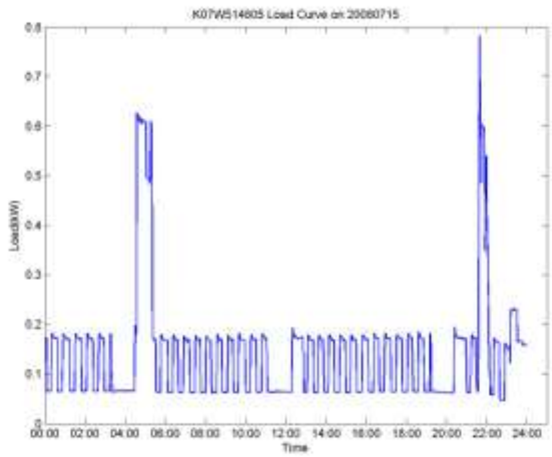

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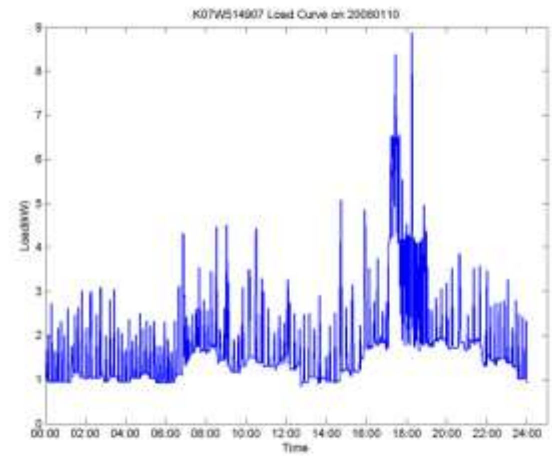

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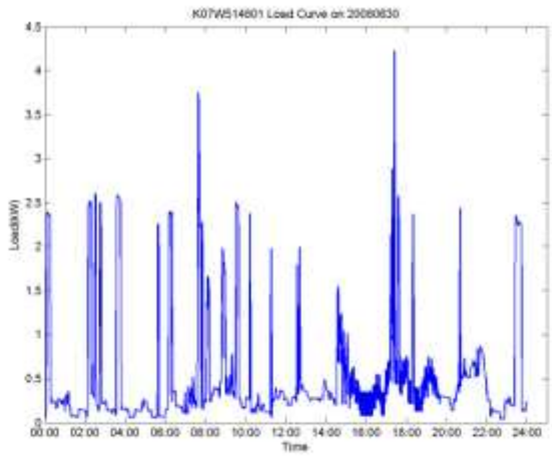

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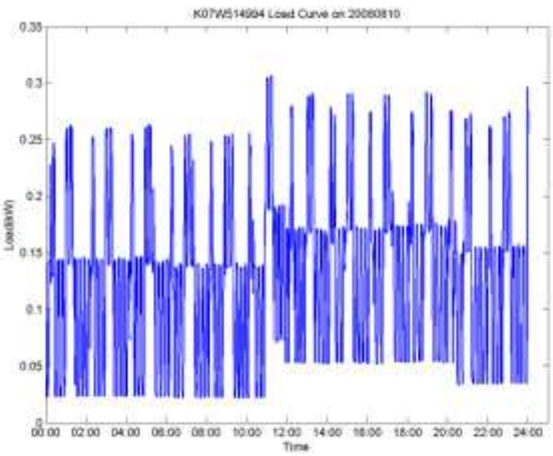

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Figure 3.5 Typical domestic daily load curves

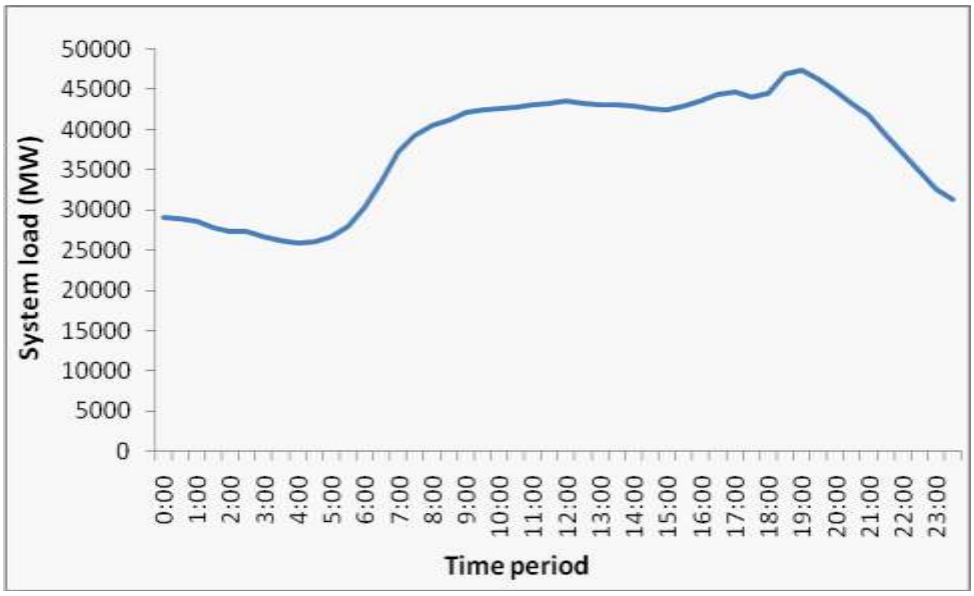


Figure 3.6 Typical aggregate UK electricity daily demand profile

Domestic load behaves very differently from the national aggregate load. In particular, the main feature is the occurrence of occasional high loads, which have a magnitude equal to many multiples of the mean value. There are distinct peak times, which take place in the morning and evening (curves a, b and c) or or throughout the day (curves d and e). Load curve f is different from others because it contains no peaks apart from regular fluctuation in the load (Note that the scale of the graph f is much smaller than for the others. In other words, it provides a zoom-in of the low load part of the scale).

These typical daily domestic load exhibit some common sub-patterns. These will be called "basic pattern components" and are identified and explained in Figure 3.7.

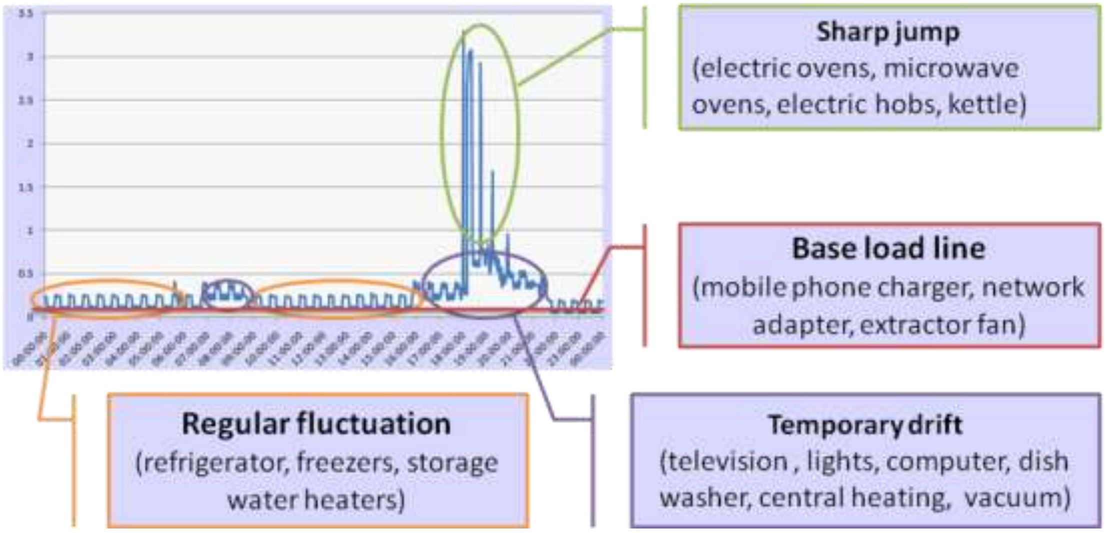


Figure 3.7 Basic pattern component in domestic load

According to Figure 3.7, domestic daily load can be regarded as the aggregation of the following four basic pattern components. These components are discussed in more details below.

1. Regular fluctuation

Regular fluctuations can be found in every consumer's load curve. These fluctuations appear as waves of small magnitude and constant frequency. Their phase also changes every day.

The most likely explanation for this load pattern is that it is the result of an appliance that has thermal inertia (e.g. refrigerator, freezers or storage water heater). These appliances are not significantly influenced by the occupation pattern of the inhabitants of the households, which explains why they appear over the whole day.

2. Temporary drift

Temporary drift is the mountain-shaped pattern that happens at almost the same time every day for each household. These patterns usually take place during the morning or evening peak. They have a relatively small magnitude and last from twenty minutes to a couple of hours.

This kind of load pattern is mainly caused by the activities of the occupants of the household such as cooking, entertainment (e.g. television, computer), lights, central heating and cleaning (vacuum cleaner, dishwasher). This component is thus heavily influence by the behavior of the occupants.

3. Sharp jump

A sharp jump is an occasional extremely high load that usually happens at the time with the basic pattern component of temporary drift. While sharp jump do not happen at exactly the same times every day, they tend to be centered on some regular time every day.

This kind of load pattern is mainly due to the existence of high-power appliance such as electric ovens, microwave ovens, electric hobs and kettles.

4. Base load line

The base load line is a load level over which the consumer does not have much control. It reflects the use of loads that are constantly on, such as mobile phone chargers, electric clocks and appliances on standby.

3.3. Load time series cross correlation analysis

This section examines to what extent consumers' time series load are correlated. If loads are highly correlated, changes in the load pattern will have a significant impact on the electricity supply system both locally and system wide. Conversely, if the load is not strongly correlated, consumers are unlikely to have their peak load at the same time and this will be beneficial for the distribution network.

The correlation among consumers' time series load is measured using their cross correlation coefficient matrix. If we define d_{it} as the load level of consumer i at minute t, C the cross correlation coefficient matrix $C(i, j)$ can be calculated as follows:

$$C(i,j)=\frac{\frac{1}{T}\sum_{t=1}^{T}\left(d_{it}-\bar{d}_i\right)\left(d_{jt}-\bar{d}_j\right)}{\sqrt{\left[\frac{1}{T}\sum_{t=1}^{T}\left(d_{it}-\bar{d}_i\right)\left(d_{it}-\bar{d}_i\right)\right]\left[\frac{1}{T}\sum_{t=1}^{T}\left(d_{jt}-\bar{d}_j\right)\left(d_{jt}-\bar{d}_j\right)\right]}} \quad (1)$$

In Equation (1), $\bar{d}_i, \bar{d}_j$ represent the mean loads of consumer i and j respectively over the available data:

$$\bar{d}_i=\frac{1}{T}\sum_{t=1}^{T}d_{it} \quad (2)$$

Considering the fact that there are missing data in each consumer's time series, data pretreatment must be carried out before this calculation is performed. Firstly, consumers with insufficient (less than 90%) load data are excluded. Secondly, among the remaining series, time periods which have one or more consumer's data unavailable are omitted.

Figure 3.8 shows the cross correlation coefficient matrix of the 13 consumers that met the data quality criterion. The calculation was performed over approximately 439680 minutes (7328 hours). The figure represents the correlation coefficient matrix using the color of each pixel. The figure only gives the lower triangular part of the matrix because the matrix is symmetrical. Numerical values of the elements of the matrix are listed in the appendix.

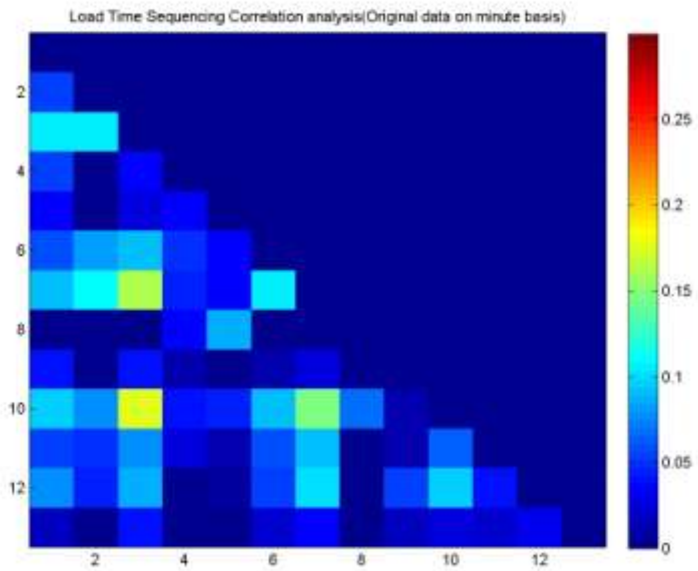


Figure 3.8 Cross correlation coefficient matrix among 13 consumers on a one-minute basis

Figure 3.8 shows that there is a little positive correlation between the loads of these consumers. The top of the color scale on the right of the figure corresponds to a correlation coefficient of 0.3. The cross correlation coefficients are all less than 0.2 / and usually less than 0.1. This suggests that while the consumers from which the data was gathered have relatively similar occupation patterns, they rarely have the same electricity consumption on a minute-by-minute basis.

Another two attempts were made to explore the correlation between the consumers' loads. Hourly average and maximum loads were calculated and the cross correlation coefficient matrix was then calculated using Equation (1). As Figure 3.9 shows, the correlations between the load time series are stronger on an hourly basis, and average loads have a higher correlation coefficient than maximum loads. This means that consumers have similar hourly electricity usage. The sharp jumps in load happen at uncorrelated times when considered on a minute-by-minute basis but contribute the most among all basic pattern components to the correlation coefficients. More in-depth research should be done on the correlations among the other basic pattern components.

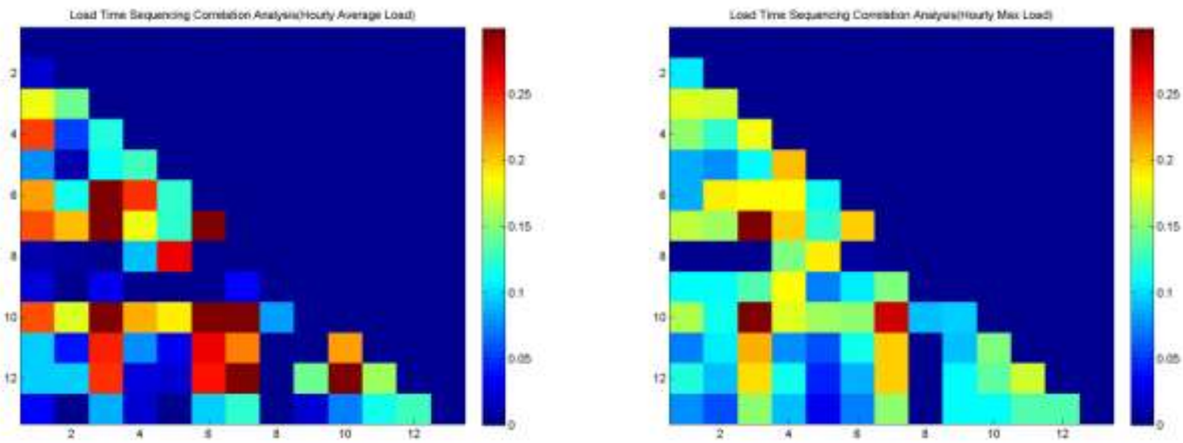
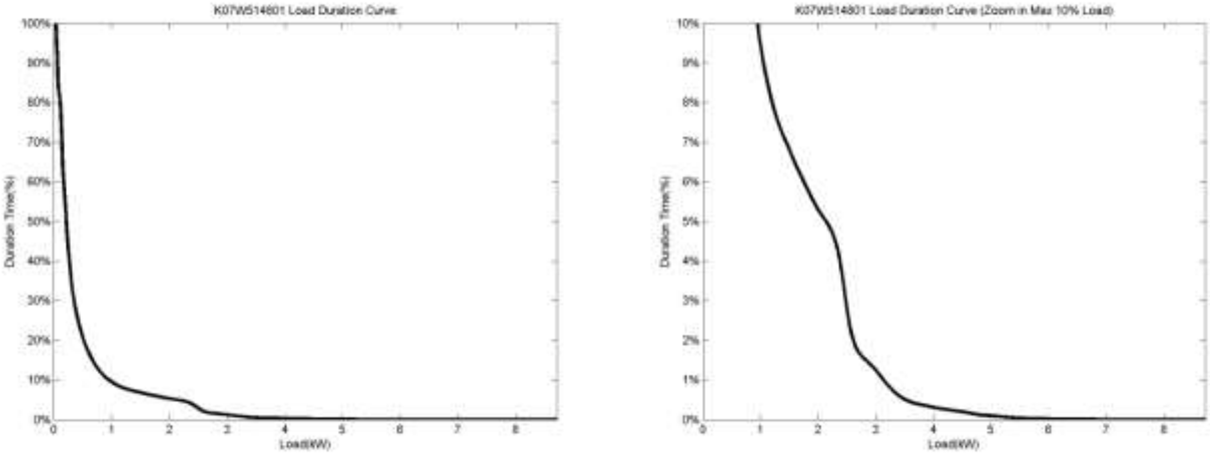


Figure 3.9 Cross correlation coefficient matrices for 13 consumers for load time series on hourly basis (left: hourly average load; right: hourly maximum load)

3.4. Load duration curve analysis

Load duration curves are used to analyze the magnitude distribution of domestic load. Three typical load duration curves are shown in Figure 3.10. In this figure, the magnitude of the load in kW is plotted along the horizontal axis while the normalized time duration are plotted along the vertical axis . The graphs on the left show the entire load duration curves of some households while the ones on the right give a zoomed view of the top 10% load to give a closer view of the high load area. The load duration curves of other consumers can be found in appendix. The aggregate UK electricity load duration curve for 2009 (source: http://www.nationalgrid.com/uk/) is shown in Figure 3.11 in order to provide a contrast with the typical domestic load.



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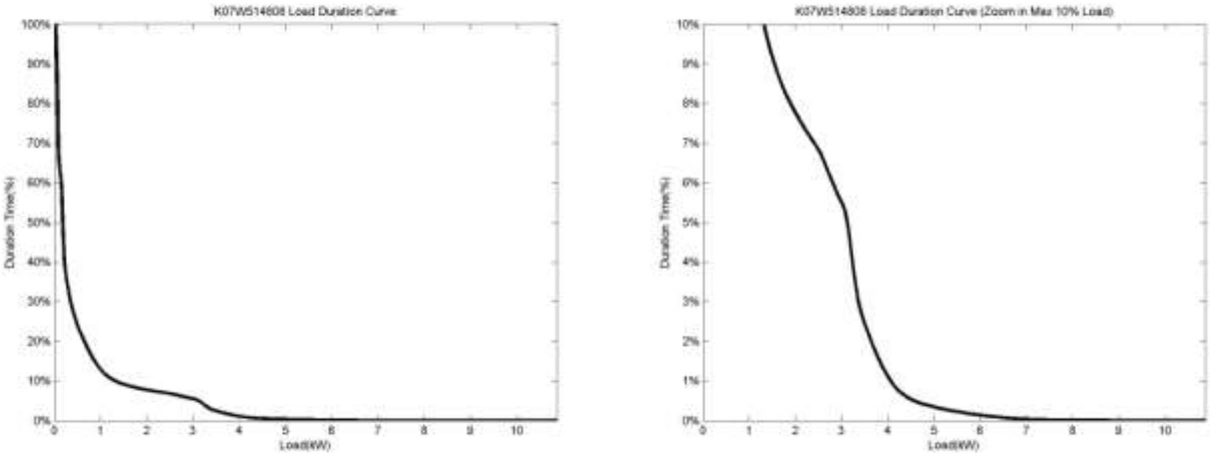

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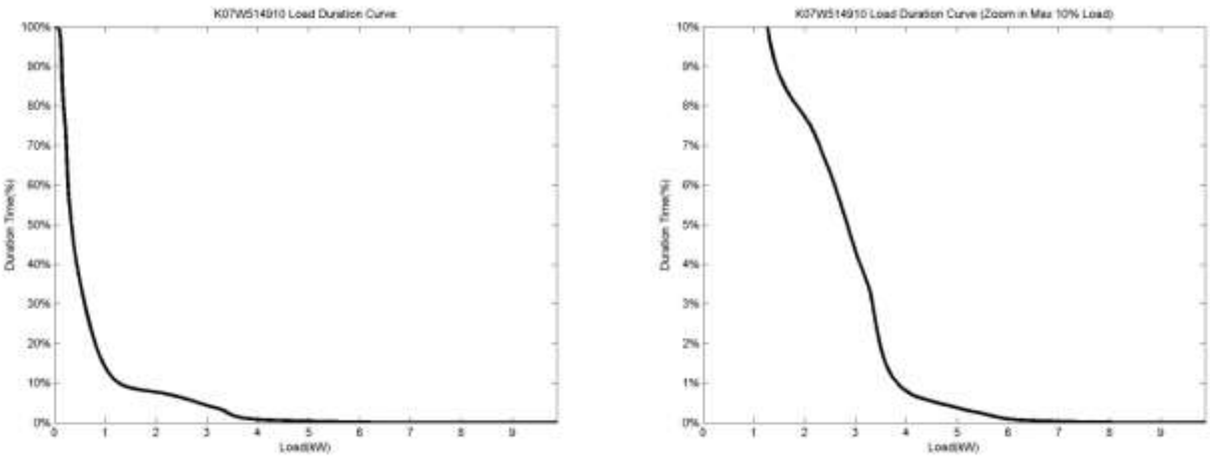

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Figure 3.10 Typical domestic load duration curves (left: entire load duration curve; right: load duration curve zoomed to show more details of the top 10% load)

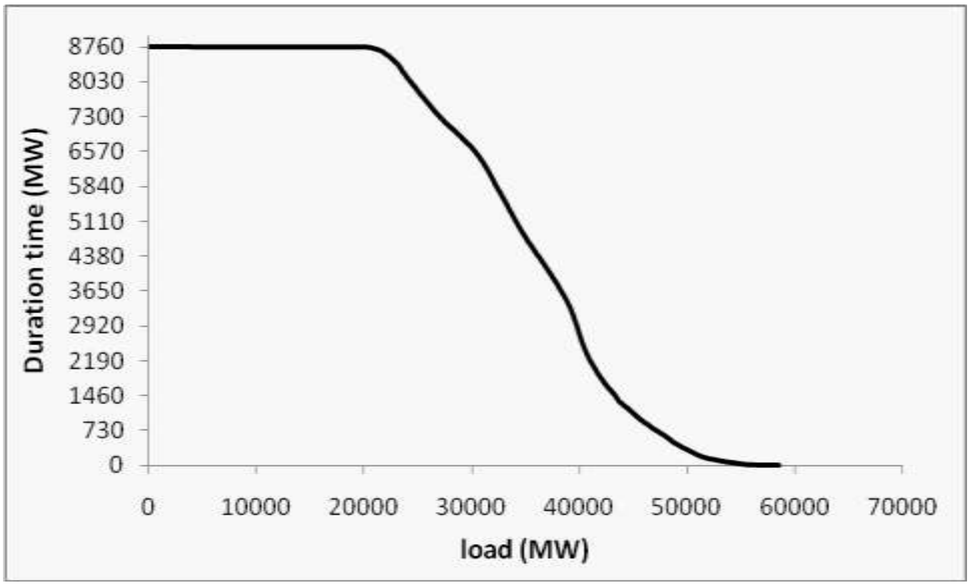


Figure 3.11 Typical duration curve of aggregate UK aggregate electricity demand

From Figure 3.10 and Figure 3.11 we can see that the domestic load duration curve is very different from the load duration curve for the whole system. Interestingly, the load duration curves of the various domestic consumers are quite similar even though the load time series are very different. The load duration curves drop exhibit a very sharp drop in the low load area, followed by a “knee-type structure” and finally a very smooth region in high load area. It is thus reasonable to divide the domestic load duration curve into three areas according to their appearance, which are low load, relatively high load and extremely high load respectively, see Figure 3.12.

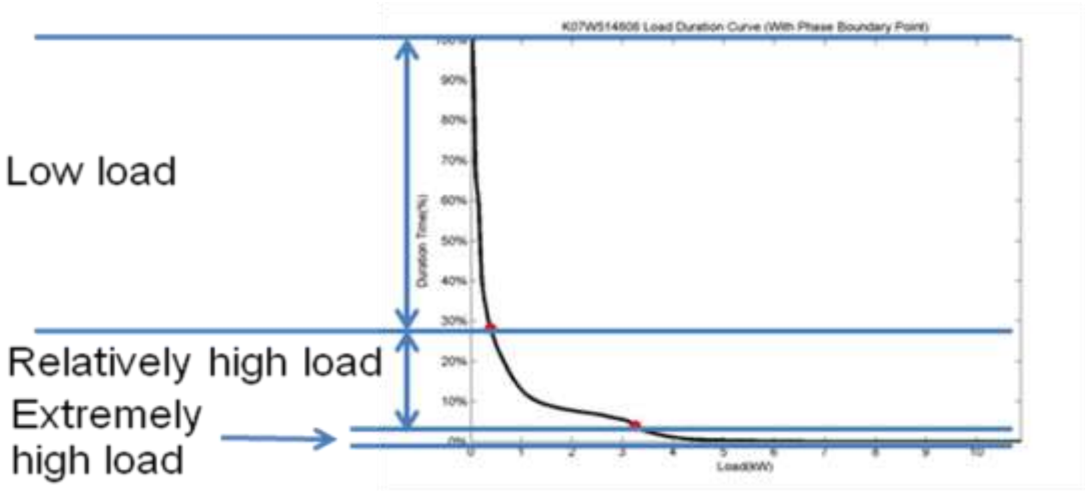


Figure 3.12 Three distinct areas of the load duration curve

Only two boundary points must be identified on the load duration curve to separate the three areas. The boundaries between these areas are not clearly defined, so criteria must be defined for the identification of the boundary points. These are described below.

1. Boundary between low load and relatively high load

A straight line is fitted to the load duration curve in the low load area (The regression data are chosen from data that located from 40% to 90% duration time on the load duration curve). The first point that deviate by more than 50% from this trend line is deemed to be the boundary point between low load and relatively high load.

2. Boundary between relatively high load and extremely high load

The “knee-type structure” in this area, where the load duration curve is gradual at first and sharply falls afterwards, is the transition from relatively high load to extremely high load. The most significant “knee-type structure” is thus identified and the middle point of the sharply falling part is deemed to be the boundary point between relatively high loads and extremely high loads.

Figure 3.13 is a schematic diagram showing the boundary point identification criteria . The exact values of the boundary points of each consumer can be found in appendix. Using these criteria, the typical areas are identified for all consumers and the results are plotted in Figure 3.14 and Figure 3.15. These figures show the magnitudes and duration time (normalized) respectively of these boundary points for all the consumers. From these two graphs the features of the three segments clearly emerge: The low load area has the longest duration but the smallest magnitude. On the other hand, the extremely high load area has the largest magnitude but a very small duration. These two graphs highlight difference in patterns of electricity usage between different consumers.

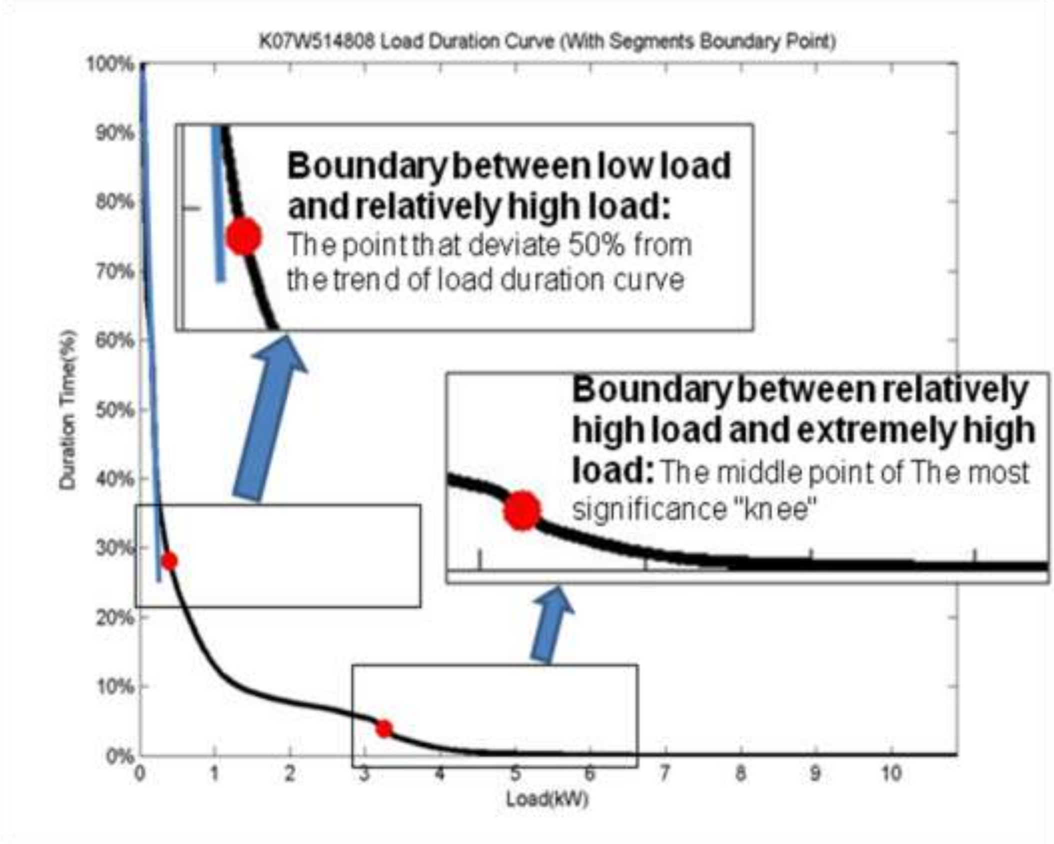


Figure 3.13 Schematic diagram of boundary point identification criterion

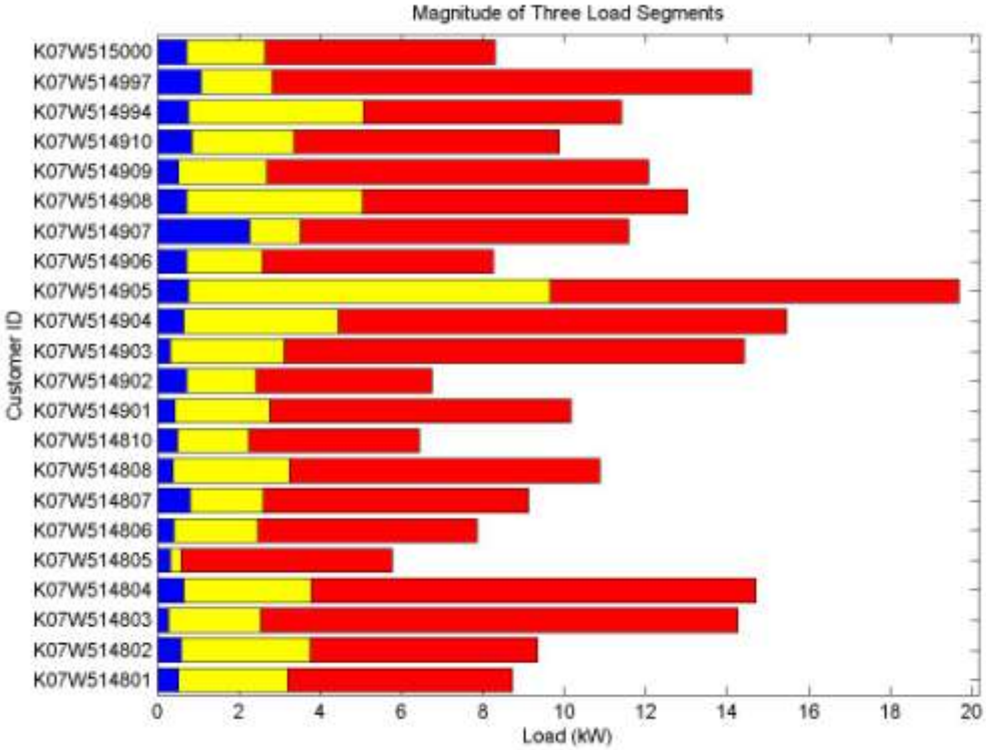


Figure 3.14 Magnitude of the three load areas for all the consumers

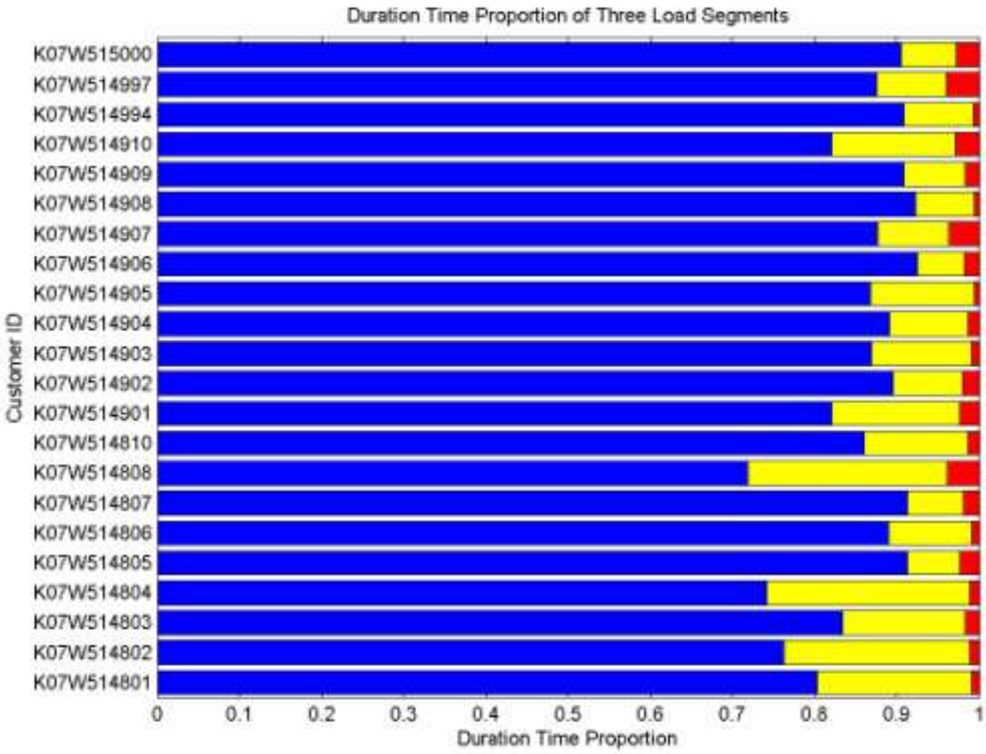


Figure 3.15 Proportion of the total duration of the three load areas for all the consumers

4. Conclusions

This report presents a preliminary analysis of the load data from 22 UK domestic consumers recorded with a one minute resolution over an 18 month period. The work in this report provides a basis for an in-depth analysis that will explore how flexibility can be built into the electricity networks of the future.

As a first step, graphical representations of domestic loads are presented to give a intuitive understanding of daily profiles and their seasonal variations. Next, time series and duration analysis are preformed to identify load patterns and their key characteristics. Cross correlations are also calculated for the time series of load data.

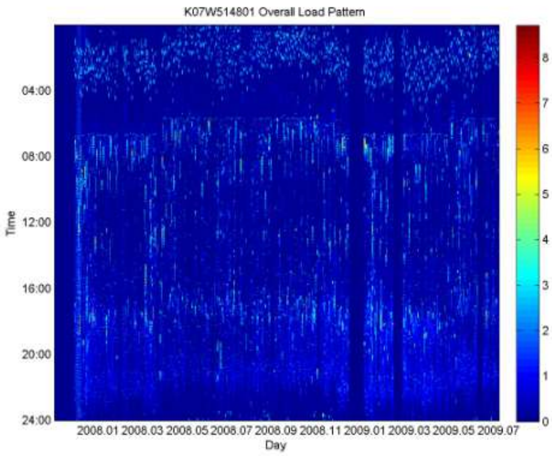
From this preliminary analysis, some initial observations can be made:

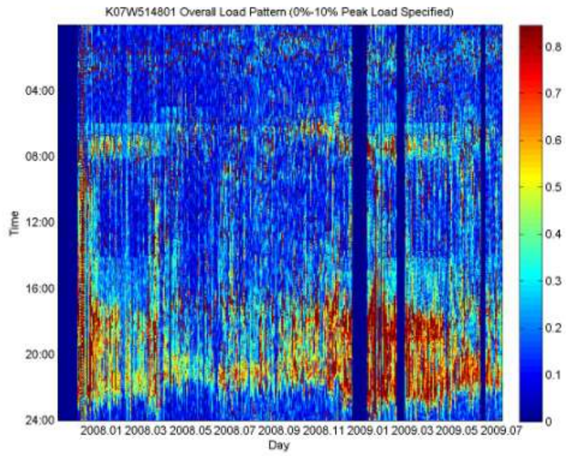
- The typical pattern of individual domestic loads is very different from the pattern of aggregated loads
- Domestic load exhibits small regular fluctuations, temporary drift, distinct big magnitude sharp jump and a low constant base load.
- The load duration curve of individual domestic consumer exhibits three main areas:
    - Long duration of low loads
    - Very short duration of very high loads
    - An intermediate region of high loads
- Domestic daily load usually has a morning peak, or an evening peak or both.
- The available data is not sufficient to identify seasonal patterns in the load profiles.
- There is not much positive cross correlation between the load time series of the different consumers included in the data.

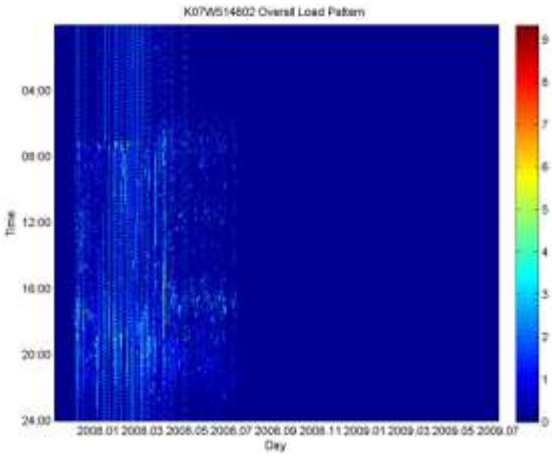
Appendix

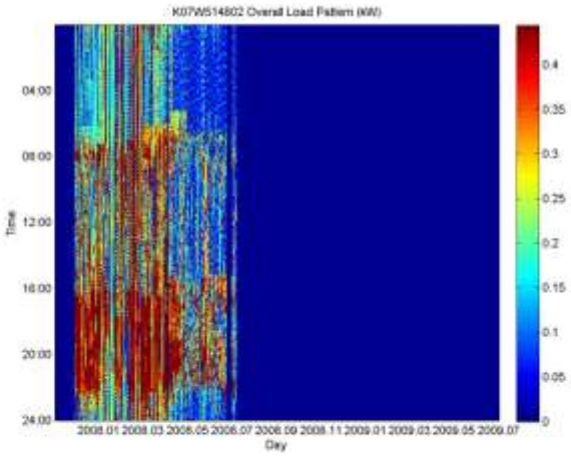
A. Overall load pattern of all consumers

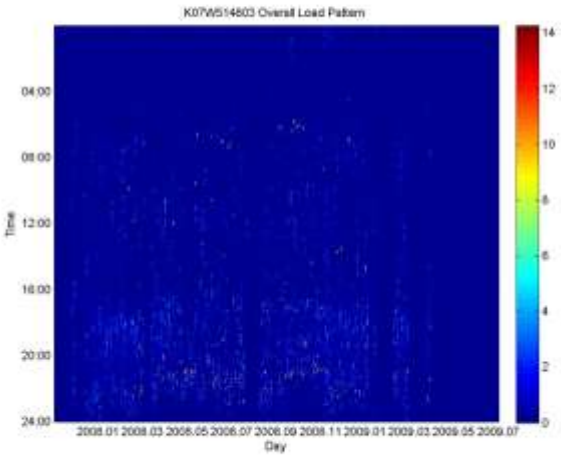
The figures on the left show the color maps for each consumer normalized based on the highest load over the whole available data. The figures on the right are scaled so that 10% peak load corresponds to the darkest red. Loads greater than 10% of the peak load are represented with the same color as 10% peak load.

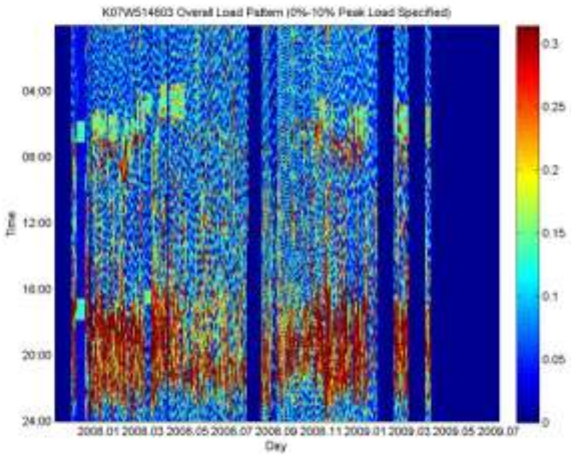


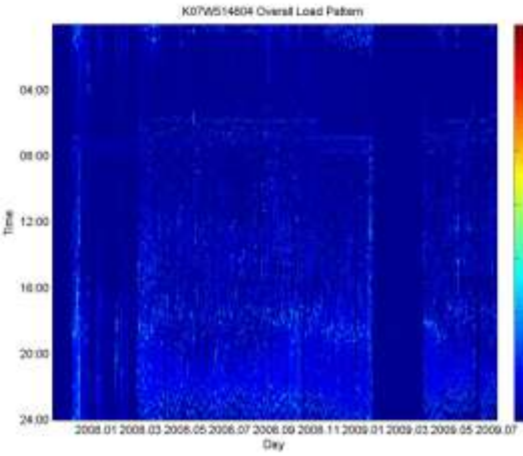


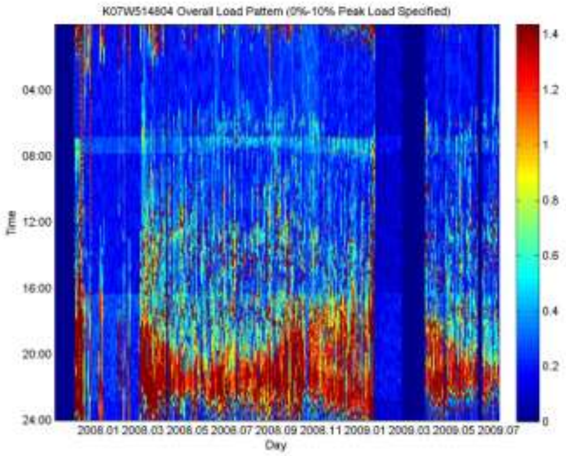









K07W514804 Overall Load Pattern
Time
Day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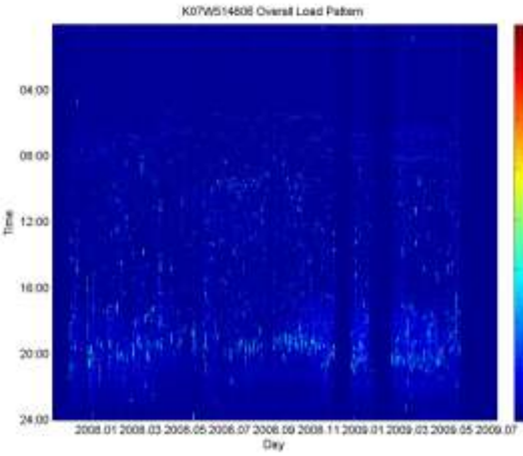
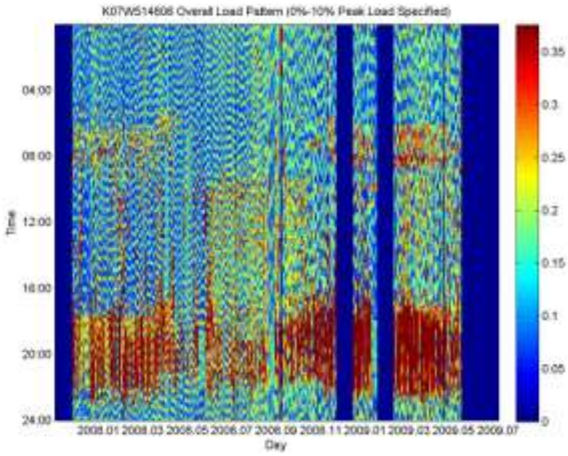
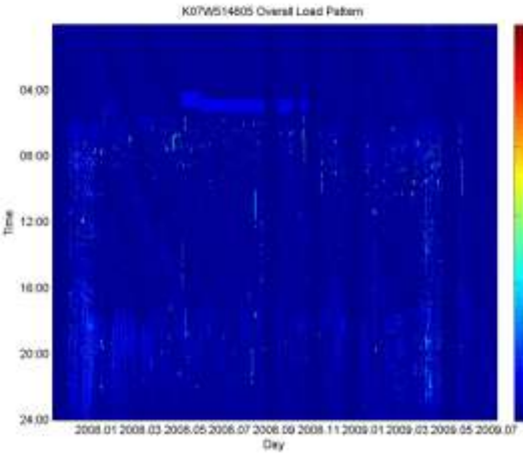
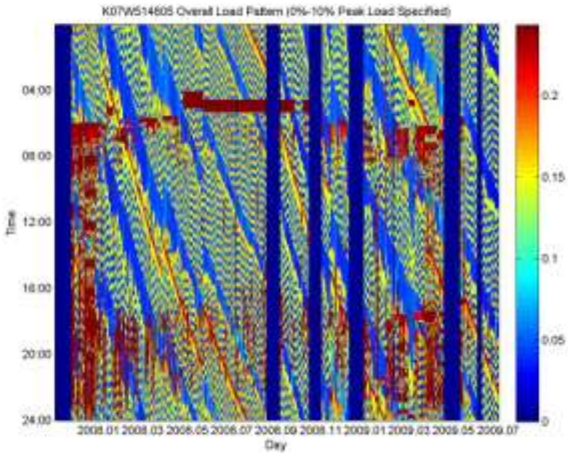
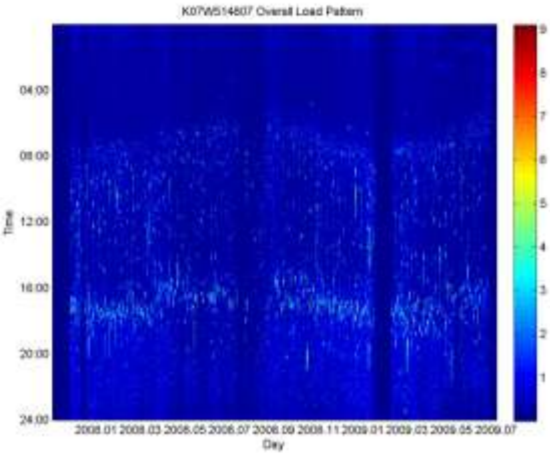
Time
Day

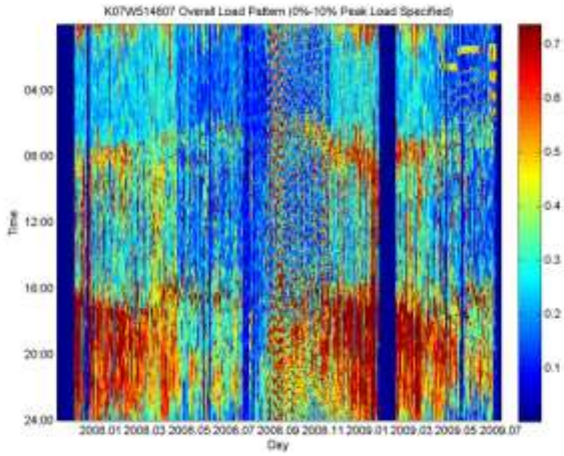

K07W514806 Overall Load Pattern
Time
Day

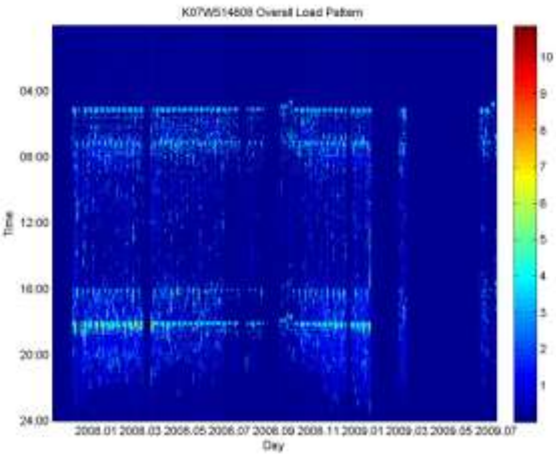

K07W514806 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

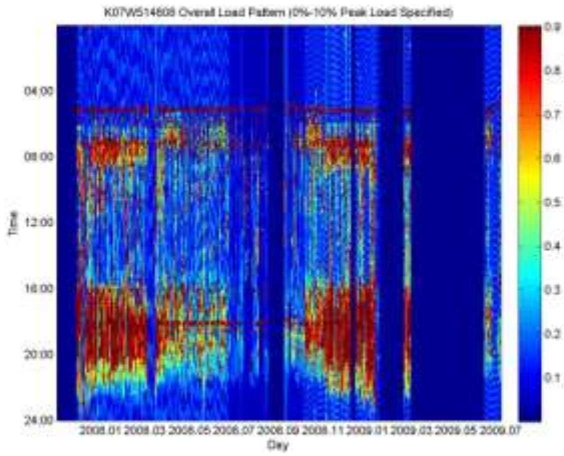

K07W514805 Overall Load Pattern
Time
Day

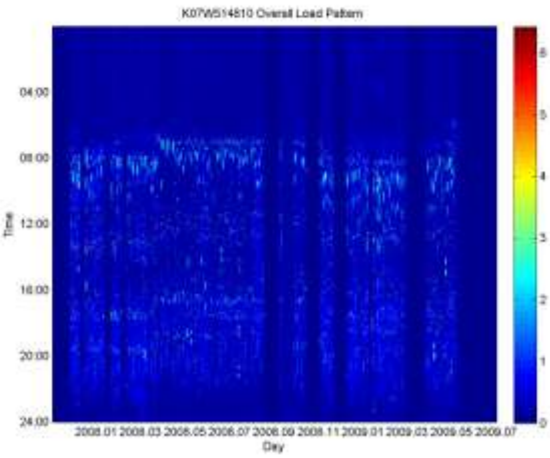

K07W514805 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

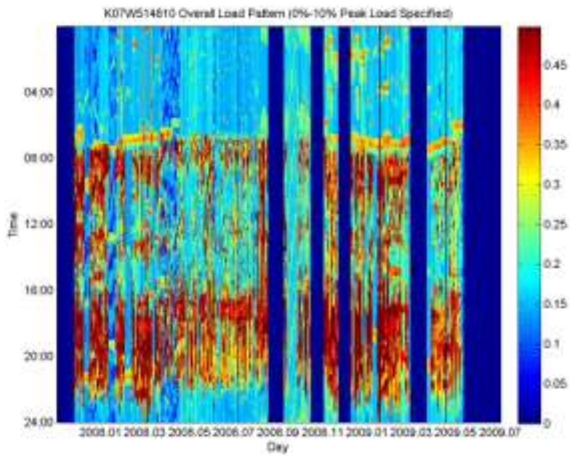

K07W514807 Overall Load Pattern
Time
Day

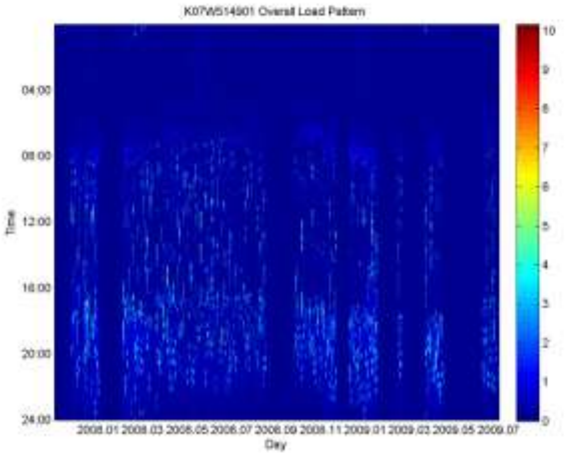

K07W514807 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

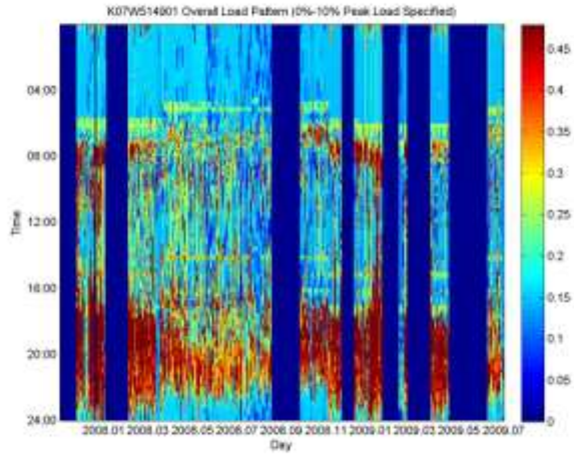

K07W514808 Overall Load Pattern
Time
Day

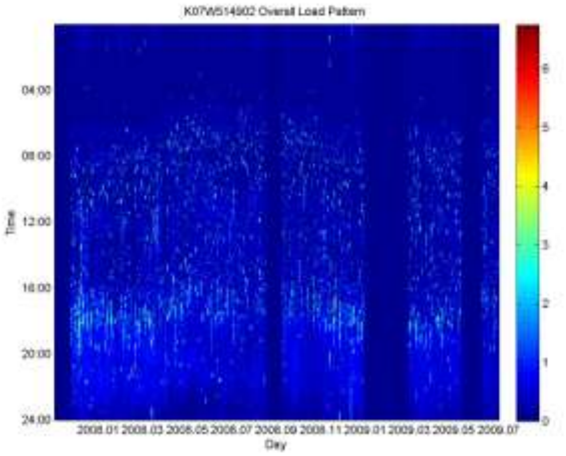

K07W514808 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

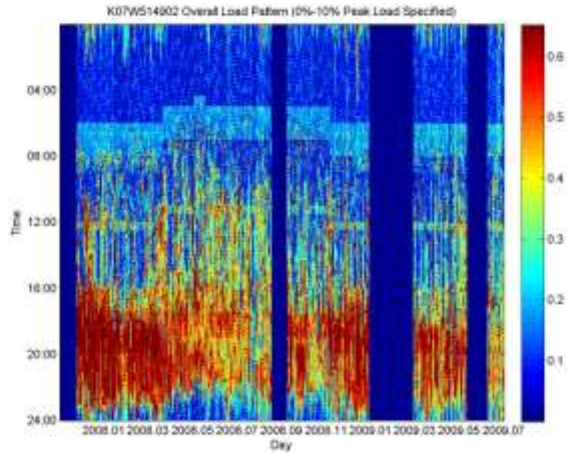

K07W514810 Overall Load Pattern
Time
Day

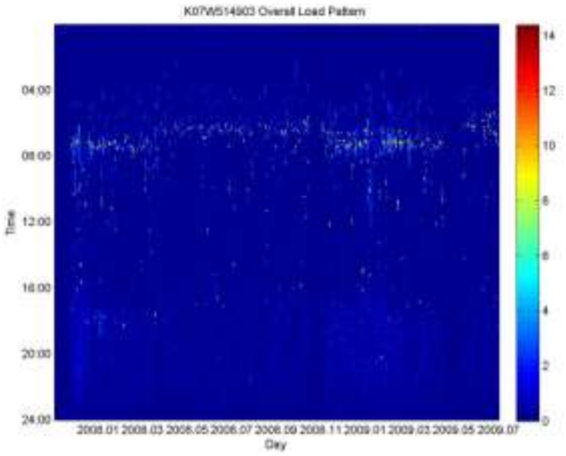

K07W514810 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

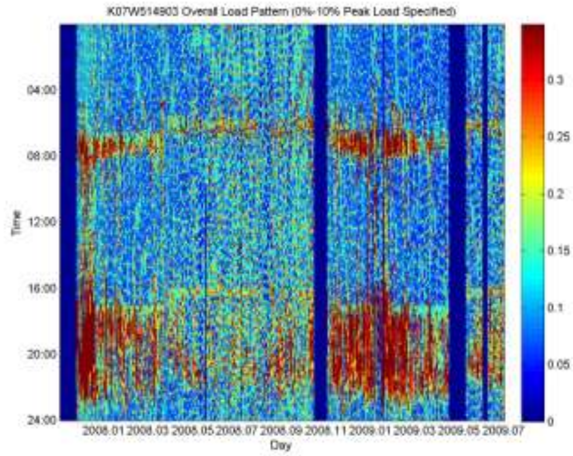

K07W514901 Overall Load Pattern
Time
Day

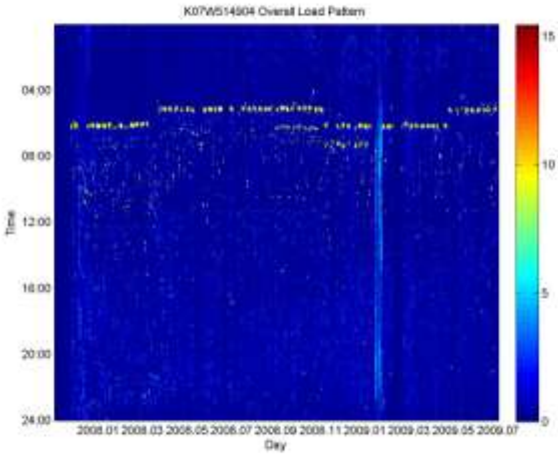

K07W514901 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

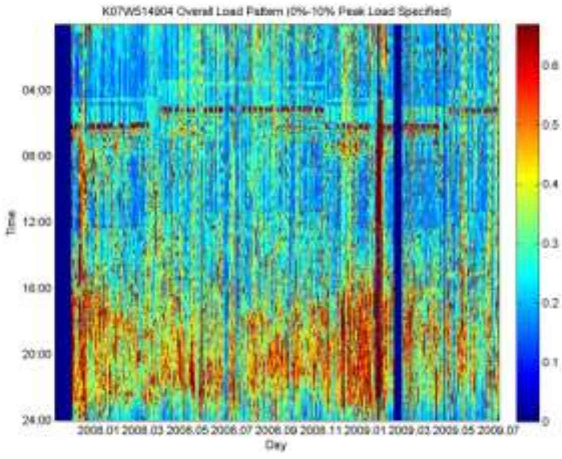

K07W514902 Overall Load Pattern
Time
Day

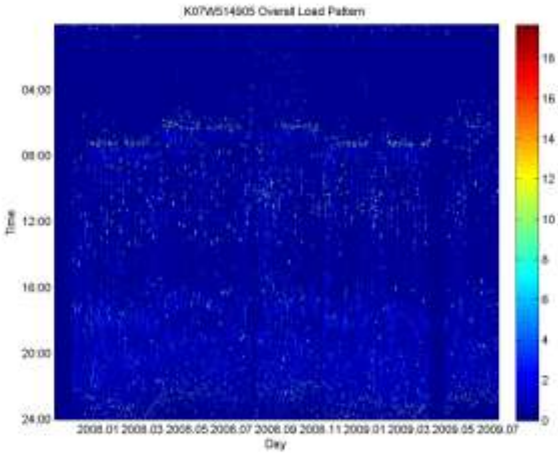

K07W514902 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

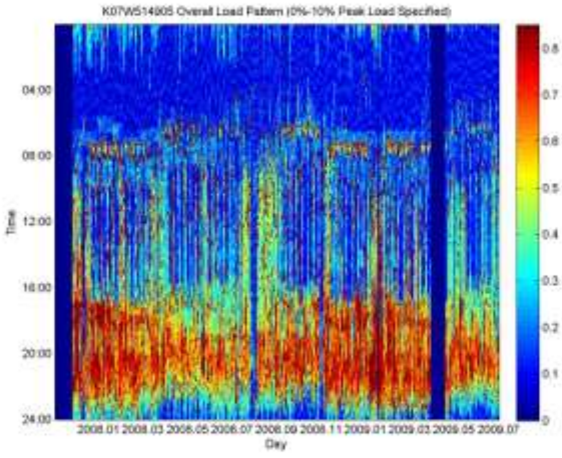

K07W514903 Overall Load Pattern
Time
Day

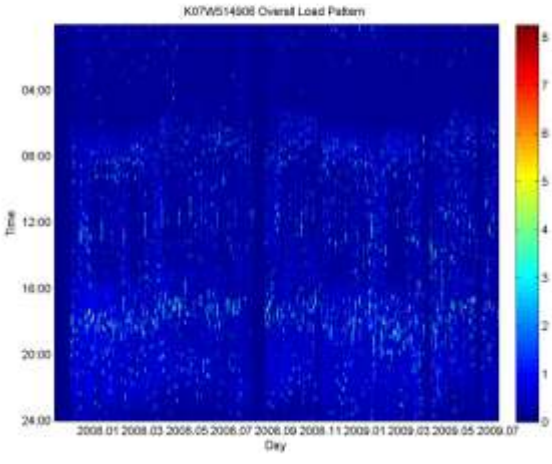

K07W514903 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

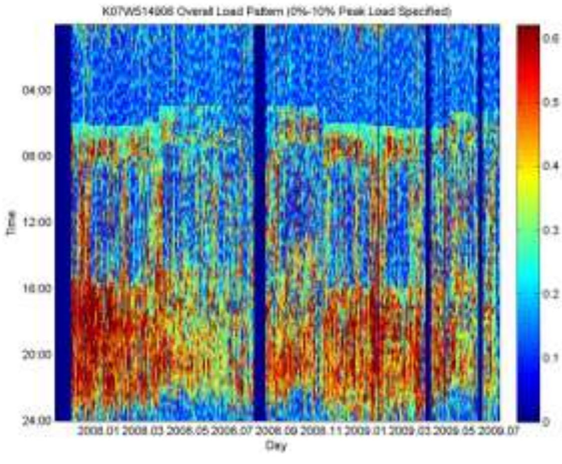

K07W514904 Overall Load Pattern
Time
Day

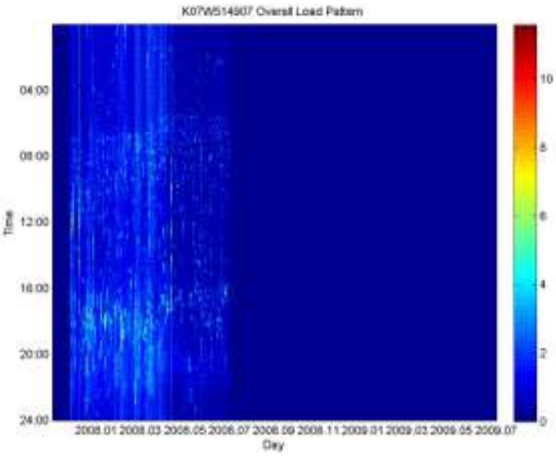

K07W514904 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

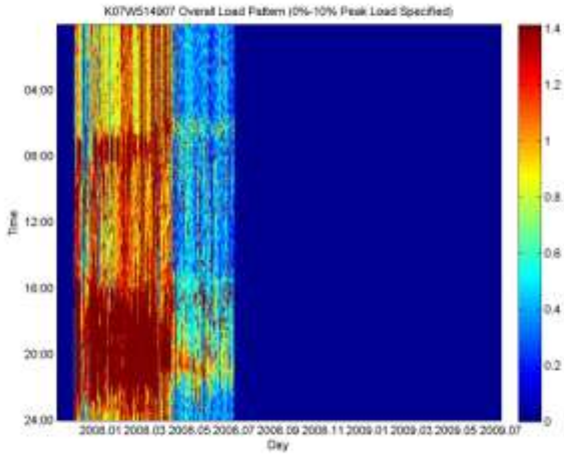

K07W514905 Overall Load Pattern
Time
Day

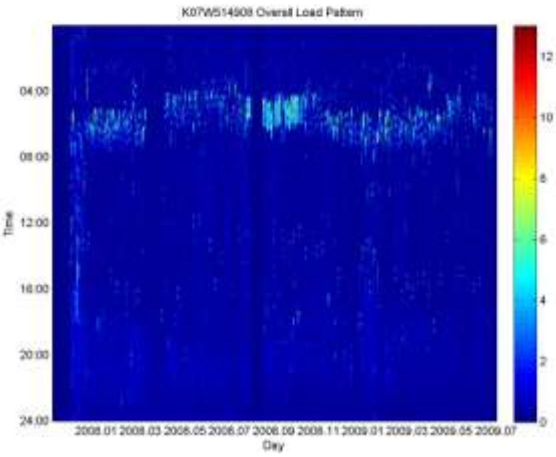

K07W514905 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

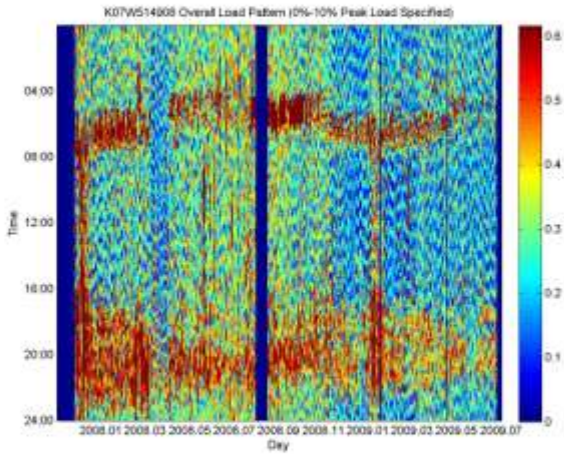

K07W514906 Overall Load Pattern
Time
Day

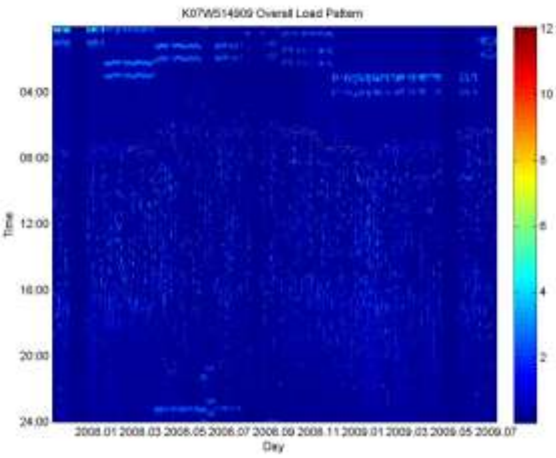

K07W514906 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

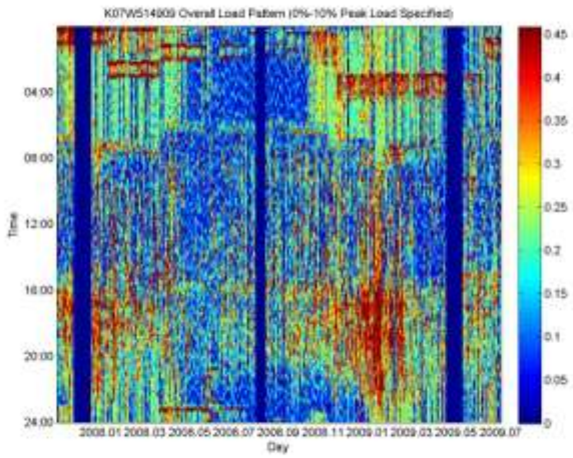

K07W514907 Overall Load Pattern
Time
Day

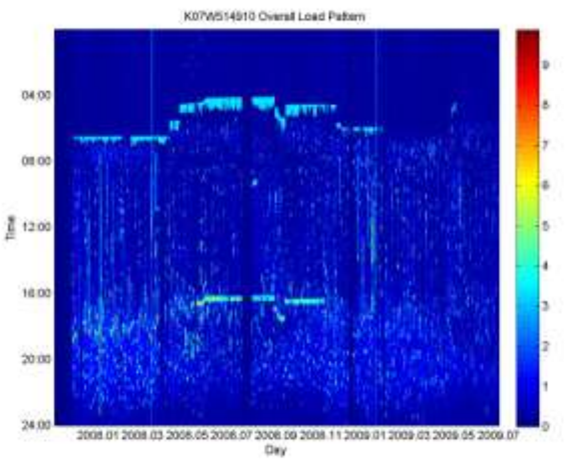

K07W514907 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

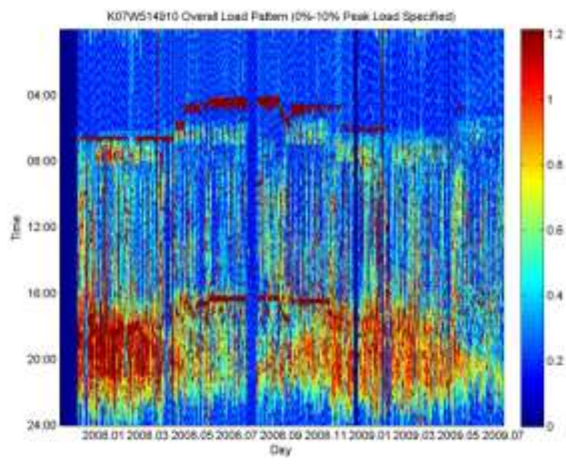

K07W514908 Overall Load Pattern
Time
Day

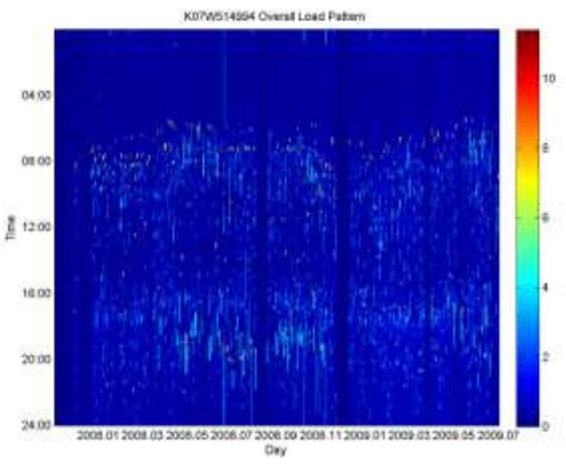

K07W514908 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

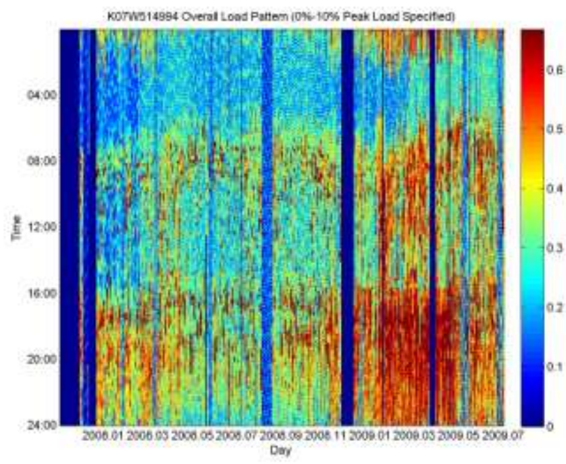

K07W514909 Overall Load Pattern
Time
Day

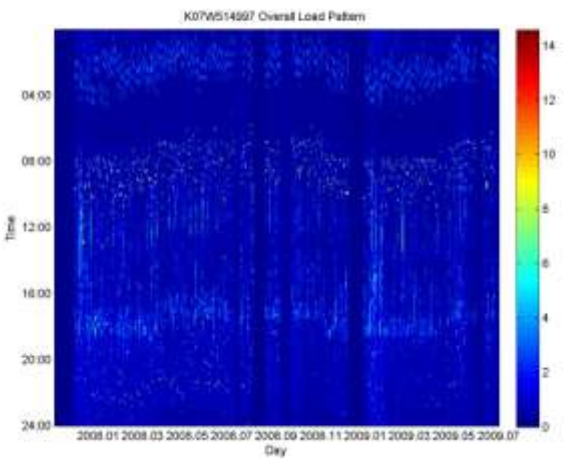

K07W514909 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

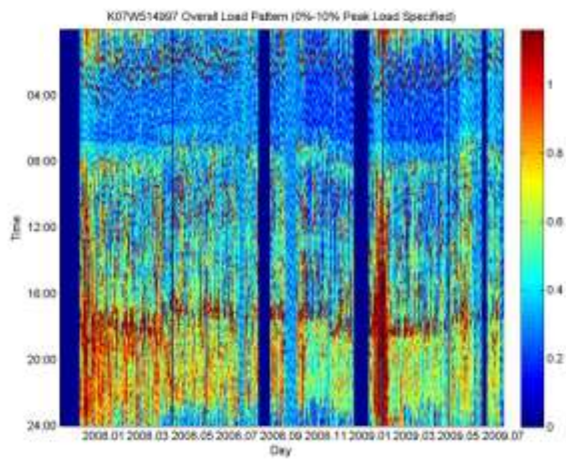

K07W514910 Overall Load Pattern
Time
Day

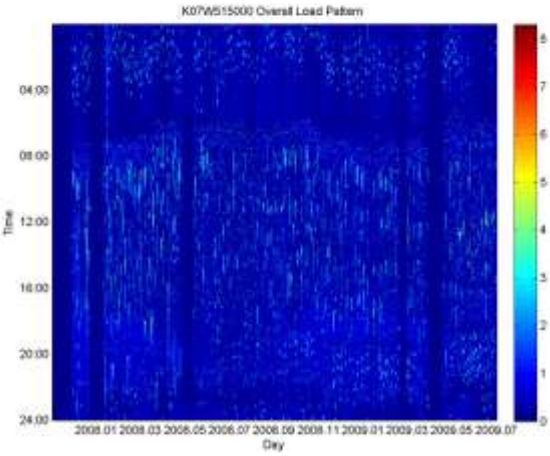

K07W514910 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day

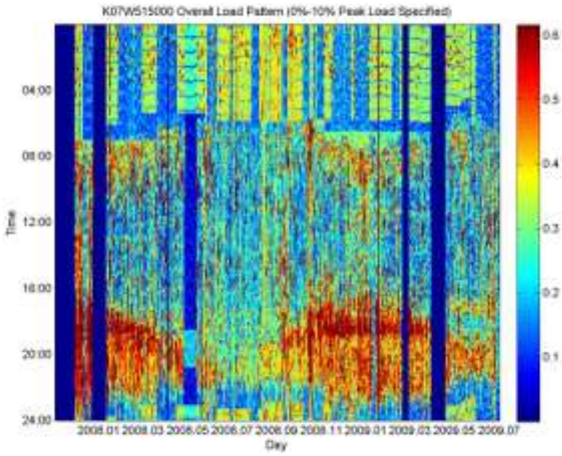

K07W514994 Overall Load Pattern
Time
Day


K07W514994 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day


K07W514997 Overall Load Pattern
Time
Day


K07W514997 Overall Load Pattern (0%-10% Peak Load Specified)
Time
Day


K07W515000 Overall Load Pattern
Time
04:00
08:00
12:00
16:00
20:00
24:00
2008.01 2008.03 2008.05 2008.07 2008.09 2008.11 2009.01 2009.03 2009.05 2009.07
Day
0
1
2
3
4
5
6
7
8


K07W515000 Overall Load Pattern (0%-10% Peak Load Specified)
Time
04:00
08:00
12:00
16:00
20:00
24:00
2008.01 2008.03 2008.05 2008.07 2008.09 2008.11 2009.01 2009.03 2009.05 2009.07
Day
0.1
0.2
0.3
0.4
0.5
0.6

B. Cross correlation coefficient matrix of consumers' time series load

Cross correlation coefficient matrix between the 13 consumers that meet the data requirements, calculated on a minute-by-minute basis.

	K07W514801	K07W514804	K07W514807	K07W514903	K07W514904	K07W514905	K07W514906	K07W514908	K07W514909	K07W514910	K07W514994	K07W514997	K07W515000
K07W514801	1.0000	0.0555	0.1041	0.0517	0.0335	0.0570	0.0902	-0.0116	0.0376	0.0974	0.0546	0.0761	0.0150
K07W514804	0.0555	1.0000	0.1047	0.0037	-0.0035	0.0841	0.1087	-0.0266	-0.0164	0.0793	0.0493	0.0438	0.0013
K07W514807	0.1041	0.1047	1.0000	0.0350	0.0238	0.0902	0.1633	-0.0173	0.0401	0.1746	0.0783	0.0884	0.0405
K07W514903	0.0517	0.0037	0.0350	1.0000	0.0350	0.0484	0.0446	0.0361	0.0102	0.0399	0.0249	-0.0022	0.0044
K07W514904	0.0335	-0.0035	0.0238	0.0350	1.0000	0.0356	0.0352	0.0878	0.0038	0.0447	0.0114	0.0078	-0.0056
K07W514905	0.0570	0.0841	0.0902	0.0484	0.0356	1.0000	0.1042	-0.0060	0.0139	0.0898	0.0606	0.0525	0.0203
K07W514906	0.0902	0.1087	0.1633	0.0446	0.0352	0.1042	1.0000	-0.0109	0.0250	0.1495	0.0895	0.1014	0.0342
K07W514908	-0.0116	-0.0266	-0.0173	0.0361	0.0878	-0.0060	-0.0109	1.0000	-0.0305	0.0669	-0.0343	-0.0477	-0.0381
K07W514909	0.0376	-0.0164	0.0401	0.0102	0.0038	0.0139	0.0250	-0.0305	1.0000	0.0132	0.0130	0.0518	0.0141
K07W514910	0.0974	0.0793	0.1746	0.0399	0.0447	0.0898	0.1495	0.0669	0.0132	1.0000	0.0648	0.0945	0.0277
K07W514994	0.0546	0.0493	0.0783	0.0249	0.0114	0.0606	0.0895	-0.0343	0.0130	0.0648	1.0000	0.0379	0.0191
K07W514997	0.0761	0.0438	0.0884	-0.0022	0.0078	0.0525	0.1014	-0.0477	0.0518	0.0945	0.0379	1.0000	0.0306
K07W515000	0.0150	0.0013	0.0405	0.0044	-0.0056	0.0203	0.0342	-0.0381	0.0141	0.0277	0.0191	0.0306	1.0000

Cross correlation coefficient matrix of hourly average loads between the 13 consumers that meet the data requirements.

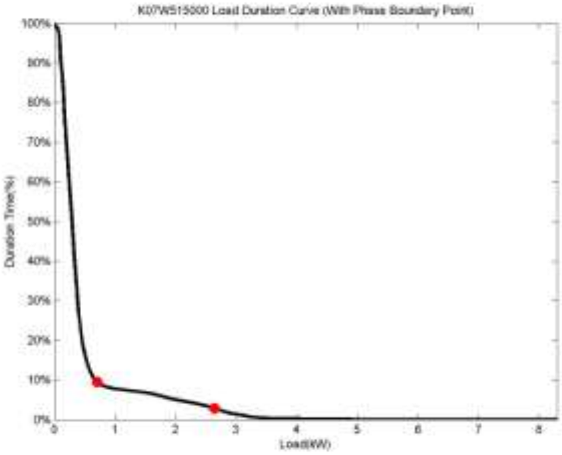
	K07W514801	K07W514804	K07W514807	K07W514903	K07W514904	K07W514905	K07W514906	K07W514908	K07W514909	K07W514910	K07W514994	K07W514997	K07W515000
K07W514801	1.0000	0.0188	0.1817	0.2416	0.0774	0.2127	0.2346	0.0099	0.0240	0.2386	0.0942	0.0983	0.0334
K07W514804	0.0188	1.0000	0.1453	0.0532	0.0106	0.1155	0.2053	0.0059	-0.0862	0.1780	0.0393	0.0946	0.0026
K07W514807	0.1817	0.1453	1.0000	0.1180	0.1090	0.3613	0.4420	-0.0360	0.0328	0.4724	0.2489	0.2481	0.0877
K07W514903	0.2416	0.0532	0.1180	1.0000	0.1283	0.2471	0.1782	0.0913	-0.0210	0.2095	0.0767	0.0253	0.0228
K07W514904	0.0774	0.0106	0.1090	0.1283	1.0000	0.1260	0.1252	0.2659	-0.0914	0.1915	0.0294	0.0226	-0.0323
K07W514905	0.2127	0.1155	0.3613	0.2471	0.1260	1.0000	0.4109	-0.0126	-0.0168	0.3995	0.2656	0.2539	0.0982
K07W514906	0.2346	0.2053	0.4420	0.1782	0.1252	0.4109	1.0000	-0.0233	0.0344	0.5045	0.2224	0.3272	0.1261
K07W514908	0.0099	0.0059	-0.0360	0.0913	0.2659	-0.0126	-0.0233	1.0000	-0.1333	0.0839	-0.0692	-0.1498	-0.1371
K07W514909	0.0240	-0.0862	0.0328	-0.0210	-0.0914	-0.0168	0.0344	-0.1333	1.0000	0.0024	0.0026	0.1426	0.0221
K07W514910	0.2386	0.1780	0.4724	0.2095	0.1915	0.3995	0.5045	0.0839	0.0024	1.0000	0.2123	0.3046	0.0732
K07W514994	0.0942	0.0393	0.2489	0.0767	0.0294	0.2656	0.2224	-0.0692	0.0026	0.2123	1.0000	0.1580	0.1158
K07W514997	0.0983	0.0946	0.2481	0.0253	0.0226	0.2539	0.3272	-0.1498	0.1426	0.3046	0.1580	1.0000	0.1308
K07W515000	0.0334	0.0026	0.0877	0.0228	-0.0323	0.0982	0.1261	-0.1371	0.0221	0.0732	0.1158	0.1308	1.0000

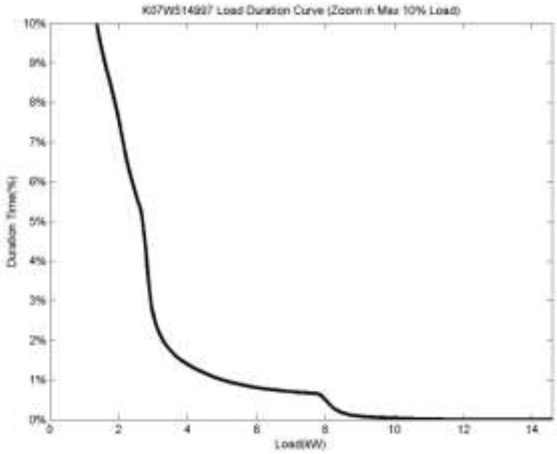
Cross correlation coefficient matrix of hourly maximum loads between the 13 consumers that meet the data requirements.

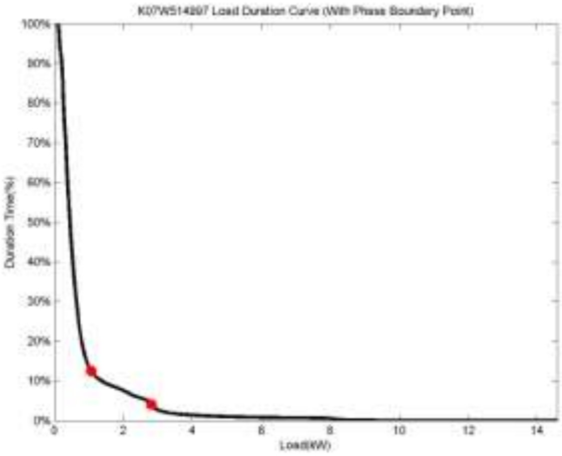
	K07W514801	K07W514804	K07W514807	K07W514903	K07W514904	K07W514905	K07W514906	K07W514908	K07W514909	K07W514910	K07W514994	K07W514997	K07W515000
K07W514801	1.0000	0.1047	0.1748	0.1538	0.0865	0.0852	0.1685	-0.0149	0.1124	0.1612	0.0722	0.1217	0.0759
K07W514804	0.1047	1.0000	0.1731	0.1238	0.0754	0.1905	0.1570	-0.0509	0.1108	0.1134	0.1066	0.0933	0.0566
K07W514807	0.1748	0.1731	1.0000	0.1782	0.1122	0.1838	0.3057	-0.0519	0.1326	0.3008	0.2104	0.1933	0.1514
K07W514903	0.1538	0.1238	0.1782	1.0000	0.2052	0.1849	0.2002	0.1498	0.1829	0.1763	0.0786	0.1134	0.0927
K07W514904	0.0865	0.0754	0.1122	0.2052	1.0000	0.1155	0.1251	0.1906	0.0703	0.1581	0.0599	0.0446	0.0306
K07W514905	0.0852	0.1905	0.1838	0.1849	0.1155	1.0000	0.1969	0.0061	0.1068	0.1505	0.1163	0.0877	0.0728
K07W514906	0.1685	0.1570	0.3057	0.2002	0.1251	0.1969	1.0000	-0.0220	0.1492	0.2719	0.1996	0.1989	0.1500
K07W514908	-0.0149	-0.0509	-0.0519	0.1498	0.1906	0.0061	-0.0220	1.0000	-0.0363	0.0902	-0.0774	-0.1015	-0.1194
K07W514909	0.1124	0.1108	0.1326	0.1829	0.0703	0.1068	0.1492	-0.0363	1.0000	0.0956	0.0914	0.1110	0.1106
K07W514910	0.1612	0.1134	0.3008	0.1763	0.1581	0.1505	0.2719	0.0902	0.0956	1.0000	0.1456	0.1400	0.1117
K07W514994	0.0722	0.1066	0.2104	0.0786	0.0599	0.1163	0.1996	-0.0774	0.0914	0.1456	1.0000	0.1702	0.1348
K07W514997	0.1217	0.0933	0.1933	0.1134	0.0446	0.0877	0.1989	-0.1015	0.1110	0.1400	0.1702	1.0000	0.1348
K07W515000	0.0759	0.0566	0.1514	0.0927	0.0306	0.0728	0.1500	-0.1194	0.1106	0.1117	0.1348	0.1348	1.0000

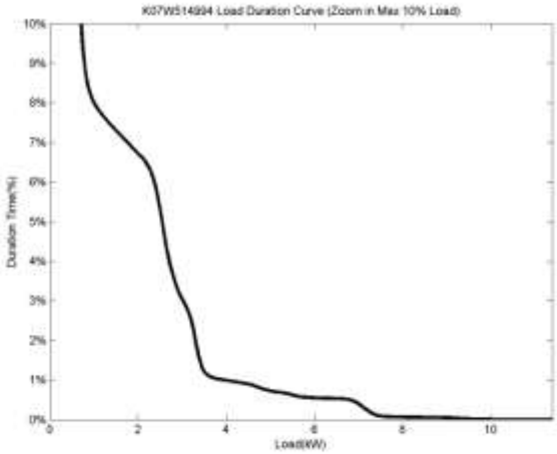
C. Load duration curve of all consumers

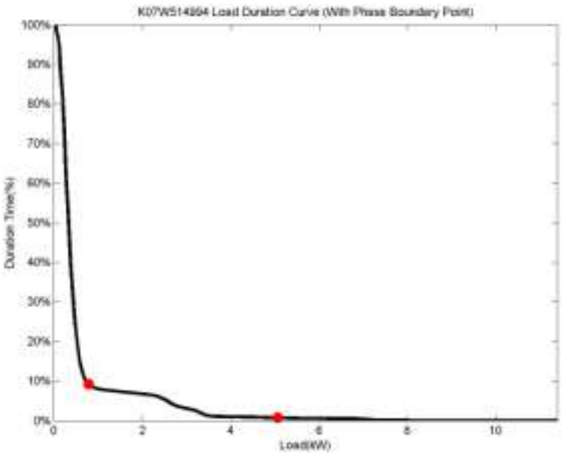
The graphs on the left show the entire load duration curves with boundary points. The graphs on the right are zoomed to show the top 10% loads in order to give a closer view of the high load area.

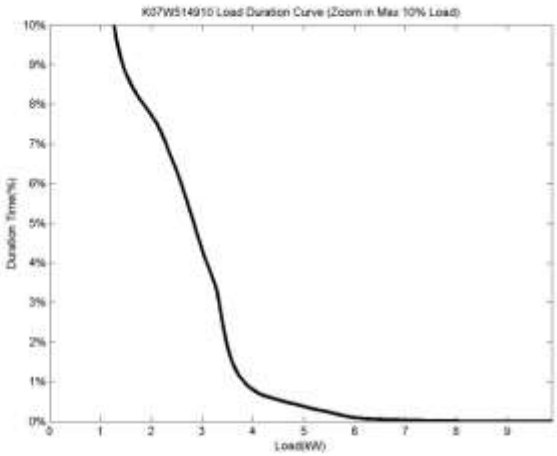


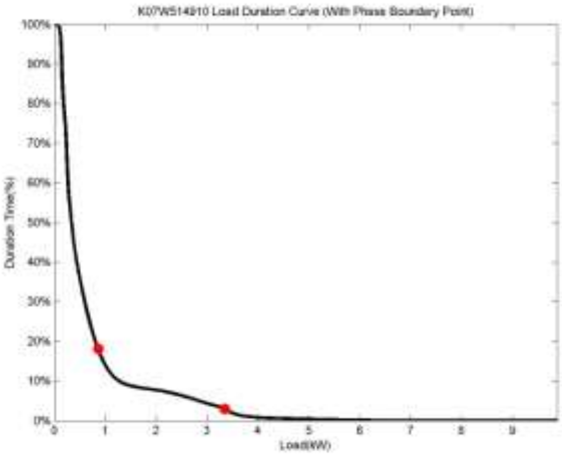








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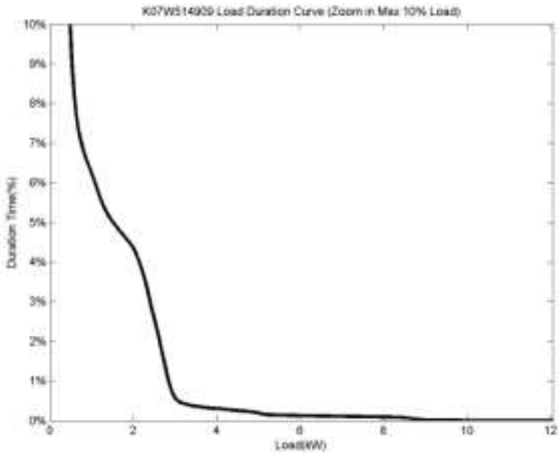
Duration Time(%)
Load(kW)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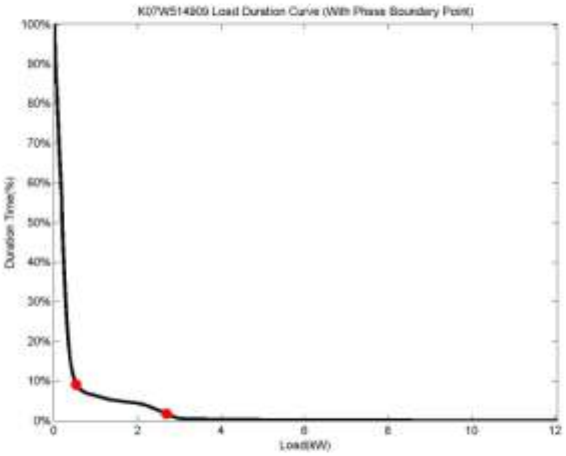
Duration Time(%)
Load(kW)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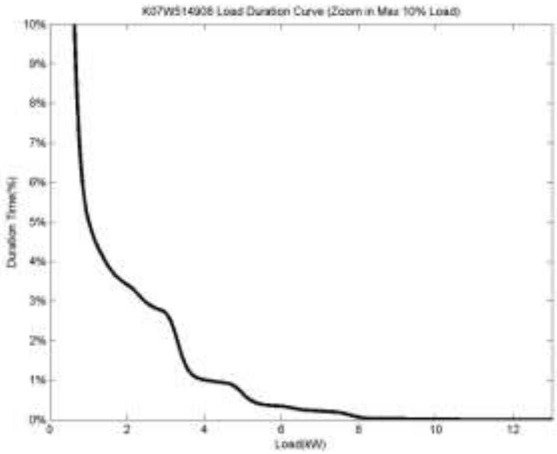
Duration Time(%)
Load(kW)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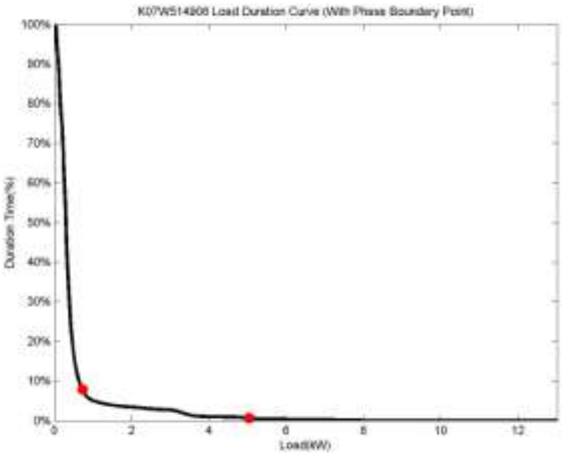
Duration Time(%)
Load(kW)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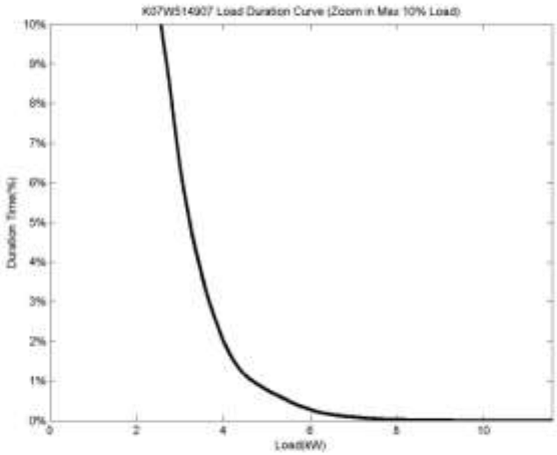
Duration Time(%)
Load(kW)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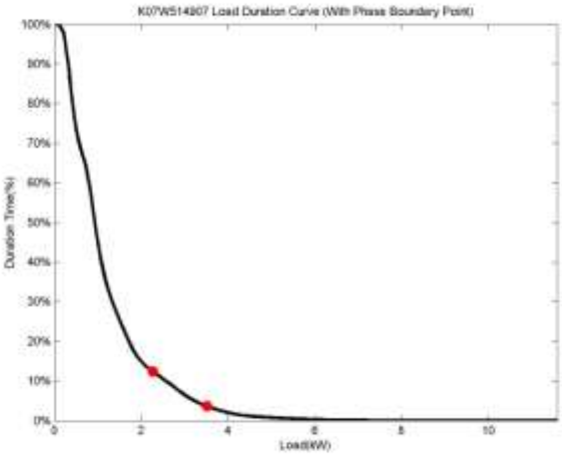
Duration Time(%)
Load(kW)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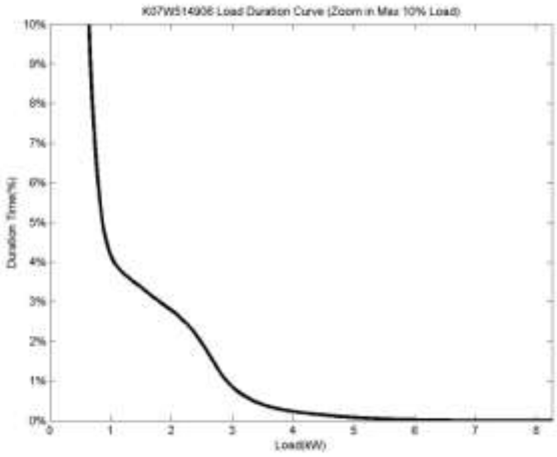
Duration Time(%)
Load(kW)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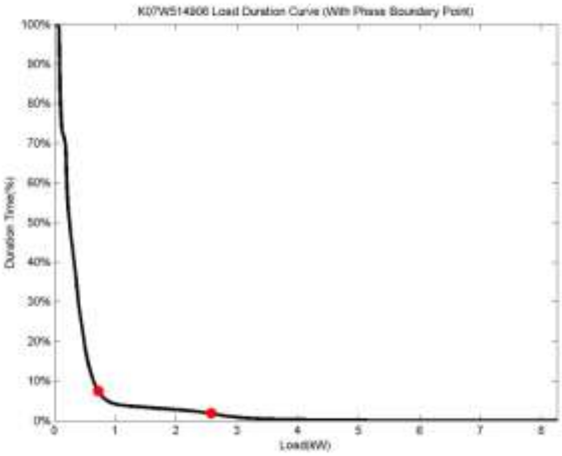
Duration Time(%)
Load(kW)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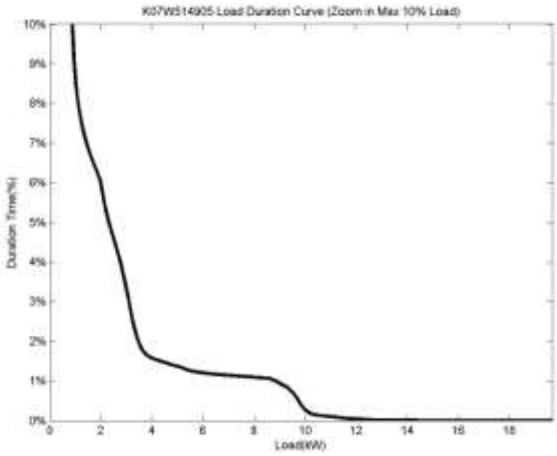
Duration Time(%)
Load(kW)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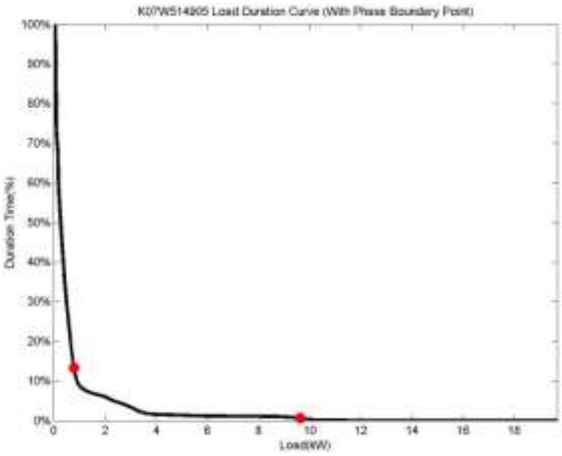
Duration Time(%)
Load(kW)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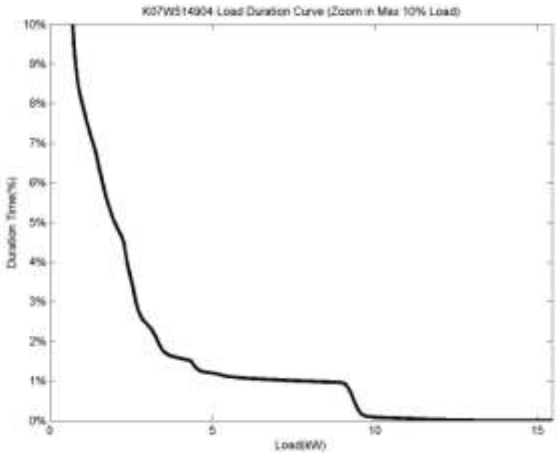
Duration Time(%)
Load(kW)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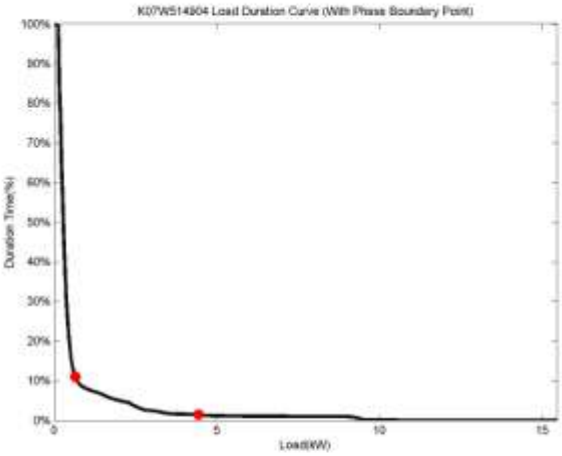
Duration Time(%)
Load(kW)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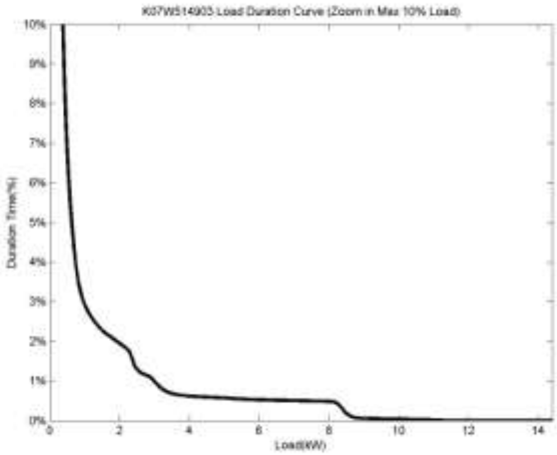
Duration Time(%)
Load(kW)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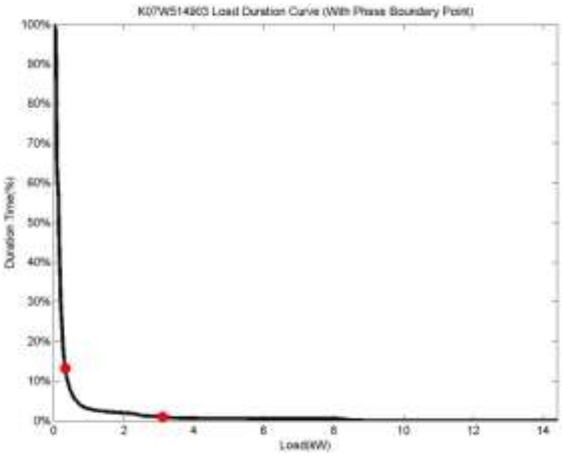
Duration Time(%)
Load(kW)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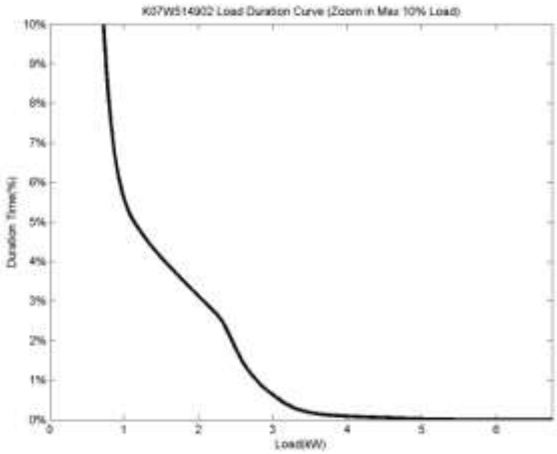
Duration Time(%)
Load(kW)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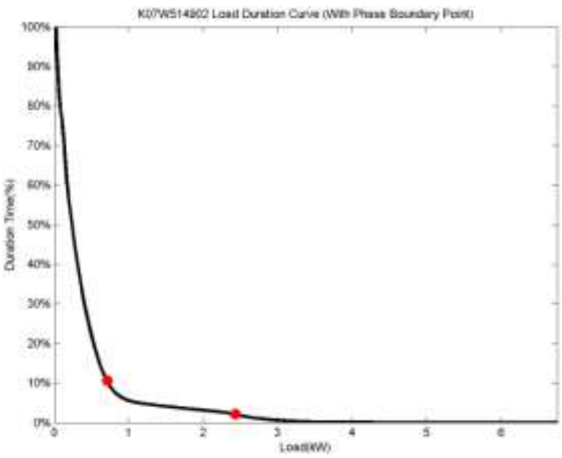
Duration Time(%)
Load(kW)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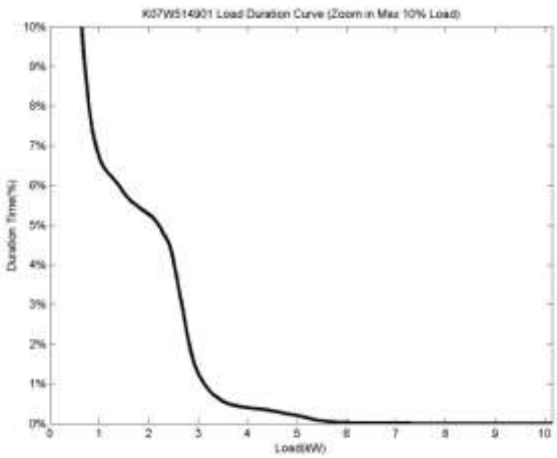
Duration Time(%)
Load(kW)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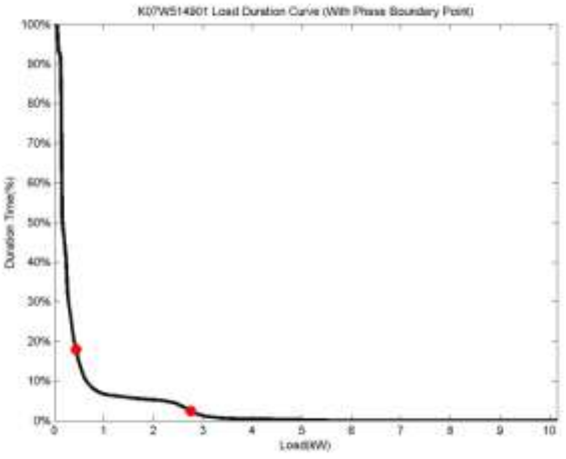
Duration Time(%)
Load(kW)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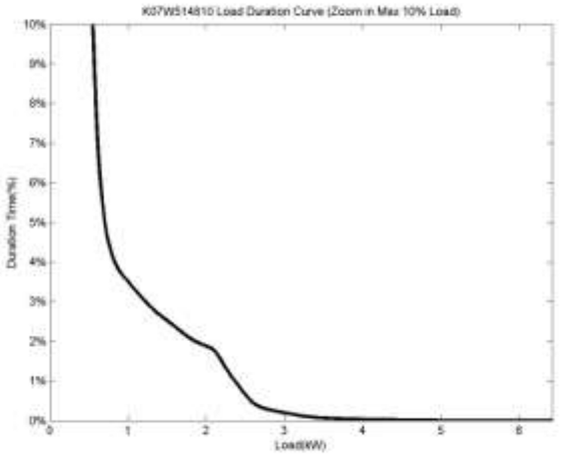
Duration Time(%)
Load(kW)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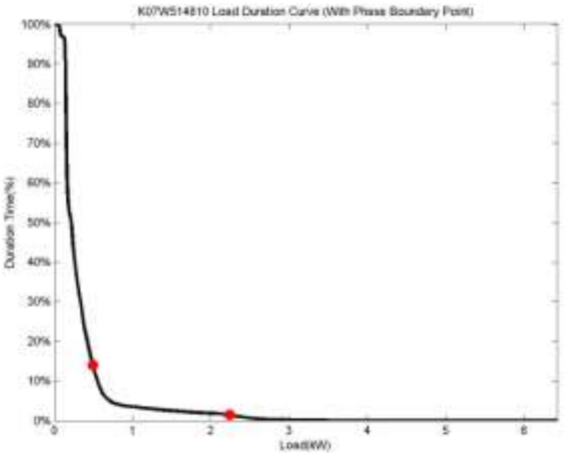
Duration Time(%)
Load(kW)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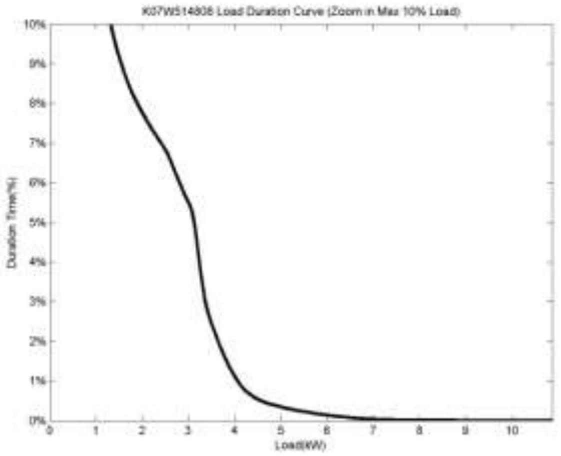
Duration Time(%)
Load(kW)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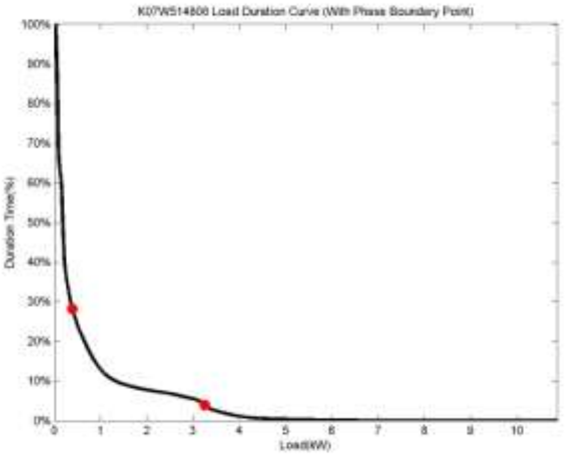
Duration Time(%)
Load(kW)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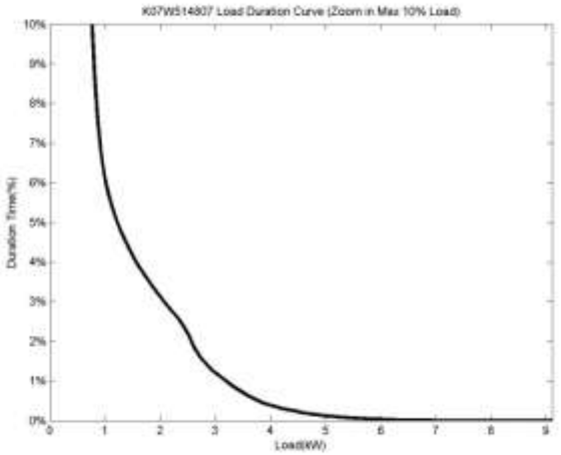
Duration Time(%)
Load(kW)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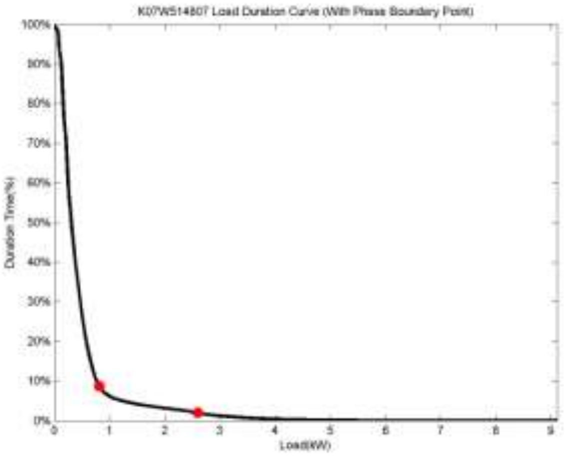
Load(kW)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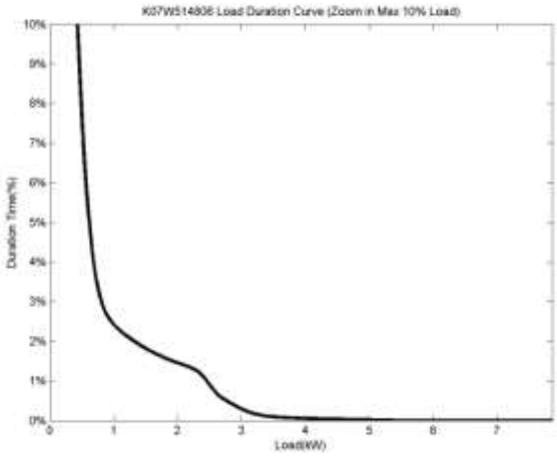
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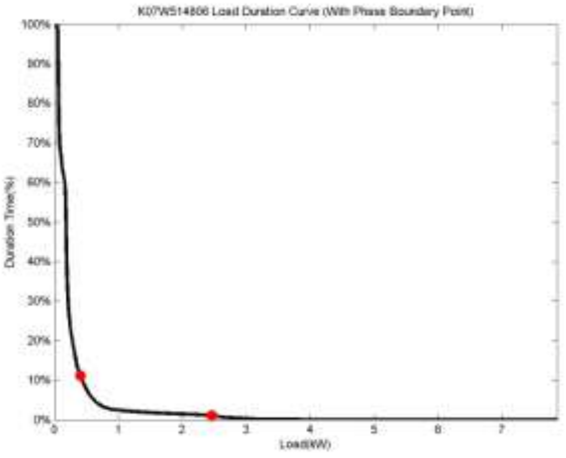
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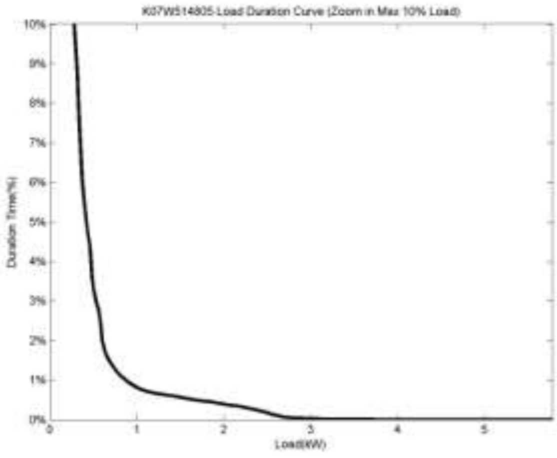
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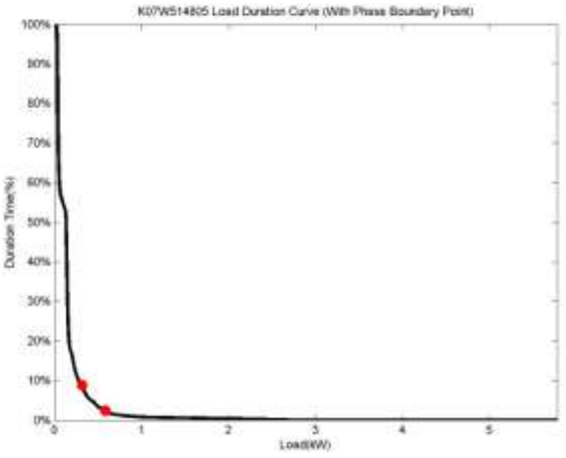
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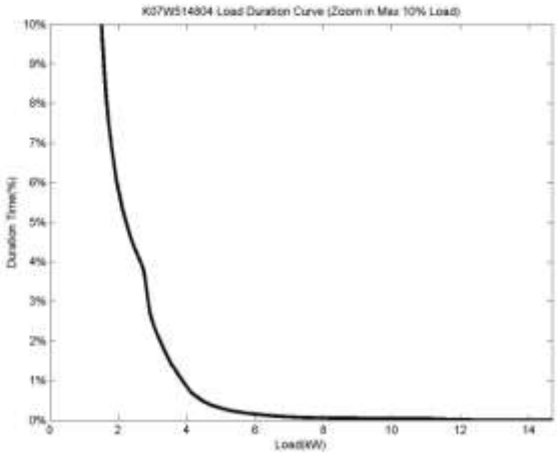
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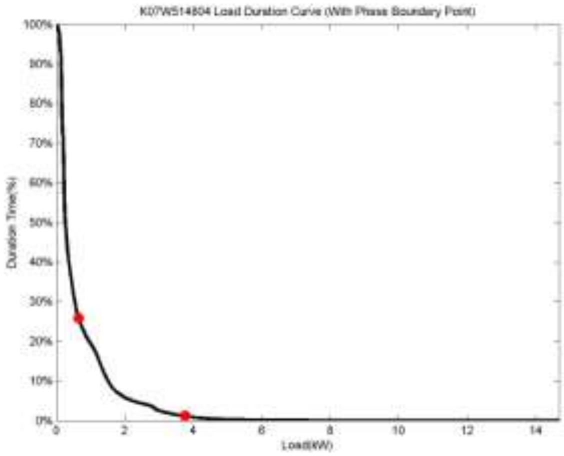
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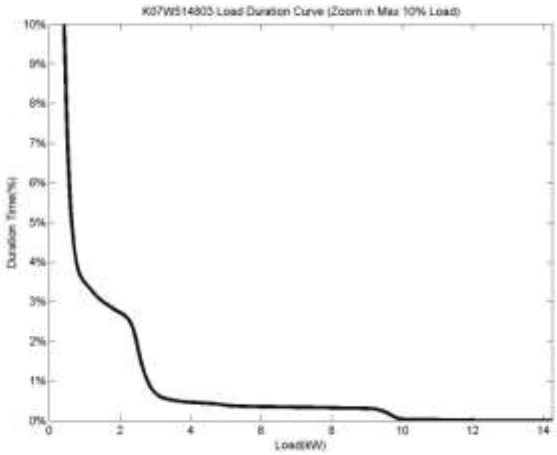
Duration Time(%)
Load(kW)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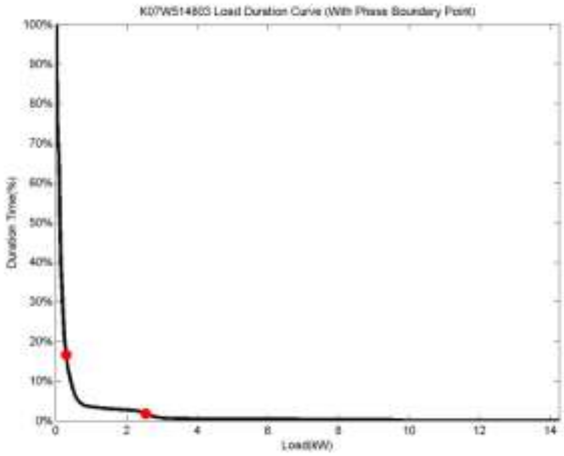
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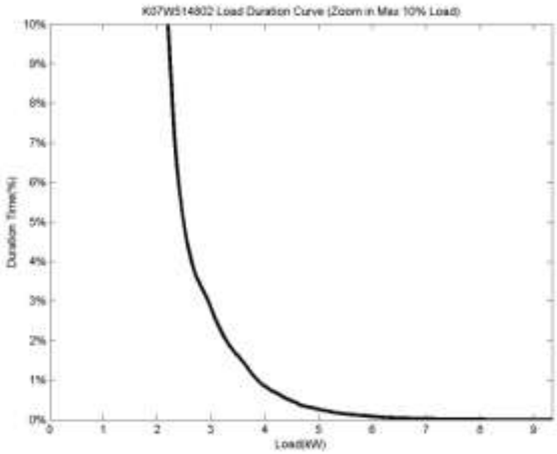
Duration Time(%)
Load(kW)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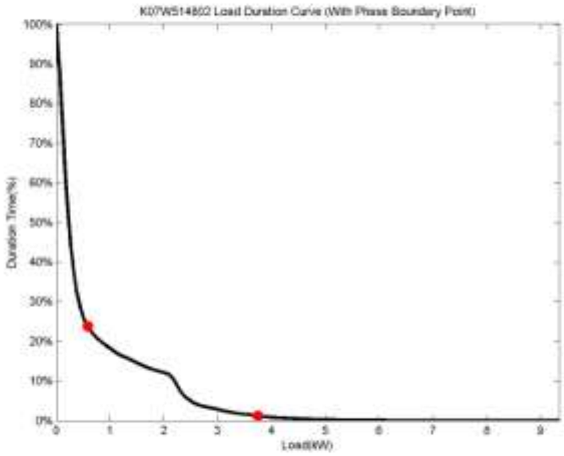
Duration Time(%)
Load(kW)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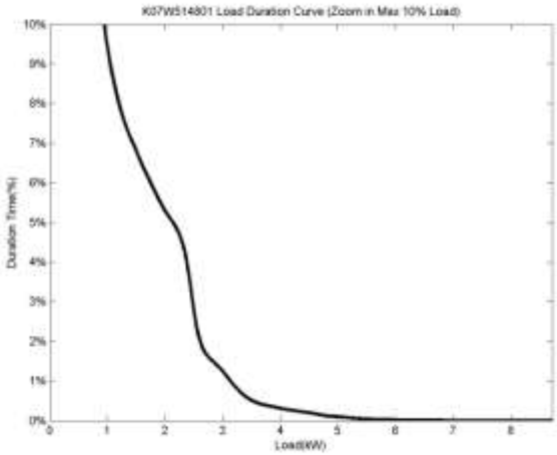
Duration Time(%)
Load(kW)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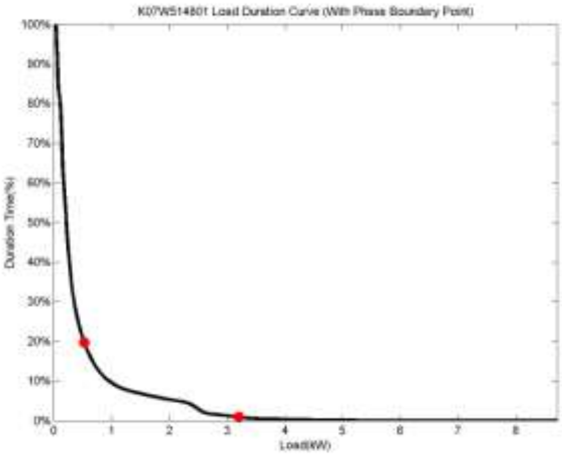
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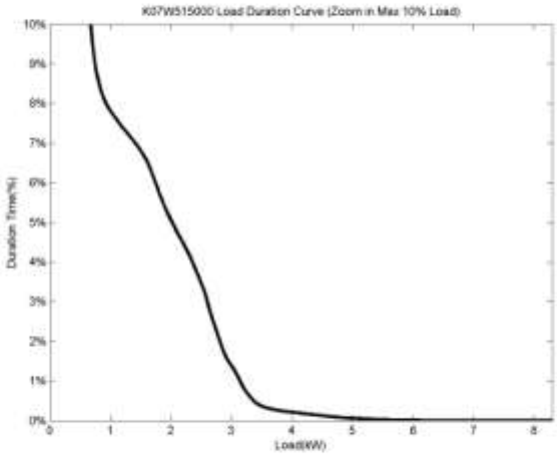
Duration Time(%)
Load(kW)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Load(kW)