# Energy Saving Report

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# 1 Executive Summary

Innovative Polymers Pte Ltd (IP) developed and manufactured the DeCaIon™ (DCI) system, an innovative approach to manage cooling water that removed scales, corrosion and manage cooling tower water bacteria.

DCI is a novel electro-chemical water treatment process developed and patented by IP. DCI is intended to replace both the blow-down and chemical dosing cycles of typical cooling towers as an 'eco-friendly' and chemical-free alternative. IP installed the DCI system at Keppel Bay Towers (KBT) located at 1 Harbourfront Avenue, Singapore, as part of the BCA-Keppel Land Joint Challenge call for test-bedding of sustainable solutions.

This report is as an extension to the of EWTCOI report, **"Performance Evaluation of DECAION Water Treatment System for a Cooling Tower System"** dated in 16 April 2019 in which the evaluation was based on data collected up to April 2019 only.

Baseline and post-retrofit data were collected from the Chiller Plant Building Management System (BMS) at KBT along with manual meter readings. While some issues with the condenser water pumps were experienced, eventually these were resolved. Data models produced were found to be statistically valid.

The main findings from the evaluation of the DCI system are as follows:

| Scope | Change |
| --- | --- |
| Chiller Power Consumption | 8 – 12% reduction |
| Chiller Plant Power consumption | 7.01% reduction at 70% Load |
| Blow down Water consumption | 81.4% reduction |
| Make up water consumption | 8.7% reduction |
| Cooling Tower water quality | Water Chemistry in DCI are kept within limits |
| Others | Bacteria in Cooling water are kept within NEA limits |
| Corrosion measured as Fe and Cu | Within industrial guideline limits |

## 2 Introduction

The purpose of this report is to compare the energy efficiency of the KBT air conditioning plant before and after installing the DCI water treatment system.

The first part of the report focuses on energy saving of the air-conditioning plant. For this purpose, four different ways are adopted to interpret the data as follows:-

1. The kW/RT baseline model established using BMS data for chillers 3 & 4
2. The chiller efficiency (chillers 3&4) comparison between different periods with inclusion of respective environmental factors.
3. The kW/RT model comparison using data from chillers 1,3 and 4
4. The plant kWh/RTh comparison of each month

All data are extracted from the KBT BMS system.

The second part of this report will discuss on the topic of water and chemical saving.

1. The DCI electrochemical method of scale removal resulting in water consumption reduction
2. The DCI CataGreen™ chemical free disinfection technology keeping the bacteria counts within the stipulated limits

# 3 kW/RT comparison

Baseline data were collected from 01 Nov – 30 Nov 2018 for the power and flow rates. Post-retrofit data were collected monthly from 01 Dec 2018 – 29 Feb 2020. Figure 1 through Figure 6 show the daily total cooling loads and power consumption in November 2018 (Figure 1 & Figure 2), August 2019 (Figure 3 & Figure 4) and February 2020 (Figure 5 & Figure 6).These data were analyzed using data analytics tools.

## 3.1 Baseline data

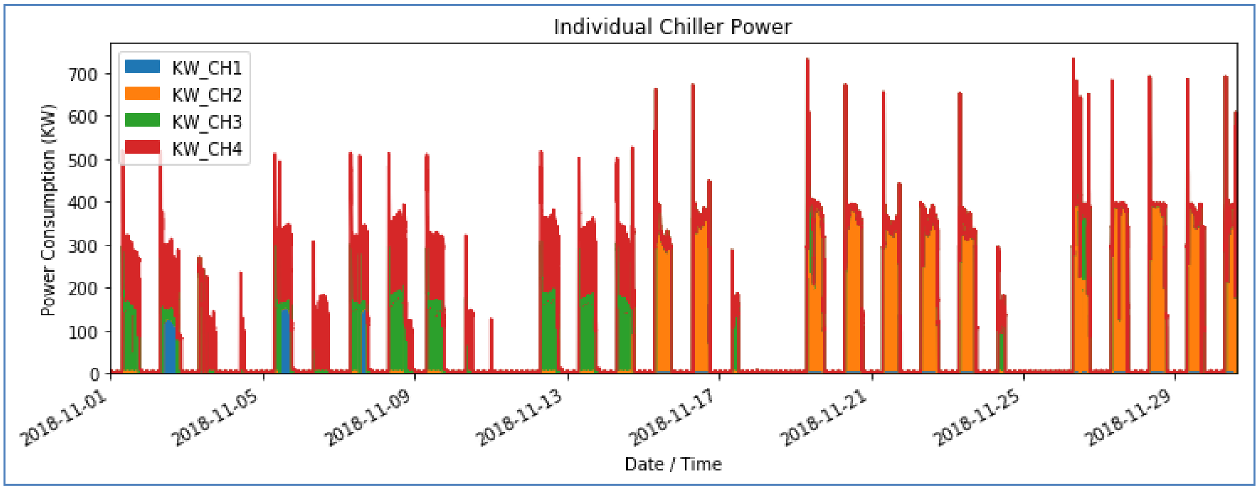



Figure 1: Daily Power Consumption by Chiller for November 2018

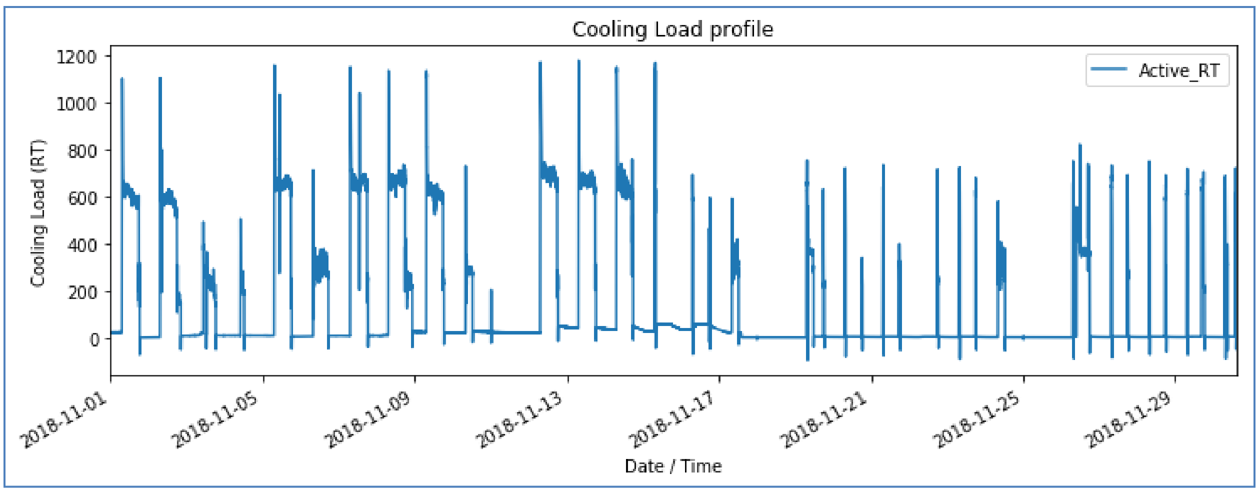



Figure 2: Daily Cooling Load for November 2018 (Excluding Chiller 2)

It is to be noted that the Chiller 2 readings are excluded in Figure 2 because its' chilled water flow rate sensor was faulty at the time of measurement.

During the baseline period shown in Figure 1, Chillers 3 and 4 simultaneously had some technical issues in the middle of the month. Chiller 2, which is older and typically not operated due to its' lower efficiency was put on line instead. As a result, only 2 weeks of baseline data were admissible for chillers 3 and 4 which were used to generate the baseline data.

## 3.2 Post Retrofit data

From all the data collected, only data from chillers 3 and 4 are selected for relevant comparison against the baseline data.

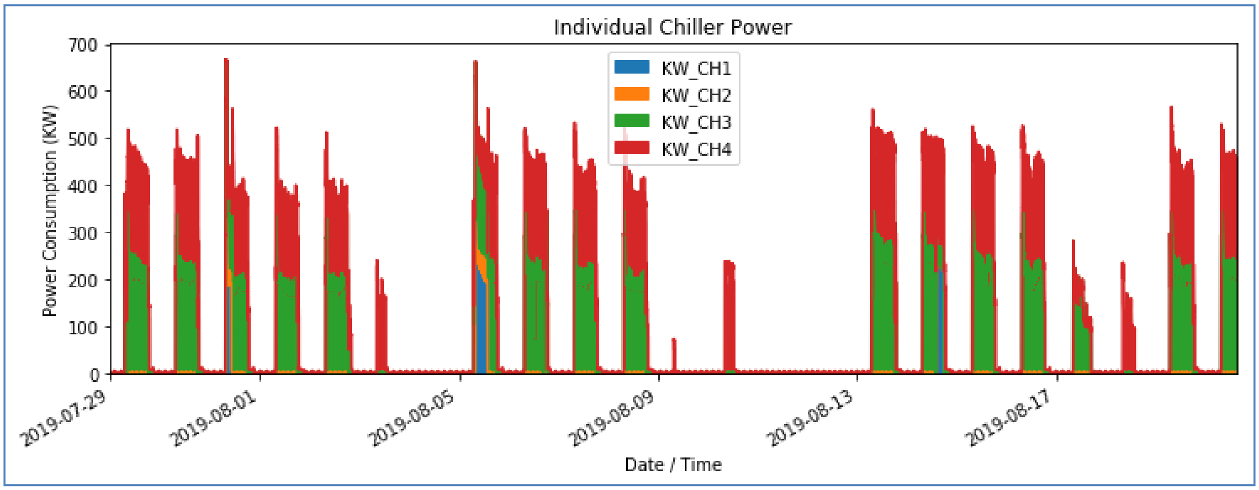



**Figure 3: Daily Power Consumption by Chiller for August 2019**

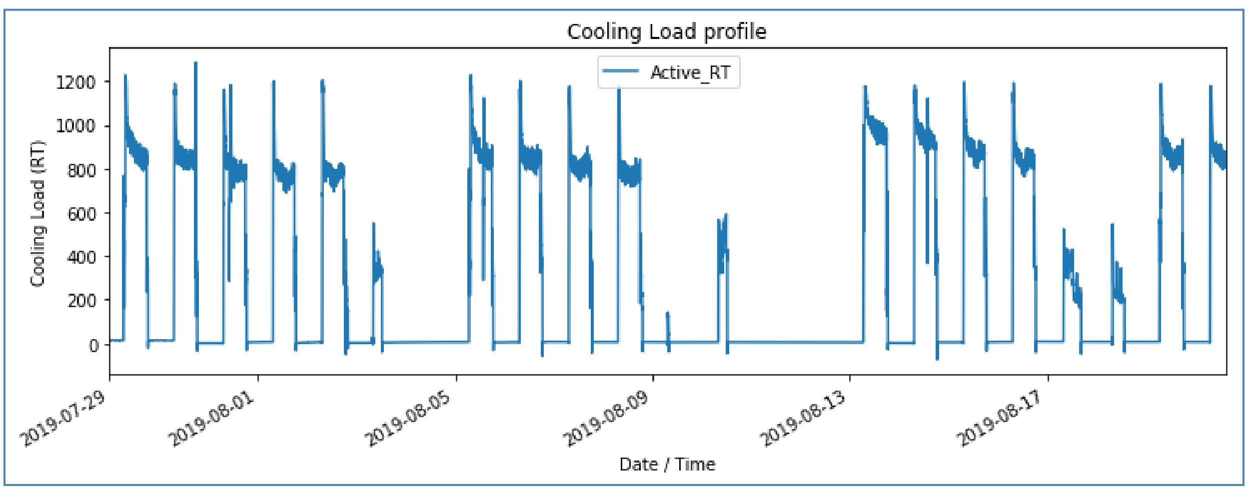



**Figure 4: Daily Cooling Load for August 2019 (Excluding Chiller 2)**

Fig 4 shows the August 2019 relevant cooling load data of chillers 3 and 4. Predominantly, only chillers 3 and 4 were used in this period.

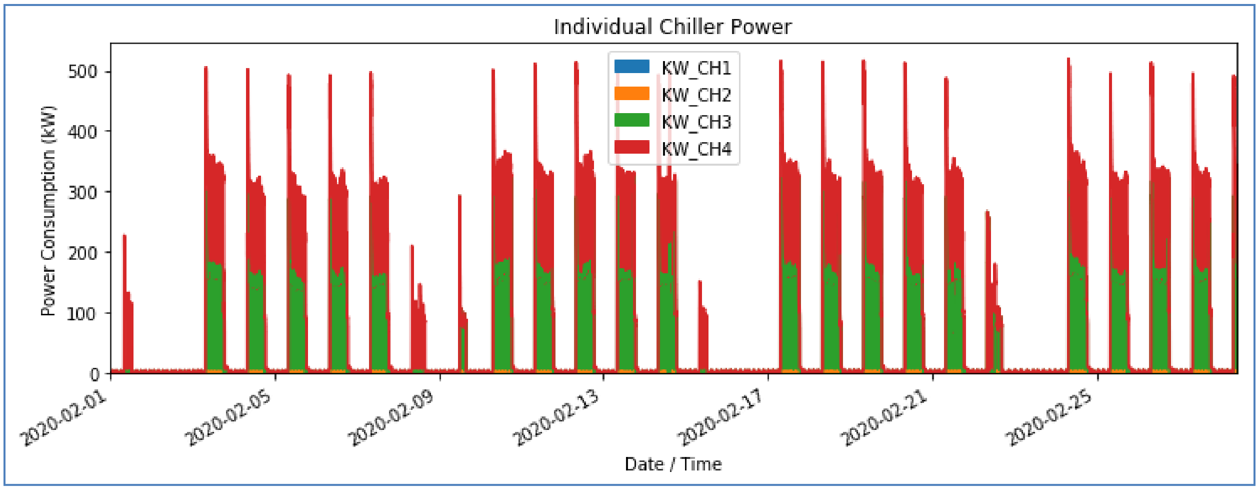



**Figure 5: Daily Power Consumption by Chiller for February 2020**

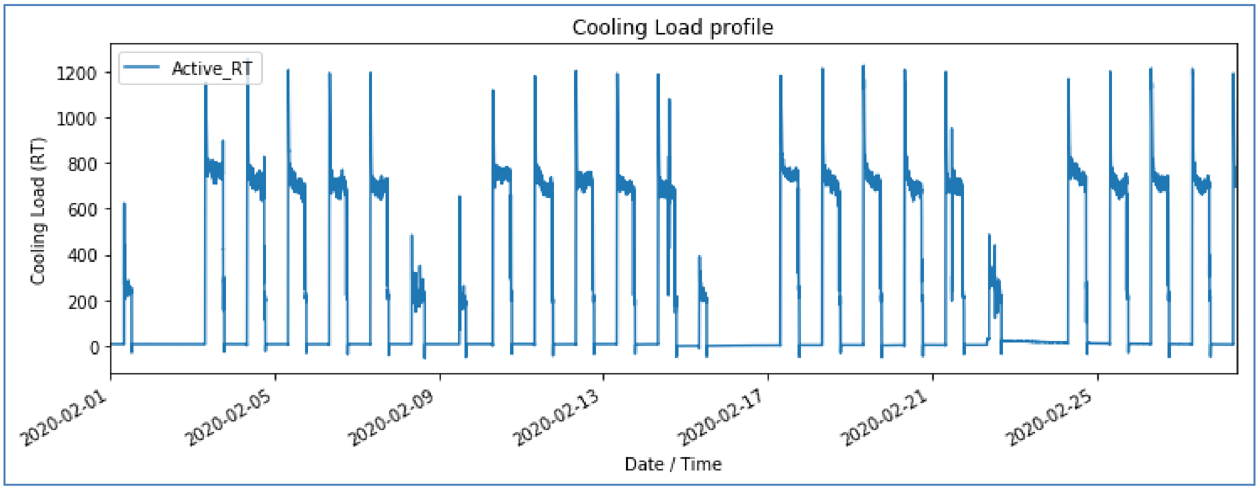



**Figure 6: Daily Cooling Load for February 2020 (Excluding Chiller 2)**

Figure 5 and Figure 6 show the February 2020 data. During this period, only chillers 3 and 4 were used throughout the entire month providing a large amount of relevant data for comparison.

Same data cleansing method was used for all 3 months to obtain the relevant datasets.

## 3.3 Energy data

A summary of the key energy parameters calculated is shown in Table 1. The values shown here are the raw overall calculated values. Therefore, the efficiency figures are required to be normalized using regression models to calculate the energy savings.

| Parameters | Units | Baseline (Nov 2018) | Post-Retrofit (Aug 2019) | Post-Retrofit (Feb 2020) |
|---|---|---|---|---|
| Average Building Load | RT | 495.0 | 738.2 | 657.0 |
| Average Chiller Power | kW | 250.1 | 363.5 | 296.5 |
| Average Plant Power | kW | 301.4 | 444.8 | 377.8 |
| Average Operating Capacity* | % | 44 | 66 | 59 |
| Average Chiller Efficiency | kW/RT | 0.505 | 0.494 | 0.451 |
| Average Plant Efficiency | kW/RT | 0.609 | 0.603 | 0.575 |

**Table 1 Summary of Key Parameters between Baseline and Post Retrofit data**

* For calculation of operating capacity, 1120 RT is used as the 100% capacity which is the combined maximum rated capacity of chillers 3 and 4 (only two chillers were used during normal operation).

To obtain the chiller power savings, the total cooling loads were mapped against the total chiller powers with regression models for each data set in Figure 7. The baseline data points are represented by the purple dots and modeled by the red dashed line. For post-retrofit data points, the Aug 2019 data are represented by the orange dots and modeled by the blue dashed line while Feb 2020 data are represented by the dark green "x" and modeled by the green dashed line. The regression model equations are also indicated in the graph. It is quite apparent when comparing the modeled lines that post-retrofit chiller power consumption was lower than that of the baseline over the full range of cooling loads.

In accordance with IPMVP guideline, drawing conclusions about energy savings requires the data to have an acceptable level of uncertainty. The models drawn from data sets must be evaluated to prove that they are statistically valid. An uncertainty analysis was carried out on the data models in Figure 7 and is shown in Table 2.

### 3.3.1 Chiller Performance

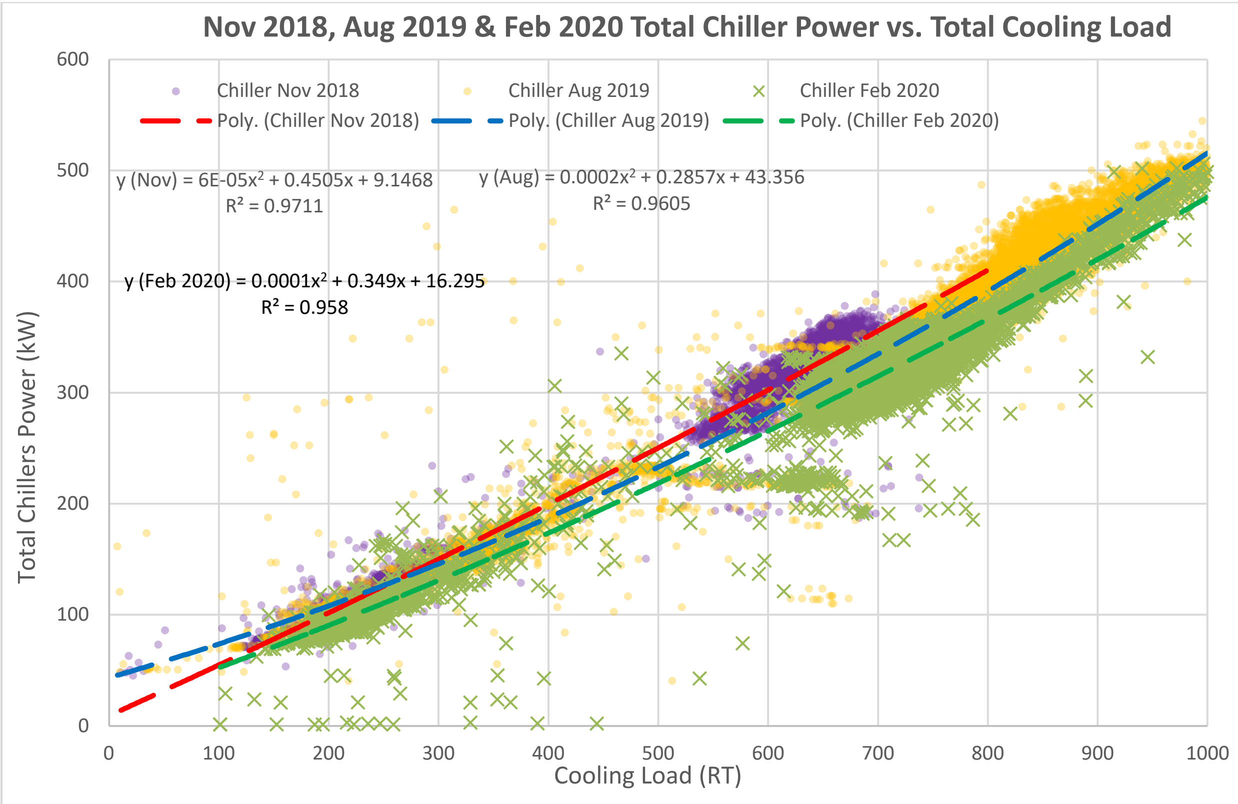



**Figure 7 Total Chiller Power Vs Total Cooling Load for Baseline and Post-Retrofit Periods**

| Statistic | Baseline (Nov 2018) | Post-Retrofit (Aug 2019) | Post-Retrofit (Feb 2020) | IPMVP Requirement |
|---|---|---|---|---|
| Sample Size | 6279 | 10660 | 12851 | More than 100 (for 95% confidence and 2% precision) |
| $R^2$ | 0.971 | 0.961 | 0.958 | More than 0.75 |

**Table 2 Uncertainty Analysis on the Chiller Power Models**

From Table 2, it is shown that the models are statistically valid.

| Load (RT) | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
|---|---|---|---|---|---|---|---|
| Operating Load (%) | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| | | | | | | | |
| Estimated Plant Power (Nov) | 223.8 | 281.4 | 340.7 | 401.5 | 464.0 | 528.0 | 593.7 |
| Estimated Plant Power (Aug) | 208.8 | 261.9 | 319.7 | 382.1 | 449.2 | 521.0 | 597.5 |
| Estimated Plant Power (Feb) | 194.8 | 246.4 | 300.8 | 357.9 | 417.8 | 480.5 | 546.0 |
| | | | | | | | |
| Aug Plant Power Savings (%) | 6.67% | 6.93% | 6.16% | 4.83% | 3.17% | 1.32% | -0.65% |
| Feb Plant Power Savings (%) | 12.92% | 12.43% | 11.71% | 10.86% | 9.94% | 9.00% | 8.03% |
| | | | | | | | |
| Plant kW/RT (Nov 18) | 0.499 | 0.503 | 0.507 | 0.512 | 0.518 | 0.524 | 0.530 |
| Plant kW/RT (Aug 19) | 0.466 | 0.468 | 0.476 | 0.487 | 0.501 | 0.517 | 0.534 |
| Plant kW/RT (Feb 20) | 0.435 | 0.440 | 0.448 | 0.457 | 0.466 | 0.477 | 0.487 |

Table 3 Chiller Power Savings at Different Part Load Conditions

From Table 3, the chiller saving at 70% is **4.83%** in August 2019 during which the environment was hotter (drought was reported) and more than **10%** in Feb 2020. The baseline chiller efficiency is 0.512 kW/RT at 70% while the post retrofit efficiency is 0.487 kW/RT and 0.457 kW/RT respectively for Aug 2019 and Feb 2020.

A yearly routine chiller (chillers 3 and 4 as well) cleaning was performed in mid January 2020. Large amount of sludge was removed from the chiller. A sample of this sludge was sent to a lab to ascertain its' nature and characteristics. The analysis report reveals that it is 17.6% organic and 82.4% inorganic. About 30% inorganic solids could have come from the air particles trapped and collected overtime in the cooling tower.

### 3.3.2 Plant Performance

Furthermore, to realize the whole chiller plant's power savings, the total plant power data are plotted against the total cooling loads with regression models for each data set in Figure 8. Since the chillers are the biggest power consumers in the chiller plant, it is expected that this graph would be quite similar to that of the chillers alone.

An uncertainty analysis is carried out on the data models in Figure 8 to ensure that they are statistically valid and are shown in Table 4.

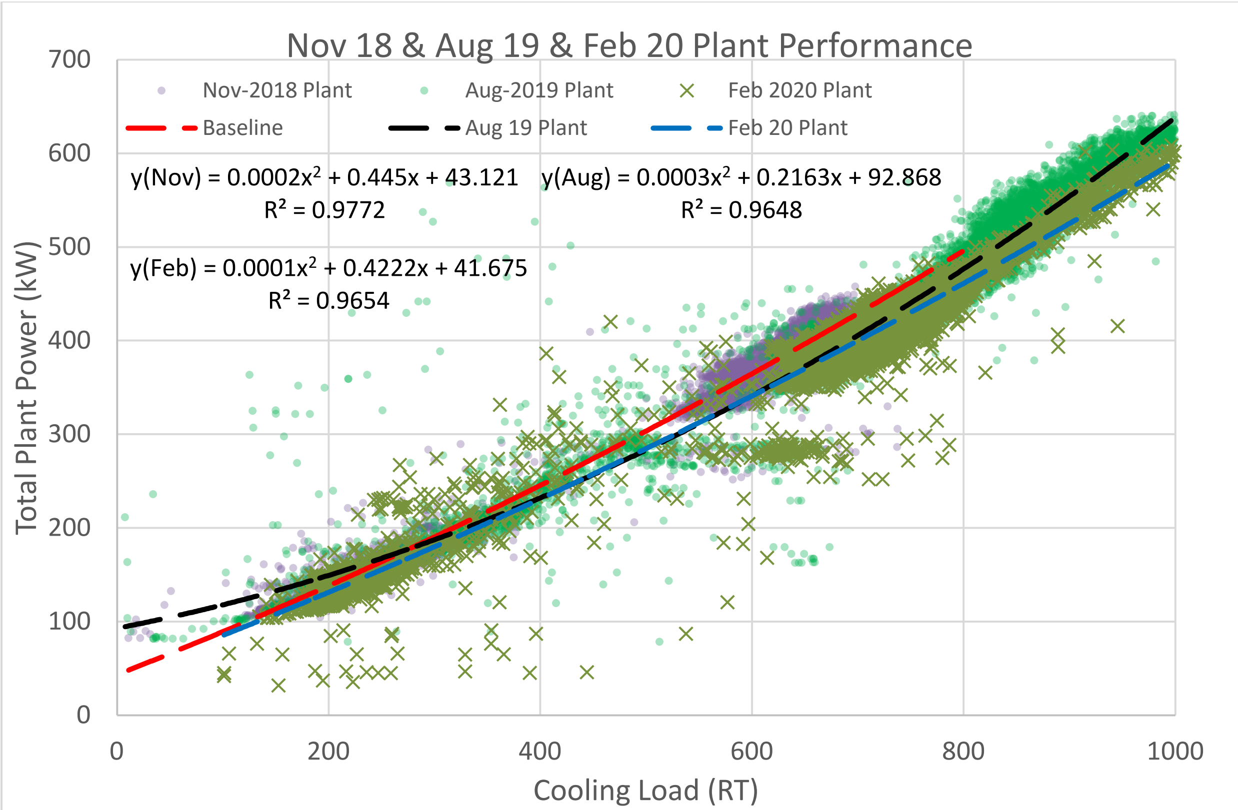



**Figure 8 Total Plant Power vs Total Cooling Load for Baseline and Post-Retrofit Periods**

| Statistic | Baseline (Nov 2018) | Post-Retrofit (Aug 2019) | Post-Retrofit (Feb 2020) | IPMVP Requirement |
|---|---|---|---|---|
| Sample Size | 6279 | 10660 | 12851 | More than 100<br>(for 95% confidence and 2% precision) |
| $R^2$ | 0.977 | 0.965 | 0.965 | More than 0.75 |

**Table 4 IPMVP Uncertainty Analysis on the Plant Power Models**

From Table 4, it is shown that the models are statistically valid.

| Load (RT) | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
|---|---|---|---|---|---|---|---|
| Load (%) | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| | | | | | | | |
| Estimated Plant Power (Nov 18) | 272.9 | 339.8 | 410.6 | 485.1 | 563.5 | 645.6 | 731.6 |
| Estimated Plant Power (Aug 19) | 255.8 | 317.2 | 386.8 | 464.7 | 550.8 | 645.2 | 747.8 |
| Estimated Plant Power (Feb 20) | 256.4 | 318.1 | 383.0 | 451.1 | 522.4 | 596.9 | 674.6 |
| | | | | | | | |
| Aug 19 Plant Power Savings (%) | 6.26% | 6.67% | 5.79% | 4.22% | 2.25% | 0.07% | -2.22% |
| Feb 20 Plant Power Savings (%) | 6.03% | 6.39% | 6.71% | 7.01% | 7.29% | 7.55% | 7.79% |
| | | | | | | | |
| Plant kW/RT (Nov 18) | 0.609 | 0.607 | 0.611 | 0.619 | 0.629 | 0.641 | 0.653 |
| Plant kW/RT (Aug 19) | 0.571 | 0.566 | 0.576 | 0.593 | 0.615 | 0.640 | 0.668 |
| Plant kW/RT (Feb 20) | 0.572 | 0.568 | 0.570 | 0.575 | 0.583 | 0.592 | 0.602 |

**Table 5 Plant Power Savings at Different Part Load Conditions**

From Table 5, it is established that there is an overall chiller plant power saving of 4.22% in August 19 (it was reported hot and drought experienced) and of 7.01% in Feb 20 (after chiller cleaning) at 70% operating capacity. All data were extracted from the KBT BMS system.

**Using all Available data**

To use all relevant data available, the Nov 2019 and Dec 2019 data were included. The details are tabulated in Table 6.

| Cooling Load (RT) | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
|---|---|---|---|---|---|---|---|
| Percent Full Load (%) | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| | | | | | | | |
| Estimated Plant Power (Nov 18) | 272.9 | 339.8 | 410.6 | 485.1 | 563.5 | 645.6 | 731.6 |
| Estimated Plant Power (Aug 19) | 255.8 | 317.2 | 386.8 | 464.7 | 550.8 | 645.2 | 747.8 |
| Estimated Plant Power (Nov 19) | 277.3 | 344.9 | 414.6 | 486.6 | 560.7 | 637.1 | 715.7 |
| Estimated Plant Power (Dec 19) | 276.6 | 346.3 | 419.0 | 494.9 | 573.8 | 655.9 | 741.0 |
| Estimated Plant Power (Jan 20) | 257.9 | 317.8 | 381.8 | 449.9 | 522.0 | 598.2 | 678.4 |
| Estimated Plant Power (Jan 20) | 256.4 | 318.1 | 383.0 | 451.1 | 522.4 | 596.9 | 674.6 |
| | | | | | | | |
| Aug 19 Plant Power Savings (%) | 6.26% | 6.67% | 5.79% | 4.22% | 2.25% | 0.07% | -2.22% |
| Nov 19 Plant Power Savings (%) | -1.63% | -1.48% | -0.98% | -0.29% | 0.49% | 1.32% | 2.17% |
| Dec 19 Plant Power Savings (%) | -1.36% | -1.89% | -2.05% | -2.01% | -1.84% | -1.59% | -1.29% |
| Jan 20 Plant Power Savings (%) | 5.50% | 6.48% | 7.01% | 7.27% | 7.36% | 7.35% | 7.27% |
| Feb 20 Plant Power Savings (%) | 6.03% | 6.39% | 6.71% | 7.01% | 7.29% | 7.55% | 7.79% |
| | | | | | | | |
| Plant kW/RT (Nov 18) | 0.609 | 0.607 | 0.611 | 0.619 | 0.629 | 0.641 | 0.653 |
| Plant kW/RT (Aug 19) | 0.571 | 0.566 | 0.576 | 0.593 | 0.615 | 0.640 | 0.668 |
| Plant kW/RT (Nov 19) | 0.619 | 0.616 | 0.617 | 0.621 | 0.626 | 0.632 | 0.639 |
| Plant kW/RT (Dec 19) | 0.617 | 0.618 | 0.624 | 0.631 | 0.640 | 0.651 | 0.662 |
| Plant kW/RT (Jan 20) | 0.576 | 0.568 | 0.568 | 0.574 | 0.583 | 0.593 | 0.606 |
| Plant kW/RT (Feb 20) | 0.572 | 0.568 | 0.570 | 0.575 | 0.583 | 0.592 | 0.602 |

**Table 6 Plant performance based on all available data**

From the above table, one can see that due to accumulation of sludge in the chiller system, the efficiency of the plant deteriorated gradually after August 2019. However, as mentioned earlier, in mid Jan 2020 the system was cleaned and washed.

This sludge problem can be solved by using a side stream filter which is not part of the DCI System. A detailed report of the sludge analysis is included in Section 4.2 of this report.

## 3.4 Chillers efficiency with external factors considered

In order to consider the external influence (such as ambient temperature, particularly the wet bulb temperature -WBT) it has on the performance, the datasets of different months within the same CEFT (Condenser Entrance Fluid Temperature) segment are compared as the CEFT affects the efficiency of the chillers.

### 3.4.1 Calculated theoretical plant efficiency

The theoretical plant efficiency as shown in Figure 9 is computed using the following information:

1. Part Load data supplied by York / JCI
2. Cooling tower power calculated as per green mark standard
3. CWP power calculated as per green mark standard
4. CHWP power calculated as per green mark standard

Chiller startup sequencing (i.e. when a particular chiller is put on service) is considered in the calculation while the power consumption of the cooling tower fans and pumps are computed as per green mark standard.

The efficiency and cooling load curve of each CEFT temperature is shown in Figure 9.

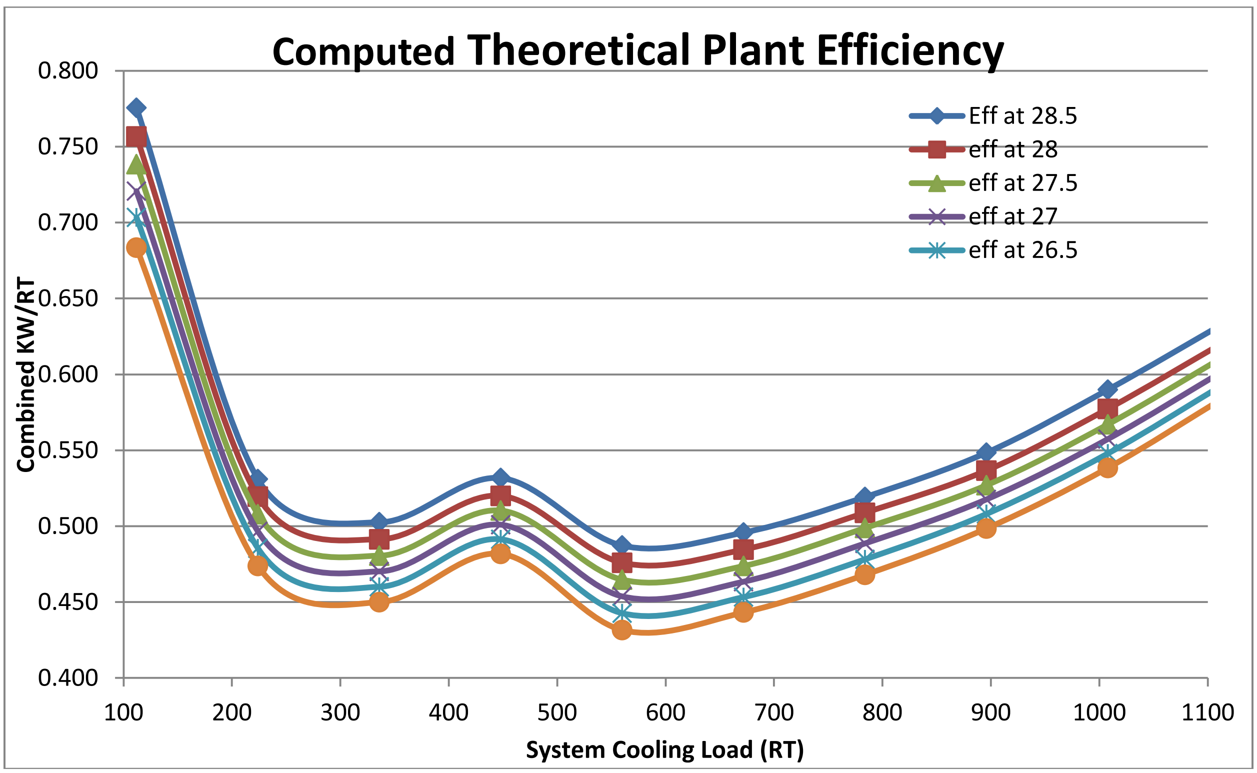



Figure 9: Computed Plant Efficiency

From Figure 9, one can see that:

1. The CEFT influences the efficiency of the plant. A higher CEFT will result in lower efficiency
2. The profile of system cooling load against the efficiency is identical at different CEFT
3. The best plant efficiency is realized when operating the plant at around 580RT (i.e. 51.7%)

Due to chiller sequencing, there are two dips (@ optimal load position) as shown in Figure 9. One of which is around 300 RT (when one chiller is running) and the other is around 580 RT (when 2 chillers are running)

For comparison, the chiller efficiency (chiller alone) against part load at different CEFT is shown in Figure 10 below.

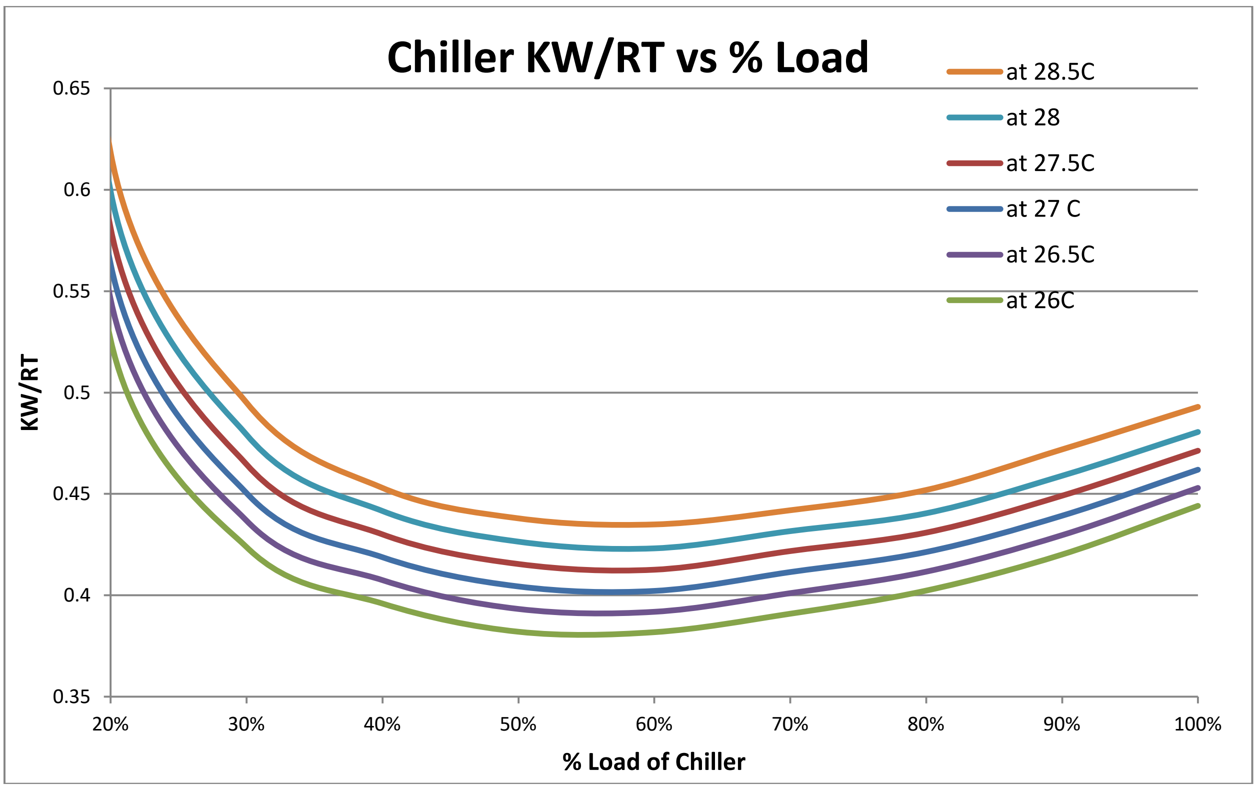



**Figure 10 : Chiller kW/RT vs Percent Part Load**

The chiller efficiency at different load is as shown in Figure 10. According to this graph, the chiller's best efficiency is also realized at around 51.7% load, i.e. 580RT.

### 3.4.2 CEFT comparison using data from chillers 3 and 4

To objectively evaluate the performance, the same chillers (3 & 4) are used. Also, to factor in the influence of climatic conditions in the performance, the data are grouped into different CEPT temperature segments.

Different chiller efficiencies were observed during the following months:

1. Baseline data (Nov 2018)
2. Data collected in August 2019 and
3. Data collected in Feb 2020

Dataset (1) was collected prior to DCI implementation and hence is used as the baseline. Datasets (2) and (3) were collected after DCI installation. All three sets of data were cleansed to remove the obvious irrelevant data points and the outliers. The data sets were then grouped into 8 CEFT temperature segments of delta 0.5 degrees Celsius each as follows:

a) < 25.5 $^{o}$C
b) 25.5 $^{o}$C to < 26.0 $^{o}$C
c) 26.0 $^{o}$C to < 26.5 $^{o}$C
d) 26.5 $^{o}$C to < 27.0 $^{o}$C
e) 27.0 $^{o}$C to < 27.5 $^{o}$C
f) 27.5 $^{o}$C to < 28.0 $^{o}$C
g) 28 .0$^{o}$C to < 28.5 $^{o}$C
h) > 28.5 $^{o}$C

The above (a) and (h) are not used in the evaluation as there are too little data points in these segments.

The Aug19 and Feb20 datasets are compared against the Nov18 baseline dataset. Each segment of Aug 19 and Feb 20 is compared with their respective segment of Nov18. Overall, more than 85% of data are used in this comparison. The number of data points is denoted by N in Table 7.

### 3.4.3 Comparing August 2019 data against baseline Nov 2018

The first batch of data that is comparable (for Chiller3 and 4 only) to the baseline data is August 2019 data which were extracted from the BMS. The percentage usage of each group as well as the total number of points (indicated as N) is as shown below. A total of 6 groups are used to compare the efficiency of the chillers between the 2 datasets.

| Month | N | <25.5 | 25.5 to <26 | 26 to <26.5 | 26.5 to <27 | 27 to <27.5 | 27.5 to <28 | 28 to 28.5 | >28.5 |
|---|---|---|---|---|---|---|---|---|---|
| Nov 18 | 6411 | 578 | 951 | 707 | 1055 | 1500 | 915 | 660 | 45 |
| % Usage Nov | | 9.0% | 14.8% | 11.0% | 16.5% | 23.4% | 14.3% | 10.3% | 0.7% |
| Aug 19 | 9983 | 270 | 387 | 837 | 738 | 1819 | 1787 | 2714 | 1431 |
| % Usage Aug | | 2.7% | 3.9% | 8.4% | 7.4% | 18.2% | 17.9% | 27.2% | 14.3% |

Table 7: Data Distribution comparison of Baseline and Aug 2019

The results for the month of Aug19 are shown in Figure 11 to Figure 16 below. In order to provide a clearer indication, the average value of the cluster is indicated in the chart. For example, in Figure 11, 0.497 kW/RT and 0.488 kW/RT is the average value for Nov18 and Aug19 respectively.

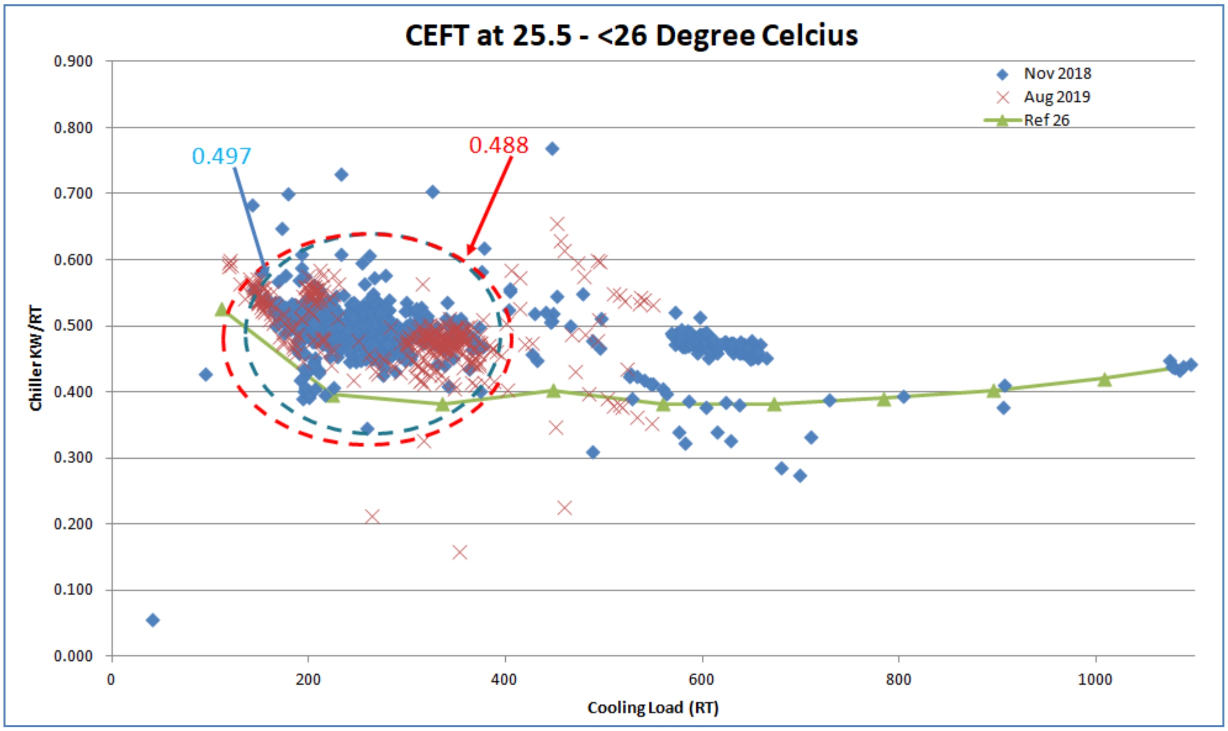



Figure 11: Baseline and Aug 2019 comparison with CEFT at 25.5 to 26°C

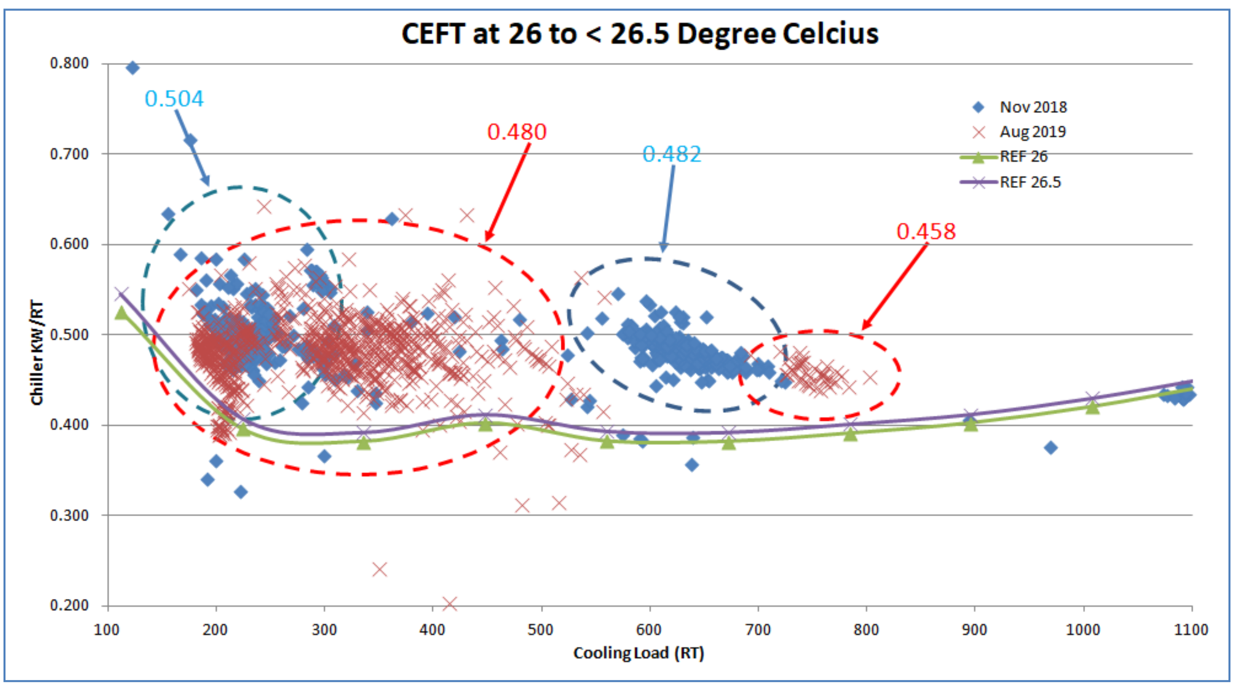



Figure 12 : Baseline and Aug 2019 comparison with CEFT at 26 to 26.5°C

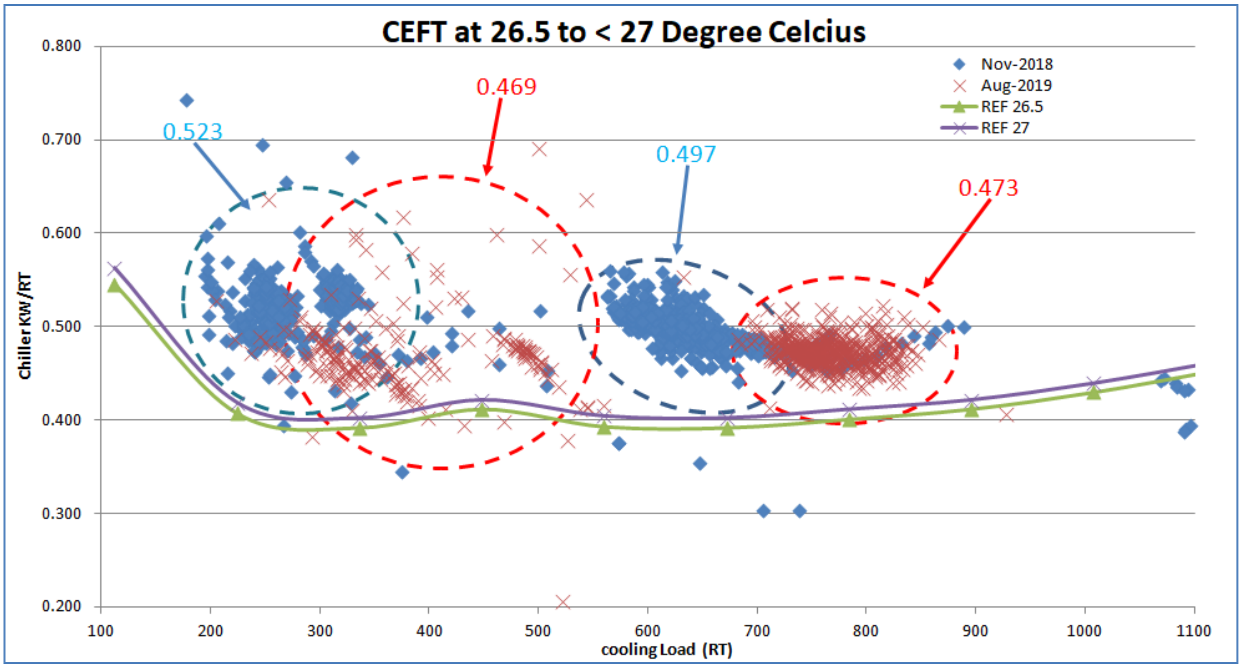



Figure 13 : Baseline and Aug 2019 comparison with CEFT at 26.5 to 27°C

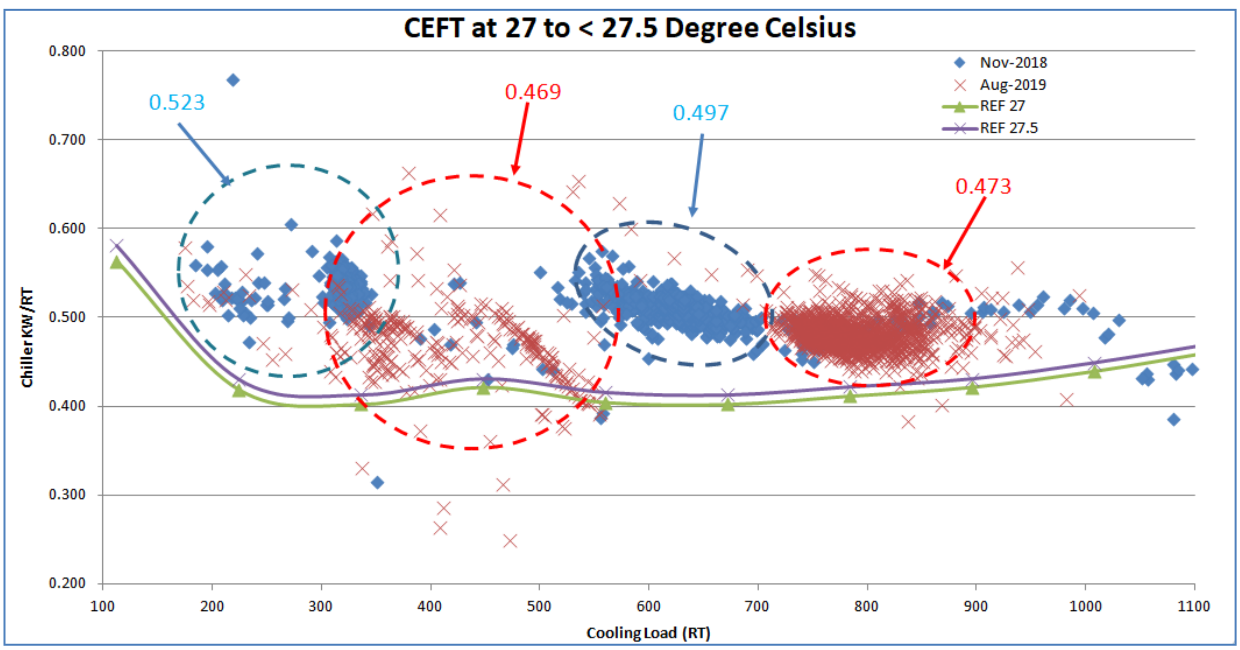



Figure 14: Baseline and Aug 2019 comparison with CEFT at 27 to 27.5°C

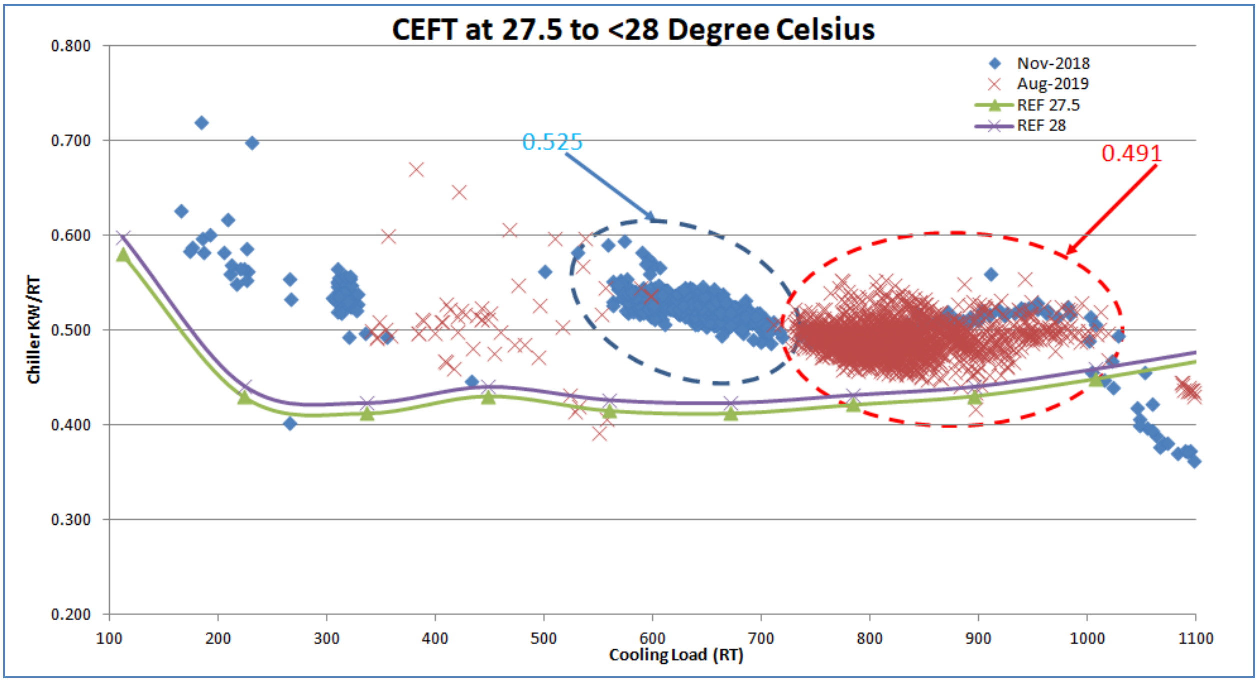



Figure 15: Baseline and Aug 2019 comparison with CEFT at 27.5 to 28°C

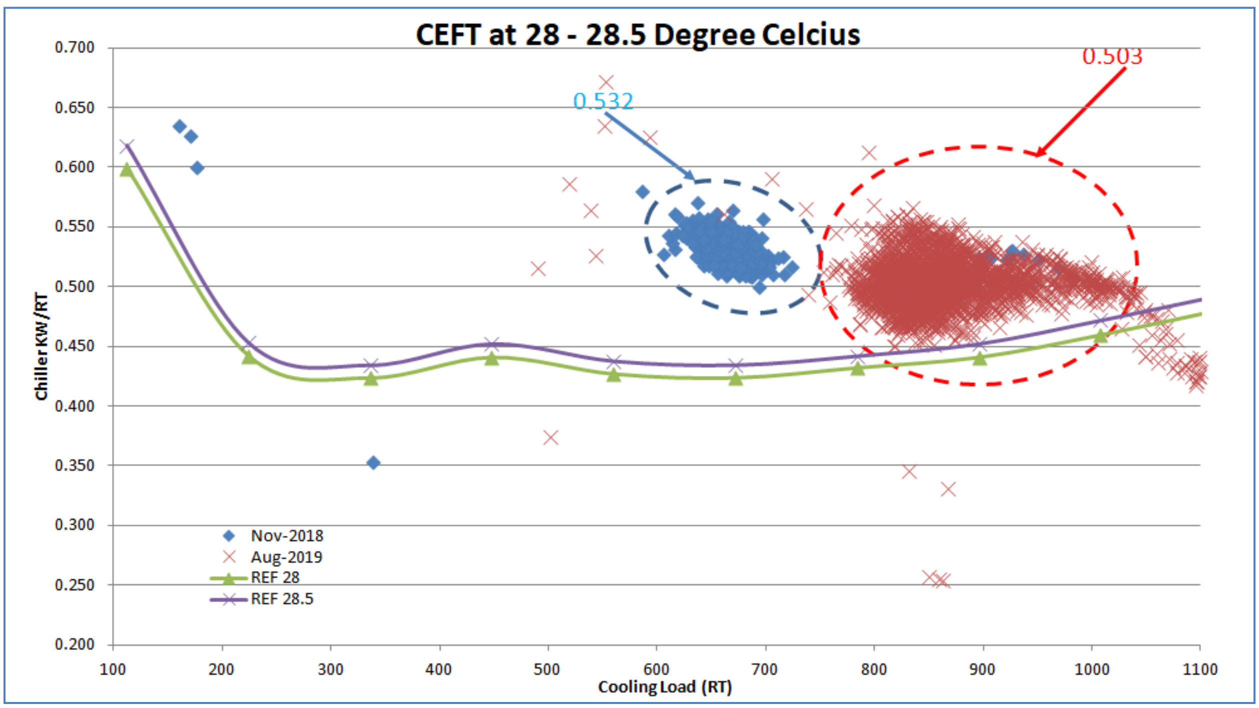



Figure 16: Baseline and Aug 2019 comparison with CEFT at 28 to 28.5°C

### 3.4.4 Comparing between Feb 2020 and baseline Nov18

February 2020 data were extracted from the KBT BMS system at the end of Feb 2020. The same data cleansing method was used. Likewise, the Feb data were categorized into the same 6 groups and compared against the baseline.

| Month | N | <25.5 | 25.5 to <26 | 26 to <26.5 | 26.5 to <27 | 27 to <27.5 | 27.5 to <28 | 28 to 28.5 | >28.5 |
|---|---|---|---|---|---|---|---|---|---|
| Nov 18 | 6411 | 578 | 951 | 707 | 1055 | 1500 | 915 | 660 | 45 |
| | | 9.0% | 14.8% | 11.0% | 16.5% | 23.4% | 14.3% | 10.3% | 0.7% |
| Feb 20 | 12851 | 579 | 495 | 1385 | 2574 | 4041 | 3012 | 614 | 151 |
| | | 4.5% | 3.9% | 10.8% | 20.0% | 31.4% | 23.4% | 4.8% | 1.2% |

Table 8: Data Distribution comparison of Baseline and Feb 2020

Figure 17 to Figure 22 show the distribution of data points of baseline and Feb 20. As the difference in kW/RT is apparent, no average numbers shall be indicated here.

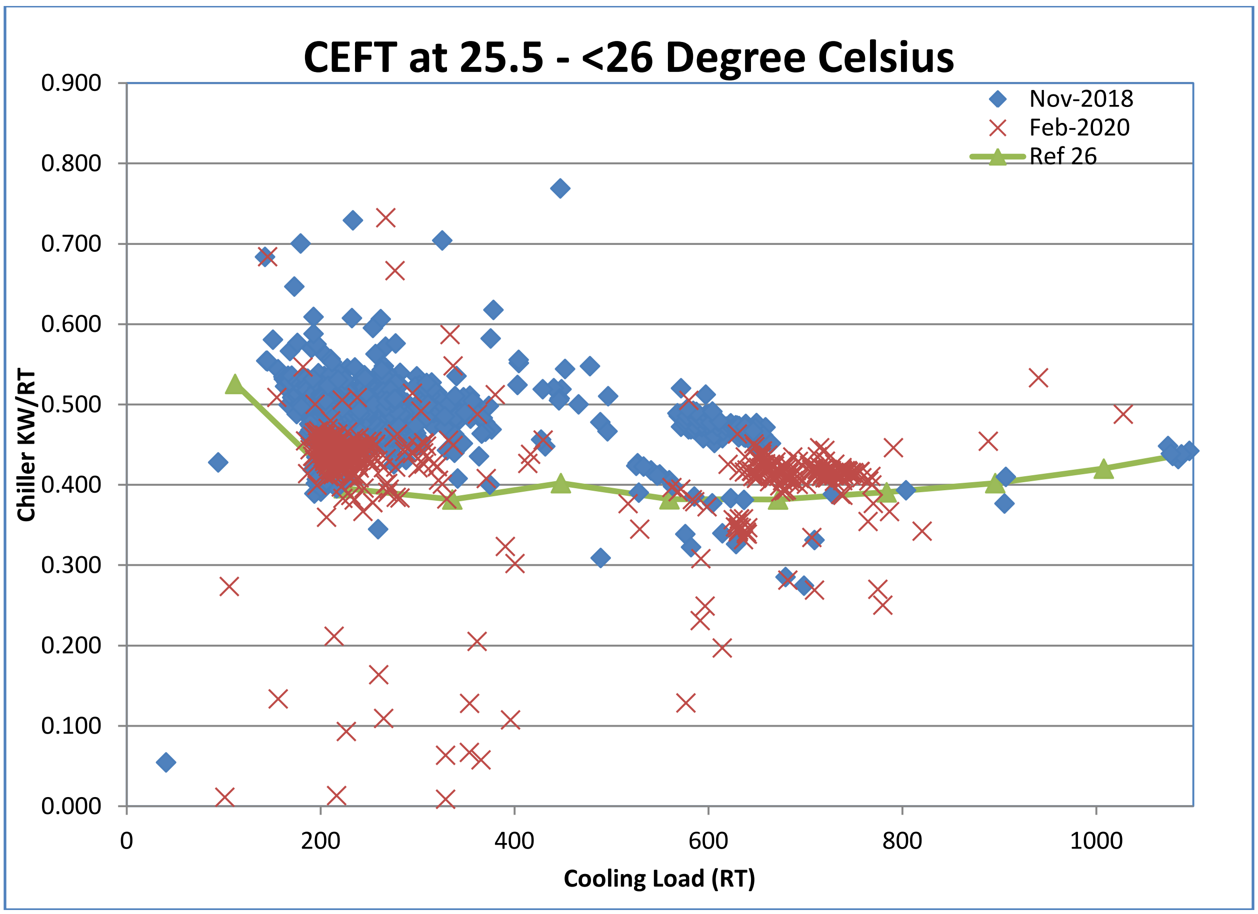



Figure 17: Baseline and Feb 2020 comparison with CEFT at 25.5 to 26°C

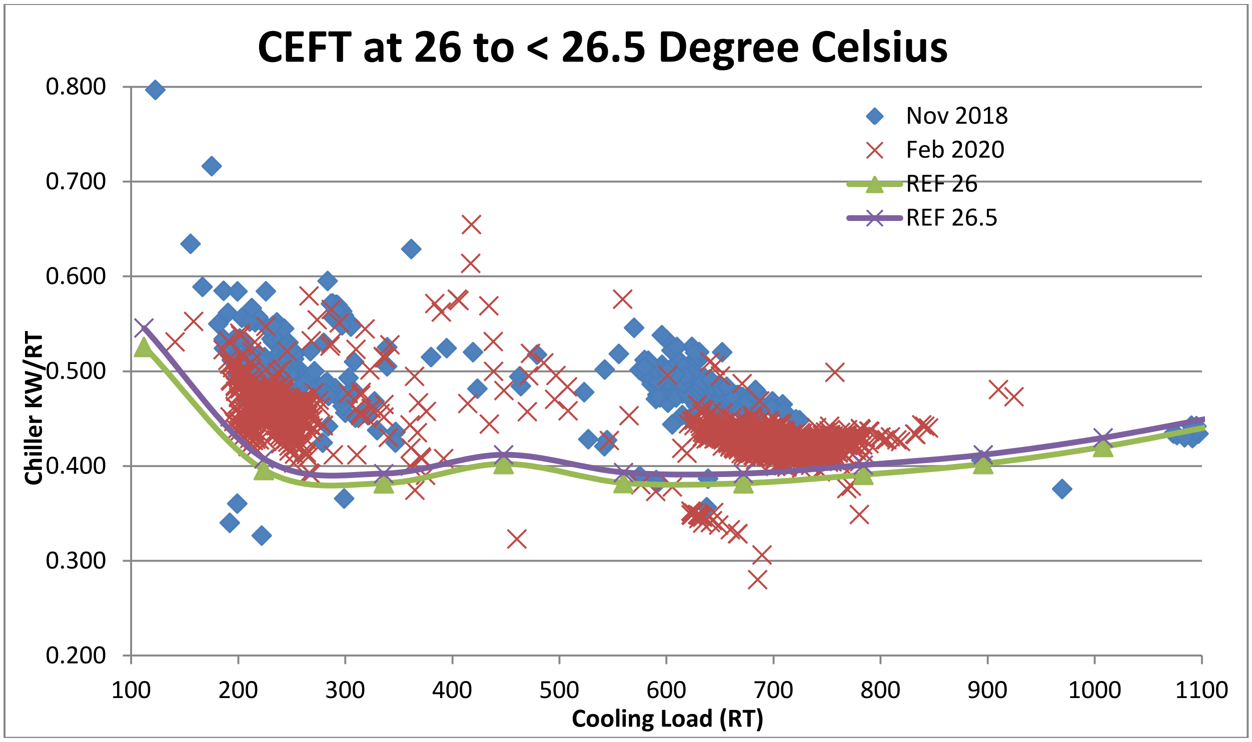



Figure 18: Baseline and Feb 2020 comparison with CEFT at 26 to 26.5°C

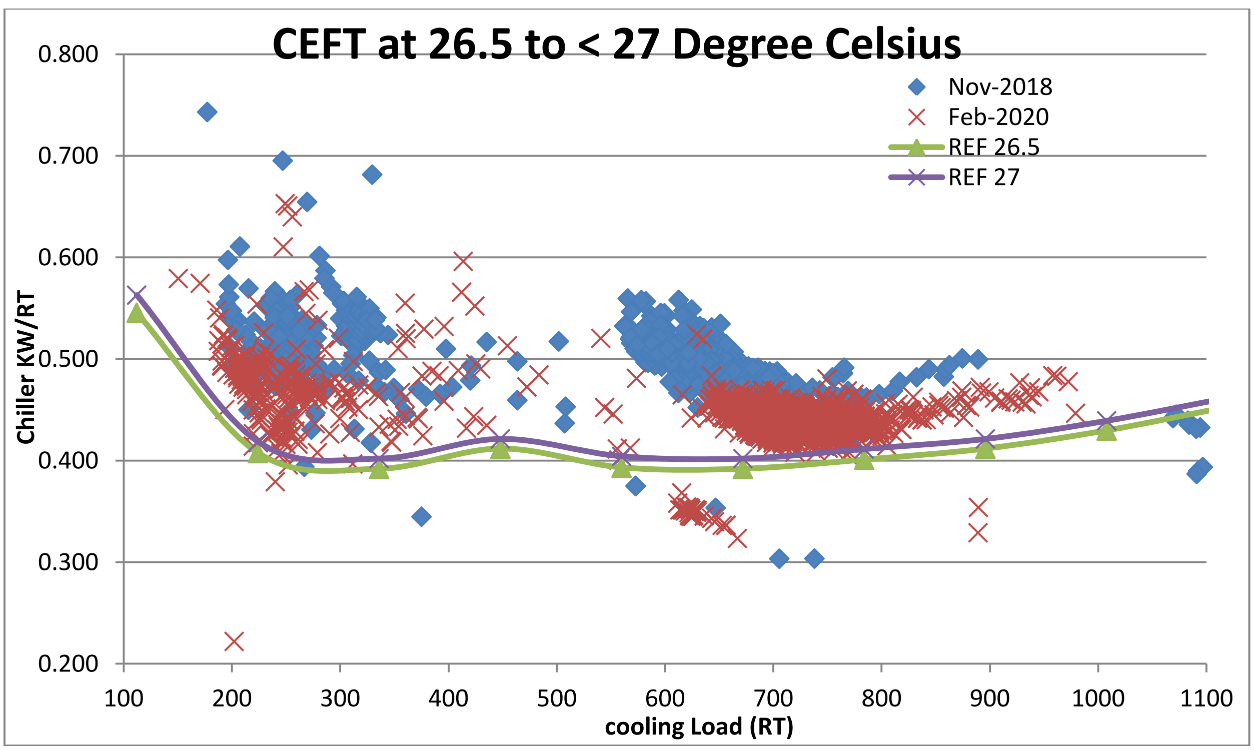



Figure 19: Baseline and Feb 2020 comparison with CEFT at 26.5 to 27°C

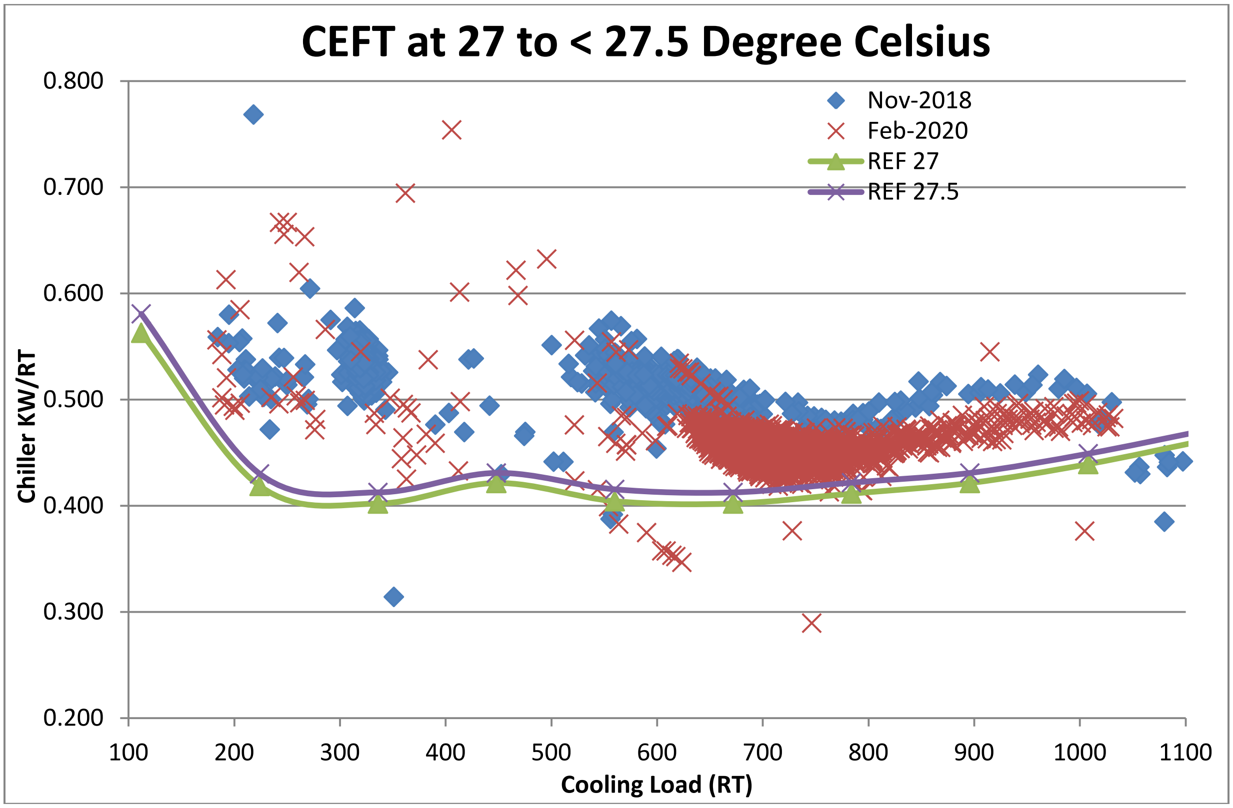



**Figure 20: Baseline and Feb 2020 comparison with CEFT at 27 to 27.5°C**

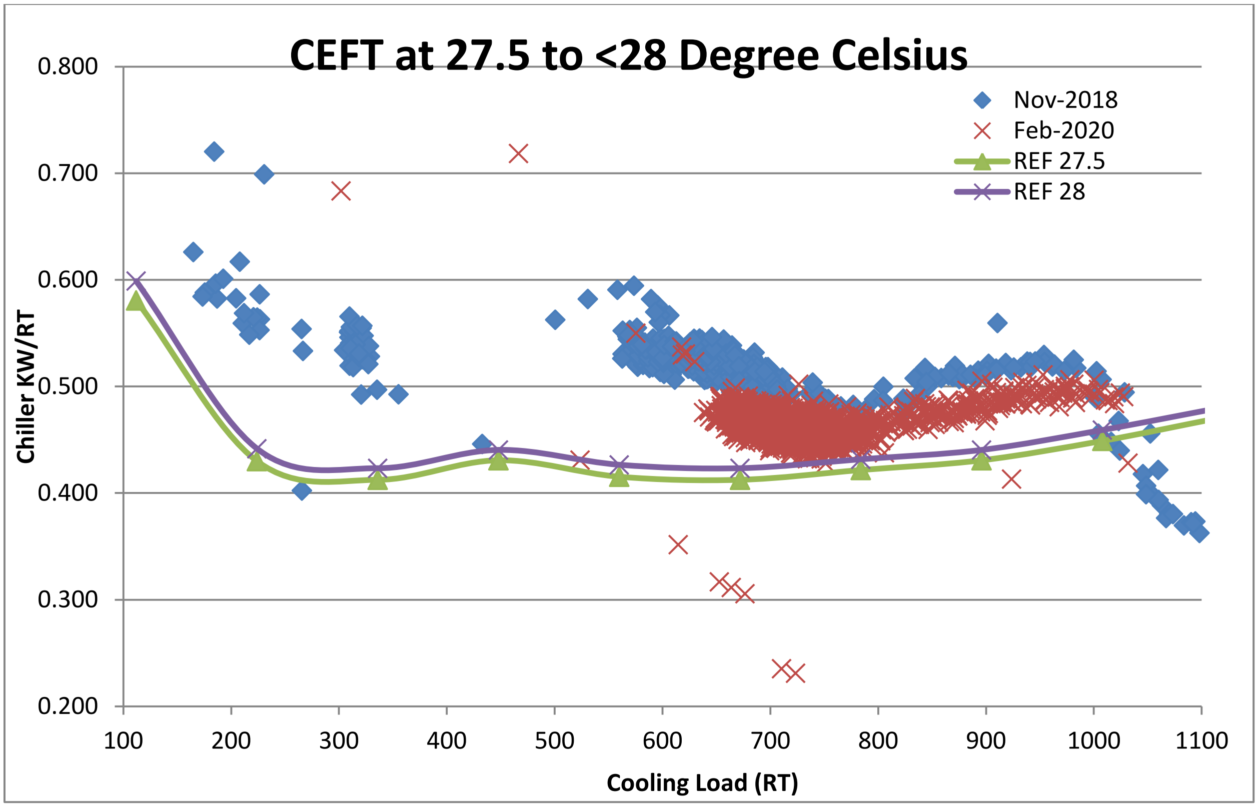



Figure 21: Baseline and Feb 2020 comparison with CEFT at 27.5 to 28$^{o}$C

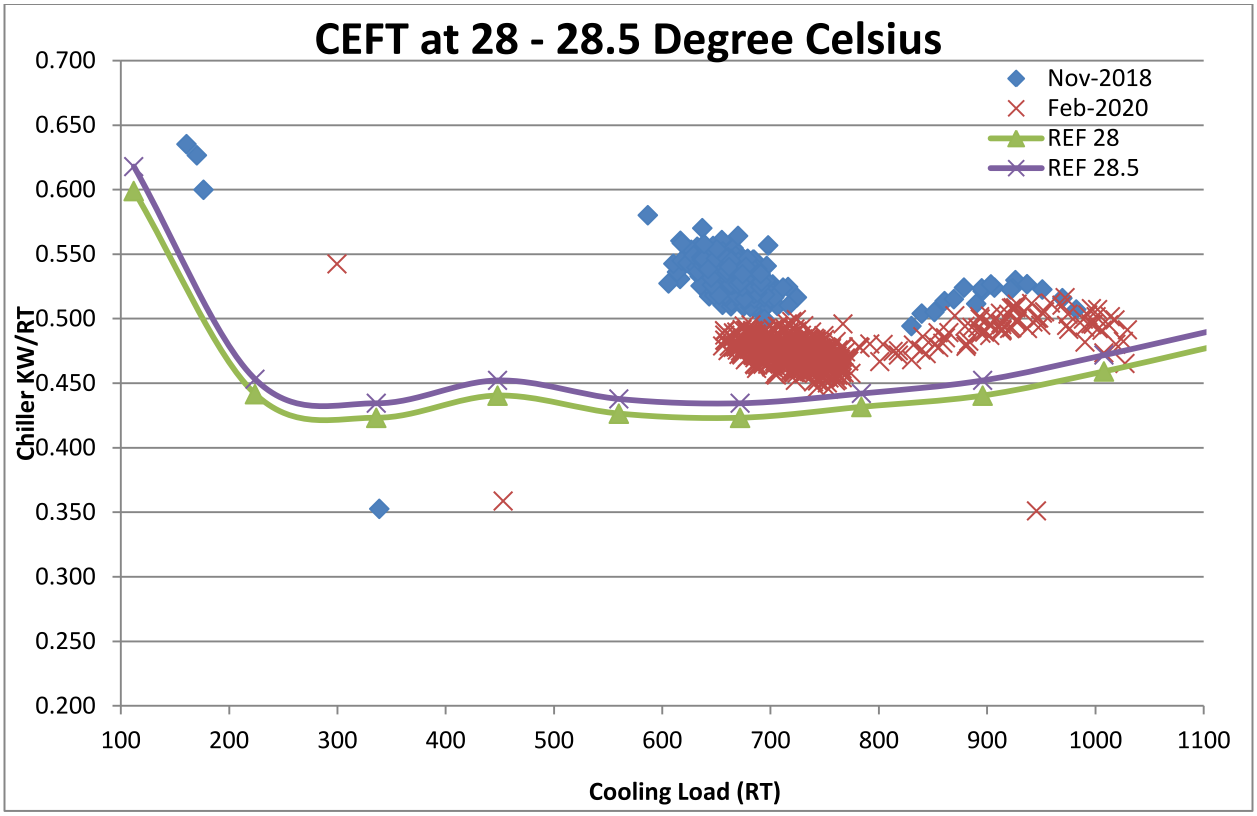



Figure 22: Baseline and Feb 2020 comparison with CEFT at 28 to 28.5°C

### 3.4.5 Interpretation of Data

Comparison between baseline data and August 2019 data is shown in Figure 11 to Figure 16. Due to a hotter weather, the August 2019 data tend to clutter on the right side of the baseline data.

From Figure 9, it is seen that the most efficient load for the system to operate on is around 380RT. beyond that, the efficiency starts to decline. The August data still suggest that the system had a better efficiency even though in Aug 2019 the chillers had to operate in a less efficient regime than the Nov 2018 baseline.

The ambient temperatures (WBT) of Nov 2018 baseline and Feb 2020 are very similar. The positions of data points having the similar cooling loads are identical too.

Figure 17 to Figure 22 clearly show that the chillers after DCI retrofits are running at a better efficiency compared to the baseline period across the entire CEFT segment.

## 3.5 Using data from any 2 of the 3 chillers

As the above chillers 3 & 4 could not provide the preferred 12 months of data, it was suggested to extract all usable data from whatever that had been collected from the other chillers.

As not all 3 chillers were used every month, the data would be influenced by the frequency of usage of a particular chiller. As discovered by EWTCOI, chiller 1 is more efficient than chiller 3 and chiller 4. The power efficiency would therefore, depend on the particular chiller(s) being used.

It is to note that chiller 2 is a different model from chillers 1, 3 and 4. It is a centrifugal unit instead of magnetic bearing technology type as in the case of 1, 3, and 4. Furthermore, the flow sensor was faulty. Therefore, the data from chiller 2 is inadmissible and thus excluded from the dataset.

Since different combination of chiller was put on service different from that of baseline, the data collected here would not be considered as a fair comparison. However, it should be sufficient as a reference to see the trend.

The following data are collated from 3 chillers (Chillers 1, 3 and 4). The data are selected using the following criteria:

1. Only data for chillers 1,3 and 4 are used
2. All datasets are subject to the same data cleansing method using data analytics tools
3. The obvious  outliers are removed

All data points are then mapped into a scatter plot to obtain the regression model for power consumption versus cooling load at 70% load from which kW/RT is derived.

The $R^2$ is computed to evaluate the validity of each model.

### 3.5.1 Energy Data (from 3 chillers)

The following graphs and Tables show the:

1. Daily power consumption by chillers
2. Total chiller power vs total cooling load
3. Plant performance at different part load conditions

The above are shown on the following pages. **Error! Reference source not found.** to Figure 55 show the operating conditions while **Error! Reference source not found.** to Table 23 show the plant performance based on part load conditions.

#### *3.5.1.1 Dec 2018*

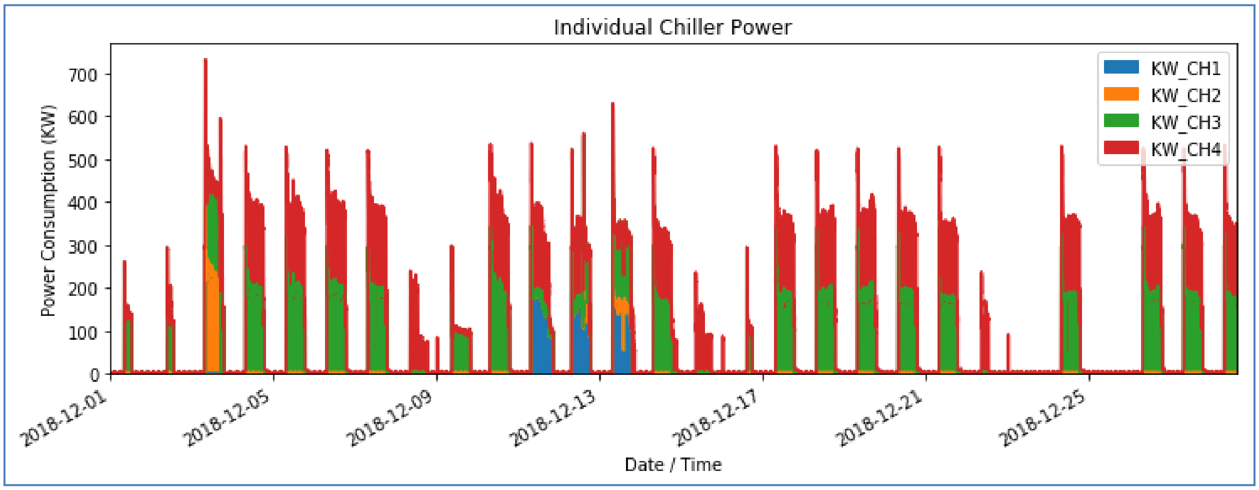



**Figure 23: Daily Power Consumption of Chillers for Dec 2018**

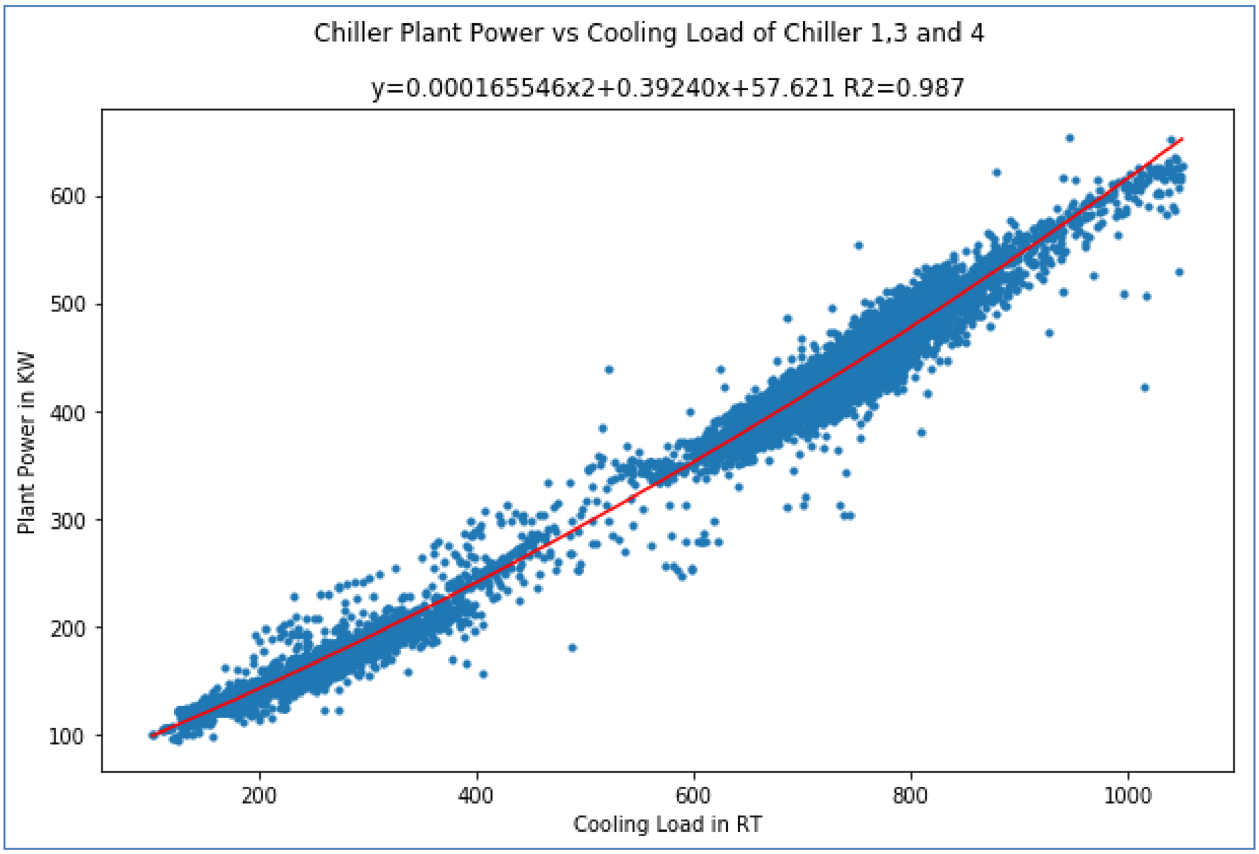



**Figure 24: Total Plant Power VS Cooling Load for Dec 2018**

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **KW** | 208.2 | 266.6 | 329.3 | 396.1 | 467.0 | 542.1 | 621.4 | 704.8 |
| **KW/RT** | 0.620 | 0.595 | 0.588 | 0.589 | 0.596 | 0.605 | 0.616 | 0.629 |

Table 9: Dec 2018 Plant Performance at different part load conditions

### *3.5.1.2 Jan 2019*

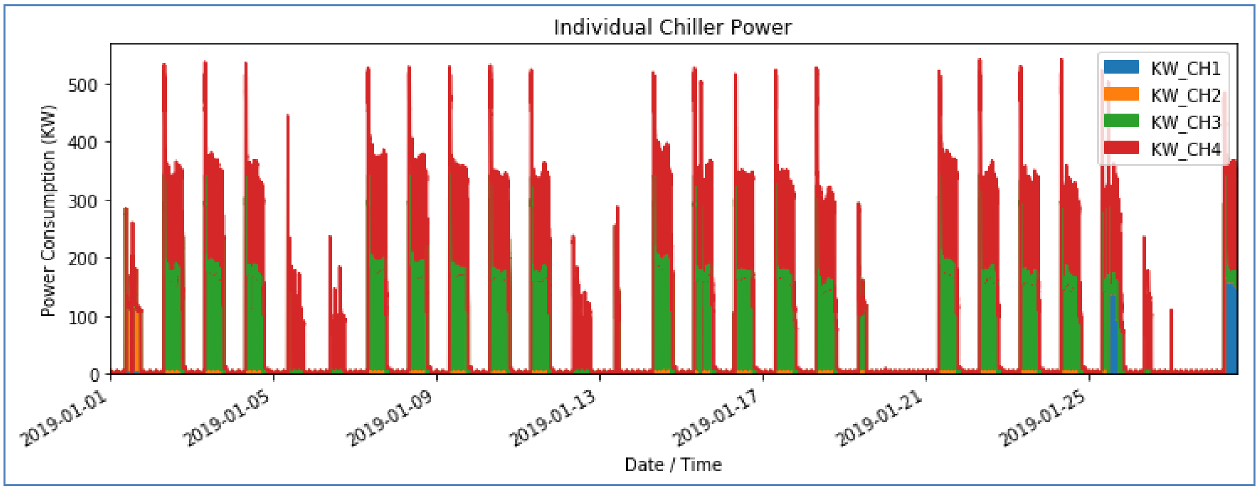



Figure 25: Daily Power Consumption by Chiller for Jan 2019

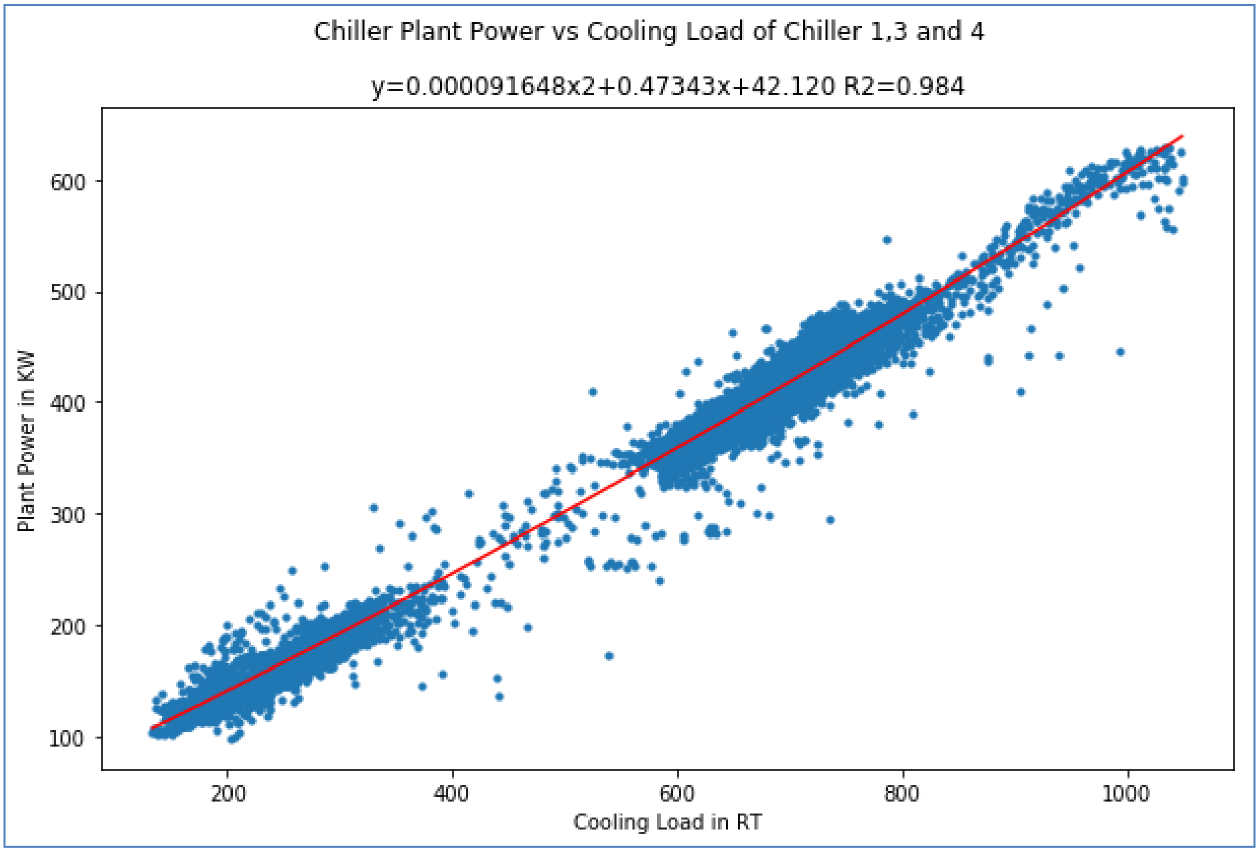



Figure 26: Total Plant Power VS Total Cooling Load for Jan 2019

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 211.5 | 272.6 | 336.0 | 401.7 | 469.6 | 539.9 | 612.5 | 687.3 |
| **KW/RT** | 0.630 | 0.609 | 0.600 | 0.598 | 0.599 | 0.603 | 0.608 | 0.614 |

**Table 10: Jan 2019 Plant Performance at different part load conditions**

#### *3.5.1.3 Feb 2019*

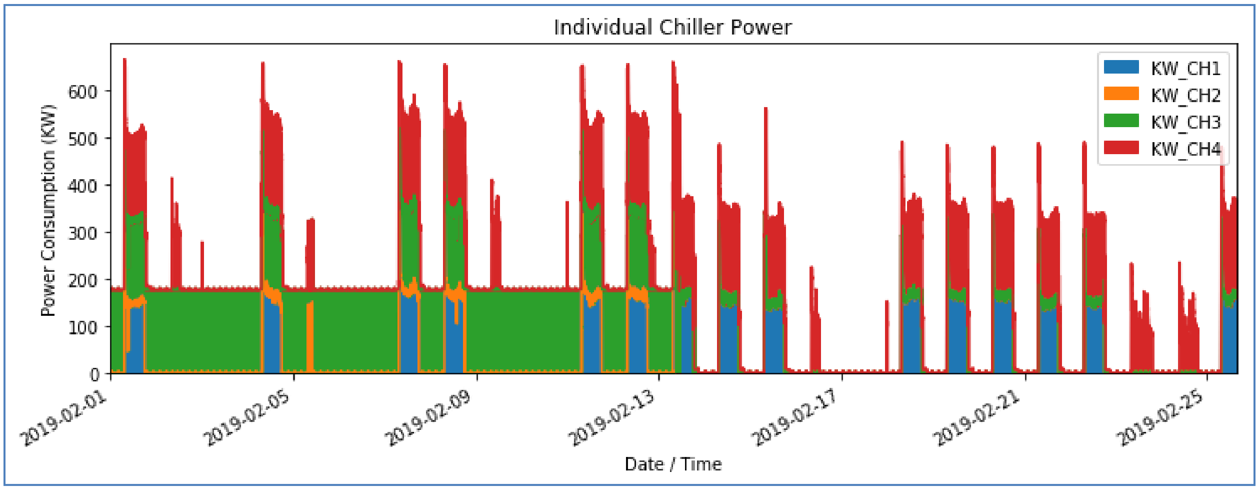



**Figure 27: Daily Power Consumption by Chiller for Feb 2019 (Original)**

Data collected from Feb 2019 are shown in Figure 27. The data don’t look correct as there appears to have a constant consumption on chiller 3 in a 24/7 manner.

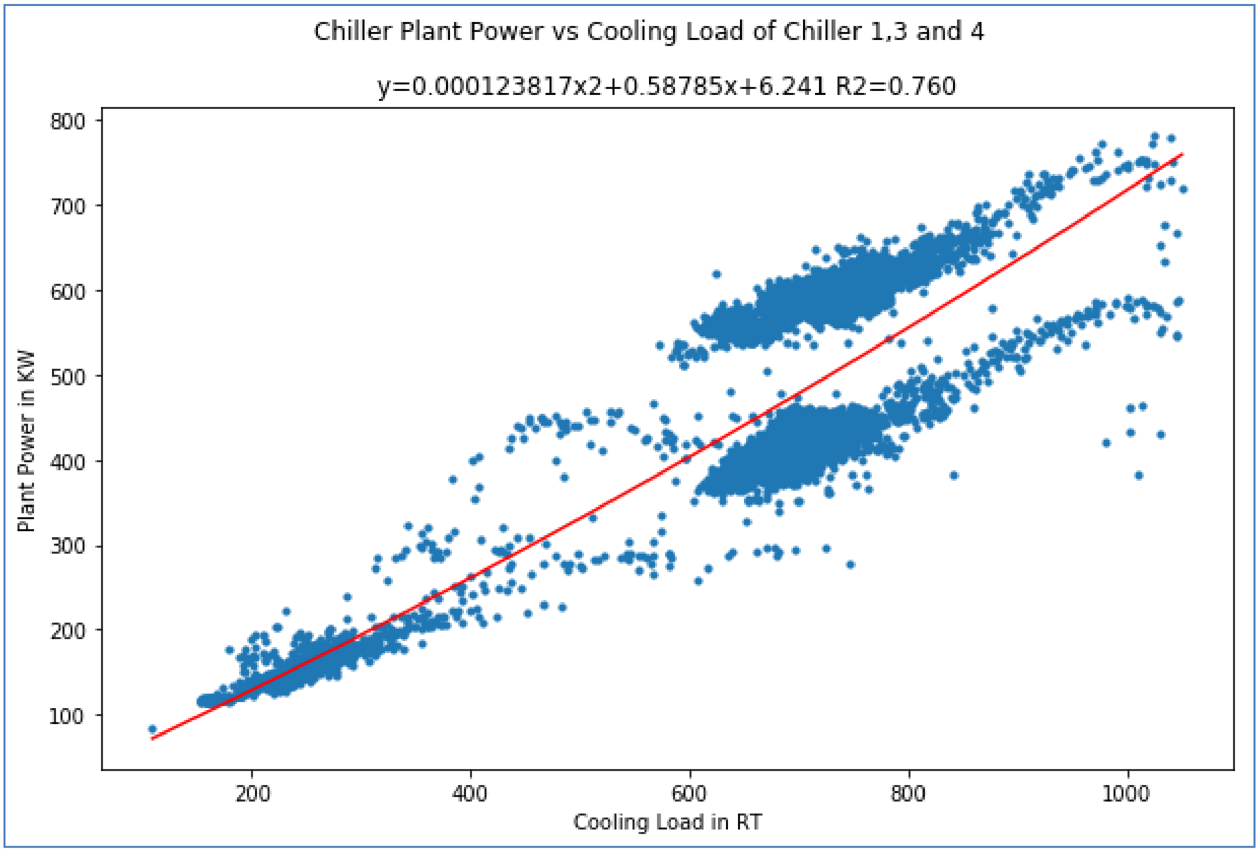



Figure 28: Total Plant Power VS Cooling Load for Feb 2019 (Original)

Figure 30 shows an abnormal distribution pattern which does not characterize the operation manner of a normal chiller plant.

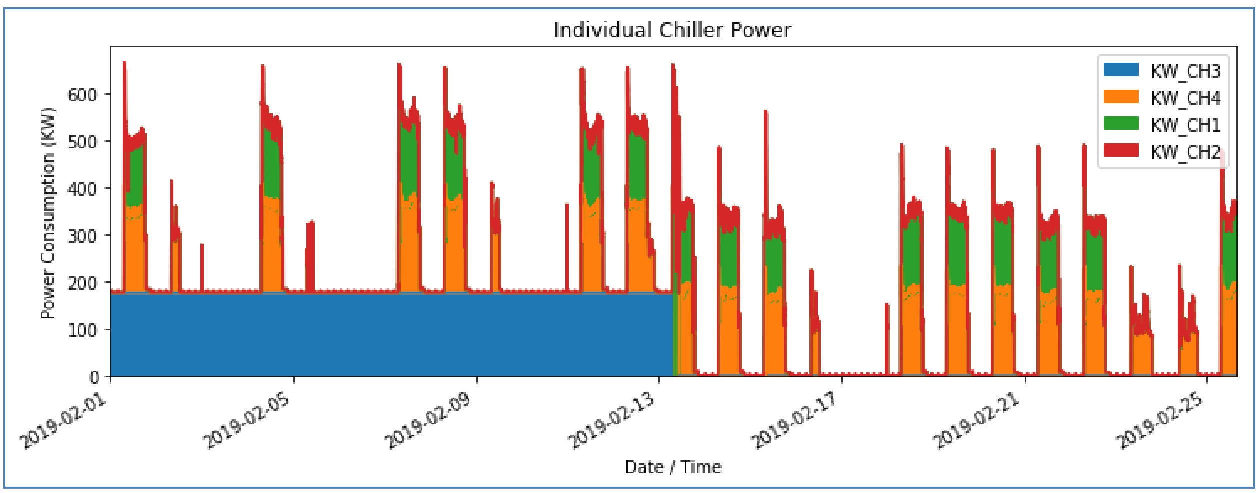



Figure 29: Daily Power Consumption by Chiller for Feb 2019 (rearranged)

By rearranging the position of the chillers, it is seen that chiller 3 is "drawing power" continuously from 1st Feb 2019 to 13th Feb 2019 as represented by the blue block in Figure 29. This could be either actual consumption by chiller 3 in a 24 /7 manner or an error caused by the measuring instrument. The former is unlikely.

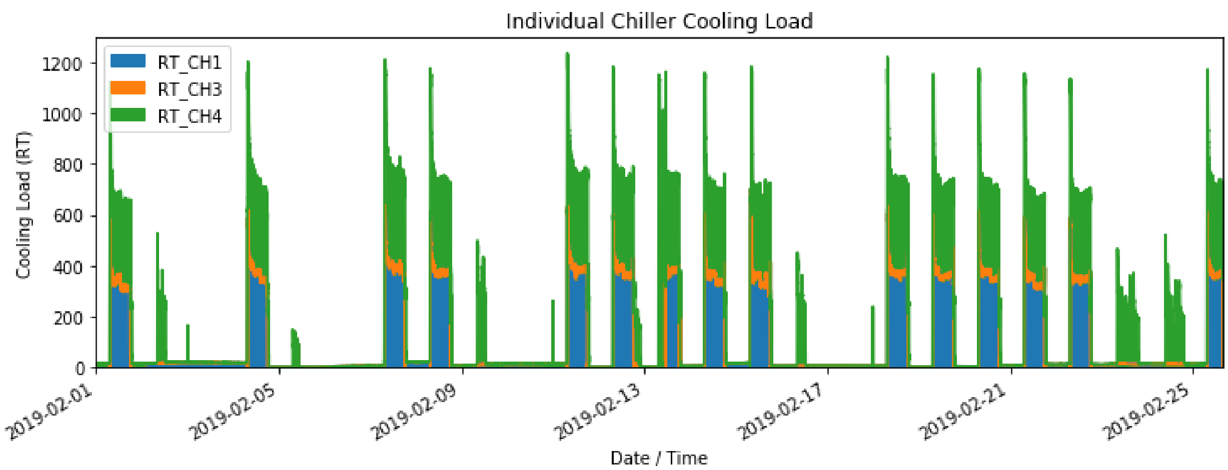



**Figure 30: Daily Cooling Load by Chiller for Feb 2019 (Chiller 2 excluded)**

The cooling load of the chillers 1,3 and 4 is plotted against time as shown in Figure 30. The data show that the cooling load does not follow the profile of power consumption of chiller 3.

Therefore the power consumption data of chiller 3 could have been caused by a faulty sensor and thus skewed the data. With the power consumption value of chiller 3 removed using data analytics tools, the consumption profile is then plotted and as shown in Figure 31.

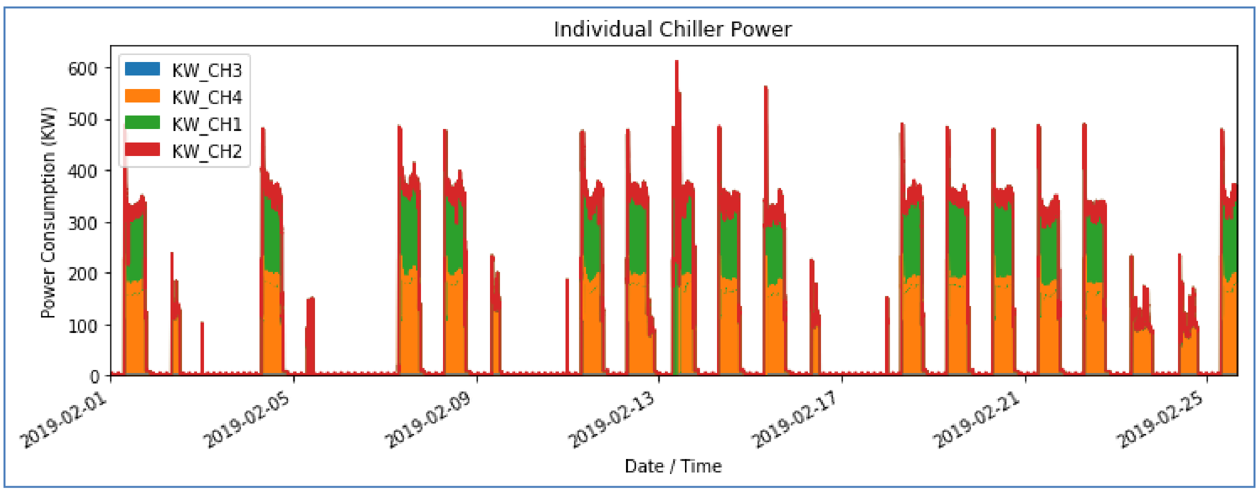



**Figure 31 Daily Power Consumption by Chiller for Feb 2019 (Chiller3 power consumption removed)**

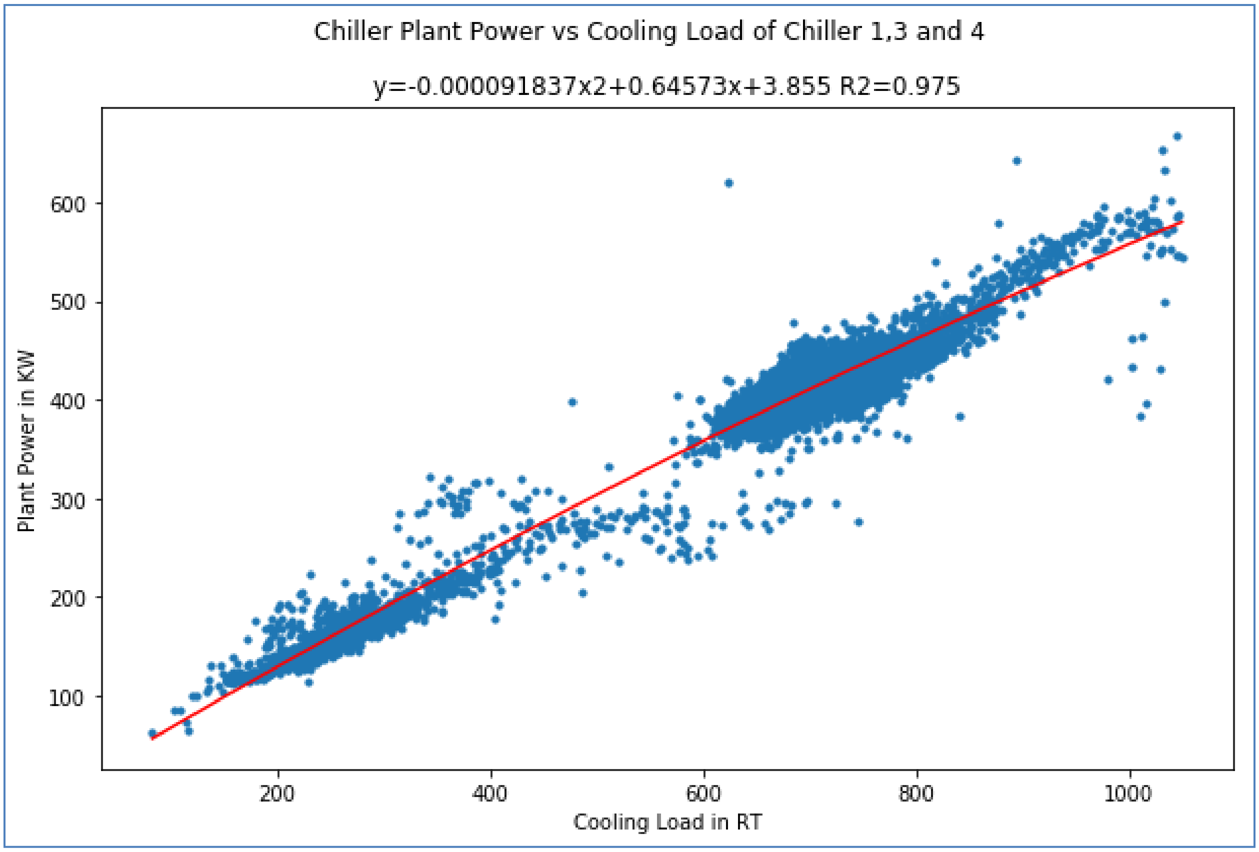



Figure 32: Total Plant Power VS Cooling Load for Feb 2019 (Chiller3 Power Consumption Removed)

This cleansed dataset is then mapped into a scatter plot as shown in Figure 32. Now the distribution of data points in this dataset appears to be reasonable. However, although the $R^2$ is 0.975 which indicates a good fit, the direction of the model is curving slightly upward which is unexpected.

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 210.5 | 274.8 | 336.7 | 396.3 | 453.6 | 508.6 | 561.3 | 611.6 |
| **KW/RT** | 0.627 | 0.613 | 0.601 | 0.590 | 0.579 | 0.568 | 0.557 | 0.546 |

Table 11: Feb 2019 Plant Performance at different part load conditions

Note

This model generated is questionable as it does not tally with the reference part load curve as shown in Figure 9, although $R^2$ is acceptable.

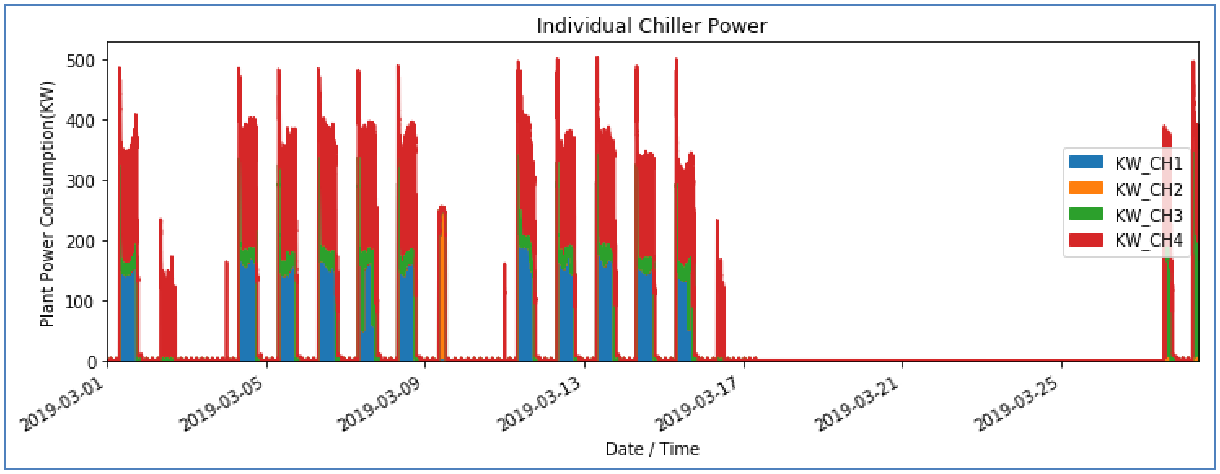



**Figure 33: Daily Power Consumption by Chiller for March 2019**

March data stopped after 17 March as there was a fault with the BMS system

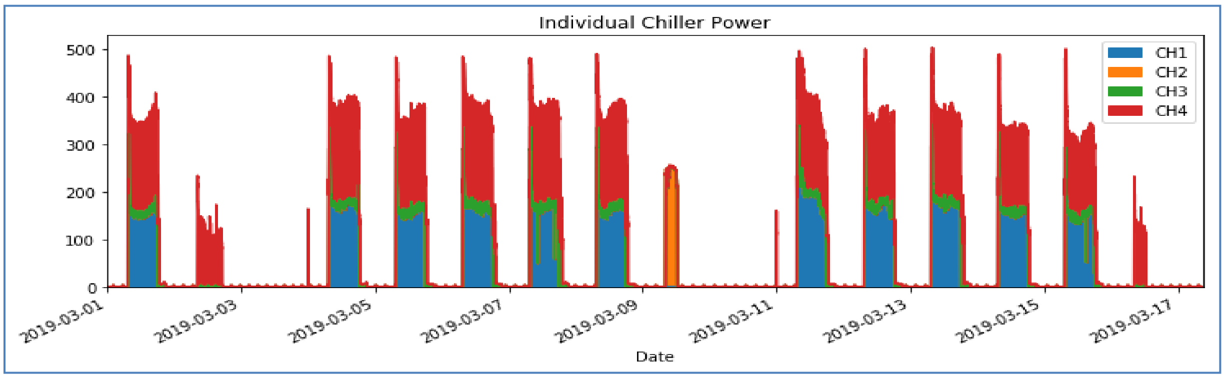



**Figure 34: Daily Power Consumption by Chiller for March 2019 (Valid data)**

The sets of valid data are as shown in Figure 34. From here, the data are extracted and mapped into a scatter plot as shown in Figure 35.

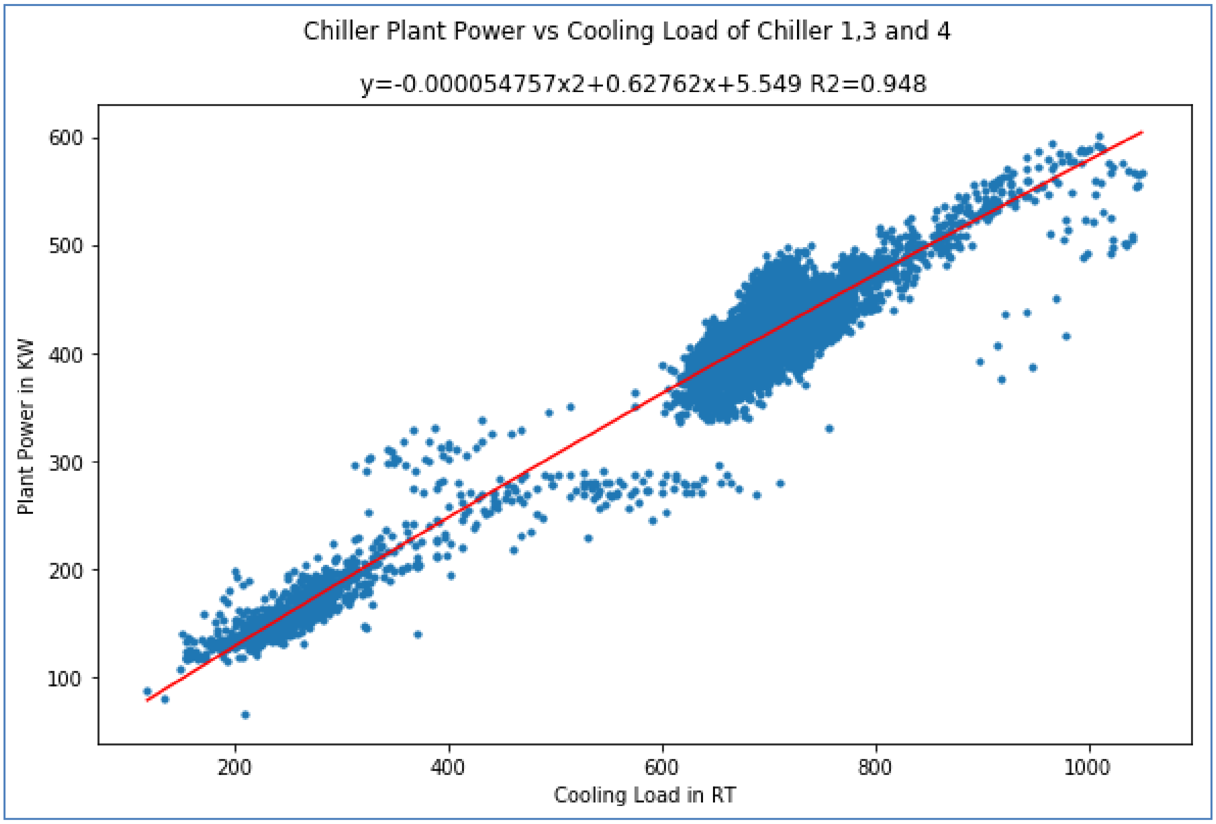



Figure 35: Total Plant Power VS Cooling Load for March 2019

The distribution of the data looks fine and the model has a $R^2$ of 0.948. However, the model curves slightly upwards which differs from the normal model. The data might be unusable.

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 210.3 | 275.7 | 339.8 | 402.6 | 463.9 | 524.0 | 582.6 | 639.9 |
| **KW/RT** | 0.626 | 0.616 | 0.607 | 0.599 | 0.592 | 0.585 | 0.578 | 0.571 |

Table 12: March 2019 Plant Performance at different part load conditions

**April 2019 – No Data**

**May 2019 – No Data**

#### *3.5.1.4 June 2019*

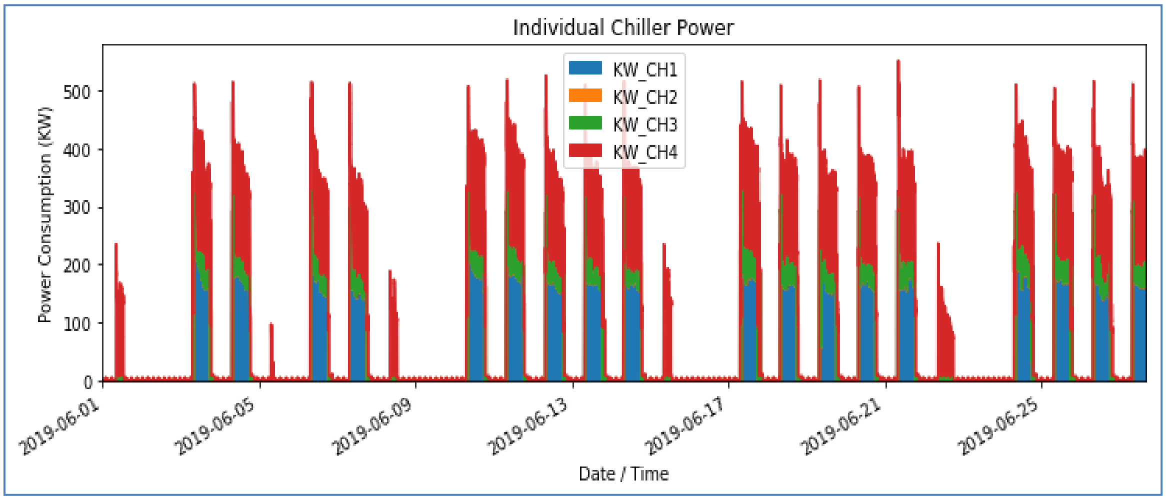



**Figure 36: Daily Power Consumption by Chiller for June 2019**

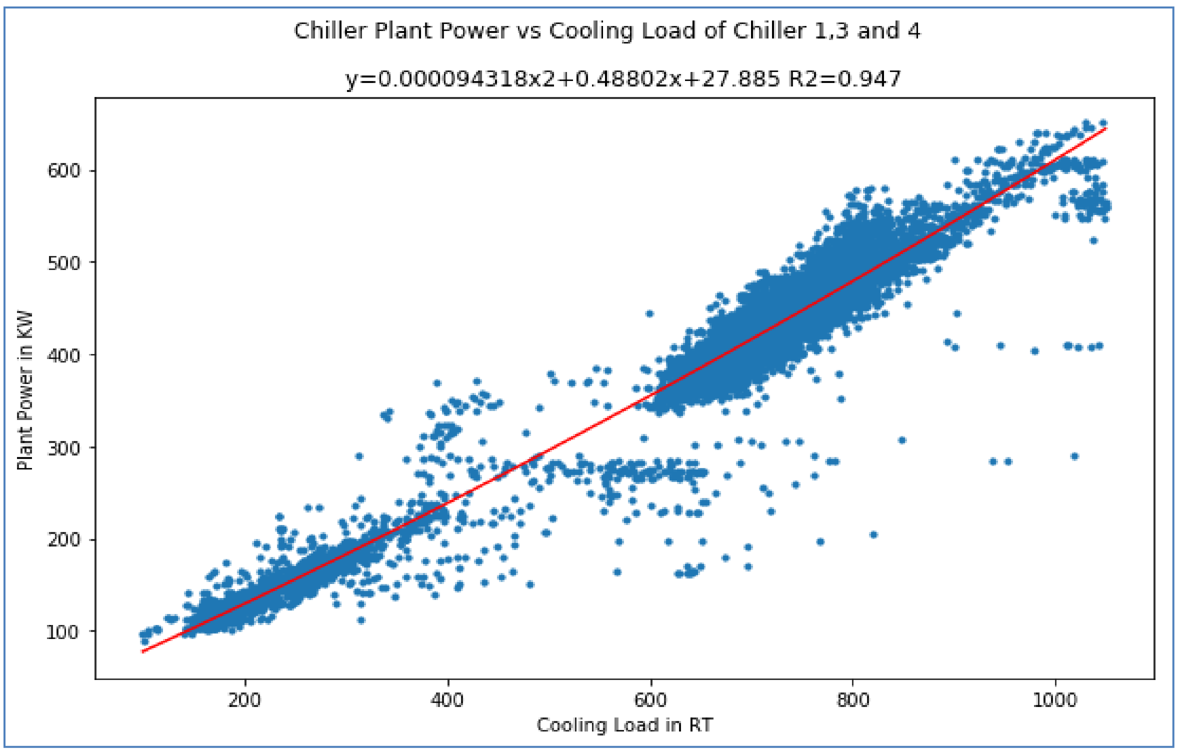



**Figure 37: Total Plant Power VS Cooling Load for June 2019**

The data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.947

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 202.5 | 265.4 | 330.8 | 398.4 | 468.5 | 540.9 | 615.6 | 692.8 |
| **KW/RT** | 0.603 | 0.593 | 0.591 | 0.593 | 0.598 | 0.604 | 0.611 | 0.619 |

**Table 13: June 2019 Plant Performance at different part load conditions**

#### *3.5.1.5 July 2019*

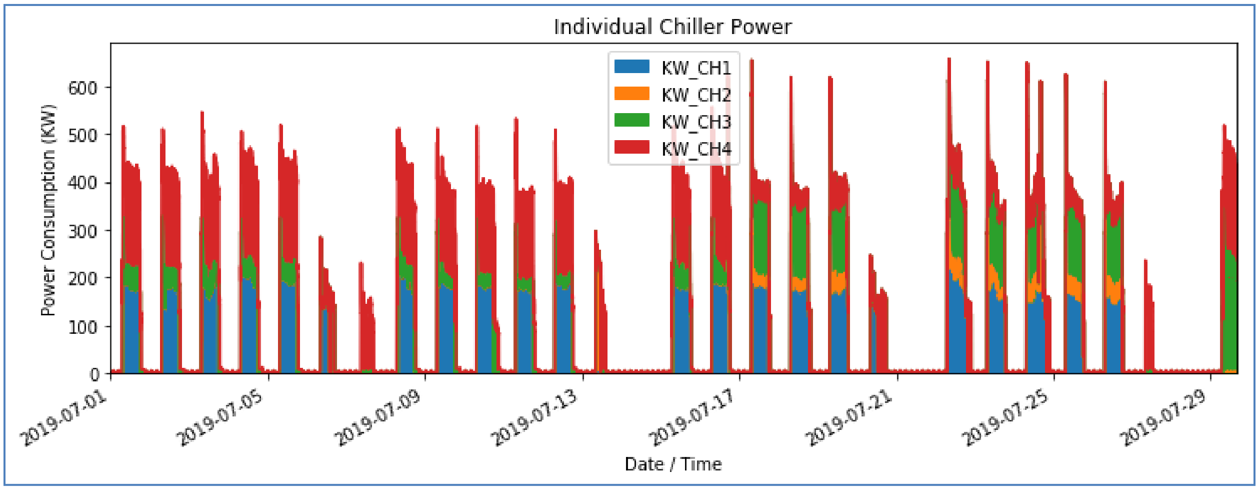



**Figure 38: Daily Power Consumption by Chiller for July 2019**

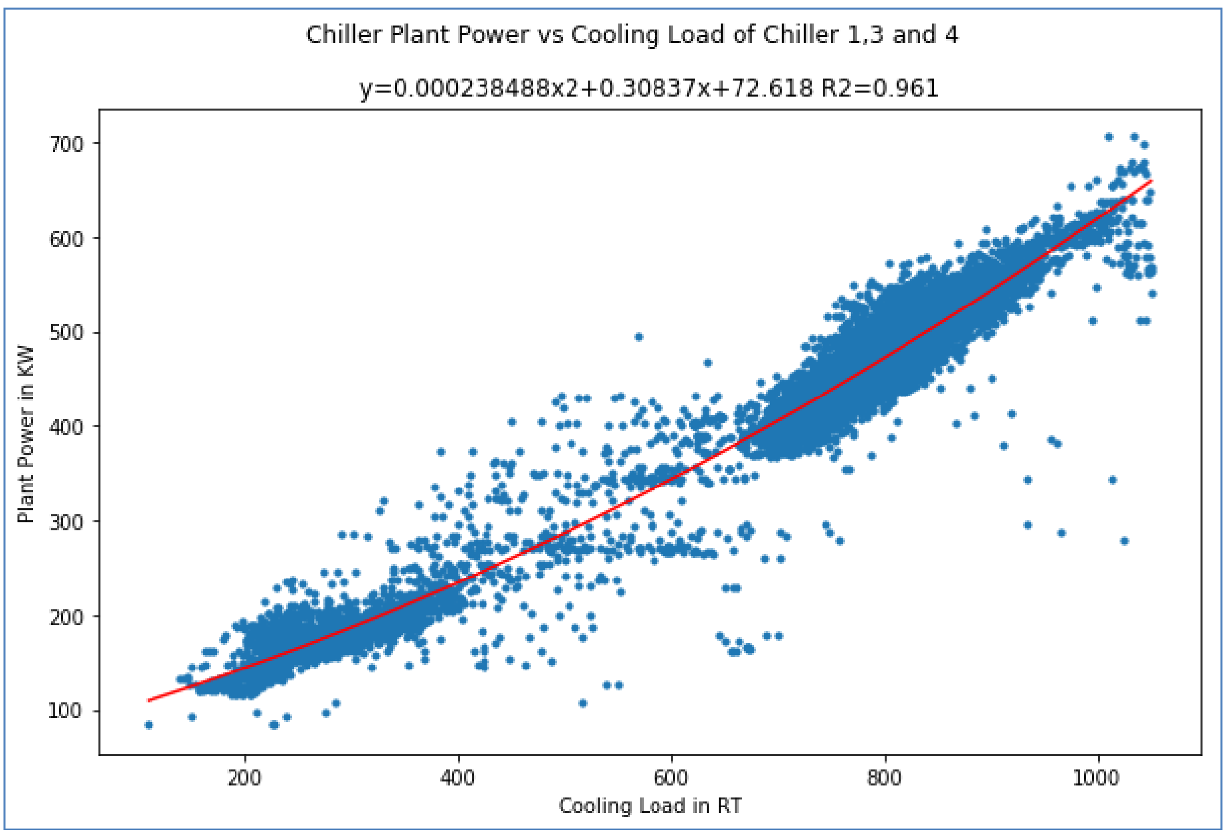



**Figure 39: Total Plant Power VS Cooling Load for July 2019**

The data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a R2 of 0.961

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 203.2 | 258.6 | 320.1 | 387.5 | 461.0 | 540.4 | 625.8 | 717.1 |
| **KW/RT** | 0.605 | 0.577 | 0.572 | 0.577 | 0.588 | 0.603 | 0.621 | 0.640 |

Table 14: July 2019 Plant Performance at different part load conditions

#### *3.5.1.6 Aug 2019*

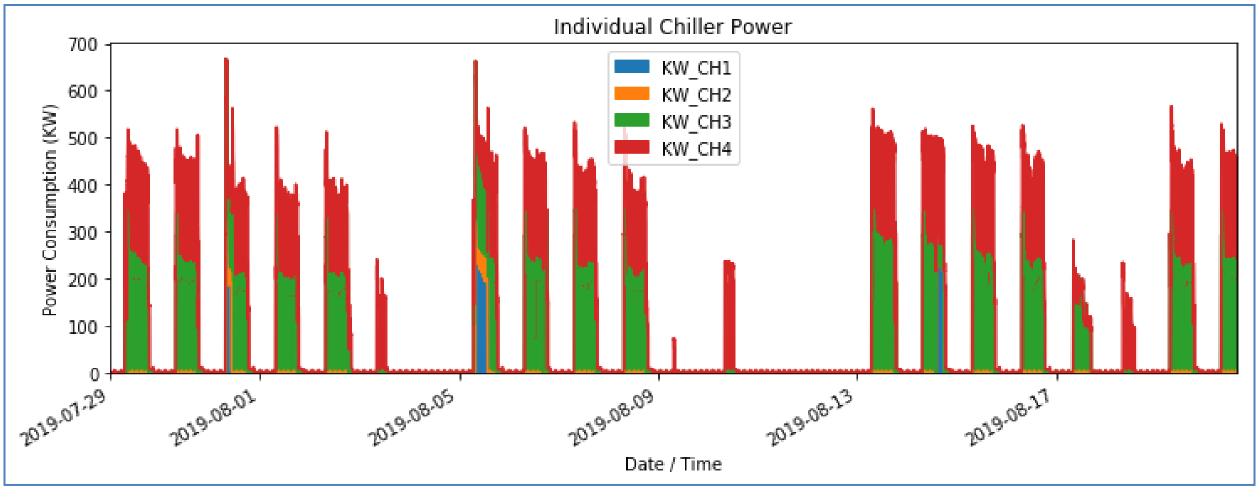



Figure 40: Daily Power Consumption by Chiller for Aug 2019

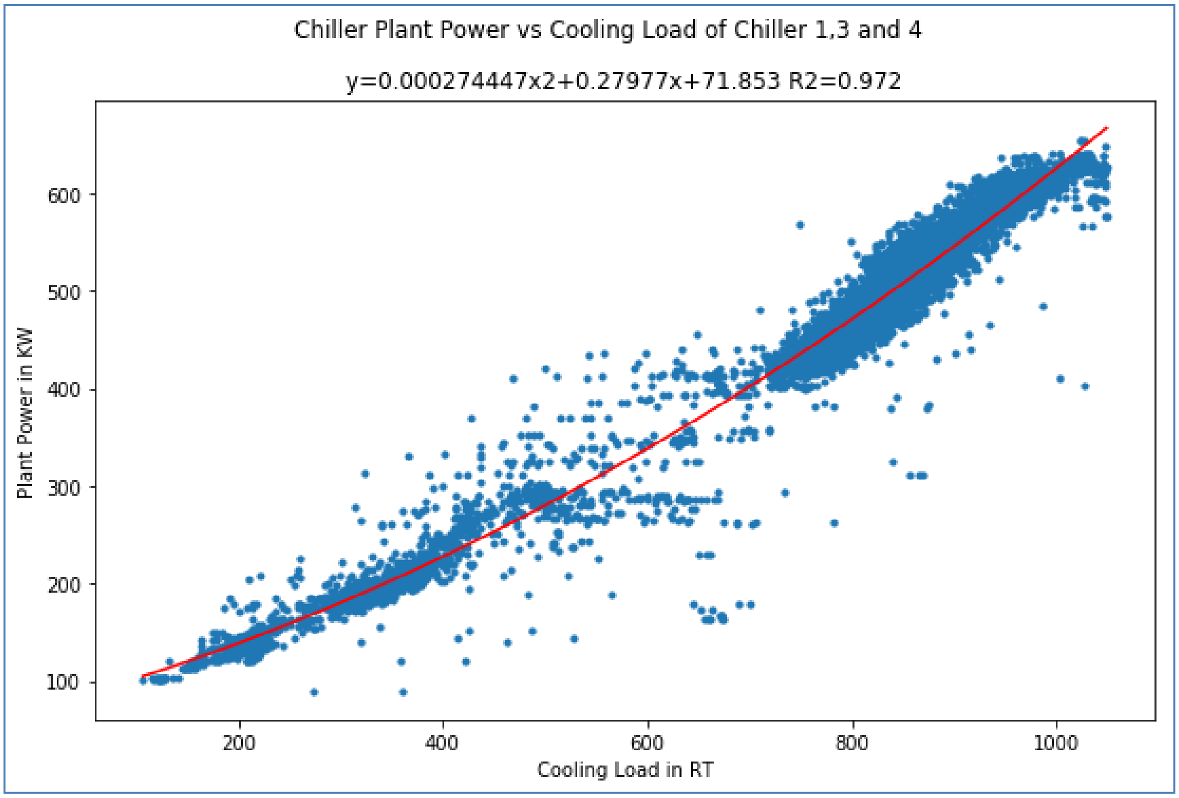



**Figure 41: Total Plant Power VS Cooling Load for Aug 2019**

The selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.972

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 196.8 | 252.3 | 314.6 | 383.8 | 459.9 | 542.9 | 632.7 | 729.5 |
| **KW/RT** | 0.586 | 0.563 | 0.562 | 0.571 | 0.587 | 0.606 | 0.628 | 0.651 |

**Table 15 : Aug 2019 Plant Performance at different part load conditions**

### *3.5.1.7 Sep 2019*

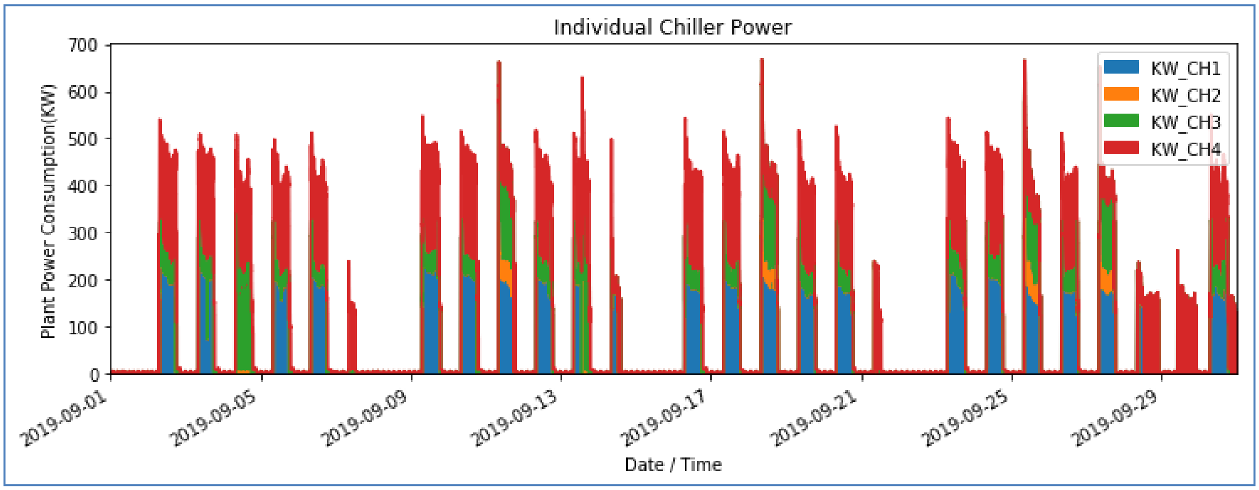



**Figure 42: Daily Power Consumption by Chiller for Sep 2019**

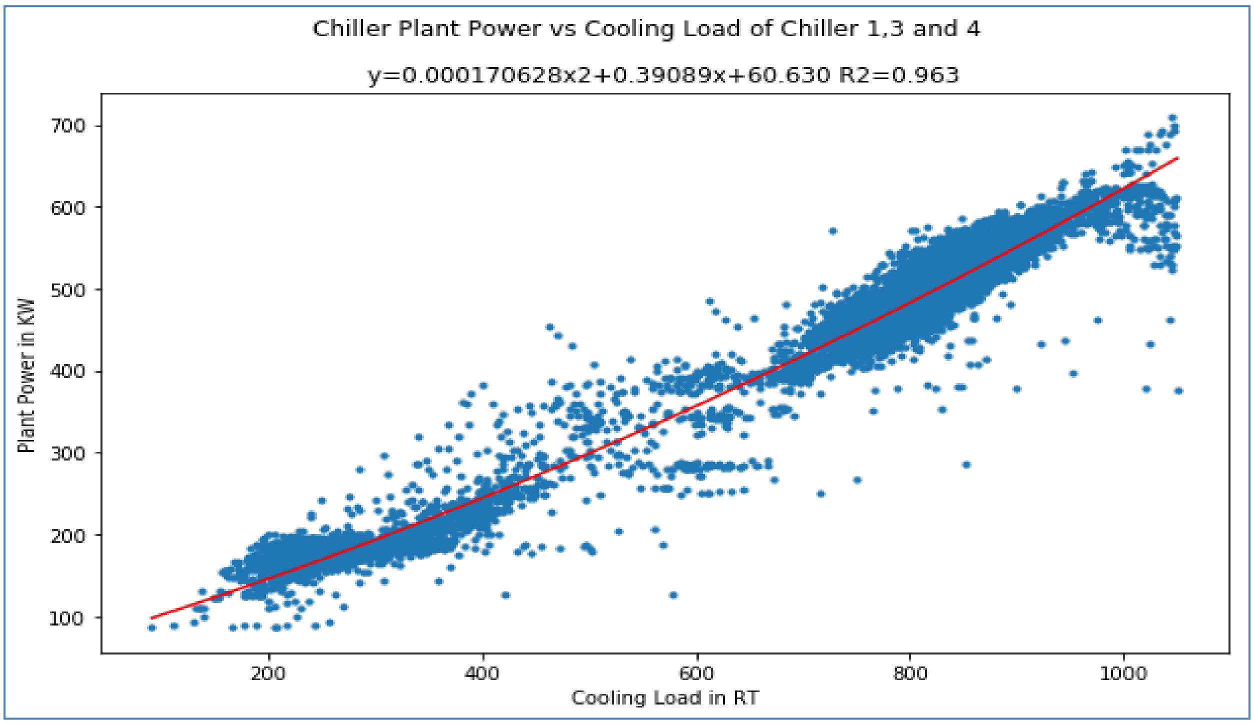



**Figure 43: Total Plant Power VS Cooling Load for Sep 2019**

The selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.963

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 211.2 | 270.0 | 333.0 | 400.3 | 472.0 | 547.9 | 628.0 | 712.5 |
| **KW/RT** | 0.629 | 0.603 | 0.595 | 0.596 | 0.602 | 0.611 | 0.623 | 0.636 |

**Table 16 : Sep 2019 Plant Performance at different part load condition**

### *3.5.1.8 Oct 2019*

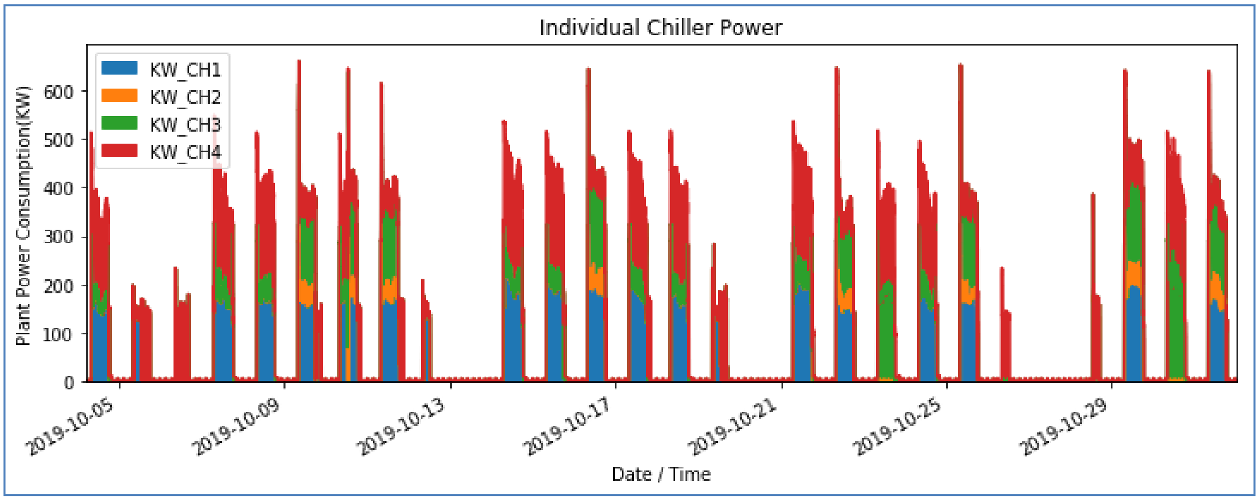



**Figure 44: Daily Power Consumption by Chiller for Oct 2019**

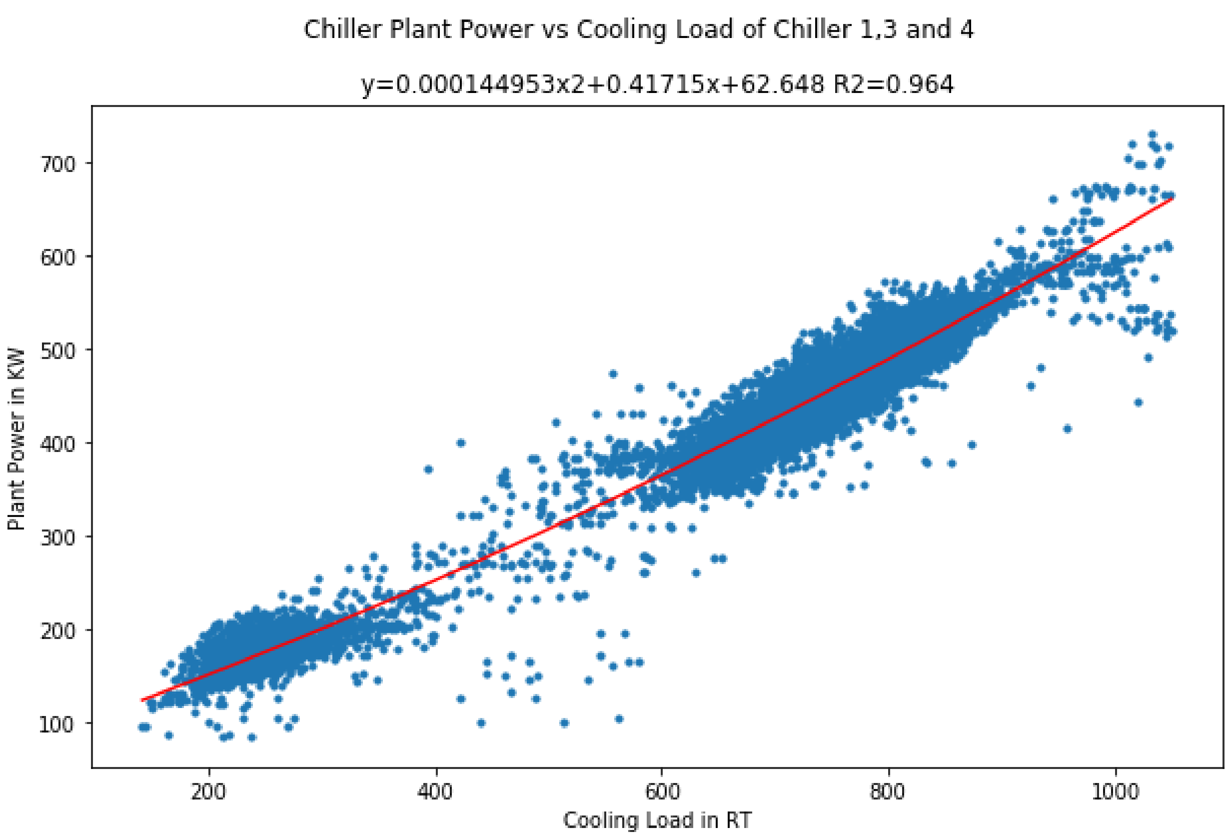



**Figure 45: Total Plant Power VS Cooling Load for Oct 2019**

The selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.964

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 219.2 | 278.6 | 341.7 | 408.4 | 478.8 | 552.8 | 630.4 | 711.7 |
| **KW/RT** | 0.652 | 0.622 | 0.610 | 0.608 | 0.611 | 0.617 | 0.625 | 0.635 |

Table 17 : Oct 2019 Plant Performance at different part load conditions

### *3.5.1.9 Nov 2019*

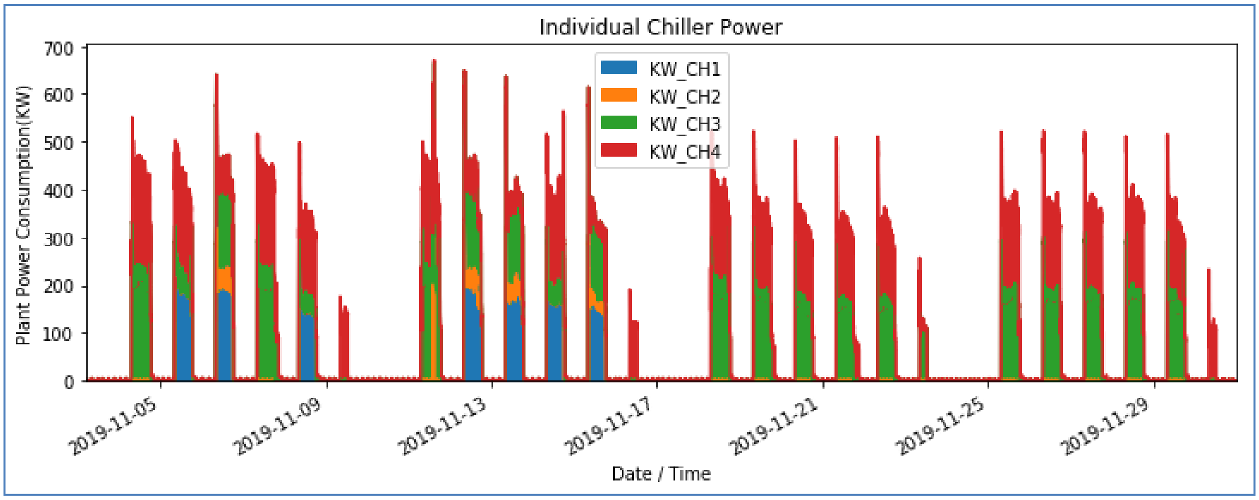



Figure 46: Daily Power Consumption by Chiller for Nov 2019

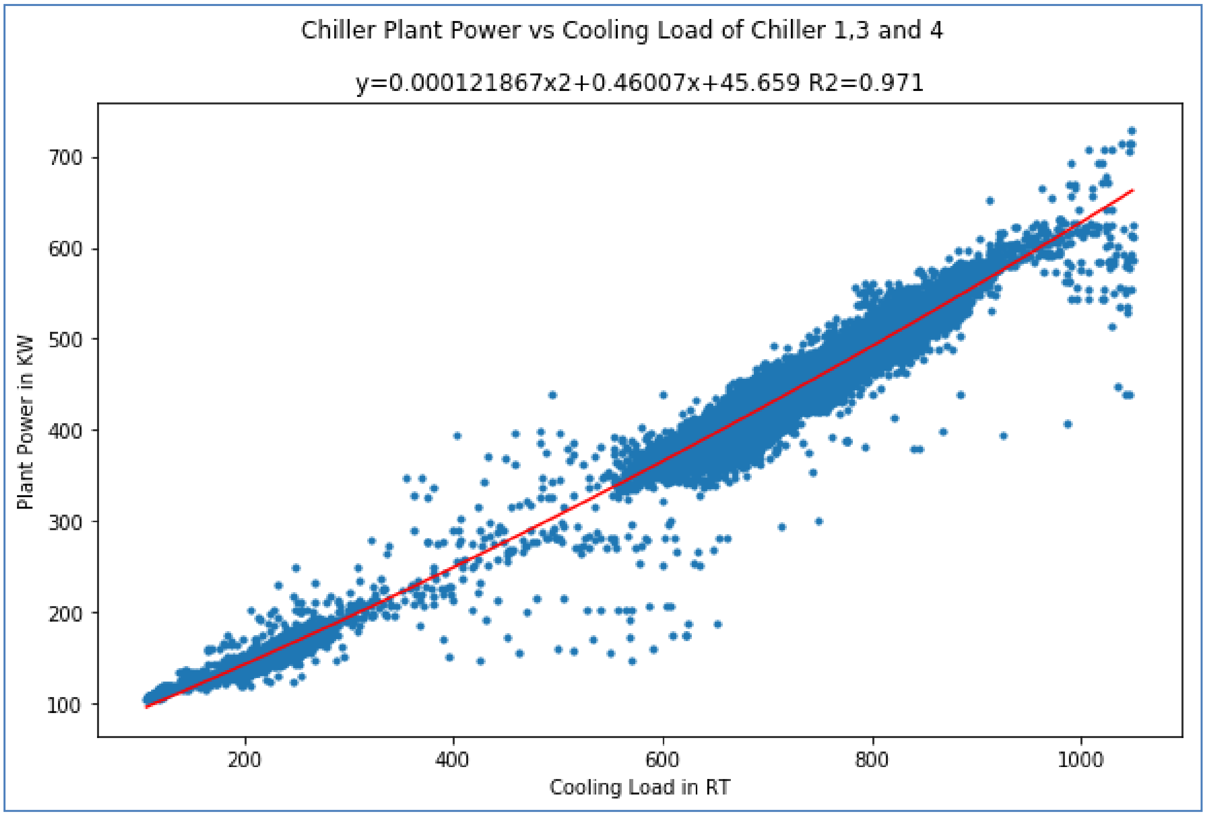



Figure 47: Total Plant Power VS Cooling Load for Nov 2019

The selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.971

| **%** | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 214.0 | 276.2 | 341.5 | 409.9 | 481.3 | 555.7 | 633.2 | 713.8 |
| **KW/RT** | 0.637 | 0.617 | 0.610 | 0.610 | 0.614 | 0.620 | 0.628 | 0.637 |

Table 18 : Nov 2019 Plant Performance at different part load conditions

### *3.5.1.10 Dec 2019*

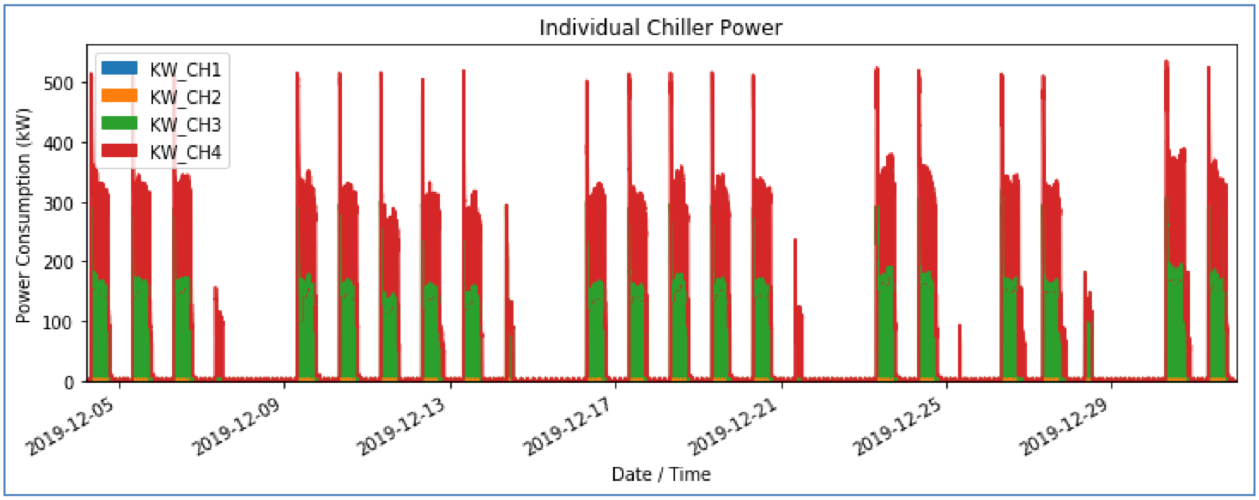



**Figure 48: Daily Power Consumption by Chiller for Dec 2019**

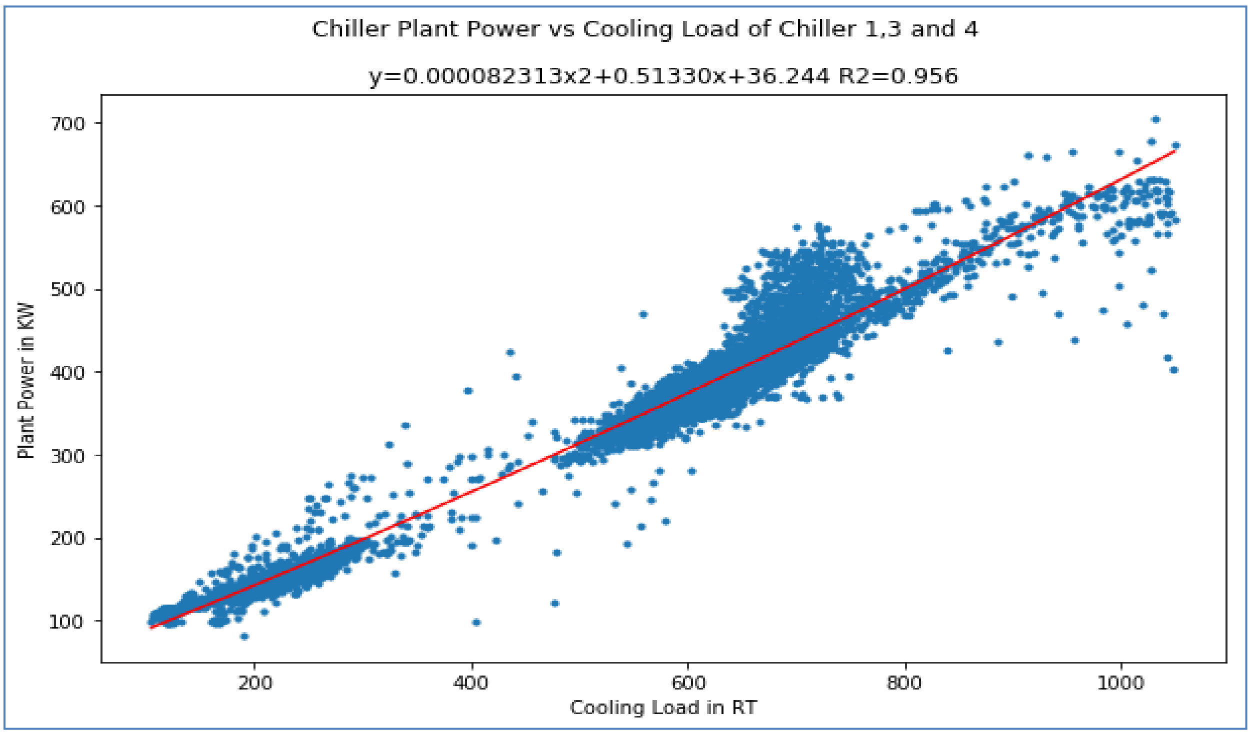



**Figure 49: Total Plant Power VS Cooling Load for Dec 2019**

The data point are mapped on a scatter plot, the distribution pattern of the data point are reasonable with a $R^2$ of 0.956

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 218.2 | 282.9 | 349.7 | 418.5 | 489.3 | 562.2 | 637.1 | 714.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **KW/RT** | 0.649 | 0.632 | 0.624 | 0.623 | 0.624 | 0.627 | 0.632 | 0.638 |

Table 19 : Dec 2019 Plant Performance at different part load conditions

#### *3.5.1.11 Jan 2020*

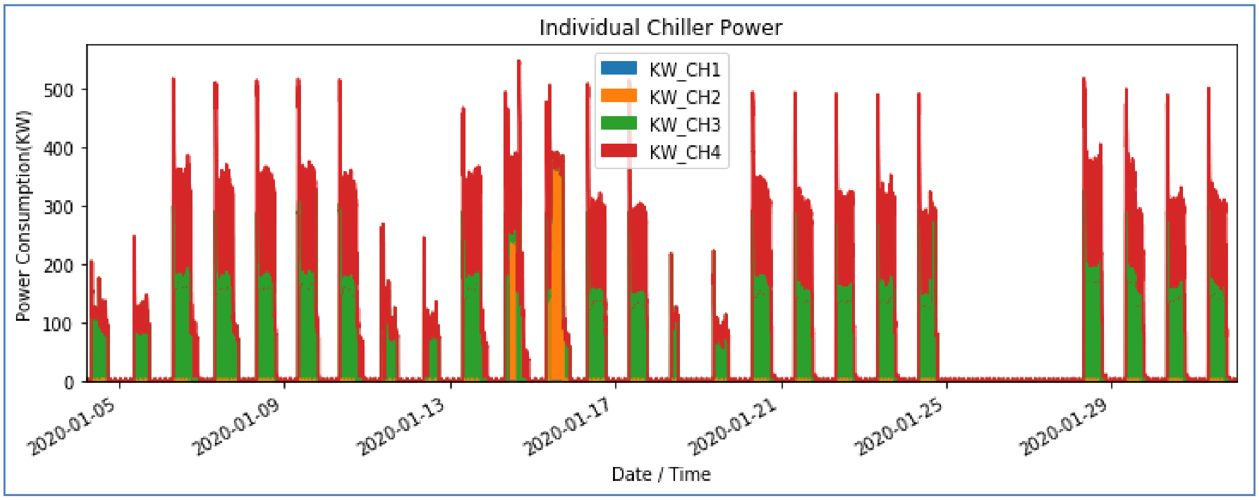



Figure 50: Daily Power Consumption by Chiller for Jan 2020

**Using all valid data points within the entire month**

Yearly servicing was performed in mid Jan 2020. The data of the entire month is used to compute the power consumption model and the result is as shown in Figure 51.

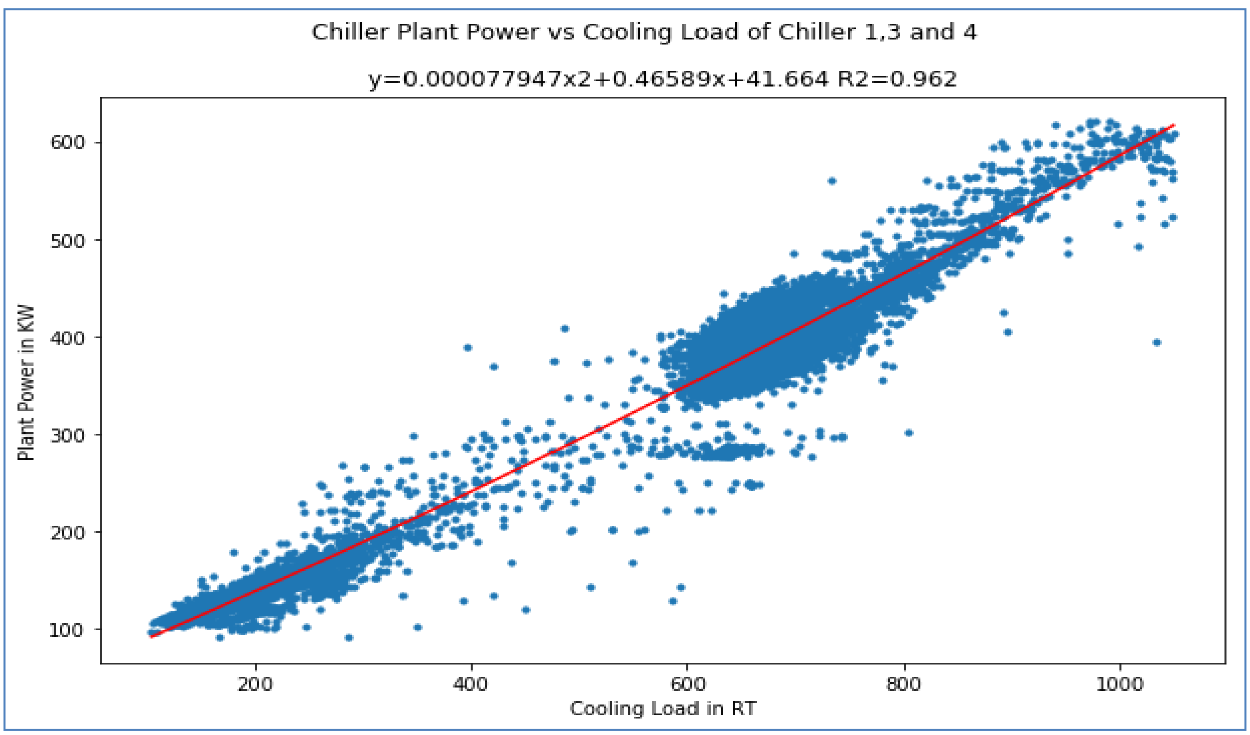



Figure 51: Total Plant Power VS Cooling Load for Jan 2020 (Entire month)

The data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.962.

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| RT | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| KW | 207.0 | 266.0 | 327.0 | 389.9 | 454.8 | 521.7 | 590.5 | 661.2 |
| KW/RT | 0.616 | 0.594 | 0.584 | 0.580 | 0.580 | 0.582 | 0.586 | 0.590 |

**Table 20 : Jan 2020 Plant Performance at different part load conditions (Entire Month)**

**Valid data points before 16 Jan 2020**

Data before the chiller cleaning is separated to plot the power consumption model. The result is as shown in Figure 52.

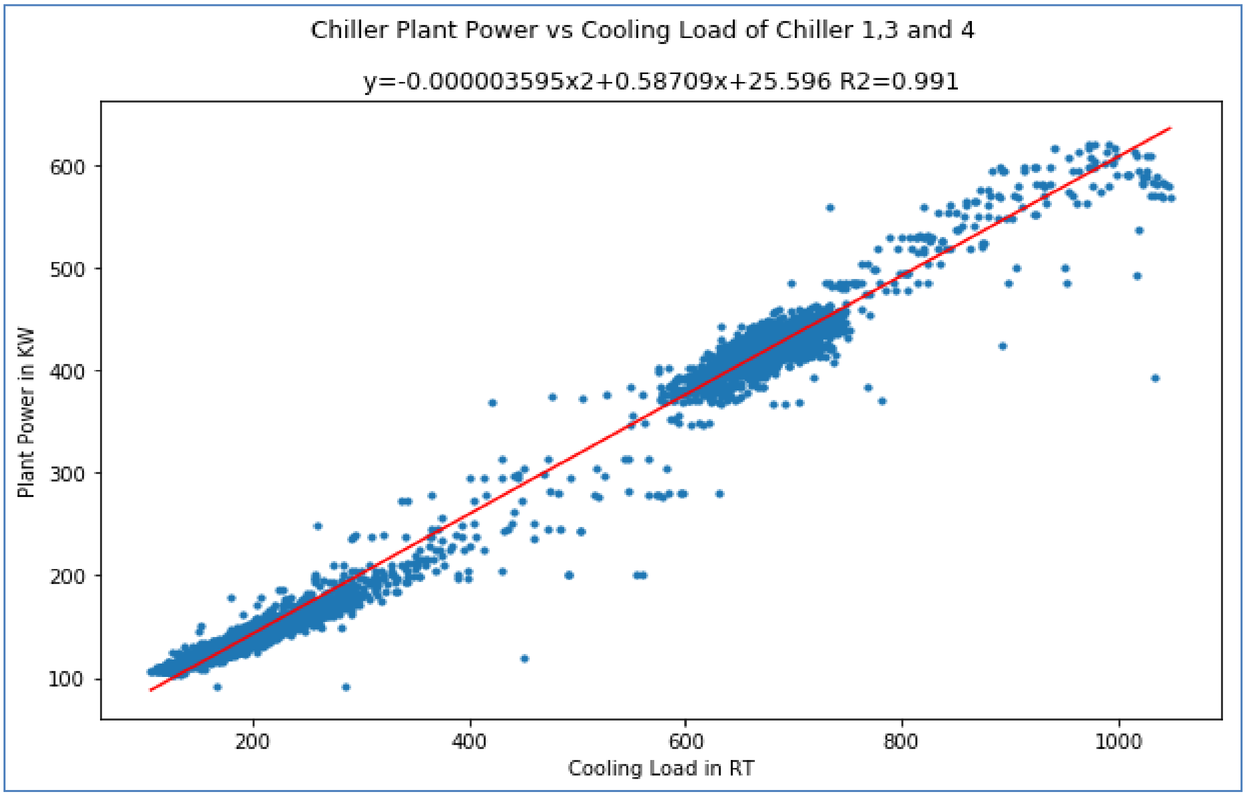



**Figure 52: Total Plant Power VS Cooling Load for Jan 2020 (First half)**

Selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.991

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 222.5 | 287.9 | 353.2 | 418.5 | 483.7 | 548.7 | 613.7 | 678.6 |
| **KW/RT** | 0.662 | 0.643 | 0.631 | 0.623 | 0.617 | 0.612 | 0.609 | 0.606 |

**Table 21: Jan 2020 Plant Performance at different part load conditions (First half)**

**All valid data points after 16 Jan 2020**

Data before the chiller cleaning are separated to plot the power consumption model. The result is as shown in Figure 53.

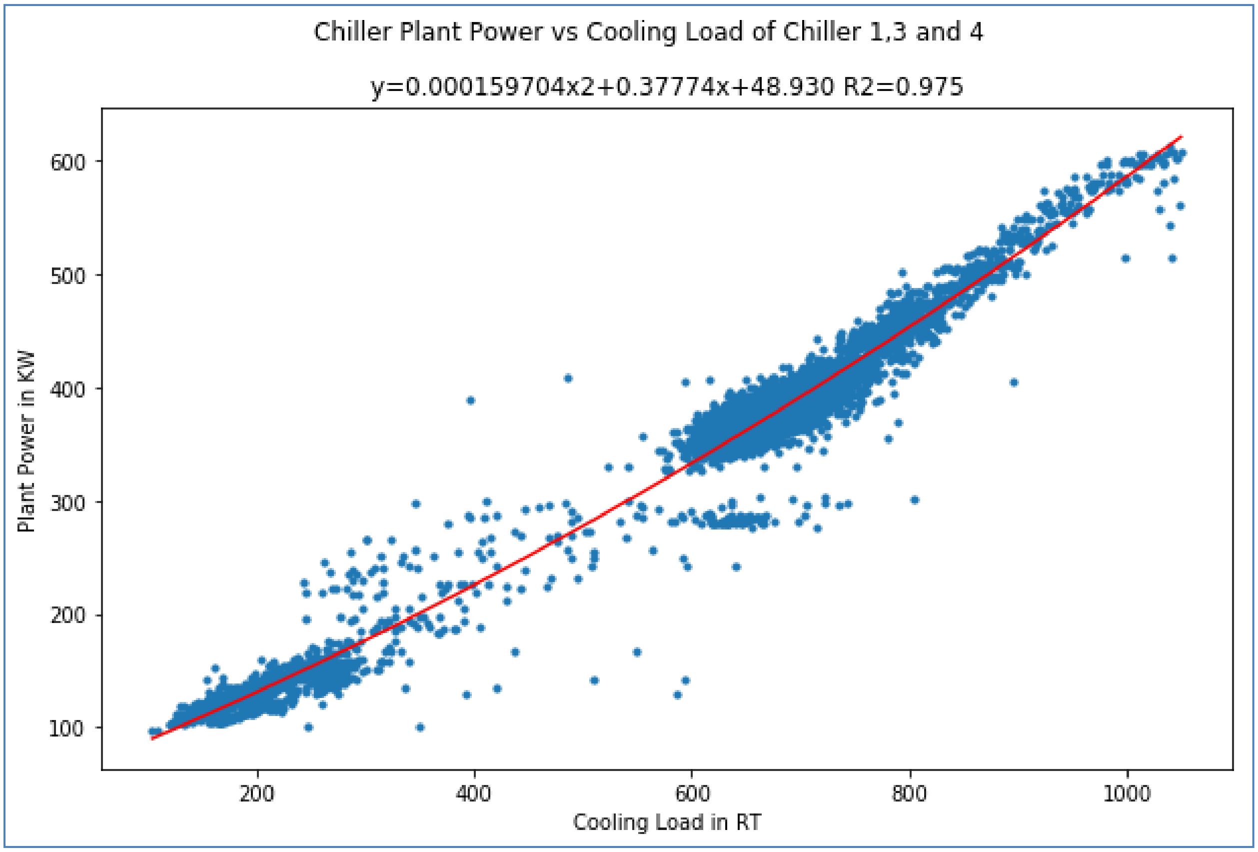



Figure 53: Total Plant Power VS Cooling Load for Jan 2020 (Second Half)

The selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.975.

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| **RT** | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| **KW** | 193.8 | 250.2 | 310.5 | 374.8 | 443.2 | 515.5 | 591.9 | 672.3 |
| **KW/RT** | 0.577 | 0.559 | 0.555 | 0.558 | 0.565 | 0.575 | 0.587 | 0.600 |

Table 22: Jan 2020 Plant Performance at different part load conditions (Second Half)

***3.5.1.12 Feb 2020***

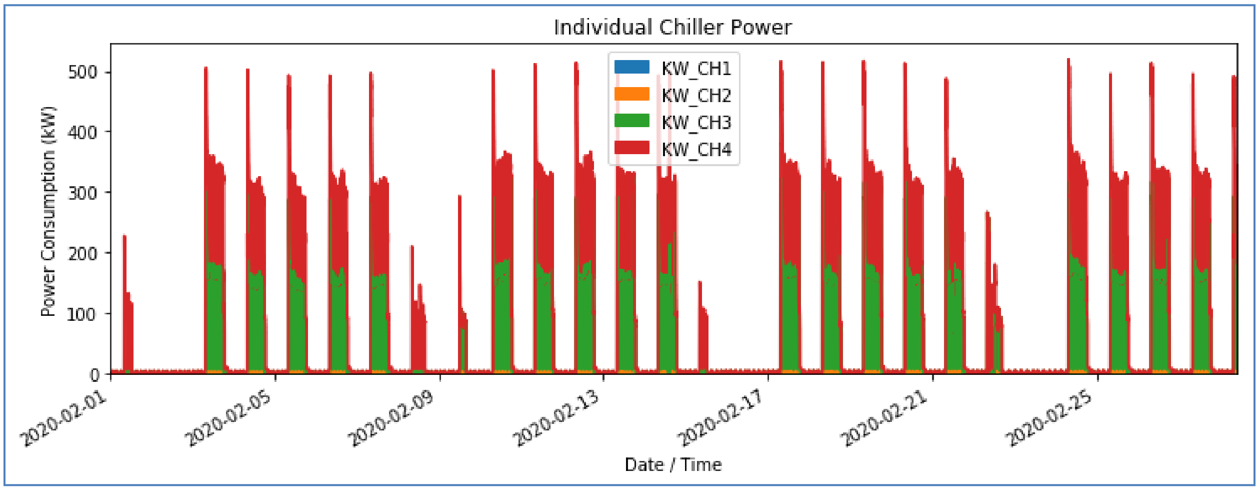



**Figure 54: Daily Power Consumption by Chiller for Feb 2020**

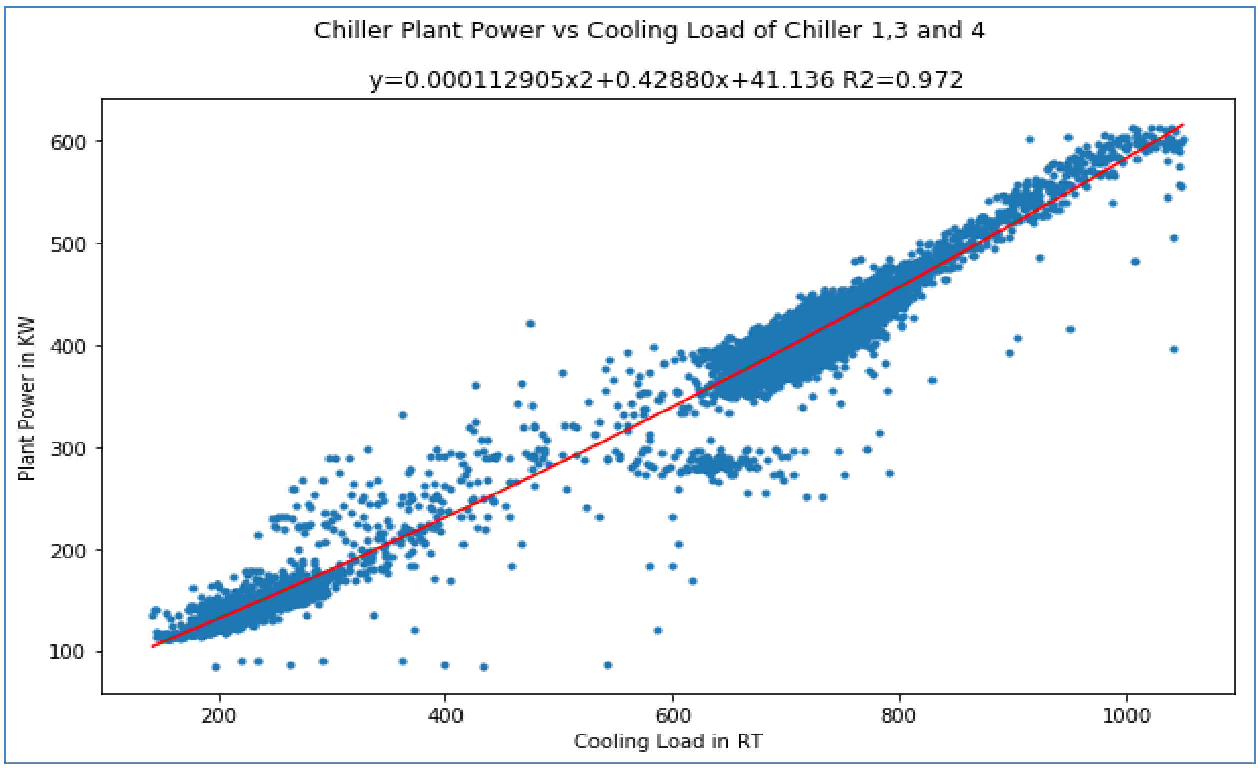



**Figure 55: Total Plant Power VS Cooling Load for Feb 2020**

The selected data points are mapped on a scatter plot. The distribution pattern of the data points is reasonable with a $R^2$ of 0.972.

| % | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| RT | 336 | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| KW | 198.3 | 256.2 | 316.9 | 380.4 | 446.7 | 515.7 | 587.5 | 662.1 |
| KW/RT | 0.590 | 0.572 | 0.566 | 0.566 | 0.570 | 0.576 | 0.583 | 0.591 |

Table 23: Feb 2020 Plant Performance at different part load conditions

### 3.5.2 Energy Data based on any 2 out of the 3 chillers

| % Full Load | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|
| RT | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
| Nov-18 ◊ | 0.609 | 0.607 | 0.611 | 0.619 | 0.629 | 0.641 | 0.653 |
| Dec-18 | 0.595 | 0.588 | 0.589 | 0.596 | 0.605 | 0.616 | 0.629 |
| Jan-19 | 0.609 | 0.600 | 0.598 | 0.599 | 0.603 | 0.608 | 0.614 |
| Feb-19* | 0.613 | 0.601 | 0.590 | 0.579 | 0.568 | 0.557 | 0.546 |
| Mar-19* | 0.616 | 0.607 | 0.599 | 0.592 | 0.585 | 0.578 | 0.571 |
| Jun-19 | 0.593 | 0.591 | 0.593 | 0.598 | 0.604 | 0.611 | 0.619 |
| Jul-19 | 0.577 | 0.572 | 0.577 | 0.588 | 0.603 | 0.621 | 0.640 |
| Aug-19 | 0.563 | 0.562 | 0.571 | 0.587 | 0.606 | 0.628 | 0.651 |
| Sep-19 | 0.603 | 0.595 | 0.596 | 0.602 | 0.611 | 0.623 | 0.636 |
| Oct-19 | 0.622 | 0.610 | 0.608 | 0.611 | 0.617 | 0.625 | 0.635 |
| Nov-19 | 0.617 | 0.610 | 0.610 | 0.614 | 0.620 | 0.628 | 0.637 |
| Dec-19 | 0.632 | 0.624 | 0.623 | 0.624 | 0.627 | 0.632 | 0.638 |
| Jan(A) 20 | 0.643 | 0.631 | 0.623 | 0.617 | 0.612 | 0.609 | 0.606 |
| Jan(B) 20 | 0.559 | 0.555 | 0.558 | 0.565 | 0.575 | 0.587 | 0.600 |
| Feb-20 | 0.572 | 0.566 | 0.566 | 0.570 | 0.576 | 0.583 | 0.591 |

Table 24 Tabulated result of obtained data (using 3 chillers)

◊ As per measured Baseline Data (Table 5)

* Model curves are consistent with the theoretical model.

Summary of the results using data from 3 chillers is as shown in Table 24 and for comparison, the 70% loads are plotted into a bar chart as shown in Figure 56.

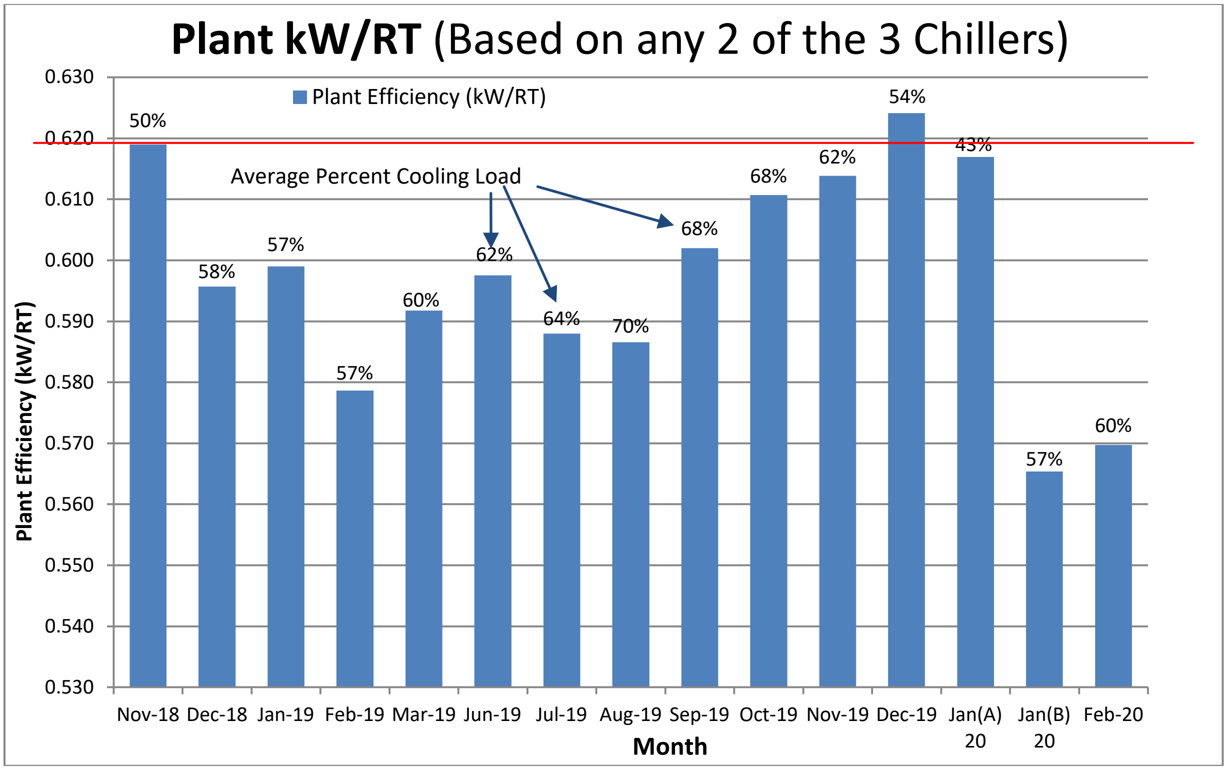



**Figure 56: Summary of 3 chillers, kW/RT in each month**

Even though Fig 58 may not be a fair comparison since chillers 3 and 4 were not consistently used, it does provide a trend that shows a better plant efficiency with the implementation of DCI. It is seen that there is power consumption improvement when compared to the Nov18 baseline.

## 3.6 Weighted average using kWh/RTh

### 3.6.1 Weighted Energy Data

The weighted average of the entire month data is computed and tabulated as follows:

| Month | Sample Size | RTh | Chiller kWh | Chiller kWh/RTh | Plant kWh | Plant kWh/RTh |
|---|---|---|---|---|---|---|
| **Nov 2018** | 7873 | 69709.7 | 33895.3 | 0.486 | 41439.9 | 0.594 |
| **Dec 2018** | 12916 | 134116.8 | 63735.4 | 0.475 | 80776.4 | 0.602 |
| **Jan 2019** | 12858 | 130003.0 | 62895.9 | 0.484 | 78591.5 | 0.605 |
| **Feb 2019** | 10511 | 106608.8 | 50925.0 | 0.478 | 62886.0 | 0.590 |
| **March 2019** | 7260 | 77291.4 | 38540.8 | 0.499 | 46277.8 | 0.599 |
| **June 2019** | 11710 | 128854.9 | 62796.0 | 0.487 | 77003.7 | 0.598 |
| **July 2019** | 14247 | 163693.3 | 79929.4 | 0.488 | 97119.5 | 0.593 |
| **Aug 2019** | 9462 | 117282.6 | 57400.6 | 0.489 | 70238.1 | 0.599 |
| **Sep 2019** | 13054 | 157648.7 | 79901.1 | 0.507 | 95867.0 | 0.608 |
| **Oct 2019** | 12375 | 132727.7 | 69144.0 | 0.521 | 81931.8 | 0.617 |
| **Nov 2019** | 12141 | 133579.6 | 66698.4 | 0.499 | 82416.3 | 0.617 |
| **Dec 2019** | 11584 | 110677.1 | 54045.9 | 0.488 | 69498.3 | 0.628 |
| **Jan (A) 2020** | 5841 | 44539.8 | 22201.7 | 0.498 | 28545.5 | 0.641 |
| **Jan (B) 2020** | 6956 | 71169.3 | 31275.9 | 0.439 | 40271.3 | 0.566 |
| **Feb 2020** | 11676 | 123950.9 | 55455.9 | 0.447 | 70921.5 | 0.572 |

**Table 25: Tabulated Chiller and Plant Weighted Average**

The plant kWh/RTh and Chiller kWh/RTh are plotted on a bar chart; as shown in Figure 56

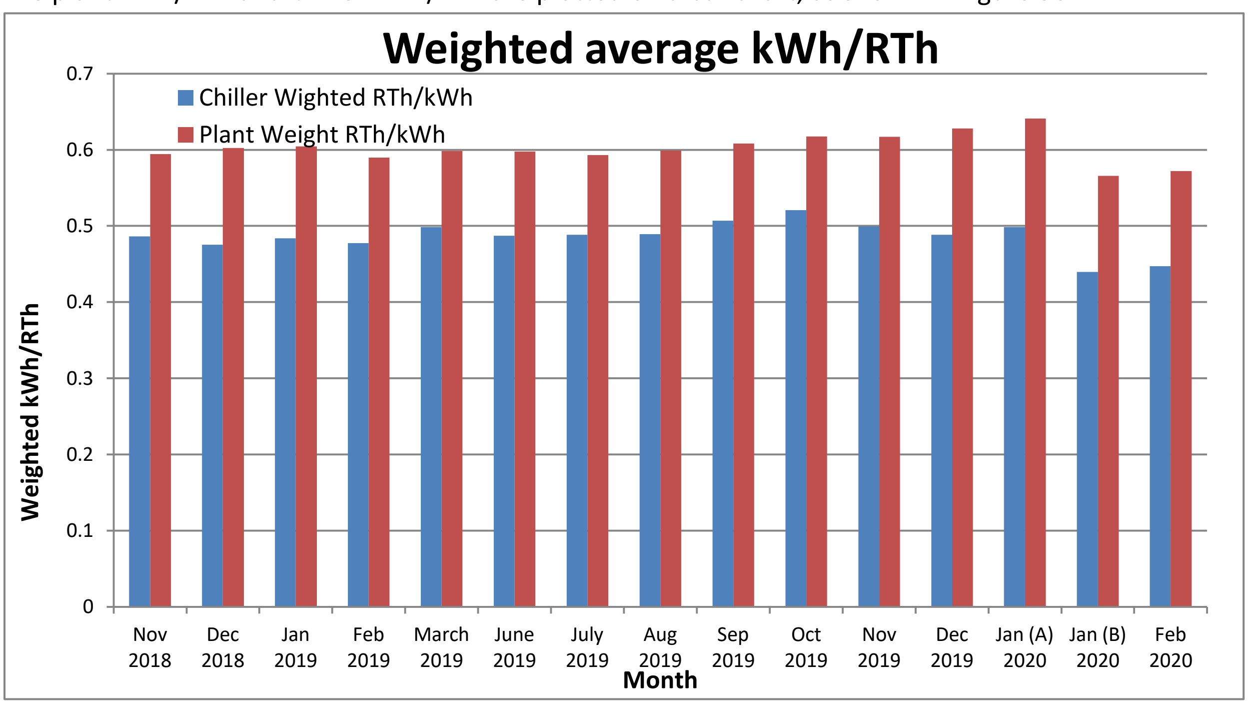



**Figure 57: Chiller and Plant Weighted average**

### 3.6.2 Chiller average operation parameters

The weighted average is the average of all valid data without taken consideration of the load and hence efficiency varies due to variation of load.

| Month | Cooling Load (RT) | Chiller Power (kW) | Plant Power (kW) |
|---|---|---|---|
| Nov 2018 | 531.3 | 258.3 | 315.8 |
| Dec 2018 | 623.0 | 296.1 | 375.2 |
| Jan 2019 | 606.6 | 293.5 | 366.7 |
| Feb 2019 | 608.6 | 290.7 | 359.0 |
| March 2019 | 638.8 | 318.5 | 382.5 |
| June 2019 | 660.2 | 321.8 | 394.6 |
| July 2019 | 689.4 | 336.6 | 409.0 |
| Aug 2019 | 743.7 | 364.0 | 445.4 |
| Sep 2019 | 724.6 | 367.2 | 440.6 |
| Oct 2019 | 726.7 | 385.6 | 433.9 |
| Nov 2019 | 660.1 | 329.6 | 407.3 |
| Dec 2019 | 573.1 | 280.0 | 360.0 |
| Jan (1-15) 2020 | 457.5 | 228.1 | 293.2 |
| Jan (16-31) 2020 | 613.9 | 269.8 | 347.4 |
| Feb 2020 | 637.0 | 285.0 | 364.4 |

**Table 26: Tabulated Average Cooling Load, Chiller and Plant Power Consumption**

The average loads are therefore compiled in tabulated in Table 26 and presented in a form of bar chart in Figure 58.

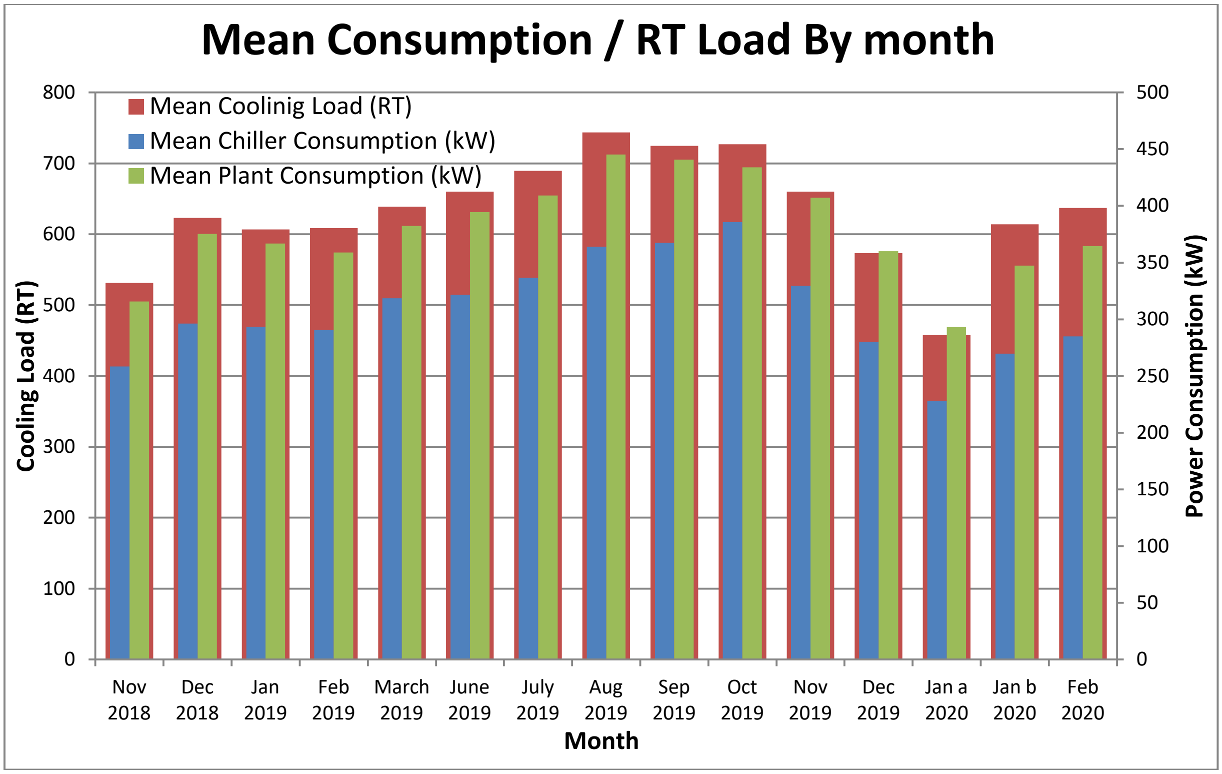



**Figure 58: Chiller and Plant Mean Cooling and Electrical Load**

From Figure 58 above, one can see the trend is consistent with the data measure in section 3.3 to 3.5.

# 4 Water

## 4.1 Water Chemistry

The water chemistry of recirculation water is as follows

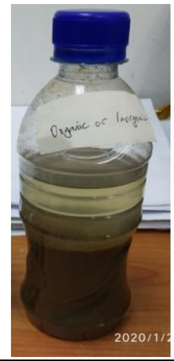
| Test Parameter | Unit | Aug 2019 | Sep 2019 | Oct 2019 | Nov 2019 | Dec 2019 | Jan 2019 | Feb 2019 |
|---|---|---|---|---|---|---|---|---|
| pH | mg/L | 8.4 | 8.5 | 8.3 | 8 | 8.2 | 8 | 8.3 |
| Calcium as Ca | mg/L | 70 | 131 | 146 | 106 | 128 | 55.3 | 83.2 |
| Magnesium as Mg | mg/L | 6.2 | 10.9 | 14 | 10.5 | 11.5 | 5.33 | 7.89 |
| Chloride as Cl | mg/L | 134 | 216 | 227 | 192 | 192 | 103 | 125 |
| Sulphate as SO4 | mg/L | 119 | 215 | 246 | 156 | 165 | 79.6 | 87.6 |
| Silica as SiO2 | mg/L | 30.3 | 52.5 | 40.4 | 26.5 | 34.2 | 25 | 33.4 |
| Conductivity | uS/cm | 911 | 1328 | 1396 | 944 | 1098 | 656 | 781 |

**Table 27: Water Chemistry**

As we can see from the Table 27, under the water management of the DCI system, the water chemistry remains within acceptable range.

## 4.2 Particles trapped in chiller system

During chiller cleaning in mid Jan 2020, excessive dirt was found in the water. However, it can be easily removed by flushing, Water from the chiller was collected and sent for analysis.



- Photo shows water collected from chiller tube washing
- 82.4% of inorganic material
- 17.6% of organic material

<u>Sample collected after heat exchanger cleaning & washing</u>

| | Test Parameters | Unit,% | Comments |
|---|---|---|---|
| A | Organic matter | 17.6 | Dead bacterial cells, algae and etc. |
| B | Inorganic matter | 82.4 | |
| | | | |
| | Inorganic matter components | | |
| 1 | Calcium as $CaCO_3$ | 10.6 | Suspended $CaCO_3$ (Easily washed off from the tubes) |
| 2 | Copper as Cu | 0.77 | |
| 3 | Zinc as Zn | 1.47 | |
| 4 | Silica as $SiO_2$ | 27.3 | Likely to be the suspended $SiO_2$ or $SiO_2$ adsorbed by $Fe(OH)_3$ example |
| 5 | Other inorganic solids | 42.26 | Mainly particles in the air that were trapped by the cooling tower. |

**Table 28: Analysis of Sample collected**

The sample did not exhibit the characteristic of scales that is normally found in a chiller system as the sludge could be easily remove by water jet during cleaning.

The dust particles from the air could have been trapped by the cooling tower during operation and deposited in the chiller as it is the lowest point in the system.

<u>Recommendation</u>

A self cleaning auto filter (which is beyond the scope of DCI System) e.g. Amiad or equal is recommended to be installed as a side stream filter at the cooling tower to reduce the solids in the cooling system.

# 5 Chemical and Bacteria Count

Bacteria Count of cooling tower water for the last 8 month is as shown in Table 29

| Test Parameter | Unit | June 2019 | July 2019 | Aug 2019 | Sep 2019 | Oct 2019 | Nov 2019 | Dec 2019 | Jan 2019 |
|---|---|---|---|---|---|---|---|---|---|
| **Std Plate Count** | | | | | | | | | |
| CT1 | cfu/ml | 130 | 70 | 51 | 42 | 95 | 1800 | 51 | 260 |
| CT2 | cfu/ml | 130 | 50 | 76 | 42 | 44 | 950 | 68 | 190 |
| CT3 | cfu/ml | 110 | 86 | 38 | 46 | 94 | 560 | 89 | 290 |
| CT4 | cfu/ml | 1400 | 60 | 90 | 48 | 2300 | 840 | 60 | 280 |
| CT4A | cfu/ml | 870 | 24 | 16 | 8 | 50 | 600 | 20 | 300 |
| **Legionella** | | | | | | | | | |
| CT1 | cfu/ml | NA | NA | 3 | NA | NA | ND | NA | NA |
| CT2 | cfu/ml | NA | NA | 3 | NA | NA | ND | NA | NA |
| CT3 | cfu/ml | NA | NA | 1 | NA | NA | ND | NA | NA |
| CT4 | cfu/ml | NA | NA | ND | NA | NA | ND | NA | NA |
| CT4A | cfu/ml | NA | NA | ND | NA | NA | ND | NA | NA |

**Table 29: Bacteria Count Record**

*NA = Not Analysed. (NEA requires Legionella Bacteria test only once every 3 months)

*ND = Not detected

SPC (Standard Plate Count) and Legionella counts are below limits set by NEA.

According to NEA, the limits for SPC count in cooling tower re-circulation water should not to exceed 100,000 cfu/ml and Legionella bacteria count must not exceed 10 cfu/ml.

# 6 Conclusion

In conclusion, it can be said that comparing baseline data against Feb 2020 is the most relevant due to the following facts:

1. Both sets of data are using the same chillers (Chiller 3 and Chiller 4)
2. Environmental conditions are similar between Nov 2018 (Baseline) and Feb 2020.

The saving of the plant power at 70% load is 7.01% compared to the baseline, as shown in Table 30 below:

| Cooling Load (RT) | 448 | 560 | 672 | 784 | 896 | 1008 | 1120 |
|---|---|---|---|---|---|---|---|
| Percent Full Load (%) | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| | | | | | | | |
| Estimated Plant Power (Nov 18) | 272.9 | 339.8 | 410.6 | 485.1 | 563.5 | 645.6 | 731.6 |
| Estimated Plant Power (Feb 20) | 256.4 | 318.1 | 383.0 | 451.1 | 522.4 | 596.9 | 674.6 |
| | | | | | | | |
| Feb 20 Plant Power Savings (%) | 6.03% | 6.39% | 6.71% | 7.01% | 7.29% | 7.55% | 7.79% |
| | | | | | | | |
| Plant kW/RT (Nov 18) | 0.609 | 0.607 | 0.611 | 0.619 | 0.629 | 0.641 | 0.653 |
| Plant kW/RT (Feb 20) | 0.572 | 0.568 | 0.570 | 0.575 | 0.583 | 0.592 | 0.602 |

**Table 30 Energy saving after implementing DCI system**

Energy saving at 70% is 485.1 – 451.1 = 34Kw.

Basis of calculations,

- 12 hours / day
- 24 operational days per month

Therefore, monthly saving at 70% load is estimated to be 12 x 24 x 34 = 9792 KWh.

# 7 Attachment

Analysis report of water sample collected during chiller washing (Mid Jan 2020)

**EN8500096992/LWW** Page 2 of 2

**Results:**

| Test Parameter | Unit | Sample 1 | Sample 2 |
|---|---|---|---|
| Arsenic as As | % | - | <0.01† |
| Calcium as Ca | % | 0.25 | 4.24 |
| Cadmium as Cd | % | - | <0.01† |
| Chromium as Cr | % | - | <0.01† |
| Copper as Cu | % | - | 0.77 |
| Iron as Fe | % | 48.7 | - |
| Magnesium as Mg | % | 0.022 | - |
| Mercury as Hg | % | - | <0.01† |
| Lead as Pb | % | - | 0.014 |
| Nickel as Ni | % | - | <0.01† |
| Zinc as Zn | % | - | 1.47 |
| Sillica as $SiO_2$ | % | - | 27.3 |
| Calcium Carbonate as $CaCO_3$ | % | - | 10.6 |
| Organic Matter | % | - | 17.6 |
| Mass Loss on Ignition (LOI) | % | - | 31.5 |
| Total Organic Carbon (TOC) | % | - | 10.3 |

***Remarks:***

1. Results expressed as per dry-weight basis.
2. † = Not detectable (The reported values are less than (<) the detection limits of the test methods).

**Results :**

| Test Parameter | Unit | Sample 2 |
|---|---|---|
| Iron as Fe | % | 12.0 |

***Remarks:***

1. Results expressed as per dry-weight basis.