Westfield Hornsby

Measurement and Verification of PlantPRO Chiller Upgrade

JCM Solutions

Final Report

18 May 2015

CONTENTS

1. EXECUTIVE SUMMARY

JCM Solutions has been engaged by Scentre Group (Westfield) to re-visit a Measurement and Verification (M&V) study of the effectiveness of a new HVAC control algorithm, called *PlantPRO*, which has been installed on the two main chiller systems in service at the Westfield Hornsby shopping centre. This report was commissioned following discussions between Westfield, OEH, JCM and Air Master that concluded that the original M&V study should be revised and hopefully improved with the inclusion of humidity data. The study is designed to predict the relative performance of the *PlantPRO* logic compared to the older chiller control regime on the McQuay Chiller System at Westfield Hornsby.

This report follows the guidelines laid down in the International Performance Measurement and Verification Protocol, January 2012, (IPMVP) prepared by the Efficiency Valuation Organisation, (EVO).

The key findings for this M&V study are:

- Weekly average statistics provided the best model of predicted energy usage versus the independent variables of Cooling Degree Days (CDD) for both wet and dry bulb temperatures with a base reference temperature of 14°C, and centre patronage.
- West Block/McQuay Chillers Analysis outcomes
    - Correlation Coefficient of 0.9426
    - Statistical Error in Model of 14%
    - Estimated energy savings: 11.9% savings at 90% confidence

The preliminary findings of this report, based on less than the standard 12 months post-implementation, are:

- Changing the energy model for this chiller system to include dry and wet bulb temperatures as well as eliminating out-of-hours energy data has improved the predictive power of the model and reduced the model errors when compared to the previous M&V study;
- For the McQuay chiller system servicing the West Block of the Westfield Hornsby shopping centre the introduction of the *PlantPRO* control logic has resulted in a statistically significant reduction in energy consumption of over 10% at a confidence level of 90%.

It is recommended that following a full 12 month cycle of *PlantPRO* control of the West Block chillers, the energy usage of the system be again assessed to fully verify savings so far identified.

2. PROJECT BOUNDARY

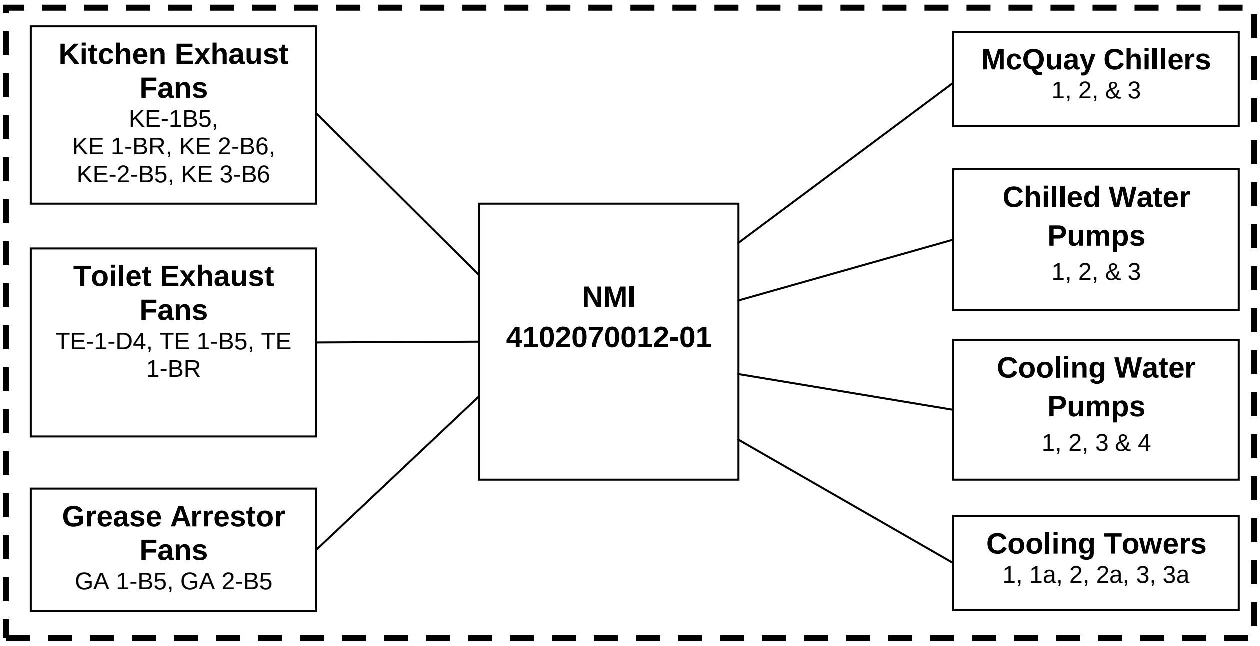
This M&V report is targeted on the McQuay chiller system used to cool the West Block of the Westfield Hornsby shopping centre, known as the "McQuay" or "West Block" system throughout this report.

This system has an individual NMI billing meter which supplies the chillers and associated pumps and cooling towers. In addition there are a number of other ancillary pieces of equipment attached to the meter which draw a relatively constant load when operating (see Figure 1). As these loads are independent of the cooling demand it was decided at the proposal stage to include them in the project boundary and so avoid the need to data log each independent load and try to estimate from the logging the baseline loads for the last 2 years.

By leaving them in the project boundary it is possible to use the calibrated 30 minute real time electricity supply data to determine the baseline energy use models of each NMI and so develop a model of each cooling system's energy use with respect to independent variables.

The figure below identifies the project boundary for the cooling system studied in this investigation.

Figure 1: System Boundary for West Block (NMI 4102070012-01). The black lines indicate supply of electricity; the dotted line indicates the system boundary



3. IPMVP OPTION CHOSEN – OPTION B

Within the IPMVP there are a number of defined M&V study options for the evaluation of the impact of Energy Conservation Measures (ECMs). For this evaluation the most appropriate option is the so called Option B – Retrofit Isolation: All Parameter Measurement. This option covers the retrofitting of a new control system, *PlantPRO*, to the chiller system which is designed to reduce the energy consumption of the cooling systems at the shopping centre. The NMI allows for the continuous measurement of energy use for both the baseline period and the reporting period of the project – that is the time following the installation and commissioning of the *PlantPRO* control software.

3.1 Methodology

This M&V assessment has been carried out in the following manner:

1. A review of the recently completed Level 2 Energy Audit report was conducted where a simple one variable regression model of the McQuay chillers over monthly analysis periods was presented;
2. A review of the recently completed M&V report on the same system was conducted considering the centre patronage and cooling degree days (CDD) with a base temperature of 14°C
3. The system boundary was established for the chiller system – refer to figure above;
4. 30 minute real time energy demand data was sourced from Westfield for the NMI identified in the system boundary, specifically NMI 4102070012-01 and the post implementation period was extended to end April 2015;
5. Half hourly temperature and humidity data for the region near Hornsby was sourced from the Bureau of Meteorology;
6. Daily patronage data for the Hornsby shopping centre was sourced from the centre management;
7. Any changes to the operating conditions or list of equipment (static factors) during the baseline periods were sourced from Westfield staff and these were taken into account. Where necessary some adjustments to the baseline data sets were made to accommodate changes to the static factors;
8. Following feedback on the original M&V study, energy use data for periods outside the normal operating hours of the chiller systems was removed from the data set;
9. As wet bulb temperatures were not directly available from the BOM the dry bulb and relative humidity data was used to calculate wet bulb temperatures every 30 minutes for the baseline and post implementation periods;
10. A review of operational hours and public holiday closures was conducted to determine periods when the cooling systems were not operating;
11. A review of 30 minute, daily and weekly energy use data was conducted to determine the best fit model;
12. The optimal model was selected and the baseline period was also selected to be longer than 12 months due to a number of factors, including the retrospective nature of this M&V analysis;
13. The baseline model of the chiller system was then used to estimate the “Adjusted Baseline Energy”. The adjusted baseline energy is the energy that the model predicts would have been used in the reporting period if the ECM had not been introduced.
14. The modelled and actual energy use were then compared and contrasted for any statistically significant differences following the introduction of the *PlantPRO* logic on the chiller system.

3.2 Baseline Data

Westfield was able to provide meter 30 minute energy use data for NMI 4102070012-01 from 1 June 2012 to 1 May 2015. The changeover to the *PlantPRO* logic did not commence until the 4th of July 2014 so the baseline data period was chosen to be from June 2012 to July 2014 as this covers two annual seasonal cycles and provides more data for developing an accurate energy use model of the chiller systems.

3.2.1 Selected Variables

In the original energy audit report for Westfield Hornsby a single variable regression analysis of energy use versus temperature was conducted but the model accuracy was not ideal. The R^2 value of the regression analysis was less than 0.76 and good regressions generally produce R^2 values greater than 0.8.

The first M&V analysis included both CDDs and daily patronage at the shopping centre in its regression model for the chiller system. This led to a regression coefficient of 0.92 which was an excellent result, however the standard error in the model was very high (due, in part, to the seasonal nature of the data set) and it was not possible to determine whether any statistically significant savings had been achieved by the implementation of *PlantPRO*.

AirMaster, the installers of *PlantPRO* suggested that it would be worthwhile including the wet bulb temperature (which is related to the humidity) in the M&V analysis as this is a control variable in the *PlantPRO* logic. They also recommended using 30 minute data, rather than weekly totals. After some discussion it was also agreed to restrict the data assessment to the operating times of the chiller systems, namely the operating hours of the AHUs attached to the chillers (as extracted by JCM from the Westfield Hornsby BMS), thus removing overnight energy uses which was expected to improve the predictive capability of the energy use model as well as possibly reduce the standard error of the model results. This could allow the M&V study to better detect any operation changes in chiller energy use following the introduction of the *PlantPRO* logic.

Centre Patronage

Westfield provided daily patronage data for the periods of interest in this analysis.

Weather Data

Half hourly temperature data for Hornsby shopping centre was sourced from the BOM for the Terrey Hills weather station. This weather station was chosen as the most geographically near to Hornsby. Some gaps in the data were found and on these days the temperature data for Sydney Olympic Park weather station was used as the nearest proxy for the Hornsby/Terrey Hills temperatures.

The data received from the BOM was the dry bulb temperature, the relative humidity and the dew point for the entire baseline and reporting period. The wet bulb temperature was not available.

The data received from the BOM contained additional data points beyond every point on the half-hour, so this additional data was filtered in Microsoft Excel to include only the half hourly data.

The wet bulb temperature was calculated from the dry bulb temperature and the humidity. This process is described in detail in Appendix A

Cooling degree days were calculated using the following formula provided by the BOM:

CDD_{ref} = (Average Daily Temperature – Reference Temperature) x 1

For example with the reference temperature of 14°C and the average temperature was 20.5°C the CDD for that day is 6.5. If this was the situation for a 7 day period the weekly CDD would thus be 7×4.5 = 31.5. If the CDD value was less than zero it was set to zero as per normal protocols.

3.2.2 Selected Time Periods

As the energy and temperature data were available on a 30 minute basis, only the data points corresponding to chiller availability were included. Thus, the following time intervals were included in the analysis:

Table 1: Included Time Periods

Day	Time Period Start	Time Period End
Monday	7:30 am	5:30 pm
Tuesday	7:30 am	5:30 pm
Wednesday	7:30 am	5:30 pm
Thursday	7:30 am	9:00 pm
Friday	7:30 am	5:30 pm
Saturday	8:30 am	5:00 pm
Sunday	9:30 am	4:00 pm

3.3 Baseline Adjustments - Data Filtering

Microsoft Excel's in built linear and multi-variable regression tools were used for all modelling calculations.

3.3.1 CDD Base Temperature

It was decided that as the best results were achieved with a CDD base temperature of 14°C in the previous report, that this would also be used in this analysis.

3.3.2 Significant Outages and Centre Closures

Information was requested from Westfield Hornsby about possible changes to operating conditions (static factors) in the baseline period that might have an impact on the modelling of energy use. It was noted that from August 2013 to mid-January 2014 a significant change to the static factors of the McQuay chiller system occurred. One of the three chillers in the system failed during the period and had to be rebuilt. This meant that for 6 months the system was not running in its normal operational mode. As a result this data period was removed from the baseline data set for this NMI.

Also it was noted that the centre is not open on Christmas Day, Boxing Day, Good Friday and Easter Sunday of each year and operates at reduced hours on Anzac Day. As a result, this data were also excluded from the model data set.

In summary, the following data was excluded from our analysis:

Table 2: Excluded Data

Date Range	Reason
25/12/12 - 26/12/12	Christmas Day and Boxing Day
29/3/13	Good Friday
31/3/13	Easter Sunday
25/4/13	Anzac Day
01/08/13 - 19/01/14	Chiller 1 inoperative due to controller breakdown
18/4/14	Good Friday
20/4/14	Easter Sunday
25/4/14	Anzac Day
25/12/14 - 26/12/14	Christmas Day and Boxing Day
3/4/15	Good Friday
5/4/15	Easter Sunday
25/4/15	Anzac Day

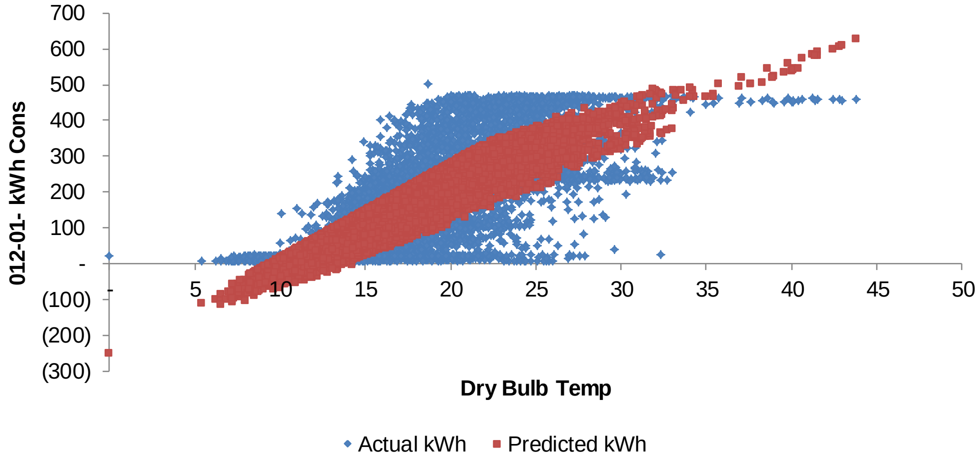
Where weekly data was analysed, the weeks containing these dates were removed.

3.3.3 30 Minute, Daily and Weekly Data

Initial modelling was conducted using 30 minute data with the dry bulb temperature and the wet bulb temperature. Centre patronage was excluded because it was not available at this resolution. This resulted in a correlation of 0.65, which was a poor result. It was not believed that the inclusion of centre patronage data would increase this to higher levels than the 0.92 seen in the previous M&V model.

The plot below shows the graphical output of the Excel linear regression calculations for temperature versus energy consumption.

Figure 2: McQuay System 30 minute kWh (Actual and Model) vs dry bulb temperature. Model numbers assume dependence on dry bulb and wet bulb temperatures.



The above figure illustrates that the daily modelled data does not accurately predict the large spread in the actual energy use data.

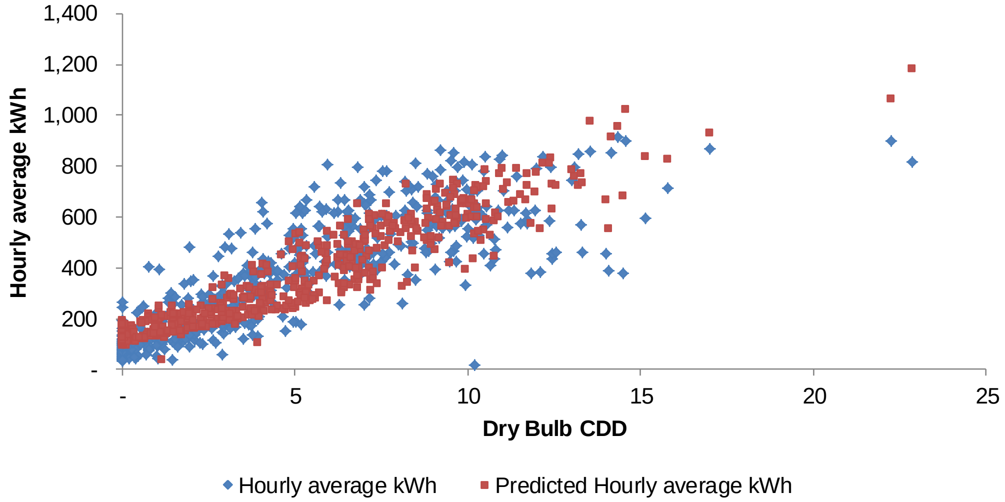
Analysis was then conducted on daily data with the dry bulb temperature, the wet bulb temperature and the centre patronage. The temperature data was manipulated in the following way. The average of temperature across the operating day was taken. The CDD value with a base temperature of 14°C was then calculated. This was done for both wet and dry bulb temperatures.

Because the operating hours varied between 7 and 13 per day, the daily total kWh was divided by the number of operating hours of each day.

This three variable analysis resulted in a correlation coefficient of 0.81 which is a definite improvement on the 30 minute data, but still far below the previous M&V analysis.

The plot below shows the graphical output of the Excel linear regression calculations for both Patronage and CDDs versus energy consumption.

Figure 3: McQuay System Daily kWh (Actual and Model) vs Dry Bulb Temperature CDD. Model numbers assume dependence on dry bulb and wet bulb temperature CDD and centre patronage



Compared to the previous M&V report weekly model this daily model is relatively poor in its predictive ability. It was decided to return to the weekly analysis as conducted in the previous M&V report.

The daily data was added together into 7 day periods from Friday to Thursday inclusive over the available data period. Similarly the weekly patronage data was added together over 7 days. Weekly CDD values were calculated by taking the sum of the daily CDD values over a 7 day period.

Once this weekly data was correlated using the inbuilt Excel regression analysis, a correlation of 0.94 was achieved. This was a significant improvement on the daily values and also an improvement on the previous M&V analysis, so it was decided that this M&V analysis should be completed on a weekly basis.

In summary, the chosen measurement frequency with the best predictive outcomes is weekly.

4. BASELINE ENERGY MODELS

The West Block chiller system utilises three McQuay chillers and was converted to the *PlantPRO* control in the week of 4th July 2014 and was reported to be in steady state by 10th July 2014. This system is monitored by NMI 4102070012-01 and 30 minute data was available from June 2012 for this meter providing a two-year baseline period for developing the baseline energy use model.

As was mentioned previously there was an extended period from August 2013 to January 2014 when one of the three chillers was not available due to a breakdown. This data period has been excluded from the modelled baseline period.

The tables below represent the output of an Excel multivariable regression analysis of the baseline data. Original filtered data can be found in Appendix B.

Table 3: Key Regression Statistics for Filtered Weekly McQuay Data

Regression Statistics	
Multiple R	0.9722
R Square	0.9452
Adjusted R Square	0.9426
Standard Error	3,707.18
Observations	68

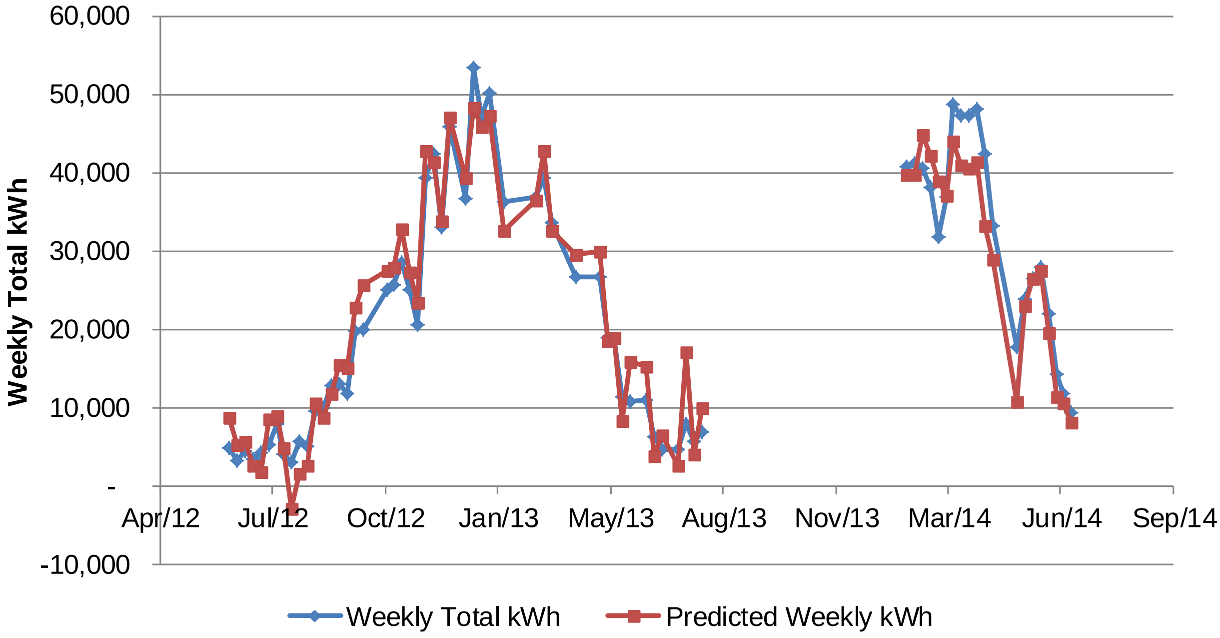
	Coefficients	*Standard Error*	*t Stat*	*Lower 95%*	*Upper 95%*
Intercept	- 55,379.28	7,667.77	-7.22	-70,697.42	-40,061.15
Weekly Total Dry CDD	263.50	43.20	6.10	177.19	349.80
Weekly Total Wet CDD	306.44	46.57	6.58	213.40	399.48
Weekly Patronage	0.04636	0.03	1.66	- 0.01	0.10

This weekly model of predicted Energy from CDDs and Patronage yields a correlation coefficient of 0.9426 and is a superior model to that obtained from daily data. The baseline energy equation for the McQuay Chiller system is as follows:

Weekly kWh = -55379.3 + 0.04636×Weekly Patronage + 263.5×Weekly Dry CDD$_{ref\ 14}$ + 306.4×Weekly Wet CDD$_{ref\ 14}$

The figure below shows the plot of the Actual Weekly kWh and the Predicted Weekly kWh for the baseline period for the McQuay chiller system.

Figure 4: Modelled versus Actual Weekly kWh – West Block



The figures below show the individual plots of each coefficient versus the weekly kWh.

Figure 5: McQuay Chillers Weekly kWh (Actual and Predicted) vs Patronage

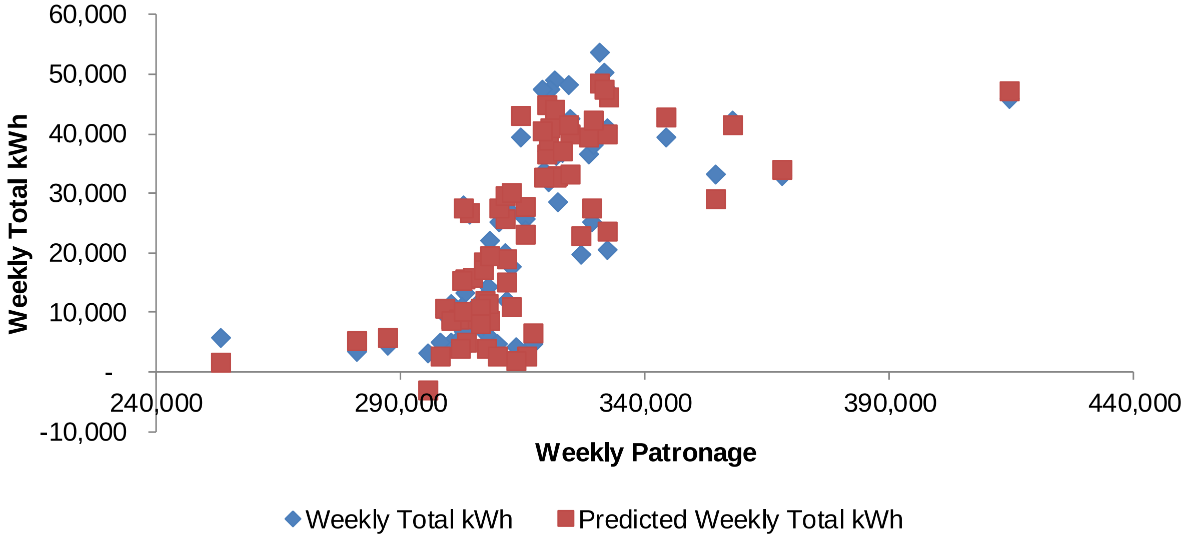


Figure 6: McQuay Chillers Weekly kWh (Actual and Predicted) vs Dry CDD

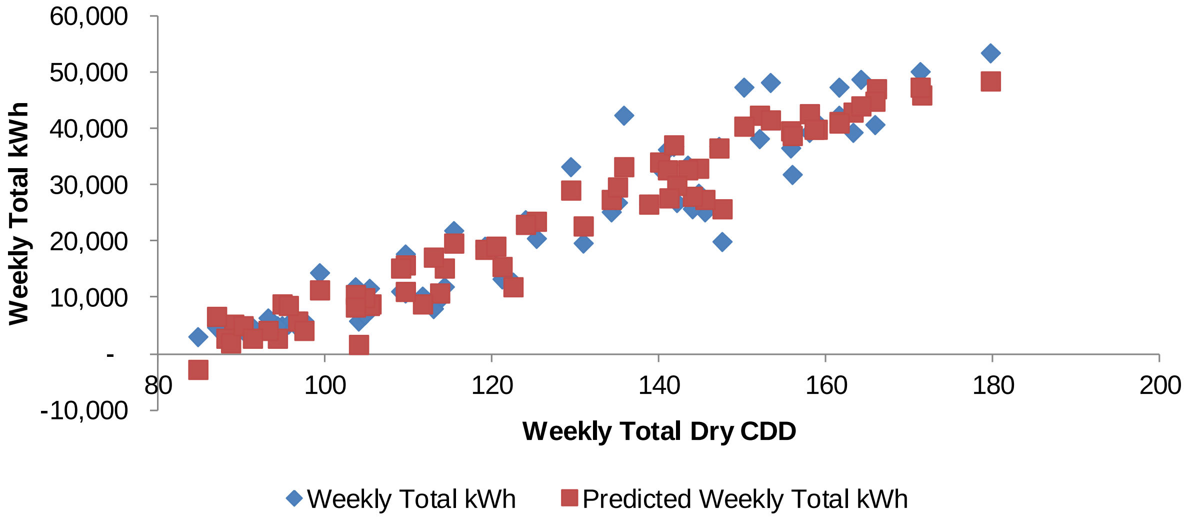
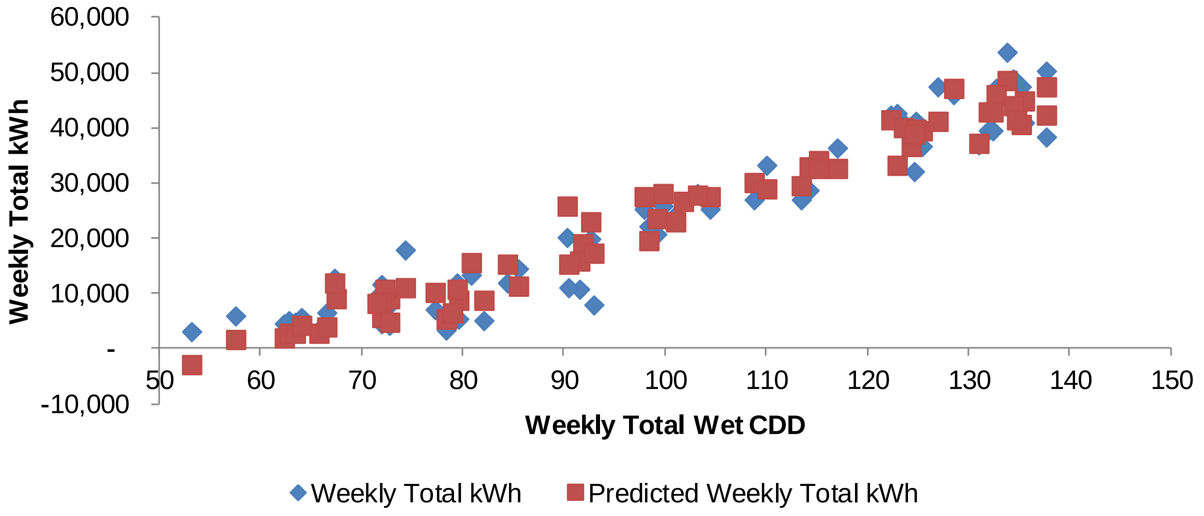


Figure 7: McQuay Chillers Weekly kWh (Actual and Predicted) vs Wet CDD



This model equation was used to predict energy use of the McQuay system in the post implementation period using weekly CDD data and patronage data for comparison with the actual energy use data.

5. RESULTS

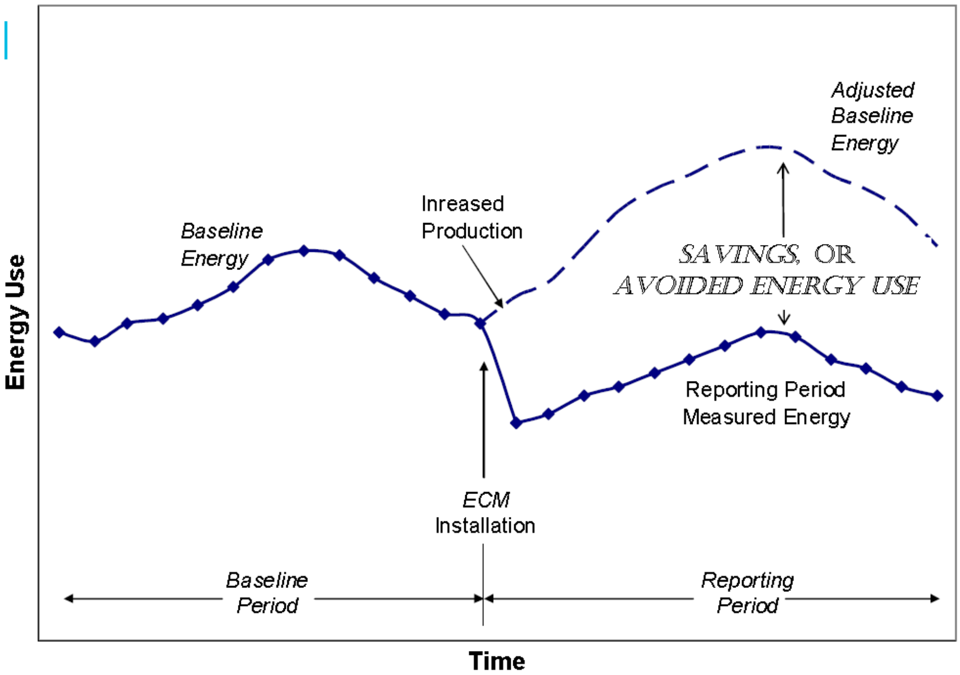
From the model developed in Section 4 it is now possible to predict the energy use during normal operating hours of the original McQuay chiller control system even after the changeover to the new *PlantPRO* logic on a weekly basis, if data on the shopping centre patronage and the CDDs are known. This can then be compared with the actual energy use during normal operating hours as measured by the NMI to determine whether the change to the *PlantPRO* control logic has resulted in real energy savings compared to the previous mode of operation.

For the McQuay chiller system the *PlantPRO* logic was installed in early July 2014. Using the model for the original control system, developed above, we have calculated on a weekly basis the predicted energy use of the old system control logic from July 2014 onwards. These values have been compared to the actual energy usage values.

5.1.1 Avoided Energy Cost Reporting

One of the IPMVP reporting of energy savings options is the "Avoided Energy Cost Reporting" method. This method allows for possible energy savings to begin to be reported as they occur rather than waiting for a 12 month annual cycle to determine whether an ECM is actually producing savings. For this project we can use the Avoided Energy Cost Reporting method because the new system's actual performance can be compared to the predictions of the old system using the regression model developed for the baseline period of the McQuay chiller system.

Figure 8: Extract from IPMVP (page 25) illustrating "Avoided Cost Reporting"

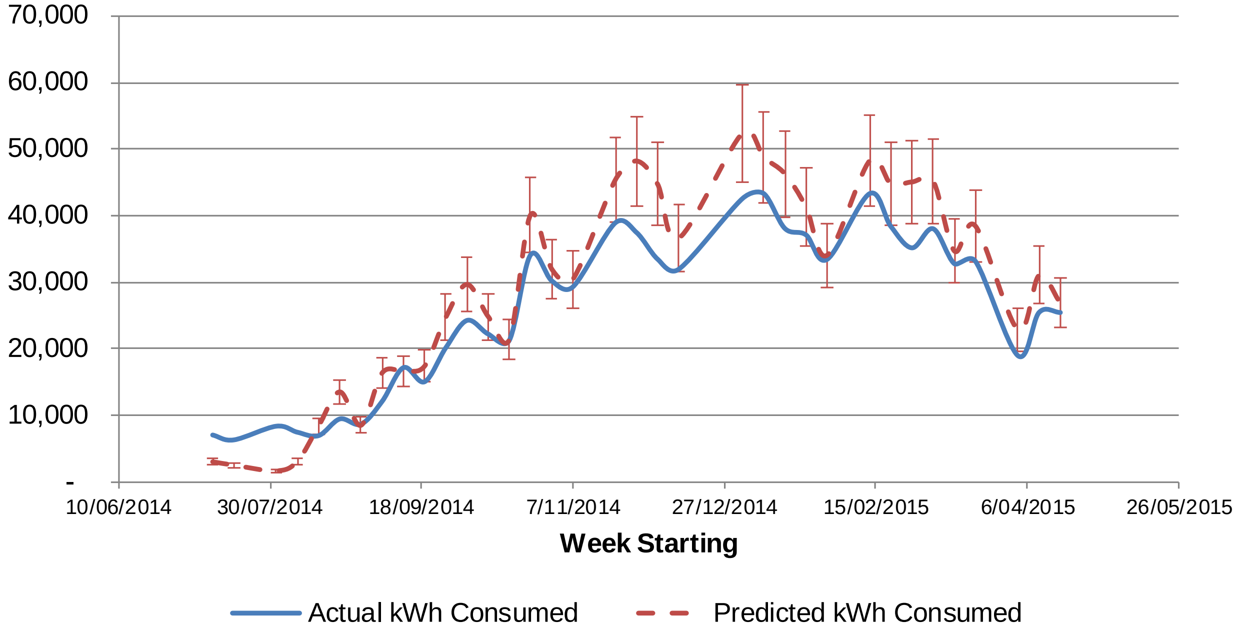


In the calculations made in this report we have only reported differences in predicted versus actual kWh at this point rather than assigning a cost to the kWhs.

Note: As the energy use of HVAC systems is directly related to ambient temperature, humidity and patronage it is not possible to simply compare the energy use of the HVAC system over time to determine whether actual energy savings are being made. Ambient temperature conditions, humidity and patronage have to be taken into account. For example one summer period may be cooler and drier than the previous summer so a simple comparison of energy use without taking CDDs into account would not be an accurate measure of whether the system was performing better than previously.

From the NMI data for the McQuay chiller system, weekly kWhs were collected from the time of introduction of the *PlantPRO* logic in the West Block and filtered to remove energy use outside the centre's normal operating hours. Also Westfield was able to provide patronage data for the centre and BOM data of dry bulb and relative humidity at 30 minute resolution was purchased. Below is a plot of the predicted energy use of the old control system compared to the actual energy use following the implementation of the *PlantPRO* controls from mid July 2014.

Figure 9: Comparison of Old and New Control Systems Energy Use – McQuay chillers. The error bars represent the 14% error in the model as discussed in Section 5.1.4 below.



From September 2014 onward it can be seen that the actual energy use of the McQuay chiller system under *PlantPRO* control is consistently less than the predicted energy use of the old control system. In the period from the week commencing 11th July 2014 to the week commencing 17th April 2015 a comparison of actual and predicted energy use was made. Actual consumption during the filtered data periods for this time period was 906,134 kWh and the predicted consumption for the same period was 1,028,322 kWh, a predicted reduction of 122.2 MWh.

Modelling a new data set that references humidity and focuses on the operating hours of the HVAC system indicated that the *PlantPRO* control logic resulted in an energy saving of 11.9% in the period from July 2014 to April 2015.

In order to understand if the new control is delivering a statistically significant energy saving we have conducted a “student’s t-test” on the data.

5.1.2 Statistical Analysis – t-test

A student's t-test is a statistical tool used to determine if the average of two different sets of numbers (populations) come from the same statistical group (not really different from each other) or are from different groups with significantly different means. The t-test allows a defined level of statistical confidence to be assigned to the result of the t-test. Usually a confidence level of 95% probability is applied to a t-test. This level of confidence indicates that there is a 95% probability that the two sample sets really do have different means if the t-test passes. If the t-test fails the groups are not statistically significantly different at the level of confidence specified.

Excel has inbuilt functions associated with its regression models which determine whether the two sets of numbers

a) have the same or different variances (f-test)
   and
b) depending on the result of the variance test can apply the appropriate form of t-test to the sample data.

To be able to determine whether the *PlantPRO* logic is delivering statistically significant energy savings for the McQuay chiller system it is necessary to conduct a t-test comparing the actual weekly energy used from mid July 2014 with the predicted energy the old control system would have used over the same time period. This was done using Excel's in-built regression t-test functions and the results are presented below.

The table below shows the key statistics generated from the two post implementation data sets of actual and predicted weekly energy consumption of the West Block chiller system from July 2014 to March 2015.

Table 4: Key f-test statistics

	Weekly Total kWh	Predicted weekly kWh
Mean	25,890	29,381
Variance	147,609,592	241,698,768
Observations	35	35
df	34	34
F	0.6107	
P(F<=f) one-tail	0.0778	
F Critical one-tail	0.5643	

From this table the F statistic for the data sets is 0.6107 and this is greater than the "F Critical one-tail" value of 0.5643. Thus it can be statistically concluded that the predicted and actual data sets have different variances. This will be an important piece of information in analysing the t statistics in the following parts of this report.

As the *PlantPRO* logic was introduced with the aim of reducing energy consumption we expect that the average energy use after its introduction will be less than under the old control system. This means that a one sided t-test is the appropriate t-test for this situation. The table below shows the Excel output of the key t-test statistics for the actual and predicted energy data sets.

Table 5: Key t-test statistics

	Weekly Total kWh	Predicted weekly kWh
Mean	25,890	29,381
Variance	147,609,592	241,698,768
Observations	35	35
Hypothesized Mean Difference	0	
df	64	
t Stat	- 1.0468	
P(T<=t) one-tail	0.1496	
t Critical one-tail	1.6690	
P(T<=t) two-tail	0.2991	
t Critical two-tail	1.9977	

To determine whether the actual weekly energy is statistically significantly less than the predicted energy level we need to refer to the t-statistic, 1.05, and the t Critical one-tail statistic, 1.67.

It can be seen that the t-stat for this comparison, 1.05, is in between -1.67 and +1.67 which indicates that there is no statistical difference between the Actual and Predicted energy consumption at a 95% confidence level.

5.1.3 Stand Alone t-test

As the t Stat value was close to that required to confirm a statistically significant difference in the means of the two data sets, it was decided to use another feature of Excel which determines the actual confidence level of a difference between two means. To do this Excel has a t-test function that can be applied to the actual energy use data and compares it to the predicted energy use data, independent of the regression analysis. This inbuilt Excel function requires a number of parameters, other than the raw data to be specified and these vary depending on the specific circumstances being tested. The parameters used in the t-test function are critical to calculating the correct outcome. In this case the data sets are paired (that is they both relate to the performance of the same chiller system), we expect the means to be different (so a one tail test is appropriate), and we know that the variances of the two groups of data are different. When all these parameters were applied to the Excel t-test function, it calculated that the probability that the actual energy use data set is statistically significantly different to the predicted energy use data was 93.2%, just below the 95% threshold normally used.

It is likely that if the savings continue at similar levels for a full 12 months the difference in the actual energy consumption and the predicted energy consumption will exceed the 95% confidence threshold. What can be said is the following:

The average actual weekly energy consumption under the *PlantPRO* logic is 11.9% lower than the predicted average weekly energy consumption at confidence level greater than 90% but less than 95%.

5.1.4 Error Analysis and Reporting

For this project it is assumed that the meter errors of the NMIs are effectively zero as these meters are used for the actual billing of energy use. This will mean that the errors in the results will be driven by the errors in the independent variables in the modelled data. Normally an error analysis would focus on the measurement errors of meters, people counters and so on but in this case a statistical treatment of error is more appropriate because of the variability in the data set used for modelling. The "standard error", SE, (statistically determined from the data) calculated by Excel for the modelled data is much larger than the sum of any individual meter errors or data errors in BOM data or door count data and so on (which are typically less than 2 to 5%). As will be seen further below the SE is larger than 5% and thus it will be used as the most appropriate estimate of the measurement error for this project.

The CDD data is derived from the BOM temperature data directly and the measurement error is not known exactly for this data. Similarly the door count data for Westfield Hornsby has an unknown precision. However, as we have a large data set of weekly energy, CDD and patronage, we have used the variation in the baseline data to determine the standard error levels of the data set.

From the regression analysis output from Excel the SE of the predicted weekly energy consumption is 3,707 kWh. Normally it is possible to use the averages of the independent variables (CDD and Patronage) to determine an average energy output for the baseline period and then report the SE as a percentage of the average energy use. In this case there is a very large seasonal impact on energy use because the Hornsby HVAC system only provides cooling and no heating in winter. This introduces a bias in the data set which makes a ratio of the SE to the average energy use somewhat larger than is really the case when the system is actually providing most of its cooling. To provide a more realistic percentage error therefore we have compared the SE to the summer average daily energy use.

For the period from December to end February 2013/14 the average weekly energy use of the McQuay chiller system during normal operating hours was 43,103 kWh. Thus the SE expressed as a percentage of the summer average energy consumption is

Relative SE $= \pm 3.707 \div 43{,}103$
$= \pm\ 8.6\%$

Also the t-value for 68 baseline data points and a 95% confidence level is 1.67. The absolute precision is approximately the t-stat times the standard error = ±6,190 kWh making the <u>overall relative precision ±14%</u>. This is less than for the previous M&V study, yet another indication that this model is superior to that used in the previous study.

5.1.5 Determination of Measurements to Detect a Significant Change in Energy Use

Knowing the variance of the weekly energy use data it is possible to determine how many weeks of measurement are required to detect a statistically significant shift in the average energy use of 10% (the desired outcome of the *PlantPRO* installation). This is determined by the following statistical formula for the sample size *n*:

$n = (Z_{\alpha/2}+Z_{\beta})^2 \times 2 \times \sigma^2 \div d^2$

where $Z_{\alpha/2}$ is the critical value of the normal distribution at $\alpha/2$ (e.g. for a confidence level of 95%, α is 0.05 and the critical value is 1.96), Z_{β} is the critical value of the normal distribution at β (e.g. for a power of 80%, β is 0.2 and the critical value is 0.84), σ^2 is the population variance, and *d* is the different you would like to detect.

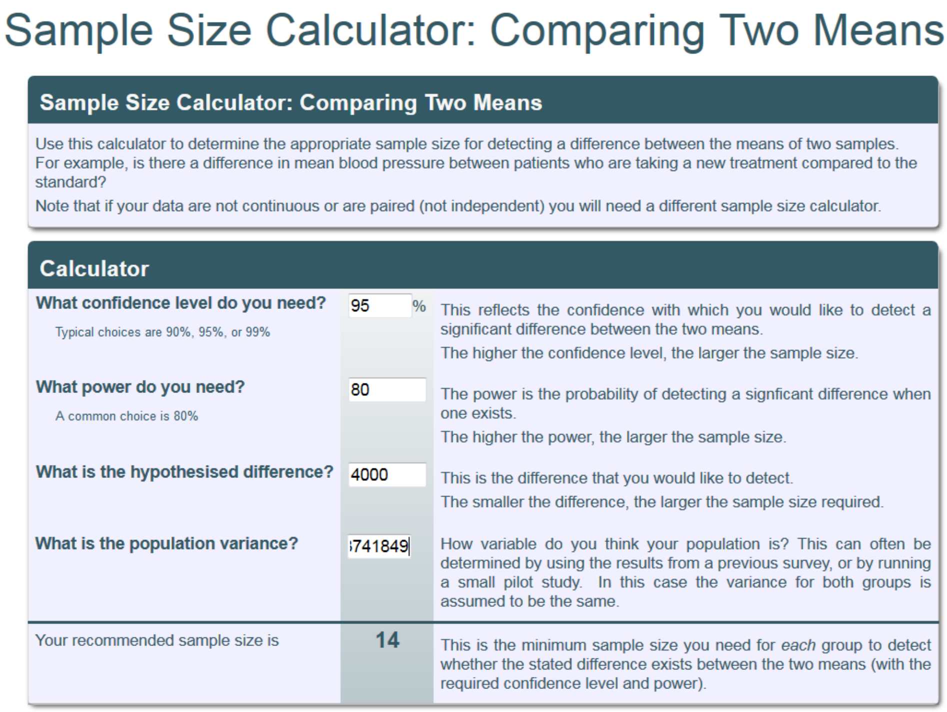
This information has been taken from the Select Statistical Services website[1].

For this project we have used the common confidence levels indicated above we have inputted the following data;

Hypothesised difference	4,000 kWh	(approximately 10% of summer average)
Variance	13,741,849	(= 3707 x 3707)

Below is the output of the sample size calculator using these values.

Figure 10: Sample Size Output from Select Statistical Services for a 10% shift in Energy Usage



In this case the number of full demand weeks required to measure the system to determine a 10% shift would be

n = 14 weeks

As mentioned earlier in this report the actual results fall just short of the 95% confidence interval to date but are very close to that level of confidence. As this summer was relatively mild there were not 14 weeks of actual data at full demand levels. It is expected that over a full annual cycle the result is likely to be significant at the 95% confidence level.

[1] http://www.select-statistics.co.uk/sample-size-calculator-two-means

5.1.6 Recommended Reporting Period

Normally for a typical M&V project the initial reporting period of results is 12 months for a HVAC system. This allows a full yearly seasonal cycle to be experienced. For this project the ECM savings modelled so far (11.9%) have been significant at greater than 90% confidence but not 95%. A full 12 month comparison may well indicate the magnitude of the savings at a 95% confidence level.

A 12 month summary report should be completed in August 2015 to confirm if the *PlantPRO* control logic has produced 10% or more verifiable savings that are statistically significant at 95% confidence for the McQuay chiller system.

6. CONCLUSIONS

Analysis of the baseline period data for the McQuay chiller system at Westfield Hornsby has allowed a good regression model to be developed. The independent variables used in the multiple linear regression models were weekly CDD based on both wet and dry bulb temperatures and weekly centre patronage. In addition the model was restricted to the actual standard operating hours of the chiller system. The model had an R^2 value of 0.9426. The model was used to estimate how much energy on a weekly basis the baseline control systems would have used in the period after the introduction of the new *PlantPRO* control logic on the chiller system. The predicted energy use was then compared to the actual energy use of the chiller system as recorded by the NMI.

For the McQuay chiller system servicing the West Block of the Westfield Hornsby shopping centre the introduction of the *PlantPRO* control logic has resulted in a statistically significant reduction in energy consumption of over 10% at a confidence level of 90%.

From the data currently available, which is less than a full year of operation, it is likely that the *PlantPRO* logic will result in statistically significant energy savings (at the 95% confidence level) over the first yearly cycle of operations. This will need to be confirmed after a full year of *PlantPRO* operation.

It is understood that the *PlantPRO* controls have delivered other operational benefits for the McQuay chillers in relation to plant reliability. At this point in time it appears that the change of control is delivering the expected benefits to Westfield Hornsby.
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APPENDIX A: CALCULATION OF WET BULB TEMPERATURE

As the wet bulb temperature could not be provided by the BOM, it was necessary to calculate it from the provided dry bulb temperature and relative humidity.

A table of the relative humidity as a function of the wet and dry bulb temperatures was sourced Houghton Mifflin (http://www.eduplace.com/science/hmxs/es/pdf/5rs_3_2-3.pdf) and is provided below:

Table 6: Standard RH Percentage as a Function of Wet and Dry Bulb Temperatures

	Number of degrees difference between wet and dry bulb temperatures									
Dry Bulb Temperature	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
10	88	77	66	56	45	35	26	16	7	--
11	89	78	67	57	47	38	28	19	11	2
12	89	79	68	59	49	40	31	22	14	5
13	89	79	69	60	51	42	33	25	16	9
14	90	80	70	61	52	43	35	27	19	11
15	90	80	71	62	54	45	37	29	22	14
16	90	81	72	63	55	47	39	31	24	17
17	91	82	73	64	56	48	41	33	26	19
18	91	82	73	65	57	50	42	35	28	21
19	91	82	74	66	58	51	44	37	30	24
20	91	83	75	67	59	52	45	38	32	26
21	91	83	75	68	60	53	47	40	34	27
22	92	84	76	69	61	54	48	41	35	29
23	92	84	77	69	62	56	49	43	37	31
24	92	84	77	70	63	57	50	44	38	32
25	92	85	77	71	64	57	51	45	40	34
26	92	85	78	71	65	58	52	46	41	35
27	93	85	78	72	65	59	53	47	42	37
28	93	86	79	72	66	60	54	49	43	38
29	93	86	79	73	67	61	55	50	44	39
30	93	86	80	73	67	61	56	50	45	40
31	93	86	80	74	68	62	57	51	46	41
32	93	87	80	74	68	63	57	52	47	42
33	93	87	81	75	69	63	58	53	48	43
34	93	87	81	75	69	64	59	54	49	44

From this table, the difference in the wet and dry bulb temperatures as a function of the RH was determined at each of the dry bulb temperature provided. The analysis resulted in the following equation for the wet bulb temperature, ΔT:

$$\Delta T \quad = \quad slope \times RH + intercept$$

where RH is the relative humidity. The slope and intercept are given by the following table:

Dry Bulb Temperature	Slope	Intercept
10	- 0.10	9.71
11	- 0.10	10.03
12	- 0.11	10.40
13	- 0.11	10.81
14	- 0.11	11.09
15	- 0.12	11.51
16	- 0.12	11.89
17	- 0.13	12.18
18	- 0.13	12.55
19	- 0.13	13.00
20	- 0.14	13.31
21	- 0.14	13.69
22	- 0.14	13.91
23	- 0.15	14.39
24	- 0.15	14.66
25	- 0.16	15.05
26	- 0.16	15.34
27	- 0.16	15.68
28	- 0.16	16.00
29	- 0.17	16.34
30	- 0.17	16.56
31	- 0.17	16.93
32	- 0.18	17.20
33	- 0.18	17.52
34	- 0.18	17.94

Thus, the slope and the intercept as a function of the dry bulb temperature could be calculated as follows:

$$slope \quad = \quad -0.003451 \times dry\ bulb\ temperature - 0.067352$$

$$intercept \quad = \quad 0.342090 \times dry\ bulb\ temperature + 6.381186$$

From this information, the wet bulb temperature can be calculated at any temperature and RH.

APPENDIX B: WEEKLY FILTERED BASELINE DATA SETS

Week Starting	Weekly Total kWh	Weekly Total Dry CDD	Weekly Total Wet CDD	Weekly Patronage
1/06/2012	4,907	94.90	82.09	300,475
8/06/2012	3,230	89.18	78.39	281,022
15/06/2012	4,461	96.91	72.14	287,567
22/06/2012	3,366	88.15	65.80	315,932
29/06/2012	4,244	88.70	62.48	313,821
6/07/2012	5,239	95.77	79.68	308,203
13/07/2012	7,880	105.54	72.86	303,814
20/07/2012	4,109	90.26	72.81	303,743
27/07/2012	3,040	84.87	53.26	295,630
3/08/2012	5,683	104.19	57.67	253,418
10/08/2012	4,978	94.33	62.94	298,361
17/08/2012	9,508	113.76	72.43	299,059
24/08/2012	10,027	111.85	67.53	301,873
31/08/2012	12,747	122.63	67.46	307,545
7/09/2012	13,099	121.31	80.98	303,193
14/09/2012	11,866	114.43	84.49	311,745
21/09/2012	19,698	131.08	92.78	326,940
28/09/2012	19,930	147.79	90.36	311,428
19/10/2012	25,100	145.68	98.06	310,379
26/10/2012	25,662	144.09	99.92	315,509
2/11/2012	28,488	144.88	114.30	322,342
9/11/2012	25,063	134.41	104.54	329,182
16/11/2012	20,491	125.42	99.19	332,412
23/11/2012	39,372	158.15	132.03	344,497
30/11/2012	42,311	161.76	122.39	358,179
7/12/2012	32,987	140.22	115.19	368,038
14/12/2012	45,871	166.17	128.56	414,713
28/12/2012	36,625	156.01	125.53	328,570
4/01/2013	53,535	179.84	133.92	330,797
11/01/2013	47,037	171.62	132.83	332,809
18/01/2013	50,171	171.45	137.75	331,748
1/02/2013	36,289	141.13	117.16	321,853
1/03/2013	36,915	147.29	124.43	320,009
8/03/2013	39,330	163.45	132.51	314,783
15/03/2013	33,535	143.52	115.32	319,558
5/04/2013	26,756	135.15	113.57	311,511
26/04/2013	26,703	142.26	108.89	312,726
3/05/2013	18,980	119.24	92.02	306,970

Week Starting	Weekly Total kWh	Weekly Total Dry CDD	Weekly Total Wet CDD	Weekly Patronage
10/05/2013	18,682	120.52	91.95	311,777
17/05/2013	11,475	105.51	72.02	300,424
24/05/2013	10,716	109.82	91.68	304,881
7/06/2013	10,985	109.11	90.62	302,522
14/06/2013	6,240	93.32	66.65	307,832
21/06/2013	4,635	87.04	79.00	317,265
5/07/2013	4,545	91.39	63.53	309,976
12/07/2013	7,879	113.07	93.09	306,987
19/07/2013	5,574	97.50	64.17	302,486
26/07/2013	6,817	104.83	77.37	302,895
24/01/2014	40,807	159.20	123.59	332,333
31/01/2014	41,106	158.80	124.82	324,746
7/02/2014	40,628	166.12	135.63	320,108
14/02/2014	38,157	152.27	137.78	329,399
21/02/2014	31,873	156.13	124.77	320,230
28/02/2014	36,872	141.84	131.06	323,079
7/03/2014	48,825	164.26	134.44	321,643
14/03/2014	47,358	161.67	127.02	320,765
21/03/2014	47,338	150.26	135.33	319,113
28/03/2014	48,095	153.46	134.84	324,581
4/04/2014	42,441	135.91	123.00	324,878
11/04/2014	33,198	129.54	110.06	354,554
2/05/2014	17,629	109.76	74.39	312,716
9/05/2014	23,867	124.18	101.13	315,495
16/05/2014	26,439	139.00	101.93	304,158
23/05/2014	27,897	141.25	103.35	303,028
30/05/2014	21,928	115.56	98.45	308,330
6/06/2014	14,213	99.54	85.52	308,027
13/06/2014	11,788	103.71	79.55	306,364
20/06/2014	9,334	103.81	71.63	306,518

APPENDIX C: WEEKLY FILTERED POST ECM IMPLEMENTATION DATA SETS

Week Starting	Weekly Total kWh	Weekly Total Dry CDD	Weekly Total Wet CDD	Weekly Patronage
11/07/2014	7,007	92.86	64.39	305,492
18/07/2014	6,275	88.38	67.18	301,519
1/08/2014	8,332	94.74	59.25	299,316
8/08/2014	7,425	91.39	66.54	301,627
15/08/2014	6,918	91.37	82.84	308,034
22/08/2014	9,424	102.10	90.20	308,969
29/08/2014	8,643	99.17	76.99	304,663
5/09/2014	12,078	112.47	89.13	318,788
12/09/2014	17,134	115.67	88.25	312,656
19/09/2014	15,013	117.56	87.27	324,002
26/09/2014	20,111	140.78	91.60	321,189
3/10/2014	24,230	142.26	108.32	309,361
10/10/2014	22,187	134.24	99.13	311,674
17/10/2014	21,249	125.78	96.99	299,447
24/10/2014	34,076	168.91	121.27	297,765
31/10/2014	30,193	150.00	108.51	314,034
7/11/2014	29,280	137.93	114.58	309,573
21/11/2014	38,895	167.39	132.34	346,393
28/11/2014	37,451	171.25	136.84	356,191
5/12/2014	33,426	158.03	135.71	363,099
12/12/2014	31,939	144.34	116.72	392,154
2/01/2015	42,547	178.19	151.20	312,149
9/01/2015	43,303	169.24	144.44	329,880
16/01/2015	38,058	169.57	137.32	320,996
23/01/2015	37,079	155.24	133.01	323,292
30/01/2015	33,420	148.10	117.88	308,084
13/02/2015	43,287	172.42	143.91	303,548
20/02/2015	38,371	157.34	144.77	309,731
27/02/2015	35,137	167.46	137.31	306,635
6/03/2015	38,006	166.23	137.90	312,121
13/03/2015	32,756	146.64	122.77	297,305
20/03/2015	33,096	151.62	127.62	317,336
3/04/2015	18,925	127.94	106.12	258,009
10/04/2015	25,441	137.80	116.51	309,876
17/04/2015	25,418	122.66	114.50	319,653