Melbourne City Council

PCM Operational Report

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design advice

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design analysis

low energy services

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EXECUTIVE SUMMARY

This report is aimed at assisting the design team in the design of the central air conditioning plant utilising phase change material (PCM) as the source of chilled water for the chilled surfaces technology being employed.

This report has identified the UK based company Environmental Process Systems Limited (EPSltd) as the preferred supplier of phase change materials.

In conjunction with EPSltd a two flow beam "tube by tube" concept is being developed for the Melbourne City Council development. The two beam concept effectively creates a closed loop between the central plant water supply being used for PCM charging and the discharge fluid to serve the chilled surfaces technology. This technology was considered important as it eliminates the need for an additional heat exchanger and assists in maximising "free cooling" charging.

EPSltd is also developing a unique PlusICE mixture with a phase change temperature of 15°C for the project. The freezing/melting characteristics of the PlusICE15 will enable improved energy efficient operation of the system by enabling a greater percentage of "free cooling" charging times by the cooling towers.

Optimal charging time for full load capacity has been identified at 8 hours for a 3 degree temperature differential based on the 15PCM.

We have been advised that the Baltimore Air Coil RCT series counterflow cooling tower will provide a leaving water temperature 2 degrees above the ambient wet bulb temperature. Taking into account charging rates and building space load requirements has resulted in the cooling tower being able to charge the PCMs for ambient wet bulb conditions below and equal to 11°C in summer and 11.5°C for the remainder of the year. The chiller plant is to provide charging at all other times with the chilled water supply to be 12°C.

The Shower Towers are to provide fresh air supply for the retail areas during the day, and by the means of a heat exchanger, pre-cooling to the entering cooling tower water at night. A 0.5 -1°C reduction in temperature is expected which will assist in the efficiency of the charging rate.

Performance testing of the PCMs, incorporating the prototype tube by tube beam concept, will be conducted in the UK at EPSltd testing facilities with representatives of Melbourne City Council and AEC present as witnesses. The testing is aimed at verifying charging/discharge rates and freezing/melting temperatures for different operational conditions.

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Date	26/5/2003	
Revision and Status		
Author	Eloise Aschberger	
Project Team Leader	Mark Cummins	

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1 INTRODUCTION

1.1 Aim

This report is aimed at assisting the design team in the design of the central air conditioning plant utilising phase change material (PCM) as the source of chilled water for the chilled surfaces technology being employed.

This report looks at the operation of the PCM with respect to:

- Charging Rates
- Cooling Tower night charging
- Operational Temperatures

This report furthers the information provided in AEC's previous report PCM-Based Cooling.

1.2 PCM Manufacturers

As detailed within AEC's PCM Based Cooling report, there are limited suppliers of phase change material products.

Within this report we are detailing products supplied by the UK based company Environmental Process Systems Limited (EPSltd).

The Western Australian based company TEAPPCM has not been included within the design development phase of this project as their existing range of products do not meet the Melbourne City Council requirements. Extensive amounts of design and development would be required to utilise this Australian Based company on this project.

EPSltd has a more extensive array of products which require only minor modifications to suit the Melbourne City Council development requirements.

The technical information provided within this report has been supplied by EPSltd.

1.3 PCM Theory

For the Melbourne City Council development phase change materials are proposed to be used as the main supply of thermal energy to the chilled panel/beams. PCM's work on the principle that when a material undergoes a phase change (solid to liquid, liquid to gas or vice versa) the material absorbs/releases energy, for no change in temperature, until the phase change is complete. The heat energy absorbed/released is called the latent heat of the material and it varies for different materials.

The phase change materials proposed for this development, comprise both mixtures of non-toxic salts and organic compounds having freezing temperatures above and below that of water. These solutions are known as Eutectic Salts and the freezing/melting points can be modified by adjusting the percentages of the mixing compounds.

One application of PCM is the Beam Technology (EPSLtd PlusICE™ Beam Technology) incorporating a metal tube being surrounded cylindrically by a Polypropylene outer annulus cavity containing the appropriate Phase Change Material. The cylinder geometry offers a more efficient heat transfer, due to surface area exposure, than compared to other PCM options available, such as the spherical balls concept outlined within the PCM Based Cooling Report.

The beam technology is able to be mounted within self stacking modules. The modules are stacked on High Density Polyurethane Saddles in flexible row and height requirements.

Water or refrigerant is circulated within the inner metal tube. During charging mode the excess capacity (heat transfer from a temperature differential) from this fluid is stored in the form of latent heat by the Eutectic Salts (PCM). The operation is reversed during discharge mode.

Charging for the PCM will occur during the night time. The lower ambient temperatures at night will enable “free cooling” during certain times of the year. “Free cooling” refers to heat rejection without operating a chiller, i.e. by utilising cooling towers or shower towers. This report will investigate the extent to which “free cooling” will be able to be employed.

2 PCM TECHNICAL DATA

2.1 Sizing

The PCM beam technology consists of a 0.0127m (½") inner metal tube surrounded by a 0.1m outer tube housing the PCM.

The beams are available in metre lengths with the maximum length being 6m.

The self stacking modules are made up to 2.3m x 2.3m x 6.5m, which are designed to fit into a 20' shipping container.

Total weight of a 20' module is estimated at 34.5 tonnes with each single beam weighing 14.7kg/m.

2.2 Installation

A standard module is able to be built on site. 600mm wide access is required to bring in the beams (up to 6m long) one at a time and with a 1m long polyurethane saddle. Alternatively the modules can be assembled off site, shipped and installed in one piece, should there be sufficient access.

PCM's are recommended to be installed with the beams parallel to the floor. Column type arrangements can force the heavier chemicals in the Eutectic mixture to sink to the bottom which may cause a degrading of performance by up to 40% and shorten life span.

2.3 Maintenance

Being a passive system the maintenance to the PCM modules is limited. We have been advised that there may be a little variation in the PCM freezing/melting performance due to chemical reactions and gravity settling during the first few cycles however the PCM should stabilize after a few dozen cycles. After it has stabilized the PCM should retain its characteristics forever and is not expected to be needed to be replaced on a regular basis.

Variations to PCM performance will only occur if the PCM is exposed to air. Air exposure results in the water in the PCM solution evaporating resulting in the PCM being reduced to dry salts.

Generally air exposure only occurs if the beams become damaged in some way or leaks. In the event of damage the beam will either need to be replaced or can be blanked off.

The supplier recommends that access be provided to replace beams in situ. Access area needs to take into account the length of the beam and the mobility required to take the damaged beam out and a new one in.

The frequency that access be required may be such that it will be a preferred option, in the event of damage or leakage, to blank the damaged beam and add additional 1m length beams to meet the capacity requirements. We understand that leakage, without some form of physical damage occurring, is uncommon.

Provided there is no exposure to air and the PCM's are installed as recommended, the life span of the materials is expected to be "forever". However we recommend that a warranty of a minimum 10 years be obtained from ESPltd upon installation.

2.4 Two Flow Beam

The EPSLtd PlusICE™ Beam Technology is such that the same fluid is used for charging and discharging. Consequently to maintain a closed loop to the chilled panel/beams it would be necessary to install a heat exchanger. A direct supply of water from the cooling tower to within the building (chilled beams/panels) is not desired for the following reasons:

1 Risk of Legionella; The perceived risk of Legionella is reduced within a closed loop system. Cooling towers can operate at temperatures which is favourable to Legionella bacteria growth. Strict Australian standards, which outlines the type of manufacturing of cooling towers and the water treatment required to minimise the growth of the bacteria, has reduced the associated risk of Legionella growth. However, as a further protective measure, cooling tower water is generally not supplied directly within buildings.

2 Higher chance of corrosion; An open loop system, where the air is exposed to the atmosphere through the cooling tower, can encourage corrosion within the pipes and in this scenario, chilled surfaces. The introduction of oxygen to water initiates the chemical reactions between the pipe metals and the water minerals which causes corrosion. Corrosion inhibitors are present in HVAC system water treatments, however it is deemed best practise to also reduce the likelihood of corrosion through minimising oxygen exposure.

It would be preferable to locate the heat exchanger in a location such that the fluid flowing through the PCM beams is on the closed loop side. This will ensure that the risk of corrosion and contaminants will be minimised through the beam pipes.

Heat exchangers are devices that transfer heat from one fluid (liquid or gas) to another while keeping them separate. A hot fluid flows on one side of a heat exchanger, transferring its heat to a lower temperature fluid on the other side. For heat transfer to work there must be a temperature differential (for effective heat transfer of at least 2-3 degrees) between the flows.

Preliminary investigations into the operational temperatures of the PCM have resulted in a preference to eliminate the need for a heat exchanger. To maximise the days of free cooling provided by the cooling towers (see section 3.3 for more details on cooling tower temperature operational requirements) it is deemed necessary to eliminate the additional temperature differential required by creating a heat exchanger within the PCM beam. By providing a separate flow for both the charging and discharging fluids we are effectively closing the chilled water supply loop to the chilled panels/beams while eliminating an additional temperature differential requirement.

We are currently investigating a "tube by tube" concept (figure 1) with EPSltd. This involves expanding on the EPSLtd PlusICE™ Beam Technology configuration. The concept comprises adding an additional tube of fluid above the PCM. The outer tube would be utilised for charging of the PCM, while the inner tube would recover the stored energy for supply to the building (discharging). Effectively the exposure to the PCM would be the same for each flow and it is deemed that there would not be any inefficiency, when compared to a single flow PCM beam, associated with utilising this design.

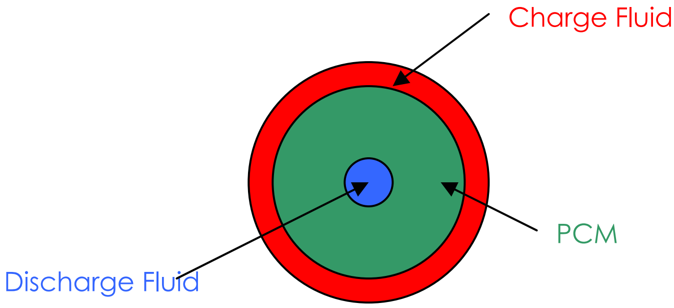

Figure 1: Tube by Tube Concept

The concept is currently under development with ESPltd with a prototype being created. The size of each beam is expected to be the same. ESPltd are proposing to use the same outer tube size for the beam which means that the PCM quantity we will be reduced within each. This allows the existing saddle support arrangement to be utilised without modification. ESPltd will advise on reduced capacity per beam, however it is not expected to be greater than 10%.

An additional scenario (figure 2) that was investigated was a larger PCM vessel with four flow pipes through it: two being a charging fluid and two being a discharge fluid. This concept has been deemed inferior by EPSltd due to the surface area exposure to the PCM being uneven throughout the vessel resulting in an increase in the charge times and a decrease in the efficiency of the system. The vessel is also required to be significantly larger than the normal beam size, approximately 150mm outer diameter. This would have significant impact on the plant room spatials. Thus it has been discarded from future investigations.

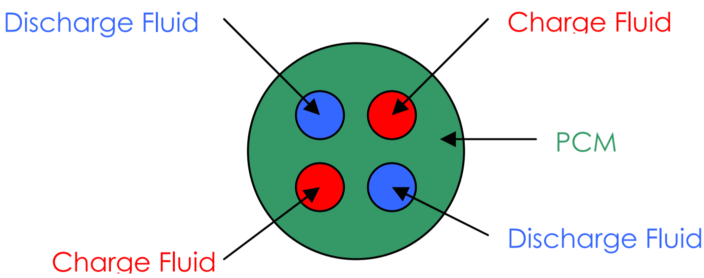

Figure 2: Large Vessel Concept

2.5 Phase Change Temperature

Each PCM is defined by its freezing and melting points, which is often referred to as the phase change temperature.

The table below details a number of PlusICE mixtures which are commercially available from EPSltd.

PlusICE Type	Phase Change Temperature (°C)	Density (kg/m3)	Latent Heat (kJ/kg)	Latent Heat (MJ/m^3)	Spec. Heat (kJ/kg K)	Thermal Cond. (W/m K)
E21	21	1480	150	222	0.68	0.43
E19	19	1484	146	216	0.67	0.43
E17	17	1487	143	213	0.67	0.43
E13	13	1489	140	208	0.67	0.43
E10	10	1519	140	213	0.66	0.43
E8	8	1469	140	206	0.67	0.44

Figure 3: Commercially Available PCM Specifications

ESPltd have advised that the phase change temperatures quoted are not the actual freezing and melting temperatures. Generally freezing will occur at 1-2 degrees below the quoted phase change temperature with melting occurring at or 1 degree above the quoted temperature.

Preliminary investigations into the operational temperatures of the PCM have indicated that a PCM with a phase change temperature of 15 would be optimal for the operation of the system (refer to section 3.4 for further details of PCM operational temperatures).

ESPltd are currently investigating the PlusICE15 solution.

3 PCM OPERATION

3.1 PCM Charging

An investigation was undertaken to review the effect of temperature differential on the overall PCM charging time and charging water flow rate. The findings are detailed within figure 4 below:

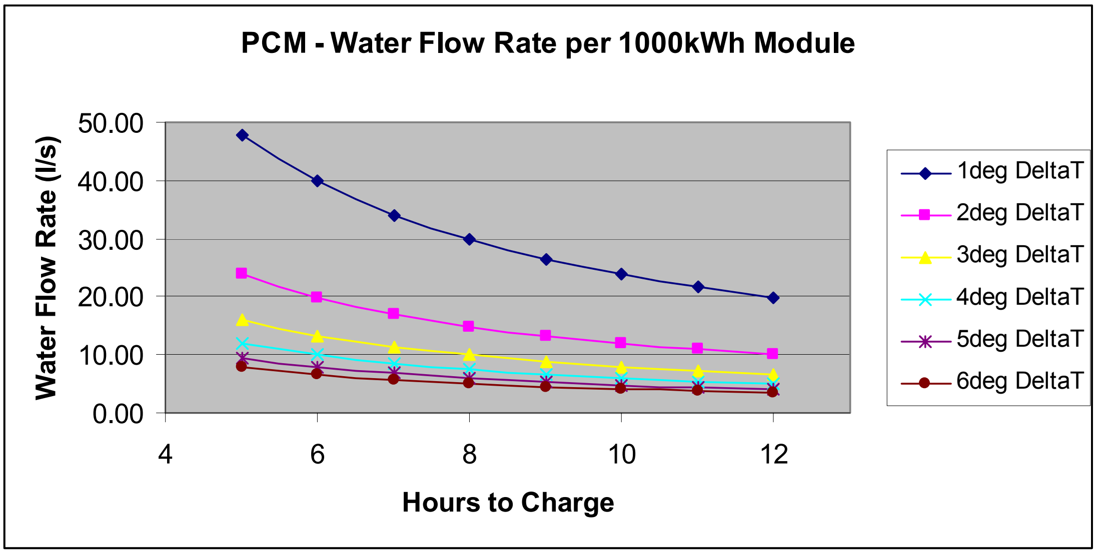

Figure 4: Water Flow Rate vs PCM Charging Times

The water flow rates required for a one degree temperature differential are unreasonably high and therefore are not being considered.

The water flow rates for the three to six degree temperature differential are fairly similar. To facilitate as much "free" cooling as possible from the cooling towers and shower towers it is imperative that the temperature differential be minimised as much as possible. Consequently a three degree temperature differential over an 8 hour charging period, for maximum load conditions, will be considered when reviewing the possible heat rejection means.

3.2 Shower Tower Charging

It is proposed to utilise the free cooling capacity of the shower towers to charge the PCM in conjunction with the cooling towers. Investigations into the operation of the system have found that the shower towers alone are unable to cope with the three degree heat rejection required to provide a sufficient charge rate.

Investigations into the operation of the shower towers have found that the towers are more effective at reducing the temperature of air than they are at reducing the temperature of water. Figure 5 below shows the relationship between the ambient air conditions (dry bulb and relative humidity) and the expected exiting air temperature for an 8m high shower tower operating at 25l/min.

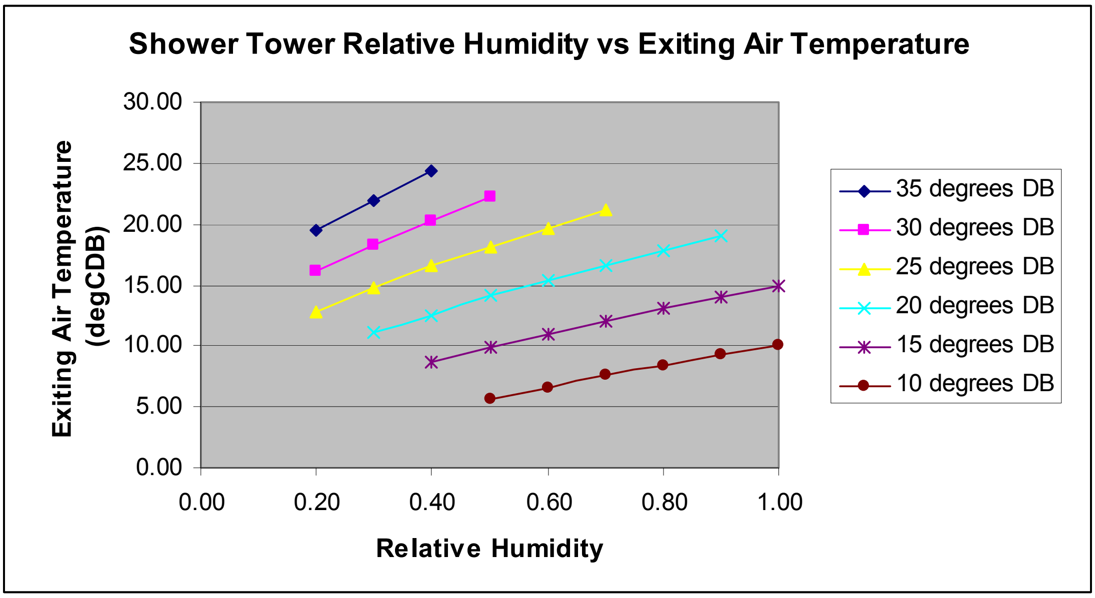

Figure 5: Shower Tower Exiting Air Temperature

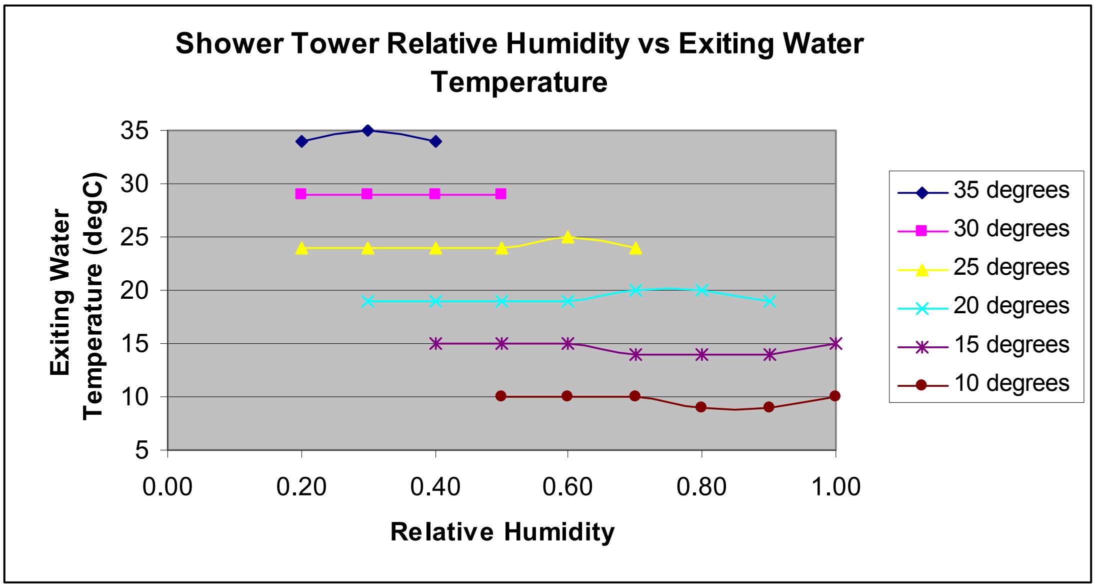

Figure 6: Shower Tower Exiting Water Temperature

Figure 6 above shows the relationship between relative humidity and the exiting water temperature for various entering water conditions. Again an 8m cooling tower with a 25l/min flow rate was used.

The two figures clearly show that large temperature differentials can be experienced on the air side. This makes the Shower Towers ideal for supplying cooler air to the retail units to satisfy their fresh air requirement during normal working hours.

In addition to the shower towers will be used at night to provide pre-cooling to the phase change cooling water. This will occur via a heat exchanger. The pre-cooling is expected to be in the order of 0.5°C to 1 °C. This 0.5°Cto 1°C will be beneficial to the resultant leaving water condition from the cooling tower, especially during higher ambient wet bulb nights, assisting in making the charging process as efficient as possible.

3.3 Cooling Tower Charging

The extent to which Phase Change Material technology can save energy in a building may be directly related back to the extent to which "free cooling" charging can be applied to the PCM's. Cooling Tower performance is directly related to the ambient wet bulb temperature, the lower the ambient wet bulb, the lower the leaving water temperature.

Advice from Pacific Heat Transfer in Melbourne, who are the official suppliers of Baltimore Aircoil Cooling (BAC) cooling towers have advised that their RCT range of counterflow cooling towers will provide a leaving water temperature of 2 degrees above the ambient wet bulb temperature. Meaning that should the ambient wet bulb temperature be 12°C the leaving water temperature would be 14°C.

Based on this information maximum ambient wet bulb temperatures were able to be calculated for different space load capacities. These are detailed in the table below:

Charging Water Delta T	Time to Charge	Total Water Quantity	Total Capacity able to be Charged	Maximum Ambient Wet Bulb Temperature
3	8 hours	29.9l/s	3000kWh	10°C
2	8 hours	29.9l/s	1980kWh	11°C
1.5	8 hours	29.9l/s	1485kWh	11.5°C

Figure 7: Maximum Ambient Wet Bulb Temperatures

An analysis of night time wet bulb temperatures and the corresponding building space loads was conducted using the Melbourne Test Reference Year (TRY) weather data, with the results for each month (Corresponding day loads compared against mean ambient wet bulb temperature between 11pm and 7am) included within Appendix A.

The charts below summarise the results with Figure 8 detailing the expected number of nights per month that conditions will be suitable for cooling tower charging of PCM. Figure 9 equates those days to a percentage for the month.

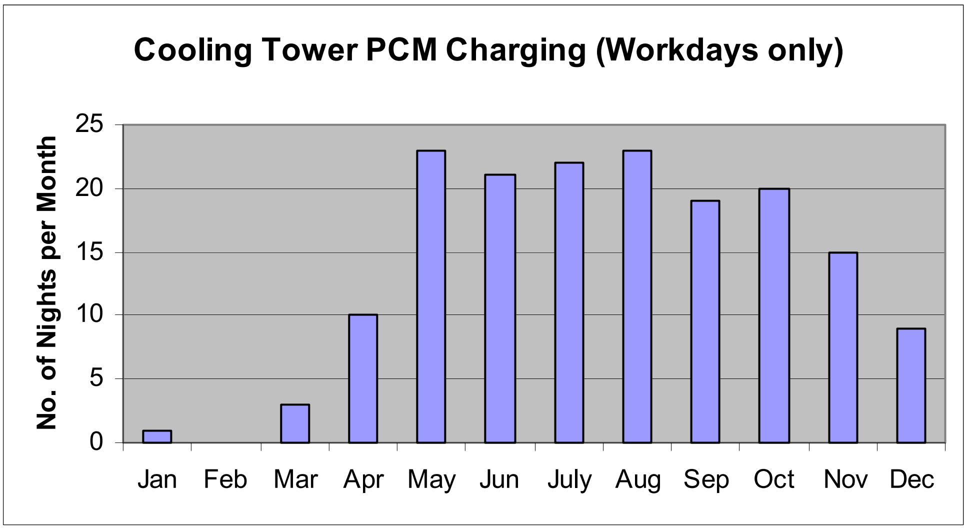

Figure 8: Cooling Tower PCM Charging No. of Nights per Month

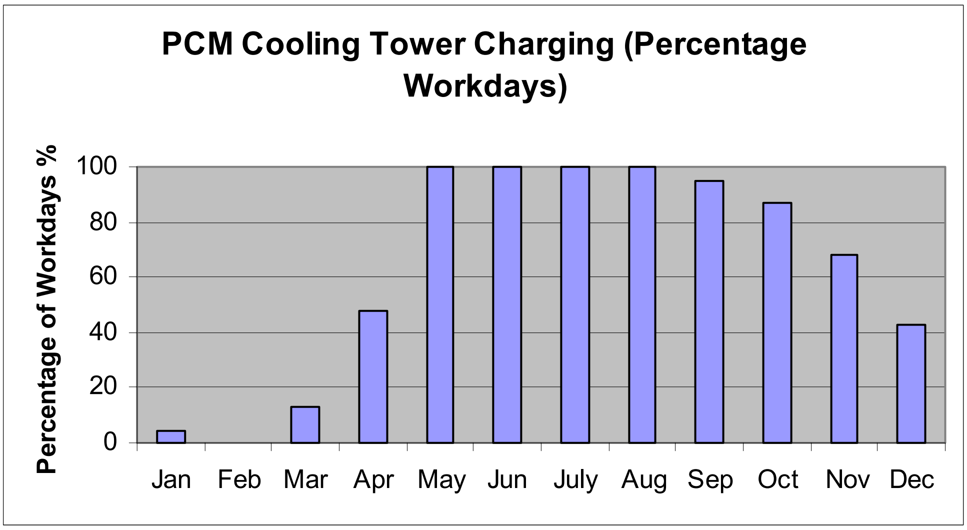

Figure 9: Cooling Tower PCM Charging Percentage of Workdays

From the above figures we find that cooling tower charging is available throughout winter but is minimal during the summer months. Based on the above data the cooling tower will be able to charge the PCMs 63% of the year. At other times the chillers will be utilised to provide the charging. As the charging occurs at night only, the chillers are operating at their most efficiently.

The above Cooling Tower charging was based on a PCM freezing temperature in the order of 14-15°C.

3.4 Operational Strategy

The current operational strategy for the PCM modules is that charging water will be supplied to the PCM cells at a maximum temperature of 13.5°C (floating with wet bulb temperature) with the charging return water to be in the order of 15°C. The return water will pass through a heat exchanger connected to the shower towers upon return to the chillers/cooling towers. This will provide pre cooling of the return water prior to return to the cooling towers. The shower tower heat exchange is estimated to reduce the water temperature by 0.5-1°C.

An ambient wet bulb temperature sensor will control the operation of the charging phase of the PCMs. To utilise the cooling towers for maximum free cooling benefits it may be necessary to change the control strategy to suit the seasonal requirements of the building.

During the summer months of December, January and February the building loads are at their highest. The mean daily space load for a summer day is 1900kWh which equates to a maximum wet bulb temperature of 11°C for the cooling towers to be utilised for PCM charging.

Referring to the charts in Appendix A we note that space loads in excess of 2000kWh generally relate to nights where the wet bulb is also high (above 13°C). Consequently during the summer months it appears that the cooling towers would be able to be able to be operated for sufficient charging when the ambient wet bulb temperature is below 11°C.

The analysis of the expected space loads versus wet bulb temperatures for the Summer months found that there were a few days in December where the mean wet bulb was between 11 and 11.5°C with a corresponding space load below 1900kWh. These days were included within figures 8 and 9. From an operational perspective during summer any wet bulb temperature above 11°C is not recommended to be used for cooling tower charging as it increases the risk of insufficient charging of the PCM. Thus utilising this operational strategy the December cooling tower charging days are reduced from 9 to 6, equating to a total summer usage of only 7 nights (based on the test reference year data)

For the remaining months, the cooling tower charging should operate for a wet bulb temperature less than or equal to 11.5°C.

On higher ambient wet bulb temperatures charging to the PCM shall be provided by the Chiller Plant. Chiller Plant Supply to be at 12°C.

PCM's to discharge supply water to the chilled panels/beams at 16°C.

3.5 Performance Testing

Performance testing of the PCM's have been proposed prior to their utilisation on this project. The testing is to be conducted by EPSltd in conjunction with Melbourne City Council.

3.5.1 Aim

1. To test the prototype tube by tube beam concept.

2. To validate the published design data PCM phase change temperatures by physically testing the PCM's through a range of chilled water supply temperatures.

3. To establish temperature difference requirements through heat exchange medium for both charging and discharge cycles.

4. To establish charge and discharge rates at various temperature differences.

3.5.2 Test

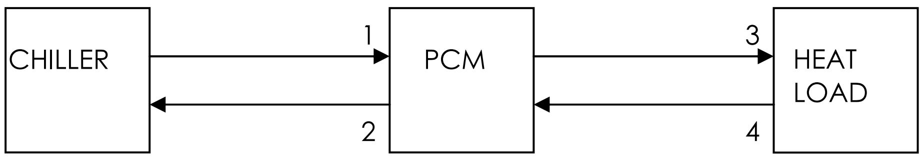

Figure 10: Phase Change Material Testing

The test itself is to involve the developed "tube by tube" beam concept, thus allowing the charging circuit (1-2) and discharging circuit (3-4) to be separate circuits.

The developed PlusICE type E15 PCM is to be tested. Each test is to be conducted for three separate batches of the PCM. PCM size is to be 15 Beams each (6m in length). Heat Load is to be a continuos heat source equivalent to 50kWh.

Two separate procedures of each test outlined below are to be witnessed at the ESPltd test facilities in the UK by AEC and Melbourne City Council representatives.

3.5.3 Procedure

1. **Test 1 – Charging.**

   The PCMs are to be charged using the following chilled water temperatures:

Chilled Water Supply Temperatures
PlusICE Type E15
10°C
11°C
12°C
13°C
14°C

   The following data is to be recorded during the test:

   - Chilled Water Supply Temperature (1.)
   - Chilled Water Return Temperature (2.)
   - Chilled Water Flow Rate
   - Total time to fully charge one module

2. **Test 2 – Discharge.**

   The PCMs to discharge chilled water to Heat Load.

   The following data is to be recorded during the test:

   - Chilled Water Supply Temperature (3.)
   - Chilled Water Return Temperature (4.)
   - Chilled Water Flow Rate
   - Total time to fully discharge one module

3.5.4 Results

All data to be recorded and provided to the design team in a concise report.

4 CONCLUSION

This report has identified the UK based company Environmental Process Systems Limited (EPSltd) as the preferred supplier of phase change materials.

In conjunction with EPSltd a two flow beam "tube by tube" concept is being developed for the Melbourne City Council development. The two beam concept effectively creates a closed loop between the central plant water supply being used for PCM charging and the discharge fluid to serve the chilled surfaces technology. This technology was considered important as it eliminates the need for an additional heat exchanger and assists in maximising "free cooling" charging.

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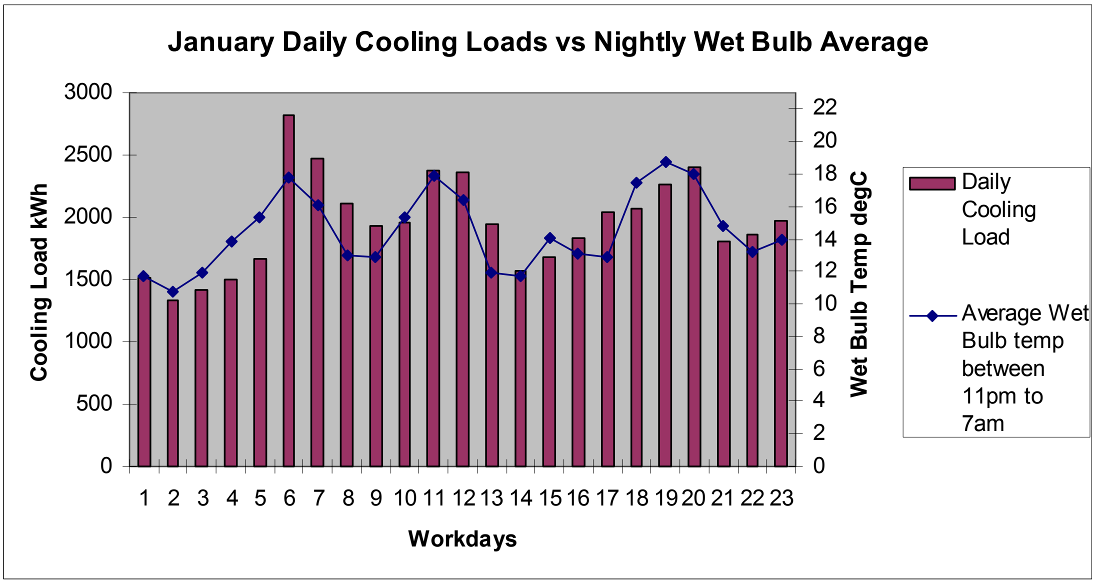
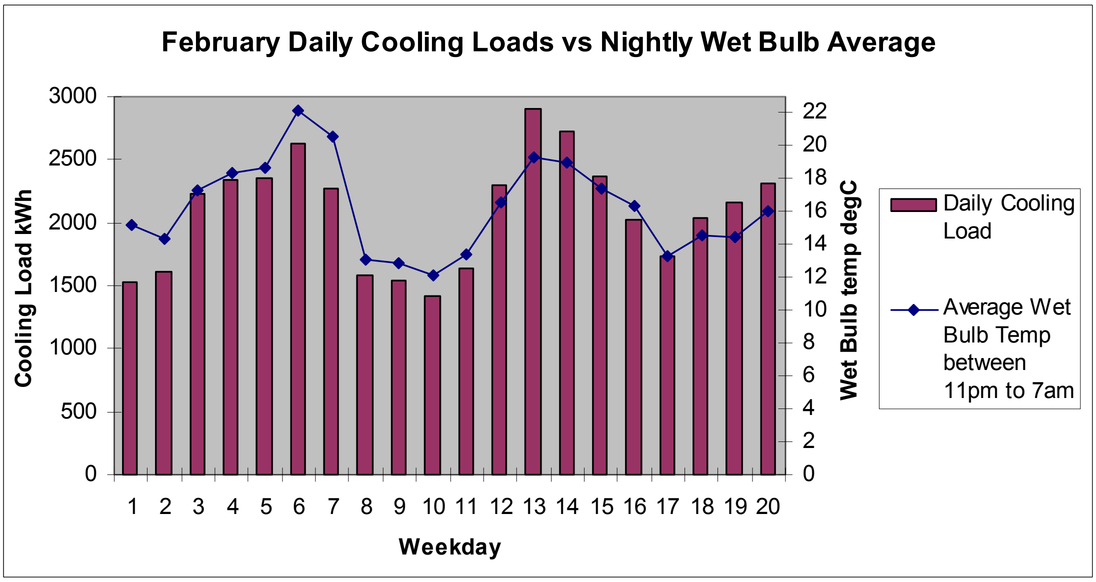
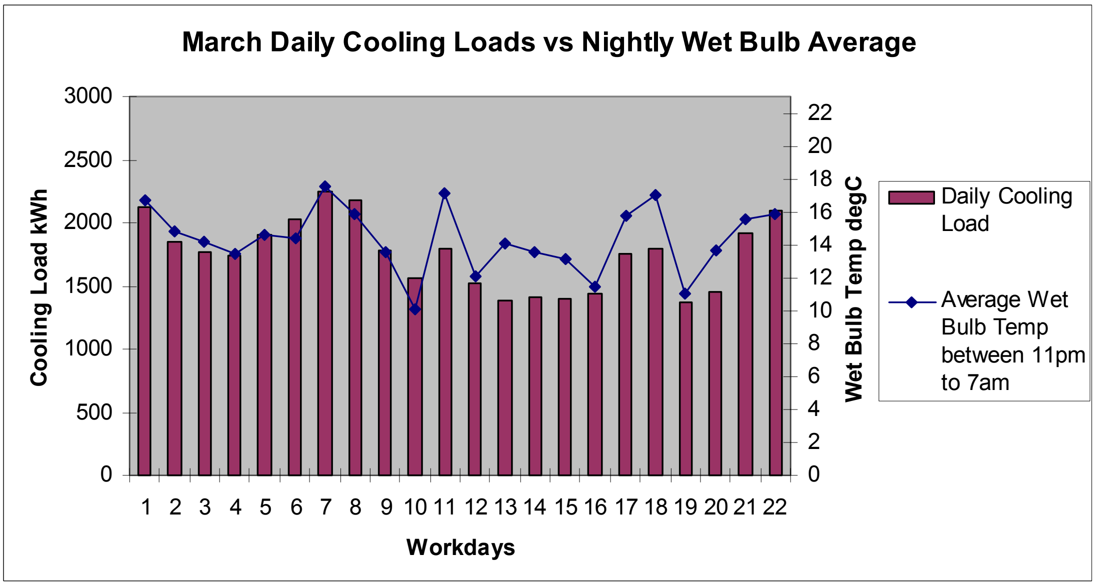
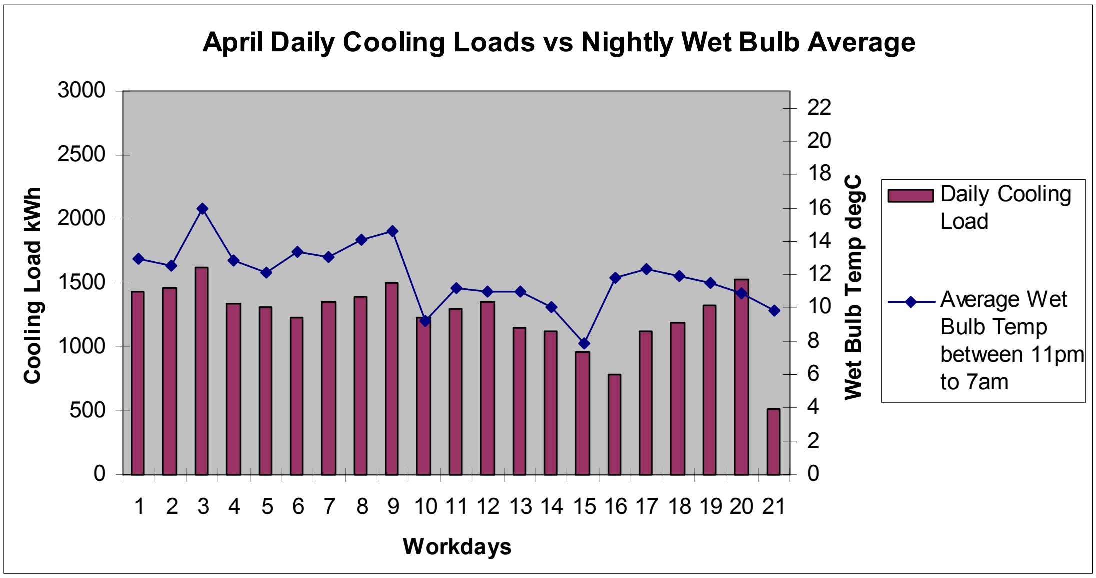
Performance testing of the PCMs, incorporating the prototype tube by tube beam concept, will be conducted in the UK at EPSltd testing facilities with representatives of Melbourne City Council and AEC present as witnesses. The testing is aimed at verifying charging/discharge rates and freezing/melting temperatures for different operational conditions.

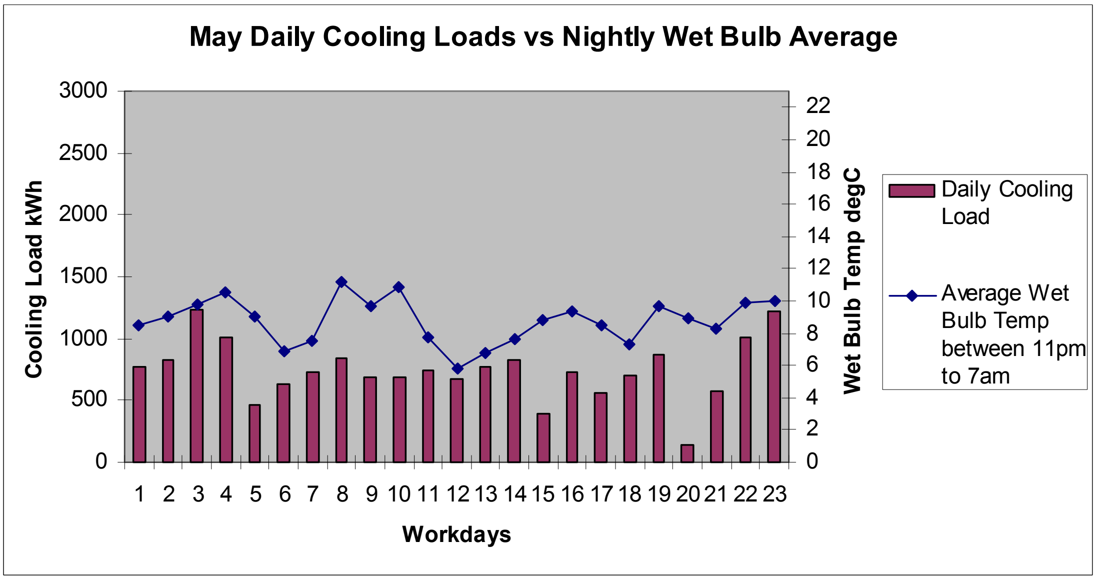
APPENDIX A – MONTHLY WET BULB/SPACE LOAD DATA

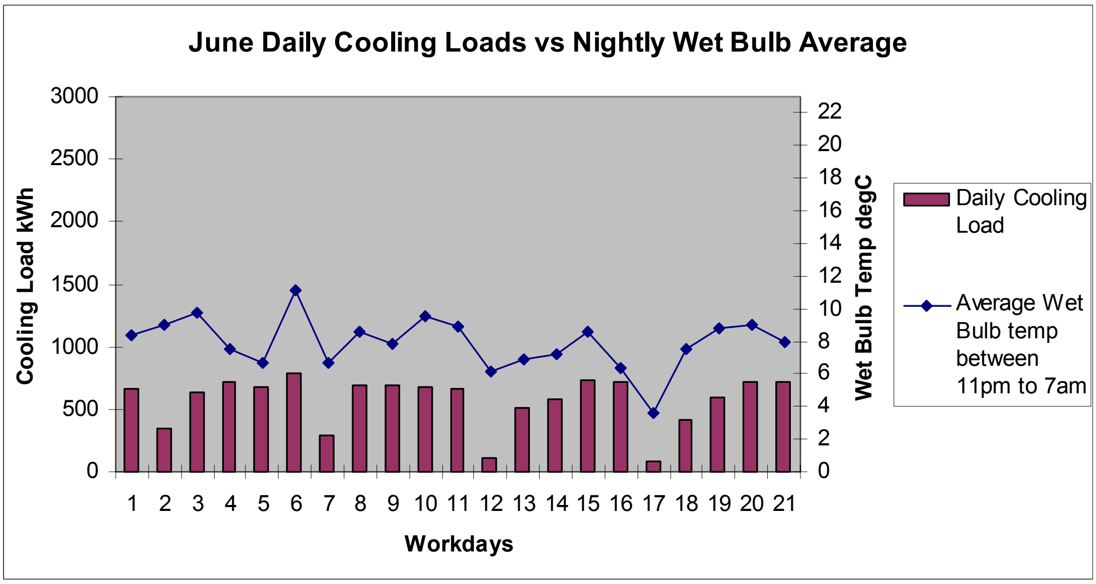

January Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
Wet Bulb Temp degC
Workdays
Daily Cooling Load
Average Wet Bulb temp between 11pm to 7am

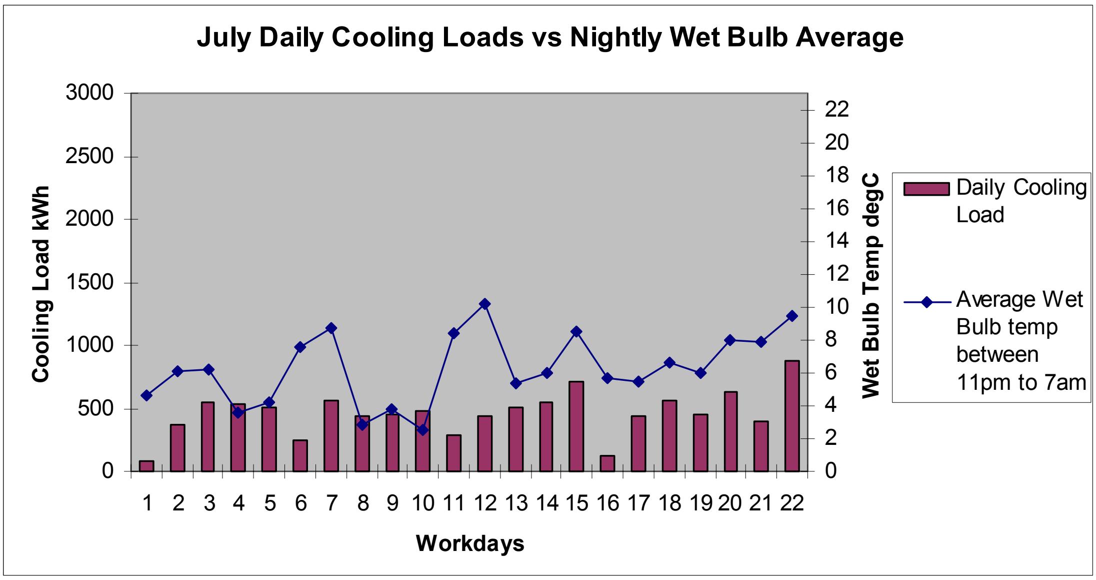

February Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
Wet Bulb temp degC
Weekday
Daily Cooling Load
Average Wet Bulb Temp between 11pm to 7am

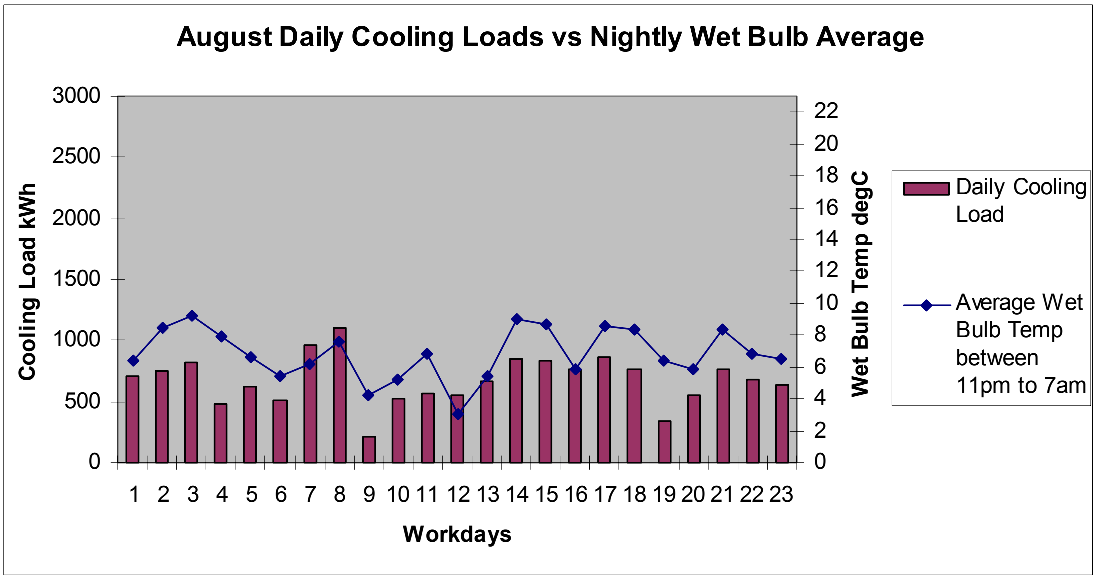

March Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
Wet Bulb Temp degC
Workdays
Daily Cooling Load
Average Wet Bulb Temp between 11pm to 7am

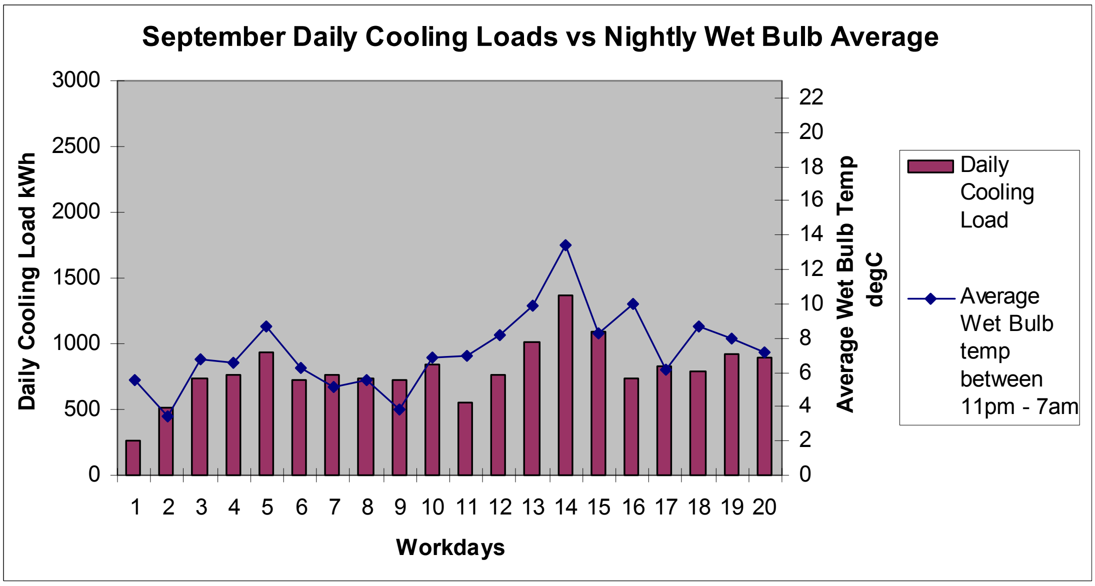

April Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
Wet Bulb Temp degC
Workdays
Daily Cooling Load
Average Wet Bulb Temp between 11pm to 7am

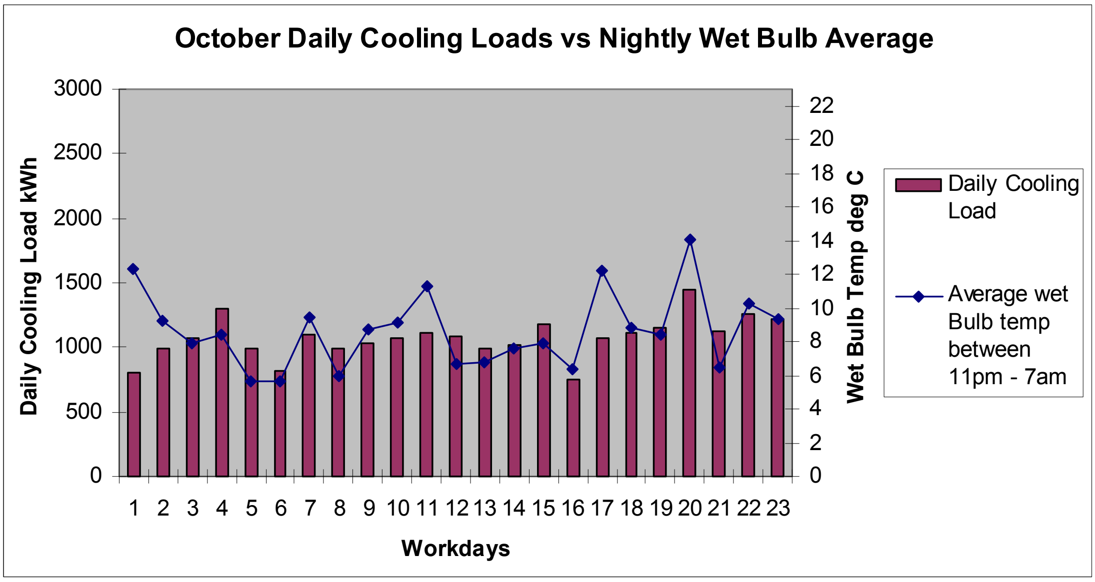

May Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
Wet Bulb Temp degC
Workdays
Daily Cooling Load
Average Wet Bulb Temp between 11pm to 7am

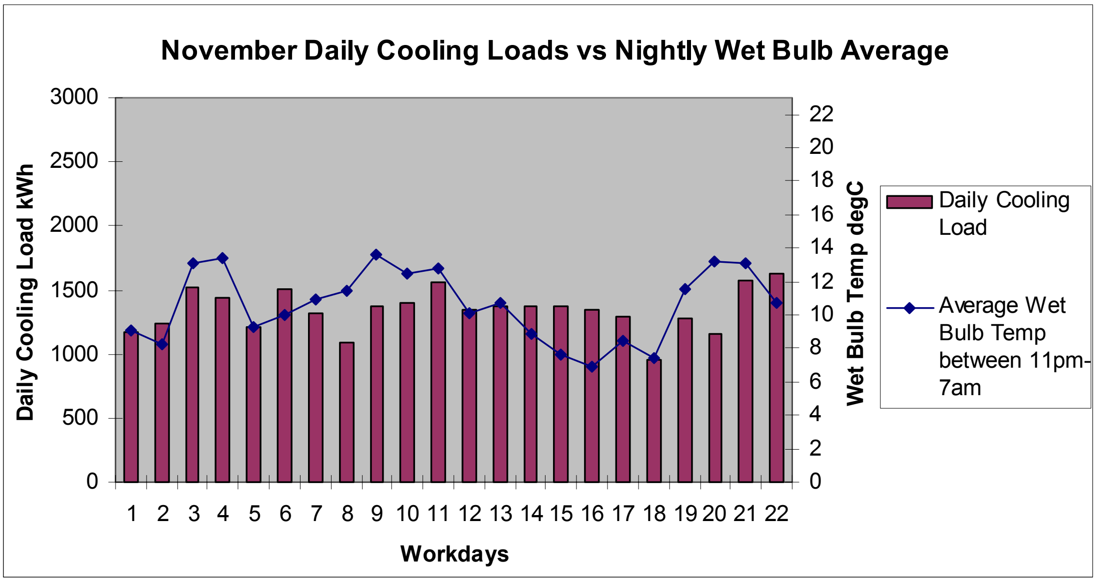

June Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
Wet Bulb Temp degC
Workdays
Daily Cooling Load
Average Wet Bulb temp between 11pm to 7am

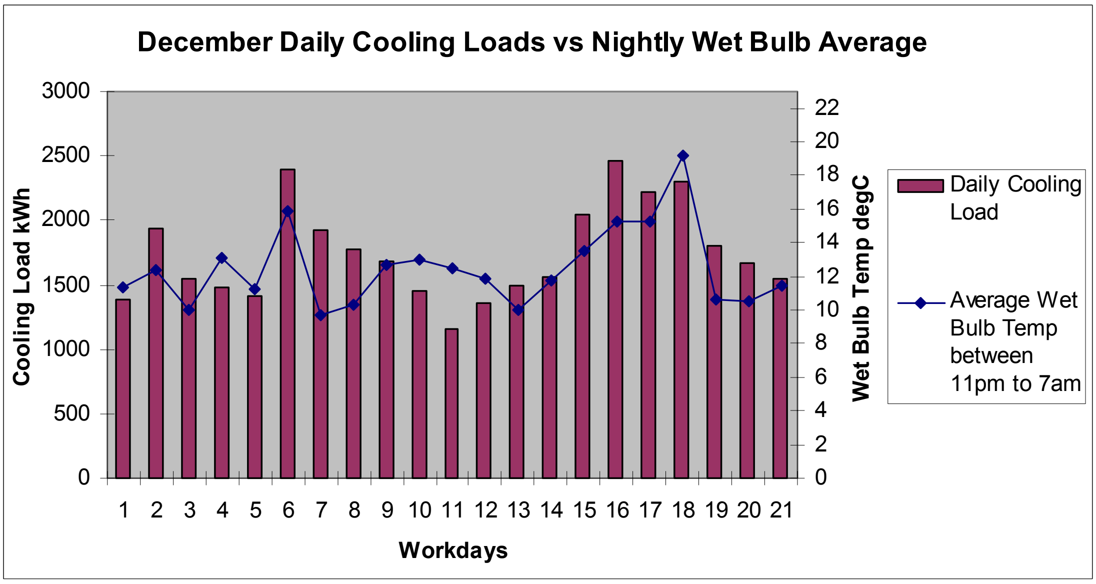

July Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
3000
2500
2000
1500
1000
500
0
22
20
18
16
14
12
10
8
6
4
2
0
Wet Bulb Temp degC
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Workdays
Daily Cooling Load
Average Wet Bulb temp between 11pm to 7am


August Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
3000
2500
2000
1500
1000
500
0
22
20
18
16
14
12
10
8
6
4
2
0
Wet Bulb Temp degC
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Workdays
Daily Cooling Load
Average Wet Bulb Temp between 11pm to 7am


September Daily Cooling Loads vs Nightly Wet Bulb Average
Daily Cooling Load kWh
3000
2500
2000
1500
1000
500
0
22
20
18
16
14
12
10
8
6
4
2
0
Average Wet Bulb Temp degC
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Workdays
Daily Cooling Load
Average Wet Bulb temp between 11pm - 7am


October Daily Cooling Loads vs Nightly Wet Bulb Average
Daily Cooling Load kWh
0
500
1000
1500
2000
2500
3000
Wet Bulb Temp deg C
0
2
4
6
8
10
12
14
16
18
20
22
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Workdays
Daily Cooling Load
Average wet Bulb temp between 11pm - 7am


November Daily Cooling Loads vs Nightly Wet Bulb Average
Daily Cooling Load kWh
0
500
1000
1500
2000
2500
3000
Wet Bulb Temp degC
0
2
4
6
8
10
12
14
16
18
20
22
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Workdays
Daily Cooling Load
Average Wet Bulb Temp between 11pm-7am


December Daily Cooling Loads vs Nightly Wet Bulb Average
Cooling Load kWh
0
500
1000
1500
2000
2500
3000
Wet Bulb Temp degC
0
2
4
6
8
10
12
14
16
18
20
22
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Workdays
Daily Cooling Load
Average Wet Bulb Temp between 11pm to 7am