District cooling case study – James Cook University, Townsville

Craig McClintock

ABSTRACT
James Cook University has built Australia’s largest central-energy chilled water plant incorporating stratified chilled water storage to provide the cooling requirements to all 28 academic buildings within its Townsville campus. The project reduces electrical demand and thus operating and transport costs, greenhouse gas emissions and maintenance, and provides the university with new refrigeration plant that has a projected economic life of 30 years.

Keywords — Central Energy Plant, (CEP), chilled water, dynamic control system, maximum demand, Thermal Energy Storage, TES

OVERVIEW OF PROJECT LANDSCAPE
James Cook University Site Topology
James Cook University (JCU) is located in tropical North Queensland, Townsville. The University topography and facilities comprise:

- 255 hectares of distributed campus with 28 academic buildings.
- Total air conditioned floor area of 69,000m².
- The earliest recorded building was built in 1967 with the majority of the building stock built before 1990.
- The university grew in stages, with additional buildings being added incrementally, each with separate, stand-alone air conditioning plant. The refrigeration chillers are in poor condition (up to 35 years old) with the majority requiring replacement in the next five years, at an estimated cost of $9M. The existing plant capacity totals approximately 11.5MW of cooling in 29 locations around the site.

Figure 1: Computer generated image of the proposed Thermal Energy Storage Tank (Source: James Cook University, 2007)
• High Voltage (HV) electrical reticulation on site is fragile and non-homogeneous with little spare capacity to meet foreseeable load growth.
• There is no master plan for the site services with poor ‘as-built’ drawing records, thus making it difficult to locate or plan alterations to existing underground services.
• Utility power bills are in the order of $2.7M pa.
• Site power maximum demand is 7.3MW (2007) with the utility feeders (consumer mains) capable of 9MW.

BUILDING PROGRAM EXPANSION DRIVERS

JCU has an ambitious building development program which will expand the site to include an additional 25,200m² of air-conditioned floor area by 2010 and a further 25,000m² by 2015. The resolutions to the following identified drivers are critical to the development program:

• The 2010 building program extrapolated maximum demand of 9.9MW would exceed the utility provider’s available capacity for the site of 9MW. This would prompt an expensive utility power upgrade and site wide high voltage power upgrade with a fourth ‘feeder’ or supply to the site being required.
• The building program for 2015 would also exceed the site high voltage maximum feeder capacity by approximately 3MW necessitating a fourth feeder and upgrades of the onsite high-voltage trunk cabling and transformers network.

ENGINEERED SOLUTION TO THE PROJECT DRIVERS

JCU Townsville is building Australia’s largest Central Energy Chilled Water Plant incorporating Stratified Chilled Water Storage to provide the cooling requirements of all 28 existing academic buildings. The project is due for completion by April 2009.

Implementation of the proposed new system after completion of the current campus expansion projects planned for 2010 will yield the following benefits:

• Reduction of the instantaneous maximum electrical demand for the site by approximately 40 per cent from 9.9MW to 5.4MW (2010 scenario) avoiding any high voltage feeder upgrades. It will also provide a relatively ‘flat’ or consistent electrical demand, which frees up capacity on site, allowing capacity for future campus expansion, and/or allows the utility provider to use this capacity elsewhere.
• Reduced electricity operating costs by approximately 30 per cent from $3,200,000 to $2,620,000, saving in the order of $400,000 pa (based on the current cost of electricity) by 2010.
• Reduced greenhouse gas emissions attributable to the University from 43,000 tonnes to 31,000 tonnes, saving approximately 12,000 tonnes CO₂ per year by 2010 (this is the equivalent to taking approximately 2650 cars off the road).
• Reduced maintenance costs and transport costs associated with servicing 28 different chillers, pump groups, cooling towers and the like. The savings are categorised into new plant versus old plant maintenance and central plant versus distributed plant. The combined benefit is anticipated to be more than half the current maintenance costs.
• New refrigeration plant with a projected economic life of 30 years and improved system reliability (redundancy).
• Reduction in noise pollution generated by multiple air conditioning plant compared with the central plant and acoustic treatment.
• A building services master plan that includes a central spine of underground service trenches throughout the campus, which streamlines existing services, and allows for future development programs.

1.0 INTRODUCTION

The Townsville Douglas Campus of the JCU represents a typical medium sized University Campus and comprises approximately 28 academic and service buildings with a total air conditioned floor area in excess of 69,000m² in 2007. The campus is situated in the coastal tropics and therefore peak summer air conditioning loads are high and there is a year round requirement for cooling. Consequently annual energy usage of refrigerated air conditioning systems is high and represents a significant part of the University’s operating costs.

Using available benchmark data, the University has identified that campus electrical energy costs are significantly higher than comparable facilities including most notably the Cairns Campus of the JCU and Charles Darwin University both of which are located in similar climatic regions and both incorporate stratified chilled water Thermal Energy Storage (TES) systems.

Due to the strategies adopted in the early development of the campus (1967) each building is served by its own small cooling plant (water cooled and air cooled) generating chilled water to satisfy the building’s cooling requirements. As a consequence, more than 28 small isolated chilled water plants currently exist on campus. The plants are of varying age (from 2 to 35 years old) and efficiency, and many are air-cooled and highly inefficient during peak load periods.

The large number of cooling plants also results in high maintenance costs, as the cost of maintenance for air conditioning systems is strongly related to the number of system elements and travel distance. Many of the small plants have exceeded or are close to the end of their economic life and major plant replacement costs will be incurred during the next five years. The redundant equipment will be recycled and sold off.

The Douglas Campus is about to embark on a major expansion program which will result in the construction of 8 new buildings by 2010 and effectively increase the air conditioned floor area by over 35 per cent.

2.0 SITE EXPANSION DRIVERS

With an ambitious building program increasing the academic air conditioning floor area from 69,000m² (2007) to 94,200m² (2010) and a further 25,000m² (2015), the following drivers were acknowledged:

1. Electrical infrastructure to the site has an upper limit of 9MW maximum demand. The current site maximum demand (2007) was recorded at 7.3MW. On a pro-rata basis future demand up to 2015 could be approximately 12MW, well above the site infrastructure limitations.
2. A significant electrical upgrade will be required by the University and utility provider if the current building services design philosophy is maintained.

3. Existing air conditioning system philosophy of stand alone chiller plants is not suitable for a large facility. Economies of scale provide greater opportunities for efficiency the larger the plant, and therefore reduced running cost, maintenance costs, and simpler upgrades as technology improves. Replacement cost of chillers over the next five years is estimated at $9M.

4. University utility operating costs are high compared with other university campuses and similar facilities ($2.6M pa).

5. Maintenance cost of chillers (and air conditioning system) is high compared to central energy plant facilities.

6. JCU recognised a need for a site master plan that combined electrical and mechanical services infrastructure in centralised services trenches for all existing and future services.

7. The design philosophy is commensurate with Ergon’s (local electricity supply authority) objective to manage peak demand with a view to reducing infrastructure capital expenditure and improving utilisation of their network assets.

The University required an engineered design solution that offered the lowest Net Present Value (NPV) solution to the electrical and mechanical services infrastructure to support the above drivers and to lessen the environmental footprint of the campus. Net Present Value is an accounting term that considers the life-cycle costing of a facility of 25 years (calculated in today’s money terms), and combines operating, maintenance, capital and replacement costs. The NPV allows the facility owners/managers to compare the efficiency of different design solutions, and plan for future cash flow.

2.1 Basic Concept of the Central Energy Plant Utilising Thermal Energy Storage

In commercial buildings today, air conditioning systems can be broadly categorised into two technologies based on the refrigerant adopted, being Direct Expansion (DX) and Chilled Water (CW).

DX systems employ the use of a gas refrigerant which is compressed to a liquid within a condensing unit, and gives off waste heat in the process. This gas is allowed to re-expand back to a gas at a controlled rate within a cooling coil, and thus absorbs heat, or creates a cooling effect as it does so. Within a fan coil unit the air that is to be cooled is blown over the cooling coils, and then passed into the desired room. While DX systems are widely used in commercial applications, they have a number of disadvantages including limitations on maximum pipe runs between the condenser and fan coil units, the space required to accommodate multiple outdoor condensing units, limitations in systems capacity and reduced operating efficiency at partial load conditions.

In contrast, chilled water systems adopt a single central chiller plant which uses water heat transfer fluid in the buildings, of which the temperature is typically lowered to 6°C, and supplies water at this temperature to all fan coil units. The flow of water is regulated through the various cooling coils using modulating valves to maintain precise control over the cooling coil and therefore the supply air-stream temperature. This system allows much more accurate control over temperature and humidity than DX systems. Water leaving the cooling coil absorbs the heat energy from the air-stream and is raised to approximately 15°C before being returned to the chiller plant.
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DEIGNED BY ENGINEERS FOR ENGINEERS
Central Energy Plant (CEP) is the centralised plant for the district cooling. It contains the chillers, cooling towers, pumps and thermal energy (chilled water) storage tank. It offers the benefits of high efficiency, central plant, reduced maintenance, ease of expansion and technological upgrades as technology advances. On large centralised plant such as this, ‘redundancy’ or back-up systems are included in the system architecture, which allows for continuous supply in the event of a component failure.

Thermal Energy Storage (TES) makes use of periods of the day or night when the site demand for cooling is less than the average demand, by running central chilled water plant during these times to chill return water (from 15°C) back to chilled water (at 6°C). During times when the site demand exceeds the average demand (typically in the afternoon), the chilled water is drawn from the storage tank. From here, the pre-cooled water is then reticulated throughout the campus and delivered to fan coil units within each building. The installation of air-conditioning systems within the buildings themselves remains essentially the same as any conventional chilled water system, except that the chiller plant takes the form of one efficient centralised plant rather than 28 different cooling plants. The central energy plant has a design Coefficient Of Performance (COP is a measure of efficiency) of 6 at summer conditions of 33°C dry bulb and 27°C wet bulb.

### 3.0 ENGINEERING DESIGN RESPONSE

The design solution proposed a new Central Energy Plant (CEP) integrated with a Thermal Energy Storage (TES) element. The final engineering design response was determined by comparing several computerised energy models of the site. (Refer to section 4.1.)

The chiller and water storage facility is located in the southeast part of the campus at sufficient elevation to ensure that water level in the thermal storage tank represents the highest point in the chilled water network, thus ensuring the ‘static head’ or pressure floods all the chilled water pipework, preventing air pockets from being trapped in the pipework, and thus affecting flow of the water. This head thus improves the efficiency of the CEP/TES interface.

The CEP building houses:
- three 4.2MW centrifugal high efficiency chillers, with provision for an additional two chillers in the future
- primary and secondary chilled water pumps (with variable speed drives)
- condenser water pumps (with variable speed drives)
- four 5.1MW cooling towers (with variable speed drives on the fans) with provision for a 5th tower
- CEP office
- low voltage and high voltage switch room
- the building is air conditioned rather than mechanically ventilated to prolong plant life and prevent condensation (corrosion) issues.

The 12 mega litre TES tank contains specially engineered top and bottom water diffusers to allow the water leaving or entering the tank to do so without turbulence. This allows the chilled and returning warm water to stratify within the one single tank.
The water is pumped out of the bottom of the TES tank with a variable speed pumping system to match the site cooling demand. The water is distributed to 7.8kM of underground uninsulated piping which is fed to each building. The primary pumping system pumps water through the chillers and into the TES tank. The secondary pumps pressurise the main water spine throughout the campus, and the tertiary pumping systems control the flow of chilled water in each building. They are controlled to deliver a variable water flow to match the instantaneous cooling demand with a fixed pressure setting throughout the building. The variable speed drives on these pumps allow them to ramp back their speed as demand for chilled water declines, and as they do this, the pump power demand reduces significantly, thus delivering energy savings.

The heat in each building is carried via the water medium back to the top of the TES tank for storage and night time cooling.

3.1 Computerised Energy Model

A detailed computer model of the electrical and refrigeration demand of the campus was developed during the feasibility study to determine the impact of the proposals on energy usage profiles and energy costs. The model was developed to:

- Analyse the energy consumption of the campus over time.
- Identify areas where energy savings could be achieved.
- Evaluate the effectiveness of the proposed cooling systems.

The model was used to simulate the operation of the cooling systems under different conditions and to predict energy usage.

Figure 4: Chiller Plant Contribution to Maximum Demand (Source: MGF, 2006)

Graph showing the power profile of the site and chiller over time.
The model was tested against actual 2007 maximum demand and electricity usage data and demonstrated close correlation. The graphs show the following.

• Over 50 per cent of the peak site electrical demand is created by chiller plant operation and “Chiller” and “Other” peaks are generally coincident.

• Maximum demand and energy consumption is highest during the on-peak periods when the cost of electricity is highest.

• Site maximum demand will increase from the current 7.3MW to 9.8 MW by year 2010

3.2 Impact of Proposed CEP/ TES System on Site Electricity Usage

The proposed CEP/TES system will significantly alter the campus electrical load profiles as follows.

• It will reduce the energy required to generate chilled water as a consequence of the superior efficiency of the large high efficiency water cooled machines proposed for incorporation in the CEP.

• It will allow chilled water to be generated at night during off-peak tariff periods when electricity costs are lower and ambient air temperatures are lower are more favourable, and stored in the TES tank for use the next day.

Figures 5 and 6 show the impact of the proposed higher efficiency CEP and TES system combination on site electrical load profiles for year 2007 and year 2010 scenarios.

Figures 5 and 6 show that implementation of the CEP/TES system will immediately reduce the current maximum demand from 7.3 MW to 5.3 MW and shift a significant part of the University’s power usage to off-peak tariff periods. A significant part of the energy reduction is due to better chiller efficiencies. More significantly it will permit the current expansion planned by the University to be undertaken without any increase in the electrical maximum demand of the campus.

3.3 Energy Efficiency Inclusions

In order to achieve best engineering practices, several computerised energy models were created for different plant configurations and manufacturers. Three chiller manufacturers were compared with performance data provided. The governing equation for each chiller was derived and run through the energy model as a function of weather data (dry bulb and wet bulb), load seasonal profiles and time. The control strategy implemented will take advantage of the selected chiller optimum performance ‘sweet spot’ which is at 80 per cent load.

The chilled water flow rate is varied pending on inventory levels of the tank to take advantage of the pumping energy savings and chiller performance. The condenser water flow rate to the cooling towers is also varied to maintain a fixed temperature difference with a minimum water flow rate setting taking advantage of the pump energy savings.

By also employing variable speed pumps for condenser water flow, coupled to a floating set point condenser water temperature adjustment, further efficiencies are gained. Traditionally the control systems in most commercial buildings have static set points which do not reflect the seasonal climatic
conditions as a function of time. The focus of the energy modelling and building management control system was to create an innovative solution that is dynamic (alive) and which constantly changes its operating parameters to reflect the seasonal variance. The plant operation is governed by an algorithm which is based on seasonal ambient conditions, and also considers the input from temperature and humidity sensors.

3.4 Further System Efficiencies

Value adding to this project over and above the CEP/TES design, included the control strategy of the central plant; the selection of the high voltage chiller motors; the CEP piping arrangement to reduce the roof steel member sizes and selection of the underground reticulated chilled water piping (7.8kM).

Using high voltage equipment: The chiller selected is a result of further energy modelling with a three stage compression centrifugal chiller selected. Due to the size of the plant, motors that operate directly on high voltage were able to be used. The chillers comprise an 11kV motor and high voltage soft starter kit to enable the site high voltage reticulation to be directly coupled to the chillers without the need to reduce the 11kV to 415V power supply (industry standard). Conventional practice would be to use motors that operate on low voltage, which incur transformer efficiency losses, transformer capital cost, switchgear and switchboard capital cost; increased building floor area to house additional indoor transformers and savings in long term maintenance. The estimated savings in avoiding these was $800,000 in capital cost.

Reduced plant-room structure: Typically plant pipe work is suspended from the roof structure, thus increasing the size of these structural elements. By using an innovative chilled water pipe manifold arrangement where five headers were stacked above each other on support frames, the weight of the headers (majority of piping weight) was carried directly by the floor slab and not the steel roof framing. The reduction in size of the steel roof members proved a cost saving of approximately $40,000 in capital cost.

Avoided insulation: Medium Density Polyethylene (MDPE) piping has been used for irrigation and water reticulation for some time. Chilled water distribution in buildings is generally constructed in metal pipes that require thermal insulation, normally 50mm polystyrene. By using MDPE pipework to reticulate the chilled water throughout the campus, insulation was avoided, and the greater 12M pipe lengths available reduced the number of joints, flexibility in the installation, and flexibility for future branch take offs, thus providing savings. The wall thickness of the 500mm diameter MDPE is 29.6mm which is directly buried in a compact sand fill, offering high thermal performance, and inherent vapour barrier and mechanical protection with the MDPE outer surface of the pipe.

High water temperature differential: The chilled water on site has a fixed supply temperature of 6°C and return temperature of 15°C, which gives
a 9° temperature differential. Conventional systems tend to operate on a 6–7° differential. Using a greater differential requires 25 per cent lower flow rate, and thus requires less pumping energy and smaller pipes, 160mm to 360mm ø. However this also required the air-handling units within the building to be calibrated for these less common parameters and the chillers to work harder to restore the 6°C water during the night time cooling cycle.

Services Master Plan: During the course of the design, a master plan of the electrical and mechanical services for the site was conceived. This enabled future designers and building expansions to utilise the parameters set for consistence and simplicity across the site. The Master planning for the university comprises three key areas:

1. Standard for site wide chilled water supply temperatures and pressures for future building connections as detailed above.
2. High voltage (HV) site upgrade and rationalisation for future building program.
3. Services corridor and common trench arrangement.

As part of the high voltage study it was revealed that the existing site network was frail and exposed to failure with non-homogenous conductors and three independent feeds. As part of the high voltage upgrade, all conductors are upgraded to a homogenous size and ring main units were installed to enable back feeding and system backup / redundancy.

The civil works created known service corridors on site with a common trench.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year 2007 Scenario</th>
<th>Year 2010 Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distributed Plant</td>
<td>With CEP/TES</td>
</tr>
<tr>
<td>Site Maximum Demand</td>
<td>7.3 MW</td>
<td>5.3 MW</td>
</tr>
<tr>
<td>Energy Usage per year [KWH]</td>
<td>32,000,000</td>
<td>23,000,000</td>
</tr>
<tr>
<td>Electricity Costs per year [2007 rate]*</td>
<td>$2,651,346.00</td>
<td>$1,786,908</td>
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<tr>
<td>Greenhouse Gas Generation per year</td>
<td>33,643 Tonnes CO2</td>
<td>24,729 Tonnes CO2</td>
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</table>

* Detailed tariff prices based on March 07 Utility rates.

Table 1: Model Predictions for proposed and business-as-usual systems (Source: MGF, 2006)
housing chilled water supply and return piping, high voltage conduits and communications conduits. Figure 6 is a typical section through the service corridor trench.

4.0 CONCLUSION

JCU Townsville Douglas Campus has embarked on the largest CEP/TES system in Australia with completion expected in April 2009 followed by 12 months of verification. Outcomes predicted by the model are summarised in tabular form below.

Accordingly the CEP/TES proposal will in year 2010 effectively reduce the site Maximum Demand by 4.5 MW, save the University $990,000 in energy costs and reduce greenhouse gas impact by 12,000 tonnes CO\textsubscript{2}-e p.a.

Currently the following large scale stratified chilled water TES systems are operating in Australia.

On completion of the project, JCU Townsville will have constructed Australia’s largest district cooling system with high efficiency central energy plant incorporating large scale thermal energy water storage. The author believes this type of system should be more commonly used and could provide an important tool for demand side management, energy reduction strategies and future infrastructure master planning.

### PROJECT AWARDS

The project has received the following awards:

- Engineers Australia Queensland Division 2008 Excellence Award, Reports, Procedures and Systems category
- Engineers Australia 2008 Australia Excellence Awards finalist.
- Townsville City Council 2008 Excellence in Sustainability and Innovation Business Award.

### BIOGRAPHY

Craig McClintock (BE Mech Hons C1; RPEQ, MIEAust, MAIRAH) is the Townsville branch manager of MGF Consultants, and is a JCU alumni. Since starting in the building services engineering industry in 1992, Craig has worked extensively in contracting, consulting and the state government engineering department to service the commercial and institutional buildings in the tropics of North Queensland. He was the principal mechanical services engineer on the JCU project.

This paper was presented at AIRAH’s Achieving the Green Dream Conference. Contact: craig@mgfnq.com.au

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### PROJECT DETAILS

**Client:** James Cook University, Facility Maintenance.

**Sponsors / Partners:** Ergon Limited

Principal Design, Mechanical and Electrical Design Consultant: MGF Consultants (NQ) P/L and MGF Consultants P/L

Building Design Consultant: MGF Consultants (NQ) P/L and Power Graham and Dempsey Architects P/L

Civil Design Consultant: Maunsell Australia P/L and MGF Consultants (NQ) P/L.

Builder: Dave Harney Constructions P/L

Mechanical Contractor (CEP): AE Smith P/L

Mechanical Contractor (Building Connections): Green APS

Electrical High Voltage Contractor: Protech P/L

TES Tank Contractor: Acqacon P/L

Civil Contractor: BMD Constructions P/L

Craig McClintock was the winner of AIRAH’S 2007 Future Leaders Award.