

**The Fine Line of Heat Rejection**

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## **Abstract**

Selection of heat rejection equipment has traditionally been a choice between higher energy consumption of an air cooled solution and high water consumption of a water cooled solution.

This paper examines advancement in heat rejection technology and the way it can be applied to air conditioning and refrigeration plant in health care and other facilities.

It also examines field difficulties encountered pipework design as the knowledge and experience levels Engineers designing systems with remote condensers diminishes.

With plant larger than 1,000kW the only option was water cooled using an array of cooling towers or perhaps an evaporative condenser as air cooled plant involved massive volumes of chemical refrigerant that posed a problem ecologically and there was the problem associated with limitations on pipe lengths for refrigeration plant.

The advent of adiabatically precooled closed circuit coolers and air cooled condensers has introduced an alternative to cooling towers that can be considered offering the possibility of water cooled performance from an air cooled solution with no serious threat of Legionella contamination.

There is a fine line that needs to be examined on a case by case basis.

The impact of adiabatic precooling is examined in detail and recent examples of its application in sub-tropical Brisbane provide evidence of the potential performance that can be achieved.

## **Bio Datum**

Phillip Carruthers is an Associate Director for Norman Disney & Young (NDY), Consulting Engineers in Brisbane having joined the practice in 1985. He has been associated with the building services industry in contracting and consulting since 1969 in both NSW and Queensland.

He has a specific interest in sustainable design and eco efficiency and is a contributor to the NDY Environment research and development group.

Phillip is a member of ASHRAE and a Presidential Fellow Member of AIRAH and is a past contributor to IHEA National Conferences.

He is a current member of the Sustainable Development and Management Committee of the Property Council of Australia, Queensland Division.

## Background

### Heat of Rejection

It is important to understand what heat of rejection is before discussing the selection of equipment or piping it in the field.

Heat of rejection is the energy removed from a refrigerant in the condensing process. Hot gaseous refrigerant enters the condenser where it loses its latent heat of evaporation to become hot liquid refrigerant. That process occurs regardless of the method adopted to absorb the heat rejected.

In typical terms the Heat of Rejection is some 18% to 28% greater than the cooling effect in the evaporator as it includes the heat of compression which is the energy input from the compressor motor. The actual percentage that occurs depends upon a number of factors including the suction pressure/temperature, discharge pressure/temperature and the refrigerant used. However, the main factor is pressure/temperature. The relationship between temperature and pressure in any refrigerant is proportional and can be read from any chart provided by refrigerant suppliers or from text books.

Low suction temperature and high discharge temperature increase the percentage.

As an example:

Heat of compression taken from the catalogue of a twelve cylinders a reciprocating compressor using HCFC22 refrigerant is:

Suction (°C)	Discharge (°C)	Capacity (kW <sub>r</sub> )	Compression (kW)	Percentage
4.4	40.6	375.6	69.7	18.6
4.4	48.9	333.3	78.7	23.6
-1.1	40.6	303.3	66.1	21.8
-1.1	48.9	267.5	73.0	27.3

Standard selection for air conditioning is usually based upon 4.4°C saturated suction in all cases and 40.6°C saturated discharge with heat rejection through a cooling tower or between 10°K and 15°K above critical ambient temperature for an air cooled solution. Obviously the closer to 10°K rise the better the system will perform in extremes of ambient and the energy efficiency will be greater.

The selection of refrigerant, or for that matter the type of compressor, has little impact upon the percentage result.

Further factors in the control of a refrigeration system are superheat and subcooling

**Superheat** happens at the expansion device before the evaporator and is a very important safety factor in the system. Liquid refrigerant is boiled off in the evaporator by absorbing the latent heat of evaporation to cool the air or water passing through the evaporator and the process happens at a constant temperature. Superheat is simply that! The refrigerant absorbs more heat from the air or water than its latent heat of evaporation increasing the temperature of the refrigerant. The process ensures that no liquid refrigerant leaves the evaporator

preventing liquid damage to the compressor. Liquid damage at the compressor can be from physical damage to the top end from trying to compress a liquid, or more likely as a result of displacing the oil from the compressor sump. Super heat should be in the order of 5.5°K.

**Subcooling** happens in the condenser as the liquid enters the liquid line or condensate line. It happens within the a water cooled vessel as part of the vessel sizing, but in an air cooled condenser or evaporative condenser there is usually a second coil in the condenser that liquid refrigerant is passed through to achieve the subcooling. The condensing process is again a constant temperature function that transforms gaseous refrigerant to liquid refrigerant. Subcooling extracts sensible heat from the liquid refrigerant after it has fully condensed to reduce its actual temperature. The benefit is two fold.

- It increased the specific heat of the refrigerant such that 1°K of subcooling can increase the refrigeration effect by up to 1% , and
- The pressure difference between saturated and subcooled liquid can offset pressure losses in the liquid line.

Optimal subcooling for an air conditioning plant is 8.3°K.

## Methods of Heat Rejection

There are several methods of heat rejection but this paper considers only three conventional methods. Geothermal heat rejection is not discussed in this paper as it is a topic that deserves a standalone discussion paper.

Further, the paper only discusses built-up plant where compressors are separate to the heat rejection plant. It does not discuss packaged air conditioning plant.

### Air Cooled

Air cooled condensers are coils arranged in either horizontal or vertical planes and fitted with any number of fans. The fans can be propeller or axial but axial usually produces better noise outcomes.

Selection criteria must be carefully considered as a small selection will create head pressure problems and a large selection will over condense with potential disastrous consequences for the compressor. The criterion is temperature difference between ambient air-on the coil and the saturated temperature of refrigerant leaving the condenser.

As a general rule ambient dry bulb used in the selection process should be some 3°K higher than normal design ambient.

In Brisbane the ambient is 32°C so the selection criteria should be 35°C with a 10°K TD results in a saturated condensing temperature of 45°C.

### Limitations

The largest air cooled condenser available in a packaged range will reject 58.1kW of heat at 1°K TD meaning the size range in 581kW to 871kW. That equates to cooling effects

between 492kW<sub>r</sub> and 708kW<sub>r</sub>. The foot print for a horizontal unit is 7.5m x 2.4m with an access need of 1.2M all around.

Noise is often a significant problem due the amount of air needed to dissipate the heat. The largest unit available has ten fans and the noise level can exceed 88dBA.

Ambient conditions are a limitation as the higher the ambient dry bulb temperature the higher the saturated discharge temperature of the refrigerant will be. However, an air cooled condenser can operate at extremely high ambient condition provided the temperature rise across the coil is low and in extreme conditions a lower pressure refrigerant such as HFC134a should be used.

Fin material for the coils is susceptible to corrosion so that is also a factor in their selection. Salt spray or traffic pollution can corrode the fins within five years. Protective coating can be applied to the fins but it's not always successful. Research is needed in respect of fin protection.

## **Warning**

Pipework design is critical! Specific design issues include:

- A separate subcooling coil should be fitted to every condenser to ensure the liquid flow from the condenser to the hot liquid side is stable.
- There must be a liquid receiver with every condenser. If there is no receiver the refrigerant charge is considered critical meaning the amount of refrigerant in the system must be exact if it is to work correctly.
- The pipe line carrying refrigerant from the condenser to the receiver is not a liquid line. It is a condensate line that must be larger than a liquid line so the liquid can drain out of the condenser into the receiver. Consequently the receiver must be below the condenser by a considerable distance.
- A liquid line leaves the bottom of the receiver and runs to the subcooling coil and then to the expansion device.
- Flash gas will form in the top of the receiver so it must vent through a small valved line to the top of the discharge (hot gas) line before it enters the condenser.

## **Closed Circuit Coolers**

A closed circuit cooler can be referred to as an evaporative cooling tower but it does not reject heat in the same manner as a cooling tower.

Heat rejection from the refrigerant is to condenser water (CW) passed through the condenser vessel or other form of heat exchanger. The CW is circulated in a closed circuit, so not open to atmosphere at any stage, and passed through a coil bank of tubes in the closed circuit cooler. Water from the basin of the cooler is sprayed over the coil bank to extract heat from the CW in the coils and ambient air is drawn over the coils to evaporative cool the spray water in what is almost an adiabatic process.

The heat transfer process from CW to the spray water is purely sensible as the result is a reduction of say 5.5°K in the CW temperature. The increase in the spray water temperature is transferred to the cooling air in an evaporative process.

A closed circuit cooler does not impact upon subcooling or superheat of the refrigeration process. Subcooling happens in the condenser vessel in what ever form it may be.

Closed circuit coolers are feasible but they are generally expensive and have a life expectancy less than a cooling tower.

### **Limitations**

Cost is usually high.

Closed circuit coolers are usually very heavy due to amount of metal in their construction, and the footprint can be relatively small. Slab or frame strength for the support structure must be checked.

They are difficult to clean. By the very nature of the evaporative effect, scale will build up on the outside of the coil bank making it almost impossible to clean.

Ambient wet bulb is a selection limitation as the heat transfer depends upon the approach between spray water temperature and the ambient wet bulb temperature. The higher the approach, the higher the cooling effect.

While approach is a key factor, selection criteria is ambient wet bulb and CW flow.

### **Benefits**

The prime benefit is that a water cooled performance is achieved in respect of the refrigeration effect with a closed water circuit. Once treated, the water should remain inert with no degradation of condenser performance due to scaling.

## **Evaporative Condenser**

An evaporative condenser is a closed circuit cooler but refrigerant replaces the water in the tubes.

The design of system pipework around an evaporative condenser should not be undertaken unless the designer has a clear understanding of refrigeration. The same rules apply to an evaporative condenser as to an air cooled condenser.

- A receiver is essential regardless of what some contractors will try to impose upon the design,
- A separate subcooling coil is also essential for the proper control of liquid flow,
- The condensate line out of the condenser coil must drain freely to the top of the receiver of the condenser simply will not work and there will be high head pressure problems,
- Flash gas must be vented off the top of the receiver to hot gas line before it enters the condenser, and

- Under no circumstances should two condensers be used in a common circuit unless the design and installation is carried out by experienced people. The balance of liquid flow out of condensers must be precise or one of the condensers will not work!

### **Limitations**

Limitations for the use of an evaporative condenser are the same as for an air cooled condenser except the footprint. The physical size of an evaporative condenser is less than needed for an air cooled solution.

The greatest limitation is capacity. As a rule of thumb a field piped refrigeration system will have a gas charge of up to 0.6kg/kWr and that means a 1000kWr plant will 600kg of chemical refrigerant in circulation. The potential for a leak is high, and the impact of the leak is financially significant but an ecological disaster. It is suggested that 750kWr be the maximum size of plant to use an evaporative condenser.

Ambient wet bulb is critical and it again relates to approach. Higher wet bulb ambient conditions produce less heat rejection capacity. It is suggested that wet bulb selection criteria be 0.5°K above the normal design ambient.

### **Water Cooled - Cooling Tower**

The traditional means of heat rejection from large air conditioning plant is through a shell and tube condenser with heat rejected to CW cooled by an evaporative cooling tower.

All refrigeration system impacts are usually encompassed in the chiller or condensing set so the designer is not concerned with factors such as superheat and subcooling.

The key component is the cooling tower as it is the final heat rejection apparatus in a water cooled solution. Selection criteria are CW flow, temperature range between entering and leaving CW, and ambient wet bulb. Ambient wet bulb criterion should be 0.5°K higher than design ambient.

Approach is extremely important in the selection process as it determines the minimum temperature that can be achieved in the evaporative cooling process.

Hot CW enters the cooling tower at the top of the fill stack and cascades through the fill to the basin. Ambient air is passed through the fill where it evaporatively cools the CW to a temperature equivalent to the ambient wet bulb plus the approach.

A minimum approach is 4.0°K meaning that in Brisbane with an ambient of 25.0°Cwb the selection criteria will 29.5°Cwb and at that condition the best CW temperature will be 29.5°C.

### **Limitations**

Limitations are really restricted to location and that relates to potential contamination of air intakes by Legionella bacteria that might be present in the cooling tower basin.

Extremes of ambient wet bulb limit the ability of cooling towers to reject heat so in areas like Far North Queensland and say Darwin, a cooling tower will need to be large and the CW temperature will most probably need to be higher than 29.5°C.

## Adiabatic

Adiabatic condensers are relatively new, and are in essence an air cooled condenser but with the ambient air pre-cooled by wetted pads.

Ambient air is drawn through the pads to be adiabatically cooled to about 80% to 85% saturation before entering to condenser coil.

Water is recirculated over the pads when needed and is dumped every night. If ambient conditions are low enough, the water is not used and the condenser is a straight air cooled device.

All refrigeration effects and impacts are the same as for an air cooled solution with the exception that water cooled performance can be achieved from an air cooled solution.

The installation still requires a receiver, but there is no subcooling coil provided. Subcooling is achieved within the condenser coil in similar manner to a shell and tube condenser. In essence, the condenser coil is larger than it need be to condense the hot gas to liquid. However, this fact makes the receiver an imperative.

Selection criteria are ambient wet bulb and dry bulb, and the desired saturated condensing temperature. The condensing temperature can be the same as a water cooled solution at say 40.5°C and the ambient wet bulb should be 0.5°K higher than design. Ambient dry bulb has an impact but it is not as great as wet bulb. Dry bulb can be the normal design dry bulb for the geographic region.

## Limitations

The largest adiabatic cooler will reject 950kW<sub>r</sub>. The foot print for a horizontal unit is 7.5m x 2.12m with an access need of 1.2M all around.

Noise is often a significant problem due the amount of air needed to dissipate the heat. The largest unit available has ten fans and the noise level can exceed 81dBA.

Fin material for the coils is susceptible to corrosion so that is also a factor in their selection. However, the pre-cooling pads act as a filter and washer to protect the coils. The impact of corrosion is not usually as high as for an air cooled condenser. However, the pads need to be cleaned annually.

Water is needed but the consumption is minimal.

Capital cost is higher than a water cooled or air cooled solution. However, if the plant size is large enough to need two air cooled condensers, the adiabatic solution is more economical.

## Advantages

If there is sufficient real estate available for an air cooled solution and the plant size does not exceed 750kW<sub>r</sub> an adiabatic condenser will provide the best energy result of all heat rejection methods.

Water cooled performance is achieved without the need for water treatment.

## Cost Analysis

The following matrix details indicative capital costs for each method based upon a 750kW<sub>r</sub> chilled water plant:

	Air Cooled	Closed Circuit	Evaporative	Water Cooled	Adiabatic
Chiller (750kW <sub>r</sub> )	\$110,000	\$110,000	\$110,000	\$140,000	\$110,000
CW Pumps		\$10,000		\$10,000	
CW Pipework		\$50,000		\$50,000	
Refrigeration pipework	\$50,000		\$50,000		\$50,000
Water treatment		\$8,000	\$8,000	\$12,000	
Condenser	\$60,000		\$56,000		\$70,000
Cooling Tower		\$80,000		\$25,000	
Electrical	\$20,000	\$30,000	\$30,000	\$30,000	\$20,000
Totals	\$240,000	\$288,000	\$254,000	\$267,000	\$250,000

Obviously there is little difference between the options with air cooled as the less cost and closed circuit cooler as the highest. The selection is then based upon other impacts such as energy, water and real estate.

## Environmental

Main environmental impacts are energy and water consumption. The following matrix indicates potential environmental impact in comparison to a normal water cooled solution.

	Air Cooled	Closed Circuit	Evaporative	Water Cooled	Adiabatic
Energy	110%	105%	105%	100%	100%
Water	0%	80%	80%	100%	25%
Chemicals	0%	50%	50%	100%	0%

Actual consumption need to be assessed for each site but in general terms the percentage figures offer represents results from Brisbane projects except for the closed circuit option.

An interesting environmental consideration is what happens at the end of the plant life. At this stage all options other than the adiabatic condenser will end up in land fill with very little recycling opportunity. The adiabatic condenser is manufactured entirely of aluminium and the manufacturer claim that it can be totally recycled at the end of its economic life.

## Summary and Recommendation

The method of heat rejection used on a project depends upon a number of issues:

- The size of plant involved – if the plant is larger than 750kW<sub>r</sub> and is not packaged, it should be water cooled as:
  - It will provide the best energy result,

- The capital cost will be appropriate to the size of plant,
- Chemical refrigerant will be minimised

Air cooled, evaporative or adiabatic condensers should only be considered for plant less than 750kW<sub>r</sub>.

However, there is a version of the Adiabatic Condenser available that is an adiabatic closed circuit cooler where water replaces the refrigerant in the tubes. If sufficient real estate is available they are a real alternative to a cooling tower but initial cost is high. Typical simple payback can be achieved within four to five years.

- The amount of real estate available. Air cooled or adiabatic solutions need more space.
- If an air cooled solution is needed or considered appropriate, an adiabatic condenser should be considered as it:
  - Provides the best energy outcome,
  - Minimises water consumption,
  - There is no chemical treatment involved,
  - Equipment life is likely to be longer due to the filter effect of the pads, and the unit is totally recyclable at the end of its life,
  - Capital expenditure is higher but the payback will be within three to four years.
- An air cooled, evaporative, or adiabatic solution should not be undertaken without input from an engineer fully conversant with refrigeration pipe work design. There are strict principles associated with refrigeration pipework design that must be followed.

## Case Study - Redland City Council

Redland City Council (RCC) is the local government authority for the Redlands catchment, which include the Southern Moreton Bay Islands, North Stradbroke Island and south eastern areas of the mainland bordered by Brisbane, Gold Coast and Logan Cities.

RCC has numerous public services properties and facilities including the “Administration Building”. This building was constructed in the mid 1980’s and the Air Conditioning plant and equipment that served the building has been in use for 25 years. As such the majority of the plant and equipment had reached the end of its life cycle of operation and an extensive upgrade was necessary.

Council had endured repeated chiller failures and resolved to replace the plant. Given the current need for water and energy efficiency, they set a very strict covenant upon the project that predicated innovative design for water efficiency, energy efficiency and they required redundancy in the plant so they would have protection against future chiller failures.

NDY were commissioned in September 2008 to devise a system that provided Council with high energy efficiency and a reduction of 95% in water usage over the previous system. The redundancy requirement was difficult to achieve as there was no plant space to install a second chiller. The requirement met by liaison with the chiller manufacturer, PowerPax to build a special machine with a redundant compressor on the machine. In essence three active

compressors met peak demand while a third compressor was provided to automatically cut in if an active compressor failed.

Council's initial covenant was met with an excellent environmental outcome and it was done while Council staff were in occupancy with no loss of conditions. Temporary chilled water plant was deployed during the two week construction phase to maintain conditions within the space.

## **Background**

Southeast Queensland is experiencing the most severe drought in recorded history, but it also coincides with a period in time where recognition of global warming impacts has placed emphasis upon energy reduction. Accommodating both environmental problems in air conditioning design is not always easy and calls for innovative or creative design.

To address the drought issue, State and Local Governments imposed restrictions on water usage and mandated Water Efficiency Management Plans (WEMPS). Commercial property owners were required to devise and implement a management plan to reduce water consumption by 25%.

Energy has been more a commercial consideration in the private sector, but the public sector has adopted the issue as something they should take the lead in. Consequently air conditioning design for public sector facilities was required to better BCA Section J standards.

Our client at Redland Shire Council was suffering repeated failure of a twenty five year old chilled water plant serving their Administration Centre in Cleveland, and following several reports looking at strategies available to them determined to replace the plant, but placed a very prescriptive covenant on the design outcomes.

The original plant comprised a water cooled chiller with dual semi hermetic reciprocating compressors and two fibreglass cooling towers for heat rejection. The building is also very close to the shores of Moreton Bay and had a history of accelerated corrosion from the bay side atmosphere.

Council's covenant was:

- Minimise energy,
- Air cooled solution preferred with no water consumption, and
- There must be redundancy in the chillers.

NDY had provided technical facilities management assistance to Council since the building was opened in 1985 and in recent years had focused upon keeping the chiller running effectively as they were suffering and obvious loss of capacity and repeated nuisance failures. The failure rate and subsequent loss of conditions was the catalyst for Council to replace the plant but with the covenant of redundancy.

A number of options were considered but each had problems when considering the covenant requirements.

- An air cooled solution would increase the energy consumed by the plant,

- History confirmed that aluminium finned coils on an air cooled condenser would corrode in the bay side atmosphere, and
- Plant space in the plantroom prohibited the installation of two chillers so redundancy was a problem

A strategy was devised to take advantage of the oil free compressor technology in TurboCor compressors, adiabatic cooling of condenser air in DriCon condensers, and the willingness of PowerPax to incorporate a redundant compressor in the design and build of the chiller.

## The Solution

A recommendation was presented to Council that incorporated the following:

- A PowerPax condenserless chiller with three active compressors that would provide full capacity to the chilled water reticulation system with a third compressor that would automatically start if one of the active compressor s failed.
- This feature met Council's requirement for redundancy as it addressed their main issue of compressor failure.
- A Muller Dricon adiabatic condenser that provide the air cooled solution required by council but addressed other issues as well:
  - The adiabatic precooling pads provide a wetted filter medium clean the condenser air before it touches the aluminium fins. This allows the fin treatment to work effectively to minimise corrosion.
  - While water is used when needed, consumption is minimal when compared to a standard water cooled solution, and
  - Energy was addressed by the inherent efficiencies of the TurboCor compressors and the fact that an adiabatic condenser provides water cooled operating conditions.

The function of a DriCon is a balance between energy consumption and water consumption. If the cooling water is allowed to flow at a low ambient, higher efficiencies can be achieved from running at lower head pressure whereas less water usage can be achieved if the water flow starts at a higher ambient. In this case the set point to start the water flow was determined to be 29°C ensuring the plant would run at water cooled conditions with minimal water usage.

Council adopted the recommendation and the design process was commenced. PowerPax applied the skill of their design team and developed a very workable solution that provided the redundancy Council required and the ModBus protocol high level interface allowed a seamless interface with the existing digital controls. The interface also effected the change to the redundant compressor when an active machine failed and sequenced a lead lag routine.

The project was tendered to a select panel of contracting firms in accord with Council's procurement policies and awarded to Airmaster Australia. However, by this stage Council had introduced another covenant item. The installation was to be carried out with Council in occupancy and without loss of conditions in the space.

A method of incorporating a temporary chiller was devised for the construction period and the installations proceed.

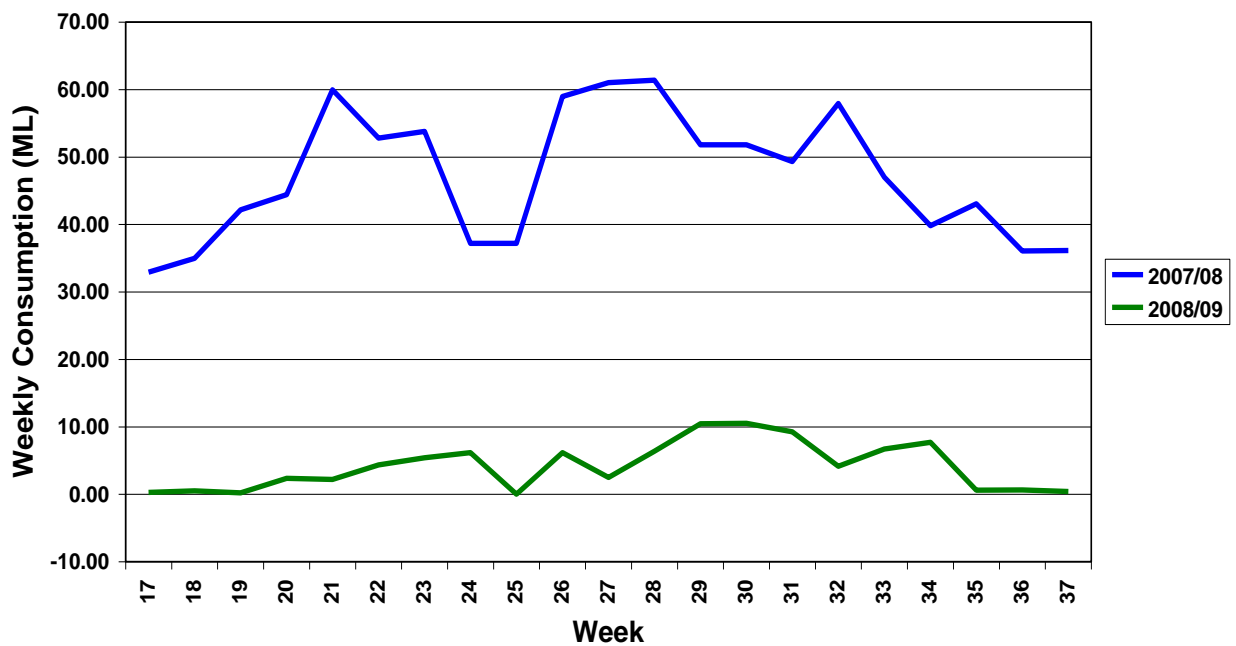
## The Outcome

The new plant was installed over a period of two weeks with the temporary plant supporting the building. Council staff would have been unaware of the work except for the obvious presence of the workforce and the temporary plant.

Water consumption was the key issue for Council in this exercise as they had identified the cooling towers as the main water consumer and they were faced with a requirement of reducing their total consumption by 25% under the terms of their WEMP. The WEMP also mandated the metering of water supplied to air conditioning cooling plant and the bleed drain from cooling towers. The meters had been fitted to the original cooling towers a year before so there were records to indicate the water consumed for that period. It was a requirement of the WEMP to record water consumption as submit the results annually.

The new plant was commissioned in July 2008 and run successfully for the ensuing year. The following chart shows the impact of the new installation over the water consumption of the previous year.

**Water Consumption July to July  
2007/08 vs 2008/09**



Analysis of the chart and the data used to compile it reveals the following statistics.

Year 2007/2008 Consumption (original plant)	1,800ML
Year 2008/2009 Consumption (new plant)	88ML
Water saving	1,712ML

The water saving represents 95% of the consumption of the original plant in 2007/2008, and Council equates to the savings to supporting one City resident for 33 year under gazetted water restriction in force at the time.

Unfortunately energy was not metered so the result cannot be assessed.

The water performance of the of the installation vindicated Council's decision to adopt the innovative solution.

**September 2009**