SIX GREEN STARS IN A WARM TROPICAL CLIMATE - WILLIAM MCCORMACK PLACE PHASE 2 - CASE STUDY

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ABSTRACT

The William McCormack Place Stage 2 (WMP2) building is located in Cairns, North Queensland. The climate is classified as tropical equatorial, hot and humid. It is a government tenanted office building comprising 9 levels and just over 9500 m^2 net lettable area (NLA).

This paper summarises the key strategies employed in the HVAC systems and discusses the thermal and CFD modelling involved during the design stage to optimise the building's environmental performance. This building's performance shows that even in a hot tropical environment, decisions made at the earliest stages of a building design, backed by sound building modelling and simulation technology can have a significant impact on the indoor environment quality, energy and water consumption.

INTRODUCTION

Green Star is a well-recognised and respected environmental rating tool for commercial buildings in Australia, developed and administered by the Green Building Coucil of Australia (GBCA), a not-for-profit organisation which is a chapter of the World Green Building Council. GBCA offers a suite of attribute-based rating tools that benchmark the potential performance of a design in a number of sustainability categories. Credits (points) are scored for design attributes in each category, multipled by appropriate environmental weighing factors and totalled to obtain a single score for rating purposes.

The WMP2 office building complements and shares some of its services with its companion building, William McCormack Place Stage 1. The Stage 1 building was the first commercial building in Australia to achieve a measured 5 Star ABGR (Australian Building Greenhouse Rating) rating in 2003, this is now known as NABERS (National Australian Built Environment Rating System).

The 9638 m^2 NLA Stage 2 building is nominally twice the floor area of Stage 1 and accommodates Queensland State departments and agencies. The building was fully tenanted as of October 2010.

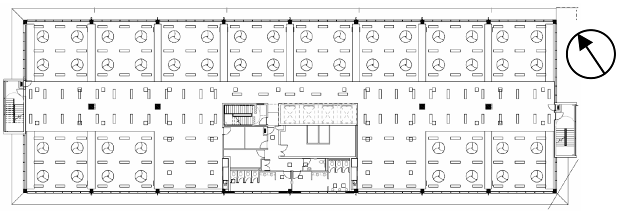

Figure 1 WMP2 typical plan layout

Features of the building responsible for the achievement of the rating include:

- Length to width ratio of 3:1 with long sides facing north and south.
- West end has minimal windows.
- East and west ends incorporate external stairs, thus eliminating the need for stairwell pressurization and providing a solid façade to limit solar penetration.
- All facades have external shading systems designed to provide a total of 96% shading in accordance with the Green Star assessment method.
- Office windows are double glazed, mainly for acoustic control, but also to reduce cooling loads.
- Combination of air conditioning and ceiling fans allow a higher air conditioning temperature set point to provide an effective comfort condition in open plan spaces.
- 410 m^2 of roof mounted photovoltaic panels providing 64 kW of power.
- Whole of building envelope pressure tested to 50 Pa with an allowable maximum leakage loss of 1.4 L/s/m^2 of external envelope area. The tested leakage rate was 1.35 L/s/m^2.
- High comfort suspended direct/indirect lighting, with a novel daylight harvesting system which measures ceiling exitance as a proxy for workplane illuminance.
- Decoupled pre conditioning outside air (PCOA) system employing total enthalpy rotary heat recovery exchanger, dehumidification cooling coil and electrostatic spill air filters.
- Dedicated meeting rooms supply air system served directly from the PCOA.
- Ventilation rates at 150% of statutory requirements, the standard stipulates 10 l/s/person minimum

outdoor airflow rate based on Australian Standard A.S. 1668.2 1991.

• Increased ventilation rates when high CO_2 levels are measured on a particular floor.

• Variable speed drives to all air handling fans and secondary chilled water pumps.

• 1.5 ML stratified chilled water thermal energy storage (TES) tank, sized to meet the requirements of Stage 1 and Stage 2 buildings.

• 1,100 kW air cooled turbine chilled water generator which, in combination with the TES tank provides sufficient capacity to serve a total maximum instantaneous building cooling load of 1,550 kW.

• Integration of the chilled water system with the Stage 1 building to provide a redundancy facility for the single chiller installed within the Stage 2 building.

• Specially developed flow control solutions for water fixtures which exceeded water efficiency labelling schemes.

• Use of air cooled chiller system allowing minimal water usage and achievement of maximum Green Star points under the water category.

• Capture and re-use of the condensate from the PCOA unit. Estimated at 170 kL/y.

• Natural ventilation to the entire covered car parking areas.

THERMAL SIMULATION

The Stage 2 thermal building model was created and developed using the IES Virtual Environment software (IES, 2008), specifically the VE-Pro modules Apache-Sim and Apache-HVAC for thermal and system simulation.

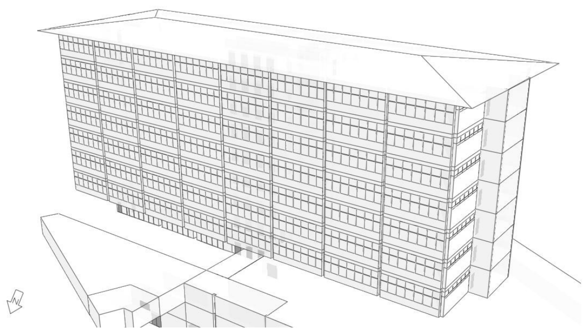

Figure 2 IES<VE> Thermal Model

In the Green Star Office Design V2 protocol, the energy credit is known as ENE-2 Energy Improvement which allows up to 15 credits based on the greenhouse performance of the rated building. An extra two points are available if the carpark energies are included in the NABERS assessement with one carpark space or greater available per 100 m^2 NLA (net lettable area).

ENE-1 is the conditional requirement of obtaining a minimum rating of 4 stars under the NABERS scheme, previously known as the ABGR rating scheme. These credits count for about 23% of a 6 star rating (75 point requirement), which is a considerably large measure of the overall holistic performance and important to maximise its potential to score well in Green Star.

At the time of analysis there were two methods to calculate the predicted greenhouse emissions. The first is to use the Green Star Energy Calculator. This was a pilot at the time, but appears to have been discontinued by the GBCA. The other method is to use the NABERS rating scheme.

The Office Design v2 Green Star energy credit methodology uses the NABERS (ABGR) base building modelling assumptions as its basis of calculation. This involves creating a single thermal model representation of the building with pre-defined default profiles for occupant gains, equipment and lighting and applied default occupant densities and plug loads. The lighting and plug loads are included in the base building model to account for impact on the HVAC system energy consumptions, but not directly aggregated in the electricity consumption figures, since these are tenancy consumptions not base building.

A local Australian TRY (Test Reference Year) weather file was used. The requirement simply lists the HVAC system model to be a ‘good’ representation of the system being installed as well as modelling the efficiency curves of major plant items. These non-explicit definitions for plant modelling can leave the door open to many poor plant representations and unrealistic building performance results.

For the WMP2 building located in Cairns the following associated energy density metric according to the NABERS methodology (v5.5) at the time was as follows:

Table 1 Cairns base building NABERS star ratings

Nabers Rating	**Maximum Normalised Emissions (kgCO2/m2/year)**
4 Star	96
4.5 Star	86
5 Star	76
5 Star +20% improvement	61
5 Star +40% improvement	46
5 Star +60% improvement	30

Cairns is located in far north Queensland which is on the Northeast coast of Australia at a latitidue of 16.9°S. Cairns has a Tropical climate, with generally hot and humid Summers and milder dryer Winters. The annual mean daily temperature is approximately 23.5°C. The tropics has fairly uniform temperatures throughout the year. Typical daytime min/max temperature ranges in Cairns are 23C/31C in mid-Summer and 18C/26C in mid-Winter.

The prevailing winds are East to Southeasterly with strongest winds (cyclones excluded) usually occuring during April and August. During the summer months, North to Northeasterly sea breezes dominate the winds along the coast.

The HVAC systems model in the software represents the actual VAV system and control design with integrated PCOA unit. This has been modelled using the Apache-HVAC module of the IES, 2008 dynamic thermal software program with simulation time steps of two minutes. A typical proportional controls sequencing strategy for heating/cooling and supply air temperature reset according to zone demand is shown below. The simulation

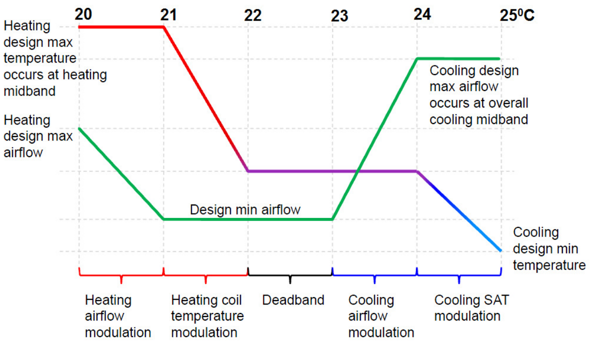

Figure 3 VAV Control Strategy

The central chilled water system comprises an air cooled turbine chiller of 1,100 kW capacity, primary and secondary chilled water pumps, backpressure control valve to service chilled water plant above the static head of the TES tank, distribution piping and controls valves etc and automatic refrigerant recovery system.

Maximum Green Star points are targeted through the adoption of a central chilled water system employing air cooled chillers thus eliminating water usage of cooling towers (WAT-4 cooling tower water consumption) and maximum demand reduction through the use of a stratified chilled water thermal energy storage (TES) tank.

The chiller operates only at night time, typically 9:30 pm to 6:30 am, to service the chilled water TES tank. The chiller start time is determined from an algorithm based on the amount of time required to fully charge the TES tank by 6:30 am the next day.

During the wet season (Nov to April) night time ambient dry bulb temperatures are usually around 24°C or lower after about 9:00 pm. This allows the air cooled chiller to operate at EER's comparable with water cooled chillers operating at typical daytime dry bulb temperatures of 30 - 33°C and 27°C wet bulb temperature. At 24°C the input power (kWe) to output cooling (kWt) ratio of the turbine chiller has an advertised rating of 0.22 at 100% load including the condenser fans.

A secondary benefit of nighttime chiller operation is that the standby generator need only be sized for the worst electrical loading of either the daytime building load or nighttime chiller load.

The single most important advantage of the TES system is the ability to "load shift" the power consumption for the production of chilled water from the typical daytime instantaneous cooling demands of the buildings to nighttime.

The obvious outcome of this action significantly reduces the maximum electrical demand registered by the power provider by about 40%, being the typical power load of the chiller group(s) contribution to a normal daytime building power profile.

An additional advantage is that there is no condenser water pump and its associated parasitic load. It should be noted that when used on a TES system the chiller operates at full load unless it is deliberately load limited from within its control features. The WMP2 chiller has nominally 10% redundancy capacity, accordingly it is load limited to 90%, and thus the effective EER will be better than noted above. Observations to date show it is closer to 0.205 and will be closely monitored over the summer wet season months.

Figure 4 WMP2 TES Tank

The TES tank is designed to service the entire 24hr cooling requirements of the new Stage 2 building and the existing Stage 1 building. The TES tank water volume is 1,500,000 litres having an effective capacity of 1,350,000 litres which equates to a daily cooling capacity of nominally 15,700 kWh (thermal) at a temperature differential of 10°C. The modelled maximum was 13,500 kWh.

TES effectiveness takes into account the loss of water volume taken by the upper and lower diffusers coverage and thermocline depth. The thermocline is the depth of water between the chilled (6°C) and warm (16°C) water conditions.

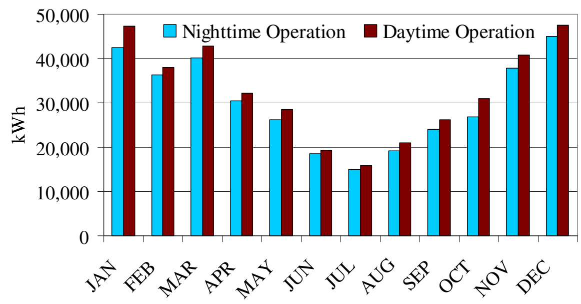

Figure 5 Comparison between monthly daytime and nighttime air-cooled chillers consumptions.

The daytime load is the worst condition and results in an emergency generator size of approximately 60% of that required for a conventional mechanical services design.

The stratified chilled water thermal energy storage (TES) tank could not be modelled directly in the software so a simple energy postprocessing spreadsheet was utilised, in order to capture the tank standing and distribution losses, chiller start time optimisation, capacity top up in the evening/nighttime and system draw down during the daytime. This proved to be a relatively simple exercise with an air cooled chiller.

Many simulation scenarios have been run for comparison purposes and analysing the performance of the building energy and comfort. One of the final default scenarios below is shown with a breakdown of the basebuilding and tenant energy consumptions. The actual predicted annual basebuilding consumption from the model is as follows:

Normalised energy	656,304 kWh
Normalised emissions	16 $kgCO_2/m^2$ per annum
Raw emissions	669,430 $kgCO_2$ per annum

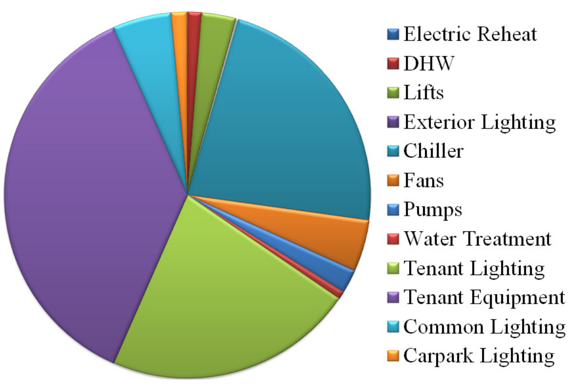

Figure 6 Base building and tenancy energy

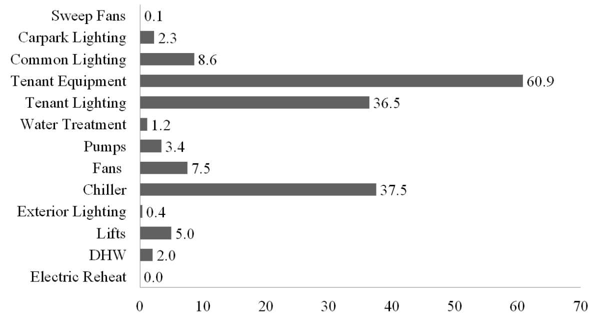

Figure 7 Base building and tenancy kWh/m²/year

This performance of 16 $kgCO_2/m^2$ per annum relates to a score under NABERS of 5 Star + 79% improvement, which is 19% better performance than the maximum rated score under Green Star office design (Version 2) of 5 Star + 60% improvement. Thus the WMP2 project achieves the full 15 credits available for the energy improvement ENE-2 category. This is further increased to 17 credits in total for the extra two credits for the carpark energy allowances in the model with at least one carpark space per 100m^2 of the NLA in the building.

CEILING FANS AND COMFORT

The Green Star thermal comfort credit is called IEQ-9; this is part of the indoor environment quality section of the protocol. This aspect uses PMV (predicted mean vote) in accordance with ISO 7730 with predefined metabolic rates, clothing levels and local air speeds. Up to two points are available.

The use of ceiling fans (and in particular single-bladed ceiling fans with a varying air velocity) provides the above energy improvement while providing superior thermal comfort to that claimed in the IEQ-9 submission.

High efficiency, low noise single-bladed aerofoil ceiling fans are provided throughout high-ceiling / open-plan zones of each tenancy from Levels 1 to 8. The ceiling fans provide improved air mixing which allow the elimination of separately ducted perimeter and core supply air zones and reduce the amount of ductwork needed on each floor.

The ceiling fans also provide some cooling effect in lieu of air conditioning. As a result, the air conditioning temperature set-point is raised from the more usual 23.5°C to nominally 25.5°C whilst providing equivalent comfort conditions for occupants wearing climate-appropriate dress.

The higher temperature set-point provides an energy benefit due to reduced conductive heat gains on the building fabric and reduced cooling demand.

Green Star Office Design credit IEQ-9 specifies particular assumptions of clothing and air velocity which preclude the benefits of 'tropical appropriate' dress and ceiling fans respectively.

Some thermal comfort modelling comparisons have been demonstrated using alternative input assumptions more appropriate to Cairns conditions when compared to the Green Star basic defaults:

• Based on local experience, a clothing value of CLO (warm) = 0.5 is adopted (i.e. halfway between shorts and t-shirt; and trousers and shirt);

• Based on the results of the CFD modelling (detailed later in this paper) and the paper *Aynsley, 2009* (a recognized expert in the field of thermal comfort) an air velocity of 0.3 m/s is adopted for the zones with ceiling fans. This is an average value for the CFD modelled domain obtained by running an area averaged report on velocity magnitude at working plane height.

• Based on PMV calculations and experience, a temperature set-point of 25.5°C in the ceiling fan zones (and 23.5°C in non-ceiling-fan zones) has been utilised. In general IEQ-9 'Thermal Comfort' specifies a thermal comfort (PMV) range of +/- 0.5 which equates to a predicted 90% of occupants satisfied with general comfort conditions (ISO7730 Category B). To demonstrate superior comfort, the criteria may be tightened to +/- 0.2 which equates to 94% of occupants satisfied with general comfort conditions (ISO7730 Category A).

On this basis, the IEQ-9 submission claims that 90% of occupants on levels 2 – 8 are satisfied for 99.91% of working hours when calculated by the simulation model – thus by multiplication this is equivalent to 89.9% of occupants being satisfied all of the time; or conversely a 10.1% dissatisfaction rate.

With the benefit of the ceiling fans, the simulation model's performance has shown that 94% of occupants on levels 2 – 8 are satisfied for 97.67% of working hours – a satisfaction rate of 93.8%; or 6.2% dissatisfaction.

Thereby it is demonstrated that the use of ceiling fans reduces the dissatisfaction rate by 38.6%. This reduced dissatisfaction, as well as being beneficial in itself (as per IEQ-9 guidance) should also translate into reduced occupant complaints and therefore a reduced tendency to 'tinker' with a HVAC system which is in fact operating as designed. This type of 'tinkering' is often a source of ongoing problems and reduced efficiency.

The following results summary demonstrates that for the typical levels 2-8 in the building, thermal comfort with ceiling fans is equivalent to the levels claimed in the IEQ-9 submission as shown below:

Table 2 Ceiling fans influence comparison

Scenario	**23.5°C without ceiling fans**	**23.5°C / 25.5°C with ceiling fans**	**Improvement**
Energy Usage (MWh/year)	727.8	656.3	10% reduction
Raw emissions (t CO_2 / year)	742.4	669.4	10% reduction
Nabers Emissions ($kgCO_2/m^2/year$)	24	16	33% reduction
Nabers Star Rating	5 Star + 68%	5 Star + 79%	11 percentage points

The simulations above show an approximate 9% reduction in chiller work which will facilitate a later start time for the chiller each evening (TES charging) for the modest energy consumption addition of the sweep fans. This allows the chiller to operate in the latest / coolest possible conditions at night time further reducing energy use below that predicted above; and moving demand deeper into the off-peak period.

CFD SIMULATION

The two Office Design V2 Green Star IEQ-2 ACE (air change effectiveness) credits available have been awarded to the WMP2 project. This credit uses computational fluid dynamics (CFD) to assess working plane air change effectiveness and ultimately the distribution performance of the mechanical ventilation system in the building. It aims to encourage and recognise systems that provide for the effective delivery of clean air through reduced mixing with indoor pollutants in order to promote a healthy indoor environment.

The CFD model is developed to help prove the case that for 90% of the NLA in the building, the ventilation systems are designed to achieve an ACE of > 0.95 when measured in accordance with ASHRAE F25-1997. ACE is to be measured in the breathing zone (nominally 1m from the finished floor level).

Air change effectiveness (ACE) is a description of an air distribution system's ability to deliver ventilation air to a building, the common definition of ACE is the ratio of a nominal time constant to a mean age of air. The nominal time constant is calculated as a ratio of the domain volume (m^3) to the supply air volume to that domain (m^3/s). The mean age of air is calcuated by the CFD code by introducing a passive scalar to the model, all inlets are set to zero seconds age.

In this case the analysis of the general levels 2-8 VAV distribution system with and without ceiling sweep fans has been tested with the commercial code CCM+ from CD-Adapco, 2008. A single level analysed by CFD will suffice due to the similar nature of all levels in the building.

The 3D Reynolds Averaged Navier-Stokes (RANS) steady-state CFD simulations were undertaken with boundary conditions taken from the thermal model at required states. The default k-ε turbulence model and standard wall functions have been used in these models. Field functions have been defined in CCM+ to model the mean age of air and air change effectiveness with a passive scaler modelling the mean age of air specifically and local ACE calculated from this in a field function.

A critical element of the CFD model is to adequately describe the performance of the supply and return air diffusers with the VAV system at minimum turndown ratios. Typically this introduces a difficulty in estimating and defining part load behaviour of the diffusers, in this case due to system configuration and control - the VAV turndown ratios for the WMP2 building are rarely lower than 80% so this has been modelled accordingly. Linear slot diffusers as well as square ceiling diffusers, two/three and four way blow are part of this model. Simple disc shaped models have been used for the ceiling fans. The fan model in the CFD simulation is based on the simple fan momentum source in the CFD software, this is based on importing a table of volume flow (m3/s) vs. pressure developed (Pa) data i.e. the fan curve, which has been obtained from the manufacturers data on the actual sweep fan proposed. A moving mesh model would be preferable but beyond the scope of this study.

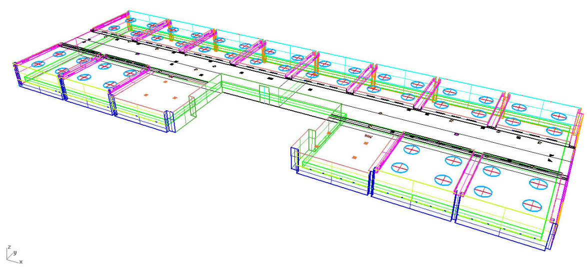

Figure 8 Typical level CFD Domain

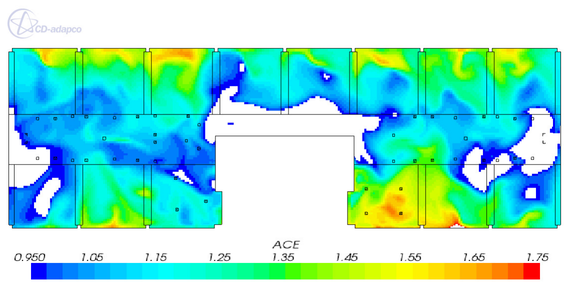

Figure 9 ACE Plot without sweep fans

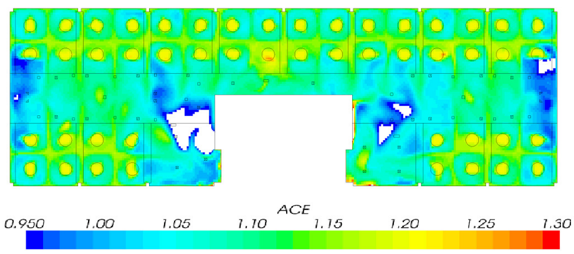

Figure 10 ACE Plot with sweep fans at 80rpm

These ACE plots show the variation in air change effectiveness over the typical floor plate. The lower limit in the results scale display have a clipping point set to 0.95. The white regions on the image show regions on the working plane where the ACE < 0.95 and doesn't meet the criteria, (the core in the centre of the building is not modelled as not contained within the NLA). It is important to calculate the area that doesn't comply in order to test for the constraint of 90% NLA showing ACE > 0.95, this can be calculated by running a simple report in the software.

Table 3 Ceiling fans impact on ACE

Scenario	**Typical level area where ACE >0.95**	**% Typical level area where ACE >0.95**
Without ceiling fans	1,016m2	78.30%
With ceiling fans @ 80rpm	1,270m2	97.80%
Improvement	25% increase	

CONCLUSION

A six star Green Star office design (version 2) rating has been awarded; this is equivalent to a LEED Platinum rating. The energy and environmental modelling has assisted the design team and permitted the building to achieve maximum scores under water and energy categories as well as strong performance in the indoor environment quality category.

Innovations such as a stratified chilled water thermal energy storage (TES) vessel for off-peak night time cooling generation, use of computational fluid dynamics modelling of sweep fans has shown improvements to comfort and air change effectiveness, complex shading and daylight harvesting systems have been modelled and performance assessed.

The building's energy savings initiatives outlined are expected to deliver in the order of AU$450,000 per year in cost savings compared to a median (2.5 star) building. The design is also predicted to deliver an impressive suite of environmental outcomes as follows:

• 60% (1,000 tonnes/y) reduction in CO2 emissions, compared to a median (2.5 Star) building, including:

- 110 MWh/year generation from 64kW Solar PV;
- 25% reduction in chilled water energy needs due to PCOA heat recovery exchanger;
- 20% reduction in cooling requirements due to ceiling fans;
- 40% reduction in whole-building demand on the electricity grid;
- 90% of the chiller work lies within the network off-peak period;

• 50% increase in fresh air to office areas; with significant further reduction in indoor air pollution;

• 6 Star Green Star Office Design v2 rating;

The completion of William McCormack Place Stage 2 in July 2010 has raised the bar for office accommodation in Cairns. It has demonstrated that world leadership in sustainable design is possible in the Tropics and was due to a large part by the knowledge of local engineers experienced in the vagaries of the tropics. More recently the WMP2 design team has won the 2011 Queensland Premier's ClimateSmart Award for best built environment and the occupied building's performance is tracking very well with the building simulation modelling figures, allowing confidence of gaining a top NABERS rating as well.

The engineering team brought intelligent and responsive design to the table and exceeded client expectations. The success of the project has placed Cairns on the sustainability map on a national and international level.

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