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The latest demonstrated technical innovations in Sydney CBD tall building. Case Study

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Abstract

This paper outlines the approach in regenerating an aging city block into a new high performing skyscraper in the Sydney. The project incorporated some of the latest technical innovations in reducing carbon emissions, reducing water consumption and ultimately achieving a 6 Star Green Star commercial office development. The 50 Storey development accommodates 55,963m^2 of commercial office space. The building achieved a World Leadership 6 Star Green Star environmental rating through a number of technical innovations including a high performance curtain wall façade, a hybrid air conditioning system comprising of a combination of low temperature VAV with active perimeter chilled beams, tri-generation, low energy lighting system, and rainwater harvesting. The paper describes the technical innovations and resilient infrastructure that was installed that allowed the building to achieve the low carbon environmental performance. Performance monitoring undertaken demonstrates the building's actual performance. This presentation demonstrates that with a commitment from the developer, design team, and the builder, all future skyscrapers can achieve very high environmentally sustainable performance whilst still providing strong business cases

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: Technical innovations; Low carbon; green building; energy efficiency; 6 Star Green Star.

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1. Introduction

The tower at 161 Castlereagh Street is located in the retail precinct of the city's Central Business District (CBD). The building is situated in a prime location which is evident when an occupant commences to rise through the building. Once above the low level floors, the north east views of Sydney's magnificent harbour become apparent. And the building responds well to this view. The form of the structure is focused on the eastern harbour with a prominent north east façade designed to maximize daylight and views.

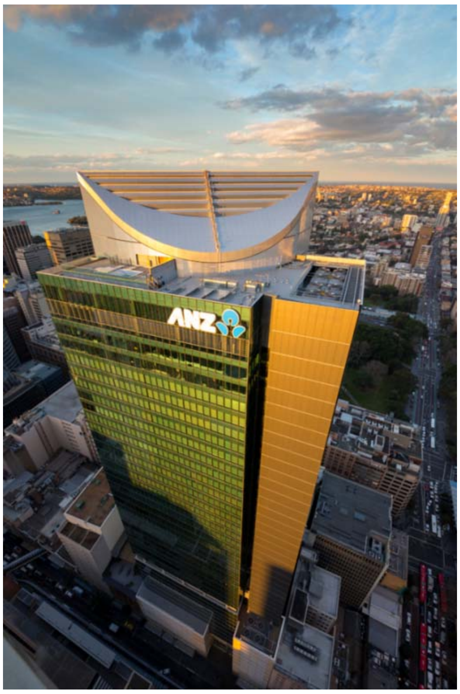

Fig.1. 161 Castlereagh Street Development

2. Design Evolution

The environmental targets of the design were set to achieve a 6 Star Green Star development with and a National Australian Built Environment Rating System (NABERS) energy target of 5 Stars.

The design team for the building was; architect Francis-Jones Morehen Thorp (FJMT); AECOM providing mechanical, electrical, communications, security, specialist lighting, sustainability, and building façade services; the structural engineer was Aurecon.

3. Architecture

The final arrangement of the building provides a 50 level, 44 storey premium grade office tower containing 55,963m^2 of office and 2,800m^2 of retail space. On level 43 and 44, there is a single residential luxury apartment which is owned by the site's previous owner. The building is divided into four rises consisting of low rise levels 5 to 14, midrise 16-25, high rise 26-33, and skyrise 34-42. Each rise is served by dedicated lifts. Major air handling plantrooms are located on levels 3, 12 and 45.

The lower levels of the building comprise:

- Basements 1: Loading area, service rooms and short term parking

- Basements 2, 3, & 4: Car parking & service rooms
- Pitt Street Level: Retail, lobby & vehicular access
- Castlereagh Street Level: Retail, lobby

The floor plates are arranged to take advantage of the spectacular views across eastern Sydney harbor towards the open ocean. FJMT achieved this by developing a triangular floorplate with the hypotenuse directed towards the harbor. The lift shaft, amenities, and services risers are located on the southern façade.

Fig. 2. North Easterly Views of Sydney Harbour from Level 43 Residential Apartment Level

A triangular shaped structural element is located centrally on the floor and provides internal fire stairs and additional services riser space. The floor plates are designed to maximize daylight and accordingly the majority of the occupied space is no more than 12.5 m from a glazed façade.

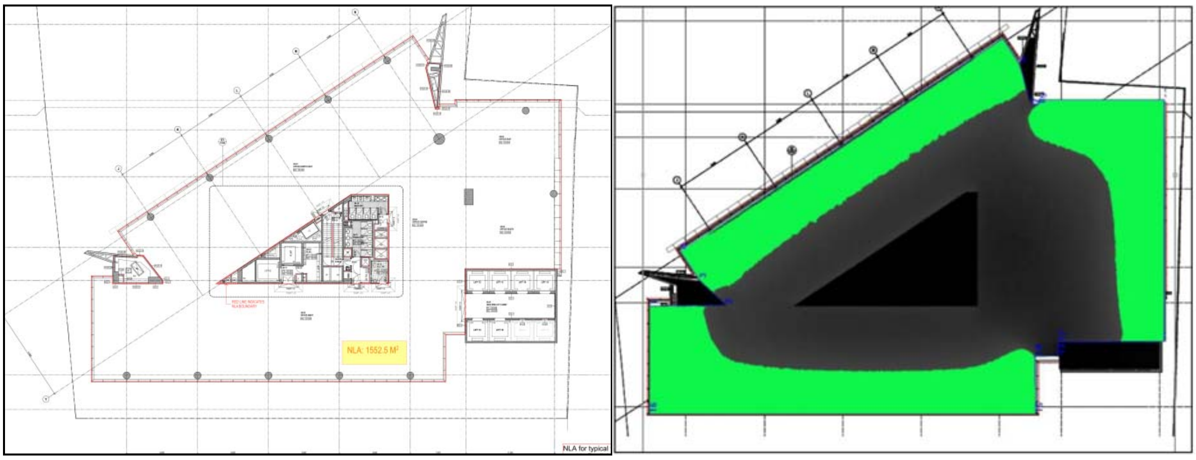

Fig.4. Highrise floor plan and daylight simulation results demonstrating 47.1% of area achieving > Daylight factor of 2.5

Designed to maximize daylight while minimizing heat gain in summer, the high performance façade consists of a curtain wall structure with full height glazing on the east, north east, north and western orientations

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The façade glazing performance is shown in table:

Table 1. Façade Glazing Performance

Location	Glass Type / Manufacturer	Visual Light Transmission	U-value (incl. Frame) (W/m2k)*	SHGC* (incl. frame)
NE facade	VNE 1-63 (Viracon) 6 / 12 Ar/ 10	62%	1.8	0.28
North & West elevations including the east and south reveals	VNE 19-63 (Viracon) 6 / 12 Ar/ 10	45%	1.7	0.22
South and east elevations	VNE 19-63 (Viracon) 6 / 12 Ar/ 10	45%	1.7	0.22
Recessed east and south elevation and recessed west elevation	VE 3-2M (Viracon) 6 / 12 Ar/ 10	35%	1.8	0.23
Podium Facade	VNE 19-63 (Viracon) 6 / 12 Ar/ 10	45%	1.7	0.22

***SHGC Solar Heat Gain Coefficient (Percentage of solar heat gain transmission through glass)**

Automatic internal blinds are provided on the northern and western perimeter zones. The control strategy of the blinds involves lowering when the incident solar radiation on glazing is higher than 400 W/m^2, and raising them when the incident solar radiation on the glazing is lower than 400 W/m^2.

4. Green Building Response

The Green Building response to the development was to achieve both a 6 Star Green Star rating and a 5 Star NABERS rating. The Green Star rating system for commercial buildings is based on achieving points under nine strategies [1]. To achieve a 6 Star rating a minimum of 75 points is required.

Table 2. Green Star Rating Strategy

Category	6 Star Strategy
Management	12
Indoor Environmental Quality	19
Energy	20
Transport	7
Water	11
Materials	12
Land Use & Ecology	4
Emissions	9
Innovation	12
Total Weighted Points	**77**
Target Points	75

Achieving a 5 Star Green Star rating is now relatively common for new CBD commercial offices. The additional points to achieve the World Leadership class above a 5 Star rating were by implementing additional design strategies in the categories of Energy, Water, Materials, and Land Use. Specifically these additional points were from:

- Energy: improving carbon emissions from 57 to 43 kgCO_2/m^2
- Water: improving water efficiency through increased rainwater harvesting potential
- Materials: implementation of an integrated fitout strategy for all new tenants, increasing the recycled content of concrete by an additional 20% to 40% of in-situ cement, plus the reduction of PVC by 60%.
- During the course of the demolition the site was found to be contaminated with traces of lead, Polycyclic Aromatic Hydrocarbons, and Petroleum Hydrocarbons which required remediation.

By far the most challenging strategy was to reduce the carbon emissions by a further 25%. This was mainly achieved through the implementation of low static air handling systems, perimeter chilled beams and the provision of a dedicated building tri-generation system.

The Sydney electricity supply is primarily generated from black coal powered thermal power stations and consequently the carbon content of the grid is high. The strategy to reduce carbon emissions substantially for this building was to minimize the consumption of mains electricity and where possible, replace it with gas fired equipment.

5. Heating Ventilation and Air Conditioning (HVAC)

The HVAC system consists of central chilled water and low temperature hot water systems serving variable volume air handling units and perimeter active chilled beams. The central base building chilled water HVAC system services the lobby, retail and all the office tenancies from Level 5 to Level 42. The low temperature Variable Air Volume (VAV) system supplies 10°C to the floors allowing a reduced airflow to the central zones, while the active chilled beams on the perimeter provides higher capacity cooling without the need to supply vast quantities of air to the facades when needed. The air handling systems are designed to overcome maximum total resistances of no more than 1000Pa at peak load which includes losses in the air handling units, and supply and return air paths. This reduced resistance has a consequence of larger air handling units and ductwork, however as fans constitutes one of the highest energy consuming items in the Sydney climate; it provides an effective energy reduction strategy.

Dedicated water cooled packaged air conditioning units serve areas that require air conditioning 24/7 such as Communications Rooms, Control Rooms, Security Room, Lift Motor Room etc. By serving these units on a dedicated condenser water circuit, the necessity to operate the main central chilled water plant inefficiently during out-of-hours periods is avoided.

There are five water cooled chillers serving the building. These consist of three high efficiency electric chillers and 2 absorption chillers. The electrical chillers include one low load chiller with a cooling capacity of 1000kWr and two high load chillers each with a cooling capacity of 2690kWr. The fourth and fifth chillers are each 319kW absorption chillers and are powered by the heat rejection of two gas fired generators.

Each chiller is served by a dedicated primary chilled water pump and primary condenser water pump. Open circuit cooling towers reject heat to atmosphere and control return water temperature to maximize the chiller efficiency at all times. Cooling towers are controlled to operate on depressed wet bulb driving the condenser water temperature down and increasing the efficiency of the chiller units.

Heating is provided by means of two gas fired boilers of 1,260 kW each with 85% efficiency.

The air conditioning system for commercial offices consists of six Air Handling Units (AHU) located in the level 43 plant room serving high rise floors and six AHUs located in the level 14 plant room serving low and midrise floors. Each of the air handling units serve a dedicated centre or a dedicated perimeter zone with the exception that east and south perimeter zones are served by one common AHU. The centre zones are served by low temperature VAV system, perimeter zones are served by Active Chilled Beam (ACB) systems. By each air handling unit serving a dedicated façade zone, the likelihood of any air handling unit having to serve differing solar loads at any one time is minimized thereby reducing any requirement to simultaneously heat and cool.

Each AHU is equipped with full outdoor air economy cycle operation and variable speed drives. Motorised outside air dampers on each AHU are linked to a Carbon Dioxide (CO_2) monitoring and control system through the Building Management System (BMS). The minimum position of the outside air dampers correspond to the minimum outside airflow rate of 11.25 L/s/person (50% improvement to Australian Standard AS1668.2-1991 requirements).

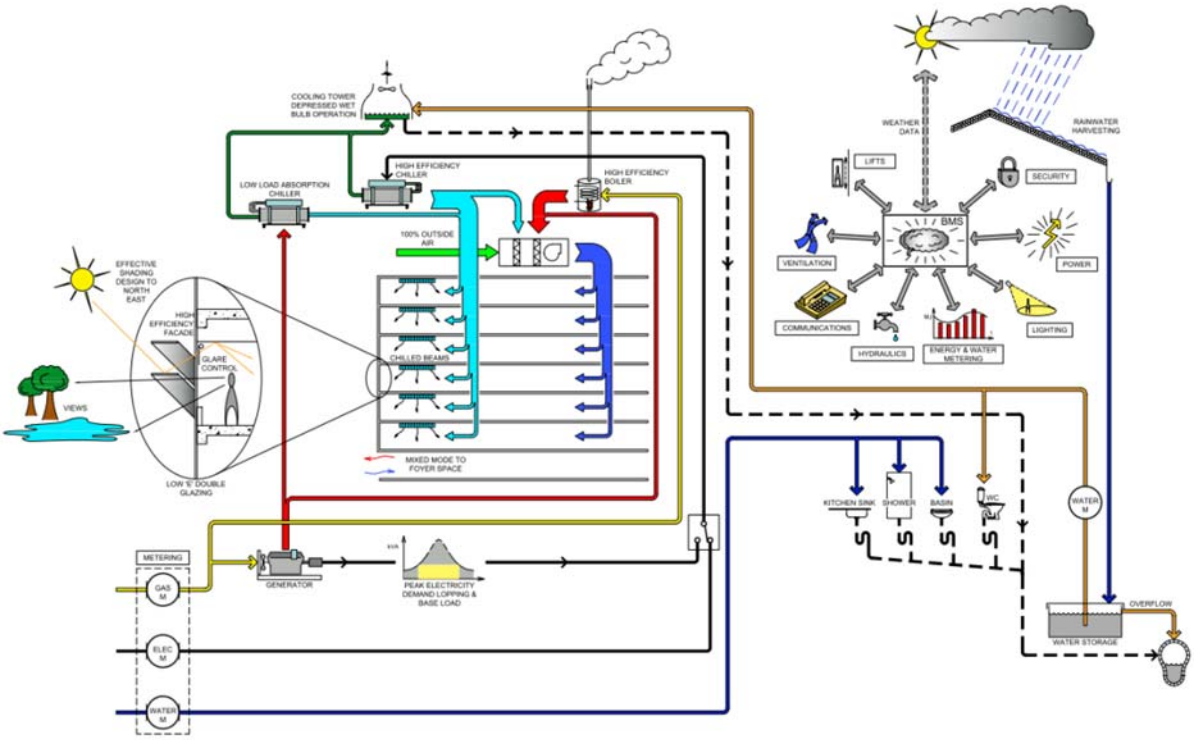

Fig. 5. Environmental initiatives Combined Services Diagrammatic

CO2 sensors are located in each return air duct on every office floor to monitor the CO2 concentration levels. A high select of all return air CO2 sensor readings is used to control the AHUs' minimum outside air dampers position.

All HVAC pumps and cooling tower fans are equipped with variable speed drives to respond to variations in load.

6. Energy Generation

The Tri-generation system uses gas to generate electricity, and then captures the excess heat for use as space heating and for powering the absorption chillers. A Tri-generation system can deliver energy at around 80 percent compared to approximately 30% percent for Grid electricity. In addition, the carbon emissions of the energy consumed is reduced by approximately on half due to the reduced carbon content of natural gas (0.18kgCO2/kWh) when compared with thermal coal powered power stations (0.86 kgCO2/kWh) [2].

The generators and absorption chillers were carefully sized for the buildings. The capital cost of these assets is high and so it makes good business sense for them to operate for extended periods of time during any given year. Tri-generation systems need to be sized to meet not only the thermal demand but also the continuous electrical demand of the base building. The continuous electrical demand of the base building was estimated to be in the order of only 800 kVA and when operating a tri-generator of this size it was found that it would not provide the necessary carbon emission reduction savings to achieve 43 kgCO2/m2 for the NABERS 5 Star + 40% requirement and gain the 15 points for a Green Star 6 Star rating.

Two smaller 525 kVA tri-generation units were selected. However as this selection of generators was larger than the minimum continuous electrical load, a control strategy was designed to sequence the generators so they could operate to include the load of some of the electrical chillers when they were also operating.

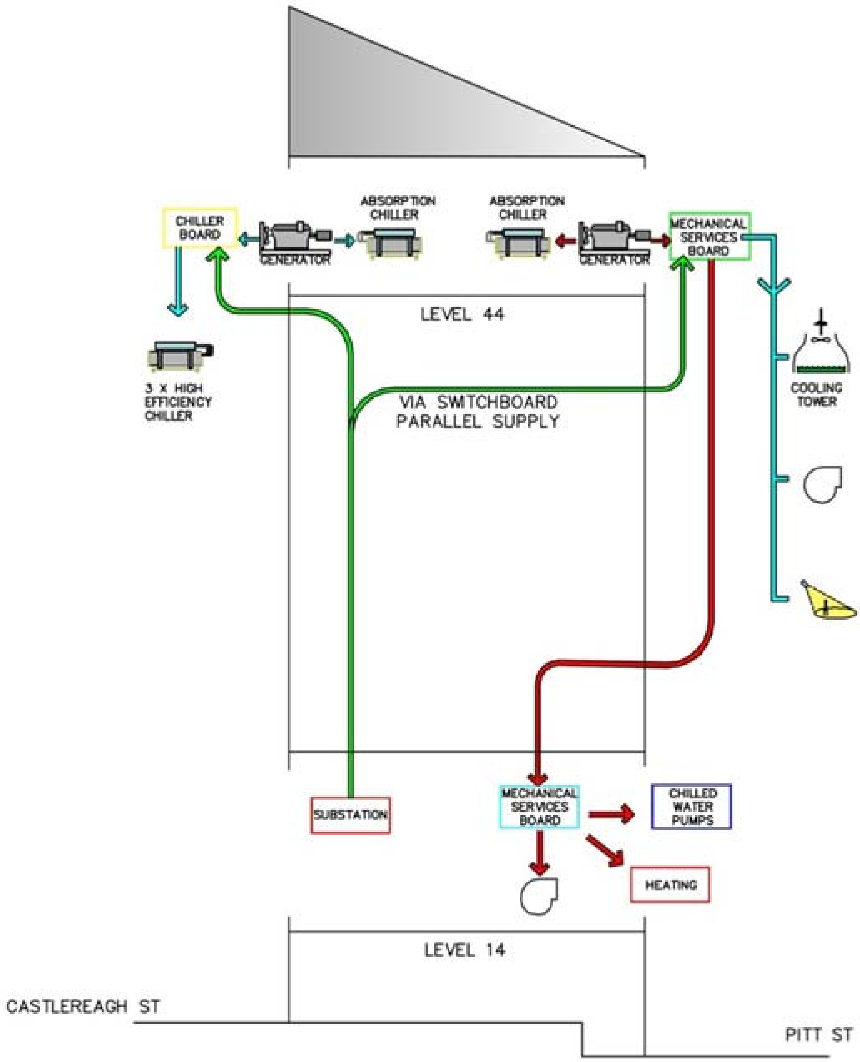

Fig. 6. Simplified Tri generation Arrangement

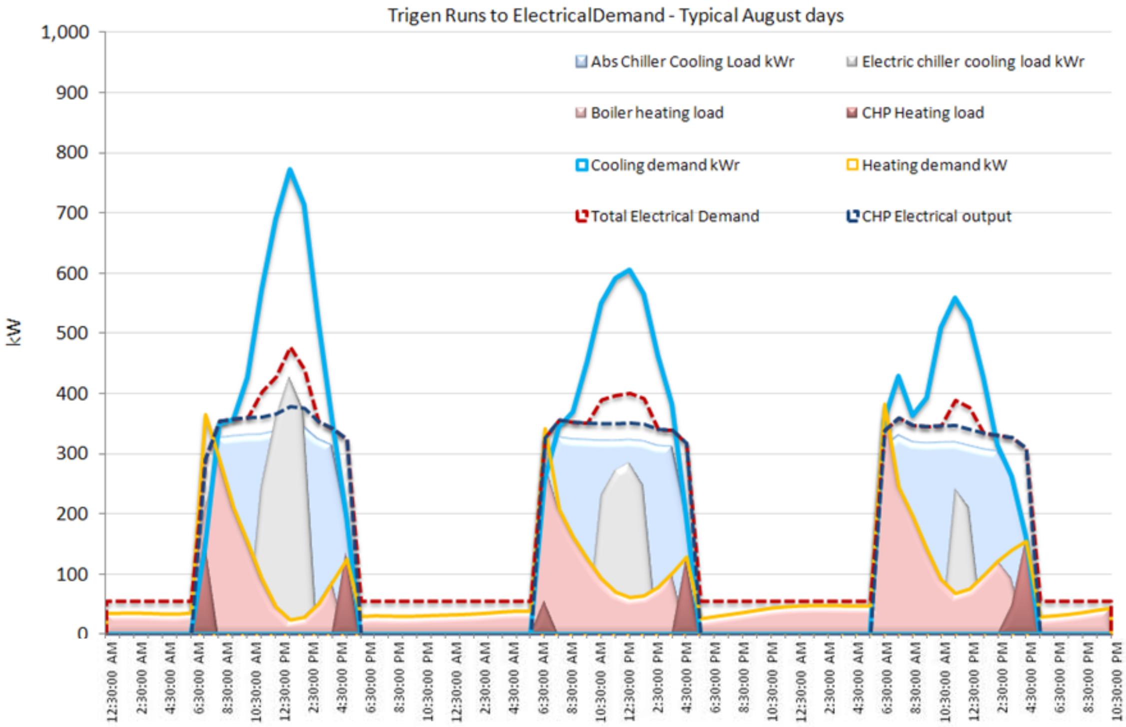

Fig. 7. Tri-generation operation – typical August (winter) days

7. Electrical Design

The mains utility power is obtained from the mains grid. Substations are located level 4 and 34 and supply low voltage power to their respective main switchboards

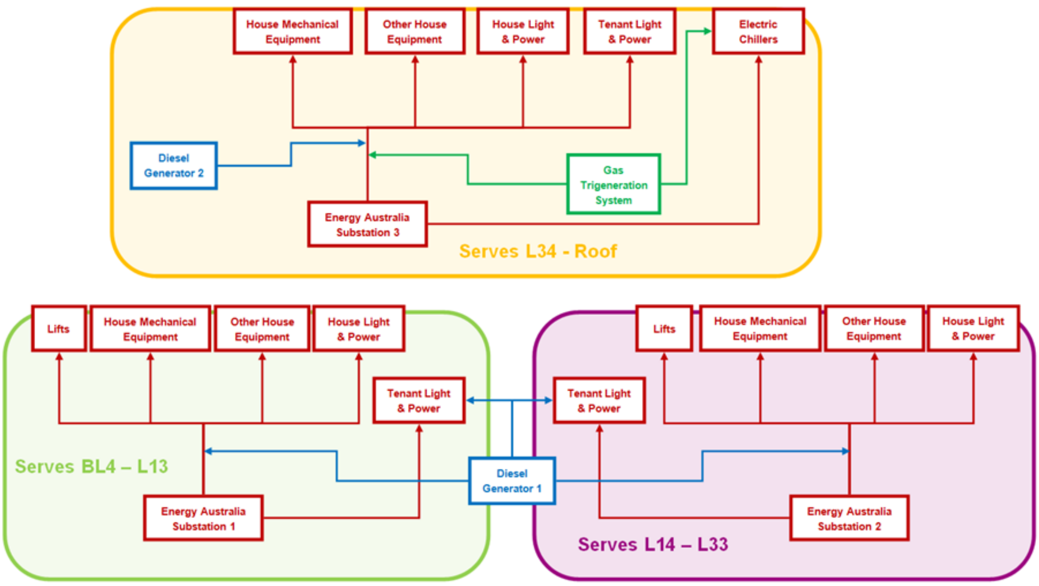

Fig. 8. Simplified Electrical Power Schematic

Sufficient energy sub-metering is provided for metering of substantive loads and tenancies to provide for a comprehensive energy metering system. All meters are connected to the BMS to provide an energy consumption monitoring system.

The BMS continually monitors and provides usable records of operational energy consumption based on the installations of the energy meters.

8. Lighting

The lighting power density across the tenant office floors is designed such that it does not exceed 2.0W/m2 per 100 lux. In addition it is designed to achieve a lighting level of no less than 320 lux and no more than 400 Lux at the working plane. To achieve these criteria and provide good uniformity, the lighting in the office areas generally consists of luminaires consisting of 1 x 35W T5 linear fluorescent with high frequency electronic ballasts.

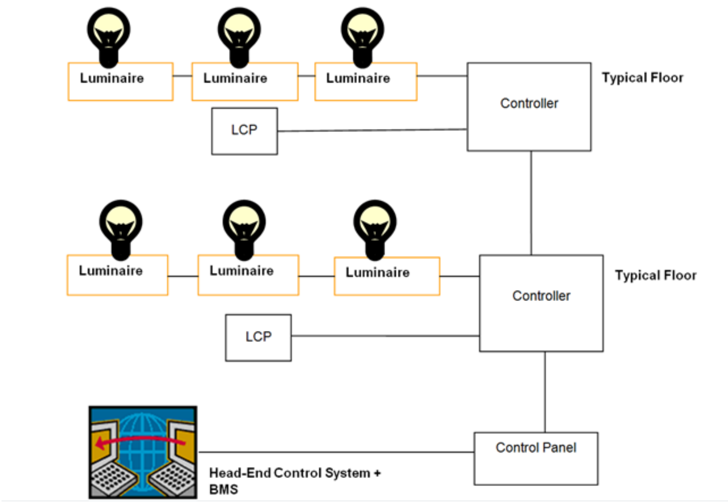

Fig. 9. Lighting Control Schematic

An intelligent lighting control system is installed for both the base building house and tenant commercial areas. The intelligent lighting control system communicates via a high level interface to the BMS.

The system incorporates manual override push buttons within the core areas to switch individual zones of lighting. All individual or enclosed spaces will have individual light switches. Individually switched lighting zones do not exceed 100m2 in area.

9. Building Energy Modelling

Early during the design stage of the project, the building was modelled using the IES<virtual environment> [3] software to determine the thermal and energy performance. The modelling simulated the building design including all HVAC, electrical, hydraulic and fire services within the building.

The energy modelling was undertaken and loads calculated on an hourly basis which provided the ability to simulate the hourly performance of the building and the proposed tri-generation system. This method of hourly simulation analysis was used to optimize the tri-generation design and ultimately resulted in the selection of the two 525kVA units installed and determine their control strategy.

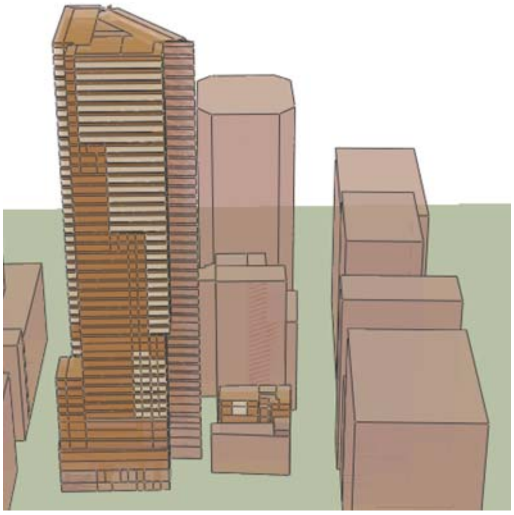

Fig. 10. Southern View of the geometry of the simulation model with adjacent building structures

The energy modelling analysis provided the following results:

Table 5. Energy Consumption Distribution

End Energy Use	Total Electricity Use (kWh/year)	Total Gas Use (MJ/year)	Total Oil Use (L/year)
Space Heating Boilers	0	1,080,518	0
Chillers	535,861	0	0
AHU Distribution Fans	653,738	0	0
Chilled + Hot Water Pumps	322,858	0	0
Cooling Tower Fans & Condenser Water Pumps	202,720	0	0
Auxiliary Ventilation Fans (carpark, exhaust)	164,773	0	0
Common Area Lighting (Incl. carpark, outdoor)	388,224	0	0
Lifts	279,815	0	0
Domestic Hot Water	0	443,227	0
Tenant Condenser Water Loop	122,807	0	0
Package Unit	62,400	0	0
Gas & Diesel Generator Testing & Auxiliary power	70,080	0	11,135
Hydraulic & Fire Pumps	127,379	0	0
Miscellaneous Non-Tenant Loads	55,963	0	0
Tri-generation Plant	-1,399,143	13,952,302	0
Total Energy Use	**1,587,474**	**15,476,047**	**11,135**

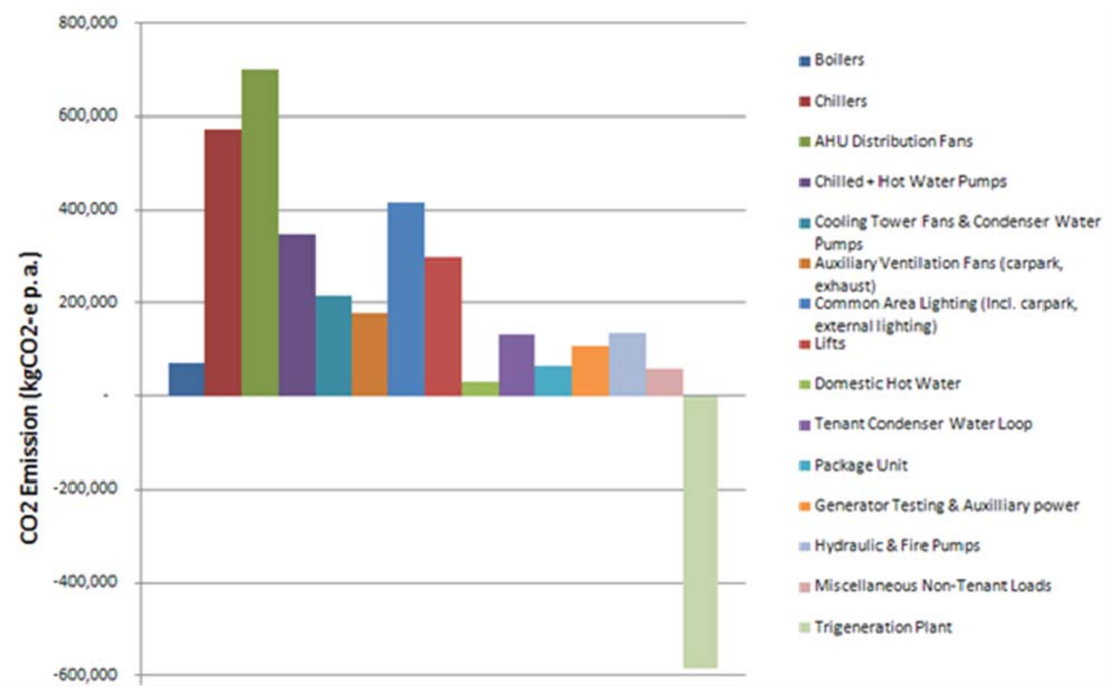

Fig. 11. CO2 Emission Distribution

Table 6 NABERS Performance data

Base Building	Value
Rated Floor Area (m^2)	55,963
Weekly hours of Use (hour)	50
Energy Intensity ($MJ/m^2.a$)	386
Benchmarking factor (Previously known as Normalised Emissions)	42
Benchmarking factor for 5 Star	71
NABERS base building star rating	5 Stars
% Improvement on NABERS Base Building Energy 5 Star	+ 40.8%

When compared to the average building performance of many existing buildings of only 2.5 Star (Equivalent benchmarking factor 150 kgCO2/m2.yr), the new 161 Castlereagh Street development provides a clear example of how building engineering has improved in the last decade.

10. Building Monitoring

As of June 2014, the building had been operating for just over 6 months and monthly monitoring of the building's energy was being compared with the simulation modelling.

The NABERS Energy rating scheme[2] utilizes the 'Benchmark Factor as the indicator for performance. This Benchmark Factor is analogous to a normalised benchmark greenhouse gas emissions (normalised against occupancy hours, after hours and office area). Benchmark emissions were used for this assessment but are reported without units due to the measure not being representative of carbon equivalent emissions.

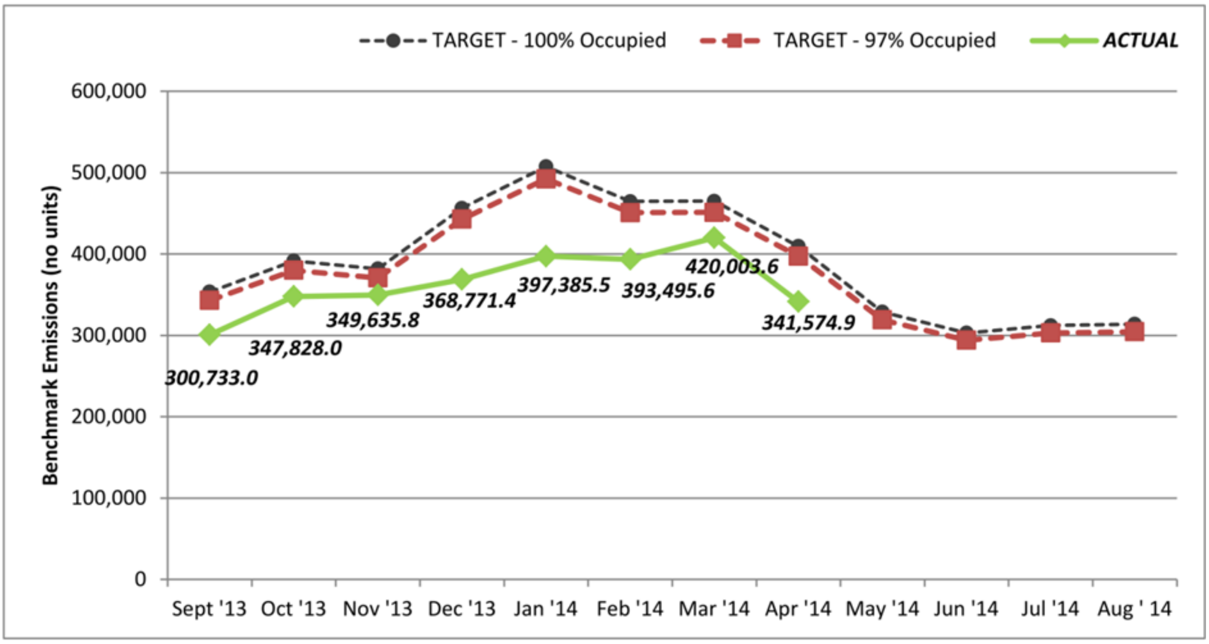

Fig. 12. Actual Monthly Benchmark Emissions vs Simulated NABERS Benchmark Emissions

The simulated energy consumption used to calculate the benchmark emissions were adjusted based on the actual building net let area, the after-hours air conditioning use and the percentage of building occupancy (vacancy). The adjustment was historically applied to the data for previous months of assessment.

The Fig. 12 demonstrates the monthly benchmark emissions calculated for the actual electricity and gas consumption, with the benchmark emissions calculated from the simulated NABERS energy consumption.

11. Conclusion

From an energy perspective alone, this high-rise building is currently on track to consume less than the modelled 219 MJ/m2 per annum (61kWh/m2 pa) when removing the impact of the tri-generation system. This compares with an average energy use of commercial buildings in Sydney of 566 MJ/m^2 pa in 1992 [4], and a Best Practice New Building target of 265 MJ/m^2 pa in 2001 [5]. It demonstrates that tall buildings can achieve high performance ratings and do not necessarily consume more energy on an area basis than low rise buildings.

Even though the installation of a tri-generation system increases the energy consumption significantly, the overall simulated target greenhouse gas consumption of the development has been significantly reduced by 11% from 47 kgCO2/m2 to 42 kgCO2/m2. This is mainly due to the efficiency of the Tri-generation process and the cleanliness of the fuel when compared to the Sydney electricity Grid.

The successful completion of the 161 Castlereagh street commercial development has demonstrated that there is a sound business case to design, build and operate a World Leadership high rise Green Building.

Acknowledgements

Grocon Constructions
FJMT Architects

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