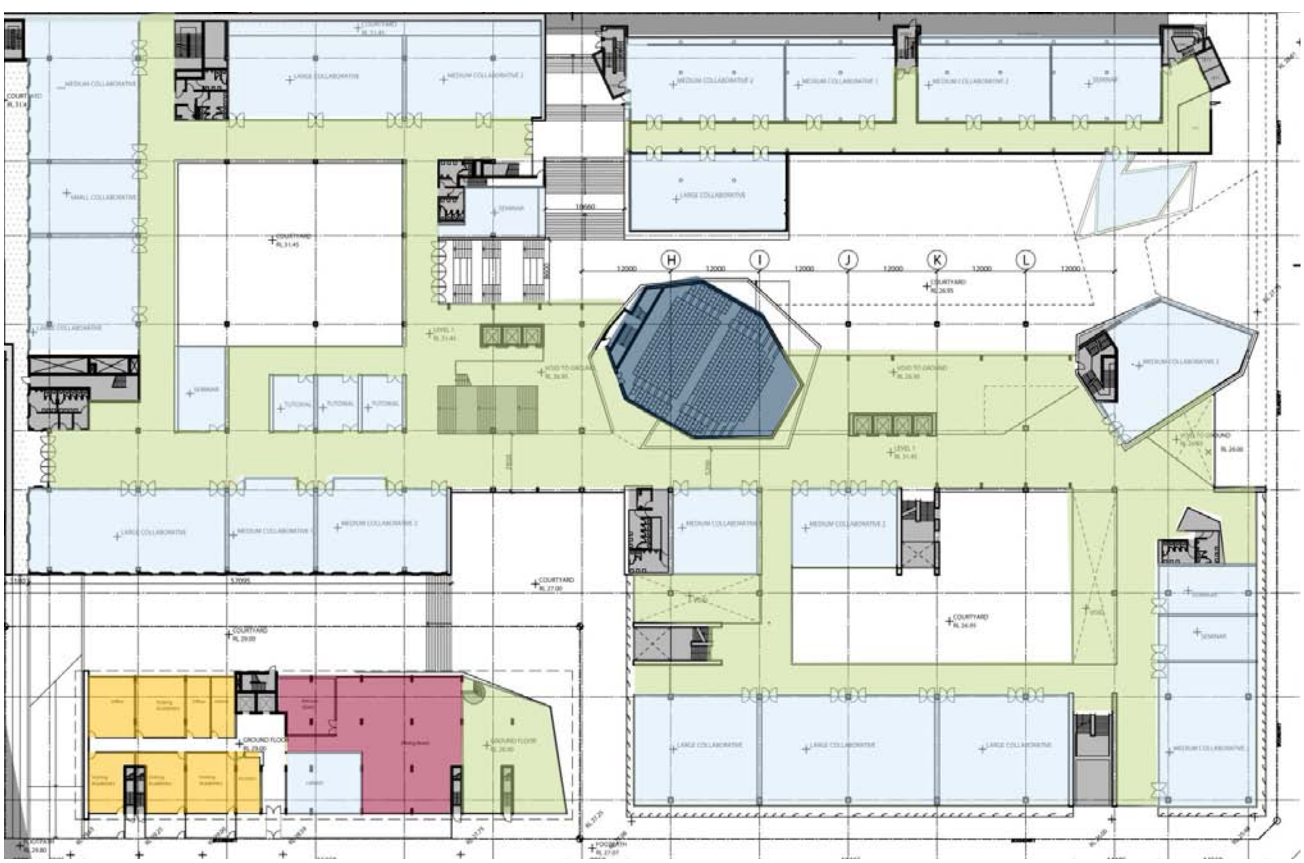
# Green Building Design - Final Report

## Abercrombie Precinct Redevelopment Project

March 8, 2011, Revision A



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*COVER IMAGE : Diagram issued during concept design to inform design development.*

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# 1 Executive Summary

The proposed design for the University's new Business and Economics School at the Abercrombie Precinct has been developed according to best-practice green building design principles.  This is supported by the proposed application of the Green Star Rating benchmark system for Education.  The development aims to achieve a minimum 5-Star rating, with an aspiration to achieve the top level 6-Star rating, subject to detailed design.

Forming part of the University's commitment to reducing greenhouse gas emissions and improving its environmental performance in terms of water, waste and energy strategies; the Abercrombie Redevelopment Project is intended to be an exemplar building. The design has been developed to take advantage of the best aspects of Sydney's climate to passively condition spaces wherever possible. A large informal learning area creates a thermal buffer zone in the building offering opportunities for semi-outdoor learning that uniquely position and differentiate Sydney's new Business and Economics School from its prestigious global competitors.

The building has been carefully designed to reduce greenhouse gas emissions and adapt to future climate change, by applying façade optimisation principles for daylight and shading according to mass and orientation.  Conditioning strategies offer a diverse range of thermal environments through both natural and mechanically ventilated spaces to reduce overall energy consumption.  As such, passive strategies for comfort are enhanced through active measures such as displacement ventilation; earth ducts offering decoupled thermal mass, and localised cool/hot spots integrating radiant panels in furniture.

Employing the ambitions of the Sustainable Sydney 2030 vision, the development also seeks to maximise opportunities for on-site energy supply. Two principle alternative strategies will be taken forward for detailed design: Ground Source Heat Pumps or a Co-Gen/Tri-Gen network to be linked with adjacent developments.  Ground Source Heat Pumps are a low carbon energy source that uses the thermal capacity of the ground as a source and sink of thermal energy that can also be supported by photovoltaic power. An alternative Co-Gen/Tri-Gen energy solution would offer a networked supply linking several building energy demands and offering an energy-efficient solution that would reduce overall greenhouse gas emissions.

Based on benchmark and best practice performance data, it is anticipated that the building will reduce its greenhouse gas emissions by 40-49 % compared to a standard practice benchmark. This could result in annual emissions of between approximately 800,000 to 940,000 kg/$CO_{2\text{-}e}$/yr.  This is a significant first step in a process that will involve driving down the carbon footprint of the business school, through detailed design, construction and occupation.  The School will be competing with international business schools, currently introducing carbon-management MBA courses, and university rankings based on carbon footprints.

Sustainable design goes further than reducing greenhouse gas emissions.  It concerns an effective use of resources and aims to ensure these are not squandered.  As a clear indicator of its best in class performance, the Abercrombie development is currently targeting potable water consumption of 0.22 litres /day/$m^2$.  This is equivalent to 4 out of 5 of the available water credits in Wat-1 of Green Star Education v1 Tool, recognising best practice.  This will be achieved through a combination of high-efficiency fixtures and fittings, stormwater management, rainwater harvesting, greywater recycling and non-potable water use for irrigation.

This report presents the overall approach to sustainable design for the Abercrombie Precinct Redevelopment Project, summarised in the following chapters regarding site design, energy, water, materials and waste.  The ambition demonstrated by adopting green building principles and a Green Star rating, extend to the function of the building as a business school environment that is intended to foster, inspire and educate.  The building will not only be a place of academic study but, by providing clear connections to the larger environment, it will foster a sense of environmental stewardship in building occupants.

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# 2 Introduction

**TARGET GREEN STAR RATING**

The proposed new Business and Economics School at Abercrombie Precinct aims to achieve a minimum 5-Star rating, with an aspiration to achieve a 6-Star rating, subject to detailed design development.

This report summarises the Green Building Design measures proposed for the Abercrombie Precinct Redevelopment Project to reduce consumption of non-renewable energy sources and natural resources. It has been compiled on behalf of the University of Sydney to support the Project Application for the development of a new Business and Economics School. This report provides supplementary information to support the Environmental Assessment.

Atelier Ten have collaborated with the design team to assist the development of design proposals to support the overall objectives of Ecological Sustainable Development, as fully described in the Environmental Assessment. There are no specific planning targets that are required for a development of this type. However, the University of Sydney has a commitment to reduce the overall carbon footprint of its estate, and advocates the achievement of Green Star ratings for all new buildings on campus. The Green Star Education v1 Tool provides a recognised benchmark to assess this development in terms of ESD principles.

This report summarises the key green building design measures to support the targeting of a Green Star rating and to mitigate future climate change, including passive design measures, energy-efficiency, renewable energy, water and ecology strategies, materials and waste management and transport.

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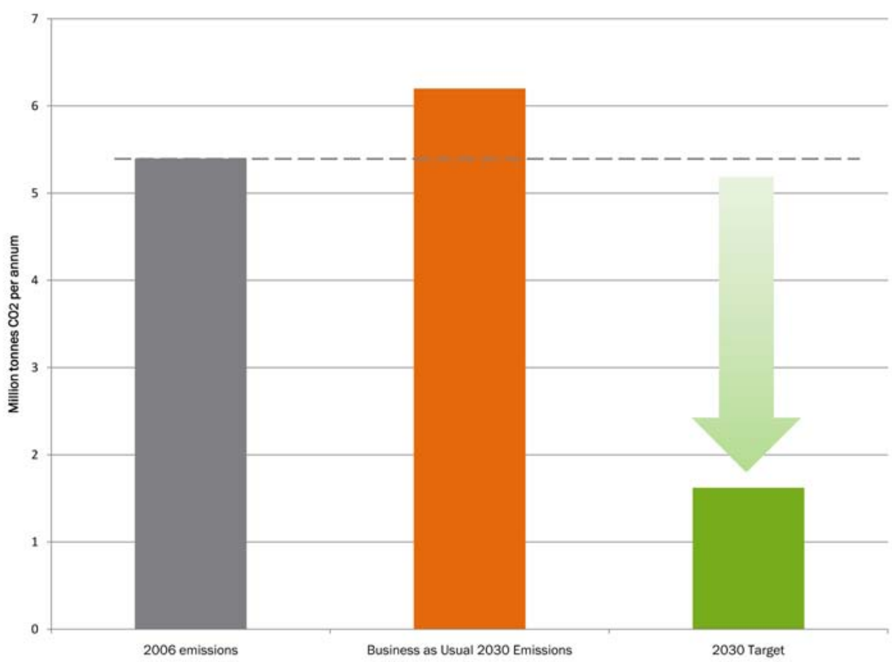
# 3 Climatic Response




SYDNEY'S EMISSIONS REDUCTION TARGETS

Source: Sustainable Sydney 2030 Vision Kinesis, Environmental Management Plan.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) released their fourth assessment report, concluding that the warming of the world's climate is unequivocal, and that human activity is the likely cause of warming experienced since 1950.

In Australia, CSIRO (Commonwealth Scientific and Industrial Research Organisation) have predicted[1] that there will be a continued increase in the frequency or warm days and warm nights, and a decrease in the frequency of cool days and cool nights. In addition, there is a trend towards reduced rainfall, but accompanied by more extreme rainfall events, particularly in the NSW area.

Sustainable Sydney 2030 sets out the city's vision and response to the challenges posed by global warming. The Target set by the Vision aims for a 70 per cent reduction of greenhouse gas emissions against the City's current performance by 2030. Within Sydney, the University has a campus the size of a small town and is committed through its Energy Savings Action Plan to reducing its emissions and offering state of the art new buildings that assist its goals to improve environmental performance in terms of energy, water and waste.

It is this context that sets the overriding principles for a green building at the Abercrombie Precinct. Green building design prioritises passive approaches that respond effectively to local climate conditions and seek to exploit

[1] CSIRO Technical Report on Climate Change in Australia (2007)

opportunities within a microclimate to minimise energy. This serves a dual purpose of making the most of renewable or passive sources of energy, as well as reducing overall greenhouse gas emissions, which are the cited cause of climate change.

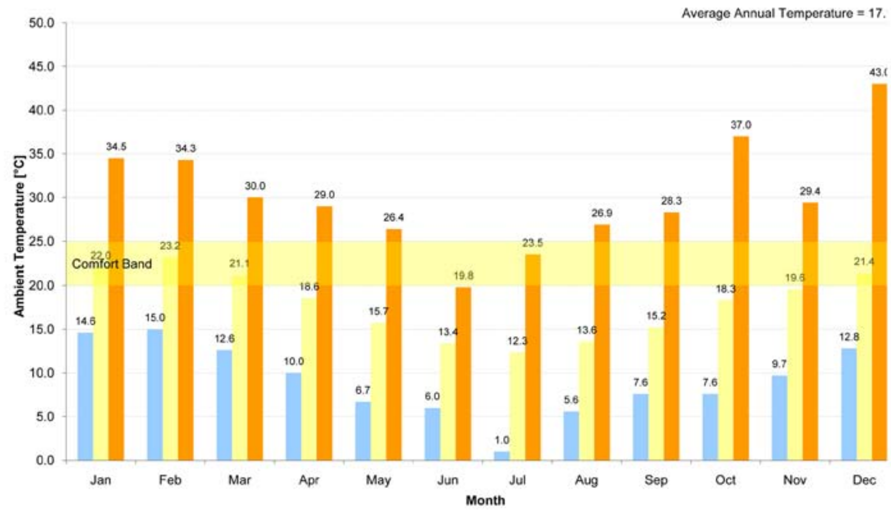
At the same time as mitigating future climate change, green buildings need to adapt to inevitable changes in the climate. This requires that buildings are energy and water efficient not just now, but into the future. It is preferable that a strategy proposed now, does not result in the need for more energy intensive retrofits, due to a change in climate conditions.

This section briefly summarises the current climatic conditions in Sydney to outline building design criteria to reduce greenhouse gas emissions (climate change mitigation). It also summarises the likely future climate conditions that the building will need to be able to adapt to over time (climate change adaptation). This is then followed by a series of chapters that detail the implementation of the building design in response to both these design criteria.

## Sydney's climate

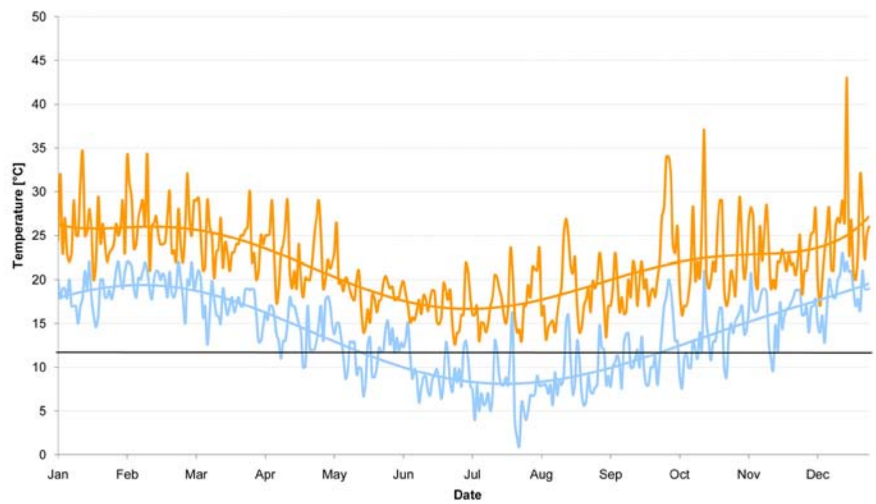
Any design that attempts to respond to the local environmental condition must be based on a close analysis of that climate. The degree to which the building needs to provide shelter and how the requirements for shelter change over the day and year directly influence the optimal design of the building and its systems. Critical climate factors are air temperature, humidity, and solar radiation.

The following section of this study summarises annual weather data for Sydney, from the weather station nearest to the University, Sydney Observatory Hill. Statistically average data is used, which has been compiled over a long time span so that no abnormal weather is included.



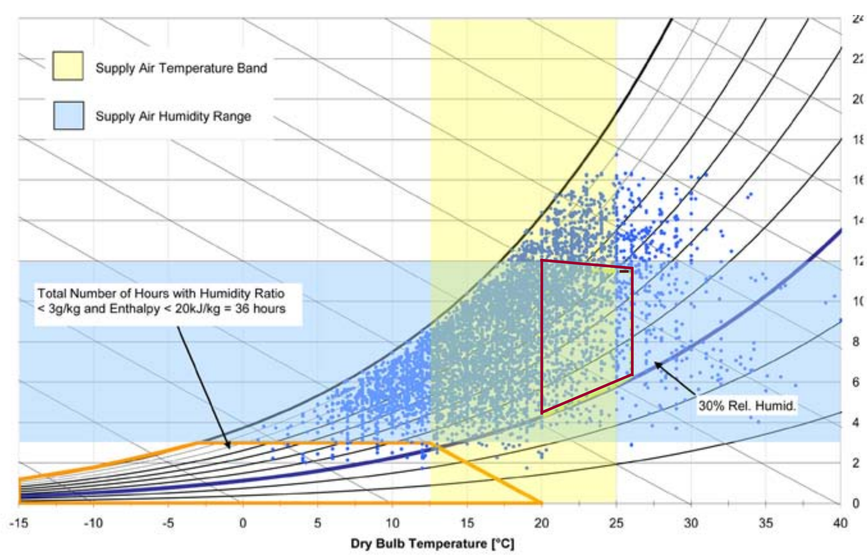

MONTHLY AMBIENT AIR TEMPERATURE

Sydney, NSW




MINIMUM & MAXIMUM TEMPERATURE

Sydney, NSW




PSYCHROMETRIC CHART

Sydney, NSW

## Temperature data

The upper graph to the left shows in yellow the temperature band at which building occupants would typically feel comfortable. The orange and blue vertical bands show the range of average temperature fluctuations for each month of the year. The vertical yellow bands in this graph show the average monthly temperature range.

What is immediately apparent in this data is the average temperature range within the summer months is the most comfortable; as these are within the comfort band. This indicates that these months provide opportunity for natural ventilation during some part of the day.
However, the summer season and most months of the year, also have the potential to reach temperatures during the day that are much hotter than the comfort zone. This indicates that additional conditioning will be required during the summer and shoulder seasons. There is some requirement for heating in the winter months, but cooling demand will dominate the conditioning requirements throughout the year. Robustly designing to cope with extreme peaks in temperature will help to future proof the building against general trends for increasing temperatures due to climate change.

The middle graph to the left shows the range between the minimum and maximum daily temperatures throughout the year.

In summer, there is a good range between daytime and night-time temperatures, indicating that a strategy using thermal mass could assist with cooling. However, occasional periods of consecutively hot days as indicated at the end of September, will reduce the effectiveness of thermal mass during peak conditions, where the night-time temperatures will be too warm to remove all of the daytime heat.

From mid-November to early May, the outdoor temperatures do not drop below 12°C, which means that additional cooling, beyond a simple night-purge strategy, would be required to cope with spaces subject to high internal loads. Approaches employing thermally massive structures are still worthwhile, but the climate data indicates that these need to be coupled with other conditioning methods to respond to peak conditions.

This summary considers climate conditions only. The high occupancy of classrooms in the new business school will further increase the times when conditioning is required and a response to this is set out in the thermal comfort section of this report.

## Psychrometric Chart

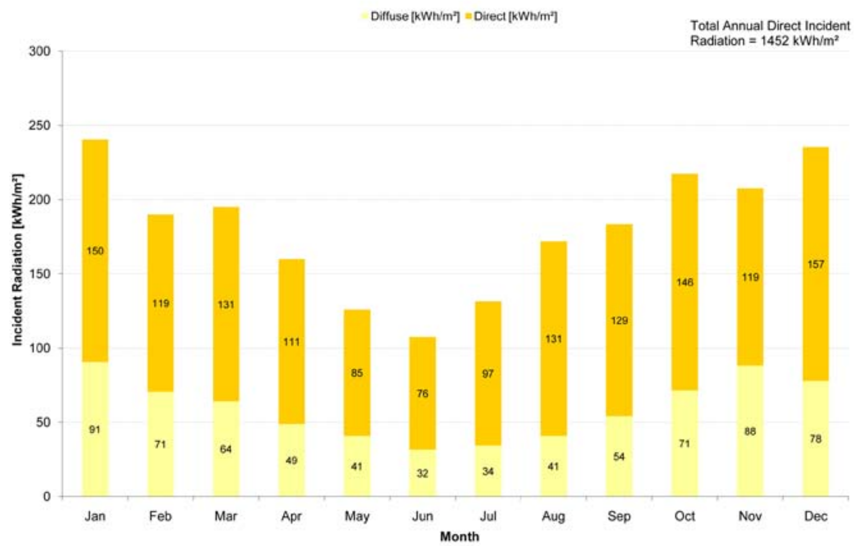
Thermal comfort is not only affected by air temperature, but also by the amount of humidity in the air. Since humidity and temperature both affect comfort, they should be analysed simultaneously. The psychrometric chart, to the lower left, displays the relationship between dry bulb air temperature (x-axis) and humidity (y-axis). The range of plotted temperatures and humidity that most people consider comfortable are outlined in red. This diagram indicates that heating, cooling and humidity control strategies will be required at different times of the year. High-humidity conditions have been separately assessed and apply to roughly 20 % of the year, although approximately 8 % of the year during occupied hours for the Business School. This means that conditioning strategies will need to provide dehumidification on occasions throughout the year.

It is possible to extend the boundaries of the indicated comfort zone to provide comfortable conditions on more occasions during the year. This is achieved by accounting for the effects of measures such as thermal mass or in winter, by embracing some carefully managed solar heat gains or occupancy loads. This demonstrates the overall objective of the passive strategies employed in the building– to increase the amount of time that the building can be thermally comfortable, whilst minimising the energy employed to achieve these conditions.

## Solar Path and Incident Radiation

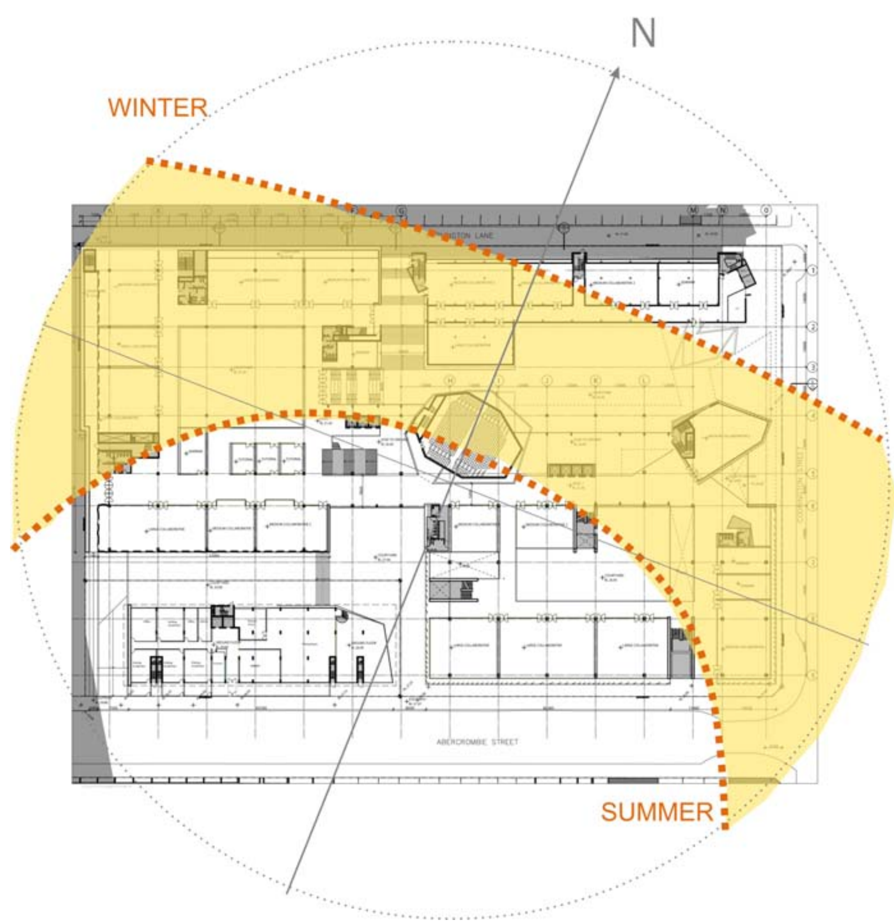
Heating and cooling requirements are greatly influenced by the amount of solar radiation available. Solar heat gain can beneficially offset heating requirements in one season while detrimentally increasing cooling requirements in another. The amount of solar heat gain within a space depends on the size and orientation of openings in relation to the position of the sun. Shading in response to the sun path is a critical part of the architectural design. To assist a conditioning point of view, cumulative incident solar radiation analysis determines the amount of solar energy on a specific surface and how that energy is distributed on that surface.

The amount of solar radiation is influenced by cloud cover and other atmospheric factors. In the top right graph, available incident solar radiation is plotted (y-axis) for each month of the year (x-axis). The data shows that the highest amount of direct horizontal solar incident radiation is available during the spring and summer. This will generate the building's peak cooling demand. In addition, the quantity of indirect light indicates cloud cover throughout the year. This will impact the effectiveness of any light pipes proposed in the building, which work most effectively with direct lighting conditions. The season with predominantly clear skies is spring.




SOLAR INCIDENT RADIATION

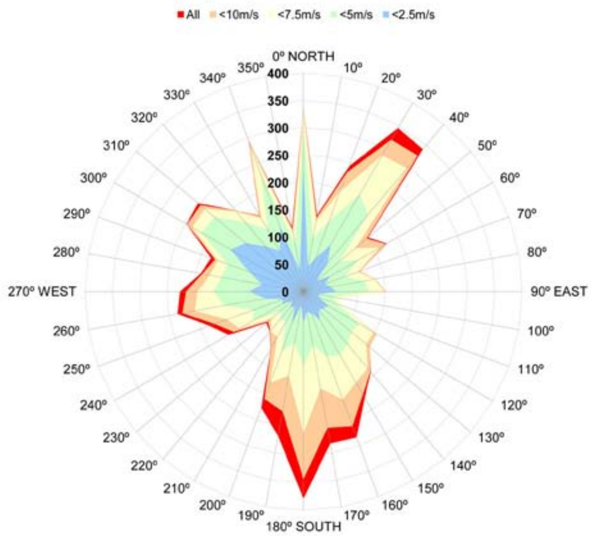
Sydney, NSW




SOLAR PATH

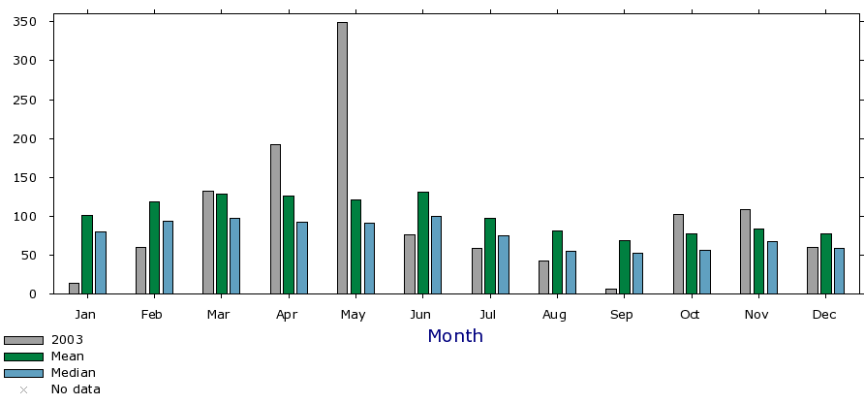
Abercrombie Site, Sydney, NSW

*Diagram issued during concept design development.*



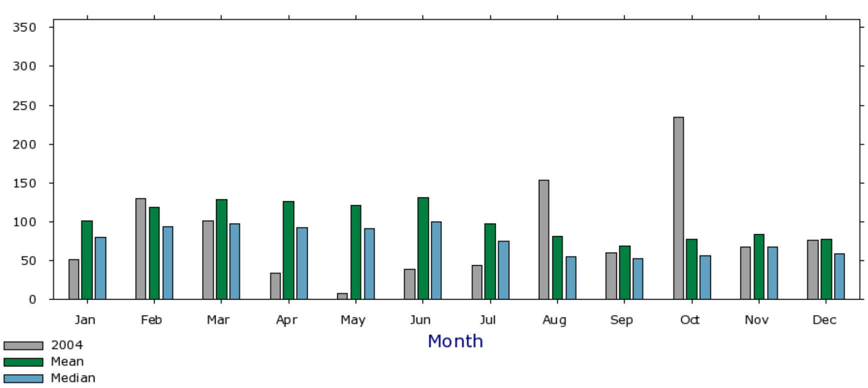

ANNUAL WIND DIRECTION & SPEED FREQUENCY

Sydney, NSW




MONTHLY RAINFALL DATA FOR 2003

Sydney, NSW, Source: the Bureau of Meterology




MONTHLY RAINFALL DATA FOR 2004

Sydney, NSW, Source: the Bureau of Meterology

## Annual Wind Pattern

A map of annual wind speed and direction indicates that the velocity of wind (areas at the outer region of the graph) is highest from the south, while the prevailing wind directions (the darker areas) are the south, west and northeast. Sydney's harbour location imposes variable wind directions and conditions, meaning that there is no overriding characteristic in the wind to apply to ventilation design for the building. While the weather information is taken from near the university in Sydney, wind occurrences on a particular site are strongly influenced by local obstructions. Thus, the available wind data should be considered as indicative of general trends only.

## Rainfall

Sydney has average annual rainfall of approximately 1,200 mm. Rainfall has a similar average each month of the year, although in the last decade there have been flash storms with higher quantities of rainfall during one or two months of the year. These are predicted to increase with climate change in the next 20 years, set within an overall trend of reduced average rainfall over the next 50 years.

Stormwater management is critical to ensure the vast quantities of rainfall from flash storms can be attenuated to reduce flooding risk. This is combined with a key driver to reduce overall water use and increase the amount of water that can be recycled, since expected increase in demand for water cannot be met by a reduced supply.

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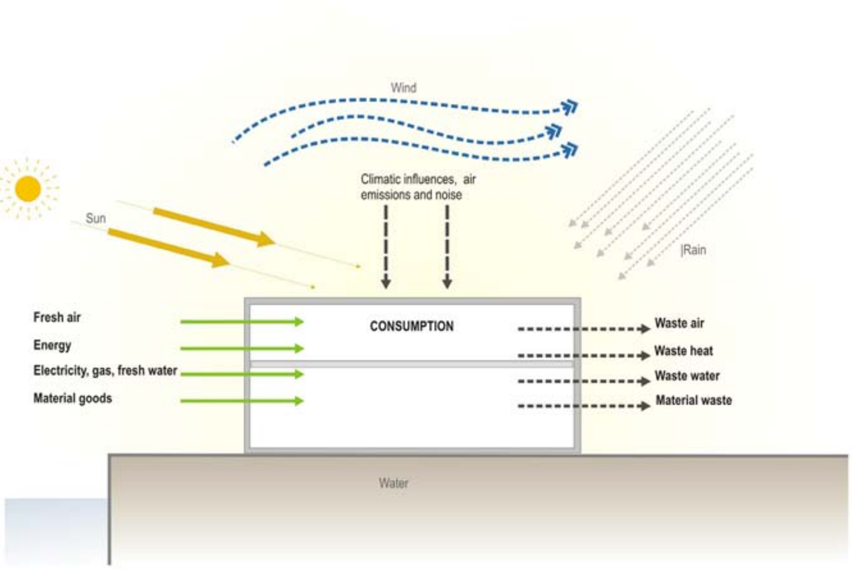
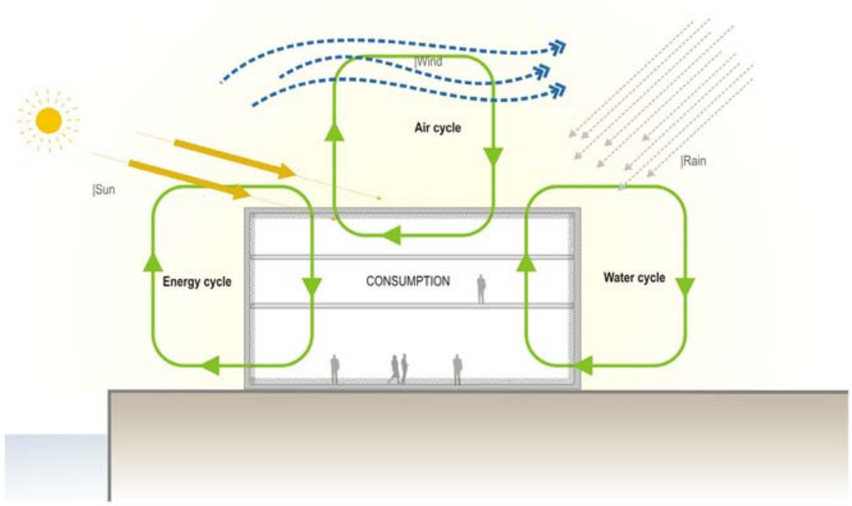



CONVENTIONAL BUILDING APPROACH




SUSTAINABLE BUILDING APPROACH

# 4 PASSIVE DESIGN MEASURES

Sustainable design goes beyond reducing greenhouse gas emissions. It concerns an effective use of resources and aims to ensure these are not squandered. A clear way of thinking about this in terms of building design is to envisage closed-loop systems that create ‘virtuous cycles’. This is where resources that are used are continually captured and reused, in a cyclical manner. This reduces the need for additional inputs and avoids wasteful outputs. In a conventional building, the inputs and outputs of resource use are assumed to be unrelated and are considered separately. A sustainable building, on the other hand, takes advantage of cyclical relationships on a small scale. Waste streams constitute unrefined supply streams, and each of the supply and demand relationships is interdependent and balanced. With this approach, the building’s outputs become a resource.

This approach to sustainable design is demonstrated in the Abercrombie Precinct Redevelopment Project and is summarised in the following chapters relating to site design, energy, water, materials and waste. The ambitions demonstrated by adopting this approach extend to the function of the building as a business school environment that is intended to foster, inspire and educate. The building will not only be a place of academic study but, by providing clear connections to the larger environment, it will foster a sense of environmental stewardship in building occupants.

This chapter summarises the range of passive design measures that have been explored and integrated into the overall design concept for the building. The goal is to make the building as energy efficient as possible by responding to climatic opportunities, outlined in the previous chapter, that suit the needs of the building. This is achieved through a response to massing and orientation, and creating an optimised building envelope for daylight, shading and thermal comfort.

The passive design objectives for the development are:
- To provide a fully day-lit working environment
- To be able to naturally ventilate as much as possible – where program and seasonal conditions allow or can be tempered accordingly.

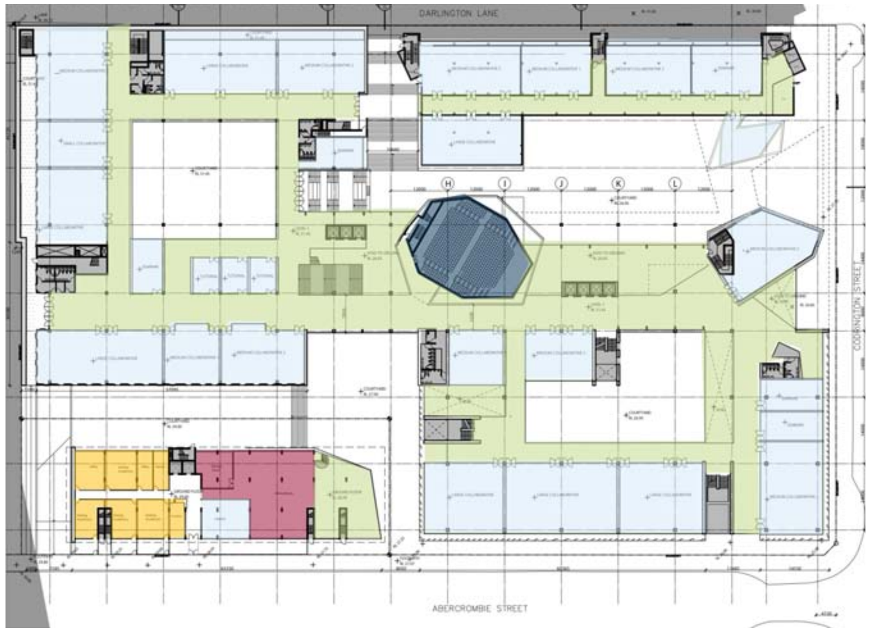



DIAGRAM OF PRIMARY SPACES - LEVEL 01

*Diagram issued to inform concept design development.*

## Site & Building requirements

The Abercrombie site is an urban block. It contains an existing building (H69) that will remain on the site and be renovated as part of the project. It is flanked by Abercrombie Street to the South, Codrington Street to the East and Darlington Lane to the North. A level change across the site buries the building at one end, providing an ideal location for the car park.

The proposed Abercrombie Business School has four primary space uses that define the requirements for the building:
- Informal learning – flexible spaces for meeting and greeting, individual or group learning.
- Classrooms – semi-flexible spaces for teaching and learning to groups of students (up to 30 people)
- Auditoriums – large spaces designed specifically for lecturing with raked seating (up to 200 people)
- Offices – workplace environment for support staff, including open plan spaces and cellular offices.

There are subsidiary and ancillary spaces in addition to these, but these four areas define the main energy demands for the building.

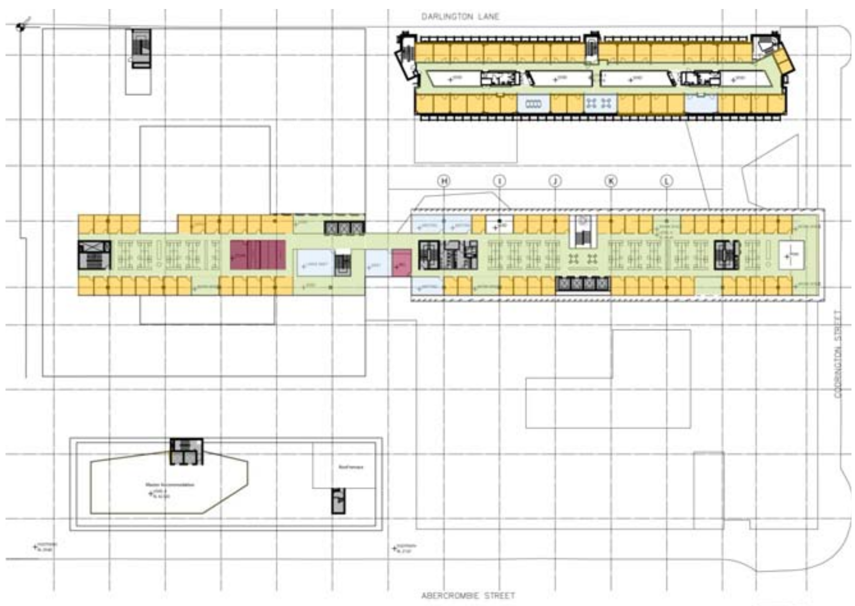



DIAGRAM OF PRIMARY SPACES - LEVEL 04

*Diagram issued to inform concept design development.*

- INFORMAL LEARNING / BUFFER AREA
- CELLULAR OFFICES
- CLASSROOMS / MEETING ROOMS
- CLASSROOMS
- AUDITORIUMS
- ANCILLARY SPACES

## Massing & Orientation

- The teaching accommodation is arranged primarily around two open courtyards and the offices are arranged in an upper floor elongated structure that extends across both courtyards.
- Office spaces have narrower floor plans on the upper levels of the building to assist strategies for natural ventilation and access to daylight. Classroom depths and proportions are also designed for daylight access and energy efficiency in lighting and conditioning.
- Classrooms are programmed to the external façade of the building to provide for access to light and views.
- Circulation space is absorbed within the informal learning spaces that form a buffer environment between the inner courtyards and the periphery teaching spaces. The buffer environment can absorb a wider range of temperature conditions and helps to reduce energy requirements for conditioning, as well as energy loss from conditioned spaces.

## Solar Exposure & Shading

The main teaching spaces and offices form the spaces adjoining the external façade of the building. The performance of these façades is crucial to the overall energy-efficiency of the project, because any solar heat gain that passes through the façade into enclosed spaces (other than the buffer zone) will need to be removed. It will not be beneficial to receive solar heat gain in these spaces in addition to the high occupancy internal loads.

Shading is an effective strategy to help minimise air-conditioning loads while maintaining occupant comfort. For this purpose, the design team has adopted the following design strategies to reduce solar gain on each façade according to orientation, and to ensure good access to daylight and reduce dependency on artificial lighting:

### General principles

- The classroom depths from façade and dimensions of buffer spaces have been designed to maximise the use of good daylight zones available in the first 6-8 metres from the exterior façade and 3-4 metres from the courtyard or atrium façade.
- The program for teachings spaces has been allocated to ensure that classrooms with a primary black-out requirement and artificial lighting requirements are located in deep-plan areas (semi-basement level), maximising the area available for other spaces benefiting from natural daylight access.
- High Performance Glazing.
- Well-Insulated Envelope.
- Glazing with Adequate Light Transmittance.
- Energy efficient lighting with occupancy / daylight sensors to supplement available daylight.
- For office lighting, where task areas are permanently located, it is more energy efficient to provide higher levels of task light on the work plane and lower levels of ambient light in surrounding areas. Light placement managed to ensure low lighting power density.

SOUTH FACADE

- The distance from the façade to the existing buildings on the opposite side of Abercrombie Street ensures good access to south ambient light at ground level.
- The south façade is not subject to high solar load, so thermal insulation is prioritised for this façade.

NORTH & WEST FACADE

- The buildings across the street are relatively low and will leave this façade fully exposed above the first floor level. the ground floor level is buried due to the typography of the site.
- The adjacent H69 building will offer some shading to the lower floors when the sun is low (morning and evening) but fully integrated shading is proposed to these façades to cope with midday / early afternoon sun.
- The upper floors containing offices are in an exposed location so mesh shading is proposed on the façade with opening apertures behind for ventilation.
- Light wells proposed to provide top-light/ clerestory light to semi-buried classroom spaces, and protected from direct sun by overhang above.
- Spaces programmed here include the auditorium that has black-out requirements and can present a solid façade, blocking unwanted solar gain.

EAST FACADE

- Classrooms set back from façade to reduce exposure.
- Building opens up in the north-east corner to provide for beneficial solar exposure to buffer spaces and the internal courtyard.

## Thermal Comfort

The approach to thermal comfort is essential in determining the main part of the building's energy consumption and future greenhouse gas emissions. If building occupiers feel uncomfortable they are much more likely to look to mechanical solutions to provide quick comfort fixes. These can create correspondingly high greenhouse gas emissions. The design of the Abercrombie Business School seeks to avoid this, responding not only to a wider range of comfort requirements but also responding to potential future changes in climate.

Thermal comfort is a relative term that combines temperature, humidity, air speed, clothing and activity level, all of which govern the heat exchange between the body and the environment. Stimulation is an additional comfort consideration, as a thermally dynamic environment can help refresh the senses throughout the day. Psychological factors also apply, where individuals can perceive the same comfort conditions differently depending on outlook or external influences, including the colour of the surroundings. Developing the most appropriate strategy for space conditioning in the building requires consideration of all of these factors and the degree to which each of them can be manipulated to achieve comfort.

In meeting the passive design aims to be able to naturally ventilate as much as possible, the Abercrombie Redevelopment Project will provide a diverse range of tempered or conditioned environments. In contrast to buildings that provide homogenous, controlled environments intended to appeal to an average perception of comfort, the Abercrombie Business School will provide diversity in thermal environments. These will meet broader expectations of perceived comfort. Within the building, people can choose places to work that they find most comfortable.

The range of thermal environments will be created using an intelligently managed palette of passive and active design approaches including controlling surface temperatures, providing radiant sources and methods of managing air movement. This results in improved comfort and reduced energy consumption.

This is particularly true of the courtyard spaces that define a new learning environment. This goes beyond the traditional classroom form and provides for informal learning, greeting and transition between other program areas. It is also a transition space in thermal terms, providing a buffer between the outside environment and the more controlled environments of the classrooms, lecture rooms and auditoriums.

In the classrooms, people will be seated for extended periods of time and will therefore have more stringent requirements for thermal comfort. As a result, these spaces need to have more steady and controlled thermal conditions.

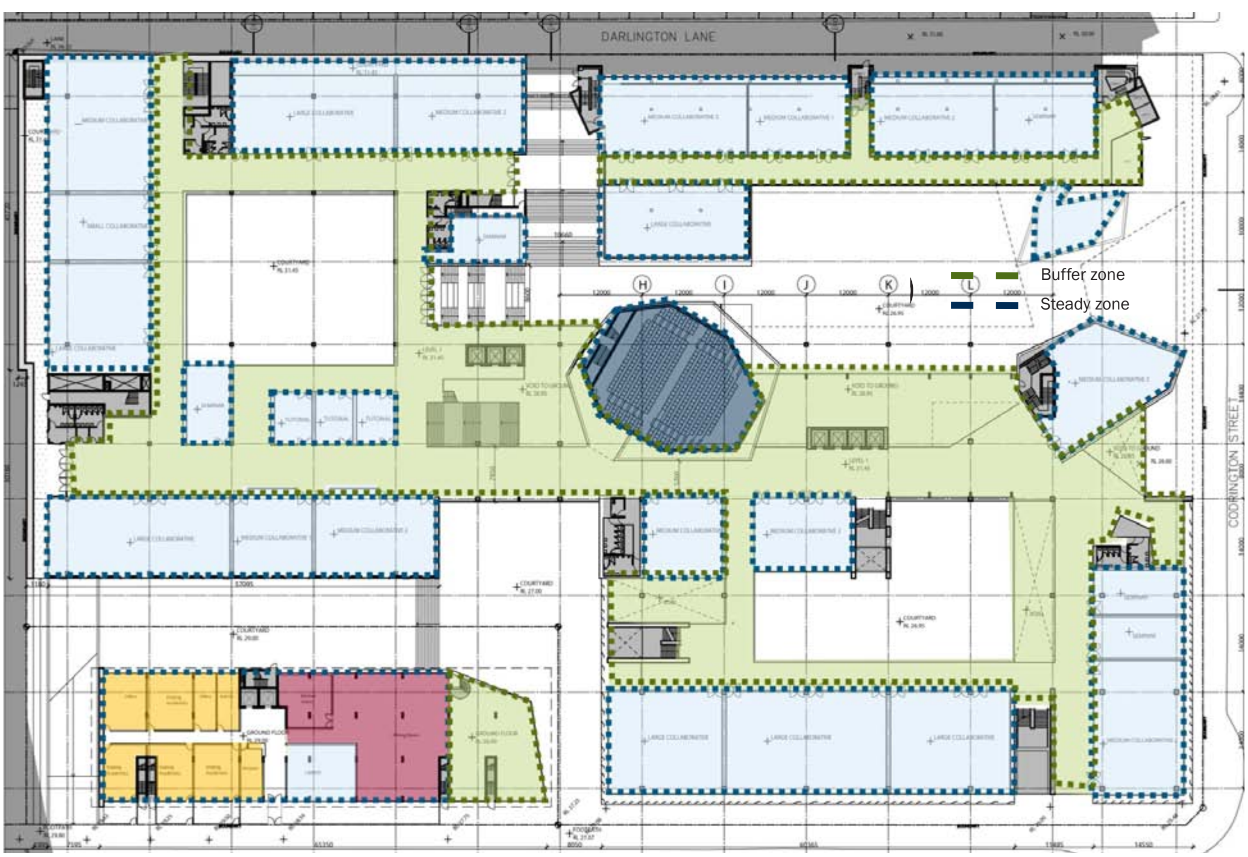
In contrast, occupants will be in the buffer zones for varying periods of time and have more freedom to move around, allowing for a broader range of thermal comfort conditions and looser conditioning requirements. To support the intention to use these spaces as informal learning areas for multiple uses, cool/hot spots are created. These integrate radiant surfaces into furniture or localised areas to provide for improved comfort in certain locations where people might choose to sit and study for longer periods.

The courtyard spaces will act as thermal buffers for the classrooms, protecting them from the full impact of the exterior climate conditions. In contrast to the conventional, static working environment, the courtyards will also provide a thermally stimulating environment for building occupants, which can increase occupant satisfaction and productivity.

The zoning diagram at left describes the thermal gradient across the building on the ground floor. There are generally two zones, which correspond to the degree of conditioning required:

- Steady zones, which are primarily auditorium and classroom spaces and are the most strictly conditioned, requiring a primarily active approach.
- Buffer zones, which are semi-conditioned and protect the steady zones from exposure to exterior conditions. These include more conditioned cool/hot spots and more passively conditioned transition spaces.

These zones are further differentiated according to the thermal criteria for classrooms, auditoriums, offices and the courtyard buffer zones. The thermal characteristics of each zone are summarised in the following pages combined with the proposed design response to achieve low-energy, thermally comfortable environments.




INDICATIVE THERMAL ZONE DIAGRAM - *Diagram issued to inform concept design development.*

## Classrooms

The main teaching spaces on the periphery edges of the building will predominantly require cooling in response to the climate and due to occupancy internal gains. Classrooms are expected to have around 30 occupants for classes requiring increased air changes to ensure comfort. Effective learning environments are created by preventing soporific conditions due to a build-up of $CO_2$.

PROPOSED DESIGN

Classrooms are approximately 15 meters deep, which assists with providing good daylight access. However, single sided ventilation will not effectively serve the spaces or the increased requirements for fresh air. Instead, an active heating and cooling strategy is proposed throughout the year, which will be enhanced by passive design approaches.

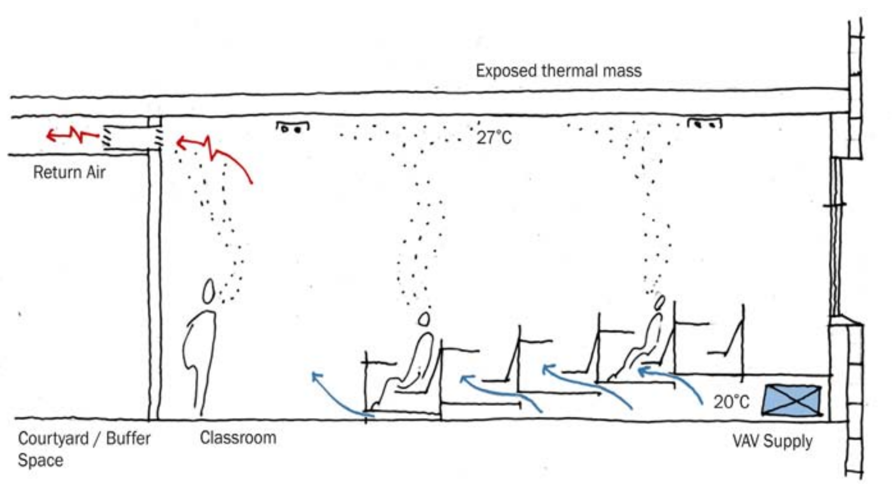
The classroom spaces will be highly-insulated and provided with displacement ventilation. Initial climate analysis indicates that displacement ventilation can halve the number of hours in the year when cooling would be required through a conventional HVAC system. Displacement ventilation is a combined passive and active strategy: Air in a displacement system is delivered at low level to the space at a minimum temperature of 20°C through floor diffusers or wall terminals. The ability to supply air at this warmer temperature reduces the energy needed to provide cooling. Heat sources (such as people or computers) in the room cause the air to rise to high level, taking contaminants and $CO_2$ out of the occupied zone towards the ceiling, creating a healthier and fresher environment.

Temperature control in individual rooms can be achieved through VAV control with re-heat, as with conventional mixed ventilation. In addition to the above, the provision of highly insulated spaces could allow the classrooms to be self-heating in the winter using heat recovery from occupants, harnessed via the air handling unit. This is an example of a virtuous cycle where the controlled use of heat from occupants displaces the need for a carbon intensive heating system.

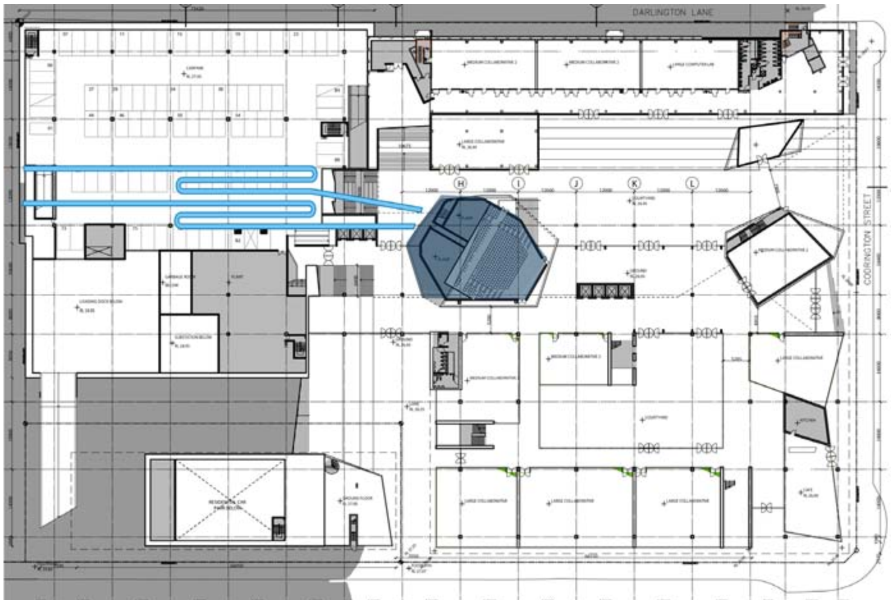
In summer, the occasional need for dehumidification could be met by desiccant pre-conditioning of the fresh air.

This strategy will assist with targeting a 5-Star Green Star Rating.

A further option to enhance this approach would be to combine it with a chilled, radiant system in the floor or lower wall area. The resulting reduced mean radiant temperature in the space gives improved comfort and a greater heat absorbing capacity. This additional approach will be explored further at detail design to assist the development of the design towards the aspiration of a 6-Star rating.

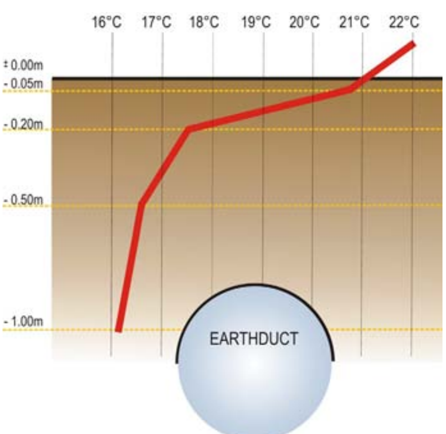



DISPLACEMENT VENTILATION




INDICATIVE EARTH DUCT DIAGRAM

*Diagram issued to inform concept design development.*




EARTH DUCTS

Earth Ducts are concrete pipes buried underneath the building. They are often standard size drainage pipes (roughly 900 mm diameter) used for supplying air into the building. Earth ducts are capable of providing passively conditioned fresh air for a displacement ventilation strategy. The air is pre-conditioned using the thermal mass of the ground to pre-heat air in winter and pre-cool in summer.

## Auditoriums

The auditoriums are large volume spaces with high ceilings, bleacher or raked seating, black-out requirements and expected occupancy levels of 150-200 people. An active mechanical approach is required to ensure comfort cooling, humidity control and fresh air requirements are met throughout the year.

To reduce energy use, complimentary passive measures have been proposed to enhance the active approach. Thermal storage strategies, decoupled from the building will reduce overall energy use.

PROPOSED DESIGN

The auditoriums are also suited to a displacement ventilation approach, which requires less energy than a conventional mechanical cooling approach. It is well suited to tiered seating arrangements as the supply air grills and under floor plenum are easily integrated under the seating. The approach also promotes a healthy environment for high occupancy areas, carrying stale air, contaminants and heat gains away from the occupied areas.

It is proposed that due to air change requirements to meet the high occupancy demands, any displacement system would be enhanced through combination with decoupled thermal mass, potentially in the form of earth ducts.

Additional cooling will be required from mechanical plant to deal with peak summer conditions in Sydney, including when the night time temperatures are too warm, but the overall effect will be to reduce energy use on an annual basis. This provides a noticeable energy saving when applied to a space that typically requires a higher energy demand, as in the case of an auditorium.

## Offices

Each of the cellular offices is adjacent to an external wall and has a proportion that is suitable for single-sided ventilation. Passive strategies have been applied to these spaces due to their size and usage, including solar control and high performance façades. Mixed-mode ventilation is required to respond to peak conditions in the summer and winter seasons.

It is envisaged that each office has occupancy levels of 1-2 people and localised controls will make these spaces comfortable according to occupants' choice.

PROPOSED DESIGN

The office spaces have the best opportunity of take advantage of the better aspects of Sydney's climate due to size and expected low occupancy. Some heating may be required in the winter, due to low occupancy, but this load will be reduced through the use of heat-recovery ventilation. Effective ventilation in the summer is essential. It is likely that natural ventilation will not always provide sufficient comfort, or is considered too noisy at times, so a mixed-mode approach is proposed. This would enable the choice between natural ventilation and mechanically assisted ventilation in each individual cellular office, according to external conditions.

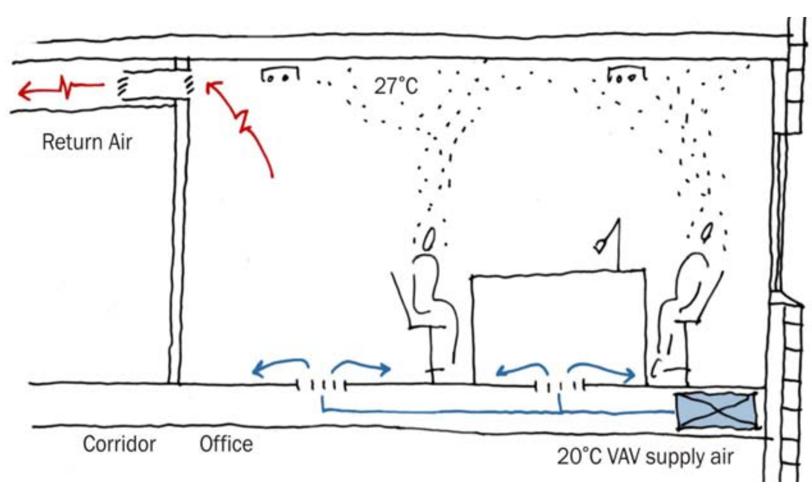
When ambient outdoor conditions fall within the comfort zone, operable windows can be used to provide ventilation and cooling for the office spaces. This approach is enhanced through a high performance envelope to reduce heat loss in the winter and façade optimisation to reduce solar heat gains, through effective shading.

At other times, ventilation will be provided through an underfloor ventilation system via an air handling unit. As in a displacement system, underfloor ventilation delivers air to the space at a minimum temperature of 20°C through floor diffusers or wall terminals. Underfloor ventilation supplies this air at a higher velocity than displacement ventilation, setting up a stack effect that pushes stale and hot air up. It has a higher cooling capacity than displacement, while still allowing individual control in each office.

Underfloor ventilation has the same air quality benefits as displacement systems and will also result in reduced energy consumption when compared to a mixed system. Underfloor ventilation is a good fit for these office spaces because it does not require sidewall terminals, which would limit furniture placement. It allows for easy reconfiguration of partitions without having to alter the mechanical system.

This approach will be used in a mixed-mode scenario with natural ventilation and controlled to operate when required. It can also be combined with a chilled beam approach or integrated with a ground source heat pump to provide low carbon cooling, providing additional adaptation options during design development to assist the design team's aspiration towards a 6-Star Green Star rating.

Occupants will be provided with the ability to decide and/or control the mode of operation according to clear information provided to their desk-tops by the building management system.




UNDERFLOOR VENTILATION

## Buffer Zones/Informal Learning

The informal learning zone is an open internal space, providing transition between formal learning rooms and also opportunities to meet, greet and study in a semi-outdoor environment. As a space and program ethos it differentiates the Sydney Business School from competitor schools by taking advantage of local climate conditions.

The space will be forgiving of a wider range of temperatures, from 16-26°C; enabling it to take advantage of the best of Sydney's climate conditions. Adaptation is supported by localised cool/hot spots, although cooling and heating will still be required at peak times during the summer and winter seasons.

PROPOSED DESIGN

Twenty percent of the usable floor area will be buffer/ informal learning space. It is critical to the low energy goals of the development that this space is passively controlled for as much of the year as possible.
The semi-outdoor zone will therefore be naturally ventilated, generating an uncontrolled stack effect via the open voids of the courtyards and by drawing air in from the periphery of the building. This is suitable for an extended shoulder season where a wider range of internal temperatures are considered acceptable in the space. However, on occasions during the summer and winter seasons when external temperatures are outside of the comfort zone, the building is designed to be flexible; providing additional enclosure to allow systems to condition efficiently.

The occasional enclosure of the buffer space provides the opportunity in winter to reuse heat recovered from occupied zones to temper localised areas. In the summer, the same localised areas can be tempered by controlled overspill from conditioned spaces.

During the shoulder seasons, additional conditioning in isolated cool/hot spots is proposed and will be further investigated during detailed design. These 'spots' are small areas, with localised conditioning supplied via integration with furniture or selected delineated areas for radiant surfaces. These are envisaged to be informal group working areas or hot desk/wifi spots.

They offer an energy efficient solution to the buffer zone in that they condition only small amounts of the space, rather than conditioning the whole space. This is considered energy efficient in the context of the generally unconditioned buffer zone and where the spots make use of waste heat sources such as heat recovery from plant, or renewable sources such as a labyrinth or earth duct. If a ground source heat pump is suitable for the project it could provide the necessary low carbon top-up for peak cooling and heating periods.

Additional measures being investigated include the introduction of overhead fans located in the cool/hot spots that are powered by photovoltaic panels.

INTEGRATED VENTILATION

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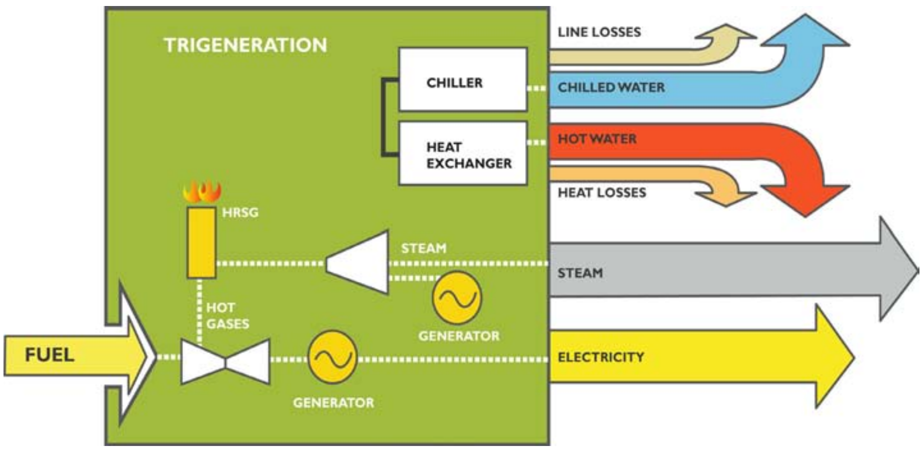
# 5 Energy & Carbon




TRI-GENERATION

In addition to the passive and active design measures, energy efficient chillers and plant proposed in the building, two primary low carbon energy supplies are currently being investigated for the development.

The two energy supply approaches considered to be appropriate for the Abercrombie Redevelopment Project are:

- Ground source heat pumps (on-site energy supply)
- Tri-gen / Co-gen (off-site energy supply in conjunction with adjacent development)

Both of these will be assessed for further technical and commercial feasibility at a detailed stage of design.

## Ground Source Heat Pumps

As previously described, it is possible to obtain 'free cooling' from the ground in a displacement ventilation approach by using earth ducts, as proposed for the auditorium. A Ground Source Heat Pump (GSHP) is an alternative approach using the thermal capacity of the ground to support a low temperature chilled water system in a cooling strategy. A GSHP uses the thermal capacity of the ground as a source and sink of thermal energy. Bore holes are drilled into the ground and water is circulated through a closed network of pipes, inserted into the borehole. The water is heated up to the ground equilibrium temperature by the surrounding soil, which acts as a heat source or heat rejection medium, depending on the season.

The added benefits of a GSHP system are the improved COP (Coefficient of Performance) during the cooling season. When ground source heat pumps are properly designed, the liquid temperature in the loop ensures that the equipment will operate with much higher efficiencies than conventional air source and fossil fuel equipment. While conventional air source systems have COP in the range of 1-2, GSHP typically have minimum COP of 4-5, and newer systems can achieve COP's as high as 10-15.
Due to external temperatures, the system may be limited to seasonal use or recharged, potentially through connection to a cooling tower.

GSHP is not a wholly renewable energy source, as it requires electricity to power the heat pumps. However, the heat pumps act as an energy multiplier and are able to supply a heat output that is many times greater than the energy input required.
The additional advantage of GSHP is that it can be supplied with low carbon electricity from photovoltaics in either onsite or offsite purchases.

A viable GSHP strategy would be subject to a geotechnical site survey, which will be undertaken at the next stage of design.

GROUND SOURCE HEAT PUMPS

## Off-site Tri-gen/Co-gen

The combined heat and power unit applies the principle of co-generation to provide heating, hot water and electricity. Waste heat can also be used to produce cooling when combined with an absorption chiller. This provides a more energy efficient cooling option to a conventional approach. This tri-generation approach reduces wasted energy and improves efficiency. However, it cannot be classed as a renewable energy source as it uses fossil fuel.

Due to its high capital cost, this system works best when applied on a large scale where a constant heat load is present. The Abercrombie Precinct Redevelopment Project has an opportunity to link energy systems with a nearby sports centre and swimming pool development and the on-site student accommodation. In combination, this range of building uses creates a more balanced load profile suited to this approach: The pool has a more constant heating demand that continues at night, whereas the Abercrombie development has a cooling demand during the day.

The main issue for successful delivery of this strategy is one of shared coordination in infrastructure delivery with the adjacent site. This will need further detailed design coordination in order to resolve whether or not it is feasible in this case.

## Additional Renewable Energy

Both of these options are considered to be suitable in conjunction with other measures proposed to target at least a minimum 5-Star rating in the Green Star Education assessment. These may be supplemented with photovoltaics in support of specific small power uses as already described, but photovoltaics will not constitute a main energy supply source.

The supply of low or zero carbon electricity produced on site can help to result in additional Green Star energy points. It is therefore likely that targeting a 6-Star rating would require the integration of photovoltaic panels. It is intended that these can serve an additional function in the façade or on the roof by doubling up as shading devices.

## GHG Emissions

At this concept stage of design it is possible to provide estimated energy consumption and carbon emissions based on benchmark data and best practice assumptions. This is intended to give an indication of the targeted performance of the building in relation to the Green Star targets. On the basis of the current schedule of accommodation, issued by Woods Bagot on 7th March 2011, the expected total greenhouse gas emissions of an equivalent baseline building would be expected to be approximately 1,572,000 kg/$CO_{2\text{-}e}$/yr. This is calculated using the Green Star Education v1 Energy Calculator.

By combining the passive and active energy strategies proposed with energy supply from either ground source heat pumps or tri-gen/co-gen approaches, it is expected, based on benchmark and best practice performance that the building could reduce its greenhouse gas emissions by 40-49 % compared to a standard practice benchmark. This would result in annual emissions of between approximately 800,000 to 940,000 kg/$CO_{2\text{-}e}$/yr.

Given that both GSHP and off-site Tri-gen/Cogen options are subject to feasibility, the project aims to achieve a 40 % improvement on a standard practice benchmark as part of overall aspirations towards a 6-Star rating.

This can be targeted through a combination of the passive and active measures proposed with evaporative coolers or absorption chillers to support an on-site cogen/trigen approach, with additional photovoltaic measures as required.

This initial benchmark assessment provides a starting point to improve upon during detailed design. A full energy model based on detailed design and specification of systems, including size and selection of energy supply, is necessary to provide a greater degree of accuracy for predicted energy and carbon performance. The initial benchmark greenhouse gas assessment is therefore subject to change. Detailed design will establish the combination of strategies to deliver beyond the minimum 5-Star Rating.

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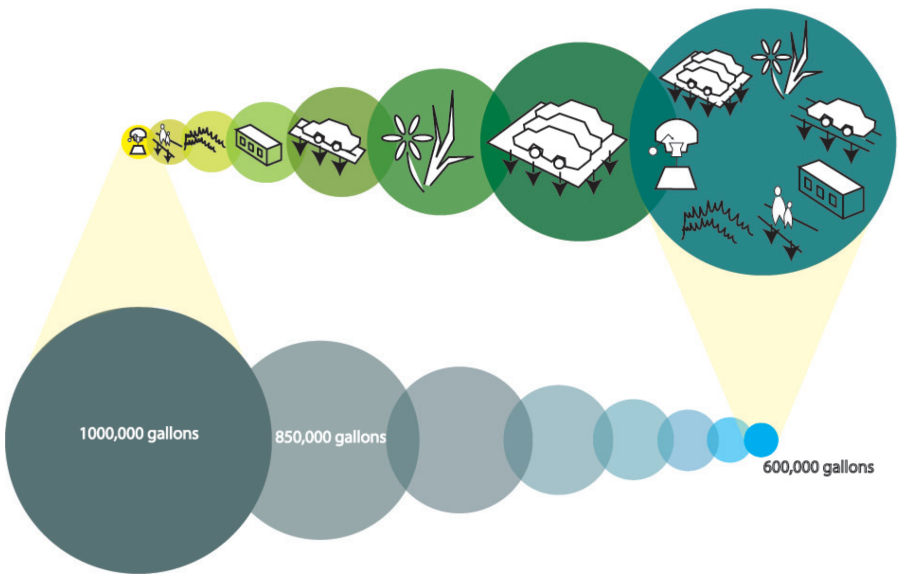
# 6 Water measures




BENEFITS OF STORMWATER REUSE

Utilising two critical water strategies will help the proposed Abercrombie Redevelopment Project to value water as a limited resource: potable water conservation and on-site water reuse.

The development will prioritise potable water reduction and then reuse water on site, based on the grade of the water, in a virtuous cycle.

Water conservation and reuse strategies will also be highlighted in the building, providing critical learning tools for building occupants that link their own behaviour and needs with the water cycle and the regional watershed.

## Water Conservation

Water conservation ensures that water demand, and thus wastewater generation, is minimised. Water reuse differentiates between non-potable and potable water demands and is based on the idea that much of a building's water does not need to be potable. While all sanitary uses (e.g. sinks, showers) require potable water, other demands like irrigation, toilet flushing, and cooling tower makeup water can all use non-potable water.

Decreasing the demand for potable water is the first step towards sustainable water management. Sinks, toilets, urinals, showers and appliances (e.g. dishwashers) that are designed to use less water than typical fixtures are widely available and, particularly when combined with conscientious use patterns, can result in large reductions in water use. The following water conservation measures are proposed for the Abercrombie Business School:

- Showers will be at least 3 star WELS, achieving flow rates no greater than 7.5 L/min
- Toilets will be 4.5/3 litre dual flush toilets
- Waterless urinals
- 6 star WELS ratings for washbasin taps
- Efficient irrigation systems for all landscaping, e.g. drip irrigation
- Dishwashers will be the highest available water rating (at least 4 star WELS)
- Domestic hot water to make use of a solar thermal system, gas boosted where required
- Installation of water metres for all major uses and connected to water consumption monitoring and display.
- Xeriscape landscaping – using drought resistant plants in one of the courtyards combined with irrigation measures that reduce potable water consumption for landscaping by 90 %.

## Water Reuse

The main water reuse strategies proposed for the Abercrombie Business School are:

- Rainwater collection (including stormwater) for use in toilets, irrigation and, where possible, cooling towers
- Greywater reuse, where stormwater is insufficient.

These strategies have been considered for Abercrombie in terms of virtuous cycles, and are strongly linked to measures to promote improvements in local ecology on site.
The current landscape proposals for the development propose the following types of landscape arrangement:

- The Laneway – this is non-vehicular hardscape connecting courtyard spaces to existing external spaces and providing pocket seating in the cool/hot spots suggested in the conditioning memo.
- South-East Courtyard – this is a planted (impermeable softscape) space over the car park, with an intensive vertical tree canopy. It may also contain some pocket hardscape areas.
- North-West Courtyard – this is an interactive, sculpted landscape with a primarily hardscape surface and some contained planted areas (permeable softscape)
- Roofscape – contains planted areas of immersion and shelter and open spaces. This is a hardscape area with planted areas / areas of green roof, providing natural bio filters and attenuation for stormwater.

The introduction of landscaped areas including planted areas, canopies and shaded roof spaces will help to regulate outdoor temperatures by reducing the urban heat island effect: This is created as hardscape and roof surfaces absorb solar energy and re-radiate the heat, causing cities to be warmer than the surrounding rural areas. The landscape proposals will also assist in the creation of comfortable outdoor and semi-outdoor microclimates in the buffer and courtyard zones.

This range of areas has differing requirements for irrigation as well as providing opportunities for water reuse.

The adjacent diagram show how these might like into a centralised water cycle for the building to assist with targeting the higher green star ratings.

## Water cycle

In summary, the proposed water reuse cycle is:

- Conservation: Low flow fixtures for sinks, toilets, urinals, and reduced irrigation demand and drip irrigation.
- Conservation + Stormwater: Stormwater is precipitation that falls on the site during storm events. This water - which would otherwise place a burden on stormwater infrastructure - will be captured off of the building roofs and site hardscape and stored in tanks for reuse. Rainwater harvesting to be reused for the largest water demands (toilets, irrigation and cooling tower). The advantages are significant water savings and reduced stormwater outflow to the city stormwater system.

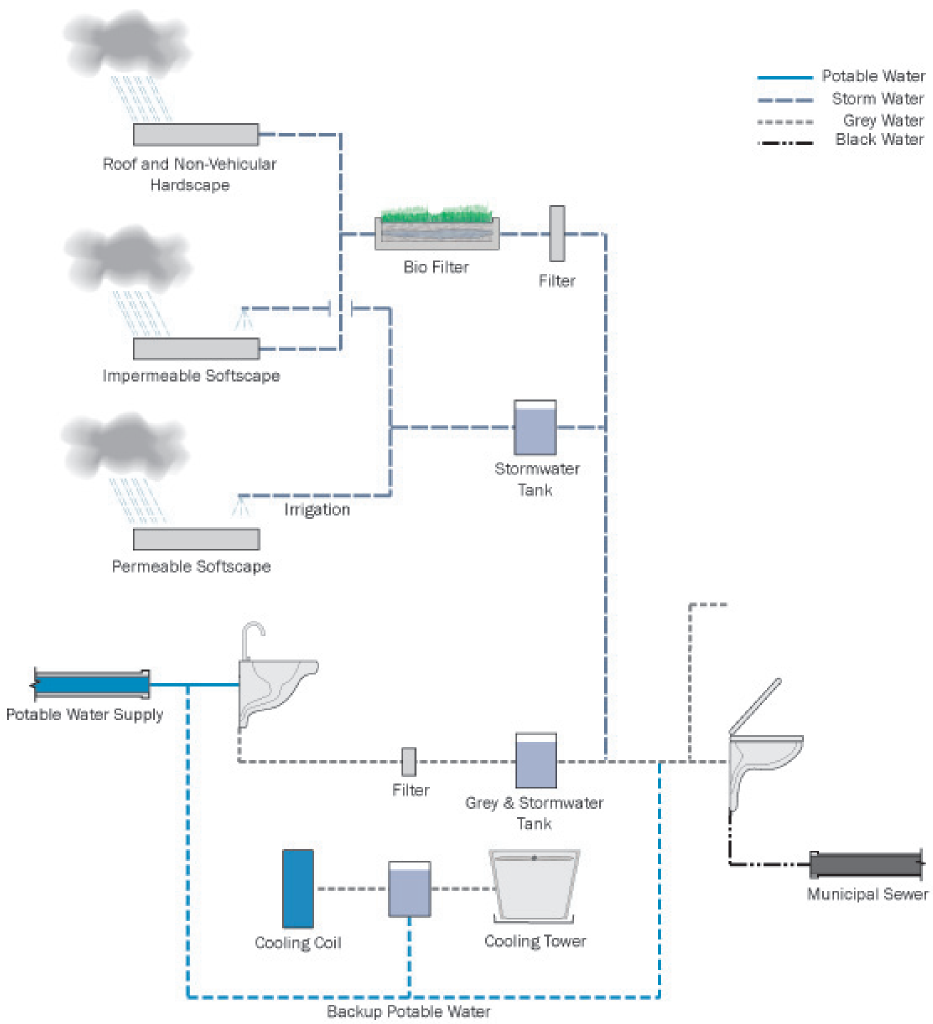
At times when there is insufficient stormwater, or the storage capacity is full, the system will adopt:

- Conservation + Greywater: Greywater is water that has been used for hand washing, showering, and clothes washing, but that has not been exposed to food products or human waste. Greywater collected from sinks will be used to flush toilets, when there is insufficient stormwater stored.

Based on an understanding of benchmarked best practice, these measures combined are expected to result in potable water consumption of 0.22 litres /day/m$^2$. This is equivalent to four out of five of the available water credits in Wat-1 of Green Star Education v1 Tool, recognising best practice.

In addition, the following strategies are identified to target the higher Green Star ratings. These will be subject to detailed design investigation for feasibility:

- Conservation + Condensate recovery: Cooling coil condensate could be collected and reused. The advantages are that condensate can be plentiful, coincident with high cooling tower requirements (which may not be consistent). It is also cleaner than stormwater and would require less filtration. The disadvantages and challenges are that it would have to be pumped from the building to the cooling towers and might require chemical treatment to be suitable for cooling tower water pH requirements.
- Additional measures for blackwater recycling and sewer mining to be investigated where possible and considered in addition to the above recommendations.




SITE WATER CYCLE

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# 7 Materials & Waste

Making sustainable choices about the materials that go into the Abercrombie Redevelopment Project will allow the project to have a positive impact on both building occupants and the building industry. At this stage of design, many materials decisions are still to be made. Therefore this section of the Green Building Report provides a summary of the principles that will apply to the detailed design stage of the project in order to target Green Star ratings of 5 or 6.

There are several environmental, economic, and aesthetic issues to consider when selecting sustainable materials. The design team intends to focus on two big-picture categories of materials that can have a large impact:

- High volume materials (e.g. concrete, gypsum board) create a domino effect, encouraging the production of sustainable alternatives throughout the supply chain.
- High visibility materials (e.g. floor and wall finishes) convey the University of Sydney's environmental commitments and can provide the opportunity to educate building occupants about all aspects of a material's life cycle.

Within these larger categories, there are several features of a material that could make it environmentally preferable, and some of these are recognised and count towards points in the Green Star Rating assessment.

## Recycled Content

Recycled materials can either be post-consumer (material that has been through the public recycling process) or pre-consumer (material that is a by-product of manufacturing). It is intended that the design team will aim to introduce recycled content in the following areas, wherever possible:

- Substitute a percentage of Portland cement in concrete with industrial waste products or oversized aggregate
- 20 % of aggregate for structural purposes is recycled or slag aggregate
- Avoid natural aggregates for non-structural purposes
- Reuse of flooring, joinery or furniture elements
- Adopt Product Stewardship principles – establish a contractual agreement to take back the material for recycling at the end of its useful life.

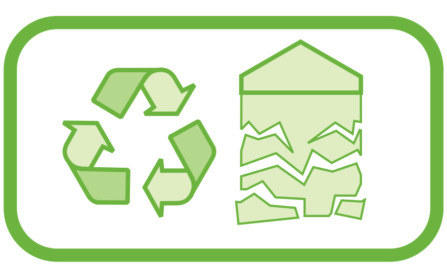
## Sustainably Harvested

Sustainably harvested products carry a third-party certification verifying that the raw materials were grown under environmentally-sound conditions. The most prominent example in Australia is the Green Building Council of Australia's 'Essential Criteria' for forest certification, which requires the Forest Stewardship Council's (FSC) certification process for wood and wood products. Third-party certification systems like the FSC track the production of wood from planting, through harvesting, import/export, and to the final distributors.

In addition, materials that are sourced from manufacturers that have EMS or EMS ISO14001 certification including measuring waste, energy and emissions from manufacture, will be preferred and specified, wherever possible.

## Rapidly Renewable

Rapidly renewable materials are those that come from sources that grow in ten years or less. Rapidly renewable products are beneficial because they use raw materials that are abundant and easy to regenerate, instead of rare or energy-intensive. Products made of agricultural by-products fall into this category, and also divert waste into a usable product. Bamboo, sorghum panels, cork, linoleum, and wheat board are examples of rapidly renewable materials that will be considered in the specification of the proposed development.



## Low-emitting materials & VOCs

Emissions from materials are a health concern, especially for people with respiratory problems or chemical sensitivity. Many materials “off gas” chemicals for a time after they are installed or manufactured. Once the building is enclosed, these chemicals remain in the indoor air. These emissions also contribute to smog and other forms of outdoor air pollution, and produce much of the odour in new buildings. Volatile Organic Compounds (VOCs) are the most common form of emissions. Many synthetic materials off gas VOCs, such as paint, joint compounds and sealants, stains and lacquers, and carpets. Low- or zero-VOC products are now widely available on the market and improve air quality and increase comfort for inhabitants with chemical sensitivities.

The Abercrombie Redevelopment Project will look to ensure that, wherever possible:

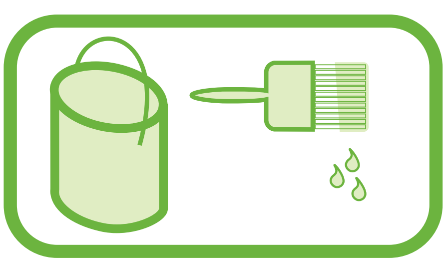
- Internal painted surfaces meet Green Star’s Total Volatile Organic Content Limits
- Carpets meet Green Star’s Total Volatile Organic Content Limits
- Internal fittings meet Green Star’s Total Volatile Organic Content Limits
- The building management system facilities the continuous monitoring of VOC pollutants
- Materials have low formaldehyde emissions or no formaldehyde.

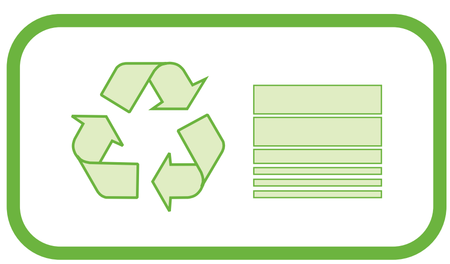
## Avoid PVC

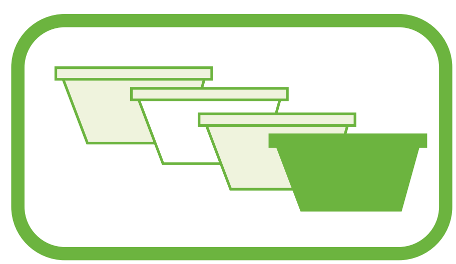
In order to target best practice ratings in Green Star, the design team will aim to follow Green Star’s PVC Best Practice Guidelines for at least 60 % (and aspire to 90 %) by cost of the common uses of PVC in the building, including cable insulation, pipe and conduits.

## Waste management

The development will include the full integration of appropriately sized waste recycling facilities on site to target maximum credits in Mat-1 of Green Star to assist with meeting the University’s waste minimisation goals.







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# 8 Transport

The Abercrombie Precinct is located in close proximity to well-serviced bus routes and both Redfern and Macdonaldtown Train Stations are less than 1km walking distance from the site. The frequency of services currently provided at these transit locations during peak hours are expected to allow the Development to target maximum 5 points in Tra-4 Mass commuting transport.

In addition to this, the development aims to achieve the following credits in Green Star:

- No more than the minimum planning allowance for car parking provision
- Minimum 25 % of the spaces will be designed in accordance with policies to accommodate mopeds/ motorcycles and small cars.
- Minimum 10 % of the spaces dedicated for car pool use, hybrid or alternative fuel vehicles
- Secure bicycle storage for minimum 5 % of the peak number of students and 5 % of the peak number of staff to meet Green Star criteria

The development is also impacted by the City of Sydney's Cycle Strategy and Action Plan 2007-2017. Abercrombie Street is a designated local bike route. The proposed regional network includes Route R10 Newtown – Bondi Junction which will run on Wilson Street, one block down from Abercrombie. This should bring improvements for access to the site by bike, so secure cycle parking will be increasingly desirable at the development.

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# 9 Green Star Summary

The proposed development for Abercrombie Business and Economics School at the University of Sydney aims to be an exemplar green building. Passive design is critical to the building's success by intelligently manipulating a wide palette of strategies to create a thermally diverse environment. This will not only be a building of low greenhouse gas emissions and improved comfort, but also a healthy learning environment. Many of the strategies for passive ventilation and conditioning offer additional health benefits by removing contaminants and odours away from the occupied zone and replacing with fresh air. These are also noise attenuation approaches, reducing the amount of mechanical plant or allowing it to run at a lower speed. These strategies, when combined with a green specification for materials, will ensure a reduced chemical and Volatile Organic Compound content in the environment.

This holistic approach is recognised in the targeted Green Star Rating of at least 5-Star, with an aspiration for 6-Star for an Education building. A brief summary of the main points targeted for a 5-Star rating follows on the next page. These are subject to change during detail design development, to ensure the most technically and economically feasible combination is identified to target the minimum 5-Star rating.

## Management

- Green Star Accredited Professional to assist the design team
- Comprehensive pre-commissioning of systems and demonstrated knowledge transfer to building manager / owner
- Building tuning and full re-commissioning one year after occupation
- Building User Guide and Building Maintenance Guide
- Contractor implements project specific Environmental Management Plan
- Contractor has ISO 14001 Environmental Management System accreditation
- Contractor waste management plan and at least 60% of construction and demolition waste is reused or recycled.
- At least three of the building's environmental attributes (energy, water and economic) are displayed to the building user.
- Maintenance review of the design proposals by Building Maintenance Personnel at both preliminary and final design stages.

## Indoor Environment Quality

- 100 % improvement over building regulation ventilation rates
- VOC & $CO_2$ monitoring system linked to Building Management System (BMS)
- Daylight Factor of 2 % achieved in at least 30 % of occupied area
- Thermal Comfort within 80 % of Acceptability Criteria
- Individual control (every four work stations) of thermal comfort according to natural ventilation or mechanical ventilation criteria.
- Comprehensive hazardous materials survey and mitigation measures as required.
- Best practice internal noise levels.
- Paints, carpets and tenant furniture meet VOC Content Limits Criteria
- Low or no formaldehyde emissions
- Humidity controls
- Daylight glare control
- High frequency ballasts in luminaires
- Better than recommended electric lighting levels / performance.
- 60 % of occupied area has direct line of sight to outdoors or internal atrium.

## Energy

- Meet conditional requirements
- Aiming for minimum 40 % better than baseline building.
- Energy sub-metering to classrooms and offices
- Peak energy demand reduced by at least 15 %
- Individually switched lighting zones
- 60 % of area either naturally ventilated or with wider temperature control band, or system shuts down when not in use.
- Highly visible stairs
- Efficient external lighting

## Transport

- Does not exceed minimum planning allowance for parking spaces
- Encourages the use of fuel-efficient vehicles
- Secure bike storage for 5 % students and 5 % staff
- Mass transport services available within 1km of site
- Dedicated pedestrian route on site and sustainable travel plan

## Water

- 4 out of 5 water consumption points
- Water meters
- Xeriscape garden or 90 % of irrigation use non-potable water

## Materials

- Storage space for separation and collection of recycled waste
- Substitute Portland cement for 30 % in-situ concrete or 20 % pre-case concrete plus recycled aggregates
- Sustainable steel specification
- Avoid PVC for 90 % of common uses in building by cost.
- FSC certified timber
- Design for future disassembly – 50 % by area of 95 % facade.
- De materialisation – using fewer materials (waterless urinals, natural ventilation etc).
- Environmental specification of flooring, joinery and loose furniture (1 out of 3 points).

## Land use and Ecology

- Reuse of land
- Increase in ecological value of land (1 out of 4 points).

## Emissions

- Ozone depleting potential (ODP) of zero.
- Refrigerant leak detection system
- Insulants avoid ODP.
- Stormwater managed on site
- Up to 40 % reduction on water discharge to sewer
- Minimise light pollution
- Eliminate risk of Legionnaire’s disease

## Additional stretch measures to target a 6-Star Rating:

### Management

- Appoint an independent commissioning agent
- At least 80 % of construction and demolition waste is reused or recycled.

### Indoor Environment Quality

- 150 % improvement over building regulation ventilation rates
- Design for Air Change Effectiveness of 95 % in both natural and mechanically ventilated spaces
- Daylight Factor of 2 % achieved in at least 60 % of occupied area
- Thermal Comfort within 90 % of Acceptability Criteria
- Adhesive Sealants meet VOC Content Limits Criteria

### Energy

- Minimum 50 % better than baseline building
- Peak energy demand reduced by at least 30 %
- 90 % of area either naturally ventilated or with wider temperature control band, or system shuts down when not in use.
- Shared energy supply (e.g. off-site Cogen/Trigen strategy)

### Transport

- Secure bike storage for 10 % students and 10 % staff

### Water

- Potable water consumption of water based heat rejection reduced by 50 %.

### Materials

- Additional sustainable steel specification criteria

### Emissions

- 100 % refrigerants have GWP of 10 or less