Section J Case Study series: Economy cycle and outside air control

Application of the new DtS provisions for a class 5 office building in climate zones 2 and 6 of a fictional office building

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INTRODUCTION

For the NCC 2019 Volume One the new requirements are based on a different methodology to the NCC 2016 Volume One. Economy cycle, demand control ventilation, heat recovery and pre-conditioning are all based on volume of airflow through a system. The 2019 NCC Section J became mandatory on May 1, 2020, with the new provisions covered in Parts J5.2 Air-conditioning system control and J5.3 Mechanical ventilation system control.

The compliance requirements in NCC 2019 for economy cycle and outside air control measures are to ensure systems have the provisions to take advantage of the climate zone benefits, or are able to manage the climate zone excesses, such as high temperature fluctuations and humidity issues:

- Economy cycle is required for total airflows above the values as listed in the table J5.2. Climate zone 1 and where dehumidification control is required are exempt.
- Outside air control and management is critical in achieving energy efficiency in a system. Having an energy reclaim or pre-conditioning device and demand control on outside air are required for systems with outside air (OA) volumes above the listed values in Table J5.3.

This is different to the sizing based method used in NCC 2016 of a 50kW and 35kW system capacity limit for economy cycle, and outside air control devices based on 1,000L/s system volume.

J5.2 Air-conditioning system control

a. An air-conditioning system –

(iii) which provides the required mechanical ventilation, other than in climate zone 1 or where dehumidification control is needed, must have an outdoor air economy cycle if the total air flow rate of any airside component of an air-conditioning system is greater than or equal to the figures in Table J5.2; and

(iv)

From the Guide to Volume One of the NCC the following additional detail is provided:

In this clause, the total air flow rate of each air side component means the air flow of each air-conditioner serving a space, not the combination of all the units serving a space because an outdoor air economy cycle is cost effective only in a larger unit.

Outdoor air economy cycles can be cost-effective, particularly in a building such as a Class 6 restaurant or café with a low occupancy. However, there may be situations where the outdoor air required by Part F4 may *be so great that an outdoor air economy cycle would admit only a small additional amount of outdoor air. The added cost of dampers and controls may not be justified for energy savings returned, so a performance-based solution may be more appropriate in these circumstances.*

An exemption is granted to applications that require humidity control. It is considered the additional cost and energy use of humidification or activation of a dehumidification plant offsets any benefit of free cooling from outdoor air economy cycle. These applications may include, but are not limited to, a frozen food section of a supermarket, a laboratory or a paper manufacturer's factory.

A dedicated outside air system (DOAS) that supplies multiple indoor DX units having a single outside air intake location would be cost-effective in the application of an economy cycle, given the outside air for all units is being provided at a single location.

Climate zone	Total air flow rate *requiring* an economy cycle (L/s)
2	9,000
3	7,500
4	3,500
5	3,000
6	2,000
7	2,500
8	4,000

Table 1 NCC 2019 Table J5.2 Requirement for an outdoor air economy cycle.

J5.3 Mechanical ventilation system control

a. General – A mechanical ventilation system, including one that is part of an air-conditioning system, except where the mechanical system serves only one sole-occupancy unit in a Class 2 building or serves only a Class 4 part of a building, must –

(i) be capable of being deactivated when the building or part of the building served by that system is not occupied; and

(ii) when serving a conditioned space, except in periods when evaporative cooling is being used –

(A) where specified in Table J5.3, have –

(aa) an energy reclaiming system that preconditions outdoor air at a minimum sensible heat transfer effectiveness of 60%; or

(bb) demand control ventilation in accordance with AS 1668.2 if appropriate to the application;

Climate zone	Outdoor air flow (L/s)	Required measure
1	>500	Modulating control
2	—	No *required* measure
3	>1,000	Modulating control
4 and 6	>500	Modulating control or energy reclaiming system
5	>1,000	Modulating control or energy reclaiming system
7 and 8	>250	Modulating control or energy reclaiming system

Table J5.3 Required outdoor air treatment

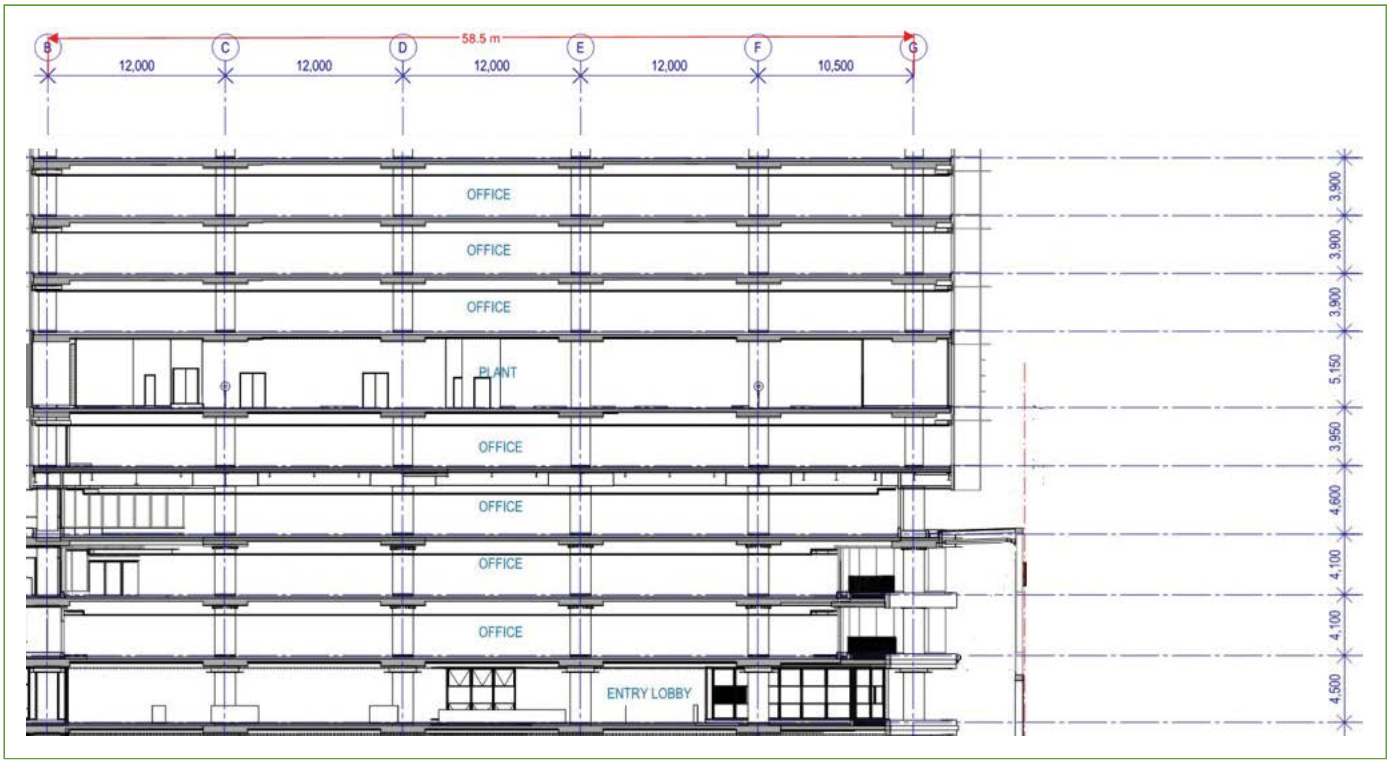

Figure 1: The plant room is located on level 5.

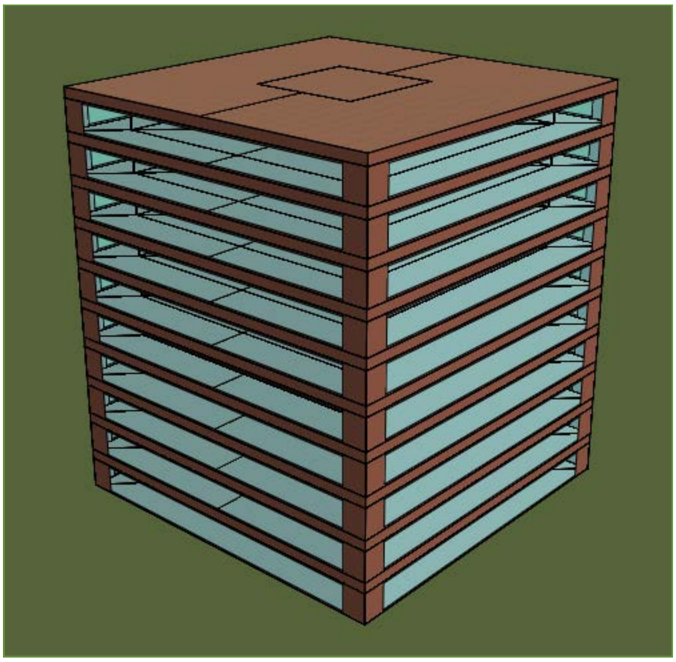

Figure 2: View of building model.

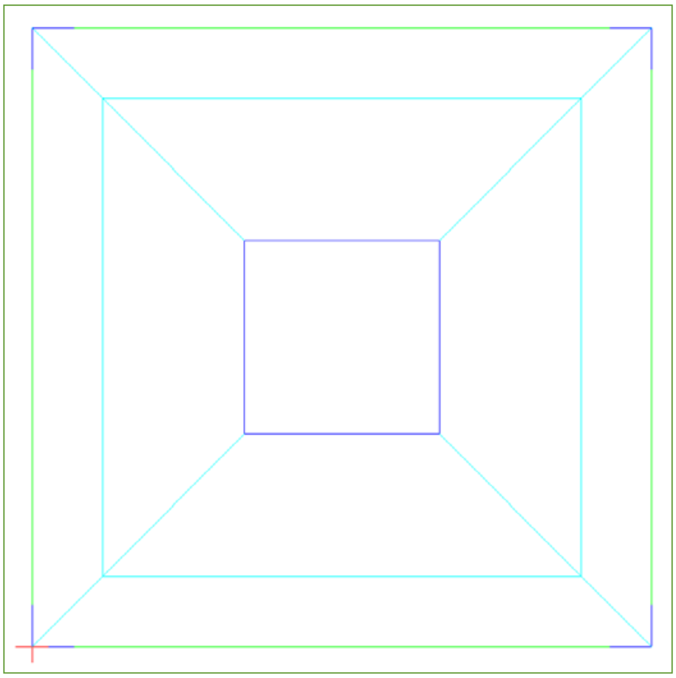

Figure 3: Floor plate showing zones

This case study will demonstrate the application of the new DtS provisions for a class 5 office building in in climate zones 2 and 6 of a fictional office building. Climate zone 1 is an extreme climate where use of economy cycle can have a negative impact on the building's energy consumption and has the potential for an increased risk associated with the humidity.

DEFINING THE AIR-CONDITIONING SYSTEM

The fictional building is a 10-storey office building. A sample of the north elevation drawing for the building is shown in Figure 1. The plant room is located on level 5.

A typical Australian office building was modelled as the base case for this study. The simulation follows Deemed-to-Satisfy provisions in Section J of NCC 2019. The base model has these characteristics:

- 10-storey building with underground carpark
- 56% Window-to-wall ratio (WWR) (NOTE: a smaller WWR ratio will result in less supply air and in climate zone 2 no need for economy cycle, so a large cost saving in HVAC and a waving in window costs, so a double saving)
- 31.6m by 31.6m floorplate, 4 perimeter zones, 4 centre zones and 1 core area per floor, the total floor area is about 9,985.6m². The total NLA is 9,000m².
- HVAC: Variable air volume (VAV) system with central cooling and heating plant (comparison of the use of economy cycle, demand control ventilation, energy reclaim and pre-conditioning is considered for this system)
- Floor to ceiling height 2.7m
- Plenum height 0.9m

Building loads

The building loads are as follows:

- Occupancy: 10m² per occupant. Sensible load of 75W/m² and 55W/m² latent load.
- Equipment: 11W/m²
- Lighting power density: The lighting power density of 4.5W/m².

Ventilation

The ventilation rate during occupied hours was set at 7.5L/s/person.

AHU configuration

Five Air handling units (AHUs) were provided for each facade and for the centre zones. Each AHU is provided with a return air from the combined floors into each unit. The plant room is used as an AO air plenum plant room.

Zone temperature control

The zone temperature control was to 22.5°C with a dead band from 21.5°C to 23.5°C and 1°C proportional bands either side of this. The VAV box minimum turndown was set to 30% for perimeter zones and 50% for centre zones.

Using all the information above, the size and layout of the HVAC system is defined in the next section. It is important to note the building design, heat load inputs and temperature requirements as these will influence the HVAC supply air sizing. Using different input values can change the results slightly, and in particular a reasonably minor change to the above information can result in the entire building in Climate zone 2 not requiring economy cycle.

DETERMINE THE PLANTROOM AND DUCTWORK REQUIREMENTS

There are many options to consider in the ductwork layout and design. The plant room size, arrangement of the AHUs, available riser space, ductwork paths and Outdoor air (OA) intake location and louvres, to name a few. In this case study we will consider two options that have been chosen to demonstrate two quite different solutions. These are not the only solutions and also may not be the most cost-effective solutions – these are provided for comparison in this case study only.

First, we must determine the system size so that we can check against the tables in the NCC Volume One Section J part J5.2 and J5.3. For the office building being considered the following table of results is obtained from completing a CAMEL heat load calculation to get the size of the AHU's required for each zone. Two climate locations have been chosen, Melbourne and Brisbane. The results shown are for the supply air and the outside air which are the values required to compare to the tables in the NCC.

Economy cycle considerations

From Table 2, the results show that in Melbourne this office building is required to have economy cycle for all AHUs. Also, the building is required to have some form of OA ventilation treatment, which could be any of the options available, either pre-conditioning, heat recovery or demand control.

From Table 2 the results show that in Brisbane this office building is required to have economy cycle for the centre zone AHU only. The controls for this configuration would require separate strategies for perimeter and centre zone cooling call. Because this building is close to needing economy cycle for all zones it will be provided with a full economy mode system for all AHUs. The building does not require any OA ventilation treatment.

A design consideration when providing a 100% OA economy cycle the ductwork may need to be sized to allow for supply and return air quantities to be equal with the ability to "dump" the return air from the system. The return air acts as the exhaust system to allow for the economy cycle to provide full OA to the space through the supply air ductwork, and not have any return air mixing. Venting at each floor level or using the return air duct are options that need to be considered in the design of the system, and the architectural considerations for the building.

Demand control on outside air design considerations

To provide the demand control system requires sensors and OA motorised dampers to control the amount of OA based on the CO_2 level due to the occupancy. A pre-conditioning system is an additional OA treatment system that could be located in the L5 plant room.

The heat exchange devices rely on the exhaust rates being equal to the OA rates, and if a ducted common exhaust is provided in the building that takes the exhaust air from each floor back to the plant room, then it is possible to use a heat recovery system on the OA. For the exhaust system from the toilets we will design the system in this case study to have exhaust of 670L/s per floor from toilets and general exhaust. All exhaust is brought into a common duct in the plant room to allow it to be used in the heat exchanger.

CAMEL sizing calculations	Melbourne (climate zone 6)		Brisbane (climate zone 2)	
	Supply air (L/s)	Outside air (L/s)	Supply air (L/s)	Outside air (L/s)
South zone	5,372	680	4,539	680
North zone	9,567	680	7,932	680
East zone	9,093	680	7,645	680
West zone	10,328	680	8,892	680
Centre zone	11,657	3,340	9,075	3,340
NCC Volume One Section J DtS values for supply air and outside air (OA) limits				
J5.2 Economy cycle	>2,000		>9,000	
J5.3 Ventilation OA treatment		>500		NA

Table 2: CAMEL results of AHU sizing 9 floors conditioned.

PLANTROOM DESIGN AND SYSTEM CONFIGURATIONS

Economy cycle (Melbourne and Brisbane):

For the given building the plant is all located on level 5. All AHUs and chiller plant is located on level 5, so the opportunity to provide OA economy cycle can be limited to a ducted system that is common to all AHUs and the five AHUs can all be supplied with the same arrangement. This system is simple, as when weather conditions are right for economy mode to be used, OA can be provided direct and all AHU chilled water or heating water valves can close.

Components required and plant changes from no economy cycle

The following are likely additional items in the AHU design. The system will require a motorised OA damper, motorised return air damper and motorised relief air damper to each of the 5 AHUs to allow them to operate in economy mode. The plant room is an OA plant room and no ducting is required to the AHUs for the OA. Temperature and humidity sensors are required to measure OA to control damper positions. The relief air damper should have a ducted exhaust from each AHU to allow relief air via the return air path to exit the building during economy mode. Additional wiring and controls are required to operate the system.

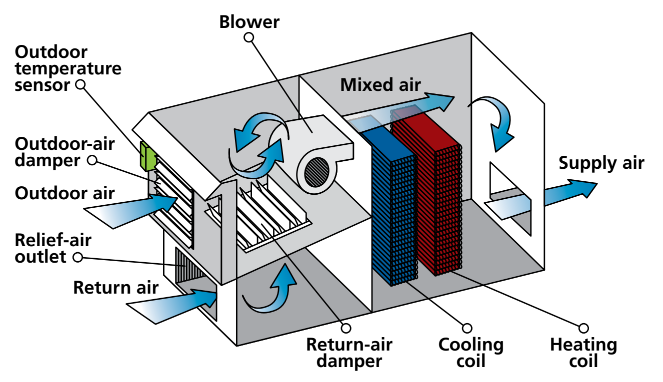

Figure 4 AHU typical arrangement for economy cycle.

OA treatment systems (Melbourne only):

The OA treatment systems have three options available.

Option 1

The use of demand control ventilation requires the use of a CO_2 sensor in the return air duct or in the spaces. The CO_2 sensor provides a modulating control signal via the Building management system (BMS) to the OA damper allowing it to open and close in response to the CO_2 generated in the space by occupants. The set point for the CO_2 sensor should be in accordance with the Table FV4.1 Maximum contaminant limits for acceptable indoor air quality. This is an averaging value, so the CO_2 level set point could be set below this value or an algorithm used that looks at the average over time and adjusts to suit.

Pollutant	Averaging time	Maximum air quality value
Carbon dioxide, CO_2	8 hours	850ppm Note 1

Table 3: Extract of Table FV4.1 Maximum contaminant limits for acceptable indoor air quality

Notes to Table FV4.1:
Based on body odour metric (i.e. 450 ppm above ambient CO_2 level of 400ppm and demand control ventilation provisions in AS 1668.2).

Components required and plant changes from no OA Treatment

The system will require a motorised OA damper controlled via the feedback from the CO_2 sensor and modulation of the OA air rates into each AHU. Because this building is split into five zones then the best solution would be to have sensors in the spaces at each floor level, or at minimum a sensor in the return air duct at each floor before the air enters the common return riser. In this building the OA damper and controls are already in place for the economy cycle, therefore just the addition of the sensors is required.

Heat exchange

The effectiveness of a heat exchanger is defined as the ratio of actual heat transfer to the maximum possible heat transfer. The key to the effectiveness is the fact that the formula contains the mass flow rate of the medium (fluid – air in this case) for each heat exchange path.

The concept of heat exchanger efficiency is a recently introduced one. It is defined as the ratio of the actual rate of heat transfer in the heat exchanger to the optimum rate of heat transfer.

This building in the case study is provided with a balanced exhaust air flow rate equal to the OA requirements as per AS1668. Similar office buildings may not have the same requirements for exhaust rates, and hence the effectiveness of the heat exchange equipment will need to be considered to ensure compliance is achieved. The exhaust air rate considered in this instance is 670L/s per floor, or 6030L/s in total. This allows the heat exchanger to achieve effective heat transfer and allow the heat exchange device to operate to meet the minimum sensible heat transfer effectiveness of 60% as per Clause J5.3(a)(ii)(A)(aa). This will need to be supplied by the equipment contractor who

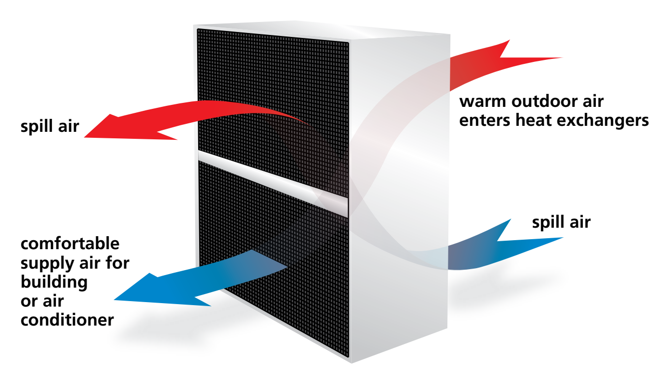

Figure 5: Air to Air heat exchanger.

$$\epsilon = C_h(Th_i - Th_o) / C_{min}(Th_i - Tc_i) = C_c(Tc_o - Tc_i) / C_{min}(Th_i - Tc_i) \quad \text{Equation 1}$$

Where:

C_h = product of mass flow rate and specific heat of hot fluid (heat capacity rate)

C_c = product of mass flow rate and specific heat of cold fluid

C_{min} = minimum value of the product of mass flow rate and specific heat of heat exchanger fluids

Th_i = Temperature of hot fluid at inlet

Th_o = Temperature of hot fluid at outlet

Tc_i = Temperature of cold fluid at inlet

Tc_o = Temperature of cold fluid at outlet

can provide the assessment of the effectiveness calculations for their heat exchange equipment.

Option 2

Air to air heat exchanger in the OA supply path using the exhaust air. The exhaust air in the building will need to be ducted via a common riser from the floors above level 5 and below level 5 to the plant room. The exhaust air will need to be dispelled from the building away from the OA intake louvres and so careful consideration should be given to the layout of the plant and the ductwork design.

Option 3

A run-around coil may be used provided the effective heat recovery can be determined to achieve the compliance requirements. The run around coil can be built into the AHUs for all zones. Determining the run around coil effectiveness is not covered in this case study.

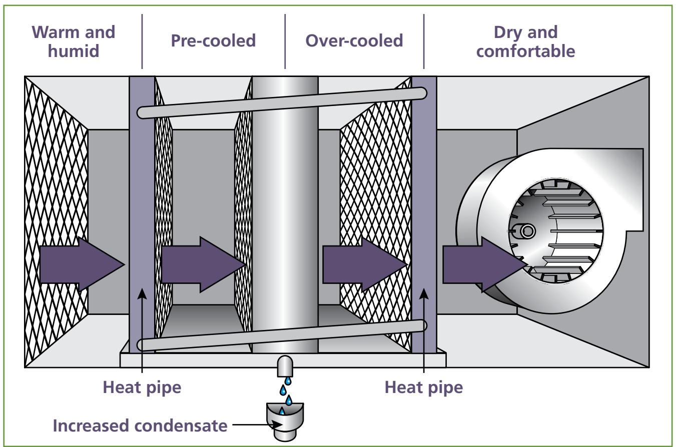

Figure 6 Run around coil AHU arrangement

The AHU size will increase to allow for the additional coils and therefore plant space must be checked such that these larger units can be installed.

CONCLUSIONS

Economy cycle and OA treatment requirements are specific to climate zones and size of the systems serving the spaces. Depending on the arrangement in the building, different options may be considered, and situations may arise where it is impractical to apply the clauses strictly as was the case for the building located in Brisbane. Economy cycle is needed to meet the DtS provisions for the centre zone; however, because the building has an open-plan office style, it makes sense to apply economy cycle to all the AHUs. This is over and above the DtS requirements; however, it makes practical sense to achieve effective temperature control and comfort conditions within the spaces.

All systems and designs still need to meet the requirements of AS1668, and also the requirements of Part F4 of the NCC Volume One. Design of the systems and the layout of the plant rooms is greatly affected by the available space to fit the additional equipment and larger equipment necessary to provide for the heat recovery units, the economy cycle dampers and controls, and some additional ductwork. System sizing and the requirements in the NCC are based on the cost-benefit analysis completed as part of the works to increase the stringency of the DtS requirements in the 2019 revision of the NCC. ▮

DEFINITIONS

Outdoor air economy cycle is a mode of operation of an air conditioning system that, when the outdoor air thermodynamic properties are favourable, increases the quantity of outdoor air used to condition the space.

Required means required to satisfy a Performance Requirement or a Deemed-to-Satisfy Provision of the NCC as appropriate.

ABOUT THE AUTHOR

Ken Thomson, M.AIRAH, has more than 25 years' experience in the building industry, and has completed numerous projects in ESD and mechanical design. These projects include HVAC system design, documentation and commissioning (including undertaking CFD analysis, façade design and analysis, and daylight and glare assessments), as well as post-occupancy inspections, energy audits and building condition audits. He is a senior engineer – mechanical, energy and ESD services at BSA | Build, based in Brisbane.

ACKNOWLEDGEMENTS

This project is supported by the Australian Government Department of Industry, Science, Energy and Resources through the Climate Solutions Package.

Thanks especially to Grace Foo, M.AIRAH, and Delta Q for letting me use the same building as for the façade case study.