NCC 2025 Energy Efficiency - Advice on the technical basis

Initial Measures Development: Electrification Report

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1 Introduction

Section J of the National Construction Code (Volume One) is undergoing a cyclic review of both stringency and coverage. This report evaluates the most cost-effective of the three pathways to electrification of three distinct commercial building system types that are commonly gas-fired: space heating, domestic hot water and, commercial kitchens/cooking.

1.1 Project Context

Section J of the National Construction Code (Volume One) last underwent a significant review for the 2019 edition. Since then, building technologies have improved and evolved with industry demand and increasing sustainability concerns. Furthermore, external pressures on Code from factors such as net zero targets at State and Australian government level have added to ambition. As it is generally recognised that decarbonisation of the grid is more feasible than decarbonisation of gas, future electrification has become broadly accepted as a prerequisite to achievement of net zero emissions.

This report covers space heating, domestic hot water and cooking appliances. It should be noted that the current (2022) version of Section J specifically excludes cooking appliances.

1.2 Purpose of this report

Building from the assumption of inevitable electrification of the commercial building sector, this report explores the lifecycle costs for three pathways to electrification based on individual assessments (referred to in the analyses as 'Scenarios'):

- Scenario 1: Future electrification with no preparation.
    - This scenario assesses the costs to construct a typical gas/electric mix building, and then electrify space heating, domestic hot water and cooking equipment at a given date.
- Scenario 2: Future electrification with provision.
    - This scenario assesses the costs to construct a typical gas/electric mix building with infrastructure provision (electrical and spatial) to facilitate future electrification, and then electrify the space heating, domestic hot water and cooking equipment at a given date.
- Scenario 3: Electrification from day 1 (design and construction of a fully electric building).

The variables that exist under the three pathways when applied to real-world examples of commercial buildings in discrete locations around Australia will result in a multitude of individual cost outcomes. These variables include timing of potential electrification upgrade, building classifications, size, location (metropolitan or regional), and services (heating/cooling and domestic hot water plant) design. Some variables have a more subtle impact than others, however the intent of this report is to provide an assessment based on common situations along with insights on the impact of some possible variables.

2 Space Heating

2.1 Technology Assessment

2.1.1 Overview

This assessment explores electrification options for space heating for two building archetypes across climate zones 2-8[1], being:

- C5OL – Class 5 Large Office
- C9A – Class 9a Hospital Ward

The remainder of the core archetypes used in the broader NCC 2025 project consist of mechanical systems that are 100% electric (typically VRF or Packaged unit solutions). The two selected archetypes provide a reasonable cross section of the market in regard to the electrification and electrification retrofits in terms of plant types and service requirements. The results from assessing these two archetypes are intended to provide a representative range of costs that can be expected for electrification scenarios.

For each building archetype, space heating plant arrangements for a base case design and each electrification case across climate zones 2 to 8 have been considered. The assessment investigated the estimated capital cost of the heating installation in each scenario including electrical infrastructure requirements and additional required plantroom area.

For each electrification scenario a modular 2-pipe air-cooled heat pump unit was considered as suitable for installation in office buildings and hospital wards across all climate zones, except for climate zone 2 and 5. These units are ideal for assessment purposes as the independent modules can operate in heating and cooling separately, are well suited to low load operation, are of average full load cooling and heating efficiency, and are average in cost on a $/kW basis. This type of heat pump is spatially efficient which optimises plantroom size and builders works costs.

For climate zone 2 (CZ 2) and 5 (CZ 5), electric duct heaters (EDHs) were used for the electrification cases. EDHs are significantly less expensive than heat pumps and are suitable for use in CZ 2 and 5 as heating requirements are generally low. However, it should be noted that while the NCC permits their use in CZ 2, revision of Section J would be required to enable this to be a compliant system in CZ5.

For the base case, condensing gas boilers were considered as the typical source of heating in both buildings in all climate zones.

2.1.2 C5OL Class 5 Large Office – Heating Arrangements

Design Criteria

The design criteria modelled for the archetype C5OL large office building for each climate zone is summarised below.

[1] As Climate zone 1 buildings do not have space heating, they have not been included in this analysis.

Summer Internal Design Temperature	24°C
Winter Internal Design Temperature	21°C
Outside Air (L/s)	8280 l/s
Conditioned Area	11040 m^2
Storeys	10

The mechanical system cooling and airside systems that have been considered for this archetype consist of two (2) water-cooled centrifugal chillers with induced draft cooling towers, five (5) Air Handling Units (AHU) with four (4) serving façade perimeter zones and one (1) serving the centre zone, on-floor Variable Air Volume (VAV) Systems with reheats to façade VAVs (electric reheat for CZ 3-5, HHW reheat for CZ 6-8).

The outdoor ambient design conditions, peak heating and peak cooling loads, heating source and cooling systems are summarised for each climate zone and electrification case below.

Table 1: Summary of Electrification Solutions for each Climate Zone, for Archetype C5OL

Climate Zone	Summer Outdoor Ambient Temp (°C)	Winter Outdoor Ambient Temp (°C)	Peak Cooling Load (kW)	Peak Cooling Load (W/m²)	Peak Heating Load (kW)	Peak Heating Load (W/m²)	Heating Source - Base Case	Heating Source - Electrification Scenarios	Cooling System - Base Case	Cooling System - Electrification Scenarios	Plant room Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
CZ2	30.7	9.8	697	63	333	30	2-off boilers (sized 60% each);	Electric Duct Heaters (EDHs) installed in each AHU supply air duct (5-off total).	2-off water-cooled chillers and cooling towers (sized 60% each)	Same as base case	N	Y
CZ3	41.8	1	1018	92	595	54	2-off boilers (sized 60% each);	4-off 2-pipe heat pump modules. Same heat pump that provides cooling.	2-off water-cooled chillers and cooling towers (sized 60% each)	1-off water-cooled chiller (sized for 60% load) and 4-off 2-pipe heat pump modules	Y	Y
CZ4	39	0.2	883	80	613	56	2-off boilers (sized 60% each);	4-off 2-pipe heat pump modules. Same heat pump that provides cooling.	2-off water-cooled chillers and cooling towers (sized 60% each)	1-off water-cooled chiller (sized for 60% load) and 3-off 2-pipe heat pump modules	Y	Y
CZ5	35.8	4.8	710	64	442	40	2-off boilers (sized 60% each);	Electric Duct Heaters (EDHs) installed in each AHU supply air duct (5-off total).	2-off water-cooled chillers and cooling towers (sized 60% each)	Same as base case	N	Y
CZ6	35.5	3.9	739	67	504	46	2-off boilers (sized 60% each);	3-off 2-pipe heat pump modules. Same heat pump that provides cooling.	2-off water-cooled chillers and cooling towers (sized 60% each)	1-off water-cooled chiller (sized for 60% load) and 3-off 2-pipe heat pump modules	Y	Y
CZ7	36.2	-2.8	739	67	700	63	2-off boilers (sized 60% each);	4-off 2-pipe heat pump modules. Same heat pump that provides cooling.	2-off water-cooled chillers and cooling towers (sized 60% each)	4-off 2-pipe heat pump modules	Y	Y
CZ8	21.7	-6.7	354	32	805	73	2-off boilers (sized 60% each);	5-off 2-pipe heat pump modules. Same heat pump that provides cooling.	2-off air-cooled chillers (sized 60% each)	2-off 2-pipe heat pump modules	Y	Y

2.1.3 C9A Class 9a Hospital Ward – Heating Arrangements

Design Criteria

A summary of the design criteria modelled for the archetype C9A hospital ward for each climate zone is summarised below.

Summer Internal Design Temperature	24°C
Winter Internal Design Temperature	21°C
Outside Air (L/s)	2775 L/s
Conditioned Area	5710 m^2
Storeys	8

The mechanical system cooling and airside systems that have been considered for this archetype consist of air-cooled chillers, one (1) AHU serving corridor areas, one (1) DOAS (Dedicated Outside Air System) AHU serving perimeter zones Fan Coil Units (FCU), and 160 FCUs with CHW and HHW coils.

The outdoor ambient design conditions, peak heating and peak cooling loads, heating source and cooling systems are summarised for each climate zone and electrification case below.

Table 2: Summary of Electrification Solutions for each Climate Zone, for Archetype C9A

Climate Zone	Summer Outdoor Ambient Temp (°C)	Winter Outdoor Ambient Temp (°C)	Peak Cooling Load (kW)	Peak Cooling Load (W/m²)	Peak Heating Load (kW)	Peak Heating Load (W/m²)	Heating Source - Base Case	Heating Source -Electrification Scenarios	Cooling System - Base Case	Cooling System - Electrification Scenarios	Plant room Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
CZ2	30.7	9.8	367	40	266	29	3-off boilers (sized 50% each for N+1 redundancy)	Electric Duct Heaters (EDHs) installed in each FCU and AHU supply air duct (162-off total).	3-off air-cooled chillers (N+1 redundancy)	Same as base case	N	Y
CZ3	41.8	1	485	53	385	42	3-off boilers (sized 50% each for N+1 redundancy)	3-off 2-pipe heat pump modules. Same heat pump that provides cooling. (N+1 redundancy).	3-off air-cooled chillers (N+1 redundancy)	1-off air cooled chiller and 3-off 2-pipe heat pump modules to provide cooling (N+1 redundancy).	Y	N
CZ4	39	0.2	436	48	401	44	3-off boilers (sized 50% each for N+1 redundancy)	4-off 2-pipe heat pump modules. Same heat pump that provides cooling. (N+1 redundancy).	3-off air-cooled chillers (N+1 redundancy)	1-off air cooled chiller and 3-off 2-pipe heat pump modules to provide cooling (N+1 redundancy).	Y	N
CZ5	35.8	4.8	376	41	350	38	3-off boilers (sized 50% each for N+1 redundancy)	Electric Duct Heaters (EDHs) installed in each FCU and AHU supply air duct (162-off total).	3-off air-cooled chillers (N+1 redundancy)	Same as base case	N	Y
CZ6	35.5	3.9	366	40	329	36	3-off boilers (sized 50% each for N+1 redundancy)	3-off 2-pipe heat pump modules. Same heat pump that provides cooling. (N+1 redundancy).	3-off air-cooled chillers (N+1 redundancy)	1-off air cooled chiller and 2-off 2-pipe heat pump modules to provide cooling (N+1 redundancy).	Y	N

Climate Zone	Summer Outdoor Ambient Temp (°C)	Winter Outdoor Ambient Temp (°C)	Peak Cooling Load (kW)	Peak Cooling Load (W/m^2)	Peak Heating Load (kW)	Peak Heating Load (W/m^2)	Heating Source - Base Case	Heating Source -Electrification Scenarios	Cooling System - Base Case	Cooling System - Electrification Scenarios	Plant room Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
CZ7	36.2	-2.8	373	41	457	50	3-off boilers (sized 50% each for N+1 redundancy)	4-off 2-pipe heat pump modules. Same heat pump that provides cooling. (N+1 redundancy).	3-off air-cooled chillers (N+1 redundancy)	3-off 2-pipe heat pump modules to provide cooling (N+1 redundancy).	N	N
CZ8	21.7	-6.7	135	15	498	55	3-off boilers (sized 50% each for N+1 redundancy)	4-off 2-pipe heat pump modules. Same heat pump that provides cooling. (N+1 redundancy).	2-off air-cooled chillers (N+1 redundancy)	2-off 2-pipe heat pump module to provide cooling (N+1 redundancy).	N	Y

2.2 Costing Methodology

Mechanical Costs

Pricing models have been created based on Opinion of Cost (OPOC) estimates generated for each archetype, base case, electrification case, and different building peak heat loads. The OPOCs have estimated the cost of space heating plants for the following peak heat load ranges, which were determined to cover the range of archetype simulation and modelling results: 300 kW, 600 kW, and 800 kW. The cost estimate from each of the OPOCs have been trended to create pricing models.

Pricing models have been created for each archetype base case and electrification cases 1, 2 and 3. These models have been used to generate a cost estimate of the heating plant for the different peak heat loads associated with each archetype case across climate zones 2-8.

For determining the cost of the electrification cases for each archetype in CZ 3, 4 and 6-8, the following items were included for the supply and installation of the heating system: heat pump units with internal primary pumps, secondary pumps, buffer tank, primary circuit pipework and insulation, hot water coils (for electrification case 1 only, as the incremental cost is negligible for a new construction), air and dirt separators, valves, controls, switchboard, building costs for a new open-air plantroom consisting of plant deck and louvres (where applicable), preliminaries, testing and commissioning. Where applicable, we have also considered the cost of electrical infrastructure upgrades such as substation, main switchboards, and submains cabling, and demolition of existing heating plant. A 10% cost premium was applied to the mechanical installations for retrofit Scenarios 1 and 2, separate to demolition, to cover additional costs that are common for these types of projects such as cranage, mobilisation, additional labour and, site establishment.

For determining the cost of the electrification cases for each archetype in CZ 2 and 5, the following items were included for the supply and installation of the heating system: electric duct heaters, duct modifications (for electrification case 1), wiring, controls, switchboard, preliminaries, testing, commissioning, electrical infrastructure upgrades (including substation, MSB and submains cabling), and demolition of existing heating plant.

For input to determination of demolition and incremental costs across the three scenarios a base case typical electric/gas mix building was developed for each archetype and climate zone. The following items were included for the supply and installation of the heating system: boilers, primary and secondary pumps, primary circuit pipework and insulation, valves, controls, gas and plumbing infrastructure, switchboard, electrical infrastructure (including substation, MSB and submains cabling), preliminaries, testing and commissioning.

The cost for each item of equipment has been gathered from a range of manufacturers, suppliers, general industry experience, and the Rawlinsons Construction Handbook. Opinion of Cost sheets have been used to calculate the costs for each electrification and base case option and are appended with this report.

For electrification case 1, retrofitting an existing building, the cost of new AHU and FCU coils have been included. Gas boiler heating plant in an existing building will typically deliver 80-60°C (flow-return) heating hot water. Low temperature (most common and efficient type) electric heat pumps are not capable of reaching these temperatures. Therefore, the heating hot water coils in existing AHUs and FCUs will need to be replaced to be suitable for lower temperatures such as 50-30°C or 45-30°C heating hot water. This adds to the cost of the retrofit significantly.

Plantroom Cost

The plantroom areas calculated in this study are for water-side plant and equipment only (heat pumps, pumps, etc). The plantrooms for Scenario 1 have been modelled as a plant deck with structural beams and columns installed above an existing sheet metal roof deck with full length 2.4m high louvres on each side and open to the sky. The cost, which has been taken from Rawlinsons, estimates the plant deck with beams at \$909/m^2 and the louvres at \$699/m^2.

For Scenarios 2 and 3 where infrastructure for a new heat pump is installed or provisioned, the required plant room and louvre area has been calculated to determine the cost of a new outside air plant area suitable for the size of the heat pump unit and associated plant, sized for each archetype/climate zone as a result of required heating capacity. According to Rawlinsons, the costs of such a plant room per m^2 is very similar to those for the Scenario 1 retrofit.

For base cases, where a boiler is installed, the required plant and louvre area has been calculated to determine the available existing plant room area, sized for each climate zone.

Electrical Infrastructure Cost

For scenarios where the electrification cases require additional electrical capacity compared to the base case, the cost of electrical infrastructure upgrades have been considered. Based on the peak cooling and heating loads for each archetype and climate zone, and an estimated COP efficiency for each system, the additional electrical kW capacity required for heating plant has been calculated.

For electrification Scenario 1, it has been assumed that some spare capacity in the electrical infrastructure (substation and MSB) exists in the original building due to common design practices. This has been estimated to roughly 50 kW of spare electrical capacity for the building, which is a figure developed based on experience in previous projects[2]. Therefore, for the purposes of estimating the electrical infrastructure costs, where the additional electrical capacity required for heating is less than 50 kW, only the cost of new submains cabling to the MSSB has been considered. Where the additional electrical capacity required for heating is 50 kW or greater, the cost of substation, MSB and submain upgrades have been considered.

For electrification Scenarios 2 and 3, the electrical infrastructure costs for the substation, main switchboard and submains cabling to the MSSB have been estimated and compared against the cost of the base electrical infrastructure required for a typical electric/gas mix building (incremental costs).

[2]In practice, the factors that predicate the requirements for a substation upgrade are widely varying (and include variables such as existing location-based grid constraints, and unique grid connection rules stipulated by local network owners/operators). The context of a building's development can also have an impact: it is common for developers of buildings in areas where electrical infrastructure exists to bear the costs of network upgrades, whereas substation and high voltage infrastructure costs at greenfield sites without existing electrical infrastructure are typically sustained by the network operator. The importance of treatment and consideration of the network/substation costs is critical to the analyses, as adjustments to these assumptions can have material impacts to the results. The 50 kW rule has been developed and applied as a realistic benchmark for analysis purposes.

Additional Cost Considerations

The economic assessment is carried out as a Net Present Value (NPV) calculation for a 50-year period with a discount rate of 5%. For Scenarios 1 and 2, the electrification upgrade is assumed to occur in year 10, at which time the existing heating plant is removed, and a new heat pump heating plant is installed. The existing chilled water plant is retained and serves the remainder of its economic lifecycle albeit at lower service loads – it's anticipated that the new heat pumps will serve part of the cooling loads with the existing chilled water plant in 'reverse' mode to reduce the service load on both the heat pumps and chillers. Treatment of the upgraded plant will vary in real-world applications. For example, one building may use the newly upgraded electric heating plant only in heating mode until the chilled water plant reaches the end of its life span and is replaced with a new unit (likely at a lower capacity to make use of the heat pump's reverse cycle). Another building may choose to use part of the heat pump plant for cooling from day one to enable all plant to operate at part load. Treatment of this aspect in the analysis is intended to provide one likely outcome for the energy costs in the NPV analysis. This will have an operational cost impact between years 10 and the chiller replacement year (20-25 depending on the chiller plant type). For Scenario 3, the chiller(s) are sized to meet the balance of the cooling load not able to be covered by the heat pumps. This results in, for example, no additional chillers required in climate zones 7 and 8 for the C5OL archetype, and climate zone 8 only for the C9A archetype. The remainder of the electrification solutions (excluding climate zones 2 and 5) see economic benefit by a reduction in total chiller capacity and cost by making use of the heat pumps in 'reverse' mode.

This leads to the consideration of residual plant value. Economic lifecycle has been applied to different plant dependant on their technology type and is presented in Table 3. These figures are based on a combination of data published by AIRAH[3] and past project experience. For air-sourced heat pump plant installed in year 10 (Scenario 1) this results a residual plant value at year 50 calculated based on 10 years of remaining plant life.

Table 3: Applicable HVAC equipment economic lifecycle

Equipment	Economic Lifecycle
Water cooled chiller	25 years
Air-cooled chiller	20 years
Air-source (air-to-water) reversible heat pump	20 years
Electric duct heater	25 years

The cooling and heating energy consumption for each climate zone, archetype and, scenario has been modelled and included in the cost for each year (using a varying energy cost as applicable) of the associated NPV analysis. Scenario 1 and 2 include gas and electricity consumption prior to the upgrade year (year 10) and electricity costs only following the upgrade, whereas Scenario 3 includes electricity cost only.

[3] AIRAH, "DA19 HVAC&R Maintenance", Fourth Edition (2019)

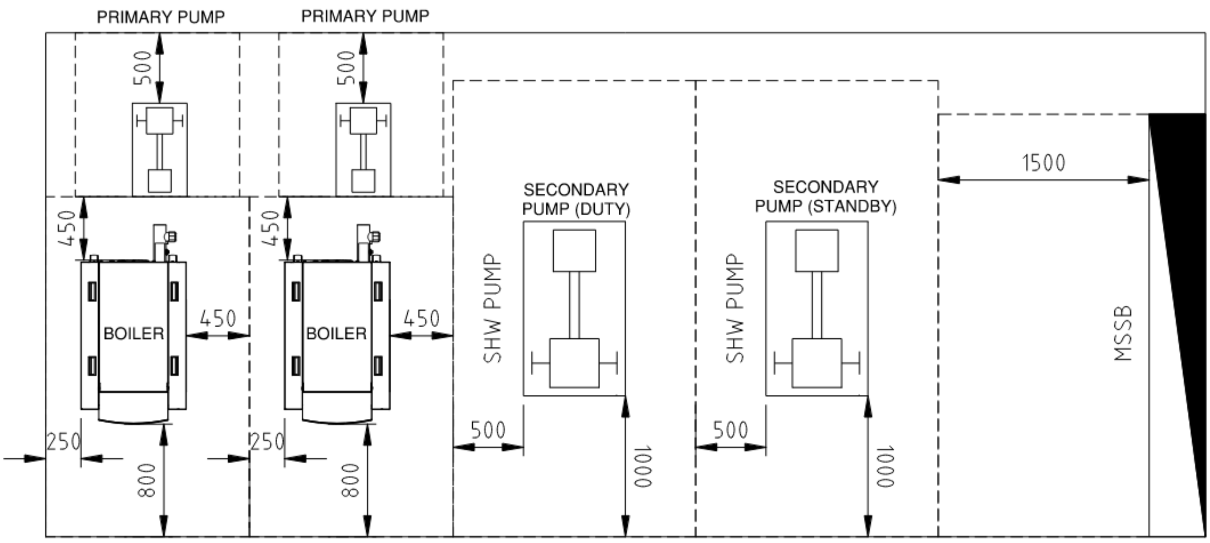
2.2.1 C5OL – Class 5 Large Office

Base Case Design

A base case heating plant design that would typically be installed in a Class 5 large office building in each climate zone consists of the following:

- Two (2) condensing gas boilers, each sized for 60% of the peak building heating load.
- Two (2) primary heating hot water pumps.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- 70-55°C heating hot water flow and return temperatures.
- Building works for an open-air plantroom with plant deck and 2.4m high louvres provided for cooling towers only.

This plant arrangement has been used as the base case design to compare against the cost of all electrification scenarios. A typical plantroom layout for the heating plant is shown below.



Scenario 1 Design – Electrification with no preparation

This case explores the cost and impact to install an electric heating plant in an existing building that was never provisioned for.

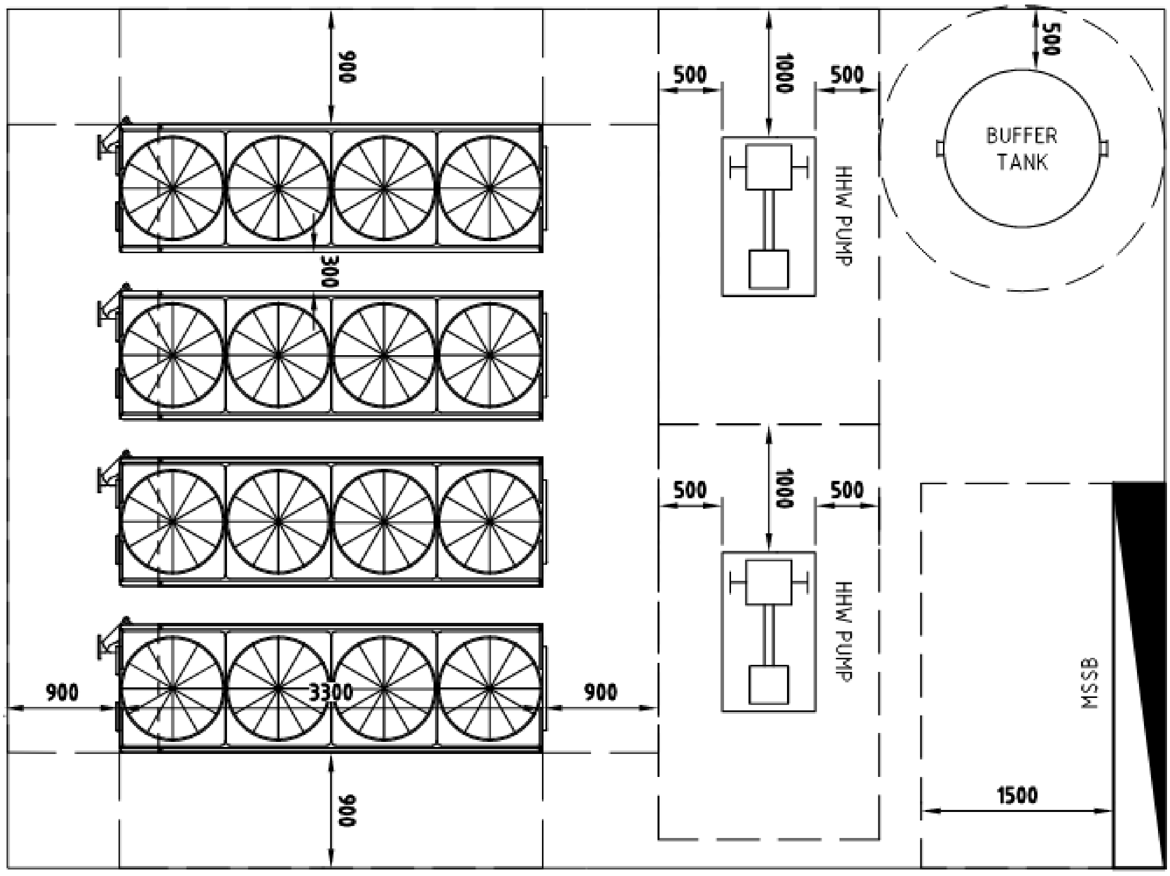
The installation of an electric heating plant for space heating to be retrofitted into an existing Class 5 large office building in climate zones 3, 4, and 6-8 would typically consist of the following, which essentially upgrades and replaces the equipment listed in the base case:

- Modular 2-pipe air-sourced heat pump units with inbuilt primary pumps as required by the building heating load.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- One (1) heating hot water buffer tank.
- New heating hot water coils for five (5) existing air handling units (AHUs) and forty (40) on-floor reheat coils for perimeter zones in climate zones 6-8 (remaining climate zones have electric reheat coils).
- 45-37°C primary circuit heating hot water flow and return temperatures.
- 45-30°C secondary circuit heating hot water flow and return temperatures.

- Building works for a new open-air plantroom with plant deck and 2.4m high louvres retrofit above an existing sheet metal roof.
- Electrical infrastructure upgrades to suit the new electric plant including substation, MSB and submain upgrades where applicable.
- Connection to the chilled water system enabling the heat pumps to serve the building in cooling mode.
- Demolition of existing waterside heating plant (condensing boilers).

Gas boiler heating plant in an existing building will typically deliver anywhere between 80-60ºC supply heating hot water at a differential to return water temperature of 15-20°C. Typical (low temperature and efficient) electric heat pumps are not capable of reaching these temperatures. Therefore, the heating hot water coils in the existing AHUs will need to be replaced to be suitable for lower temperatures such as 45-30ºC (supply and return) hot water.

A typical plantroom layout for the heating plant is shown below. The layout is typical for electrification scenarios across climate zones 3, 4, and 6-8.



For climate zones 2 and 5, the electric heating system would simply consist of five (5) large electric duct heaters (EDH) installed in the main supply air duct for each AHU. Ductwork modifications and general power and control wiring would also be required to facilitate the EDH installation. Electrical infrastructure upgrades to the substation, main switchboard, and submains cabling are likely to be required for the EDH installation and are included where applicable.

Scenario 2 Design – Electrification with preparation (infrastructure provisions from day 1)

This case explores the cost and impact to install electric heating plant in an existing building that has previously provisioned infrastructure for future electrification.

Typically, the day one provisions would consist of the following:

- Additional building works for a new open-air plantroom with plant deck and 2.4m high louvres.
- Additional electrical infrastructure capacity within the substation, main switchboard, and submains cabling where required to suit the new heat pump installation.
- AHU heating coils capable of operating at the lower secondary water temperatures of 45-30°C.

The upgraded plant installation for space heating for a new Class 5 office building in climate zones 3, 4, and 6-8 would ultimately consist of the following:

- Modular 2-pipe air-cooled heat pump units with inbuilt primary pumps as required by the building heating load.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- One (1) heating hot water buffer tank.
- 45-37°C primary circuit heating hot water flow and return temperatures.
- 45-30°C secondary circuit heating hot water flow and return temperatures.
- Connection to the chilled water system enabling the heat pumps to serve the building in cooling mode.
- Demolition of existing waterside heating plant.

For climate zones 2 and 5, the upgraded electric heating system would simply consist of five (5) large electric duct heaters installed in the main supply air duct for each AHU. The electrical infrastructure capacity required by the substation, main switchboard, and submains cabling will be included in the day 1 provisions, as required for the EDH installation.

Scenario 3 Design – Day 1 electrification

This case explores the cost and impact to install an electric heating plant in a new building from day one of its life. The costs captured are the difference between the electric only scenario described below and the electric/gas mix described earlier in this section.

The installation of an electric heating plant for space heating for a new Class 5 office building in climate zones 3, 4, and 6-8 would consist of the following:

- Modular 2-pipe air-cooled heat pump units with inbuilt primary pumps as required by the building heating load.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement;
- One (1) heating hot water buffer tank;
- 45-37°C primary circuit heating hot water flow and return temperatures.
- 45-30°C secondary circuit heating hot water flow and return temperatures.
- Additional building works for a new open-air plantroom with plant deck and 2.4m high louvres.
- Connection to the chilled water system enabling the heat pumps to serve the building in cooling mode.
- Additional electrical infrastructure capacity within the substation, main switchboard, and submains cabling where required to suit the new heat pump installation.

For climate zones 2 and 5, the electric heating plant would simply consist of five (5) large electric duct heaters installed in the main supply air duct for each AHU on day 1, along with the required associated electrical infrastructure capacity (substation, main switchboard, and submains cabling).

2.2.2 C9A – Class 9a Hospital Ward

Typically for a hospital ward with the above cooling loads, the base case cooling system would be served by air-cooled chillers sized and arranged to provide N+1 cooling redundancy. For the electrification cases, the chilled water system would be served by one air-cooled chiller with the remaining cooling capacity and redundancy being provided by the 2-pipe heat pumps plant in cooling mode.

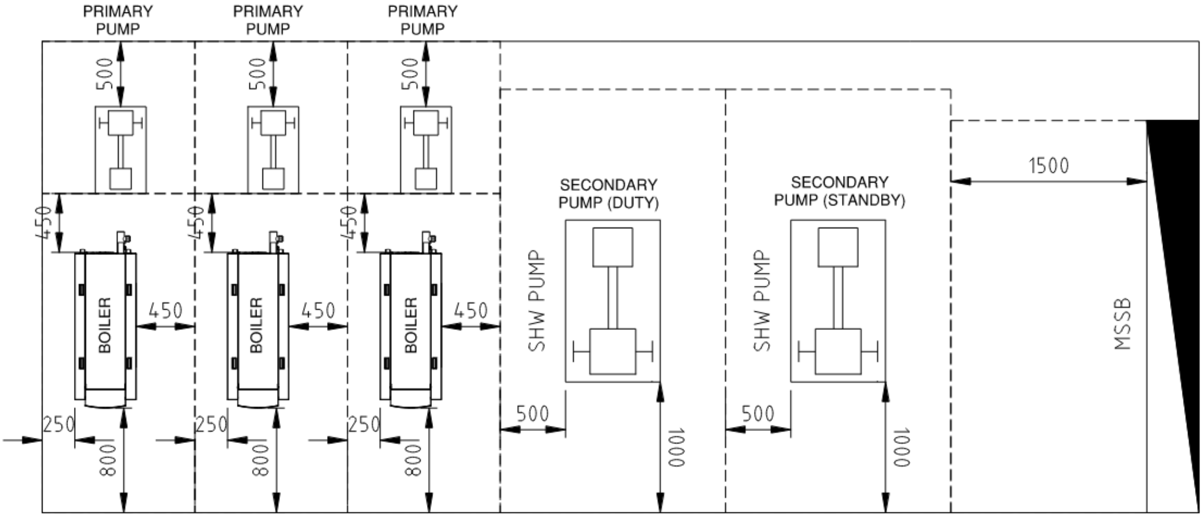
The base case heating system would be served by condensing gas boilers also sized and arranged to provide N+1 heating redundancy, while the electrification cases in climate zones 3, 4, and 6-8 would be served by heat pumps providing the same heating redundancy. Similar to the C5OL office, in climate zones 2 and 5 the electric heating system will be electric duct heaters installed to the FCUs. The heating plant arrangements for each case are summarised in further detail below.

Base Case Design

A base case heating plant design that would typically be installed in a Class 9a hospital ward in each climate zone consists of the following:

- Three (3) condensing gas boilers, each sized for 50% of the peak building heating load and providing N+1 redundancy.
- Three (3) primary heating hot water pumps.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- 70-55°C heating hot water flow and return temperatures.
- Building works for an open-air plantroom with plant deck and 2.4m high louvres is provided for the air-cooled chillers only.

This plant arrangement has been used as the base case design to compare against the cost for each of the electrification cases. A typical plantroom layout for the heating plant is shown below.



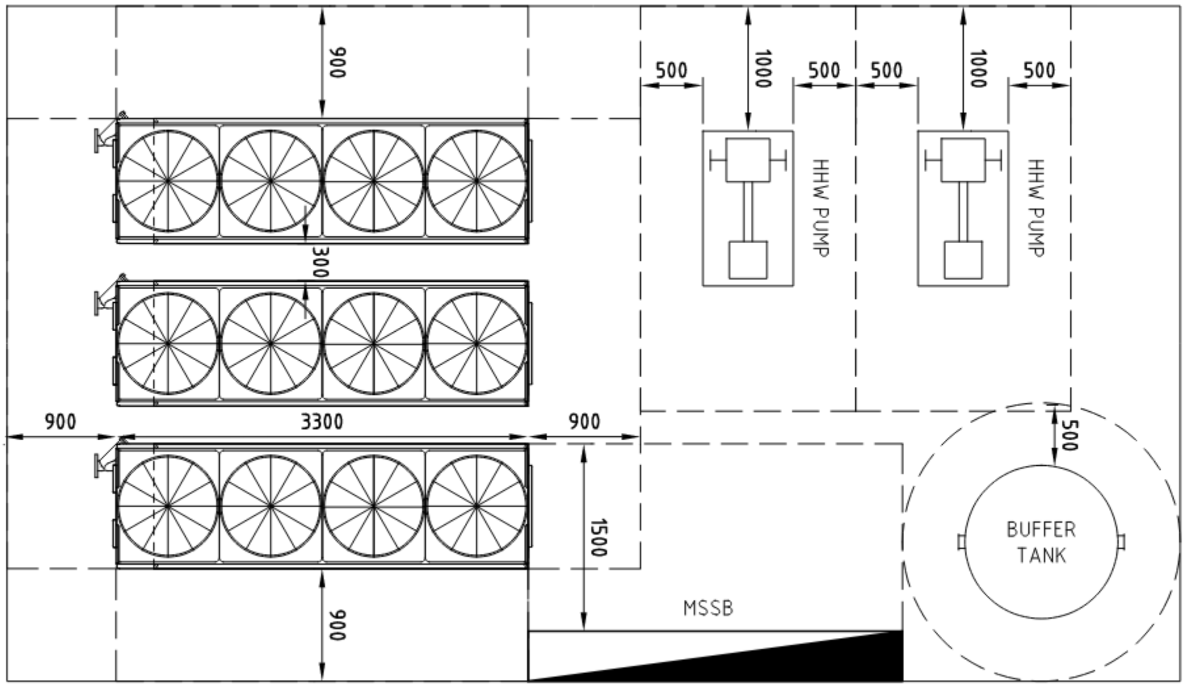
Scenario 1 Design – Electrification with no preparation

The installation of an electric heating plant to be retrofitted in an existing hospital ward in climate zones 3, 4, and 6-8 would typically consist of the following, which essentially upgrades and replaces the equipment listed in the base case:

- Modular 2-pipe air-sourced heat pump units with independent modules sized for N+1 redundancy and inbuilt primary pumps to replace both the boilers and one air-cooled chiller.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- One (1) heating hot water buffer tank.
- 45-37°C primary circuit heating hot water flow and return temperatures.
- 45-30°C secondary circuit heating hot water flow and return temperatures.
- One (1) new set of heating hot water coils for an existing AHU serving core areas.
- One (1) new set of heating hot water coils for an existing DOAS (Dedicated Outside Air System) AHU serving perimeter fan coil units (FCUs).
- 160 new sets of heating hot water coils for 160 existing FCUs serving the ward areas.
- Building works for a new open-air plantroom with plant deck and 2.4m high louvres retrofit above an existing sheet metal roof.
- Electrical infrastructure upgrades to suit the new electric plant including substation, MSB and submain upgrades where applicable.
- Connection to the chilled water system enabling the heat pumps to serve the building in cooling mode.
- Demolition of existing waterside heating plant.

Gas boiler heating plant in an existing building will typically deliver anywhere between 80-60°C supply heating hot water at a differential to return water temperature of 15-20°C. Typical (low temperature and efficient) electric heat pumps are not capable of reaching these temperatures. Therefore, the heating hot water coils in the existing AHUs will need to be replaced to be suitable for lower temperatures such as 45-30°C (supply and return) hot water.

A typical plantroom layout for the heating plant is shown below. The layout is typical for electrification scenarios across climate zones 3, 4, and 6-8.



For climate zones 2 and 5, the electric heating plant consists of 162 electric duct heaters (EDH) installed in the supply air duct of each AHU (2-off) and FCU (160-off). Ductwork modifications and general power and control wiring would also be required to facilitate the EDH installation. Electrical infrastructure upgrades to the substation, main switchboard, and submains cabling are likely to be required for the EDH installation and are included where applicable.

Scenario 2 Design – Electrification with preparation (infrastructure provisions from day 1)

Typically, the day one provisions would consist of the following:

- Additional building works for a larger open-air plantroom with plant deck and 2.4m high louvres.
- Additional electrical infrastructure capacity within the substation, main switchboard, and submains cabling where required to suit the new heat pump installation.
- AHU heating coils capable of operating at the lower secondary water temperatures of 45-30°C.

An upgraded electric heating plant arrangement for an existing hospital in climate zones 3, 4, and 6-8 would ultimately consists of the following:

- Modular 2-pipe air-sourced heat pump units with independent modules sized for N+1 redundancy and inbuilt primary pumps to replace both the boilers and one air-cooled chiller.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- One (1) heating hot water buffer tank.
- 45-37°C primary circuit heating hot water flow and return temperatures.
- 45-30°C secondary circuit heating hot water flow and return temperatures.
- Connection to the chilled water system enabling the heat pumps to serve the building in cooling mode.
- Demolition of existing waterside heating plant.

For climate zones 2 and 5, the electric heating plant consists of 162 electric duct heaters installed in the main supply air duct of each AHU and FCU. Electrical infrastructure capacity within the substation, main switchboard, and submains cabling will be included in the day 1 provisions, as required by the particular EDH installation.

Scenario 3 Design – Day 1 electrification

Scenario 3 captures the cost difference between the electric only scenario described below and the electric/gas mix described earlier in this section. A typical heating plant arrangement for a new hospital in climate zones 3, 4, and 6-8 consists of the following:

- Modular 2-pipe air-sourced heat pump units with independent modules sized for N+1 redundancy and inbuilt primary pumps to replace both the boilers and one air-cooled chiller.
- Two (2) secondary heating hot water pumps in a duty/standby arrangement.
- One (1) heating hot water buffer tank.
- 45-37^{o}C primary circuit heating hot water flow and return temperatures.
- 45-30^{o}C secondary circuit heating hot water flow and return temperatures.
- Building works for a new open-air plantroom with plant deck and 2.4m high louvres.
- Connection to the chilled water system enabling the heat pumps to serve the building in cooling mode.
- Electrical infrastructure capacity within the substation, main switchboard, and submains cabling suitable for a new heat pump installation.

For climate zones 2 and 5, the electric heating plant consists of 162 electric duct heaters installed in the main supply air duct of each AHU and FCU. Electrical infrastructure capacity within the substation, main switchboard, and submains cabling will be included in the day 1 construction, as required by the particular EDH installation.

2.3 Lifecycle Costing Results

The cost of each of the electrification scenarios in climate zones 2-8 for each archetype are summarised in Figure 1 and Figure 2 below. In summary of previous detailed descriptions, these broadly include:

- Capital equipment, plantroom and electrical costs
- Incremental equipment, plantroom and electrical costs
- Demolition costs
- Energy costs
- Residual plant value

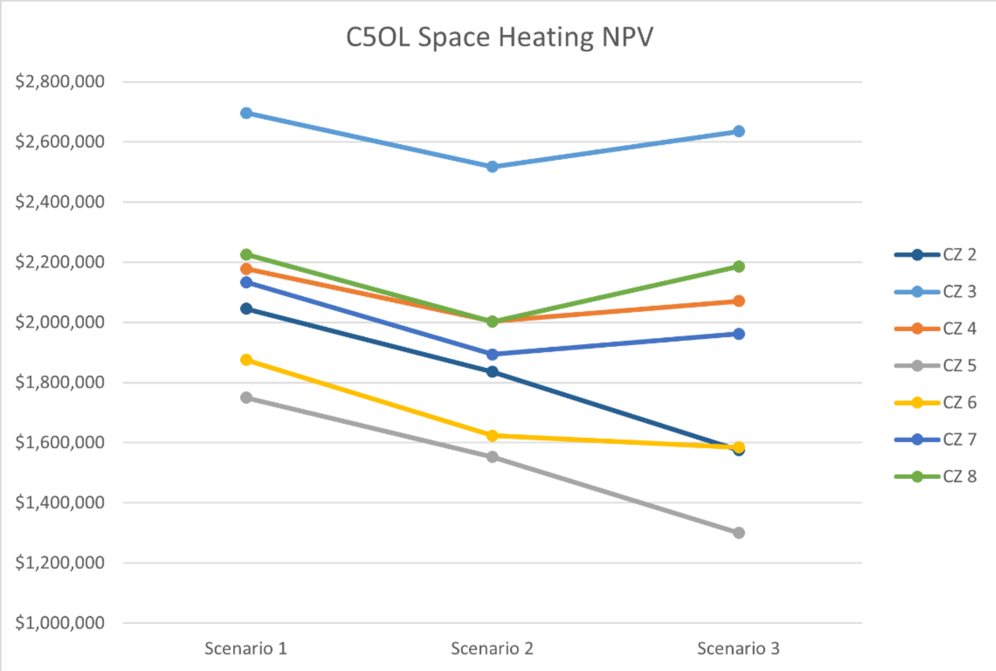


Figure 1: Space heating NPV results for the large office archetype across all scenarios and climate zones.

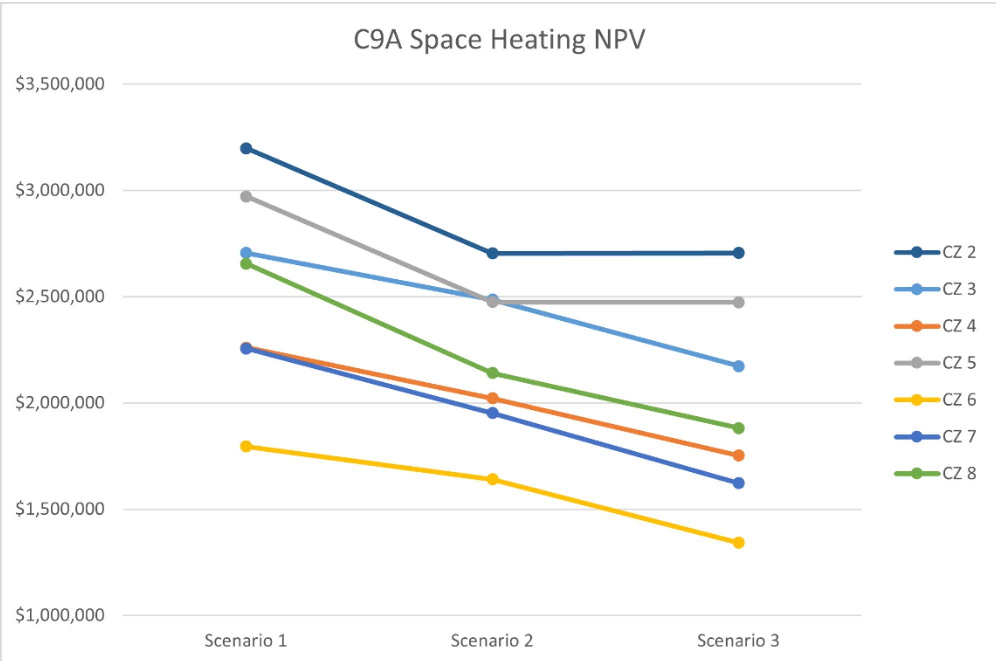


Figure 2: Space heating NPV results for the large hospital archetype across all scenarios and climate zones.

Given the emergence of mixed results with only a slight overall trend to Scenario 3 being present, the results were simplified in to three categories for each Scenario to determine the underlying trend. With the expectation that substation costs have the largest impact on lifecycle cost, the cases where a larger substation was required was separated out and plotted, along with the overall average.

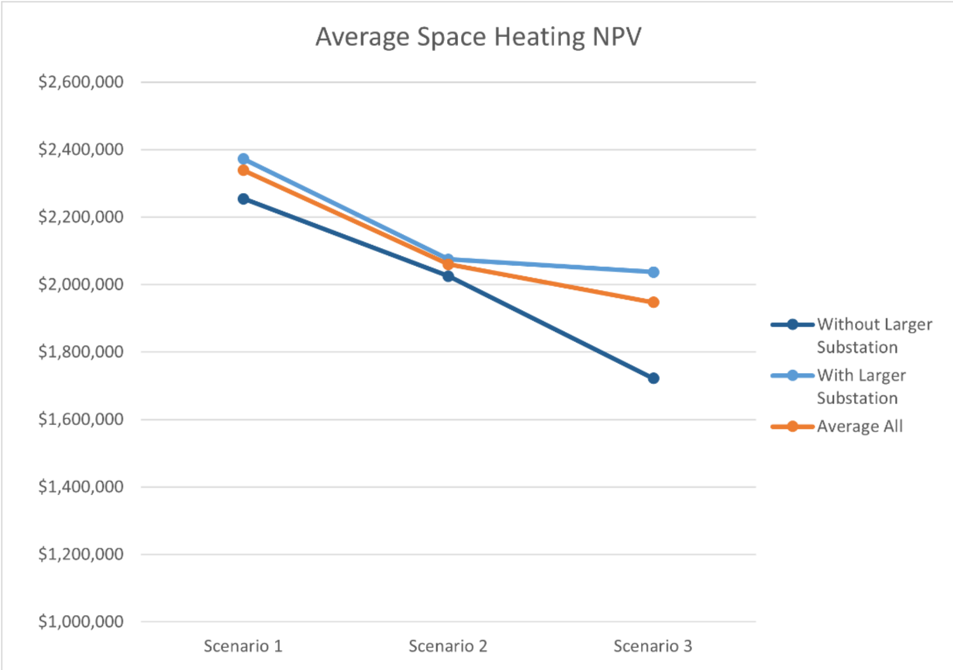


Figure 3: Space heating NPV summary

Further, the lifecycle plant (capital) and energy (operational) costs were separated and plotted for each scenario and climate zone, as presented in Figure 4 and Figure 5.

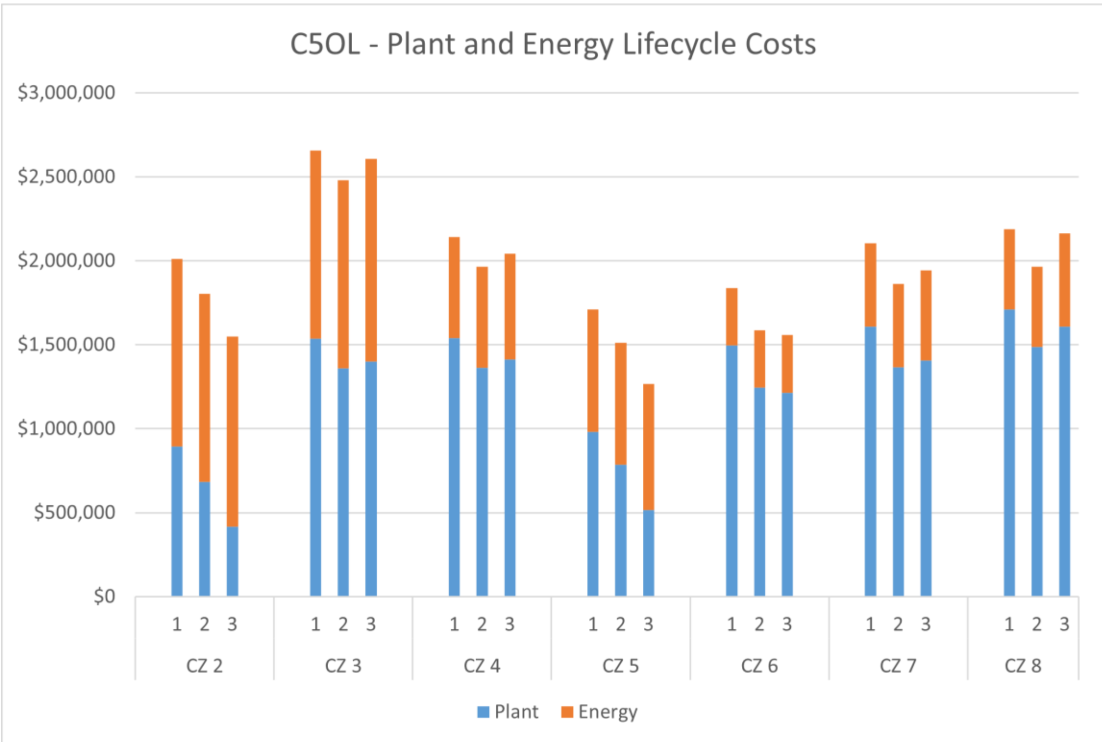


Figure 4: C5OL space heating NPV results for plant and energy costs, per scenario and climate zone

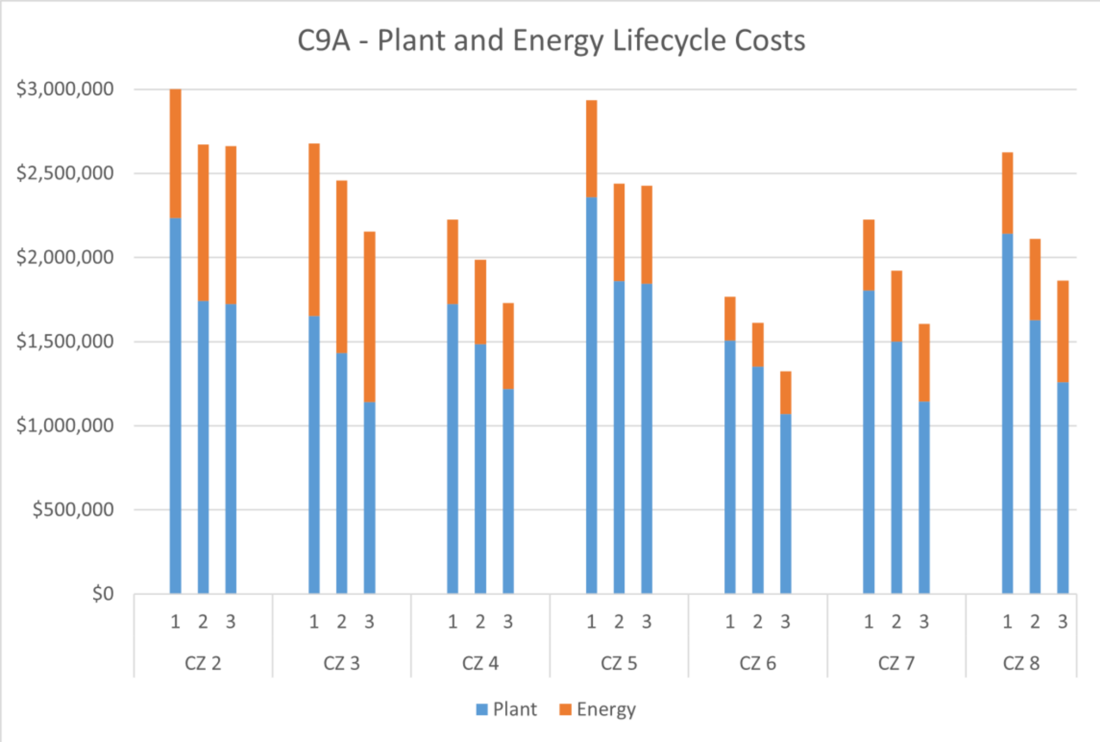


Figure 5: C9A space heating NPV results for plant and energy costs, per scenario and climate zone.

2.4 Discussion

Four out of fourteen cases did not require an increased substation capacity. However, the resulting trend shows that the mechanical plant retrofit/upgrade costs associated with Scenario 1 were more dominant than the substation costs but became more dominant in Scenarios 2 and 3 where retrofit costs for plant were much lower or non-existent. Figure 1 and Figure 2 also show the clear impact that climate zone has on electrification costs – with decreasing seasonal ambient temperatures, costs increase with increasing plant sizes/capacities.

Overall, the average lifecycle costs are shown to be less for Scenario 3 when compared to Scenario 2, with the cost difference for the average being approximately 5% (approximately $120,000 in absolute terms), with the deferred capital required for the upgrade in Scenario 2 and lower operating costs for the gas/electric mix building assisting to balance the cost savings of avoiding retrofit and additional heating plant costs altogether in Scenario 3. The costs for the four cases not requiring an increased substation capacity show a clear trend in favour of Scenario 3 (day 1 electrification), highlighting the importance of how substation costs are treated. Further sensitivity analyses by adjusting calculation inputs would be beneficial to determine the extent of how cost results are impacted dependent on key factors. These should include:

- Timing of electrification upgrade,
- Treatment of plant design and integration with existing site conditions (both physically and operationally),
- Building classification, and
- Plant lifecycle inputs.

Less tangible factors must also be considered. Scenario 3 presents a relatively simple pathway that's easily enforceable and easy to understand as the provisions required by Scenario 2 raise a complete new set of questions regarding what level of provision should be imposed. Further, Scenario 2 results in significant waste: electrical infrastructure of sufficient capacity for electrification is installed on Day 1 to suit a future requirement of an upgrade at an approximate and largely unknown date; gas-fired equipment is likely to be made redundant before the end of its typical lifespan; and either the originally installed chiller capacity is rendered partially redundant or the cooling capacity of heat pumps is left unutilised. Further, this analysis has revealed that there exists a multitude of variables that apply to Scenario 2 in regards to timing of upgrade and integration with existing HVAC plant. Such variables give rise to the potential for provision and integration to be executed counter or outside of code intent. A less efficient end result may be achieved if provision isn't ideally suited to <u>both</u> the day one gas-fired plant and ultimate fully electric HVAC plant. For these reasons, combined with the clear trend toward Scenario 3 being the lowest cost pathway, our recommendation is to pursue Scenario 3 and mandate day 1 electrification in code.

2.5 Proposed Measures

Proposed measures for full electrification and electrification readiness are presented here for clarity and information.

Full electrification text

J6D10 Space heating

(1) A heater used for *air-conditioning* or as part of an *air-conditioning* system must be—

[2019: J5.9]

- (a) a solar heater; or
- ~~(b) a gas heater; or~~
- (b) a heat pump heater; or
- (c) a heater using reclaimed heat from another process such as reject heat from a refrigeration plant; or
- (d) an electric heater if-
  - (i) the heating capacity is not more than 40W/m²; or
    - ~~(A) 10 W/m² of the *floor area* of the *conditioned space* in *climate zone* 1; or~~
    - ~~(B) 40 W/m² of the *floor area* of the *conditioned space* in *climate zone* 2; or~~
    - ~~(C) the value specified in Table J6D10 where reticulated gas is not available at the allotment boundary; or~~
  - ~~(ii) the annual energy consumption for heating is not more than 15 kWh/m² of the *floor area* of the *conditioned space* in *climate zones* 1, 2, 3, 4 and 5; or~~
  - (iii) the in-duct heater complies with J6D3(1)(b)(iii); or
- (e) any combination of (a) to (~~e~~d).

NSW J6D10(2)

(2) An electric heater may be used for heating a bathroom in a Class 2, 3, 9a or 9c building if the heating

capacity is not more than 1.2 kW and the heater has a timer.

(3) A fixed heating or cooling appliance that moderates the temperature of an outdoor space must be configured to automatically shut down when—

(a) there are no occupants in the space served; or

(b) a period of one hour has elapsed since the last activation of the heater; or

(c) the space served has reached the design temperature.

~~(4) A gas water heater, that is used as part of an *air-conditioning* system, must—~~

~~(a) if rated to consume 500 MJ/hour of gas or less, achieve a minimum gross thermal efficiency of 86%; or~~

~~(b) if rated to consume more than 500 MJ/hour of gas, achieve a minimum gross thermal efficiency of 90%.~~

~~**Table J6D10: Maximum electric heating capacity**~~

~~*Floor area of the conditioned space*~~	~~W/m^2 of *floor area* in *climate zone* 3~~	~~W/m^2 of *floor area* in *climate zone* 4~~	~~W/m^2 of *floor area* in *climate zone* 5~~	~~W/m^2 of *floor area* in *climate zone* 6~~	~~W/m^2 of *floor area* in *climate zone* 7~~
~~≤ 500 m^2~~	~~50~~	~~60~~	~~55~~	~~65~~	~~70~~
~~> 500 m^2~~	~~40~~	~~50~~	~~45~~	~~55~~	~~60~~

Electrification preparation text

J6D10 Space heating

(1) A heater used for *air-conditioning* or as part of an *air-conditioning* system must be—

[2019: J5.9]

(a) a solar heater; or

(b) a gas heater; or

(c) a heat pump heater; or

(d) a heater using reclaimed heat from another process such as reject heat from a refrigeration plant; or

(e) an electric heater if-

(i) the heating capacity is not more than 40W/m^2; or

~~(A) 10 W/m^2 of the *floor area* of the *conditioned space* in *climate zone* 1; or~~

~~(B) 40 W/m^2 of the *floor area* of the *conditioned space* in *climate zone* 2; or~~

(C) ~~the value specified in Table J6D10 where reticulated gas is not available at the allotment boundary; or~~

(ii) ~~the annual energy consumption for heating is not more than 15 kWh/m² of the *floor area* of the *conditioned space* in *climate zones* 1, 2, 3, 4 and 5; or~~

(iii) the in-duct heater complies with J6D3(1)(b)(iii); or

(f) any combination of (a) to (~~e~~d).

NSW J6D10(2)

(2) An electric heater may be used for heating a bathroom in a Class 2, 3, 9a or 9c building if the heating capacity is not more than 1.2 kW and the heater has a timer.

(3) A fixed heating or cooling appliance that moderates the temperature of an outdoor space must be configured to automatically shut down when—

(a) there are no occupants in the space served; or

(b) a period of one hour has elapsed since the last activation of the heater; or

(c) the space served has reached the design temperature.

(4) A gas water heater, that is used as part of an *air-conditioning* system, must ~~—~~

~~(a) if rated to consume 500 MJ/hour of gas or less, achieve a minimum gross thermal efficiency of 86%; or~~

(b) ~~if rated to consume more than 500 MJ/hour of gas,~~ achieve a minimum gross thermal efficiency of 90%.

~~**Table J6D10: Maximum electric heating capacity**~~

~~*Floor area of the conditioned space*~~	~~W/m² of *floor area* in *climate zone* 3~~	~~W/m² of *floor area* in *climate zone* 4~~	~~W/m² of *floor area* in *climate zone* 5~~	~~W/m² of *floor area* in *climate zone* 6~~	~~W/m² of *floor area* in *climate zone* 7~~
~~≤ 500 m²~~	~~50~~	~~60~~	~~55~~	~~65~~	~~70~~
~~> 500 m²~~	~~40~~	~~50~~	~~45~~	~~55~~	~~60~~

(5) A building that uses a gas heater for space heating must be provided with the facility to readily convert to electrical or heat pump space heating of equivalent functionality at a future date, comprising as a minimum -

(a) Electrical distribution board space, riser space and transformer capacity dedicated to the future provision of electrical space heating to replace the gas heater using:

(i) Direct electric heating if the required heating capacity is less than 30W/m²; or

(ii) Heat pump(s) of EER 3.25

(b) Reserved physical space for the siting the electrical space heating plant in a location that:

(i) Facilitates future connection to the space heating system; and

(ii) Is of sufficient size to accommodate the plant required in (a) either by specific design or (b) by default 36m² plus 0.04m² of required heating capacity; and

(iii) Has sufficient air movement to ensure efficient and effective operation.

(c) Use of a hot water circulation system and associated coils and heat exchanger designed to operate a peak temperature of less than 50°C

3 Domestic Hot Water

3.1 Technology assessment

3.1.1 Overview

This assessment explores electrification options for domestic hot water for three building archetypes across all climate zones. The following building archetypes were assessed[4]:

- C50L – Class 5 Large Office
- C9A – Class 9a Hospital Ward
- C9C – Class 9c Aged Care

It is anticipated that the selected archetypes will provide a good cross section to the range of costs and impacts for electrification scenarios across commercial buildings.

For each of the remaining three building archetypes, domestic hot water plant arrangements for a base case design and each electrification scenario across all climate zones have been considered. The assessment investigated the estimated capital cost of the plant installation in each case, electrical infrastructure impacts and additional required plantroom area.

A central plant system (as opposed to point-of-use) is a common design choice due to the increased domestic hot-water demand and improved economics. As such this forms the basis of the domestic hot water design for these archetypes. For the base case it was determined that gas instantaneous systems would be assessed for all climate zones as this is also a common design choice for the following reasons:

- Lower capital and operational costs;
- Smaller plant area; and
- Ease for maintenance and replacement.

For the electrification scenarios, a heat pump system is used for the assessment as this design choice is most common for the archetypes selected due to their high COPs (being 3-4) which provides an ongoing lower running cost. However, it is also important to recognise that heat pump systems do come at a higher capital cost compared to electric storage tank systems – so heat pump systems are often at risk of becoming cost-valued out of a project if it is struggling to meet construction budgets. To assess the reality and practicalities of this aspect a second electrification option was assessed for the C5OL large office archetype only, as this is the most likely archetype to be subject to this type of value management as the anticipated domestic hot water consumption (relative to the C9A and C9C archetypes) is lower.

[4] During initial assessment, a C5OM (Class 5 Medium Office) archetype was also considered but disregarded upon design assessment as it was determined that electric instantaneous hot-water units servicing base-building basins within bathrooms (supplemented by boiling/chilled water units servicing tenancy tea-point sinks) were the mostly likely option for installation for the base case.

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3.1.2 C5OL – Class 5 Large Office

Design Criteria

The design criteria to determine the requirements for domestic hot water for this archetype were determined from NCC 2022 D2D18 to determine occupancy rates (based on area per person) and NCC 2022 F4 D2/D4 to determine required facilities for the number of people. The below table outlines the assumptions made.

Table 4. DHW design criteria, large office (C5OL) archetype.

Item	Value
Occupancy Rate	10 m^2/person
Area	12,250 m^2
# Occupants	1,225 people
Facilities:	
Basin	50
Water Closet	80
Urinals	20
Kitchen Sink (Tea Points)	20

A central-plant solution is the most appropriate solution for a class 5 large office space based on the larger domestic hot-water demand.

For this study, it has been assumed that this archetype does not include any end-of-trip (EOT) facilities (including showers). Whilst the system chosen for each case would remain the same with the inclusion of an end of trip facilities, the hot water storage capacity of each system would likely be increased based on the number of showers within the EOT facility.

Base Case Design

A base case domestic hot water system that would typically be installed in a Class 5 large office building in climate zones 1 - 7 consists of the following:

- Five (5) gas instantaneous hot water units mounted externally (or internally within a plantroom with the appropriate fluing requirements).

A base case domestic hot water design that would typically be installed in a Class 5 large office building in climate zone 8 consists of the following:

- Six (6) gas instantaneous hot water units mounted externally (or internally within a plantroom with the appropriate fluing requirements).

These plant arrangements have been used as the base case design for the purpose of assessing demolition costs in electrification Scenarios 1 and 2 and incremental plant costs for Scenario 3.

It should be noted that other plant which would be required within the domestic hot-water system would include a circulating pump-set, flow/ return pipework, insulation, balancing valves and isolation valves. However, since this equipment is required (and would be retained) for the electric domestic hot water central plant arrangements, it is not required to be considered further in the costing assessment.

All Electrification Scenarios Design

Given the relative (to space heating) simplicity of the electric domestic hot water system the design solution is common across all scenarios. Small differences will be applied in the costing calculations – for example, demolition and timing of upgrade/retrofit.

The installation of an electric based domestic hot water plant designed/selected for a Class 5 large office building is summarised by the following table. The plant capacity differs between climate zones due to differences in potable water temperatures that enter the building and ambient air temperature. So, in climates that are cooler on average, the potable water supply is generally colder and plant must increase in size to support more heat input required in the coldest periods of the year. Further, the lower ambient temperatures prevailing in the cooler climate zones also derate the heat pump performance, as it is more difficult for the units to extract heat from the air.

Table 5. Summary of Electrification Solutions for each Climate Zone, for C5OL (Option A).

Climate Zone	Domestic hot Water Heating Plant	Plant Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
1, 2 and 5	• Two (2) 35kW Heat Pump • One (1) 2,000L Storage Tank	Y	N
3, 4, 6 and 7	• Two (2) 35kW Heat Pump • One (1) 315L 6 element cylinder; • One (1) 2,000L Storage Tank	Y	N
8	• Two (2) 35kW Heat Pump; • Two (2) 315L 6 element cylinder; • One (1) 2,000L Storage Tank	Y	Y

As noted previously, for some projects a heat pump solution is at times considered a 'premium' solution and can be subject to value management via replacement with a less efficient but cheaper direct electric type system. To explore these impacts over the large office building's lifecycle across the three electrification scenarios, direct electric options were assessed as an alternative solution to the above. The plant arrangements are summarised as follows:

Table 6. Summary of Electrification Solutions for each Climate Zone, for C5OL (Option B).

Climate Zone	Domestic hot Water Heating Plant	Plant Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
1, 2 and 5	• Three (3) 315L 6 element cylinder • One (1) 1,000L Storage Tank	N	Y
3, 4, 6 and 7	• Three (3) 315L 6 element cylinder • One (1) 1,000L Storage Tank	N	Y
8	• Four (4) 315L 6 element cylinder • One (1) 1,000L Storage Tank	N	Y

3.1.3 C9A – Class 9a Hospital Ward

Design Criteria

The design criteria to determine the requirements for domestic hot water for this archetype were determined from NCC 2022 D2D18 to determine occupancy rates (based on area per person) and NCC 2022 F4 D2/D4 to determine required facilities for the number of people. This archetype assumed a Class 9a building made up of 10 wards. The below table outlines the assumptions made.

Item	Value
Occupancy Rate	10 m^2/person (see note)
Area	10,368 m^2
# Occupants	1036 people (see note)
Facilities:	
Basin	130
Shower	130
Water Closet	13
Baths	10
Kitchen Sink (Tea Points)	20
Laundry Tub	10

Table 7. DHW design criteria for hospital ward (C9A) archetype. Note: While such high occupancy rates are not typical nor expected for a hospital, this rate is used to account for additional facilities typical for a hospital such as on-site laundries.

Base Case Design

A base case domestic hot water design that would typically be installed in a Class 9a hospital in climate zones 1 - 7 consists of the following:

- Eleven (11) gas instantaneous hot water units mounted externally (or internally within a plantroom with the appropriate fluing requirements).

A base case domestic hot water design that would typically be installed in a Class 9a hospital in climate zone 8 consists of the following:

- Thirteen (13) gas instantaneous hot water units mounted externally (or internally within a plantroom with the appropriate fluing requirements).

These plant arrangements have been used as the base case design for the purpose of assessing demolition costs in electrification Scenarios 1 and 2 and incremental plant costs for Scenario 3.

It should be noted that other plant which would be required within the domestic hot-water system would include a circulating pump-set, flow/ return pipework, insulation, balancing valves and isolation valves. However, since this equipment is required (and would be retained) for the electric domestic hot water central plant arrangements, it does not require to be considered further in the costing assessment.

All Electrification Scenarios Design

As per the above description for the large office archetype, the electrification solution for the hospital archetype is common across the three scenarios, with minor adjustments for timing and demolition. The installation of an electric based domestic hot water plant designed/selected for the large hospital archetype is summarised by the following table. The plant capacity differs between climate zones due to differences potable water temperatures that enter the building. So, in climates that are cooler on average, the potable water supply is generally colder and plant must increase in size to support more heat input required in the coldest periods of the year.

Table 8. Summary of Electrification Solutions for each Climate Zone, for C5OL (Option A)

Climate Zone	Domestic hot Water Heating Plant	Plant Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
1, 2 and 5	• Three (3) 35kW Heat Pump. • Three (3) 315L 6 element cylinder. • Four (4) 2,000L Storage Tank.	Y	Y
3, 4, 6 and 7	• Four (4) 35kW Heat Pump. • Three (3) 315L 6 element cylinder. • Four (4) 2,000L Storage Tank.	Y	Y
8	• Four (4) 35kW Heat Pump. • Four (4) 315L 6 element cylinder. • Four (4) 2,000L Storage Tank.	Y	Y

3.1.4 C9C – Class 9c Aged Care

Design Criteria

The design criteria to determine the requirements for domestic hot water for this archetype were determined from NCC 2022 D2D18 to determine occupancy rates (based on area per person) and NCC 2022 F4 D2/D4 to determine required facilities for the number of people. The below table outlines the assumptions made.

Item	Value
Occupancy Rate	15 m^2/person
Area	2,048 m^2
# Occupants	130 people
Facilities:	
Basin	130
Shower	130
Water Closet	130
Staff Hand Basin	13
Kitchen Sink (Tea Points)	3
Laundry Tub	3

Table 9. DHW design criteria for aged care (C9C) archetype.

Base Case Design

A base case domestic hot water design that would typically be installed in a Class 9c aged care building in climate zones 1 - 7 consists of the following:

- Six (6) gas instantaneous hot water units mounted externally (or internally within a plantroom with the appropriate fluing requirements).

A base case domestic hot water design that would typically be installed in a Class 9c aged care building in climate zones 8 consists of the following:

- Seven (7) gas instantaneous hot water units mounted externally (or internally within a plantroom with the appropriate fluing requirements).

These plant arrangements have been used as the base case design for the purpose of assessing demolition costs in electrification Scenarios 1 and 2 and incremental plant costs for Scenario 3.

It should be noted that other plant which would be required within the domestic hot-water system would include a circulating pump-set, flow/ return pipework, insulation, balancing valves and isolation valves. However, since this equipment is required (and would be retained) for the electric domestic hot water central plant arrangements, it does not require to be considered further in the costing assessment.

All Electrification Scenarios Design

As per the previous archetype description, the electrification solution for the aged care archetype is common across the three scenarios, with minor adjustments for timing and demolition. The installation of an electric based domestic hot water plant designed/selected for the aged care archetype is summarised by the following table. The plant capacity differs between climate zones due to differences in potable water temperatures that enter the building and ambient air temperature. So, in climates that are cooler on average, the potable water supply is generally colder and plant must increase in size to support more heat input required in the coldest periods of the year. Further, the lower ambient temperatures prevailing in the cooler climate zones also derate the heat pump performance, as it is more difficult for the units to extract heat from the air.

Table 10. Summary of Electrification Solutions for each Climate Zone, for C9C

Climate Zone	Domestic hot Water Heating Plant	Plant Modifications required for electric heating plant (Y/N)	Electrical infrastructure upgrade required (Y/N)
1, 2 and 5	• Two (2) 35kW Heat Pump. • One (1) 315L 6 element cylinder. • Two (2) 2,000L Storage Tank.	Y	N
3, 4, 6 and 7	• Three (3) 35kW Heat Pump. • One (1) 315L 6 element cylinder. • Two (2) 2,000L Storage Tank.	Y	Y
8	• Three (3) 35kW Heat Pump. • Two (2) 315L 6 element cylinder. • Two (2) 2,000L Storage Tank.	Y	Y

3.2 Costing Methodology

Hydraulic Costs

Pricing models have been created based on Opinion of Cost (OPOC) estimates generated for archetypes C5OL, C9A and C9C, base case and electrification scenarios. The cost estimate from each of the OPOCs have been graphed to create pricing models.

Pricing models have been created for each archetype base case and electrification scenario. These models have been used to generate a cost estimate of the heating plant for the different peak heat loads associated with each archetype case across all climate zones.

Items included within each costing model include;

- Hydraulic Hot Water Plant (not inclusive of distribution pipework, insulation and circulating pump sets – as this would remain the same across various central hot water plant options – however, inclusive of pipework to circulate water between the heat pump source, and storage tank); and
- Demolition costs of hydraulic plant for electrification Scenarios 1 and 2 (assumed to be $1000/m2 of hydraulic hot water plant).

The cost for each item of equipment has been gathered from a range of manufacturers, suppliers, general industry experience, and the Rawlinsons Construction Handbook. OPOC spreadsheets have been used to calculate the costs for each electrification and base case. Where applicable, a 10% retrofit premium has been applied to plant and electrical upgrades. This figure has been applied as an approximate average between figures presented by Rawlinsons and those gathered from past project experience.

Plantroom Cost

The plantrooms for the electrification scenarios (the base case is not relevant to the assessment as electrification scenarios result in additional plant room space required only) have been modelled as a plant deck with structural beams and columns. The cost, which has been taken from Rawlinsons, estimates the plant deck with beams at $909/m^2. Louvres have not been accounted for in the cost calculation as outdoor heat pumps are relatively small and assumed to not be intrusive enough to warrant screening by louvres.

Electrical Infrastructure Cost

For all electrification scenarios the domestic hot water scenario will require additional electrical capacity compared to the base case – the level of upgrade required was assessed on a case-by-case basis depending on the domestic hot water system demand. Using an approximate COP efficiency for each system (depending on climate zone), the additional electrical demand capacity required for the new domestic hot water plant has been calculated.

For electrification Scenario 1, it has been assumed that some spare capacity in the electrical infrastructure (substation and MSB) exists in the original building. As per the analysis for space heating (Section 2.2) this has been estimated to roughly 50 kW of spare electrical capacity for the building. Where the additional electrical capacity required for the new domestic hot water system is 50 kW or greater, the cost of substation, MSB and submain upgrades have been considered.

For electrification Scenarios 2 and 3, the electrical infrastructure costs for the substation, main switchboard and submains cabling to the MSSB have been estimated and applied as an incremental cost where the demand is 50 kW or greater. If the demand is less than 50 kW only the electrical infrastructure required for the domestic hot water plant is accounted for – that is, incremental submains and distribution boards.

Operating Costs

Operating costs for each of the three archetypes was calculated for the nominated gas-fired and electric domestic hot water plant. These calculations were based on a method developed using the ‘end use breakdown’ calculations in a range of energy audits carried out for a range of building types. This calculation was used in the Rapid and Least Cost Pathways for Decarbonising Buildings Operations[5] report. A derating factor (COP adjustment based on manufacturer data) has been

[5] Foo et. al., 'Rapid and Least Cost Pathways for Decarbonising Building Operations'. DeltaQ, 19 October 2022.

applied to heat pumps in relation to their climate zone group, as well as an adjustment to the duty shared between heat pumps and their direct electric boost back ups, to account for defrost action of heat pumps during low ambient temperatures. The DHW plant inputs used for the energy calculations were as presented in Table 11.

Table 11: Applicable HVAC equipment economic lifecycle

Archetype	Climate Zone	Heat Pump COP	Proportion of Heat pump vs. Direct Electric (Boost)
C5OL-A	1, 2, 5	4.2	100%
C5OL-A	3, 6, 7	3.5	75%
C5OL-A	8	3.2	50%
C5OL-B	1, 2, 5	N/A – Direct Electric only	N/A – Direct Electric only
C5OL-B	3, 6, 7	N/A – Direct Electric only	N/A – Direct Electric only
C5OL-B	8	N/A – Direct Electric only	N/A – Direct Electric only
C9A	1, 2, 5	4.2	80%
C9A	3, 6, 7	3.5	70%
C9A	8	3.2	50%
C9C	1, 2, 5	4.2	90%
C9C	3, 6, 7	3.5	70%
C9C	8	3.2	50%

Additional Cost Considerations

The economic assessment is carried out as a Net Present Value (NPV) calculation for a 50-year period with a discount rate of 5%. For Scenarios 1 and 2 the electrification upgrade is assumed to occur in year 10, at which time the existing DHW plant is removed and replaced with a new electric plant.

This leads to the consideration of residual plant value. Economic lifecycle has been applied to different plant dependant on their technology type and is presented in Table 12. For air-sourced heat pump plant installed in year 10 (Scenario 1) this results a residual plant value at year 50 calculated based on 5 years of remaining plant life.

Table 12: Applicable DHW equipment economic lifecycle

Equipment	Economic Lifecycle
Air-source (air-to-water) heat pump	15 years
Direct electric immersion heater storage tank	25 years

The energy consumption for each climate zone group, archetype and scenario has been modelled as per the description provided earlier in this section and included in the cost for each year (using a varying energy cost as applicable) of the associated NPV analysis. Scenarios 1 and 2 include gas and electricity consumption prior to the upgrade year (year 10) and electricity costs only following the upgrade, whereas Scenario 3 includes electricity cost only.

3.3 Lifecycle Costing Results

The lifecycle cost of each electrification scenario for each climate zone group for each of the three archetypes (with the two large office options) are summarised in the following charts.

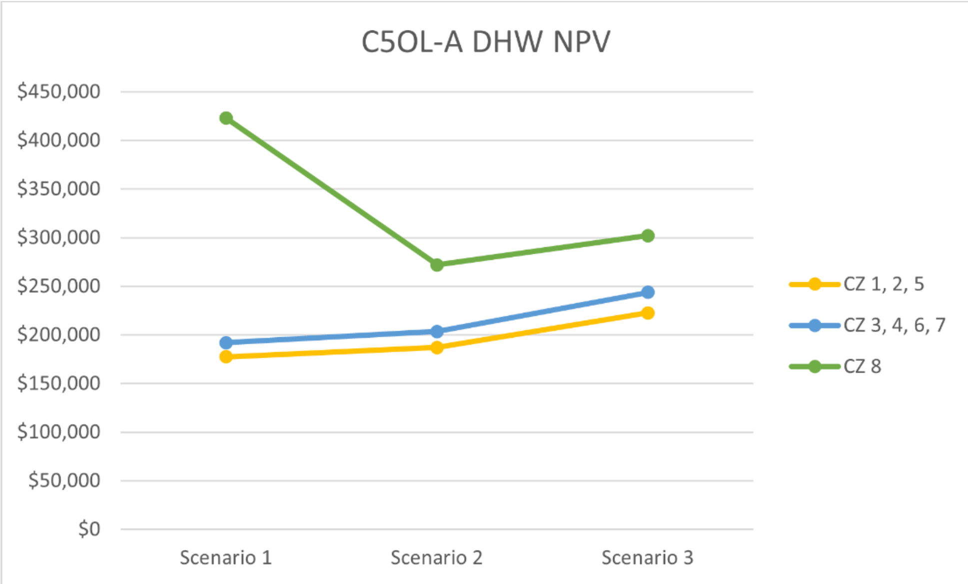

Figure 6: DHW NPV results for the large office archetype across all scenarios and climate zone groups (heat pump plant)

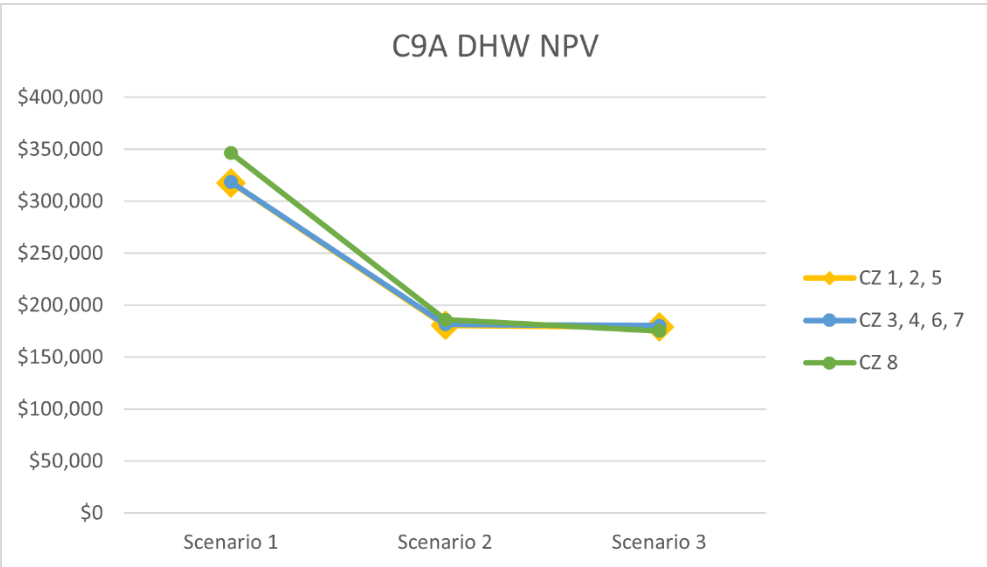

Figure 7: DHW NPV results for the large office archetype across all scenarios and climate zone groups (direct electric plant)

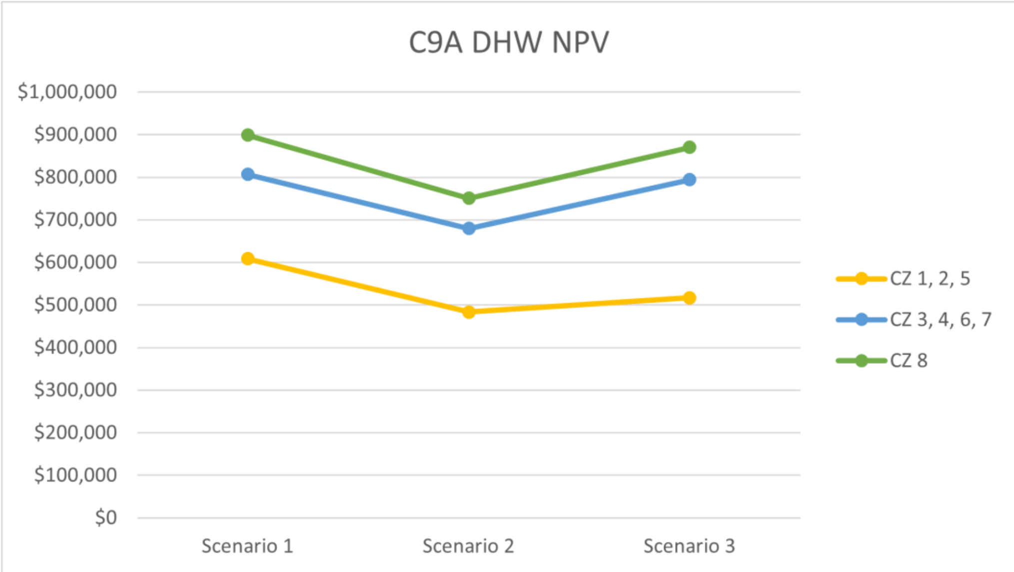

Figure 8: DHW NPV results for the large hospital archetype across all scenarios and climate zone groups

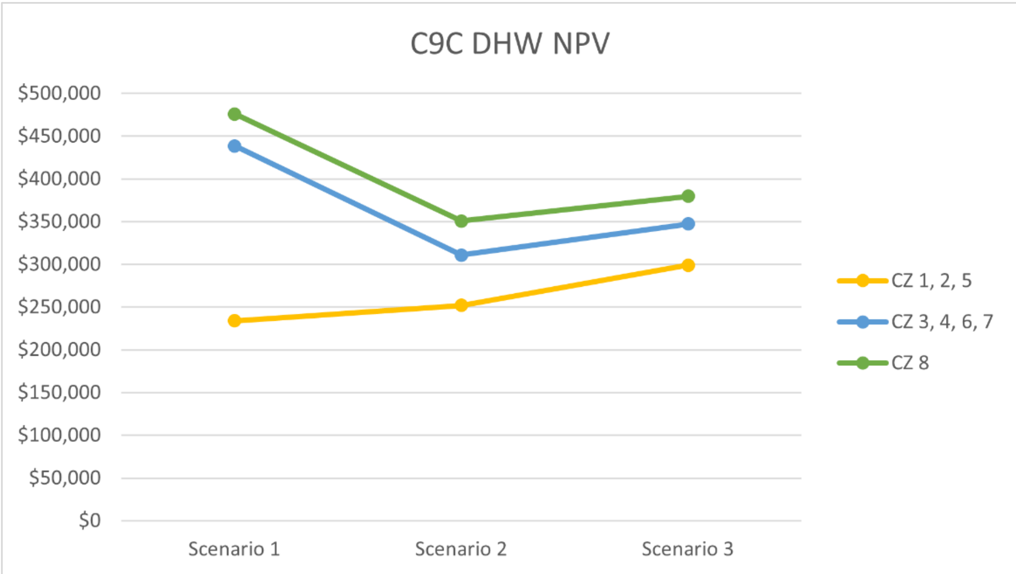

Figure 9: DHW NPV results for the aged care archetype across all scenarios and climate zone groups

Noting the emerging trend showing a high impact due to electrical and substation increase/installation costs, the average of the associated archetypes/climate zone groups were plotted against each other to further investigate the underlying details.

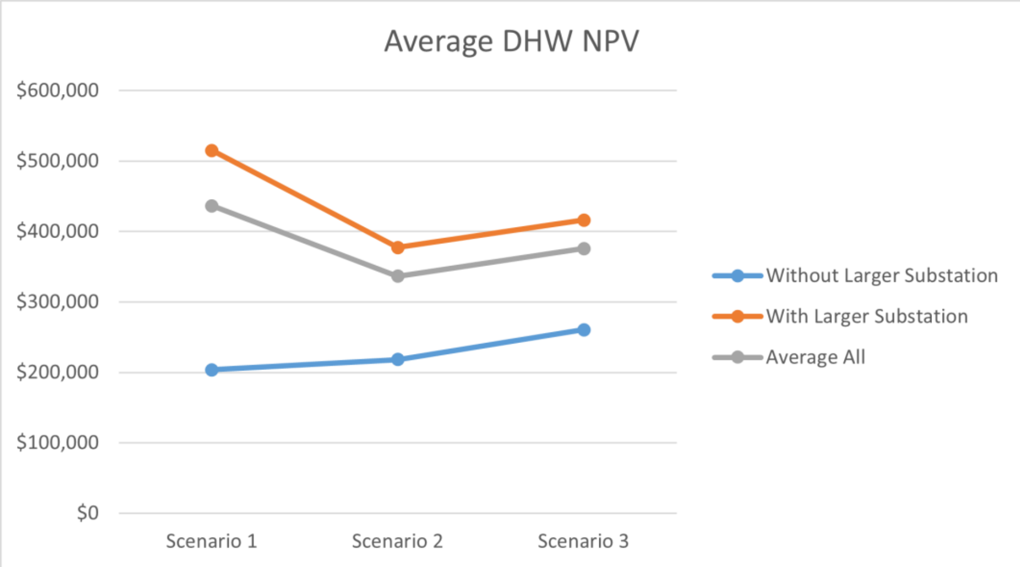

Figure 10: Average DHW NPV results separating substation/electrical impacts

Further, to illustrate the impacts of operating/energy costs and capital costs separately, the overall averages of each cost category were plotted separately and presented in Figure 11.

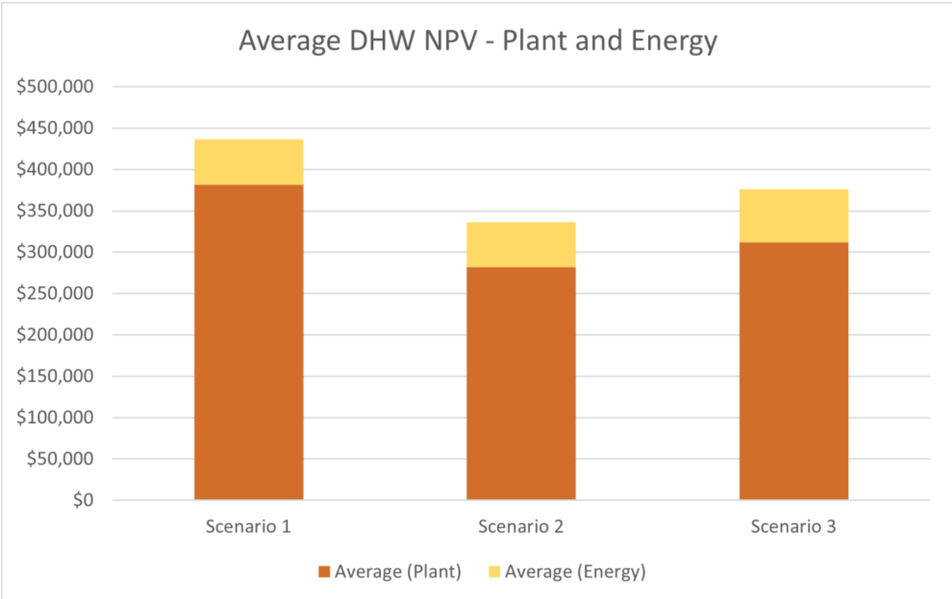

Figure 11: Average DHW NPV results for plant and energy costs

3.4 Discussion

Figure 11 shows the largest impact to cost lies in the capital equipment costs, as the underlying trend between this and the overall lifecycle costs are very similar. The obvious reduction in cost when comparing Scenarios 1 and 2 is dominated by the premium required to retrofit additional electrical capacity. The plant retrofit costs are also noteworthy but impose a much lower cost impact when compared with the electrical costs. The increase in energy costs for Scenario 3 are a result of gas being 25-35% of the cost of electricity at any given time. This means that the electric DHW system needs to operate at a seasonal/annual average COP of 3-4 to become operationally cost neutral compared to the gas-fired alternative. The overall average is dominated by a combination of the C9A archetype (which has much higher DHW loads, requiring more direct electric boost) and all the remaining cooler climate zones.

Again, the results that exclude cases that require substation upgrades in Figure 10 illustrate the benefit of delaying upgrade and retrofit requirements to year 10 and beyond. It should also be noted that this figure also illustrates how the trend is altered dependant on the treatment of substation costs. If substation costs were excluded, found to have more available/spare capacity for upgrade, or combined with another upgrade (for example, space heating) the lifecycle cost could be altered to provide a slightly different overall result.

Under the methodology used, the clearer trend overall is that Scenario 2 provides a lower cost pathway to electrification.

3.5 Proposed Measures

Proposed measure for electrification readiness is as follows.

J8D5 Domestic Hot Water

(1) Heating for domestic hot water in a class 3-10 building must be by—

(a) a solar heater; or

(b) a heater using reclaimed heat from another process such as reject heat from a refrigeration plant; or

(c) a geothermal heater; or

(d) a heat pump; or

(e) a gas heater; or

(f) an electric heater for a non-circulating system only; or

(g) an electric heater as a boost to (a) to (e); or

(h) a combination of (a) to (e).

(2) Domestic hot water pipework in a class 3-10 building must be insulated in accordance with Table J6D9a

(3) Where a gas heater has been used for domestic hot water heating, provision must be made for the domestic hot water heating to be converted to heat pump or electric heating of equivalent functionality at a future date, comprising as a minimum -

(a) Electrical distribution board space, riser space and transformer capacity dedicated to the future provision of domestic hot water heating, to replace the gas heater assuming a heat pump of EER 3.25 for circulating systems or direct electric heating for non-circulating systems; and.

(b) Reserved physical space for the siting the heat pump or electric domestic hot water plant and associated hot water storage in a location that:

(i) Facilitates future connection to the domestic hot water system(s); and

(ii) Is of sufficient size to accommodate the plant required in (a) either by specific design or (b) by default 7m^2 plus 0.04m^2 of required heating capacity

(iii) Has sufficient air movement to ensure efficient and effective operation.

4 Cooking

4.1 *Technology assessment*

4.1.1 *Overview*

This assessment explores electrification options for cooking equipment and appliances for eight sample and representative commercial kitchens. The following building sample kitchens were assessed:

- C6S – Small Retail: Take Away restaurant
- C6S – Small Retail: Take Away restaurant
- C9A – Hospital
- C9A – Mental health Unit
- C5L – Office Building
- C5L – Office Building
- C5M – Office Building
- C9C – Age Care

The cooking processes described in the ventilation design standard (which includes commercial kitchens) AS 1668.2 (Section 3.4) were referenced to generate a comprehensive list of common cooking processes. To carry out a practical assessment that is relevant in real-world applications this was coupled with actual kitchen layouts which are typical for common commercial kitchens with the aim of covering as much of the processes listed in the Australian Standard. These are referred to as the 'Base Cases' and are based on a randomly selected group of past projects. A number of appliances already have readily available and widely accepted electric alternatives, so this approach minimises unnecessary biases that may exist in more theoretical commercial kitchens.

A review was conducted for each equipment to assess the sizes, capacities, and available technologies in Australia. Further details for each appliance can be found in Appendix C: Cooking. Generally, there is a wide range of electrical appliances available in Australia that can replace gas-fuelled appliances.

Induction appliances are highly efficient due to their heat transfer mechanism, which directly transfers energy to the cookware. When an induction-compatible pan or cookware is used, there is an instant transmission of energy, resulting in efficient cooking. Moreover, when the pan is not present on the induction surface, there is minimal energy consumption, reducing heating losses and enhancing cooking precision. However, consideration needs to be given to their higher cost and the potential need to change cookware.

In terms of infrastructure requirements, induction appliances typically require clearance for ventilation for the purpose of heat dissipation from the appliance mechanism. A minimum of 250 mm of space is recommended between the appliance and side walls and 100 mm from the rear wall.

On the other hand, alternative direct electric appliances (for example, ceramic cooktops) offer good temperature control, but generally take longer to reach the desired temperature in comparison with induction appliances due to the reliance on heat transfer due to conduction from the appliance surface to the cookware. They are considered safer than gas as there is no open flame involved[6], which also

[6] Pears A. (May 2017). It's Heating Up: Energy Efficient Cooking. *The All-Electric Home, ATA Publications*, Pages 68-71

contributes to a more comfortable working environment. It should be noted, the major advantage of such types of cooking appliances is their significantly lower capital cost relative to induction alternatives.

Gas appliances are widely used across commercial kitchens due to their common characteristics, including rapid heat-up time and high heat output. These features make them particularly well-suited for applications that require intense heat, such as deep frying or wok cooking.

Base Case Layouts

A selection of 8 sample commercial kitchen layouts – base case layouts – were taken to determine typical commercial kitchen design across a range of typical arrangements. Table 13 shows the different scenarios selected and their respective building classifications. The gas to electric proportion column refers to the prevalence of gas-powered appliances in each kitchen. A high gas-to-electric proportion refers to a kitchen where all the appliances commonly available in gas-fuelled options are indeed powered by gas whereas a low gas-to-electric proportion indicates a kitchen where a significant portion of the appliances commonly available in gas-fuelled options have been transitioned to electric alternatives. It should be noted that Layout 5 was designed and constructed as a fully electric kitchen. It will not be included in further costing and analysis, however it is illustrated and described here for information.

Table 13: Commercial kitchen base case scenarios.

Layout	Building Class / Archetype	Detail	Gas to Electric equipment proportion
1	C6S	Small Retail - Take Away restaurant	High
2	C6S	Small Retail - Take Away restaurant	Medium
3	C9A	Hospital	Medium
4	C9A	Mental health Unit	Medium
5	C5L	Office Building	Nil
6	C5L	Office Building	High
7	C5M	Office Building	Low
8	C9C	Age Care	Medium

For each of these layouts an electrification option was evaluated to determinate the difference in their electric requirements and appliance cost. As an example, the list of gas appliances for Layout 1 is shown in Table 14, and to determine their electrical alternative each appliance was evaluated separately. Commercial options with equivalent or similar characteristics (in terms of cooking productivity) were selected as follows:

- Equivalent capacity. For example, for a cooktop same number of burners;
- Similar dimensions. For example, appliances with dimensions within approximately 100mm of the gas appliances were considered.

Table 14: List of appliances in Layout 1. Take away restaurant.

Unit	Model Name	Specification	Gas Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	FFR-1-300S	25 L	36 MJ/hr	345	753	1095
Chargrill	AT80G6C-F	600x700	53 MJ/hr	600	800	1115
Combi-oven	CXGBD10.10	11 Trays	81 MJ/hr	875	792	1058
Cooktop	RN8600G-B	6 Burners	168MJ/hr	900	805	80
Noodle cooker	PC8140E7	40 L	47MJ/hr	365	450	1130

Table 15 shows the selected electric appliances for Layout 1.

Table 15: List of electric appliances in Scenario 1. Take away restaurant.

Unit	Model Name	Specification	Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	RE114	25 L	14kW	396	786	1149
Chargrill	392271 EVO900	630x640	15kW	800	700	250
Combi-oven	XEVC-1011-E1RM	10 Trays	14 kW	750	773	1010
Cooktop (electric)	MOE516	6 Elements	14.4kW	900	812	1085
Cooktop (induction)	900XP-4	4 Elements	20 kW	800		
Cooktop (induction)	900XP-2	2 Elements	10 kW			
Noodle cooker	PC8140E7	40 L	10.5kW	365	450	1130

Seven of the eight layouts (Layouts 1-7) used gas cooktops with 6 burners; however, induction cooktops with 6 elements were not able to be sourced in Australia (the maximum was four). Further, it is possible that selecting two induction cooktops (four and two elements) would be prohibitively expensive compared to a ceramic electric alternative. Nevertheless, for comparison and assessment purposes, the electrification alternative for layouts 1-7 considered both technologies, and hence the results are presented as a range of costs, representing the difference in costs. Further, it should be noted that the ceramic electric element cooktop performs at a much lower power output and as a result is likely to provide a lower cooking performance. For all layouts that included both electric ceramic and electric induction technologies in their available options, the electrical and cost impacts are presented as a range. As a result, an ‘a’ and ‘b’ case has been developed for each layout to cover a range of electrification options, and is summarised in

Table 16: Electrification layouts summary

Layout case	Detail
a	Ceramic electric cooktop
b	Induction electric cooktop – separate cooktops allowed for (4 and 2) where the base case includes 6 burners

Layout 8 included two gas cooktops with four burners each in their base case. For consistency of assessment both induction and electric ceramic alternatives were used in the costing calculations.

Layout 6 included a six burner gas range – a direct replacement electric alternative with ceramic electric elements exists and is readily available in the Australian market, however the same cannot be said for an electric unit with an induction cooktop.

This same process was carried out for each layout with the details presented further in Appendix C.II: Appliances . Table 17 shows the additional electrical capacity for each layout, which is used to form the basis of electrical costing.

Table 17: Additional electrical capacity required per scenario.

Layout	Building Class / Archetype	Detail	kW
1	C6S	Small Retail - Take Away restaurant	67.4 – 83
2	C6S	Small Retail - Take Away restaurant	43.4 – 59
3	C9A	Hospital	21.4 – 37
4	C9A	Mental health Unit	35.9 – 51.5
6	C5L	Office Building	311.7
7	C5M	Office Building	17
8	C9C	Age Care	52 – 68.4

4.2 Costing Methodology

Three individual scenarios were assessed for comparison and are described in summary as follows, along with their cost elements non-exhaustively listed:

- Scenario 1: Electrification of an existing building with no provision or planning from a typical electric/gas building base case.
    - Capital cost of new electric equipment procurement is included and added to the cost of the existing gas-fuelled equipment.
    - Upgrade of an existing substation, Main Switch Board (MSB) and submains where the peak electrical load increases by >50kW. Note, this is assessed simply as an addition to the building's existing peak load, as it can be expected that the new peak cooking load is likely to occur concurrent with the building's existing peak load (for example, mid-summer at peak cooling). If the additional load was found to be <50kW, only minor electrical costs are required (for example, submains upgrade for new electric equipment).
- Scenario 2: Electrification with infrastructure provision. Electrification of an existing building where provision has been made during the initial construction of the building.
    - Capital cost of new electric equipment procurement is included and added to the cost of the existing gas-fuelled equipment.
    - Incremental electrical infrastructure costs (the same assessment as Scenario 1 applies here, but calculations are incremental costs for a new installation only):

    - Substation, MSB and submains costs where additional load is >50kW.
    - Submains costs only where additional load is <50kW.
  - Incremental cost for additional plant room space where applicable.
  - Demolition of existing heating plant and replacement with heat pumps or direct electric type (procurement and installation costs).
- Scenario 3: Electrification from day 1. This essentially captures any costs within the scope of assessment of the previous scenarios for a fully electric building constructed from day 1. For example, the electric appliances are included but the gas-fired equipment is excluded.

For Scenarios 1 and 2 the assessment assumes electrification is carried out in year 10.

Equipment Costs

Equipment costs have been compiled based on equipment procurement/capital costs only and excludes installation, which is expected to vary little between scenarios. Base case costs have been developed for the equipment specified on all eight layouts and thus forms the basis of the electric equipment alternatives. Equivalence of equipment quality and productivity/cooking capacity have been maintained to the maximum possible extent.

Given the vast majority of installation costs will be associated with electrical infrastructure and installation, further equipment procurement costs have not been included. Commercial cooking equipment is typically free standing and does not often require specialist contractor involvement for installation (beyond electrical requirements).

Layout/Spatial Costs

As noted previously the spatial requirements for electric equipment were investigated and found to be in the order of an additional 100mm to allow for ventilation of the induction equipment, for example. Given that the electric equipment alternatives were typically dimensionally ± 100mm compared to the gas appliances, this requirement was deemed to have negligible impact on capital costs and thus was ignored.

Electrical Infrastructure Cost

For all electrification scenarios the new all electric cooking layout will require additional electrical capacity compared to the base case – the level of upgrade required was assessed on a case-by-case basis depending on the additional equipment electrical demand.

Equivalent to the space heating and domestic hot water assessments, for electrification Scenario 1, it has been assumed that 50kW spare capacity in the electrical infrastructure (substation and MSB) exists in the original building due to common design practices. Therefore, for the purposes of estimating the electrical infrastructure costs, where the additional electrical capacity required for cooking is less than 50 kW, only the cost of new submains cabling to the kitchen's local Distribution Board (DB) has been considered, along with the cost of the distribution board and final circuitry. Where the additional electrical capacity required for cooking is 50 kW or greater, the cost of substation, DB, submain and final circuitry upgrades have been considered.

For electrification Scenarios 2 and 3, the electrical infrastructure costs for the substation, main switchboard, submains cabling to the DB and final circuitry to the equipment have been estimated and compared against the cost of the base electrical infrastructure required for a typical electric/gas mix kitchen (incremental costs).

Operating Costs

Operating costs for each of the layouts were calculated for the nominated gas-fired and electric kitchens. These calculations were based on a method developed from a real-world kitchen appliance gas consumption case and converting to electricity using cooking efficiency conversions dependent on the type of appliance and fuel source. This method was used in the Rapid and Least Cost Pathways for Decarbonising Buildings Operations[7] report. The efficiencies used for each equipment type is presented in Table 18.

Table 18: Cooking efficiency for gas-fired and electric equipment.

Equipment	Cooking Efficiency - Gas	Cooking Efficiency - Electric
Deep Fryer	50%	70%
Chargrill	22%	70%
Combi-oven	50%	70%
Cooktop	35%	70% (ceramic), 80% (induction)
Noodle cooker	35%	70%

Additional Cost Considerations

The economic assessment is carried out as a Net Present Value (NPV) calculation for a 50-year period with a discount rate of 5%. For Scenarios 1 and 2 the electrification upgrade is assumed to occur in year 10, at which time the existing gas-fired equipment is removed and replaced with a new electric plant. In recognition of the (relative to space heating and DHW systems) short life span of commercial kitchens equipment replacement timeframes has been reduced to 15 years to coincide with assumed major kitchen refurbishments. For Scenarios 1 and 2 the first refurbishment is assumed to coincide with the upgrade year (year 10), then every 15 years thereafter. Whereas the Scenario 3 refurbishment occurs every 15 years from year 0. Residual value has been applied at the end of the 50-year period dependant on the equipment's' remaining life within the 15 year refurbishment cycle.

The energy cost for each layout has been calculated for each year (using a varying energy cost as applicable) of the associated NPV analysis. Scenarios 1 and 2 include gas and electricity consumption prior to the upgrade year (year 10) and electricity costs only following the upgrade, whereas Scenario 3 includes electricity cost only. Residual equipment value is not considered in this assessment.

4.3 Technology Costs

4.3.1 Appliances Cost

After selecting the feasible electrical appliances to replace the gas-fuelled ones, as explained in Section 4.1, the costs for each appliance were obtained from Australian commercial kitchen suppliers. For more detailed information, please refer to Appendix C.I. Table 19 presents the results for each layout. Currently, the disparity between gas and electrical appliances in the market is not significant (excluding induction cooktops), resulting in relatively low reported differences. It is important to note that the cost presented below only covers the price of each appliance and does not take into account potential

[7] Foo et. al., 'Rapid and Least Cost Pathways for Decarbonising Building Operations'. DeltaQ, 19 October 2022.

costs associated with changing cookware, such as when using induction appliances, which can account for an additional 1-4% of capital cost in addition to the cooktop appliance.

Table 19 Appliances cost for each base case scenario and its electrification cost.

Layout	Building Classification / Archetype	Detail	Base case cost	100% Electrical appliances cost
1	C6S	Small Retail - Take Away restaurant	$44,200	$43,200 – $66,700
2	C6S	Small Retail - Take Away restaurant	$36,500	$43,200 – $66,700
3	C9A	Hospital	$26,900	$31,700 – $55,300
4	C9A	Mental health Unit	$78,300	$76,200 – $99,700
6	C5L	Office Building	$297,300	$275,000
7	C5M	Office Building	$75,000	$75,200
8	C9C	Age Care	$68,900	$73,400 – $108,000

In layout 7, for instance, a fryer was the only appliance that needed to be changed to electric. The price for the electrical option with the same capacity and dimension only differs by $200. In addition, this layout has a high base case cost relative to its size due to already incorporating induction cooktops.

The three more common appliances that are used in the base cases are cooktops, combi ovens and deep fryers. In Table 20 the average prices per burner, tray, and litre are shown, reflecting the capacity or specifications of each appliance. The average costs demonstrate that the difference between gas and electrical appliances is similar across the range of equipment except for cooktops, where the average cost per burner is significantly higher for induction technology.

Table 20: Average technology cost for cooktops, combi oven and fryers

Cooktop	Average ($ per burner/element)
Induction	$5,260
Electricity	$1,210
Gas	$1,390
Combi Oven	**Average ($ per tray)**
Electricity	$1,900
Gas	$2,072
Fryer	**Average ($ per L)**
Electricity	$231
Gas	$246

4.3.2 Electrical Cost

The cost for the electrical cost components for all scenarios, were evaluated and summarised in Table 21 for each layout.

Table 21: Electrical works cost for case 1.

Base scenario	kW	Scenario 1	Scenario 2 & 3
1a	67	$355,100	$87,100
1b	83	$357,900	$89,900
2a	43	Nil	Nil
2b	59	$353,600	$85,600
3a	21.4	Nil	Nil
3b	37	Nil	Nil
4a	35	Nil	Nil
4b	51.5	$352,300	$84,300
6	311.7	$411,100	$141,100
7	59.4	$353,700	$85,692.00
8a	92.4	$359,600	$91,600
8b	108.8	$368,600	$99,600

4.4 Lifecycle Costing Results

The cost of each of the electrification scenarios for each kitchen layout are summarised in Figure 12 and Figure 13 below. In summary of previous detailed descriptions, these broadly include:

- Capital equipment/appliance costs
- Incremental electrical costs
- Energy costs

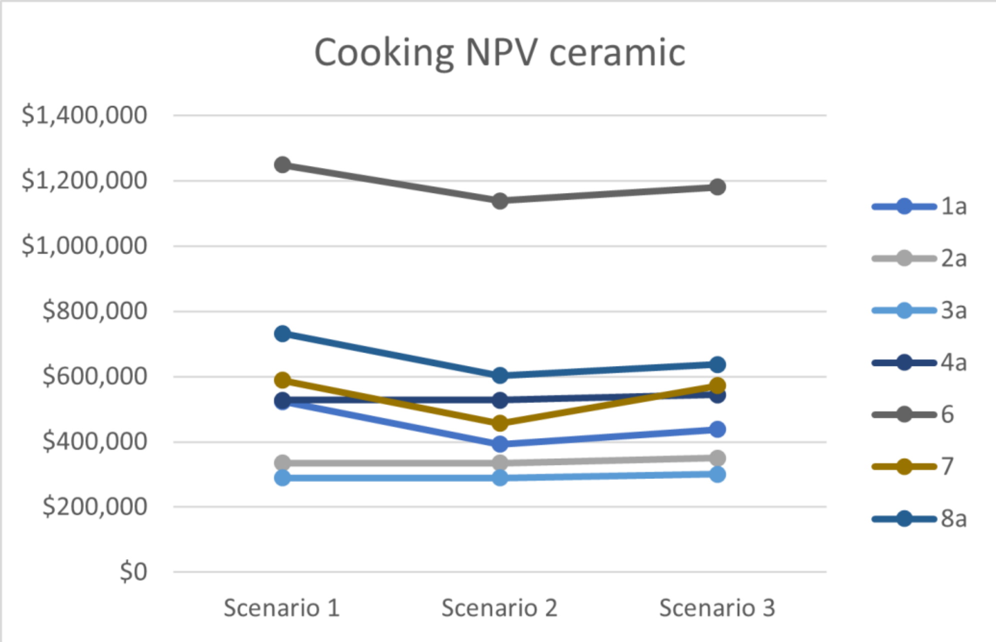

Figure 12: Cooking NPV results for layouts using ceramic electric cooktop options across all scenarios.

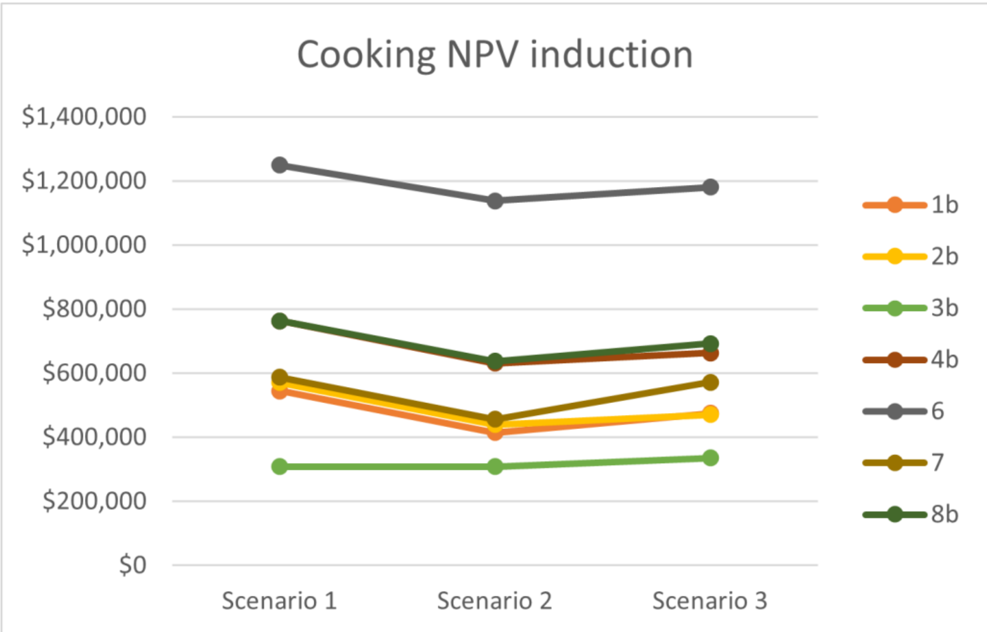

Figure 13: Cooking NPV results for layouts using induction electric cooktop options across all scenarios.

Noting the emerging trend showing a high impact due to electrical and substation increase/installation costs, the overall average of three groups were plotted against each other to further investigate the underlying details.

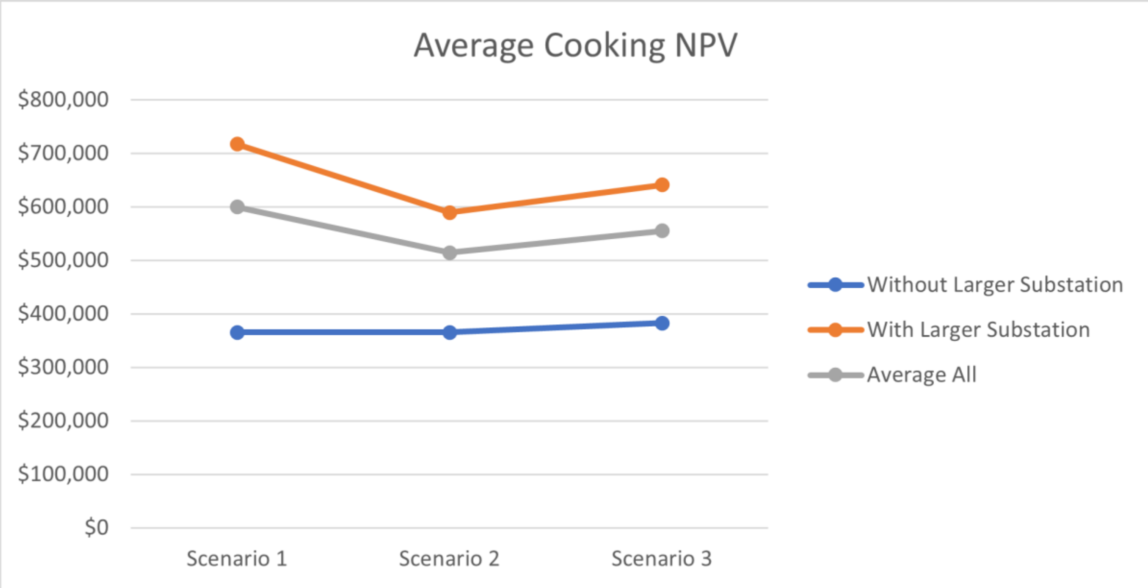

Figure 14: Average cooking NPV results for three groups of layouts.

To investigate the equipment and energy costs individually, the average of each for the three scenarios was combined and presented in Figure 15.

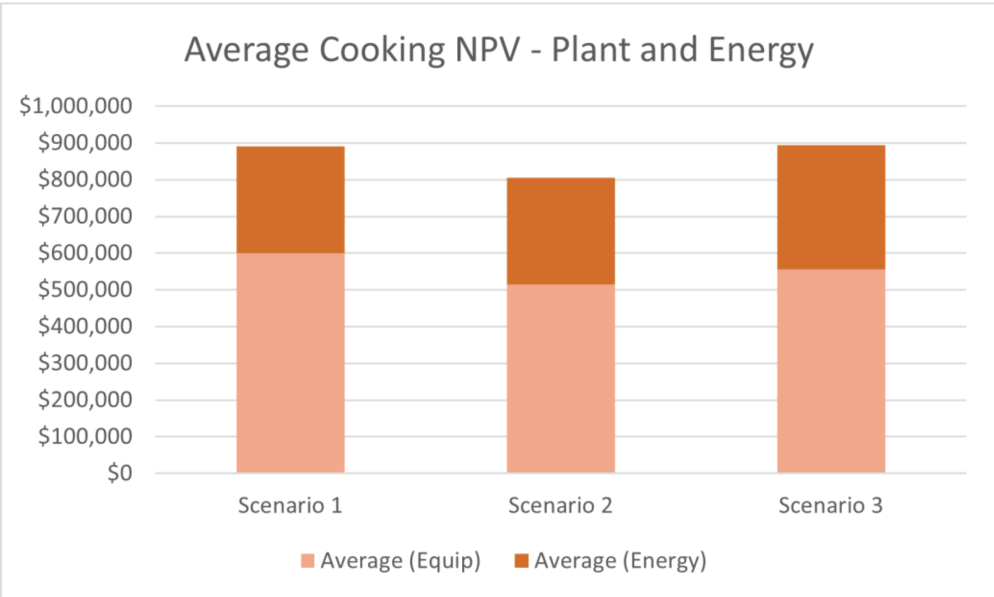

Figure 15 Average Cooking NPV results for equipment and energy costs.

4.5 Discussion

The costing results summarised in Figure 14 highlight that the cost impact is entirely dependent on whether an electrical substation upgrade/capacity increase is required. This is the case for 8 out of 12 Layouts. Beyond this factor, the layouts which did not need a larger substation (demand increases by <50 kW) show that the electrification scenario/preparedness level and timing has very little impact on the lifecycle cost.

Scenario 3 does show a very slight reduction in lifecycle cost, which is a result of both a reduction in energy cost (thanks to more efficient equipment) and the avoidance of first purchasing gas-fired equipment and later replacing with new all-electric equipment. It should also be noted that the induction electrification layouts (those names with ‘b’ appended) include two layout (2b and 4b) that requires a larger substation when compared with the ceramic element ‘a’ alternative. This fact has occurred because the induction stovetops were available with larger power outputs, more in line with the outputs of the original gas-fired counterparts. It is possible that the ceramic electric element type cooktops will not receive the same widespread uptake as the induction cooktops due to a reduction in productive capacity – however induction cooktops do come at a premium price point. Which technology will be the dominant type is likely to be dependent on the financial priorities of a given commercial kitchen.

The cost results and methodology used show that Scenario 2 on average is the most cost-effective pathway to electrification. For this reason, it is recommended to pursue Scenario 2 for electrification provision in code.

4.6 Proposed Measures

Proposed measure for electrification readiness is as follows.

J8D6 Cooking

(4) Where a gas has been used for a cooking appliance other than a portable cooking appliance, the building must be provided with electrical distribution board space and risers dedicated to the future provision of a functionally equivalent electrical cooking appliance to replace the gas cooking appliance.

Appendix A: Space Heating

Appendix A.I: Equipment Tables

Table 22: Gas-fired heating equipment data

	Unit A	Unit B	Unit C
Nominal heat output at 80/60 ºC (kW)	190,4	381,3	476,7
Minimum heat output at 80/60 ºC (kW)	42,0	75,2	94,6
Nominal heat output at 50/30 ºC (kW)	199,9	401,1	503,2
Minimum heat output at 50/30 ºC (kW)	47,0	85,0	106,1
Nominal heat input Hi full load (kW)	194,0	388,0	485,0
Minimum heat input Hi min. load (kW)	43,1	77,6	97,0
Efficiency at 80/60 ºC full load (%)	98,2	98,3	98,3
Efficiency at 50/30 ºC min. load (%)	109,2	109,5	109,4
Efficiency at 40/30 ºC min. load (%)	110,0	110,3	110,3
Max. permissible flue resistance (Pa)	200	400	300
Water flow at ΔT=10K (m^3/h)	16,2	32,5	40,7
Hydraulic resistance at ΔT=10K (kPa)	107	129	137
Water flow at ΔT=20K (m^3/h)	8,1	16,3	20,3
Hydraulic resistance at ΔT=20K (kPa)	27	32	34
Water flow at ΔT=30K (m^3/h)	5,4	10,8	13,6
Hydraulic resistance at ΔT=30K (kPa)	12	14	15
Electrical connection (V)	230/400	230/400	230/400
Electrical power consumption (excl. pump) (W)	267	504	620
Weight (empty) (kg)	332	496	540
Dimensions			
Air intake connection (A) (for room sealed use) (mm)	130	130	150
Condensate connection (S) (mm)	32	32	32
Boiler length without water connection (mm)	1315	1302	1452
Boiler Height (mm)	1470	1470	1470
Boiler Width (mm)	470	750	750

Table 23: Air Sourced Heat Pump Data

	Unit A	Unit B
Electrical Supply	380V/400V/415V	
Cooling capacity (kW)	180	200
Heating capacity (kW)	180	200
Exterior Dimensions: H (mm) x W(mm) x D(mm)	2350 x 1000 x 3300	2350 x 1000 x 3300
Shipping weight (kg)	1,348	1,357
Operating weight (kg)	1,384	1,393
Power supply	3-phase 4-wire 50/60Hz 380V/400V/415V	3-phase 4-wire 50/60Hz 380V/400V/415V
Reference current for power supply design (A)	103	119
Electrical Data Cooling	-	-
Nominal current (A)	84.8	99.7
Nominal input (kW)	55.2	64.9
EER	3.26	3.08
SEER	4.77	4.75
Power factor (%)	99	99
Electrical Data Heating	-	-
Nominal current (A)	79.6	90.1
Nominal input (kW)	51.9	59
COP	3.47	3.39
SCOP	4.35	4.28
Power factor (%)	99	99
Compressor	-	
Type	Hermetic rotary x 4	Hermetic rotary x 4
Motor output x number of units (kW)	11.2 x 4	13.3 x 4
Type d start	Inverter starter	Inverter starter
Case heater (W)	37x4	37 x 4
Condenser coil - airside	Plate fin coil	Plate fin col
Fan	-	-
Type	Propeller fan	Propeller fan
Air quantity (m3/min)	1,230 (maximum)	1,230 (maximum)
Type of start	Inverter starter	Inverter starter
Motor output x number of units (kW)	1.2x4	1.2x4
Pump	-	-
Motor output (kW)	1.5	22
Type	Centrifugal pump	Centrifugal pump
Flow control	Inverter	Inverter
Maximum current (A)	3.1	43

Minimum input (kW)	2	2.8
Refrigerant Type	R32	R32
Refrigerant charge (kg)	8.8x4	88x4
Refrigerant Control	Electric expansion valve	Electric expansion valve

Appendix A.II: Simulation results

Table 24: C5OL simulation results - before electrification upgrade

Climate Zone	Boilers energy (MWh gas)	EHC heating energy (MWh)	Chillers energy (MWh)	Distr fans energy (MWh)	Distr pumps energy (MWh)	Heat rej fans/pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)
2	7.21	0.27	243.30	72.42	55.40	81.78	236.78	524.86
3	37.33	2.19	211.23	90.21	53.79	74.32	236.78	524.86
4	121.06	6.39	99.17	64.01	31.20	36.88	236.78	524.86
5	17.59	1.08	155.44	59.48	37.49	51.75	236.78	524.86
6	70.82	0.00	69.48	48.81	20.53	23.14	236.78	524.86
7	182.20	0.00	67.31	55.76	23.49	22.76	236.78	524.86
8	330.35	0.00	31.25	78.75	11.48	0.00	236.78	524.86

Table 25: C5OL simulation results - after electrification upgrade

CZ	CPHP heating energy (MWh)	CPHP cooling energy (MWh)	CPHP defrost energy (MWh)	EHC heating energy (MWh)	Chillers energy (MWh)	Distr fans energy (MWh)	Distr pumps energy (MWh)	Heat rej fans/ pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)
2	-	-	-	6.87	243.30	72.40	55.23	81.77	236.78	524.86
3	11.00	243.65	1.99	2.17	72.37	90.06	44.01	23.10	236.78	524.86
4	32.41	99.30	6.86	6.18	28.16	63.57	24.11	15.73	236.78	524.86
5	-	-	-	17.33	155.42	59.45	37.07	51.75	236.78	524.86
6	19.34	65.00	1.35	0.00	16.22	48.51	14.77	4.66	236.78	524.86
7	54.44	92.17	12.35	0.00	0.00	55.08	15.50	0.00	236.78	524.86
8	107.07	25.71	33.18	0.00	0.00	73.38	10.75	0.00	236.78	524.86

Table 26: C9A simulation results - before electrification upgrade

Climate Zone	Boilers energy (MWh gas)	EHC heating energy (MWh)	Chillers energy (MWh)	Distr fans energy (MWh)	Distr pumps energy (MWh)	Heat rej fans/pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)
2	24.11	0.00	259.83	104.38	47.56	0.00	167.64	157.68

3	83.04	0.00	289.61	112.27	47.37	0.00	167.64	157.68
4	107.54	0.00	126.38	171.98	27.09	0.00	167.64	157.68
5	17.27	0.00	164.11	169.58	33.18	0.00	167.64	157.68
6	47.61	0.00	76.51	164.73	19.14	0.00	167.64	157.68
7	167.33	0.00	72.45	176.21	21.08	0.00	167.64	157.68
8	321.40	0.00	13.79	178.64	14.54	0.00	167.64	157.68

Table 27: C9A simulation results - after electrification upgrade

CZ	CPHP heating energy (MWh)	CPHP cooling energy (MWh)	CPHP defrost energy (MWh)	EHC heating energy (MWh)	Chillers energy (MWh)	Distr fans energy (MWh)	Distr pumps energy (MWh)	Heat rej fans/ pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)
2	-	-	-	22.16	259.84	104.38	46.72	0.00	167.64	157.68
3	25.16	195.86	5.47	0.00	68.79	112.27	35.36	0.00	167.64	157.68
4	32.35	85.69	11.58	0.00	23.45	171.98	19.35	0.00	167.64	157.68
5	-	-	-	16.38	164.13	169.58	32.19	0.00	167.64	157.68
6	13.38	49.97	1.46	0.00	13.44	164.73	11.48	0.00	167.64	157.68
7	53.40	60.76	23.06	0.00	0.00	176.21	15.08	0.00	167.64	157.68
8	108.59	13.21	56.63	0.00	0.00	178.64	13.42	0.00	167.64	157.68

Appendix A.III: Cost results

Table 28: C5OL space heating capital cost NPV inputs

CZ	Scenario	Mechanical Plant costs - Base Cost (Gas)	Mechanical Plant costs - Electrification Cost	Plant Room/Deck Cost	Electrical Cost	Lifecycle Replacement Cost - Chiller	Lifecycle Replacement Cost - Heat Pump
2	1	$288,688	$356,444	$-	$414,523	$374,261	$153,750
2	2	$288,688	$318,250	$-	$79,574	$374,261	$93,750
2	3	$-	$185,797	$-	$79,574	$374,261	$93,750
3	1	$326,854	$1,102,477	$96,984	$399,439	$253,845	$560,000

3	2	$326,854	$1,056,902	$96,984	$57,138	$253,845	$560,000
3	3	$-	$841,937	$96,984	$57,138	$253,845	$560,000
4	1	$329,476	$1,116,922	$97,847	$390,132	$238,404	$560,000
4	2	$329,476	$1,071,843	$97,847	$54,535	$238,404	$560,000
4	3	$-	$862,362	$97,847	$54,535	$238,404	$560,000
5	1	$304,567	$438,137	$-	$441,372	$377,235	$185,000
5	2	$304,567	$396,107	$-	$99,788	$377,235	$185,000
5	3	$-	$226,334	$-	$99,788	$377,235	$185,000
6	1	$313,598	$1,153,078	$92,619	$377,531	$221,934	$435,000
6	2	$313,598	$981,368	$92,619	$49,701	$221,934	$435,000
6	3	$-	$738,679	$92,619	$49,701	$221,934	$435,000
7	1	$342,149	$1,310,361	$102,021	$406,352	$-	$560,000
7	2	$342,149	$1,144,057	$102,021	$71,871	$-	$560,000
7	3	$-	$961,080	$102,021	$71,871	$-	$560,000
8	1	$357,445	$1,394,620	$107,057	$407,848	$-	$685,000
8	2	$357,445	$1,231,211	$107,057	$86,014	$-	$685,000
8	3	$-	$1,080,224	$107,057	$86,014	$-	$685,000

Table 29: C9A space heating capital cost NPV inputs

CZ	Scenario	Mechanical Plant costs - Base Cost (Gas)	Mechanical Plant costs - Electrification Cost	Plant Room/Deck Cost	Electrical Cost	Lifecycle Replacement Cost - Chiller	Lifecycle Replacement Cost - Heat Pump
2	1	$332,070	$2,368,697	$-	$398,020	$265,896	$551,250
2	2	$332,070	$1,846,976	$-	$70,260	$265,896	$551,250
2	3	$-	$1,345,305	$-	$70,260	$265,896	$551,250
3	1	$372,298	$1,689,828	$108,420	$-	$179,231	$435,000
3	2	$372,298	$1,263,151	$108,420	$-	$179,231	$435,000
3	3	$-	$789,083	$54,210	$-	$179,231	$435,000
4	1	$377,706	$1,745,046	$109,333	$-	$172,470	$560,000
4	2	$377,706	$1,287,216	$109,333	$-	$172,470	$560,000

4	3	$-	$807,241	$54,667	$-	$172,470	$560,000
5	1	$360,466	$2,484,227	$-	$418,711	$268,380	$616,750
5	2	$360,466	$1,955,663	$-	$84,484	$268,380	$616,750
5	3	$-	$1,430,271	$-	$84,484	$268,380	$616,750
6	1	$353,367	$1,496,562	$103,801	$-	$162,810	$435,000
6	2	$353,367	$1,178,923	$103,801	$-	$162,810	$435,000
6	3	$-	$725,529	$51,901	$-	$162,810	$435,000
7	1	$396,637	$1,938,312	$113,749	$-	$-	$560,000
7	2	$396,637	$1,371,443	$113,749	$-	$-	$560,000
7	3	$-	$870,796	$-	$-	$-	$560,000
8	1	$410,497	$2,079,810	$119,078	$379,113	$-	$560,000
8	2	$410,497	$1,433,110	$119,078	$68,447	$-	$560,000
8	3	$-	$917,327	$-	$68,447	$-	$560,000

Appendix B: Domestic Hot Water

Appendix B.I: Equipment Tables

Table 30: Gas-fired DHW systems

		Unit A	Unit B	Unit C	Unit D	Unit E
General						
Input	MJ/h	1,025	1,230	1435	2255	2870
Recovery Rate at 50°C rise	L/hr	4,115	4,935	5761	9053	11522
Peak Flow Rate at 50°C rise	L/min	68	81	96.0	150.7	191.8
Approx Weight	kg	245	270	350	470	570
Electrical						
Electrical Supply (240V/50Hz)	Amps	6.62	7.92	10.24	14.24	17.24
Electrical Connection	Amps	Hard Wired	Hard Wired	-	-	-
Dimensions						
Width	mm	2050	2410	2670	4110	-
Depth (Free Standing Frame)	mm	500	500	1980	2700	3310

Table 31: Heat pump DHW system

ELECTRICAL INPUT		
Voltage/Phase		380 - 415 Volts / 3 Phase / 50 Hz
Full Load Amps Per Phase		32.34 Amps (inc pump)
Min. Circuit Size		40 Amps
Refrigerant		R134a
Nominal Heating capacity		39.55 kW
Power input		10.25 kW
COP		3.86
Noise Level		69 dBa @ 3 m
Rated Load Amps @ 10°C SST / 51°C SCT		28.33 Amps
TECHNICAL DATA		
	Compressor	**Fan**
Make	Copeland	EBM-Papst
Type	Scroll 20056	Axial
Number Per Unit	1	2
FLA (Full Load Amps)	25.54 Amps	1.2 Amps (Each)
Voltage / Phase	380 - 415 / 3	380 - 415 / 3
Pole/RPM	2/2,900	6/890
Air Flow	N/A	5270 L/s @ 20 Pa external static
HEAT EXCHANGER (Water Side)		
Type of Water Tube		Stainless steel
Design		Plate Vented
Flow Rate Excl. By Pass		2.2 L/s
Max. Outlet Water Temp		65°C
Design Pressure Drop		40 kPa
Max. Operating Pressure		2,450 kPa
GENERAL INFORMATION		
Water Connections		Male 2” BSP
Drain		20mm Aluminium
Defrost		Hot Gas Injection
Cabinet Construction		1.2mm Stucco Aluminium
Approx. shipping weight		300 kg
Size L x W x H		1805 x 807 x 1378 mm
Min ventilation per inlet and outlet		1.93 m²

Table 32: DHW storage tank data

Storage capacity	Litres	2055
Dimensions		
Height	mm	2565
Diameter	mm	1300

Weight Empty	kg	245/245

Appendix B.II: Consumption Calculations

Domestic Hot Water energy consumption calculations have been developed based on energy intensity of end use breakdown assessments across 12 energy audits.

Table 33: DHW energy consumption calculation

Archetype	Climate Zone	Area	MJ/m2	Before Upgrade - Gas consumption (MJ)	After Upgrade - COP	After Upgrade - Proportion of heat pump operation vs direct electric	After Upgrade - Electricity Consumption (kWh)
C5OL-A	1, 2, 5	12,250	1	12,250	4.2	100%	648
C5OL-A	3, 6, 7	12,250	1	13,475	3.5	75%	1,390
C5OL-A	8	12,250	1	14,700	3.2	50%	2,144
C5OL-B	1, 2, 5	12,250	1	12,250	1	0%	2,722
C5OL-B	3, 6, 7	12,250	1	13,475	1	0%	2,994
C5OL-B	8	12,250	1	14,700	1	0%	3,267
C9A	1, 2, 5	10,368	43.69	452,927	4.2	80%	39,302
C9A	3, 6, 7	10,368	43.69	498,220	3.5	70%	55,358
C9A	8	10,368	43.69	543,513	3.2	50%	79,262
C9C	1, 2, 5	2,048	43.69	89,467	4.2	90%	6,248
C9C	3, 6, 7	2,048	43.69	98,414	3.5	70%	10,935
C9C	8	2,048	43.69	107,361	3.2	50%	15,657

Appendix B.III: Cost Results

Table 34: C5OL-A DHW capital cost NPV inputs

CZ	Scenario	Base Plant Cost (Gas)	Electrification Cost (Plant)	Plant deck cost	Electrical Cost	Lifecycle Replacement Cost - Heat Pump	Lifecycle Replacement Cost - Direct Electric
1	1	$26,120	$147,820	$13,145	$22,797	$85,235	$-
1	2	$26,120	$147,820	$13,145	$18,690	$85,235	$-
1	3	$-	$121,212	$13,145	$18,690	$85,235	$-
2	1	$26,120	$147,820	$13,145	$22,797	$85,235	$-
2	2	$26,120	$147,820	$13,145	$18,690	$85,235	$-
2	3	$-	$121,212	$13,145	$18,690	$85,235	$-
3	1	$26,120	$159,708	$15,280	$27,851	$85,235	$7,719
3	2	$26,120	$159,708	$15,280	$22,578	$85,235	$7,719
3	3	$-	$131,118	$15,280	$22,578	$85,235	$7,719
4	1	$26,120	$159,708	$15,280	$27,851	$85,235	$7,719
4	2	$26,120	$159,708	$15,280	$22,578	$85,235	$7,719
4	3	$-	$131,118	$15,280	$22,578	$85,235	$7,719
5	1	$26,120	$147,820	$13,145	$22,797	$85,235	$-
5	2	$26,120	$147,820	$13,145	$18,690	$85,235	$-
5	3	$-	$121,212	$13,145	$18,690	$85,235	$-
6	1	$26,120	$159,708	$15,280	$27,851	$85,235	$7,719
6	2	$26,120	$159,708	$15,280	$22,578	$85,235	$7,719
6	3	$-	$131,118	$15,280	$22,578	$85,235	$7,719
7	1	$26,120	$159,708	$15,280	$27,851	$85,235	$7,719
7	2	$26,120	$159,708	$15,280	$22,578	$85,235	$7,719
7	3	$-	$131,118	$15,280	$22,578	$85,235	$7,719
8	1	$40,168	$169,104	$16,781	$365,406	$85,235	$15,438
8	2	$40,168	$169,104	$16,781	$67,026	$85,235	$15,438
8	3	$-	$138,528	$16,781	$67,026	$85,235	$15,438

Table 35: C5OL-B DHW capital cost NPV inputs

CZ	Scenario	Base Cost (Gas)	Electrification Cost	Plant deck cost	Electrical Cost	Direct Electric Lifecycle Replacement Cost
1	1	$26,120	$85,198	$-	$370,718	$30,875
1	2	$26,120	$85,198	$-	$90,552	$30,875
1	3	$-	$69,027	$-	$90,552	$30,875
2	1	$26,120	$85,198	$-	$370,718	$30,875

2	2	$26,120	$85,198	$-	$90,552	$30,875
2	3	$-	$69,027	$-	$90,552	$30,875
3	1	$26,120	$85,198	$-	$370,718	$30,875
3	2	$26,120	$85,198	$-	$90,552	$30,875
3	3	$-	$69,027	$-	$90,552	$30,875
4	1	$26,120	$85,198	$-	$370,718	$30,875
4	2	$26,120	$85,198	$-	$90,552	$30,875
4	3	$-	$69,027	$-	$90,552	$30,875
5	1	$26,120	$85,198	$-	$370,718	$30,875
5	2	$26,120	$85,198	$-	$90,552	$30,875
5	3	$-	$69,027	$-	$90,552	$30,875
6	1	$26,120	$85,198	$-	$370,718	$30,875
6	2	$26,120	$85,198	$-	$90,552	$30,875
6	3	$-	$69,027	$-	$90,552	$30,875
7	1	$26,120	$85,198	$-	$370,718	$30,875
7	2	$26,120	$85,198	$-	$90,552	$30,875
7	3	$-	$69,027	$-	$90,552	$30,875
8	1	$40,168	$94,090	$-	$381,772	$38,594
8	2	$40,168	$94,090	$-	$75,000	$38,594
8	3	$-	$76,437	$-	$75,000	$38,594

Table 36: C9A DHW capital cost NPV inputs

CZ	Scenario	Base Plant Cost (Gas)	Electrification Cost (Plant)	Plant deck cost	Electrical Cost	Lifecycle Replacement Cost - Heat Pump	Lifecycle Replacement Cost - Direct Electric
1	1	$60,064	$187,652	$29,487	$372,859	$127,852	$23,156
1	2	$60,064	$187,652	$29,487	$92,199	$127,852	$23,156
1	3	$-	$149,960	$29,487	$92,199	$127,852	$23,156
2	1	$60,064	$179,952	$29,487	$372,859	$127,852	$23,156
2	2	$60,064	$179,952	$29,487	$92,199	$127,852	$23,156
2	3	$-	$149,960	$29,487	$92,199	$127,852	$23,156
3	1	$60,064	$404,837	$33,904	$381,257	$170,469	$23,156
3	2	$60,064	$404,837	$33,904	$94,044	$170,469	$23,156
3	3	$-	$330,948	$33,904	$94,044	$170,469	$23,156
4	1	$60,064	$404,837	$33,904	$381,257	$170,469	$23,156
4	2	$60,064	$404,837	$33,904	$94,044	$170,469	$23,156
4	3	$-	$330,948	$33,904	$94,044	$170,469	$23,156
5	1	$60,064	$179,952	$29,487	$372,859	$127,852	$23,156
5	2	$60,064	$179,952	$29,487	$92,199	$127,852	$23,156
5	3	$-	$149,960	$29,487	$92,199	$127,852	$23,156
6	1	$60,064	$404,837	$33,904	$381,257	$170,469	$23,156
6	2	$60,064	$404,837	$33,904	$94,044	$170,469	$23,156
6	3	$-	$330,948	$33,904	$94,044	$170,469	$23,156

7	1	$60,064	$404,837	$33,904	$381,257	$170,469	$23,156
7	2	$60,064	$404,837	$33,904	$94,044	$170,469	$23,156
7	3	$-	$330,948	$33,904	$94,044	$170,469	$23,156
8	1	$86,092	$414,544	$35,654	$386,312	$170,469	$30,875
8	2	$86,092	$414,544	$35,654	$75,000	$170,469	$30,875
8	3	$-	$338,358	$35,654	$75,000	$170,469	$30,875

Table 37: C9C DHW capital cost NPV inputs

CZ	Scenario	Base Plant Cost (Gas)	Electrification Cost (Plant)	Plant deck cost	Electrical Cost	Lifecycle Replacement Cost - Heat Pump	Lifecycle Replacement Cost - Direct Electric
1	1	$31,394	$186,264	$19,144	$27,851	$85,235	$7,719
1	2	$31,394	$186,264	$19,144	$27,851	$85,235	$7,719
1	3	$-	$165,513	$19,144	$22,578	$85,235	$7,719
2	1	$31,394	$186,264	$19,144	$27,851	$85,235	$7,719
2	2	$31,394	$186,264	$19,144	$27,851	$85,235	$7,719
2	3	$-	$165,513	$19,144	$22,578	$85,235	$7,719
3	1	$31,394	$231,268	$22,334	$359,750	$127,852	$7,719
3	2	$31,394	$231,268	$22,334	$84,423	$127,852	$7,719
3	3	$-	$206,425	$22,334	$84,423	$127,852	$7,719
4	1	$31,394	$231,268	$22,334	$359,750	$127,852	$7,719
4	2	$31,394	$231,268	$22,334	$84,423	$127,852	$7,719
4	3	$-	$206,425	$22,334	$84,423	$127,852	$7,719
5	1	$31,394	$186,264	$19,144	$27,851	$85,235	$7,719
5	2	$31,394	$186,264	$19,144	$27,851	$85,235	$7,719
5	3	$-	$165,513	$19,144	$22,578	$85,235	$7,719
6	1	$31,394	$231,268	$22,334	$359,750	$127,852	$7,719
6	2	$31,394	$231,268	$22,334	$84,423	$127,852	$7,719
6	3	$-	$206,425	$22,334	$84,423	$127,852	$7,719
7	1	$31,394	$231,268	$22,334	$359,750	$127,852	$7,719
7	2	$31,394	$231,268	$22,334	$84,423	$127,852	$7,719
7	3	$-	$206,425	$22,334	$84,423	$127,852	$7,719
8	1	$46,855	$240,119	$26,725	$364,804	$127,852	$15,438
8	2	$46,855	$240,119	$26,725	$88,311	$127,852	$15,438
8	3	$-	$213,835	$26,725	$88,311	$127,852	$15,438

Appendix C: Cooking

Appendix C.I: Appliances Tables

The following tables show the diversity in prices, brands, sizes and capacities for each appliance evaluated in section 4.

Table 38 Sample of commercial cooktop available in Australia.

Brand	Model Name	Energy source	Technology	It does need a Bench	Power Requirements	Gas / Electric Rating	Burners	W mm	D mm	H mm	Price
Electrolux	700XP 2	Electricity	Induction	Yes	400 V/3N ph	10kW	2	400	730	250	$11,041
Electrolux	700XP 4 Hot Plate Electric	Electricity	Induction	Yes	380-415 V/3 ph	14 kW	4	800	730	250	$17,753
COOKTEK	LUUS WZ-1SP	Natural Gas	Natural Gas	Yes		90Mj	1	600	600	1300	$3,610
COBRA	C6D 600mm	Natural Gas	Natural Gas	No		5.0kW	4	600	800	915	$2,723
Goldstein	PFB24 - 4	Natural Gas	Natural Gas	Yes		96Mj	4	610	800	548	$3,452
Goldstein	PEB4S	Electricity	Electric	Yes	415V, 3ph	12kW	4	610	800	520	$5,937
Baron	Q70PC/E400	Electricity	Electric	Yes	400V /3ph 50-60 Hz		2	400	700	250	$2,241
Baron	Q70PCV/VCE800	Electricity	Electric	No	400V /3ph 50-60 Hz	16kW	4	800	700	900	$5,755
Baron	Q90PC/VCE400	Electricity	Electric	Yes	400V /3ph 50-60 Hz	8kW	2	400	900	250	$3,303
BLUE SEAL	MOE516	Electricity	Electric	No	400V /3ph 50-60 Hz	14.4kW	6	900	812	1085	$6,205
Waldorf	RN8600G-B	Natural Gas	Electricity	Yes		168MJ	6	900	805	80	$5,334
Garland	GF36-6T-NG	Natural Gas	Natural Gas	No		184MJ	6	900	876	294	$5,465
MKN	2023105	Electricity	Induction	no		20kW	4	800	850	700	$23,266
Waldorf	RN8640G	Natural Gas	Natural Gas	No		168 MJ/hr	6	900	805	915	$13,597

WALDORF	IN8200E-CB	Electricity	Induction	No	400V /3ph 50-60 Hz	10kW	2	450	805	1130	$15,670
Garland	GF24-4T	Natural Gas	Natural Gas	No		122.4mj	4	600	876	1153	$4,382
Blue Seal	G516C-CB	Natural Gas	Natural Gas	No		124 MJ	6	900	812	1085	$6,204
Goldstein	PEB6S	Electricity	Electric	Yes	400V /3ph 50-60 Hz	12kW	6	914	800	520	$5,081
Giorik	SPGI.CG760GT	Natural Gas	Natural Gas	Yes		173 MJ/hr	6	1200	720	905	$6,182
LUUS	CS-6B3C	Natural Gas	Natural Gas	No		201 MJ/hr	6	1200	800	1100	$5,938
Electrolux	900xp	Electricity	Induction	No	400V /3ph 50-60 Hz	20kW	4	800	930	250	$24,523
Zanussi	392045	Electricity	Electric	No	400V /3ph 50-60 Hz	13.6 kW	4	800	900	250	$7,906
Giorik	CI740GT	Electricity	Induction	Yes	400V /3ph 50-60 Hz	20kW	4	720	800	930	$20,428

Table 39 Commercial Ovens available in Australia

Brand	Model Name	Energy source	Type	Power Requirements	Gas / Electric Rating	Trays	W mm	D mm	H mm	Price
Moduline	RRO 061E	Electricity	Static Regeneration Oven	415V	6.2kW	6	800	710	855	$8,424
Moduline	RRO 081E	Electricity	Static Regeneration Oven	415V	12.5kW	8	800	710	1155	$9,588
UNOX	XEVC-0711-GPRM	Electricity	Combi steamer	380-417 V	9.9kW	7	750	773	843	$9,467
Unox	XECC-0513-EPRM	Electricity	Combi steamer	415V	9.2 kW	5	535	862	649	$9,467
Unox	XEVC-0311-	Electricity	Combi steamer	240V	5 kW	3	750	773	538	$7,366
Unox	XEVC-1011-E1RM	Electricity	Combi steamer	415V	14 kW	10	750	773	1010	11,978
Unox	XEVL-2011-E1RS	Electricity	Combi steamer	415V	29.3 kW	20	882	1043	1866	22,041
Turbofan	EC40M10	Electricity	Combi steamer	415V	14kW	10	812	725	1170	$11,000
RATIONAL	ICP61	Electricity	Combi Oven	415V	10.8kW	6	850	842	804	$18,757
Blue Seal	E40SDW	Electricity	Combi Oven	415V	61.8 kW	40	1290	895	1810	$49,890
RATIONAL	SCC5S61E	Electricity	Combi Oven	415	11.2kW	6	847	776	782	$18,054
RATIONAL	SCC101	Electricity	Combi Oven	415V 3P 50 Hz	18 kW	10	847	771	1017	$12,990
RATIONAL	SCC61	Electricity	Combi Oven	415V	10.5kW	6	900	770	1500	$12,000
RATIONAL	SCC5S101E	Electricity	Combi Oven	415V	20.2kW	10	847	779	1042	$24,438
Convotherm	C4ESD-1010C	Electricity	Combi Oven	415V	19.5kW	11	875	792	1058	$21,805
Convotherm	C4DEST20.20D Elec	Electricity	Combi Oven	400-415V, 50/60Hz	67.3 kW	40	1247	1020	1942	$62,937

Brand	Model Name	Energy source	Type	Power Requirements	Gas / Electric Rating	Trays	W mm	D mm	H mm	Price
TURBOFAN	G32D4	Gas	Convection Oven With Humidity		35Mj/hr	4	735	810	1790	$6,490
UNOX	XEVC-0711-GPRM gas	Gas	Combi steamer		68.4 MJ/hr	7	750	783	842	$13,846
Convotherm	C4DGBT20.20D	Gas	Combi steamer		230 MJ/hr	40	1247	1020	1942	$67,229
Convotherm	C4DGBT12.20D	Gas	Combi steamer		122 MJ/hr	24	1247	1020	1406	$51,036
Convotherm	CXGBD10.10	Gas	Combi steamer		81 MJ/hr	11	875	792	1058	$25,462
Convotherm	CXGSD6.10	Gas	Combi steamer		42 MJ/hr	7	875	792	786	$17,401
Rational	SCC5S202G	Gas	Combi oven		390 MJ	40	1084	996	1782	$67,332.5
Convotherm	C4DGBD12.20	Gas	Combi oven		122 MJ/hr	24	1135	1020	1406	$51,143.4
UNOX	XEBC-10EU-GPRM	Gas	Combi oven		90 MJ/hr	12	860	967	1163	$18,095
Rational	ICP101G	Gas	Combi oven		1064 MJ/hr	10	580	842	1064	$29,302
UNOX	XEBL-16EU-GPRS	Gas	Combi oven		126 MJ/hr	16	892	1018	1875	$31,630
UNOX	XEVC-0621-GPRM	Gas	Combi oven			6				$18,018
Convotherm	C4DGBD20.20	Gas	Combi oven		230 MJ/hr	40	1135	1020	1942	$59,966
MENUMASTER	MXP5223TLT	Electricity	Speed Cook Oven		5.8 kW	7	638	707	516	$26,978

Table 40 Sample of commercial Deep frier available in Australia.

Brand	Model Name	Energy source	It does need a Bench	Gas/ Electric Rating	Oil Capacity	W mm	D mm	H mm	Price
Austheat	ROAF822	Electric	No	14kW	28	450	800	918	$6,140
AUSTHEAT	AF813R	Electric	No	21.5kW	40	600	805	1080	$5,465
WALDORF	FN8224E	Electric	No	17kW	25	450	805	1130	$7,710
Anets	AEH14X	Electric	No	14kW	20	397	993	1306	$6,300
Austheat	AF812R	Electric	No	18kW	29	450	805	1080	$4,685
Austheat	AF812	Electric	No	14kW	29	450	805	1080	$4,621
Austheat	AF813	Electric	No	16.6kW	40	600	805	1080	$5,056
Goldstein	FRE24DL	Electric	No	21kW	45	610	800	1120	$6,536
Waldorf	FN8127EE	Electric	No	17kW	27	450	805	1130	$7,789
Blue Seal	E604	Electric	No	34kW	60	1200	585	1030	$9,852
Frymaster	RE114	Electric	No	14kw	25	396	786	1149	$9,955
Frymaster	RE117SD	Electric	No	17 kW	25	397	786	1152	$8,860
Moffat	MOFF18	Gas	No	90 MJ/hr	18	400	735	915	$2,264
Cobra	CF2	Gas	No	90MJ/hr	18	400	800	915	$3,015
Cookon	FFR-1-300S	Gas	No	36 MJ/hr	25	345	753	1095	$4,150
Anets	JM14T	Gas	No	100 MJ/hr	22	397	974	1982	$5,790
Cookon	MCFR-1	Gas	No	40 MJ/hr	29	540	725	525	$4,015
Cookon	FFR-2-460S	Gas	No	100 MJ/hr	68	932	752	1095	$7,942

Cookon	FFR-1-525S	Gas	No	74 MJ/hr	40	531	753	1095	$4,806
Cookon	FFR-2-525S	Gas	No	148MJ/hr	80	1062	753	1095	$8,317
Cookon	MKII	Gas	No	125 MJ/hr	38	650	753	1095	$6,935
Frymaster	FMJ250-NG	Gas	No	220 MJ/hr	50	793	800	1211	$27,391
Frymaster	FPH255-NG	Gas	No	168.8 MJ/hr	50	794	752	1158	$35,987
Frymaster	MJH55-2	Gas	No	84.4 MJ/hr	25	397	799	1158	$7,552
Frymaster	MJ140	Gas	No	107 MJ/hr	20	406	803	1051	$5,628
Frymaster	PMJ235GSD-NG	Gas	No	214 MJ/hr	40	794	801	1168	$8,299
Frymaster	MJ1CF	Gas	No	158.3 MJ/hr	40	530	202	1214	$10,380
MKN	2020325B			20 kW	25	600	850	900	

Table 41 Sample of Commercial Chargrill available in Australia

Brand	Model Name	Energy source	It does need a Bench	Gas/ Electric Rating	W mm	D mm	H mm	Price
Electrolux	700XP	Electric	Yes	8kW	800	730	250	$7,512
Zanussi	392270 EVO900	Electric	Yes	15KW	800	900	850	$8,000
MKN	2121501	Electric	No	7kW	600	700	900	$6,790
Electrolux	371240	Electric	Yes	8kW	700	730	250	$5,831
WALDORF	CH8120G-CB	Gas	No	133 MJ/hr	1200	805	1130	$8,410
Cobra	MOCB9-N	Gas	No	99MJ/hr	900	850	1085	$3,480
TRUEHEAT	RCB6	Gas	Yes	66MJ/hr	455	803	455	$2,415

FED QR-24E	FED QR-24E	Gas	Yes	84MJ/hr	610	770	460	$1,870
Cookrite	AT80G6C-F	Gas	No	53 MJ/h	600	800	1115	$2,238
FED	QR-48E	Gas	Yes	176MJ/h	1220	770	460	$2,805
Cobra	CB9-B	Gas	Yes	99MJ/hr	800	540	432	$2,876
Cobra	CB6	Gas	No	66MJ/hr	600	800	585	$2,907
LKK	CG9	Gas	No	100MJ/hr	900	800	1145	$3,675
LUUS	CS-12C	Gas	No	132MJ/hr	1200	800	1100	$5,738
LUUS	CS-9C	Gas	No	99MJ/hr	900	800	110	$4,918
LKK	CG12	Gas	No	140 MJ/hr	1200	800	1145	$4,350
Blue Seal	G594 B	Gas	Yes	66MJ/hr	600	812	415	$6,159
Waldorf	CH9800G	Gas	No	100 MJ/hr	900	805	1130	$6,557

Appendix C.II: Appliances per Base Layouts

The following tables show the breakdown of appliances found in each layout and its resulting configuration in an electrification layout; the additional electrical demand for the electrification layouts mentioned in section 4.1.

Layout 2 - Office Building - Take Away restaurant.

Table 42 List of appliances in Layout 2. Small retail take away restaurant.

Unit	Model Name	Specification	Gas /Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	RE114	25 L	14kW	396	786	1149
Chargrill	AT80G6C-F	N/A	53 MJ/hr	600	800	1115
Combi-oven	XEVC-1011-E1RM	10 Trays	14 kW	750	773	1010
Cooktop	RN8600G-B	6 Burners	168MJ/hr	900	805	80
Noodle cooker	PC8140E7	40 L	47 MJ/hr	365	450	1130

Table 43. List of electric appliances for layout 2. Small retail take away restaurant.

Unit	Model Name	Specification	Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	RE114	25 L	14kW	396	786	1149
Chargrill	392270 EVO900	N/A	15kW	800	900	850
Combi-oven	XEVC-1011-E1RM	10 Trays	14 kW	750	773	1010
Cooktop	MOE516	6 Elements	14.4kW	900	812	1085
Noodle cooker	PC8140E7	40 L	10.5kW	365	450	1130

Layout 3 - Hospital

Table 44 List of appliances in layout 3. Hospital

Unit	Model Name	Specification	Gas Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	FN8224E	25 L	17 kW	450	805	1130
Chargrill	CB6	N/A	66 MJ/hr	600	800	585
Combi-oven	EC40M10	10 Trays	14 kW	812	725	1170

Cooktop	RN8600G-B	6 Burners	46.6 kW	900	805	80

Table 45 . List of electric appliances for layout 3. Hospital.

Unit	Model Name	Specification	Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	FN8224E	25L	17kW	450	805	1130
Chargrill	2121501	N/A	7kW	600	700	900
Combi-oven	EC40M10	10 Trays	14kW	812	725	1170
Cooktop	MOE516	6 Elements	14.4kW	900	812	1085

Layout 4 – Hospital

Table 46 List of appliances in layout 4. Hospital

Unit	Model Name	Specification	Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	PMJ235GSD-NG	40 L	0	794	801	1168
Speed Cook Oven	MXP5223TLT	7 Trays	5.8kW	638	707	516
Combi-oven	ICP61	6 Trays	10.8kW	850	842	804
Combi-oven	ICP61	6 Trays	10.8kW	850	842	804
Cooktop	GF36-6T-NG	6 Burners	184 MJ	900	876	294

Table 47 List of electric appliances for layout 4. Hospital.

Unit	Model Name	Specification	Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	AF813R	40L	21.5kW	600	805	1080
Speed Cook Oven	MXP5223TLT	7 Trays	5.8kW	638	707	516
Combi-oven	ICP61	6 Trays	10.8kW	850	842	804
Combi-oven	ICP61	6 Trays	10.8kW	850	842	804
Cooktop	MOE516	6 Elements	14.4kW	900	812	1085

Layout 6 – Office Building

Table 48. List of appliances in layout 6. Office building

Unit	Model Name	Specification	Gas Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	PMJ235GSD-NG	40 L	214MJ/hr	794	801	1168
Chargrill	CH9800G	-	100 MJ/hr	900	805	1130
Combi-oven	C4DGBT20.20D	40 Trays	230 MJ/hr	1247	1020	1942
Combi-oven	C4DGBT20.20D	40 Trays	230 MJ/hr	1247	1020	1942
Combi-oven	C4DGBT20.20D	40 Trays	230 MJ/hr	1247	1020	1942
Combi-oven	C4DGBT20.20D	40 Trays	230 MJ/hr	1247	1020	1942
Range	RN8610G	6 Trays	198 MJ/hr	900	805	1130

Table 49 List of electric appliances for layout 6. Office Building

Unit	Model Name	Specification	Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	AF813R	40L	21kW	600	805	1080
Chargrill	392270 EVO900	-	15kW	800	900	850
Combi-oven	C4DEST20.20D Elec	40 Trays	67.3 kW	1247	1020	1942
Combi-oven	C4DEST20.20D Elec	40 Trays	67.3 kW	1247	1020	1942
Combi-oven	C4DEST20.20D Elec	40 Trays	67.3 kW	1247	1020	1942
Combi-oven	C4DEST20.20D Elec	40 Trays	67.3 kW	1247	1020	1942
Range	PE6S28	-	18.5kW	914	800	1120

Layout 7 – Office Building

Table 50 . List of appliances in layout 7. Office building

Unit	Model Name	Specification	Gas / Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	MJH55-2	25 L	84.4MJ/hr	397	799	1158
Combi-oven	SCC5S61E	6 Trays	11.2kW	847	776	782
Combi-oven	SCC5S61E	6 Trays	11.2kW	847	776	782
Cooktop	IN8200E-CB	2 Burners	10kW	450	805	1130
Cooktop	IN8200E-CB	2 Burners	10kW	450	805	1130

Note: Cooktops in this layout are in induction

Table 51. List of electric appliances in layout 7. Office building

Unit	Model Name	Specification	Gas / Electric Rating	W (mm)	D (mm)	H (mm)

Deep Fryer	FN8224E	25 L	17kW	450	805	1130
Combi-oven	SCC5S61E	6 Trays	11.2kW	847	776	782
Combi-oven	SCC5S61E	6 Trays	11.2kW	847	776	782
Cooktop	IN8200E-CB	2 Burners	10kW	450	805	1130
Cooktop	IN8200E-CB	2 Burners	10kW	450	805	1130

Layout 8 – Age Care

Table 52 List of appliances in layout 8. Age care

Unit	Model Name	Specification	Gas / Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	MJ140	20 L	107MJ/hr	406	803	1051
Deep Fryer	MJ140	20 L	107MJ/hr	406	803	1051
Combi-oven	SCC5S101E	10 Trays	20.2kW	847	779	1042
Combi-oven	SCC5S101E	10 Trays	20.2kW	847	779	1042
Cooktop	GF24-4T	4 Burners	122.4MJ/hr	600	876	1153
Cooktop	GF24-4T	4 Burners	122.4MJ/hr	600	876	1153

Table 53 List of electric appliances in layout 8. Age Care

Unit	Model Name	Specification	Gas / Electric Rating	W (mm)	D (mm)	H (mm)
Deep Fryer	AEH14X	20 L	14kW	397	993	1306
Deep Fryer	AEH14X	20 L	14kW	397	993	1306
Combi-oven	SCC5S101E	10 Trays	20.2kW	847	779	1042
Combi-oven	SCC5S101E	10 Trays	20.2kW	847	779	1042
Cooktop	PEB4S	4 Burners	12kW	610	800	520
Cooktop	PEB4S	4 Burners	12kW	610	800	520