Australian Government

Nationwide House Energy Rating Scheme (NatHERS)

CONSULTATION PAPER

Proposed NatHERS Whole of Home National Calculations Method Apartment Centralised Services

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Contents

Background

With the proposed 2025 changes to the National Construction Code, to accommodate centralised heated water systems, changes are also proposed to the NatHERS Whole of Home Calculations Method to include centralised services in apartment buildings.

The paper presents the technical setting proposed for the incorporation of apartment centralised hot water and space conditioning services in NatHERS Whole of Home. The document is in the form of two new proposed chapters for the NatHERS Whole of Home Calculations Method which underpins the NatHERS Whole of Home modules and rating in the benchmark tool (AccuRate Home).

Refer to NatHERS Whole of Home Calculations Method for background to NatHERS Whole of Home.

The scope of the inclusion of apartment centralised services in NatHERS is centralised hot water and centralised space conditioning in sole occupancy units of Class 2 and Class 4[1] buildings; the method excludes services to apartment building common areas[2].

The key elements of the expansion of the NatHERS Whole of Home method are:

- a methodology for calculating energy demand for centralised hot water and centralised space conditioning in Class 2 and Class 4 buildings, and
- a method of apportioning the energy demand of the centralised system to each sole occupancy unit (SOU) in the building.

By incorporating methods for apartment centralised services into the NatHERS Whole of Home Calculations Method, it will be possible to assess and benchmark the energy performances of central hot water and space conditioning systems in apartment buildings, as part of a NatHERS Whole of Home rating.

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[1] Class 2 buildings are apartment buildings. They are typically multi-unit residential buildings where people live above and below each other. The NCC describes the space considered as an apartment as a sole-occupancy unit (SOU). A Class 4 part of a building is a sole dwelling or residence within a building of a non-residential nature.

[2] Apartment buildings common area energy uses are covered by NABERS certification, see Apartment Buildings | NABERS.

FAQs

Why are apartment centralised services currently not included in NatHERS Whole of Home?

Decisions were made in June 2022 on the scope of NatHERS Whole of Home. These decisions were based on the Australia Building Codes Board Deemed to Satisfy (DTS) Elemental pathway which NatHERS needs to align with, and which did not include centralised hot water and space conditioning services in apartment buildings.

What is included in the scope of the NatHERS Apartment Centralised Services method?

The scope of the inclusion of apartment centralised services in NatHERS is centralised hot water and centralised space conditioning in sole occupancy units of Class 2 and Class 4 buildings; the method excludes energy consuming services for the common areas[2] in the apartment building.

How does the proposed method operate?

For both Hot Water and Heating and Cooling, the key steps in the proposed method are:

- Step #1 – Determine thermal load for all sole occupancy units (SOU) in the apartment building: heating, cooling and/or hot water thermal loads of assessed dwellings must be determined using the same method as currently applied for decentralised services. This step is identical to the current NatHERS Whole of Home method.
- Step #2 – Account for design efficiency: heat losses from pipes, ducts or storage tanks are then accounted for, based on length of pipe and/or duct runs, location of pipe and/or duct runs (conditioned or unconditioned spaces), external conditions, and insulation installed.
- Step #3 – Determine system type and account for system efficiency: After determining total thermal loads, the technology intended for meeting the requirements is selected.
- Step #4 – Calculate auxiliary energy requirements: the auxiliary energy requirement (i.e. pumps, cooling towers, air handling units vary with the chosen technology).
- Step #5 – Calculate total annual energy requirement for central services: The total energy demand can then be calculated.
- Step #6 – Apportion to SOU's: The overall energy requirement for central services is then apportioned to each SOU based on thermal load for the SOU, as well as length of pipe to the SOU for reticulated hot water systems.

Do centralised hot water systems perform similarly to decentralised?

Each design scenario and assessment are different and as such it is difficult to outline a general trend in the performance of centralised and decentralised system. In testing the method we found some technologies, such as heat-pump hot water, perform similarly, whereas for others decentralised systems perform better, for example electric storage. When incorporated into NatHERS software tools, the centralised services method will allow users to test both centralised and decentralised systems.

Will NatHERS software tools incorporate this Apartment Centralised Services method?

When incorporated into NatHERS Whole of Home, NatHERS accredited software tools who choose to do so will be able to seek approval against the NatHERS Apartment Centralised Services method. The decision on whether to add this into each of the four NatHERS software rests with the software tool providers.

1 Central Hot Water Systems

The methodology for determining apartment building central DHW system energy requirements is summarised as follows:

- **Step #1 – Determine Thermal Load of DHW Demand:** Thermal loads of DHW usage from individual dwellings are first determined to understand the energy requirement to meet the hot water demand of the assessed building.
- **Step #2 – Determine Design Losses:** Upon determining the thermal loads of the assessed building, heat losses are accounted for to determine the actual thermal load not only to meet the demand of hot water but also to make up for the losses from the piping infrastructure.
- **Step #3 – Determine Water Heating Technology:** After determining the DHW thermal load, the technology intended for meeting this load is then selected. Different DHW technologies have different efficiency patterns, which is then accounted for after the technology is selected.
- **Step #4 – Account for Other Auxiliary Energy:** The main auxiliary energy requirement for central DHW systems are circulation pumps, this calculation is performed separately from the energy requirement of the water heating technology to meet the hot water demands.
- **Step #5 – Calculating Total Annual Energy Requirement for Central DHW Services:** Upon establishing the energy requirement for hot water heating and accounting for circulation pump energy, the total energy demand to provide hot water heating through central DHW services can then be calculated.
- **Step #6 – Apportion for Shared Services:** Once the overall energy requirement for the building for central DHW services has been established, it is then possible to allocate the energy requirements to each individual sole occupancy unit.

The main steps in the method are shown visually in Figure 1. Detailed explanation of each step in the prescribed framework above are presented in the following sections.

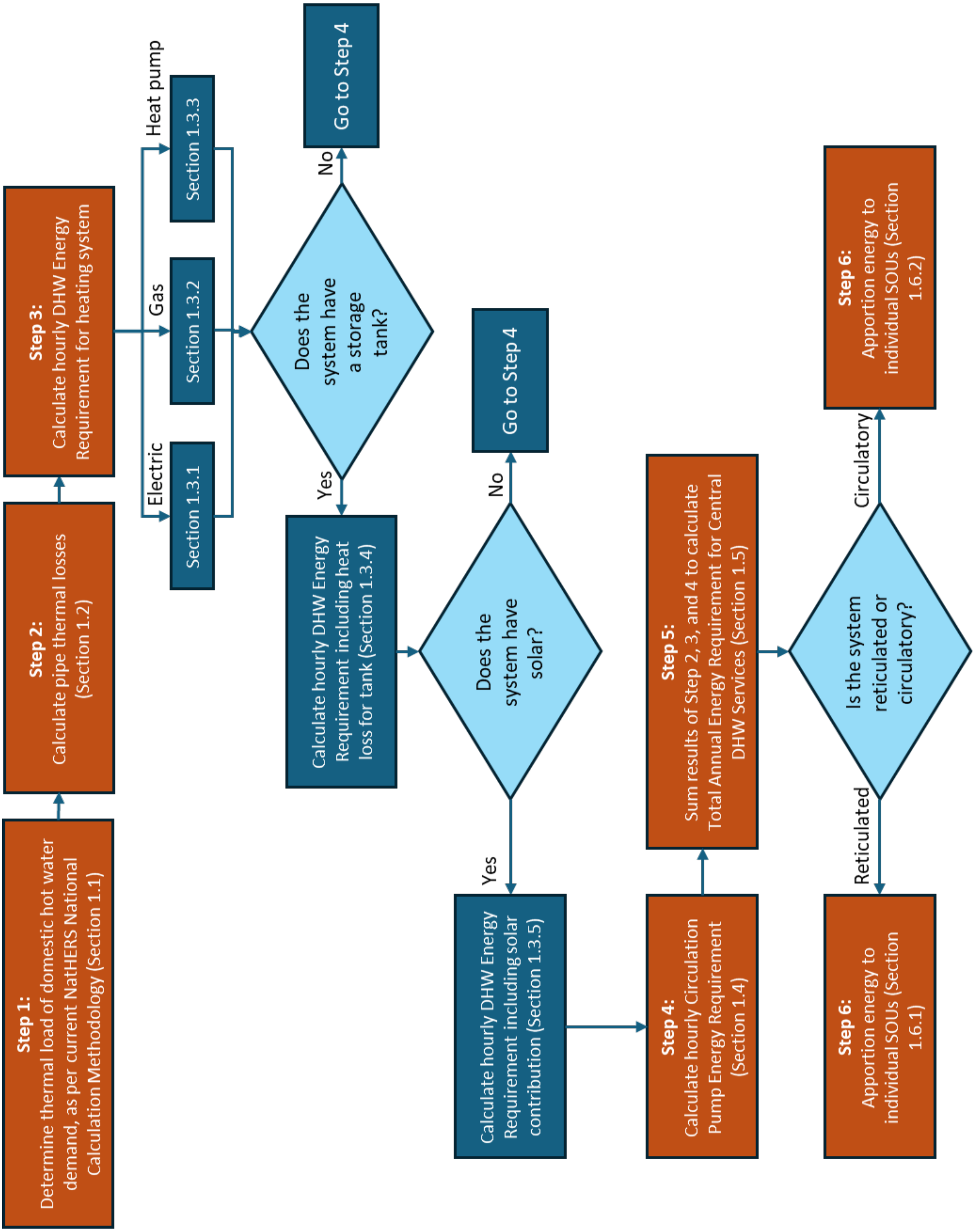

Figure 1.Summary of centralised hot water system calculation method.

1.1 Step 1 – Determine Thermal Load of DHW Demand

The calculation of the annual thermal load for DHW demand in apartment buildings involves a three-step process outlined in the NatHERS Whole of Home Calculations Method.

Delivered hot water is assumed to be a nominal 40 L/person/day, winter peak demand. The number of occupants is defined in section 3.2.1 of the NatHERS Whole of Home Calculations Method.

Initially, the peak thermal load for individual apartment units is determined. Subsequently, a seasonal energy load multiplier profile is applied based on the months, adjusting the daily thermal load according to the specific month's characteristics. Finally, the monthly thermal loads of DHW for all twelve months are summed to arrive at the total annual thermal load.

1.2 Step 2 – Determine Design Losses

Among the significant sources of heat in central DHW systems are heat losses attributed to heat dissipation from pipes. To determine the overall annual heat losses from pipes involves employing time series modeling throughout a reference year.

Hourly heat losses from pipes can be estimated via **Equation 1** as follows:

Equation 1: calculation of Total Thermal Loss from Pipes

$$
\begin{aligned}
Q_{Pipe-Loss} &= Q_{Pipe-Loss-Cond.-Area} + Q_{Pipe-Loss-Uncond.-Area} \\
&= \left(2 \times \pi \times L_{Pipe-Cond.} \times \left(\frac{1}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_{pipe-a}} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{insul.-a}}} \right) \times \left(T_{DHW-Supply-Temp.} - T_{Cond.}\right) + \right. \\
&\left. 2 \times \pi \times L_{Pipe-Uncond.} \left(\frac{1}{\frac{ln\left(\frac{r_5}{r_4}\right)}{k_{pipe-b}} + \frac{ln\left(\frac{r_6}{r_5}\right)}{k_{insul.-b}}} \right) \times \left(T_{DHW-Supply-Temp.} - T_{Uncond.}\right) \right) \times 0.0036
\end{aligned}
$$

$Q_{Pipe-Loss}$ = Total Thermal Loss from Pipes (MJ_{th}/hour)
$Q_{Pipe-Loss-Cond.-Area}$ = Thermal Loss from Pipes within Conditioned Areas (MJ_{th}/hour)
$Q_{Pipe-Loss-Uncond.-Area}$ = Thermal Loss from Pipes within Unconditioned Areas (MJ_{th}/hour)
$L_{Pipe-Cond.}$ = Total Length of Pipe within Conditioned Areas (m). This includes the following:

- Pipes exposed to conditioned spaces
- Pipes within risers or plenums that are adjacent to conditioned areas
- Pipes located within risers, plenums or internal spaces, with segments of their perimeters in contact with an adjacent unconditioned space, while the envelope of the adjacent unconditioned space is enclosed by conditioned zones

$L_{Pipe-Uncond.}$ = Total Length of Pipe within Unconditioned Areas (m). This includes the following:

- Pipes exposed to unconditioned spaces
- Pipes exposed to ambient environment
- Pipes located within risers, plenums or internal spaces, where a section of the perimeter is in contact with the ambient environment
- Pipes located within risers, plenums or internal spaces, with segments of their perimeters in contact with an adjacent unconditioned space, while a segment of the envelope of the adjacent unconditioned space is exposed to the ambient environment

k_{pipe-a} = Weighted Average Thermal Conductivity of Pipe Material in Conditioned Areas (W/m.K)
$k_{insul.-a}$ = Weighted Average Thermal Conductivity of Pipe Insulation in Conditioned Areas (W/m.K)
k_{pipe-b} = Weighted Average Thermal Conductivity of Pipe Material in Unconditioned Areas (W/m.K)
$k_{insul.-b}$ = Weighted Average Thermal Conductivity of Pipe Insulation in Unconditioned Areas (W/m.K)
$T_{DHW-Supply-Temp.}$ = Supply Temperature of DHW System (^{o}C)
$T_{Cond.}$ = Set-point Temperature of Conditioned Spaces (^{o}C)
$T_{Uncond.}$ = Temperature of Unconditioned Areas (^{o}C)
r_1 = Weighted Average Inner Radius of Pipes within Conditioned Areas (m)
r_2 = Weighted Average Outer Radius of Pipes within Conditioned Areas (m)
r_3 = Weighted Average Outer Radius of Pipe Insulation within Conditioned Areas (m)
r_4 = Weighted Average Inner Radius of Pipes within Unconditioned Areas (m)
r_5 = Weighted Average Outer Radius of Pipes within Unconditioned Areas (m)
r_6 = Weighted Average Outer Radius of Pipe Insulation within Unconditioned Areas (m)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented in table 1.

Table 1: Summary of Inputs and Source of Parameters in Section 1.2

Parameters		User Inputs	Benchmark
$Q_{Pipe\text{-}Loss}$	Total Thermal Loss from Pipes (MJ_{th}/hour)	Calculated through provided methodology from Equation 1	
$Q_{Pipe\text{-}Loss\text{-}Cond.\text{-}Area}$	Thermal Loss from Pipes within Conditioned Areas (MJ_{th}/hour)	Calculated through provided methodology from Equation 1	
$Q_{Pipe\text{-}Loss\text{-}Uncond.\text{-}Area}$	Thermal Loss from Pipes within Unconditioned Areas (MJ_{th}/hour)	Calculated through provided methodology from Equation 1	
$L_{Pipe\text{-}Cond.}$	Total Length of Pipe within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
$L_{Pipe\text{-}Uncond.}$	Total Length of Pipe within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
$k_{pipe\text{-}a}$	Weighted Average Thermal Conductivity of the Pipe Material within Conditioned Areas (W/m.K)	Yes – Hydraulic Consultant	= User Input
$k_{insulation\text{-}a}$	Weighted Average Thermal Conductivity of the Pipe Insulation within Conditioned Areas (W/m.K)	Yes – Hydraulic Consultant; Default value will be referenced to Table 8.2.2 – Minimum Thermal insulation – Other Heated Water Piping from AS3500.4-2021	Weighted Average Thermal Conductivity of the Pipe Insulation within Conditioned Areas (W/m.K)
$k_{pipe\text{-}b}$	Weighted Average Thermal Conductivity of the Pipe Material within Unconditioned Areas (W/m.K)	Yes – Hydraulic Consultant	= User Input (Hydraulic Consultant)
$k_{insulation\text{-}b}$	Weighted Average Thermal Conductivity of the Pipe Insulation within Unconditioned Areas (W/m.K)	Yes – Hydraulic Consultant / Supplier; Default value will be referenced to Table 8.2.2 – Minimum Thermal insulation – Other Heated Water Piping from AS3500.4-2021	Referenced to Table 8.2.2 – Minimum Thermal insulation – Other Heated Water Piping from AS3500.4-2021
$T_{DHW\text{-}Supply\text{-}Temp.}$	Supply Temperature of DHW System (^{o}C)	Yes – Mechanical / Hydraulic Consultant; Default value will be set at 70^{o}C, fulfilling minimum temperature for Legionella Control	= User Input
$T_{Cond.}$	Temperature of Conditioned Areas (^{o}C)	During the extended heating season (April to September inclusive), the temperature is assumed to be 19^{o}C, which is taken as simplified average of the heating thermostat settings prescribed from Table 3 within the NatHERS Whole of Home Calculations Method; During the extended cooling season (October to March inclusive), the temperature of conditioned space is the value prescribed from Table 88 within the NatHERS Whole of Home Calculations method.	
$T_{Uncond.}$	Temperature of Unconditioned Areas (^{o}C)	To be conservative, temperature of unconditioned areas can be regarded as the same as temperature of ambient temperature. Hourly temperature profile is based on Typical Meteorological Year (TMY) data representative of each climate zone.	
r_1	Weighted Average Inner Radius of Pipes within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_2	Weighted Average Outer Radius of Pipes within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_3	Weighted Average Outer Radius of Pipe Insulation within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input

r_4	Weighted Average Inner Radius of Pipes within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_5	Weighted Average Outer Radius of Pipes within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_6	Weighted Average Outer Radius of Pipe Insulation within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input

1.3 Step 3 – Determine DHW Heating Technology

Various heating technologies influence the energy consumption profile and overall performance DHW systems. Consequently, the subsequent phase in assessing energy consumption of a central DHW system entail identifying the DHW heating technology's design configuration.

The following are possible technologies applicable for a central DHW system:

1.3.1 Instantaneous Electric DHW Heaters

Technology	Fuel Type	Description
Electrical Instantaneous Heaters	Electricity	Electrical instantaneous heaters, also known as tankless electric resistance heaters, are heating devices that use electrical energy to generate heat. They consist of heating elements, typically made of nichrome or other resistance wire, which produce heat when an electric current passes through them.

The energy requirement for electric instantaneous systems to supply sufficient heating for the annual DHW thermal load of all dwellings can be calculated via **Equation 2** below:

Equation 2: Calculation of Hourly Hot Water Energy Requirement

$$E_{Hourly} = \frac{Q_{DHW-Hourly} + Q_{Pipe-Loss}}{\eta_{Ave.-Inst.-Elec.}} + N_{Inst.-Elec.} \times E_{Standby} \times t_{Standby}$$

E_{Hourly} = Hourly Hot Water Energy Requirement (MJ, Electricity)
$Q_{DHW-Hourly}$ = Hourly DHW Thermal Load of Multi-residential Building (MJ_{th}/hour)
$Q_{Pipe-Loss}$ = Total Thermal Loss from Pipes (MJ_{th}/hour)
$\eta_{Ave.-Inst.-Elec.}$ = Average Efficiency of Instantaneous Electric DHW Heaters (%)
$N_{Inst.-Elec.}$ = Quantity of Instantaneous Electric DHW Heater (number of)
$E_{Standby}$ = Standby Energy Requirement of Instantaneous System (MJ/hour, Electricity)
$t_{Standby}$ = Amount of Time in Standby (hour)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is in table 4:

Table 2: Summary of Inputs and Source of Parameters in Section "Instantaneous Electric DHW Heaters"

Parameters	User Inputs	Benchmark
$E_{Thermal-Hourly}$	Hourly Hot Water Thermal Energy Requirement (MJ, Electricity)	Calculated through provided methodology from Equation 2
$Q_{DHW-Hourly}$	Hourly DHW Thermal Load of Multi-residential Building (MJ_{th}/hour)	Calculated through provided methodology from NatHERS Whole of Home Calculations Method.
$Q_{Pipe-Loss}$	Total Thermal Loss from Pipes (MJ_{th}/hour)	Calculated through provided methodology from Equation 1
$\eta_{Ave.-Inst.-Elec.}$	Average Efficiency of Instantaneous Electric DHW Heaters (%)	Default value of 97%. (referenced from Clause C under Section 2.4.2 within AS/NZS 4234:2021)
$N_{Inst.-Elec.}$	Quantity of Instantaneous Electric DHW Heater	Yes – Mechanical Consultant

$E_{Standby}$	Standby Energy Requirement of Instantaneous Electric System (MJ/hour, Electricity)	0.036MJ (referenced from Clause B under Section 4.11 within AS/NZS 4234:2021)
$t_{Standby}$	Amount of Time in Standby (hour)	Can be derived from time series, where time is 1 hour when there's no thermal load during a modelled hour, and where time is 0.9 hour when there's thermal load during a modelled hour.

1.3.2 Instantaneous Gas-fired DHW Heaters

Technology	Fuel Type	Description
Gas- Fired Instantaneous Heaters	Natural Gas	**Gas-fired instantaneous heaters**, also known as tankless water heaters or on-demand water heaters, are a type of water heating system that heats water directly without the need for a storage tank. These heaters are fueled by natural gas or propane and provide hot water on demand whenever it is needed.

The calculation method to determine energy consumption for gas-fired instantaneous DHW systems share strong similarity with the calculation method for electric instantaneous DHW systems.

The energy requirement for gas-fired instantaneous systems to supply sufficient heating for the annual DHW thermal load of all dwellings can be calculated via **Equation 3** below:

Equation 3: Calculation of Hourly Hot Water Thermal Energy Requirement

$$E_{Thermal-Hourly} = \frac{Q_{DHW-Hourly} + Q_{Pipe-Loss}}{\eta_{Ave.-Inst.-Gas.}} + N_{Inst.-Gas} \times E_{Standby} \times t_{Standby}$$

$E_{\text{Thermal-Hourly}}$ = Hourly Hot Water Thermal Energy Requirement (MJ, Natural Gas)
$Q_{\text{DHW-Hourly}}$ = Hourly DHW Thermal Load of Multi-residential Building (MJ_{th}/hour)
$\eta_{\text{Ave.-Inst.-Gas.}}$ = Average Efficiency of Instantaneous Gas-fired DHW Heaters (%)
$N_{\text{Inst.-Gas}}$ = Quantity of Instantaneous Gas-fired DHW Heaters (number of)
E_{Standby} = Standby Energy Requirement of Instantaneous System (MJ/hour, Electricity)
t_{Standby} = Amount of Time in Standby (hour)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 3: Summary of Inputs and Source of Parameters in Section "Instantaneous Gas-fired DHW Heaters"

Parameters		User Inputs	Benchmark
$E_{\text{Thermal-Hourly}}$	Hourly Hot Water Thermal Energy Requirement (MJ, Natural Gas)	Calculated through provided methodology from Equation 2	
$Q_{\text{DHW-Hourly}}$	Hourly DHW Thermal Load of Multi-residential Building (MJ_{th}/hour)	Calculated through provided methodology from NatHERS Whole of Home Calculations Method.	
$Q_{\text{Pipe-Loss}}$	Total Thermal Loss from Pipes (MJ_{th}/hour)	Calculated through provided methodology from Equation 1	
$\eta_{\text{Ave.-Inst.-Gas}}$	Average Efficiency of Instantaneous Gas-fired DHW Heaters (%)	Yes – Selected gas products must be rated 5-star. Default value of 85%.	
$N_{\text{Inst.-Gas}}$	Quantity of Instantaneous Gas-fired DHW Heater	Yes – Mechanical / Hydraulic Consultant	= User Input
E_{Standby}	Standby Energy Requirement of Instantaneous Gas-fired System (MJ/hour, Electricity)	0.036MJ (referenced from Clause B under Section 4.11 within AS/NZS 4234:2021)	
t_{Standby}	Amount of Time in Standby (hour)	Can be derived from time series, where time is 1 hour when there's no thermal load during a modelled hour, and where time is 0.9 hour when there's thermal load during a modelled hour.	

$T_{DHW\text{-}Supply\text{-}Temp.}$	Supply Temperature of DHW System (°C)	Yes– Mechanical / Hydraulic Consultant; Default value will be set at 70°C	= User Input

1.3.3 Air-Water Heat Pump

Technology	Fuel Type	Description
Air-water Heat Pump	Electricity	An **Air-Water Heat Pump** is a technology designed to efficiently and economically provide hot water for residential or commercial purposes. This type of heat pump system utilizes the principles of thermodynamics to transfer heat from the ambient air to the water, thereby raising its temperature for various domestic uses.

The energy requirement for DHW heating systems using heat pumps only to supply sufficient heating for the annual DHW thermal load of all dwellings can be calculated via **Equation 4** below:

Equation 4: Hourly Hot Water Energy Requirement

$$E_{Thermal-Hourly} = \frac{Q_{DHW-Hourly} + Q_{Pipe-Loss}}{COP_{HP}}$$

$E_{Thermal\text{-}Hourly}$ = Hourly Hot Water Energy Requirement (MJ, Electricity)
$Q_{Pipe\text{-}Loss}$ = Total Thermal Loss from Pipes (MJ_{th}/hour)
$Q_{DHW\text{-}Hourly}$ = Hourly DHW Thermal Load of Multi-residential Building (MJ_{th}/hour)
COP_{HP} = Average Coefficient of Performance for Heat Pumps

The above equation assumes a heat pump water heating system that is capable to supply heating for DHW at the desired supply temperature ($T_{DHW\text{-}Supply\text{-}Temp.}$).

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 4: Summary of Inputs and Source of Parameters in Section "Air-Water Heat Pump"

Parameters		User Inputs	Benchmark
$E_{Thermal\text{-}Hourly}$	Hourly Hot Water Thermal Energy Requirement (MJ, Natural Gas)	Calculated through provided methodology from Equation 2	
$Q_{DHW\text{-}Hourly}$	Hourly DHW Thermal Load of Multi-residential Building (MJ_{th}/hour)	Calculated through provided methodology from NatHERS Whole of Home Calculations Method.	
$Q_{Pipe\text{-}Loss}$	Total Thermal Loss from Pipes (MJ_{th}/hour)	Calculated through provided methodology from Equation 1	
COP_{HP}	Average Coefficient of Performance for Heat Pumps	Default value to be 2.5. The user must also be prompted to verify if the heat pump can supply heating for DHW at the desired supply temperature.	Default value to be 2.5.
$T_{DHW\text{-}Supply\text{-}Temp.}$	Supply Temperature of DHW System (°C)	Yes - Mechanical / Hydraulic Consultant; Default value may be set at 70°C	= User Input

1.3.4 DHW Heaters with Storage

Technology	Primary Fuel Type	Description
Instantaneous Electric Heater with Thermal Storage	Electricity	An **instantaneous electric heater with thermal storage** is a type of water heating system that combines both electric instantaneous heating and thermal storage capabilities.
Instantaneous Gas Heater with Thermal Storage	Natural Gas	An **instantaneous gas-fired heater with thermal storage** is a type of water heating system that combines both gas-fired instantaneous heating and thermal storage capabilities.
Electrical Water Storage Heaters	Electricity	**Electric water storage heater** is a device that heats and stores a specific volume of hot water for later use. It consists of an insulated tank that holds the water and electric heating elements that heat the water to the desired temperature.
Gas- Fired Storage Heaters	Gas	A **gas-fired storage water heater** is a type of water heating system that utilizes natural gas or propane as a fuel source to heat and store hot water in a storage tank.
Air-water Heat Pump with Thermal Storage	Electric	An **air-water heat pump with thermal storage** is a heating system that utilizes the principles of heat pump technology to efficiently provide hot water for residential or commercial use, coupled with thermal storages serving as reservoir for storing the heated water until it is needed.

When instantaneous systems are paired with thermal storages, the methodology no longer assumes all hourly thermal load is sufficiently. Hourly heat loss from storage as well as remaining hot water from the previous hour must be considered.

Tanks are available in diverse dimensions and configurations. To simplify the calculation of heat loss, an idealized tank with uniform insulation thickness on all surfaces is presumed, as depicted in the figure below. The cross-section of this idealized tank could be circular or rectangular, contingent upon the design of the tank under evaluation.

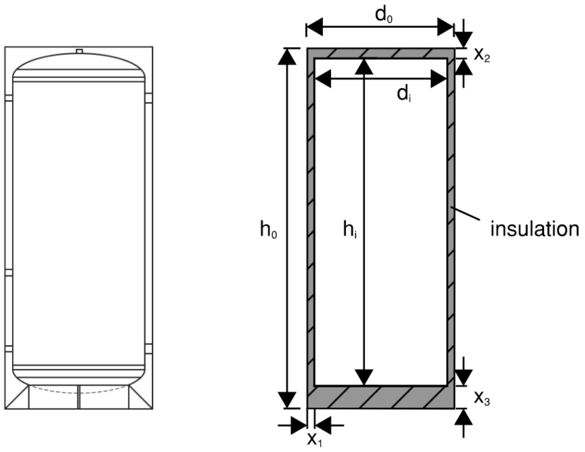

Figure 2: Typical Tank (left) vs Idealized Tank Schematic (right)

Heat loss for any thermal storages can be calculated via **Equation 5** below, which has been modified from E.9 and E.10 within AS/NZS 4234:2021 to suit an hourly time-series model that takes in TMY data:

Equation 5: Calculation of Total Heat Loss for Tank

$$Q_{Tank-Loss} = \left(1.35\left(Q_{Top} + Q_{Side} + Q_{Bottom}\right) \times 0.001 + Q_{Fittings}\right) \times 0.0036$$

$$= (1.35\left(\frac{\pi d_i^2 k \Delta T}{4x_2} + \frac{2\pi h_i k \Delta T}{\ln\left(\frac{d_0}{d_i}\right)} + \frac{\pi d_i^2 k \Delta T}{4x_3}\right) \times 0.001$$

$$+ A_0 \times 1.125 + d_{Tank-Pipe-Uninsul.} \times 0.208 + d_{Tank-Pipe-Insul.} \times 0.146) \times 0.0036$$

$Q_{Tank\text{-}Loss}$ = Total Heat Loss for Tank (MJ_{th}/hour)
Q_{Top} = Heat Loss Through Top of Tank (MJ_{th} /hour)
Q_{Side} = Heat Loss Through Side of Tank (MJ_{th}/hour)
Q_{Bottom} = Heat Loss Through Bottom of Tank (MJ_{th}/hour)
d_i = Tank Inner Diameter (m)
d_0 = Tank Outer Diameter (m)
h_i = Inner Height of Tank (m)
k = Insulation Thermal Conductivity (W/m.K)
x_1 = Tank Side Insulation Thickness (m)
x_2 = Tank Top Insulation Thickness (m)
x_3 = Tank Bottom Insulation Thickness (m)
ΔT = Temperature Difference of Tank Surface Temperature and Stored Water Temperature (^oC)

- Stored Water Temperature is assumed to be DHW Supply Temperature ($T_{DHW\text{-}Supply\text{-}Temp.}$)
- Tank Surface Temperature is assumed to be Ambient Temperature ($T_{ambient}$)

$Q_{Fittings}$ = Heat Losses through Tank Openings and Fittings (J_{th})

A_0 = Tank Opening (e.g. Thermostat Pocket) (m^2)
$d_{Tank\text{-}Pipe\text{-}Uninsul.}$ = Uninsulated Pipe or Fitting (e.g. PTR Valve) (m)
$d_{Tank\text{-}Pipe\text{-}Insul.}$ = Insulated Pipe or Fitting (m)

Hourly energy profile for DHW systems can then be calculated via Equation 6 (Electric), Equation 7 (Gas-fired), Equation 8 (Heat Pump) below:

Electric DHW Heaters with Storage

Equation 6

$$E_{Thermal-Hourly} = \frac{\left(Q_{Pipe-Loss} + Q_{Tank-Loss} + Q_{DHW-Hourly}\right)}{\eta_{Ave.-Elec.}}$$

For Gas-fired DHW Heaters with Storage:

Equation 7

$$E_{Thermal-Hourly} = \frac{\left(Q_{Pipe-Loss} + Q_{Tank-Loss} + Q_{DHW-Hourly}\right)}{\eta_{Ave.-Gas}}$$

For Electric Heat Pumps with Storage:

Equation 8

$$E_{Thermal-Hourly} = \frac{\left(Q_{Pipe-Loss} + Q_{Tank-Loss} + Q_{DHW-Hourly}\right)}{COP_{HP}}$$

$E_{Thermal\text{-}Hourly}$ = Hourly Hot Water Energy Requirement (MJ, Electricity/Natural Gas)
$Q_{Pipe\text{-}Loss}$ = Total Thermal Loss from Pipes (MJth/hour)
$Q_{Tank\text{-}Loss}$ = Total Heat Loss for Tank (MJth/hour)
$Q_{DHW\text{-}Hourly}$ = Hourly DHW Thermal Load of Multi-residential Building (MJth/hour)
$\eta_{Ave.\text{-}Elec.}$ = Average Efficiency of Electric DHW Heaters (%)
$\eta_{Ave.\text{--}Gas.}$ = Average Efficiency of Gas-fired DHW Heaters (%)
COP_{HP} = Average Coefficient of Performance for Heat Pumps

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 5: Summary of Inputs and Source of Parameters in Section DHW Heaters with Storage

Parameters		User Inputs	Benchmark
$Q_{Tank-Loss}$	Total Heat Loss for Tank (MJ_{th}/hour)	Calculated through provided methodology from Equation 5	
Q_{Top}	Heat Loss Through Top of Tank (MJ_{th}/hour)	Calculated through provided methodology from Equation 5	
Q_{Side}	Heat Loss Through Side of Tank (MJ_{th}/hour)	Calculated through provided methodology from Equation 5	
Q_{Bottom}	Heat Loss Through Bottom of Tank (MJ_{th}/hour)	Calculated through provided methodology from Equation 5	
d_i	Tank Inner Diameter (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
d_0	Tank Outer Diameter (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
h_i	Inner Height of Tank (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
k	Insulation Thermal Conductivity (W/m.K)	Yes – Mechanical / Hydraulic Consultant	There is currently no minimum standard for tank insulation. Benchmark value of 0.09 W/m.K is to be assumed based on lowest thermal conductivity of insulation materials from Table E.6 within AS/NZS 4234:2021.
x_1	Tank Side Insulation Thickness (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
x_2	Tank Top Insulation Thickness (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
x_3	Tank Bottom Insulation Thickness (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
ΔT	Temperature Difference of Tank Surface Temperature and Stored Water Temperature (°C)	Stored water temperature requires user input = DHW Supply Temperature ($T_{DHW-Supply-Temp.}$). Tank Surface Temperature = Temperature of Ambient Environment (°C) and is based on Typical Meteorological Year (TMY) data representative of each climate zone.	
$Q_{Fittings}$	Heat Losses through Tank Openings and Fittings	Calculated through provided methodology from Equation 5	
A_0	Tank Opening (e.g. Thermostat Pocket) (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
$d_{Tank-Pipe-Uninsul}$	Uninsulated Pipe or Fitting (e.g. PTR Valve) (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
$d_{Tank-Pipe-Insul.}$	Insulated Pipe or Fitting (m)	Yes – Mechanical / Hydraulic Consultant	= User Input
$E_{Thermal-Hourly}$	Hourly Hot Water Energy Requirement (MJ, Electricity/Natural Gas)	Can be calculated through Equation 5 for Electric DHW Heaters with Storage, Equation 6 for Gas-fired DHW Heaters with Storage and Equation 7 for Electric Heat Pumps with Storage.	

1.3.5 Solar-boosted Systems

Technology	Fuel Type	Description
Solar-boosted DHW System	Electricity	A **solar-boosted system** is a DHW heating solution that integrates both solar theraml system and other water heating technologies coupled with thermal storages.

Solar-boosted systems are always coupled with thermal storage solutions. Consequently, assessing the impact of solar thermal systems on thermal load reduction necessitates the calculation of the hourly solar thermal load supplied. This methodology aligns with the process outlined for the development of hourly DHW thermal load, as detailed in Section 1.1.

To facilitate the development of hourly supplied thermal load from the solar thermal system, monthly peak sun hour shall be determined for the locality of the assessed project, which can be reference from Table 6 below:

Table 6: Reference Monthly Peak Sun Hours based on Locations

Month	Darwin (800 – 886)	Sydney (2000 - 2914)	Melbourne (3000 – 3996	Brisbane (4000 - 4895)	Adelaide (5000 - 5291)	Perth (5301 - 6256)	Hobart (7000 - 7470)
Jan	4.5	6.9	6.8	6.1	7.1	7.9	6.1
Feb	5.3	6.3	6.6	6.1	7.2	7.7	5.6
Mar	5.9	5.7	5.7	5.4	6.2	6.9	4.9
Apr	6.8	4.7	4.3	5.2	5.1	5.5	3.8
May	6.8	4.6	3.0	5.3	3.8	4.6	2.4
Jun	6.9	3.5	2.7	4.7	3.7	3.8	2.0
Jul	7.0	4.3	2.7	4.9	3.4	3.8	2.6
Aug	7.2	5.0	3.6	6.0	4.2	5.0	3.3
Sep	7.1	5.7	4.7	6.5	5.7	5.8	3.9
Oct	6.1	5.6	5.5	6.1	6.0	6.9	4.8
Nov	5.2	5.8	5.6	6.6	5.9	6.6	4.6
Dec	4.9	6.3	6.3	5.6	6.7	7.4	5.3

A reference locality has been selected from postcodes covered within the NatHERS Whole of Home Calculations Method for the purpose of developing reference monthly peak sun hours. The above Peak Sun Hours are modelled based on prescribed solar system Tilt of 25^{o}, and Azimuth of 0^{o} from Table A.3 within AS/NZS 4234:2021.

Average Daily Peak Sun Hours Profile for each reference locality are prescribed below:

Table 7: Reference Daily Peak Sun Hours Profile based on Postcode

Locality | Time	Darwin (800 - 886)	Sydney (2000 - 2914)	Melbourne (3000 - 3996	Brisbane (4000 - 4895)	Adelaide (5000 - 5291)	Perth (5301 - 6256)	Hobart (7000 - 7470)
12:00 AM	-	-	-	-	-	-	-
1:00 AM	-	-	-	-	-	-	-
2:00 AM	-	-	-	-	-	-	-
3:00 AM	-	-	-	-	-	-	-
4:00 AM	-	-	-	-	-	-	-
5:00 AM	-	0.1%	0.1%	0.1%	0.2%	-	0.1%
6:00 AM	0.3%	1.0%	1.0%	1.3%	1.3%	0.4%	0.8%
7:00 AM	3.2%	4.0%	4.0%	5.2%	4.8%	2.8%	2.8%
8:00 AM	7.1%	8.0%	8.0%	8.9%	8.5%	6.7%	6.9%
9:00 AM	10.3%	11.2%	11.2%	11.5%	11.3%	9.9%	10.4%
10:00 AM	12.5%	13.0%	13.0%	13.0%	13.4%	12.2%	13.3%
11:00 AM	13.6%	14.0%	14.0%	13.3%	13.6%	13.5%	14.2%
12:00 PM	13.7%	13.6%	13.6%	13.2%	13.5%	13.8%	13.7%
1:00 PM	12.7%	12.7%	12.7%	12.0%	12.5%	13.3%	12.9%
2:00 PM	11.2%	10.6%	10.6%	10.2%	10.3%	11.7%	11.1%
3:00 PM	8.4%	7.5%	7.5%	7.3%	7.0%	9.0%	8.0%
4:00 PM	5.2%	3.4%	3.4%	3.5%	3.0%	5.1%	4.0%
5:00 PM	1.6%	0.7%	0.7%	0.5%	0.6%	1.4%	1.3%
6:00 PM	0.1%	0.1%	0.1%	-	-	0.1%	0.2%
7:00 PM	-	-	-	-	-	-	-
8:00 PM	-	-	-	-	-	-	-
9:00 PM	-	-	-	-	-	-	-
10:00 PM	-	-	-	-	-	-	-
11:00 PM	-	-	-	-	-	-	-

Therefore, Hourly Solar Thermal Load modelled within a 8760-time series can be calculated via **Equation 9** as follows:

Equation 9: Calculation of Hourly Solar Thermal Load of Designed System

$$Q_{Solar-Th.} = A_{solar} \times P_{Th.} \times MPSHM \times HSEDM \ \times \eta_{Solar-Design}$$

$Q_{Solar\text{-}Th.}$ = Hourly Solar Thermal Load of Designed System (MJth/hour)
A_{Solar} = Exposed Solar Panel Area (m^2)
$P_{TH.}$ = Nominal Panel Thermal Power (MJth/hour/m^2)
MPSHM = Monthly Peak Sun Hour Multiplier per Table 6
HSEDM = Hourly Solar Energy Distribution Multiplier per Table 7
$\eta_{Solar\text{-}Design}$ = Design Efficiency of the Solar Thermal System (%) per Table 9

Numerous factors may influence the efficiency of a solar thermal system. Apart from uncontrollable elements like the inherent efficiency of panel materials, environmental factors (such as dust, and dirt), and ambient temperature, the design of the solar system plays important role in determining its efficiency. This methodology addresses the following controllable design factors that can impact the overall efficiency of the solar thermal system:

- **Tilt**, θ – The angle at which solar panels are inclined relative to the horizontal plane. The tilt angle affects the amount of sunlight that directly strikes the solar panels.
- **Azimuth,** β – The compass direction to which solar panels face. The azimuth angle determines how well solar panels are oriented towards the sun.
- **Shading,** S – Shading occurs when objects like buildings, trees, or other obstructions cast shadows on solar panels. Shading reduces the amount of sunlight that can reach the solar panels, diminishing the system's ability to capture and convert solar heat into usable energy. Shading can also result in uneven heat distribution, decreased temperature differentials, and overall lower thermal output.

The system efficiency ($\eta_{\text{Solar-Design}}$) of the solar thermal system for Equation 9 can be determined via a scoring system. For each design factor, a specific weightage is assigned to each category based on its influence on system efficiency, per Table 8 below:

Table 8: Scoring of Solar System's Design

Orientation, θ	**Weight**
North (> 0° & ≤ 45°, > 315° & ≤ 360°)	3
East (> 45° & ≤ 135°)	2
South Facing (> 135° & ≤ 225°)	1
West Facing (> 225° & ≤ 315°)	2
Tilt, β	**Weight**
> 0° & ≤ 20°	2
> 20° & ≤ 45°	3
> 45° & ≤ 70°	2
> 70° & ≤ 90°	1
Shading, S	**Weight**
Little to no shading (*Solar panels are mostly free from shading during the day.*)	4
Minorly shaded (*Some parts of the solar panels experience intermittent shading, but the impact is limited.*)	3
Moderately shaded (*Substantial portions of the solar panels are shaded at various times during the day.*)	2
Heavily Shaded (*A significant portion of the solar panels is consistently shaded, either by structures or vegetation.*)	1

The cumulative scores from these factors are then used to determine the overall efficiency of the solar system, per Table 9 below:

Table 9: Allocation of Solar Design Efficiency Values Based on Cumulative Scores from Solar Design Factors

Score	Solar Design Efficiency
1	-
2	-
3	60%
4	64%
5	69%
6	73%
7	77%
8	81%
9	86%
10	90%

An extension of the hourly thermal energy requirement for the covered water heating systems coupled with thermal storage to account for the thermal reduction potential from solar thermal systems can be calculated as **Equation 10**, **Equation 11**, or **Equation 12** below:

For Electric DHW Heaters with Storage:

Equation 10

$$E_{Thermal-Hourly} = \frac{MAX\left(\left(Q_{Pipe-Loss} + Q_{Tank-Loss} + Q_{DHW-Hourly} + Q_{Tank-Make-up} - Q_{Solar-Th.}\right), 0\right)}{\eta_{Ave.-Inst.-Elec.}}$$

For Gas-fired DHW Heaters with Storage:

Equation 11

$$E_{Thermal-Hourly} = \frac{MAX\left(\left(Q_{Pipe-Loss} + Q_{Tank-Loss} + Q_{DHW-Hourly} + Q_{Tank-Make-up} - Q_{Solar-Th.}\right), 0\right)}{\eta_{Ave.-Inst.-Gas}}$$

For Electric Heat Pumps with Storage:

Equation 12

$$E_{Thermal-Hourly} = \frac{MAX\left[\left(Q_{Pipe-Loss} + Q_{Tank-Loss} + Q_{DHW-Hourly} + Q_{Tank-Make-up} - Q_{Solar-Th.}\right), 0\right]}{COP_{HP}}$$

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 10: Summary of Inputs and Source of Parameters in Section Solar-boosted Systems.

Parameters		User Inputs	Benchmark
$Q_{Solar\text{-}Th.}$	Hourly Solar Thermal Load of Designed System (MJ_{th}/hour)	Calculated through provided methodology from Equation 9	
A_{Solar}	Exposed Solar Panel Area (m^2)	Yes – Electrical Consultant	= User Input
$P_{TH.}$	Nominal Panel Thermal Power (MJ_{th}/m^2)	Yes – Electrical Consultant	= User Input
MPSHM	Monthly Peak Sun Hour Multiplier per Table 6	Referenced to Table 6	
HSEDM	Hourly Solar Energy Distribution Multiplier per Table 7	Referenced to Table 7Table 6	
$\eta_{Solar\text{-}Design}$	Design Efficiency of the Solar Thermal System (%) per Table 9	Yes – Electrical Consultant	= User Input

1.4 Step 4 – Account for Other Auxiliary Energy

There are various sources of auxiliary energy demand for a central DHW system that contributes to additional energy consumption on top of the heating energy requirement. Auxiliary loads such as standby power and storage losses have been considered in Section 1.3. Another main source of auxiliary load within multi-residential buildings comes from Circulation Pumps, which is responsible for circulating hot water from the DHW storage tank or hot water heating units to the various hot water outlets. The amount of energy consumed by the circulation pump depends on factors such as the pump's power rating, operating hours, and efficiency.

The annual pump energy requirement for central DHW systems can be presented as **Equation 13** below:

Equation 13: Calculation of Hourly Circulation Pump Energy Requirement

$$\begin{aligned} E_{Circ.-Pump} &= N_{DHW-Pump} \times \eta_{DHW-Pump+Motor} \times P_{DHW-Pump} \times t_{Operation} \\ &= N_{DHW-Pump} \times \eta_{DHW-Pump} \times \eta_{DHW-Motor} \times P_{DHW-Pump} \times t_{Operation} \end{aligned}$$

$E_{Circ.-Pump}$ = Hourly Circulation Pump Energy Requirement (MJ, Electricity)
$N_{DHW-Pump}$ = Number/Quantity of Circulation Pumps
$\eta_{DHW-Pump+Motor}$ = Efficiency of Circulation Pumps (%)
$\eta_{DHW-Pump}$ = Efficiency of the Pump component within the DHW Pump System (%)
$\eta_{DHW-Motor}$ = Efficiency of the Motor component within the DHW Pump System (%)
$P_{DHW-Pump}$ = Rated Power of Circulation Pump (MJ/hr)
$t_{Operation}$ = Modelled Operational Hours of Pumps (hours)

- In accordance with AS4234:2021, a draw-off time of 0.1 hour is assumed for instantaneous systems. Within open loop designs, this value represents $t_{Operation}$ during hours with thermal loads. However, in closed-loop systems, where circulation pumps operate continuously, the assumed $t_{Operation}$ for closed-loop designs is 1 hour for each modeled hour.

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 11: Summary of Inputs and Source of Parameters in Section 1.4

Parameters		User Inputs	Benchmark
$E_{Circ.-Pump}$	Hourly Pump Energy Requirement (MJ, Electricity)	Calculated through provided methodology from Equation 13	
N_{Pump}	Number/Quantity of Circulation Pumps	Yes – Mechanical Consultant	= User Input
$\eta_{DHW-Pump+Motor}$	Efficiency of Circulation Pumps (%)	Calculated through provided methodology from Equation 13	
$\eta_{DHW-Pump}$	Efficiency of the Pump component within the DHW Pump System (%)	Yes – Mechanical Consultant; Default value assumed to be 75%	= User Input
$\eta_{DHW-Motor}$	Efficiency of the Motor component within the DHW Pump System (%)	Yes – Mechanical Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
P_{Pump}	Rated Power of Pump (MJ/hr)	Yes – Mechanical Consultant	= User Input
$t_{Operation}$	Modelled Operational Hours of Pumps (hours)	Derived through design selection from user	

1.5 Step 5 – Calculating Total Annual Energy Requirement for Central DHW Services

Annual energy consumption of central DWH system can be calculated via **Equation 14**:

Equation 14: Calculation of Annual DHW Energy Requirement

$$E_{DHW-Central} = \sum_{i=1}^{8760} \left(E_{Thermal-Hourly} + E_{Circ.-Pump}\right)$$

$E_{\text{DHW-Central}}$ = Annual DHW Energy Requirement (MJ, Electricity or Natural Gas & Electricity)
$E_{\text{Thermal-Hourly}}$ = Hourly Thermal Energy Loads (MJ, Electricity or Natural Gas & Electricity)
$E_{\text{Circ.-Pump}}$ = Hourly Pump Energy Requirement (MJ)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 12: Summary of Inputs and Source of Parameters in Section 1.51.4 Instantaneous Electric DHW Heaters

Parameters		User Inputs	Benchmark
$E_{\text{DHW-Central}}$	Annual DHW Energy Requirement (MJ, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 14	
$E_{\text{Thermal-Hourly}}$	Hourly Thermal Energy Loads (MJ, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 14 depending on system configuration	
$E_{\text{Circ.-Pump}}$	Hourly Pump Energy Requirement (MJ)	Calculated through provided methodology from Equation 13	

1.6 Step 6 – Apportioning to sole occupancy unit

In central DHW system applications, the methodology for apportioning is contingent upon the design of the hot water loop.

1.6.1 Reticulated Systems (non-circulating)

In a reticulated DHW system, hot water is efficiently delivered directly from a centralized source to individual dwellings or specific points of use. This is accomplished by blending hot water generated by the central DHW system with cold water sourced from the main supply through a thermostatic mixing valve. The resulting mixture is then distributed to various endpoints, primarily fixtures and fittings within the building. Once the water has been utilized at these fixtures, it is considered as having exited the water heating system and is typically discharged into a wastewater drain.

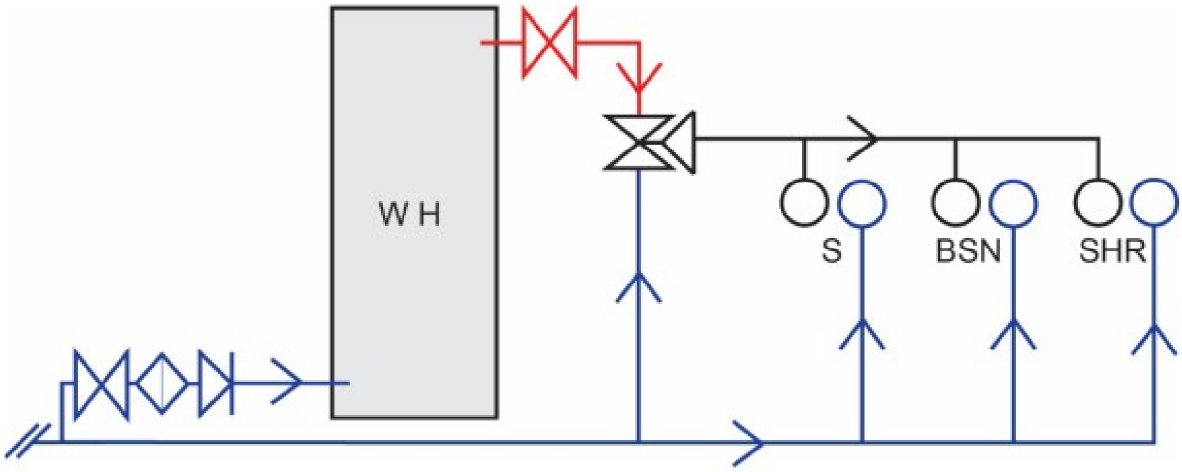

Figure 3: Illustration of Reticulated DHW Systems (Source: Warm Water Systems 2020, Figure 4.1, ABCB)

In a reticulated DHW system, when apportioning energy consumption from a central system to individual dwellings, it's important to note that the piping heat loss for each dwelling can exhibit differences. This discrepancy arises due to the direct circulation of hot water from the central source to each dwelling. Given that the length of piping within each dwelling can vary, these differences in piping length directly contribute to varying levels of heat loss experienced by each individual dwelling.

Equation 15: Calculation of annual DHW energy consumption of an assessed dwelling

$$E_{DHW-Dwelling} = E_{DHW-Central} \times \frac{Q_{DHW-Dwelling} \times \Delta L_{Pipe-Dwelling}}{\sum_{i=1}^{n} Q_{DHW-Dwelling-Annual-Th.} \times \Delta L_{Pipe-Dwelling-N}}$$

$E_{DHW\text{-}Dwelling}$ = Annual DHW energy consumption of an assessed dwelling (MJ, Electricity or Natural Gas & Electricity)
$E_{DHW\text{-}Central}$ = Annual DHW Energy Requirement (MJ, Electricity or Natural Gas & Electricity)
$Q_{DHW\text{-}Dwelling}$ = Total Annual DHW Thermal Requirement of assessed dwelling (MJ_{th}/a)
$Q_{DHW\text{-}Dwelling\text{-}Annual\text{-}Th.}$ = Total Annual DHW Thermal Requirement of assessed building (MJ_{th}/a)

$\Delta L_{Pipe\text{-}Dwelling}$ = Length of DHW piping from central DHW system to assessed dwelling (m)

1.6.2 Circulatory Systems

In a circulatory DHW system, hot water circulates within a sealed network of pipes. The process entails generating hot water at a central source, which is then transported within a closed-loop and be mixed with cold water from the mains. The key distinction between this system and a reticulated system lies in the closed-loop nature of the hot water circulation. In a closed-loop system, hot water is continually recirculated from the mixing point back to the heating source to ensure that it is instantly available at the point of connection to the SOU. This continuous circulation means that hot water is always in motion within the closed-loop piping system, maintaining a consistent supply.

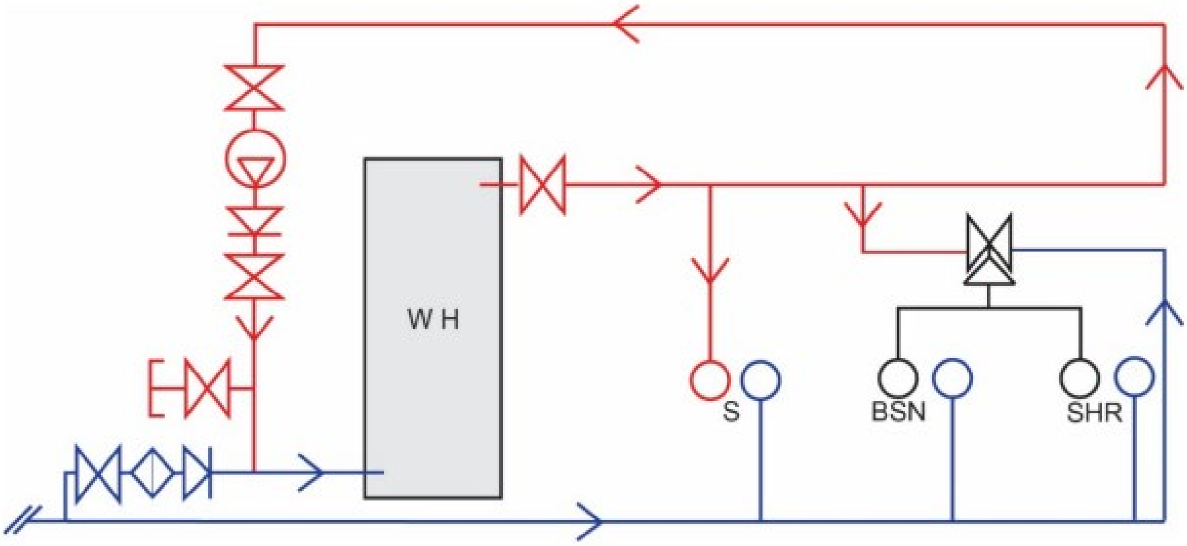

Figure 4: Illustration of Closed Loop DHW Systems (Source: Warm Water Systems 2020, Figure 4.5, ABCB)

In a closed loop DHW system, where hot water circulates within a sealed network of pipes, the piping heat loss for each dwelling is generally assumed to be uniform. This uniformity arises from the design of the piping network within a closed loop system, which is typically standardized across all dwellings. In this configuration, the shared heating source is responsible for providing extra heating to the hot water loop to compensate for heat losses. As a result, additional heating isn't usually supplied directly to each individual apartment within the system.

Equation 16: Calculation of annual DHW energy consumption of an assessed dwelling

$$E_{DHW-Dwelling} = E_{DHW-Central} \times \frac{Q_{DHW-Dwelling}}{\sum_{i=1}^{n} Q_{DHW-Dwelling-Annual-Th.}}$$

$E_{DHW\text{-}Dwelling}$ = Annual DHW energy consumption of an assessed dwelling (MJ, Electricity or Natural Gas & Electricity)

$E_{DHW\text{-}Central}$ = Annual DHW Energy Requirement (MJ, Electricity / Electricity & Natural Gas)
$Q_{DHW\text{-}Dwelling}$ = Total Annual DHW Thermal Requirement of assessed dwelling (MJ_{th}/a)

$Q_{DHW\text{-}Dwelling\text{-}Annual\text{-}Th.}$ = Total Annual DHW Thermal Requirement of assessed building (MJ_{th}/a)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 13: Summary of Inputs and Source of Parameters in Section 1.61.4Instantaneous Electric DHW Heaters

Parameters		User Inputs	Benchmark
$E_{DHW\text{-}Dwelling}$	Annual DHW energy consumption of an assessed dwelling (MJ, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 15 or Equation 16	
$E_{DHW\text{-}Central}$	Annual DHW Energy Requirement (MJ, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 14	
$Q_{DHW\text{-}Dwelling}$	Total Annual DHW Thermal Requirement of assessed dwelling (MJ_{th}/a)	Calculated through provided methodology from Section 1.3	
$Q_{DHW\text{-}Dwelling\text{-}Annual\text{-}Th}$	Total Annual DHW Thermal Requirement of assessed building (MJ_{th}/a)	Calculated through provided methodology from Section 1.3	
$\Delta L_{Pipe\text{-}Dwelling}$	Length of DHW piping from central DHW system to assessed dwelling (m)	Yes – Hydraulic Consultant	= User Input

2 Central HVAC

The methodology for determining central HVAC system energy requirements for apartment buildings is summarised as follows:

- **Step #1 – Determine Heating Load and Cooling Load:** Heating loads and cooling loads of assessed dwellings/building must be first determined to understand the energy requirement to meet the heating/cooling demand.
- **Step #2 – Account for Design Efficiency:** Upon determining the heating load and cooling load of the assessed building, heat losses from pipes or ducts shall be accounted for to determine the actual heating load and cooling load required to not only meet the conditioning demand of the assessed dwellings but also to make up for the losses from the mechanical infrastructure.
- **Step #3 – Determine Heating/Cooling System Type and Account for System Efficiency:** After determining heating loads and cooling loads, the technology intended for meeting the conditioning requirements shall be selected. Different HVAC technologies have different efficiency patterns, which is then accounted for after technology selection.
- **Step #4 – Calculate Auxiliary Energy Requirements:** The auxiliary energy requirement varies with the chosen HVAC technology, and this calculation is made after identifying the specific auxiliary equipment needed to facilitate the operation of the conditioning technology.
- **Step #5 – Calculate Total Annual Energy Requirement for Central HVAC Services:** After establishing the energy needs for conditioning and accounting for auxiliary energy requirements, the total energy demand to provide heating and cooling through central HVAC services can then be calculated.
- **Step #6 – Apportion for Shared Services:** Once the overall energy requirement for the building for central HVAC services has been established, it is then possible to allocate the energy requirements for each individual dwelling.

The main steps in the method are shown visually in Figure 5. Detailed explanation of each step in the prescribed framework above are presented in the following sections.

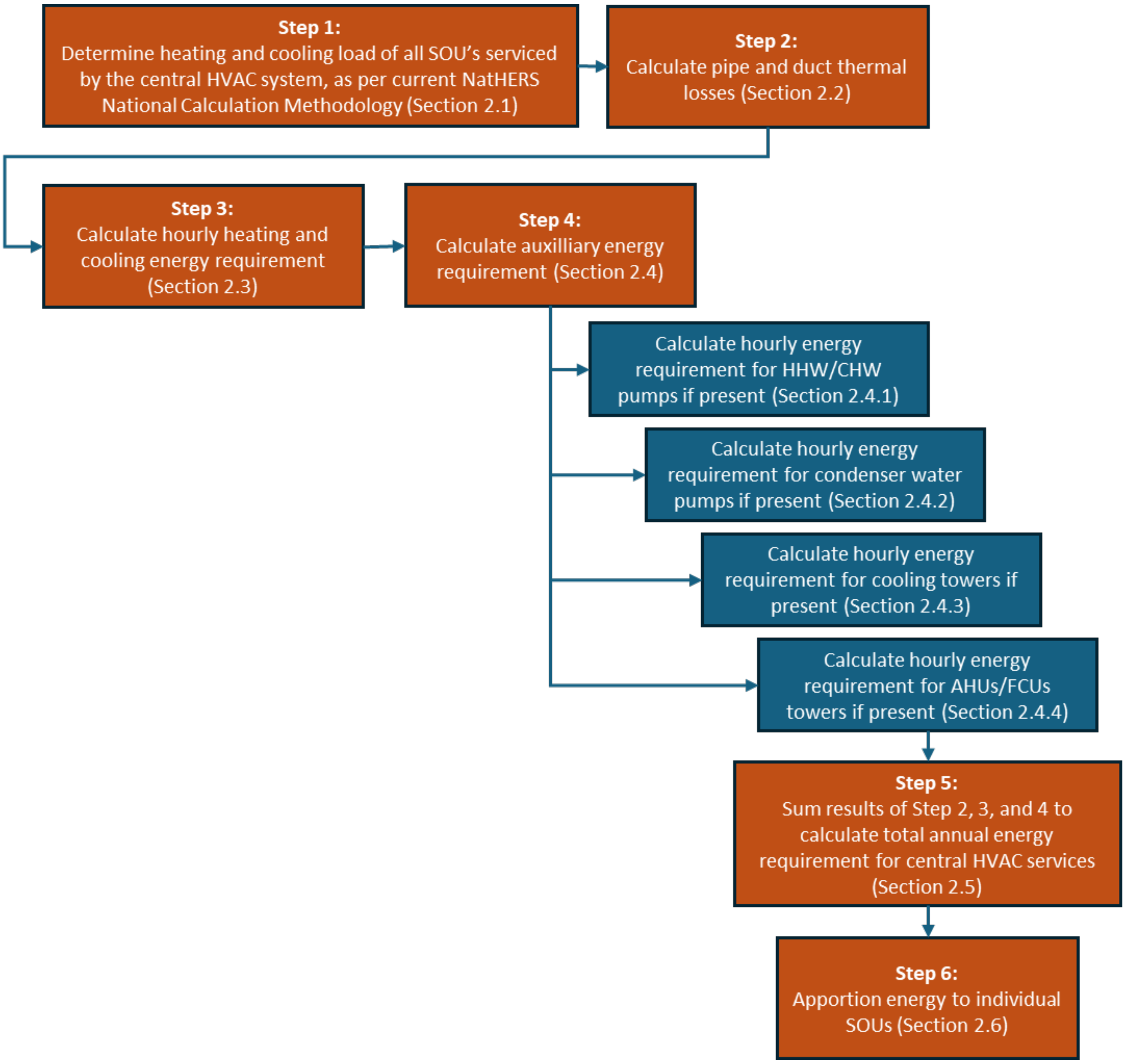

Figure 5. Summary of centralised HVAC calculation method.

2.1 Step 1 – Determine the Heating Load and Cooling Load

The hourly thermal loads are calculated by the Chenath engine based on inputs defined in section 3.1 of the NatHERS Whole of Home Calculations Method and blended using Equation 3 in section 3.2.3. This is the ‘demand’ for space heating or cooling in that zone for that hour, not the amount of fuel consumed.

Annual energy load for each zone is the sum of the energy loads in each hour for the entire year.

2.2 Step 2 – Account for Design Efficiency

Depending on the designated heating and cooling technology and intended mechanical design, the central HVAC system may experience one or both of the following design losses:

- **Piping Loss** – Piping loss refers to the energy loss that occurs as a result of the transport of heated or chilled water or refrigerants through a network of pipes from the central HVAC system to various terminal units (such as radiators, air handling units or fan coil units) in a building.
- **Duct Loss** – Duct loss pertains to the energy loss that takes place as conditioned air travels through the ductwork from the HVAC system to the individual rooms or spaces within a building.

To determine the overall annual heat losses from pipes and ducts, an approach involves employing time series modeling throughout a reference year is required.

Piping Loss

Hourly heat losses from pipes can be estimated via Equation 17 and Equation 18 as follows:

For pipe loss under heating scenario:

Equation 17: Calculation of Total Hourly Thermal Loss from Pipes under Heating Scenario

$$Q_{H-Pipe-Loss} = Q_{H-Pipe-Loss-Cond.-Area} + Q_{H-Pipe-Loss-Uncond.-Area}$$

$$= \left(2 \times \pi \times L_{Pipe-Cond.} \times \left(\frac{1}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_{pipe-a}} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{insul.-a}}} \right) \times (T_{HHW-Supply-Temp.} - T_{Cond.}) + 2 \times \pi \times L_{Pipe-Uncond.} \left(\frac{1}{\frac{ln\left(\frac{r_5}{r_4}\right)}{k_{pipe-b}} + \frac{ln\left(\frac{r_6}{r_5}\right)}{k_{insul.-b}}} \right) \times (T_{HHW-Supply-Temp.} - T_{Uncond.}) \right) \times 0.0036$$

For pipe loss under cooling scenario:

Equation 18: Calculation Total Hourly Thermal Loss from Pipes under Cooling Scenario

$$Q_{C-Pipe-Loss} = Q_{C-Pipe-Loss-Cond.-Area} + Q_{C-Pipe-Loss-Uncond.-Area}$$

$$= \left(2 \times \pi \times L_{Pipe-Cond.} \times \left(\frac{1}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{k_{pipe-a}} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{insul.-a}}} \right) \times (T_{CHW-Supply-Temp.} - T_{Cond.}) + 2 \times \pi \times L_{Pipe-Uncond.} \left(\frac{1}{\frac{ln\left(\frac{r_5}{r_4}\right)}{k_{pipe-b}} + \frac{ln\left(\frac{r_6}{r_5}\right)}{k_{insul.-b}}} \right) \times (C - T_{Uncond.}) \right) \times 0.0036$$

$Q_{H\text{-}Pipe\text{-}Loss}$ = Total Hourly Thermal Loss from Pipes under Heating Scenario (MJth/hour)
$Q_{C\text{-}Pipe\text{-}Loss}$ = Total Hourly Thermal Loss from Pipes under Cooling Scenario (MJth/hour)
$Q_{H\text{-}Pipe\text{-}Loss\text{-}Cond.\text{-}Area}$ = Thermal Loss from Pipes within Conditioned Areas under Heating Scenario (MJth/hour)
$Q_{H\text{-}Pipe\text{-}Loss\text{-}Uncond.\text{-}Area}$ = Thermal Loss from Pipes within Unconditioned Areas under Heating Scenario (MJth/hour)
$Q_{C\text{-}Pipe\text{-}Loss\text{-}Cond.\text{-}Area}$ = Thermal Loss from Pipes within Conditioned Areas under Cooling Scenario (MJth/hour)
$Q_{C\text{-}Pipe\text{-}Loss\text{-}Uncond.\text{-}Area}$ = Thermal Loss from Pipes within Unconditioned Areas under Cooling Scenario (MJth/hour)
$L_{Pipe\text{-}Cond.}$ = Total Length of Pipe within Conditioned Areas (m). This includes the following:

- Pipes exposed to conditioned spaces
- Pipes within risers or plenums that are adjacent to conditioned areas
- Pipes located within risers, plenums or internal spaces, with segments of their perimeters in contact with an adjacent unconditioned space, while the envelope of the adjacent unconditioned space is enclosed by conditioned zones

$L_{Pipe\text{-}Uncond.}$ = Total Length of Pipe within Unconditioned Areas (m). This includes the following:

- Pipes exposed to unconditioned spaces
- Pipes exposed to ambient environment
- Pipes located within risers, plenums or internal spaces, where a section of the perimeter is in contact with the ambient environment
- Pipes located within risers, plenums or internal spaces, with segments of their perimeters in contact with an adjacent unconditioned space, while a segment of the envelope of the adjacent unconditioned space is exposed to the ambient environment

$k_{pipe\text{-}a}$ = Weighted Average Thermal Conductivity of Pipe Material in Conditioned Areas (W/m.K)
$k_{insul.\text{-}a}$ = Weighted Average Thermal Conductivity of Pipe Insulation in Conditioned Areas (W/m.K)
$k_{pipe\text{-}b}$ = Weighted Average Thermal Conductivity of Pipe Material in Unconditioned Areas (W/m.K)
$k_{insul.\text{-}b}$ = Weighted Average Thermal Conductivity of Pipe Insulation in Unconditioned Areas (W/m.K)
$T_{HHW\text{-}Supply\text{-}Temp.}$ = Supply Temperature of Heating Hot Water or Heated Refrigerant loop (^{o}C)
$T_{CHW\text{-}Supply\text{-}Temp.}$ = Supply Temperature of Chilled Water or Chilled Refrigerant loop (^{o}C)
$T_{Cond.}$ = Set-point Temperature of Conditioned Areas (^{o}C)
$T_{Uncond.}$ = Temperature of Unconditioned Areas (^{o}C)
r_1 = Weighted Average Inner Radius of Pipes within Conditioned Areas (m)
r_2 = Weighted Average Outer Radius of Pipes within Conditioned Areas (m)
r_3 = Weighted Average Outer Radius of Pipe Insulation within Conditioned Areas (m)
r_4 = Weighted Average Inner Radius of Pipes within Unconditioned Areas (m)
r_5 = Weighted Average Outer Radius of Pipes within Unconditioned Areas (m)
r_6 = Weighted Average Outer Radius of Pipe Insulation within Unconditioned Areas (m)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 14: Summary of Inputs and Source of Parameters in Section “Piping Loss”

Parameters		User Inputs	Benchmark
$Q_{H\text{-}Pipe\text{-}Loss}$	Total Hourly Thermal Loss from Pipes under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 17	
$Q_{C\text{-}Pipe\text{-}Loss}$	Total Hourly Thermal Loss from Pipes under Cooling Scenario (MJth/hour)	Calculated through provided methodology from Equation 18	
$Q_{H\text{-}Pipe\text{-}Loss\text{-}Cond.\text{-}Area}$	Thermal Loss from Pipes within Conditioned Areas under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 17	
$Q_{H\text{-}Pipe\text{-}Loss\text{-}Uncond.\text{-}Area}$	Thermal Loss from Pipes within Unconditioned Areas under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 17	
$Q_{C\text{-}Pipe\text{-}Loss\text{-}Cond.\text{-}Area}$	Thermal Loss from Pipes within Conditioned Areas under Cooling Scenario (MJth/hour)	Calculated through provided methodology from Equation 18	
$Q_{C\text{-}Pipe\text{-}Loss\text{-}Uncond.\text{-}Area}$	Thermal Loss from Pipes within Unconditioned Areas under Cooling Scenario (MJth/hour)	Calculated through provided methodology from Equation 18	
$L_{Pipe\text{-}Cond.}$	Total Length of Pipe within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
$L_{Pipe\text{-}Uncond.}$	Total Length of Pipe within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
$k_{pipe\text{-}a}$	Weighted Average Thermal Conductivity of the Pipe Material within Conditioned Areas (W/m.K)	Yes – Hydraulic Consultant	= User Input
$k_{insulation\text{-}a}$	Weighted Average Thermal Conductivity of the Pipe Insulation within Conditioned Areas (W/m.K)	Yes – Hydraulic Consultant; Default value will be referenced to Table J6D9a – Minimum Insulation R-Value from NCC 2022	Referenced to Table J6D9a – Minimum Insulation R-Value from NCC 2022
$k_{pipe\text{-}b}$	Weighted Average Thermal Conductivity of the Pipe Material within Unconditioned Areas (W/m.K)	Yes – Hydraulic Consultant	= User Input
$k_{insulation\text{-}b}$	Weighted Average Thermal Conductivity of the Pipe Insulation within Unconditioned Areas (W/m.K)	Yes – Hydraulic Consultant; Default value will be referenced to Table J6D9a – Minimum Insulation R-Value from NCC 2022	Referenced to Table J6D9a – Minimum Insulation R-Value from NCC 2022
$T_{HHW\text{-}Supply\text{-}Temp.}$	Supply Temperature of Heating Hot Water or Heated Refrigerant loop (^{o}C)	Yes – Mechanical / Hydraulic Consultant	= User Input
$TC_{HW\text{-}Supply\text{-}Temp.}$	Supply Temperature of Chilled Water or Chilled Refrigerant loop (^{o}C)	Yes – Mechanical / Hydraulic Consultant	= User Input
$T_{Cond.}$	Set-point Temperature of Conditioned Areas (^{o}C)	When on Heating, the set-point is assumed to be 19^{o}C, which is taken as simplified average of the heating thermostat settings prescribed from Table 3; When on Cooling, the value of the set-point temperature of conditioned space shall inherit the values prescribed from Table 88 of the NatHERS Whole of Home Calculation Method.	

$T_{Uncond.}$	Temperature of Unconditional Areas (^{o}C)	To be conservative, temperature of unconditioned areas can be regarded as the same as temperature of ambient temperature, which hourly temperature profile is based on Typical Meteorological Year (TMY) data representative of each climate zone.	
r_1	Weighted Average Inner Radius of Pipes within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_2	Weighted Average Outer Radius of Pipes within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_3	Weighted Average Outer Radius of Pipe Insulation within Conditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_4	Weighted Average Inner Radius of Pipes within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_5	Weighted Average Outer Radius of Pipes within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input
r_6	Weighted Average Outer Radius of Pipe Insulation within Unconditioned Areas (m)	Yes – Hydraulic Consultant	= User Input

Duct Loss

Hourly heat losses from ducts can be estimated via Equation 19 and 23, as follows:

For Duct Loss under heating scenario:

Equation 19: Calculation of Hourly Thermal Loss from ducts under Heating Scenario

$$Q_{H-Duct-Loss} = Q_{H-Duct-Loss-Cond.-Area} + Q_{H-Duct-Loss-Uncond.-Area}$$

$$= \frac{1}{R_{Duct-a}} \times A_{Cond.} \times \left(T_{H-SA-Temp.} - T_{Cond.}\right) + \frac{1}{R_{Duct-b}} \times A_{Uncond.} \times \left(T_{H-SA-Temp.} - T_{Uncond.}\right)$$

For Duct Loss under cooling scenario:

Equation 20: Calculation of Hourly Thermal Loss from ducts under Cooling Scenario

$$Q_{C-Duct-Loss} = Q_{C-Duct-Loss-Cond.-Area} + Q_{C-Duct-Loss-Uncond.-Area}$$

$$= \frac{1}{R_{Duct-a}} \times A_{Cond.} \times \left(T_{C-SA-Temp.} - T_{Cond.}\right) + \frac{1}{R_{Duct-b}} \times A_{Uncond.} \times \left(T_{C-SA-Temp.} - T_{Uncond.}\right)$$

$Q_{H\text{-}Duct\text{-}Loss}$ = Hourly Thermal Loss from ducts under Heating Scenario (MJ_{th}/hour)
$Q_{C\text{-}Duct\text{-}Loss}$ = Hourly Thermal Loss from ducts under Cooling Scenario (MJ_{th}/hour)
$Q_{H\text{-}Duct\text{-}Loss\text{-}Cond.\text{-}Area}$ = Thermal Loss of ducts within Conditioned Areas under Heating Scenario. (MJ_{th}/hour) Conditioned Areas Include the following:

- Ducts exposed to conditioned spaces
- Ducts within risers or plenums that are adjacent to conditioned areas
- Ducts located within risers, plenums or internal spaces, with segments of their perimeters in contact with an adjacent unconditioned space, while the envelope of the adjacent unconditioned space is enclosed by conditioned zones

$Q_{H\text{-}Duct\text{-}Loss\text{-}Uncond.\text{-}Area}$ = Thermal Loss of ducts within Conditioned Areas under Heating Scenario. (MJth/hour) Unconditioned Areas Include the following:

- Ducts exposed to unconditioned spaces
- Ducts exposed to ambient environment
- Ducts located within risers, plenums or internal spaces, where a section of the perimeter is in contact with the ambient environment
- Ducts located within risers, plenums or internal spaces, with segments of their perimeters in contact with an adjacent unconditioned space, while a segment of the envelope of the adjacent unconditioned space is exposed to the ambient environment

$Q_{C\text{-}Duct\text{-}Loss\text{-}Cond.\text{-}Area}$ = Hourly Thermal Loss of ducts within Conditioned Areas under Cooling Scenario (MJ_r)
$Q_{C\text{-}Duct\text{-}Loss\text{-}Uncond.\text{-}Area}$ = Hourly Thermal Loss of ducts within Unconditioned Areas under Cooling Scenario (MJ_r)
$R_{Duct\text{-}a}$ = Weighted Average Thermal Resistance of the Duct Material including Insulation within Conditioned Areas (K.m²/W)
$R_{Duct\text{-}b}$ = Weighted Average Thermal Resistance of the Duct Material including Insulation within Uconditioned Areas (K.m²/W)
$A_{Cond.}$ = Total Surface Area of Ducts within Conditioned Areas (m^2)
$A_{Uncond.}$ = Total Surface Area of Ducts within Unconditioned Areas (m^2)
$T_{H\text{-}SA\text{-}Temp.}$ = Nominal Temperature of Supply Air under Heating Conditions (^oC)
$T_{C\text{-}SA\text{-}Temp.}$ = Nominal Temperature of Supply Air under Cooling Conditions (^oC)
$T_{Cond.}$ = Set-point Temperature of Conditioned Areas (^oC)
$T_{Uncond.}$ = Temperature of Unconditioned Areas (^oC)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 15: Summary of Inputs and Source of Parameters in Section "Duct Loss"

Parameters		User Inputs	Benchmark
$Q_{H\text{-}Duct\text{-}Loss}$	Hourly Thermal Loss from ducts under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 19	
$Q_{C\text{-}Duct\text{-}Loss}$	Hourly Thermal Loss from ducts under Cooling Scenario (MJ_{th}/hour)	Calculated through provided methodology from For Duct Loss under cooling scenario: Equation 20	
$Q_{H\text{-}Duct\text{-}Loss\text{-}Cond.\text{-}Area}$	Thermal Loss of ducts within Conditioned Areas under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 19	
$Q_{H\text{-}Duct\text{-}Loss\text{-}Uncond.\text{-}Area}$	Thermal Loss of ducts within Unconditioned Areas under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 19	
$Q_{C\text{-}Duct\text{-}Loss\text{-}Cond.\text{-}Area}$	Hourly Thermal Loss of ducts within Conditioned Areas under Cooling Scenario (MJ_r)	Calculated through provided methodology from Equation 23	
$Q_{C\text{-}Duct\text{-}Loss\text{-}Uncond.\text{-}Area}$	Hourly Thermal Loss of ducts within Unconditioned Areas under Cooling Scenario (MJ_r)	Calculated through provided methodology from Equation 23	
$R_{Duct\text{-}a}$	Weighted Average Thermal Resistance of the Duct Material including Insulation within Conditioned Areas (m^2K/J)	Yes – Mechanical Consultant; Default value will be referenced to Table J6D6 – Ductwork and Fittings – Minimum Insulation R-Value from NCC 2022, factoring only thermal resistance from duct insulation.	= User Input
$R_{Duct\text{-}b}$	Weighted Average Thermal Resistance of the Duct Material including Insulation within Unconditioned Areas (m^2K/J)	Yes – Mechanical Consultant; Default value will be referenced to Table J6D6 – Ductwork and Fittings – Minimum Insulation R-Value from NCC 2022, factoring only thermal resistance from duct insulation.	= User Input
$A_{Cond.}$	Total Surface Area of Ducts within Conditioned Areas (m^2)	Yes – Mechanical Consultant	= User Input
$A_{Uncond.}$	Total Surface Area of Ducts within Unconditioned Areas (m^2)	Yes – Mechanical Consultant	= User Input
$T_{H\text{-}SA\text{-}Temp}$	Nominal Temperature of Supply Air under Heating Conditions (^oC)	Yes – Mechanical Consultant	= User Input
$T_{C\text{-}SA\text{-}Temp.}$	Nominal Temperature of Supply Air under Cooling Conditions (^oC)	Yes – Mechanical Consultant	= User Input
T_{Cond}	Set-point Temperature of Conditioned Areas (^oC)	When on Heating, the set-point is assumed to be 19^{o}C, which is taken as simplified average of the heating thermostat settings prescribed from Table 3; When on Cooling, the value of the set-point temperature of conditioned space shall inherit the values prescribed from Table 88.	
$T_{Uncond.}$	Temperature of Unconditional Areas (^oC)	To be conservative, temperature of unconditioned areas can be regarded as the same as temperature of ambient temperature, which hourly temperature profile is based on Typical Meteorological Year (TMY) data representative of each climate zone.	
$L_{Cond.}$	Length of Duct within Conditioned Areas (m)	Yes – Mechanical Consultant	= User Input
$L_{Uncond.}$	Length of Duct within Unconditioned Areas (m)	Yes – Mechanical Consultant	= User Input

2.3 Step 3 – Determine Heating/Cooling System Type and Account for System Efficiency

Different combinations of HVAC technologies can be utilized for central systems, leading to varying energy requirements for meeting a building's heating and cooling needs, depending on the chosen technology. The following HVAC technologies are applicable for central systems in apartment complexes:

Technology	Fuel Type	Heating	Cooling	Description
Atmospheric Boiler	Natural Gas	✓		An **atmospheric boiler**, also known as a natural draft boiler, is a type of heating system that relies on the natural draft of air to facilitate combustion and exhaust flue gases.
Condensing Boiler	Natural Gas	✓		A **condensing boiler** is a type of heating system that is designed to maximize energy efficiency by extracting more heat from the combustion process compared to traditional boilers. It achieves this by recovering heat from the flue gases that would normally be lost in non-condensing boilers.
Electric Boiler	Electric	✓		An **electric boiler** is a type of heating system that uses electricity as its primary source of energy to generate heat. Unlike traditional boilers that burn fuel such as gas or oil, electric boilers convert electrical energy.
Air-sourced Variable Refrigerant Flow/ Variable Refrigerant Volume (VRF/VRV) System	Electric	✓	✓	**Air-sourced VRF/VRV system** is a type of HVAC system that uses outdoor air as the heat exchange medium for heating and cooling operations. It is a flexible system that can provide individualized temperature control in different zones or areas of a building.

Water-cooled Variable Refrigerant Flow/ Variable Refrigerant Volume (VRF/VRV) System	Electric	✓	✓	A **water-cooled VRF/VRV system** is a type of HVAC system that utilizes water as the heat exchange medium for cooling and heating operations. It is a versatile system that provides individualized temperature control in different zones or areas of a building.
Air-cooled Packaged Air Conditioning (PAC) System	Electric	✓	✓	An **air-cooled packaged air conditioning (PAC) system** is a self-contained HVAC system that uses outdoor air for cooling and heating. It achieves cooling by drawing in outdoor air and passing it over a condenser coil, expelling the heated air back outside, which allows the refrigerant to cool and continue the cycle. This system supplies conditioned air directly to the served areas.
Water-cooled Packaged Air Conditioning (PAC) System	Electric	✓	✓	A **water-cooled packaged air conditioning (PAC) system** is an HVAC system that uses water as the heat exchange medium for cooling. It's a self-contained system suitable for various settings, offering efficient cooling with the help of water circulation. It supplies conditioned air directly to the areas it serves.
Reverse-cycle Air-Water 2-Pipe Heat Pump	Electric	✓	✓	A **reverse-cycle air-water 2-pipe heat pump** is a type of heating and cooling system that uses an air-to-water heat pump technology to provide both heating and cooling to a building or space. It operates by extracting heat from the outdoor air during the heating mode and transferring it to a water loop, which then distributes the heat to the indoor spaces. During cooling mode, the process is reversed, and heat is extracted from the indoor spaces and rejected into the water loop, which is then dissipated into the outdoor environment.

Reverse-cycle Water-Water 2-pipe Heat Pump	Electric	✓	✓	A **reverse-cycle 2-pipe water-water heat pump** is a type of heating and cooling system that uses water as the heat exchange medium for both heating and cooling operations. It operates by extracting heat from a water source, during the heating mode, and rejecting heat into the water source during cooling mode.
Air-cooled Chiller	Electric		✓	An **air-cooled chiller** is a type of refrigeration system used for cooling applications that operates by transferring heat from the process or building to the surrounding air. It is a self-contained unit that does not require an external water source for heat rejection.
Water-cooled Chiller	Electric		✓	A **water-cooled chiller** is a type of refrigeration system used for cooling applications that operates by transferring heat from the process or building to a water source for heat rejection. It requires a separate water loop and cooling tower or heat exchanger to dissipate the heat into the environment.

When the heating and cooling technology is chosen, the annual energy requirement for meeting the heating and cooling demand of the assessed dwelling can be calculated. This calculation involves summing the annual hourly heating and cooling loads, accounting for pipe and duct losses, and then factoring the average efficiency of the selected heating and cooling technology. This calculation can be represented as Equation 21 follows:

Equation 21: Calculation of Total Energy Requirement from Heating and Cooling Equipment

$$\begin{aligned} E_{Conditioning} &= E_{Heating} + E_{Cooling} \\ &= \frac{Q_{Heating} + Q_{H-Pipe-Loss} + Q_{H-Duct-Loss}}{\eta_{Heating-Average}} \\ &\quad + \frac{Q_{Cooling} + Q_{C-Pipe-Loss} + Q_{C-Duct-Loss}}{\eta_{Cooling-Average}} \\ &= \frac{\sum_{i=1}^{n=8760} Q_{Heating-Dwelling} + \sum_{i=1}^{n=8760} Q_{H-Pipe-Loss} + \sum_{i=1}^{n=8760} Q_{H-Duct-Lossp}}{\eta_{Heating-Average}} \\ &\quad + \frac{\sum_{i=1}^{n=8760} Q_{Cooling-Dwelling} + \sum_{i=1}^{n=8760} Q_{C-Pipe-Loss} + \sum_{i=1}^{n=8760} Q_{C-Duct-Lossp}}{\eta_{Cooling-Average}} \end{aligned}$$

$E_{Conditioning}$ = Total Energy Requirement from Heating and Cooling Equipment (MJ/a, Electricity or Natural Gas & Electricity)
$E_{Heating}$ = Total Energy Requirement from Heating Equipment (MJ/a, Electricity or Natural Gas & Electricity)
$E_{Cooling}$ = Total Energy Requirement from Cooling Equipment (MJ/a, Electricity)
$Q_{Heating}$ = Total Heating Load of building in a year (MJ_{th}/a)
$Q_{Cooling}$ = Total Cooling Load of building in a year (MJ_{th}/a)
$Q_{Heating-Dwelling}$ = Annual Heating Load of Individual Assessed Building (MJ_{th}/a)
$Q_{Cooling-Dwelling}$ = Annual Cooling Load of Individual Assessed Building (MJ_{th}/a)
$Q_{H-Pipe-Loss}$ = Hourly Thermal Loss from Pipes under Heating Scenario (MJ_{th})
$Q_{C-Pipe-Loss}$ = Hourly Thermal Loss from Pipes under Cooling Scenario (MJ_{th})
$Q_{H-Duct-Loss}$ = Hourly Thermal Loss from ducts under Heating Scenario (MJ_{th})
$Q_{C-Duct-Loss}$ = Hourly Thermal Loss from ducts under Cooling Scenario (MJ_{r})
$\eta_{Heating-Average}$ = Average Heating Efficiency of applied heating technology (%)
$\eta_{Cooling-Average}$ = Average Cooling Efficiency of applied cooling technology (%)

Efficiency data for various heating and cooling technologies can be sourced from suppliers and should align with specific rating standards. **Table 16** provided below outlines the criteria for determining the average energy efficiency of various heating and cooling technologies:

Table 16: System Efficiency Input Guidelines

Heating/Cooling Technology	System Efficiency Input Guideline	
	Heating	Cooling
Atmospheric Boiler	The inputs should be derived from rated efficiency from supplier's technical data.	N/A
Condensing Boiler		N/A
Electric Boiler		N/A
Air-sourced VRF/VRV System	The inputs should be derived from tested efficiency values obtained from supplier's technical data. These values should be incorporated into the following energy performance test metrics in the order of decreasing preference: • ACOP – Average Coefficient of Performance • SCOP – Seasonal Coefficient of Performance • HSPF – Heating Seasonal Performance Factor • COP – Coefficient of Performance	The inputs should be derived from tested efficiency values obtained from supplier's technical data. These values should be incorporated into the following energy performance test metrics in the order of decreasing preference: • AEER – Average Energy Efficiency Ratio • SEER – Seasonal Energy Efficiency Ratio • TCSPF – Total Cooling Seasonal Performance Factor • EER – Energy Efficiency Ratio
Water-cooled VRF/VRV System		
Air-cooled PAC System		
Water-cooled PAC System		
Reverse-cycle Air-Water 2-Pipe Heat Pump		
Reverse-cycle Water-Water 2-Pipe Heat Pump		
Air-cooled Chiller	N/A	The inputs should be derived from IPLV (Integrated Part Load Value) from supplier's technical data.
Water-cooled Chiller	N/A	

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 17: Summary of Inputs and Source of Parameters in Section 2.3

Parameters		**User Inputs**	**Benchmark**
$E_{Conditioning}$	Total Energy Requirement from Heating and Cooling Equipment (MJ/a, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 21	
$E_{Heating}$	Total Energy Requirement from Heating Equipment (MJ/a, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 21	
$E_{Cooling}$	Total Energy Requirement from Cooling Equipment (MJ/a, Natural Gas / Electricity)	Calculated through provided methodology from Equation 21	
$Q_{Heating}$	Total Heating Load of building in a year (MJ_{th}/a)	Sum of the hourly thermal loads are calculated by the Chenath engine based on inputs defined in section 3.1 of the NatHERS Whole of Home Calculations Method and blended using Equation 3 in section 3.2.3.	
$Q_{Cooling}$	Total Cooling Load of building in a year (MJ_r/a)		
$Q_{H\text{-}Pipe\text{-}Loss}$	Total Hourly Thermal Loss from Pipes under Heating Scenario (MJth/hour)	Determined through provided methodology from Equation 17	
$Q_{C\text{-}Pipe\text{-}Loss}$	Total Hourly Thermal Loss from Pipes under Cooling Scenario (MJth/hour)	Calculated through provided methodology from Equation 18	
$Q_{H\text{-}Duct\text{-}Loss}$	Total Hourly Thermal Loss from ducts under Heating Scenario (MJth/hour)	Calculated through provided methodology from Equation 19	
$Q_{C\text{-}Duct\text{-}Loss}$	Total Hourly Thermal Loss from ducts under Cooling Scenario (MJ_r)	Determined through provided methodology from Equation 20	
$\eta_{Heating\text{-}Average}$	Average Heating Efficiency of applied heating technology (%)	Yes – Mechanical Consultant; Default minimum efficiency for different heating technologies below: **Atmospheric Boiler & Condensing Boiler** *86% if rated ≤ 500MJ/hr, 90% if rated > 500MJ/hr. Referenced to Clause 4 under Section J6D10 of NCC 2022* **Electric Boiler** *97%, Referenced to Clause C under Section 2.4.2 within AS/NZS 4234:2021* **Air-sourced VRF/VRV System & Water-cooled VRF/VRV System & Air-cooled PAC System & Water-cooled PAC System, Reverse-cycle Air-Water 2-Pipe Heat Pump, Reverse-cycle Water-Water 2-Pipe Heat Pump** *Assumed minimum average efficiency – 300% (COP 3.0)*	= User Input
$\eta_{Cooling\text{-}Average}$	Average Heating Efficiency of applied cooling technology (%)	Yes – Mechanical Consultant; Default minimum efficiency for different heating technologies below: **Air-sourced VRF/VRV System & Water-cooled VRF/VRV System & Air-cooled PAC System & Water-cooled PAC System, Reverse-cycle Air-Water 2-Pipe Heat Pump, Reverse-cycle Water-Water 2-Pipe Heat Pump** *Assumed minimum average efficiency to be 300% or EER of 3.0. Must also meet MEPS requirement of EER of*	= User Input

		2.62, which is referenced to Table 2.1 under Section 2 within AS 4965.2 (2008). **Air-cooled Chillers & Water-cooled Chillers** *Referenced to Table J6D11 under Section J within NCC 2022*	

2.4 Step 4 – Account for Other Auxiliary Energy

For the covered technologies within the central systems, depending on the mechanical heating/cooling infrastructure and design, the following auxiliary energy categories may be present – HHW/CHW Pumps, Condenser Water Pumps, Cooling Towers, Air Handling Units (AHUs), and Fan Coil Units (FCUs).

2.4.1 HHW/CHW Pumps

Central heating and cooling systems, like boilers, chillers, and heat pumps, involve the circulation of heated or chilled water from the source to the intended area. The energy needed to operate the pumps exhibits a correlation with the heating or cooling loads. Hence, pump energy for HHW pumps or CHW pumps can be estimated via **Equation 22** and **Equation 23** below:

Equation 22: Calculation of Total Energy Requirement for HHW Pump

$$E_{HHW-Pump} = \sum_{i=1}^{n=8760} \left(\frac{P_{HHW-Pump}}{\eta_{HHW-Pump+Motor}} \times Load_H\right)$$

$$= \sum_{i=1}^{n=8760} \left(\frac{P_{HHW-Pump}}{\eta_{HHW-Pump} \times \eta_{HHW-Motor}} \times \left(\frac{Q_H + Q_{H-Pipe-Loss} + Q_{H-Duct-Loss}}{Q_{H-Peak} + Q_{H-Pipe-Loss-Peak} + Q_{H-Duct-Loss-Peak}}\right)\right)$$

Equation 23: Calculation of Total Energy Requirement for CHW Pump

$$E_{CHW-Pump} = \sum_{i=1}^{n=8760} \left(\frac{P_{CHW-Pump}}{\eta_{CHW-Pump+Motor}} \times Load_C\right)$$

$$= \sum_{i=1}^{n=8760} \left(\frac{P_{CHW-Pump}}{\eta_{CHW-Pump} \times \eta_{CHW-Motor}} \times \left(\frac{Q_C + Q_{C-Pipe-Loss} + Q_{C-Duct-Loss}}{Q_{C-Peak} + Q_{C-Pipe-Loss-Peak} + Q_{C-Duct-Loss-Peak}}\right)\right)$$

$E_{HHW-Pump}$ = Total Energy Requirement for HHW Pump (MJ/a, Electricity)
$E_{CHW-Pump}$ = Total Energy Requirement for CHW Pump (MJ/a, Electricity)
$P_{HHW-Heating}$ = HHW Design Pump Power (J/s)
$P_{CHW-Heating}$ = CHW Design Pump Power (J/s)
$\eta_{HHW-Pump+Motor}$ = HHW Pump System Efficiency (%)
$\eta_{CHW-Pump+Motor}$ = CHW Pump System Efficiency (%)
$\eta_{HHW-Pump}$ = Efficiency of the Pump component within the HHW Pump System of Heating Loop(%)
$\eta_{CHW-Pump}$ = Efficiency of the Pump component within the CHW Pump System of Cooling Loop (%)
$\eta_{HHW-Motor}$ = Efficiency of the Motor component within the HHW Pump System of Heating Loop (%)
$\eta_{CHW-Motor}$ = Efficiency of the Motor component within the CHW Pump System of Cooling Loop (%)
$Load_H$ = Operational Load of the Heating Equipment (%)
$Load_C$ = Operational Load of the Cooling Equipment (%)
Q_H = Sum of Heating Load of all assessed dwellings at the reference hour during Heating (MJth/hour)
Q_C = Sum of cooling load of all assessed dwellings at the reference hour during Cooling (MJ$_r$)
$Q_{H–Peak}$ = Peak Hourly Heating Load of all assessed dwellings combined within the modelled year during Heating (MJ$_{th}$/hour)
$Q_{C–Peak}$ = Peak Hourly Cooling Load of all assessed dwellings combined within the modelled year during Cooling (MJ$_{th}$/hour)
$Q_{H-Pipe-Loss}$ = Pipe Loss at the reference hour when Heating (MJ$_{th}$/hour)
$Q_{C-Pipe-Loss}$ = Pipe Loss at the reference hour when Cooling (MJ$_{th}$/hour)
$Q_{H-Pipe-Loss-Peak}$ = Pipe Loss at the hour where Peak Heating occurs (MJ$_{th}$/hour)
$Q_{C-Pipe-Loss-Peak}$ = Pipe Loss at the hour where Peak Cooling occurs (MJth/hour)
$Q_{H-Duct-Loss}$ = Duct Loss at the reference hour when Heating (MJth/hour)
$Q_{C-Duct-Loss}$ = Duct Loss at the reference hour when Cooling (MJth/hour)
$Q_{H-Duct-Loss-Peak}$ = Duct Loss at the hour where Peak Heating occurs (MJth/hour)

$Q_{C-Duct-Loss-Peak}$ = Duct Loss at the hour where Peak Cooling occurs (MJth/hour/hour)

The methodology assumes that the HHW Pumps and chilled water (CHW) Pumps are variable speed drive (VSD) controlled.

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 18: Summary of Inputs and Source of Parameters in Section "HHW/CHW Pumps"

Parameters		User Inputs	Benchmark
$E_{HHW-Pump}$	Total Energy Requirement for HHW Pump (MJ/a, Electricity)	Calculated through provided methodology from Equation 22	
$E_{CHW-Pum`p}$	Total Energy Requirement for CHW Pump (MJ/a, Electricity)	Calculated through provided methodology from Equation 23	
$P_{HHW-Heating}$	HHW Design Pump Power (J/s)	Yes – Mechanical / Hydraulic Consultant; The input required is the design pump power requirement only. It includes total design pump power of primary pumps and secondary pumps combined, however excludes the added pump power resulted from redundancy or from duty-standby arrangement.	= User Input
$P_{CHW-Heating}$	CHW Design Pump Power (J/s)	Yes – Mechanical / Hydraulic Consultant; The input required is the design pump power requirement only. It includes total design pump power of primary pumps and secondary pumps combined, however excludes the added pump power resulted from redundancy or from duty-standby arrangement.	= User Input
$\eta_{HHW-Pump+Motor}$	HHW Pump System Efficiency (%)	Calculated through provided methodology from Equation 22	
$\eta_{CHW-Pump+Motor}$	CHW Design Pump Power (J/s)	Calculated through provided methodology from Equation 23	
$\eta_{HHW-Pump}$	Efficiency of the Pump component within the HHW Pump System of Heating Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value assumed to be 75%	= User Input
$\eta_{CHW-Pump}$	Efficiency of the Pump component within the CHW Pump System of Cooling Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value assumed to be 75%	= User Input
$\eta_{HHW-Motor}$	Efficiency of the Motor component within the HHW Pump System of Heating Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at Schedule 1 of GEMS (three phase cage induction motors) determination 2019	= User Input
$\eta_{CHW-Motor}$	Efficiency of the Motor component within the CHW Pump System of Cooling Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at Schedule 1 of GEMS (three phase cage induction motors) determination 2019	= User Input
$Load_H$	Operational Load of the Heating Equipment (%)	Calculated through provided methodology from Equation 22	
$Load_c$	Operational Load of the Cooling Equipment (%)	Calculated through provided methodology from Equation 23	
Q_H	Sum of Heating Load of all assessed dwellings at the reference hour during Heating (MJth/hour)	Derivable from existing 8760-time series model.	
Q_C	Sum of Cooling Load of all assessed dwellings at the reference hour during Cooling (MJ_r)	Derivable from existing 8760-time series model.	

$Q_{H\text{–}Peak}$	Peak Hourly Heating Load of all assessed dwellings combined within the modelled year during Heating (MJ_{th})	Derivable from existing 8760-time series model.
$Q_{C\text{–}Peak}$	Peak Hourly Cooling Load of all assessed dwellings combined within the modelled year during Cooling (MJ_r)	Derivable from existing 8760-time series model.
$Q_{H\text{-}Pipe\text{-}Loss}$	Pipe Loss at the reference hour when Heating (MJ_{th})	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{C\text{-}Pipe\text{-}Loss}$	Pipe Loss at the reference hour when Cooling (MJ_r)	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{H\text{-}Pipe\text{-}Loss\text{-}Peak}$	Pipe Loss at the hour where Peak Heating occurs (MJ_{th})	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{C\text{-}Pipe\text{-}Loss\text{-}Peak}$	Pipe Loss at the hour where Peak Heating occurs (MJ_r)	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{H\text{-}Duct\text{-}Loss}$	Duct Loss at the reference hour when Heating (MJ_{th})	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{C\text{-}Duct\text{-}Loss}$	Duct Loss at the reference hour when Cooling (MJ_r)	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{H\text{-}Duct\text{-}Loss\text{-}Peak}$	Duct Loss at the hour where Peak Heating occurs (MJ_{th})	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2
$Q_{C\text{-}Duct\text{-}Loss\text{-}Peak}$	Duct Loss at the hour where Peak Cooling occurs (MJ_r)	Derivable from 8760-time series model after incorporating methodology prescribed in Section 2.2

2.4.2 Condenser Water Pumps

Water-sourced or water-cooled direct expansion systems, such as water-cooled VRF/VRV systems, water-cooled PAC systems, water-water heat pumps, and water-cooled chillers, employ a distinct condenser water loop designed to reject heat from the condenser water into the ambient environment through the use of a cooling tower. The energy necessary to operate the condenser water pumps is directly linked to the heating or cooling loads. However, a minimum consistent pump flow rate is required to be maintained even during non-operational periods, following the best practice guidelines for Legionella control, as recommended in AIRAH DA17 Cooling Towers. Hence, the estimation of pump energy requirements for Condenser Water Pumps can be derived via **Equation 24** and **Equation 25** as provided below:

Equation 24: Calculation of Total Energy Requirement for Condenser Pump of Heating Loop Equation 21

$$E_{H-Condenser-Pump} = \sum_{i=1}^{n=8760} MAX\left(\left(\frac{P_{H-Condenser-Pump}}{\eta_{H-Condenser-Pump+Motor}} \times Load_H\right), E_{H-CP-LC}\right)$$

$$= \sum_{i=1}^{n=8760} MAX\left(\left(\frac{P_{H-Condenser-Pump}}{\eta_{H-Condenser-Pump} \times \eta_{H-Condenser-Motor}} \times Load_H\right), E_{H-CP-LC}\right)$$

Equation 25: Calculation of Total Energy Requirement for Condenser Pump of Cooling Loop

$$E_{H-Condenser-Pump} = \sum_{i=1}^{n=8760} MAX\left(\left(\frac{P_{C-Condenser-Pump}}{\eta_{C-Condenser-Pump+Motor}} \times Load_C\right), E_{C-CP-LC}\right)$$

$$= \sum_{i=1}^{n=8760} MAX\left(\left(\frac{P_{C-Condenser-Pump}}{\eta_{C-Condenser-Pump} \times \eta_{C-Condenser-Motor}} \times Load_C\right), E_{C-CP-LC}\right)$$

$E_{H\text{-}Condenser\text{-}Pump}$ = Total Energy Requirement for Condenser Pump of Heating Loop (MJ/a, Electricity)

$E_{C\text{-}Condenser\text{-}Pump}$ = Total Energy Requirement for Condenser Pump of Cooling Loop (MJ/a, Electricity)
$P_{H\text{-}Condenser\text{-}Pump}$ = Design Pump Power for Condenser Water Pump of Heating Loop (J/s)
$P_{C\text{-}Condenser\text{-}Pump}$ = Design Pump Power for Condenser Water Pump of Cooling Loop (J/s)
$\eta_{H\text{-}Condenser\text{-}Pump+Motor}$ = Condenser Pump System Efficiency of Heating Loop (%)
$\eta_{C\text{-}Condenser\text{-}Pump+Motor}$ = Condenser Pump System Efficiency of Cooling Loop (%)
$\eta_{H\text{-}Condenser\text{-}Pump}$ = Efficiency of the Pump component within the Condenser Pump System of Heating Loop (%)
$\eta_{C\text{-}Condenser\text{-}Pump}$ = Efficiency of the Pump component within the Condenser Pump System of Cooling Loop (%)
$\eta_{H\text{-}Condenser\text{-}Motor}$ = Efficiency of the Motor component within the Condenser Pump System of Heating Loop (%)
$\eta_{C\text{-}Condenser\text{-}Motor}$ = Efficiency of the Motor component within the Condenser Pump System of Cooling Loop (%)
$Load_H$ = Operational Load of the Heating Equipment (%)
$Load_C$ = Operational Load of the Cooling Equipment (%)
$E_{H\text{-}CP\text{-}LC}$ = Energy requirement of maintaining the required flow for Legionella control for cooling tower design of the Heating loop (MJ/a, Electricity)
$E_{C\text{-}CP\text{-}LC}$ = Energy requirement of maintaining the required flow for Legionella control for cooling tower design of the Cooling loop (MJ/a, Electricity)

The methodology assumes that the Condenser Water Pumps of the Heating loop and Cooling loop are VSD controlled.

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 19: Summary of Inputs and Source of Parameters in Section "Condenser Water Pumps"

Parameters		User Inputs	Benchmark
$E_{H\text{-}Condenser\text{-}Pump}$	Total Energy Requirement for Condenser Pump of Heating Loop (MJ/a, Electricity)	Calculated through provided methodology from Equation 24	
$E_{C\text{-}Condenser\text{-}Pump}$	Total Energy Requirement for Condenser Pump of Cooling Loop (MJ/a, Electricity)	Calculated through provided methodology from Equation 25	
$P_{H\text{-}Condenser\text{-}Pump}$	Design Pump Power for Condenser Water Pump of Heating Loop (J/s)	Yes – Mechanical / Hydraulic Consultant; The input required is the design pump power requirement only. It excludes the added pump power resulted from redundancy or from duty-standby arrangement.	= User Input
$P_{C\text{-}Condenser\text{-}Pump}$	Design Pump Power for Condenser Water Pump of Cooling Loop (J/s)	Yes – Mechanical / Hydraulic Consultant; The input required is the design pump power requirement only. It excludes the added pump power resulted from redundancy or from duty-standby arrangement.	= User Input
$H_{H\text{-}Condenser\text{-}Pump+Motor}$	Condenser Pump System Efficiency of Heating Loop (%)	Calculated through provided methodology from Equation 24	
$H_{C\text{-}Condenser\text{-}Pump+Motor}$	Condenser Pump System Efficiency of Cooling Loop (%)	Calculated through provided methodology from Equation 25	
$\eta_{H\text{-}Condenser\text{-}Pump}$	Efficiency of the Pump component within the Condenser Pump System of HHW Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value assumed to be 75%	= User Input
$\eta_{C\text{-}Condenser\text{-}Pump}$	Efficiency of the Pump component within the Condenser Pump System of Cooling Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value assumed to be 75%	= User Input

$\eta_{H\text{-}Condenser\text{-}Motor}$	Efficiency of the Motor component within the Condenser Pump System of Heating Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
$\eta_{C\text{-}Condenser\text{-}Motor}$	Efficiency of the Motor component within the Condenser Pump System of Cooling Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
$Load_H$	Operational Load of the Heating Equipment (%)	Calculated through provided methodology from Equation 22	
$Load_C$	Operational Load of the Cooling Equipment (%)	Calculated through provided methodology from Equation 23	
$E_{H\text{-}CP\text{-}LC}$	Energy requirement of maintaining the required flow for Legionella control for cooling tower design of the Heating loop (MJ/a, Electricity)	Yes – Mechanical / Hydraulic Consultant; Requirements of Section 2.5.18 under AIRAH DA17 must be fulfilled upon calculation of pump power requirement for maintaining minimum flow rate in the condenser water loop.	= User Input
$E_{C\text{-}CP\text{-}LC}$	Energy requirement of maintaining the required flow for Legionella control for cooling tower design of the Cooling loop (MJ/a, Electricity)	Yes – Mechanical / Hydraulic Consultant; Requirements of Section 2.5.18 under AIRAH DA17 must be fulfilled upon calculation of pump power requirement for maintaining minimum flow rate in the condenser water loop.	= User Input

2.4.3 Cooling Towers

Cooling Towers are present when water-sourced based or water-cooled based direct expansion systems are utilized to supply heating and cooling to reject heat from the condenser water into the ambient environment. While condenser water pumps are required to continuously maintain a minimum flow rate for legionella control, the fan component within the cooling tower is not required to operate during hours where there is no heating or no cooling. Hence, energy requirement for Cooling Tower can be provided via **Equation 26** and **Equation 27** below:

For Heating scenario:

Equation 26: Calculation of Total Energy Requirement for Cooling Tower under Heating Scenario

$$E_{H-CT} = \sum_{i=1}^{n=8760} \left(\frac{P_{H-CT}}{\eta_{H-CT}} \times Load_H\right)$$

For Cooling scenario:

Equation 27: Calculation of Total Energy Requirement for Cooling Tower under Cooling Scenario

$$E_{C-CT} = \sum_{i=1}^{n=8760} \left(\frac{P_{C-CT}}{\eta_{C-CT}} \times Load_C\right)$$

$E_{H\text{-}CT}$ = Total Energy Requirement for Cooling Tower under Heating Scenario (MJ/a, Electricity)
$E_{C\text{-}CT}$ = Total Energy Requirement for Cooling Tower under Cooling Scenario (MJ/a, Electricity)
$P_{H\text{-}CT}$ = Cooling Tower Design Power of Heating Loop (J/s)

$P_{C\text{-}CT}$ = Cooling Tower Design Power of Cooling Loop (J/s)
$\eta_{H\text{-}CT}$ = Cooling Tower Efficiency of Heating Loop (%)
$\eta_{C\text{-}CT}$ = Cooling Tower Efficiency of Cooling Loop (%)
$Load_H$ = Operational Load of the Heating Equipment (%)
$Load_C$ = Operational Load of the Cooling Equipment (%)

The methodology assumes that the Cooling Towers are VSD controlled.
A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 20: Summary of Inputs and Source of Parameters in Section "Cooling Tower"

Parameters		User Inputs	Benchmark
$E_{H\text{-}CT}$	Total Energy Requirement for Cooling Tower under Heating Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 26	
$E_{C\text{-}CT}$	Total Energy Requirement for Cooling Tower under Cooling Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 27	
$P_{H\text{-}CT}$	Cooling Tower Design Power of Heating Loop (J/s)	Yes– Mechanical / Hydraulic Consultant; The input required is the design cooling tower power requirement only. It excludes the added motor power resulted from redundancy.	= User Input
$P_{C\text{-}CT}$	Cooling Tower Design Power of Cooling Loop (J/s)	Yes – Mechanical / Hydraulic Consultant; The input required is the design cooling tower power requirement only. It excludes the added motor power resulted from redundancy.	= User Input
$\eta_{H\text{-}CT}$	Cooling Tower Efficiency of Heating Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
$\eta_{C\text{-}CT}$	Cooling Tower Efficiency of Cooling Loop (%)	Yes – Mechanical / Hydraulic Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
$Load_H$	Operational Load of the Heating Equipment (%)	Calculated through provided methodology from Equation 22	
$Load_C$	Operational Load of the Cooling Equipment (%)	Calculated through provided methodology from Equation 23	

2.4.4 Air Handling Units (AHUs) and Fan Coil Units (FCUs)

For apartment buildings, Air Handling Units (AHUs) are present when conditioned air is supplied directly from the central heating and cooling services to the individual apartments. Fan Coil Units (FCUs) on the other hand are present when air is conditioned close to, or at a central point within an apartment, then distributed to zones within the apartment.

Table 4 and Table 5 under Section 3.3.1 has prescribed daily patterns of conditioning for different occupancy profiles. These tables outline the recommended daily conditioning patterns for various occupancy profiles. These patterns specify when specific areas should be conditioned. During some timeframes, only certain zones are designated for conditioning, while during other timeframes, all areas with space conditioning may or may not be conditioned.

Hence, Energy Requirement for AHUs and FCUs may be estimated via Equation 28 and Equation 29 below:

For Heating scenario:

Equation 28: Calculation for Total Energy Requirement for AHUs or FCUs under Heating Scenario

$$E_{H-\frac{AHU}{FCU}} = \sum_{i=1}^{n=8760} \left(\frac{P_{H-\frac{AHU}{FCU}}}{\eta_{H-\frac{AHU}{FCU}-WA}} \times \frac{V_{H-Cond.}}{V_{H-Total}}\right)$$

$$= \sum_{i=1}^{n=8760} \left(\frac{P_{H-\frac{AHU}{FCU}}}{\eta_{H-\frac{AHU}{FCU}-1} \times \frac{V_{H-\frac{AHU}{FCU}-1}}{V_{H-Total}} + \ldots + \eta_{H-\frac{AHU}{FCU}-n} \times \frac{V_{H-\frac{AHU}{FCU}-n}}{V_{H-Total}}} \times \frac{V_{H-Cond.}}{V_{H-Total}}\right)$$

For Cooling scenario:

Equation 29: Calculation for Total Energy Requirement for AHUs or FCUs under Cooling Scenario

$$E_{H-\frac{AHU}{FCU}} = \sum_{i=1}^{n=8760} \left(\frac{P_{C-\frac{AHU}{FCU}}}{\eta_{C-\frac{AHU}{FCU}-WA}} \times \frac{V_{C-Cond.}}{V_{C-Total}}\right)$$

$$= \sum_{i=1}^{n=8760} \left(\frac{P_{C-\frac{AHU}{FCU}}}{\eta_{C-\frac{AHU}{FCU}-1} \times \frac{V_{C-\frac{AHU}{FCU}-1}}{V_{C-Total}} + \ldots + \eta_{C-\frac{AHU}{FCU}-n} \times \frac{V_{C-\frac{AHU}{FCU}-n}}{V_{C-Total}}} \times \frac{V_{C-Cond.}}{V_{C-Total}}\right)$$

$E_{H\text{-}AHU/FCU}$ = Total Energy Requirement for AHUs or FCUs under Heating Scenario (MJ/a, Electricity)
$E_{C\text{-}AHU/FCU}$ = Total Energy Requirement for AHUs or FCUs under Cooling Scenario (MJ/a, Electricity)
$P_{H\text{-}AHU/FCU}$ = Total Design Power of AHUs/FCUs of Heating Loop (J/s)
$P_{C\text{-}AHU/FCU}$ = Total Design Power of AHUs/FCUs of Cooling Loop (J/s)
$\eta_{H\text{-}AHU/FCU\text{-}WA}$ = Weighted Average AHU/FCU Efficiency of Heating Loop (%)
$\eta_{C\text{-}AHU/FCU\text{-}WA}$ = Weighted Average AHU/FCU Efficiency of Cooling Loop (%)
$\eta_{H\text{-}AHU/FCU\text{-}n}$ = Efficiency of individual AHUs and FCUs of Heating Loop (m^3/s)
$\eta_{C\text{-}AHU/FCU\text{-}n}$ = Efficiency of individual AHUs and FCUs of Cooling Loop (m^3/s)
$V_{H\text{-}AHU\text{-}FCU\text{-}n}$ = Design Air Flow Rate of individual AHUs or FCUs of Heating Loop (m^3/s)
$V_{C\text{-}AHU\text{-}FCU\text{-}n}$ = Design Air Flow Rate of individual AHUs or FCUs of Cooling Loop (m^3/s)
$V_{H\text{-}Cond.}$ = Total Air Flow Rates supplied to Conditioned Zones at the reference hour under Heating Scenario (m^2)
$V_{C\text{-}Cond.}$ = Total Air Flow Rates supplied to Conditioned Zones at the reference hour under Cooling Scenario (m^2)
$V_{H\text{-}Total}$ = Total Air Flow Rate of all AHUs or FCUs combined of Heating Loop (m^3/s)
$V_{C\text{-}Total}$ = Total Air Flow Rate of all AHUs or FCUs combined of Cooling Loop (m^3/s)

The methodology assumes that the AHUs are VSD controlled, and that the FCUs are variable speed systems.

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 21: Summary of Inputs and Source of Parameters in Section "Air Handling Units (AHUs) and Fan Coil Units (FCUs)"

Parameters	User Inputs	Benchmark

$E_{H-AHU/FCU}$	Total Energy Requirement for AHUs or FCUs under Heating Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 28	
$E_{C-AHU/FCU}$	Total Energy Requirement for AHUs or FCUs under Cooling Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 29	
$P_{H-AHU/FCU}$	Total Design Power of AHUs/FCUs of Heating Loop (J/s)	Yes – Mechanical Consultant; The input required is the design AHU/FCU power requirement only. It excludes the added motor power resulted from design redundancy.	= User Input
$P_{C-AHU/FCU}$	Total Design Power of AHUs/FCUs of Cooling Loop (J/s)	Yes – Mechanical Consultant; The input required is the design AHU/FCU power requirement only. It excludes the added motor power resulted from design redundancy.	= User Input
$\eta_{H-AHU/FCU-WA}$	Weighted Average AHU/FCU Efficiency of Heating Loop (%)	Calculated through provided methodology from Equation 28	
$\eta_{C-AHU/FCU-WA}$	Weighted Average AHU/FCU Efficiency of Cooling Loop (%)	Calculated through provided methodology from Equation 29	
$\eta_{H-AHU/FCU-n}$	Efficiency of individual AHUs and FCUs of Heating Loop (m^3/s)	Yes – Mechanical Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
$\eta_{C-AHU/FCU-n}$	Efficiency of individual AHUs and FCUs of Cooling Loop (m^3/s)	Yes – Mechanical Consultant; Default value to be referenced to applicable minimum motor efficiencies tested at 2-pole from Table A1, Table A2, Table A3, Table B1, Table B2, or Table B3 under Section 3 within AS 1359.5:2004.	= User Input
$V_{H-AHU-FCU-n}$	Design Air Flow Rate of individual AHUs or FCUs of Heating Loop (m^3/s)	Yes – Mechanical Consultant; The input required is the Design Air Flow Rate of AHUs/FCUs only. It excludes the added air flow rates resulted from redundancy.	= User Input
$V_{C-AHU-FCU-n}$	Design Air Flow Rate of individual AHUs or FCUs of Cooling Loop (m^3/s)	Yes – Mechanical Consultant; The input required is the Design Air Flow Rate of AHUs/FCUs only. It excludes the added air flow rates resulted from redundancy.	= User Input
$V_{H-Cond.}$	Total Air Flow Rates supplied to Conditioned Zones at the reference hour under Heating Scenario (m^2)	User will be required to input design air-flow rate for each conditioned zones within the building project model. Total air flow rates supplied to conditioned zones at a reference hour can then be derived.	
$V_{C-Cond.}$	Total Air Flow Rates supplied to Conditioned Zones at the reference hour under Cooling Scenario (m^2)	User will be required to input design air-flow rate for each conditioned zones within the building project model. Total air flow rates supplied to conditioned zones at a reference hour can then be derived.	
$V_{H-Total}$	Total Air Flow Rate of all AHUs or FCUs combined of Heating Loop (m^3/s)	Yes – Mechanical Consultant; The input required is the Design Air Flow Rate of AHUs/FCUs only. It excludes the added air flow rates resulted from redundancy.	= User Input
$V_{C-Total}$	Total Air Flow Rate of all AHUs or FCUs combined of Cooling Loop (m^3/s)	Yes – Mechanical Consultant; The input required is the Design Air Flow Rate of AHUs/FCUs only. It excludes the added air flow rates resulted from redundancy.	= User Input

2.5 Step 5 – Calculating Total Annual Energy Requirement for Central HVAC Services

After assessing the individual energy demand of different energy-consuming equipment and accounting for the losses attributed to central HVAC services, the total energy requirement for central HVAC services can be ascertained using via **Equation 30** and **Equation 31** below:

For Central Heating Services:

Equation 30: Calculation of Total Energy Requirement for Heating

$$E_{Heating-Central} = E_{Heating} + E_{HHW-Pump} + E_{H-Condenser-Pump} + E_{H-CT} + E_{H-\frac{AHU}{FCU}}$$

For Central Cooling Services:

Equation 31: Calculation of Total Energy Requirement for Cooling

$$E_{Cooling-Central} = E_{Cooling} + E_{CHW-Pump} + E_{C-Condenser-Pump} + E_{C-CT} + E_{C-AHU/FCU}$$

$E_{Heating\text{-}Central}$ = Total Energy Requirement for Heating (MJ/a, Electricity or Natural Gas & Electricity)
$E_{Cooling\text{-}Central}$ = Total Energy Requirement for Cooling (MJ/a, Electricity)
$E_{Heating}$ = Total Energy Requirement from Heating Equipment (MJ/a, Electricity or Natural Gas & Electricity)
$E_{Cooling}$ = Total Energy Requirement from Cooling Equipment (MJ/a, Electricity)
$E_{HHW\text{-}Pump}$ = Total Energy Requirement for HHW Pump (MJ/a, Electricity)
$E_{CHW\text{-}Pump}$ = Total Energy Requirement for CHW Pump (MJ/a, Electricity)
$E_{H\text{-}Condenser\text{-}Pump}$ = Total Energy Requirement for Condenser Pump of Heating Loop (MJ/a, Electricity)
$E_{C\text{-}Condenser\text{-}Pump}$ = Total Energy Requirement for Condenser Pump of Cooling Loop (MJ/a, Electricity)
$E_{H\text{-}CT}$ = Total Energy Requirement for Cooling Tower under Heating Scenario (MJ/a, Electricity)
$E_{C\text{-}CT}$ = Total Energy Requirement for Cooling Tower under Cooling Scenario (MJ/a, Electricity)
$E_{H\text{-}AHU/FCU}$ = Total Energy Requirement for AHUs or FCUs under Heating Scenario (MJ/a, Electricity)
$E_{C\text{-}AHU/FCU}$ = Total Energy Requirement for AHUs or FCUs under Cooling Scenario (MJ/a, Electricity)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 22: Summary of Inputs and Source of Parameters in Section 2.51.4Instantaneous Electric DHW Heaters

Parameters		User Inputs	Benchmark
$E_{H\text{-}AHU/FCU}$	Total Energy Requirement for AHUs or FCUs under Heating Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 30	
$E_{C\text{-}AHU/FCU}$	Total Energy Requirement for AHUs or FCUs under Cooling Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 31	
$E_{Heating}$	Total Energy Requirement from Heating Equipment (MJ/a, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 21	
$E_{Cooling}$	Total Energy Requirement from Cooling Equipment (MJ/a, Natural Gas / Electricity)	Calculated through provided methodology from Equation 21	
$E_{HHW\text{-}Pump}$	Total Energy Requirement for HHW Pump (MJ/a, Electricity)	Calculated through provided methodology from Equation 22	
$E_{CHW\text{-}Pump}$	Total Energy Requirement for CHW Pump (MJ/a, Electricity)	Calculated through provided methodology from Equation 23	
$E_{H\text{-}Condenser\text{-}Pump}$	Total Energy Requirement for Condenser Pump of Heating Loop (MJ/a, Electricity)	Calculated through provided methodology from Equation 24	

$E_{C\text{-Condenser-Pump}}$	Total Energy Requirement for Condenser Pump of Cooling Loop (MJ/a, Electricity)	Calculated through provided methodology from Equation 25
$E_{H\text{-CT}}$	Total Energy Requirement for Cooling Tower under Heating Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 26
$E_{C\text{-CT}}$	Total Energy Requirement for Cooling Tower under Cooling Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 27
$E_{H\text{-AHU/FCU}}$	Total Energy Requirement for AHUs or FCUs under Heating Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 28
$E_{C\text{-AHU/FCU}}$	Total Energy Requirement for AHUs or FCUs under Cooling Scenario (MJ/a, Electricity)	Calculated through provided methodology from Equation 29

2.6 Step 6 – Apportion to sole occupancy unit

For central HVAC system applications in residential apartments, conditioning of individual dwellings can be delivered either from the source (i.e. heated air supplied directly from boiler and AHUs to dwellings) or occurs at the field (i.e. heated water is supplied from boiler but heating is delivered via radiators within the dwellings). Hence, the method of apportioning heating and cooling services to individual dwellings will depend on the method of conditioning.

The methodology assumes that the mechanical design of the HVAC systems is designed to be closed-loop, where a common heating/cooling source is responsible for supplying chilled refrigerant, heated refrigerant, CHW, or HHW to all the apartments or units. However, the chilled refrigerant, heated refrigerant, CHW, or HHW or conditioned air returns to the heating/cooling sources to be heated or cooled once again before being transported to individual apartments again. For mechanical designs where conditioned air is supplied directly from the source (i.e. from central AHUs), it is assumed that a proportion of the supply air will return to the source or be mixed with the make-up air as return air, and is hence also considered a close loop system. Under this circumstance, the common heating/cooling source is required to supply additional cooling/heating to the heating/cooling loop to make up for the heat losses rather than supplying additional cooling/heating to each individual dwelling.

Therefore, apportioning of HVAC energy consumption for individual dwellings can be performed via **Equation 32** and **Equation 33** below:

For systems which heating is supplied from the source:

Equation 32: Calculation of Total Annual Energy Required for Heating of an assessed dwelling

$$E_{Heating-Dwelling-n} = E_{Heating-Central} \times \frac{Q_{Heating-Dwelling-n}}{Q_{Heating}}$$

For systems which cooling occurs from the source:

Equation 33: Calculation of Total Annual Energy Required for Cooling of an assessed dwelling

$$E_{Cooling-Dwelling-n} = E_{Cooling-Central} \times \frac{Q_{Cooling-Dwelling-n}}{Q_{Cooling}}$$

$E_{\text{Heating-Dwelling-n}}$ = Total Annual Energy Required for Heating of an assessed dwelling (MJ/a, Electricity or Natural Gas & Electricity)
$E_{\text{Cooling-Dwelling-n}}$ = Total Annual Energy Required for Cooling of an assessed dwelling (MJ/a, Electricity)
$E_{\text{Heating-Central}}$ = Total Energy Requirement for Heating (MJ/a, Electricity or Natural Gas & Electricity)
$E_{\text{Cooling-Central}}$ = Total Energy Requirement for Cooling (MJ/a, Electricity)
$Q_{\text{Heating-Central}}$ = Total Heating Load of building in a year (MJ_{th}/a)
$Q_{\text{Cooling-Central}}$ = Total Cooling Load of building in a year (MJ_{th}/a)
$Q_{\text{Heating-Dwelling-n}}$ = Annual Heating Load of Individual Assessed Building (MJ_{th}/a)
$Q_{\text{Cooling-Dwelling-n}}$ = Annual Cooling Load of Individual Assessed Building (MJ_{th}/a)

A summary of inputs and the sources of all parameters introduced in the preceding subsection is presented below:

Table 23: Summary of Inputs and Source of Parameters in Section 2.6

Parameters		User Inputs	Benchmark
$E_{Heating-Dwelling-n}$	Total Annual Energy Required for Heating of an assessed dwelling (MJ/a, Electricity or Natural Gas & Electricity)	Calculated through provided methodology from Equation 32	
$E_{Cooling-Dwelling-n}$	Total Annual Energy Required for Cooling of an assessed dwelling (MJ/a, Electricity)	Calculated through provided methodology from Equation 33	
$E_{Heating-Central}$	Total Cooling Load of building in a year (MJ_r/a)	Calculated through provided methodology from Equation 34	
$Q_{Cooling-Dwelling}$	Annual Cooling Load of Individual Assessed Building (MJ_r/a)	Derived from building project model	