CO_2 ASHPs for Domestic Hot Water

VIENNA HOUSE CASE STUDY, BC HOUSING

August 2021

A PROPOSED EAST VANCOUVER HOUSING COMMUNITY
AIMS TO ADVANCE INNOVATIVE SOLUTIONS TO AFFORDABILITY, CLIMATE CHANGE, AND SOCIAL EQUITY.

VIENNA HOUSE

FOLLOW OUR PROGRESS
AT **VIENNAHOUSE.CA**

INTEGRAL

PROFESSIONAL ENGINEER
S. A. HOOD
29634
12 Aug 2021

CO_2 ASHPs for Domestic Hot Water

VIENNA HOUSE CASE STUDY, BC HOUSING

August 2021

A PROPOSED EAST VANCOUVER HOUSING COMMUNITY AIMS TO ADVANCE INNOVATIVE SOLUTIONS TO AFFORDABILITY, CLIMATE CHANGE, AND SOCIAL EQUITY.

VIENNA HOUSE

FOLLOW OUR PROGRESS AT **VIENNAHOUSE.CA**

INTEGRAL

Issue	**Description**	**Date** (MM.DD.YY)	**Prepared By**	**Signed Off**
0.1	Draft	07.12.21	J.Watson	S.Hood
1.0	Final	08.11.21	J.Watson	S.Hood

Project Office
Integral Group
Suite 180 – 200 Granville St
Vancouver, BC Canada V6C 1S4
1.604.687.1800

Project Contact:

Stuart Hood

shood@integralgroup.com

Disclaimer

www.integralgroup.com

V1.1

Table of Contents

1 Introduction

This report presents the findings of a study into the available carbon dioxide (CO_2) air source heat pump (ASHP) products and their features for use in heating domestic hot water for the residential pilot project, Vienna House, Vancouver. Vienna House is a social housing project with an area of 7737m² and 108 residential units.

1.1 Benefits of CO_2

Heat pumps provide an efficient method of heating building systems by transferring heat energy from the outside air to a useful temperature via a refrigerant vapour compression cycle. More common modern heat pumps use refrigerants with a high potential to cause global warming if leaked into the atmosphere, which unfortunately occurs too often. CO_2 however, has a much lower effect if leaked having 1000-2000+ times less potential to contribute to global warming.

CO_2 is also best suited to the heating requirements of domestic hot water applications due to its temperature and pressure characteristics. Please refer to section 2 for a more technical description.

1.2 Study Scope

The scope of the study is set as follows.

- Generate schematic designs for each manufacturer to suit the domestic hot water demand
- Select equipment and all associated devices for the DHW plant and prepare equipment lists
- Identify the size limitations/range of equipment available
- Locate the equipment on plan and define indoor and outdoor area requirements
- Provide information on electrical design to allow comparison costing of electrical service
- Outline in conjunction with the architect any architectural or acoustic screening
- Calculate energy performance for each system, including COP at specific outside temperatures
- Include the relative pros and cons for each system, considering maintenance, equipment cost, market familiarity, winter freeze protection, noise, space, complexity and energy costs
- Work with a cost consultant (under separate scope) to provide cost data

2 Why CO_2 ASHPs?

Air source heat pumps (ASHPs) have been widely accepted and are established within the construction industry as reliable technology used for space heating applications. These modern ASHPs typically use refrigerants such as R-410a or R-134a, which are hydrofluorocarbons and a blend in the case of R-410a. The blending of refrigerants is a method used to refine the properties so that the resultant substances volatility, hazard to health, environmental impacts etc are reduced while still maintaining reasonable performance in terms of phase transition temperatures and heat capacity to suit typical heating and cooling applications.

Though refrigerants produced in this way do achieve incremental improvements, unfortunately the global warming potential (GWP) of R-410a is still >2000 and for R-134a is >1300. GWP is measured using CO_2 as a baseline which is given a GWP of 1, with all other refrigerants then scored to show their global warming potential compared to CO_2. This clearly demonstrates the environmental benefits of using CO_2 as a refrigerant in these applications.

GWP is not however the only metric to use when selecting a suitable refrigerant for a certain application. The prominent performance difference between CO_2 and R-410a for example, is the critical point, which is the minimum temperature ensuring the refrigerant is always a saturated gas no matter the pressure. For R410a the critical point is ~71°C (160°F), so it can operate absorbing and releasing heat via phase change through a typical vapour-compression cycle below this temperature, which is very useful for building heating applications and allows the system to reduce the need for subcooling to minimise the required refrigerant charge in the system. Keeping the refrigerant charge to a minimum is obviously beneficial considering the large GWP of this refrigerant type.

CO_2 however, has a critical point of ~32°C (90°F). This means that for common building applications needing higher temperatures the refrigerant must operate trans-critically. This leads to the refrigerant being significantly superheated and the resultant heat transfer to useful applications occurring 'sensibly', i.e. without the refrigerant condensing back into a liquid. The useful heat transfer therefore occurs in a gas-cooler heat exchanger instead of a more traditional condenser. Because of this difference in the refrigerant cycle CO_2 heat pumps achieve their highest efficiency when delivering high heat outputs to low temperature input flows, as the more the refrigerant can be cooled sensibly the more capacity it has for heat absorption. This trans-critical cycle does however require a larger refrigerant charge, but the very low GWP of CO_2 allows this to be implemented with lower risks, though large quantities of CO_2 leakage can pose a risk to human safety especially in semi-enclosed spaces, so this risk needs to be considered in the application of this equipment.

The differences described above in trans-critical and sub-critical refrigerant cycles show how a more common sub-critical R410a ASHP would be best suited to a space heating application with a relatively small ΔT in the system flow/return hydronic circuit. Whereas an ASHP using the more recent trans-critical CO_2 cycle technology is ideally suited to domestic hot water applications aiming to heat mains cold water from ~8°C all the way up to 60-65°C+.

The images on the page below (Image 2-1 and Image 2-2) show the difference in typical sub-critical and trans-critical refrigerant cycles when plotted on their respective pressure-enthalpy charts.

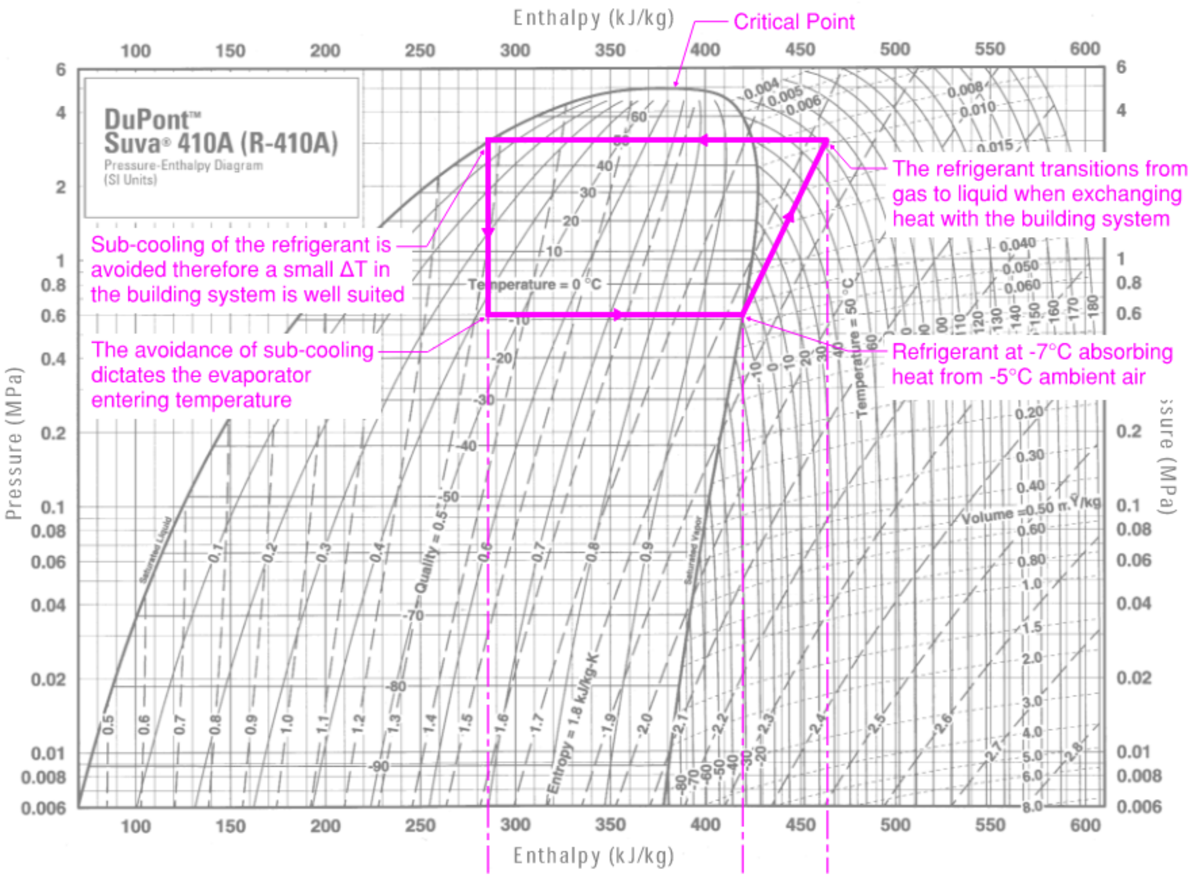


Image 2-1. R410a P-H Chart

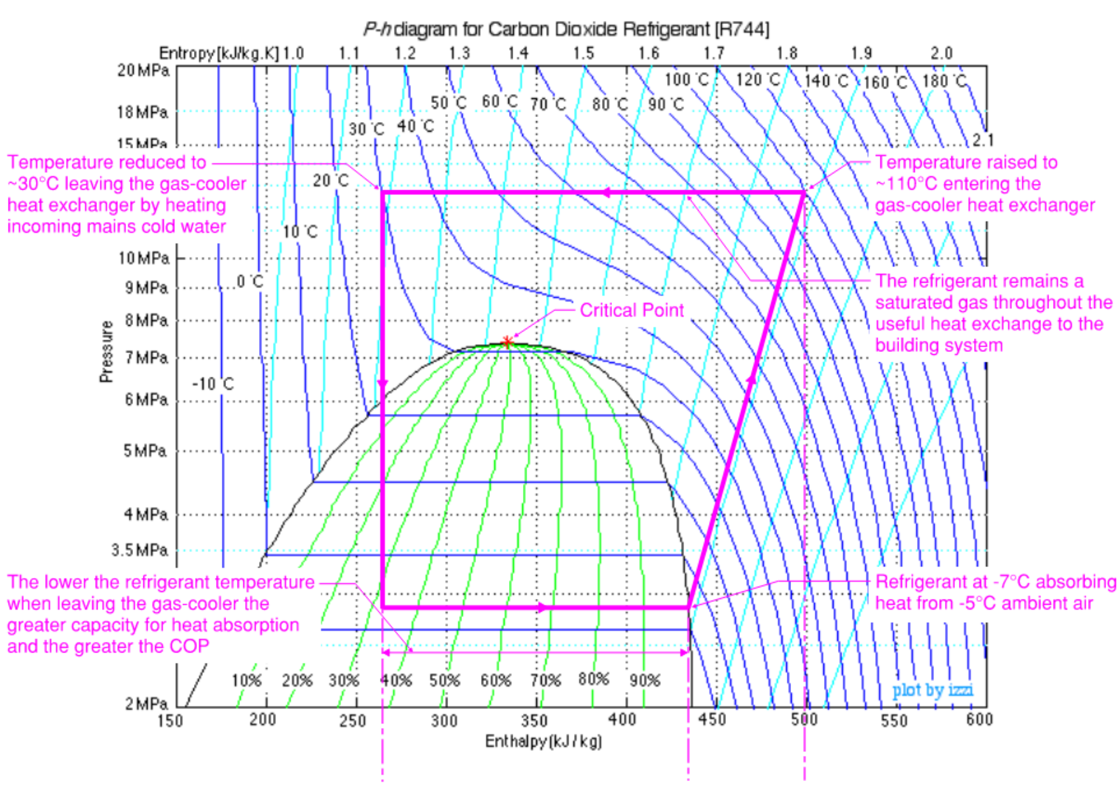


Image 2-2. CO_2 P-H Chart

3 Product Comparisons

The below table illustrates comparisons of the CO_2 ASHP equipment under review using metrics which are relevant to consider the suitability for various applications.

3.1 Comparison Matrix

Metric	Small Planet Supply SANCO2	Riada Sales Lync by WATTS	Mitsubishi QAHV
			
Model Reference	GS4-45HPC	Aegis A 250 / 350 / 500	QAHV-N136TAU-HPB
Output Power (select conditions)	4.5 kW	56.5 / 85 / 124.3 kW	40 kW
Refrigerant Charge	1.6 lbs (0.35 lbs/kW)	44 / 55 / 66 lbs (0.78 / 0.65 / 0.53 lbs/kW)	14.3 lbs (0.36 lbs/kW)
Power Supply	208/230v 1ph 60Hz	480v 3ph 60Hz	208/230v 3ph 60Hz
Simultaneous Hydronic Cooling?	No	Yes (optional)	No
Acoustic Sound Pressure Level	37 dB(A)	68 / 73 / 76 dB(A)	56 dB(A)

For verified information refer to manufacturers' specific product data

Metric	Small Planet Supply SANCO₂	Riada Sales Lync by WATTS	Mitsubishi QAHV
			
Manufacturing Location	Japan (Sanden)	Italy (Enerblue)	Japan (Mitsubishi)
Local Market Availability	USA since 2014 BC since 2016	Launched North America Q2 2021	Launched Canada End July 2021
Current Market Depth	Millions worldwide	None local ~100 units worldwide	Sales in Japan since 2007 and more recent European sales
Local Product Representation	Eco2 Systems exclusive North America distributor, Small Planet Supply exclusive distributor within BC	Lync by Watts exclusive North America distributor, Riada Sales exclusive distributor for Lync by Watts in BC	Mitsubishi direct sales
Local Maintenance Capability	Small Planet Supply service team	3rd party technicians trained specifically on Lync equipment	Mitsubishi direct after sales support
Manufacturer Case Study Availability	First commercially available CO_2 water heater in North America with many installed systems throughout the states and BC	Yes, European only	Yes, Europe and Japan

For verified information refer to manufacturers' specific product data

3.2 Comparison Considerations

Some of the comparison metrics included within the matrix above need to be considered from the perspective of an installed assembly and not simply by comparing the individual equipment units available, as expanded upon below.

3.2.1 Refrigerant Leakage

CO_2 has the lowest GWP of available refrigerants which gives its use great benefits from an environmental perspective. However, high concentrations in enclosed or semi-enclosed spaces create a significant risk to human health due to oxygen depletion and asphyxiation risk so it is important that suitable detection monitoring, alarms and ventilation is provided in-line with the requirements of the Mechanical Refrigeration Code CSA B52-13 and the supporting guidance documents.

The ventilation requirement is driven by the potential concentration created by a refrigerant leak in the space, and protection is assessed based on a single circuit failure. With this in mind there is a lower risk to health due to refrigerant leakage when using multiples of smaller heat pump units compared to a single larger unit, as the smaller unit carries a smaller CO_2 charge in its circuit(s). Though all of the options under review have the ability to be installed safely in residential developments such as Vienna House, as all of the equipment containing CO_2 is predominantly located outside or in very well ventilated semi-outdoor spaces.

3.2.2 Acoustics

For comparison purposes the acoustic sound pressure levels of equivalent assemblies should be reviewed, as opposed to the individual equipment units sound pressure level value. This is because an array of multiple units will create more noise than a single unit and has multiple sound source locations throughout the array.

An acoustic assessment needs to be made on a case by case basis to understand various aspects, such as the maximum allowable noise in a certain location, the background noise already present at various times of day, the ability to introduce screens and shrouds in a certain location without hindering the required air flow to the units, etc.

3.2.3 Power Supply

The mains power supplies available in Vancouver are 208v-3ph-60Hz or 575v-3ph-60Hz, with 208v-1ph-60Hz regularly used within buildings. The Lync by Watts unit utilizes 480v-3ph-60Hz which means it will require a transformer to serve its power supply unless the building it is installed within is designed using a 480v system. 480v systems are standard in the USA which is why the units are supplied in this voltage given the large size of the US market. Over time 575v units may be produced but currently there are no firm plans to do this.

3.2.4 Frost Protection

The Lync by WATTS and Mitsubishi units use a circuit which transfers heat to the domestic hot water through a heat exchanger, meaning the outdoor pipework is hydraulically separated from the domestic hot water and can therefore be treated with the addition of glycol to prevent freezing and reduce the risk of pipe bursts. However, the outdoor water circuit to the SANCO2 unit(s) carries the domestic hot water in a single hydraulically connected system. This means that the water in the outdoor circuit for the SANCO2 unit(s) cannot be glycol treated, so in the event of a power outage which prevents the heat pumps from running during cold weather the outdoor pipework is at a high risk of freezing. The possible solutions are electric trace heating, which can be expensive when covering a large array of units pipework, or to include a solenoid valve controlled drain-down feature which removes the water from the outdoor circuit in a potential freezing event, which also requires anti-vacuum valves to facilitate safe quick drain-down.

4 Performance Curves

The comparison curves below illustrate the coefficient of performance at varying outside ambient air temperatures for the equipment under review. They have been compiled using product data provided by the equipment suppliers.

4.1 Product Performance

Due to a lack of standardized performance testing procedures for this type of equipment the manufacturers available data for comparison varies, and attention needs to be paid to the fact that the performance data for each item of equipment uses slightly different inlet and outlet water temperature parameters.

4.1.1 Mitsubishi QHAV

The product data sheet leaflet for the QAHV heat pump states two coefficient of performance (COP) figures as 4.11 and 3.83. These figures are achieved at specific 'normal heating conditions' as stated within the extract below, and therefore they do not represent the operating performance across a range of outside air, inlet water and water delivery temperatures. It is important to understand the performance across the potential operating range to gain a clearer understanding for comparison purposes.

Specifications

Model			QAHV-N136TAU-HPB(-BS)
Power Source			3-phase 3-wire 208–230 V 60 Hz
Capacity *1		Btu/h	136,480
		kW	40
		kcal/h	34,400
	Power input	kW	9.73
	Current input	A	30.0-27.2
	COP	kW/kW	4.11
Capacity *2		Btu/h	136,480
		kW	40
		kcal/h	34,400
	Power input	kW	10.44
	Current input	A	32.2-29.1
	COP	kW/kW	3.83

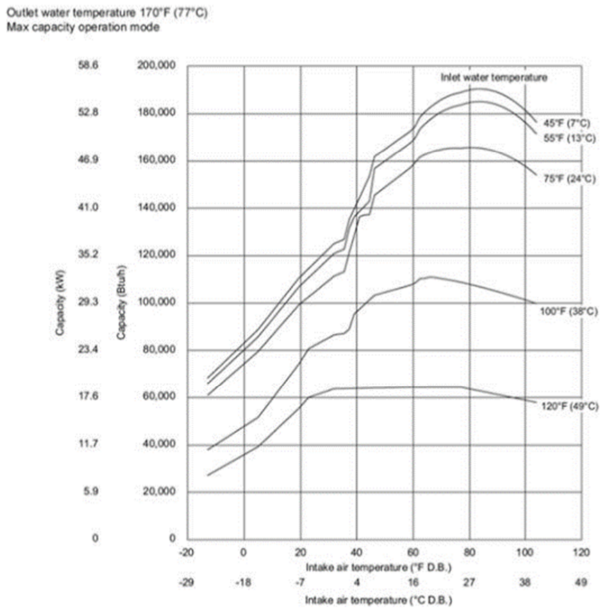
Notes:
*1 Under normal heating conditions at the outdoor temperature of 80.6°FDB/71.2°FWB (27.0°CDB/21.8°CWB), the outlet water temperature of 120°F (48.9°C), and the inlet water temperature of 70°F (21.1°C)
*2 Under normal heating conditions at the outdoor temperature of 80.6°FDB/71.2°FWB (27.0°CDB/21.8°CWB), the outlet water temperature of 149°F (65°C), and the inlet water temperature of 70°F (21.1°C)

Image 4-1. Extract from Mitsubishi QAHV Product Leaflet

To achieve a better understanding of the product performance Mitsubishi provided data for the QAHV heat pump in the form of power input and output capacity curves, which illustrate the variance of these parameters as the outside ambient air temperature varies for five set inlet water temperatures, which are 7°C, 13°C, 24°C, 38°C & 49°C. All performance data given is based upon an outlet/delivery water temperature of 77°C.

See the image of the curves provided by Mitsubishi below.

QAHV-N136TAU-HPB



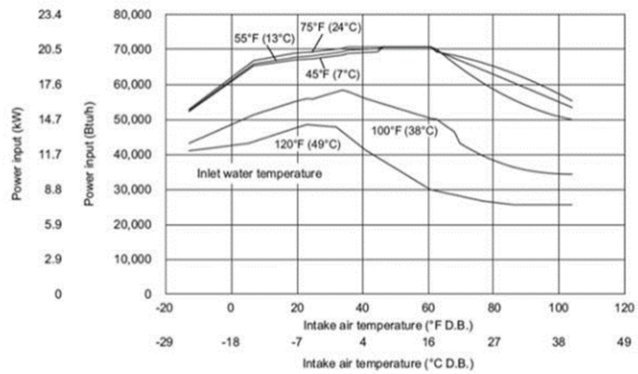


Image 4-2. QAHV Manufacturer Performance Charts

For comparison of the performance data, input and output power figures have been read from the charts provided using outside ambient air temperatures at 2°C intervals from -25°C to 40°C, with the resultant COP calculated at each data point. The data is compiled into the following table.

Mitsubishi QAHV-N136TAU-HPB (read from manufacturer charts, delivering 77°C water at outlet)																
Outside Ambient DB °C	-25	-23	-21	-19	-17	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5
Inlet Water Temp °C																
Power Input kW	15.52	16.14	16.936	17.81	18.61	19.34	19.7	19.89	20.06	20.22	20.29	20.43	20.49	20.57	20.68	20.67
Capacity kW	20.04	21.25	22.55	23.67	24.96	26.25	27.83	29.53	31.16	32.67	33.96	35.2	36.32	37.13	40.27	42.91
COP	1.2912	1.3166	1.3315	1.329	1.3412	1.3573	1.4127	1.4847	1.5533	1.6157	1.6737	1.723	1.7726	1.8051	1.9473	2.076
Inlet Water Temp °C																
Power Input kW	15.52	16.135	16.93	17.71	18.43	19.15	19.43	19.62	19.77	19.87	19.96	20.09	20.21	20.39	20.47	20.5
Capacity kW	19.33	20.56	21.76	22.91	24.09	25.32	26.91	28.52	30.1	31.6	32.8	34.02	35.2	35.88	39.23	40.9
COP	1.2455	1.2742	1.2853	1.2936	1.3071	1.3222	1.385	1.4536	1.5225	1.5903	1.6433	1.6934	1.7417	1.7597	1.9165	1.9951
Inlet Water Temp °C																
Power Input kW	15.52	16.13	16.924	17.61	18.28	18.99	19.27	19.44	19.55	19.68	19.72	19.87	19.95	20.12	20.22	20.27
Capacity kW	17.84	18.98	20.13	21.25	22.37	23.4	25	26.48	27.84	29.3	30.36	31.46	32.36	33.08	36.51	40.21
COP	1.1495	1.1767	1.1894	1.2067	1.2237	1.2322	1.2974	1.3621	1.424	1.4888	1.5396	1.5833	1.6221	1.6441	1.8056	1.9837
Inlet Water Temp °C																
Power Input kW	12.67	13.1	13.54	13.98	14.43	14.99	15.33	15.63	15.96	16.26	16.4	16.66	16.91	17.08	16.74	16.38
Capacity kW	11.15	11.98	12.78	13.56	14.39	15.34	17.07	18.78	20.46	22.19	23.8	24.53	25.19	25.5	26.92	28.83
COP	0.88	0.9145	0.9439	0.97	0.9972	1.0233	1.1135	1.2015	1.282	1.3647	1.4512	1.4724	1.4897	1.493	1.6081	1.7601
Inlet Water Temp °C																
Power Input kW	12.06	12.15	12.29	12.41	12.53	12.67	13.01	13.36	13.63	13.98	14.16	14.07	14	13.43	12.65	11.94
Capacity kW	7.95	8.68	9.44	10.15	10.88	11.7	12.91	14.09	15.31	16.57	17.73	18.22	18.6	18.74	18.79	18.8
COP	0.6592	0.7144	0.7681	0.8179	0.8683	0.9234	0.9923	1.0546	1.1233	1.1853	1.2521	1.295	1.3286	1.3954	1.4854	1.5745

Outside Ambient DB °C	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	40
Inlet Water Temp °C	Inlet Water Temp 7°C																	
Power Input kW	20.61	20.65	20.61	20.61	20.61	20.56	20.13	19.93	19.7	19.44	19.16	18.8	18.45	18.04	17.59	17.08	16.57	16.31
Capacity kW	46.3	48.2	48.65	49.52	50.46	52.11	53.56	54.46	55.05	55.45	55.81	55.88	55.73	55.41	54.76	53.86	52.6	51.84
COP	2.2465	2.3341	2.3605	2.4027	2.4483	2.5345	2.6607	2.7326	2.7944	2.8524	2.9128	2.9723	3.0206	3.0715	3.1131	3.1534	3.1744	3.1784
Inlet Water Temp °C	Inlet Water Temp 13°C																	
Power Input kW	20.54	20.64	20.6	20.6	20.6	20.55	20.02	19.62	19.26	18.89	18.47	18.1	17.66	17.19	16.83	16.38	15.96	15.77
Capacity kW	44.07	46.65	47.12	48.07	48.98	50.67	51.94	52.94	53.47	53.89	54.26	54.35	54.18	53.85	53.21	52.33	51.1	50.38
COP	2.1456	2.2602	2.2874	2.3335	2.3777	2.4657	2.5944	2.6983	2.7762	2.8528	2.9377	3.0028	3.068	3.1326	3.1616	3.1947	3.2018	3.1947
Inlet Water Temp °C	Inlet Water Temp 24°C																	
Power Input kW	20.48	20.62	20.59	20.59	20.59	20.54	19.86	19.08	18.48	17.85	17.2	16.68	16.22	15.79	15.44	15.08	14.82	14.7
Capacity kW	41.53	43.37	43.86	44.85	45.82	47.22	47.96	48.33	48.49	48.52	48.63	48.52	48.33	47.97	47.42	46.71	45.72	45.19
COP	2.0278	2.1033	2.1302	2.1782	2.2254	2.2989	2.4149	2.533	2.6239	2.7182	2.8273	2.9089	2.9797	3.038	3.0712	3.0975	3.085	3.0741
Inlet Water Temp °C	Inlet Water Temp 38°C																	
Power Input kW	16.05	15.76	15.6	15.34	15	14.7	14.01	12.84	12.21	11.7	11.24	10.89	10.61	10.39	10.25	10.17	10.1	10.1
Capacity kW	30.07	30.64	30.78	31.15	31.54	32.24	32.56	32.45	32.22	31.95	31.69	31.41	31.03	30.73	30.35	29.96	29.45	29.29
COP	1.8735	1.9442	1.9731	2.0306	2.1027	2.1932	2.3241	2.5273	2.6388	2.7308	2.8194	2.8843	2.9246	2.9577	2.961	2.9459	2.9158	2.9
Inlet Water Temp °C	Inlet Water Temp 49°C																	
Power Input kW	11.3	10.71	10.39	9.82	9.22	8.78	8.49	8.29	8.11	7.86	7.77	7.61	7.58	7.56	7.55	7.549	7.548	7.548
Capacity kW	18.82	18.83	18.87	18.89	18.92	18.92	18.94	18.93	18.93	18.93	18.71	18.41	18.17	17.98	17.64	17.49	17.17	17.07
COP	1.6655	1.7582	1.8162	1.9236	2.0521	2.1549	2.2309	2.2835	2.3342	2.4084	2.408	2.4192	2.3971	2.3783	2.3364	2.3169	2.2748	2.2615

Image 4-3. QAHV Extracted Data Table

The tabulated data is written into graphical form to demonstrate the variance in COP across the outside ambient air temperature range for the five inlet water temperatures given, as illustrated on the chart below.

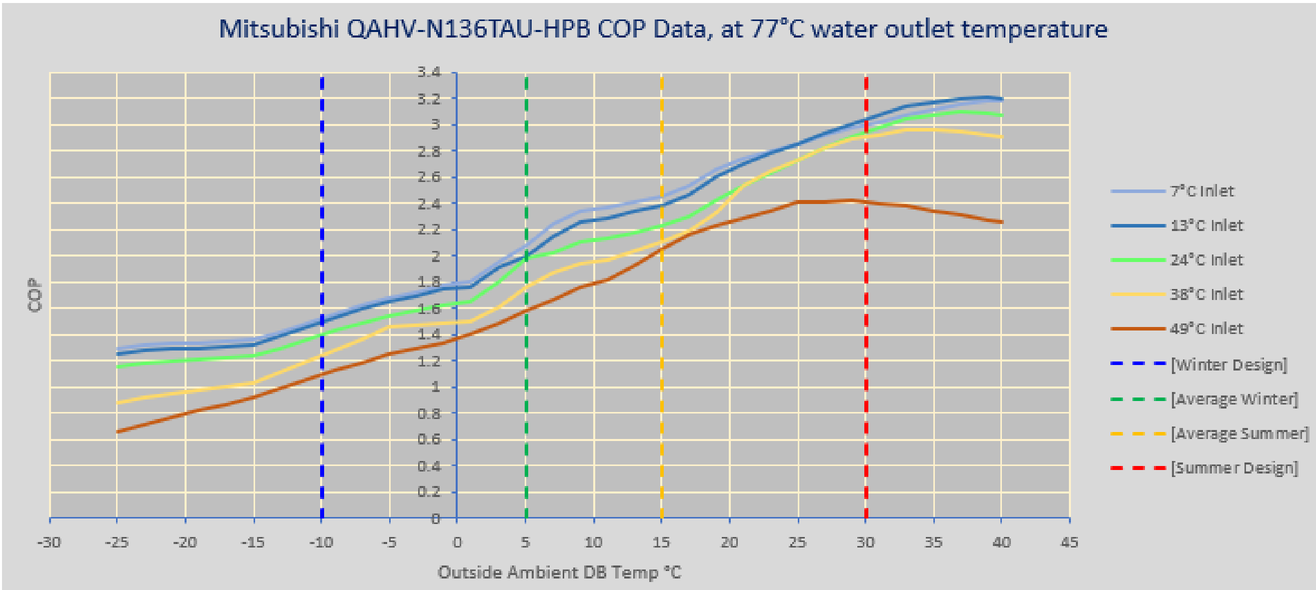


Image 4-4. QAHV Extracted COP Chart

This demonstrates the COP generally improving as the outside ambient air temperature increases, as would be expected, and it also shows that the highest performance efficiency is achieved with the lowest inlet water temperature.

4.1.2 SANCO2 GS4-45HPC

The product data sheet leaflet for the SANCO2 heat pump states three COP figures as 5.5, 4.2 and 2.8. These figures are achieved at specific outdoor ambient air temperatures as stated within the extract below, and therefore they do not represent the operating performance across a range of outside air, inlet water and water delivery temperatures. It is important to understand the performance across the potential operating range to gain a clearer understanding for comparison purposes.

Specifications	
Water Temperature Setting	145 or 150°F
Ambient Air Operating Range	-25 to 104°F
Nom Heating Capacity (Btu/h)	15,400 Btu/h
Nom Heating Capacity (kw)	4.5kw
Heating COP @80/47/17°F	5.5 / 4.2 / 2.8
Refrigerant Type	R744 (CO_2)
Power Voltage	208/230v-1Ph-60Hz
Breaker Size	15 Amps
MCA (Amps)	7.2 Amps
Compressor Type	Rotary
Noise Level (DbA)	37
Weight (lbs)	108lbs
Pipe Size (Tank to Heat Pump)	½"(Both Hot Supply & Cold Return)
Max Length inc Vertical Sep	66ft
Max Vertical Separation	23ft
Max Incoming Water Pressure	95Psi

Image 4-5. Extract from SANCO2 Product Brochure

To achieve a better understanding of the product performance Small Planet Supply provided data for the SANCO2 heat pump in the form of a COP curve which illustrates the variance of these parameters as the outside ambient air and inlet water temperatures vary. The performance data given is based upon an outlet/delivery water temperature of ~65.5°C (150°F) but dropping to ~63°C (145°F) at lower extremes of the performance range.

See the image of the curves provided by Small Planet Supply below.

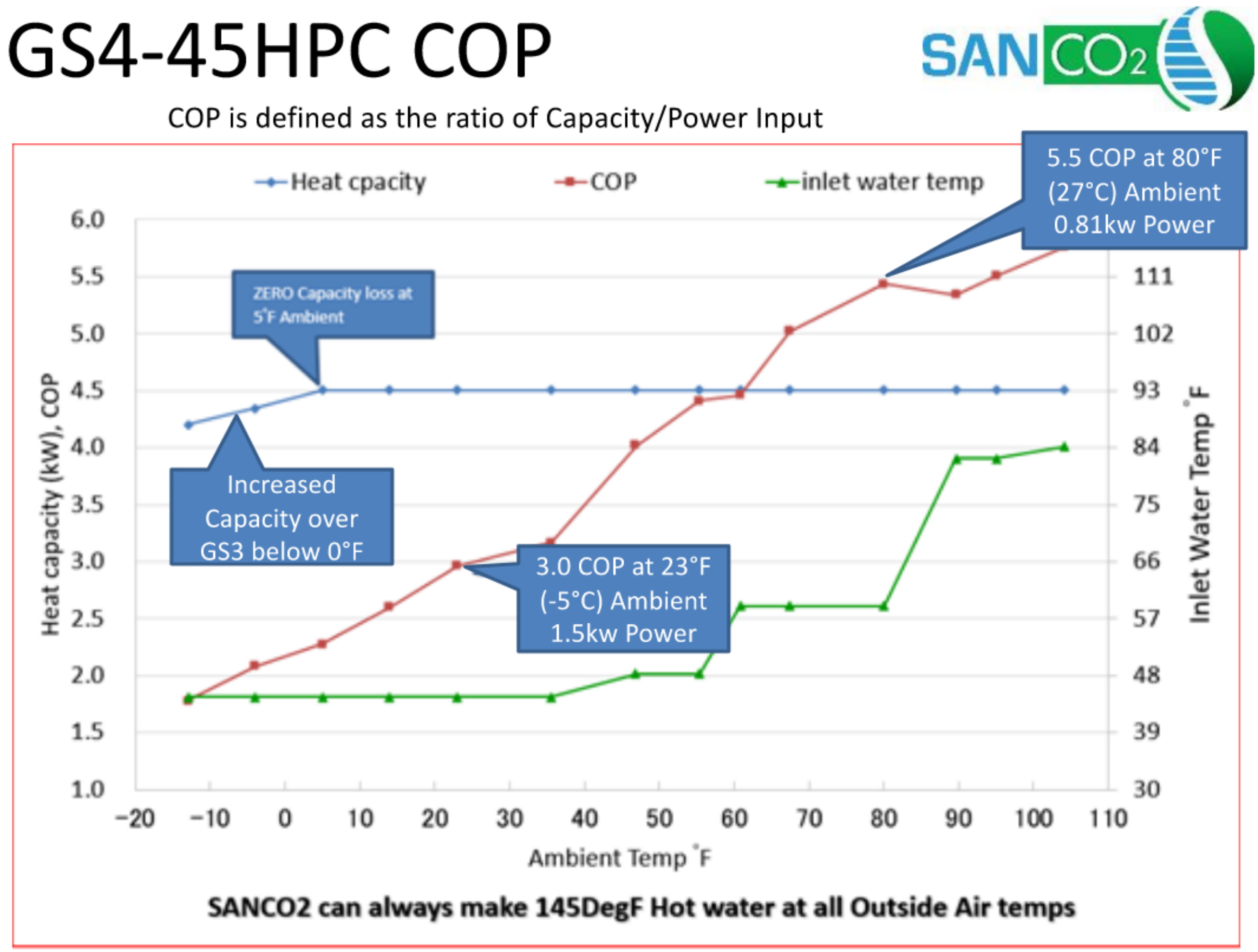


Image 4-6. SANCO2 Manufacturer Performance Chart

For comparison of the performance data, COP and output power (heat capacity) figures have been read from the chart provided using outside ambient air temperatures at 2°C intervals from -25°C to 40°C, with the resultant input power calculated at each data point. The data is compiled into the following table.

SANCO2 GS4-45HPC (read from manufacturer chart, delivering ~65.5°C (150°F) water at outlet but droping to ~63°C (145°F) at lower extreme of performance)

Outside Ambient DB °C	-25	-23	-21	-19	-17	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5
Inlet Water Temp °C	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7.34	8
Power Input kW	2.3204	2.2421	2.1709	2.066	2.0182	1.9651	1.875	1.7717	1.6854	1.6014	1.5203	1.495	1.461	1.4331	1.3678	1.257
Capacity kW	4.2	4.26	4.32	4.38	4.44	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
COP	1.81	1.9	1.99	2.12	2.2	2.29	2.4	2.54	2.67	2.81	2.96	3.01	3.08	3.14	3.29	3.58

Outside Ambient DB °C	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	40
Inlet Water Temp °C	8.56	9.08	9.08	9.08	13.1	14.95	14.95	14.95	14.95	14.95	15.72	20.4	25.37	27.93	27.93	28.37	28.79	28.89
Power Input kW	1.1688	1.1029	1.0613	1.0181	1.0112	0.974	0.9184	0.8824	0.8637	0.8427	0.8272	0.8333	0.8396	0.8333	0.8167	0.8021	0.7881	0.7826
Capacity kW	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
COP	3.85	4.08	4.24	4.42	4.45	4.62	4.9	5.1	5.21	5.34	5.44	5.4	5.36	5.4	5.51	5.61	5.71	5.75

Image 4-7. SANCO2 Extracted Data Table

The tabulated data is written into graphical form to demonstrate the variance in COP across the outside ambient air temperature range for the varying inlet water temperature given, as illustrated on the chart below.

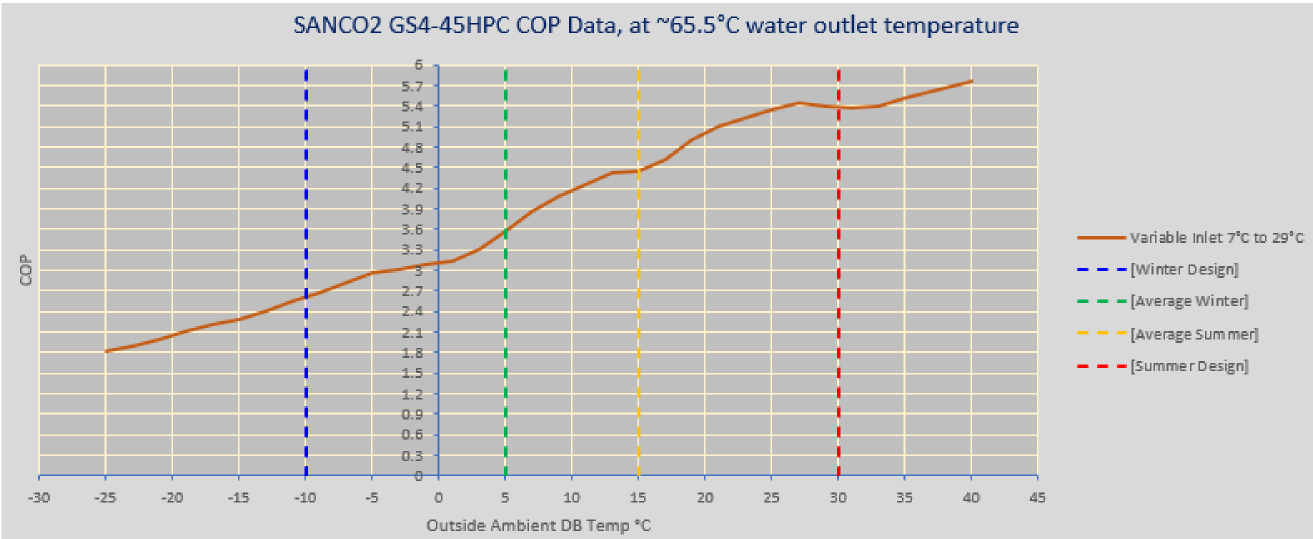


Image 4-8. SANCO2 Extracted COP Chart

This demonstrates the COP generally improving as the outside ambient air temperature increases, as would be expected, but please note the performance chart is drawn considering the increase in inlet water temperature at higher outside ambient air temperatures as given by the manufacturer and listed in the data table above. In most climates supplied city water approximates ground temperature which reflects average air temperature in Vancouver, this would result in a range between 5-10°C.

4.1.3 Lync by Watts Aegis A 250, 350 & 500

The product data sheet leaflet for the Lync by Watts Aegis heat pumps state a COP figure for each sized product as 3.2, 3.0 and 3.0. These figures are achieved at specific outdoor ambient air temperatures as stated within the extract below, and therefore they do not represent the operating performance across a range of outside air, inlet water and water delivery temperatures. It is important to understand the performance across the potential operating range to gain a clearer understanding for comparison purposes.

Technical Data

			250	350	500
Performance	Nominal Heating Capacity*	MBH	191	305	430
	Output Power	kW	56.5	85.0	124.3
	Nominal Recovery Capacity (20-80°C)	GPH	212	339	479
	COP*		3.2	3.0	3.0
	Heating Capacity w/ Recovery	MBH	199	319	477
	Cooling Capacity	MBH	145	229.0	340
	Input Power	kW	15.7	26.3	40.1
	TER		6.4	6.1	6.0
	Cool Recovery Water Flow Rate	GPH	1938	3064	4556
	Cool Recovery HX Pressure Drop	PSI	3.5	7.7	7.1
	Cool Recovery Pump Power Available		230 V / 1 ph / 60 Hz / 2.1 A		
	Nominal Compressor Size	HP	14	25	35
	Number of Fans		3	2	2
	Refrigerant Charge	lbs	44	55	66
	Sound Pressure	dB(A)	68	73	76

*Nominal performance data based on the following conditions: External air temperature 44.6°F (7°C) RH of 87% with user side inlet temperature of 68°F (20°C) and an outlet temperature of 176°F (80°C)

Image 4-9. Extract from Lync by Watts Technical Data Sheet

To achieve a better understanding of the product performance a request for a data set was made to the supplier. Unfortunately, a full data set was not available but the supplier was able to supply a limited number of representative data points across the performance range in the form of a data table which illustrates the variance of output power and COP as the outside ambient air temperature varies. The performance data given is based upon an outlet/delivery water temperature of ~60°C.

See the image of the data table provided by Riada below.

Aegis A 250
-10°C: 132,700 BTU/hr, 2.7 COP
0°C: 175,500 BTU/hr, 3.4 COP
10°C: 220,500 BTU/hr, 4.1 COP
25°C: 270,700 BTU/hr, 5.2 COP

Aegis A 350
-10°C: 220,600 BTU/hr, 2.7 COP
0°C: 283,900 BTU/hr, 3.2 COP
10°C: 352,800 BTU/hr, 3.9 COP
25°C: 438,800 BTU/hr, 5.0 COP

Aegis A 500
-10°C: 304,500 BTU/hr, 2.6 COP
0°C: 389,300 BTU/hr, 3.1 COP
10°C: 479,700 BTU/hr, 3.6 COP
25°C: 628,200 BTU/hr, 4.6 COP

Image 4-10. Riada Lync by Watts Performance Data Table

For comparison of the performance data, the data given has been tabulated, with the resultant input power calculated at each data point. The data is compiled into the following table.

Lync by Watts Aegis A 250 (read from manufacturer data points, delivering 60°C water at outle				
Outside Ambient DB °C	**-10**	**0**	**10**	**25**
Inlet Water Temp °C	**10°C**			
Power Input kW	14.393	15.115	15.746	15.242
Capacity kW	38.86	51.39	64.56	79.26
COP	2.7	3.4	4.1	5.2
Lync by Watts Aegis A 350 (read from manufacturer data points, delivering 60°C water at outle				
Outside Ambient DB °C	**-10**	**0**	**10**	**25**
Inlet Water Temp °C	**10°C**			
Power Input kW	23.922	25.978	26.487	25.698
Capacity kW	64.59	83.13	103.3	128.49
COP	2.7	3.2	3.9	5
Lync by Watts Aegis A 500 (read from manufacturer data points, delivering 60°C water at outle				
Outside Ambient DB °C	**-10**	**0**	**10**	**25**
Inlet Water Temp °C	**10°C**			
Power Input kW	34.292	36.771	39.017	39.987
Capacity kW	89.16	113.99	140.46	183.94
COP	2.6	3.1	3.6	4.6

Image 4-11. Lync by Watts Extracted Data Table

The tabulated data is written into graphical form to demonstrate the variance in COP across the outside ambient air temperature range for the fixed inlet and outlet water temperatures given, as illustrated on the chart below.

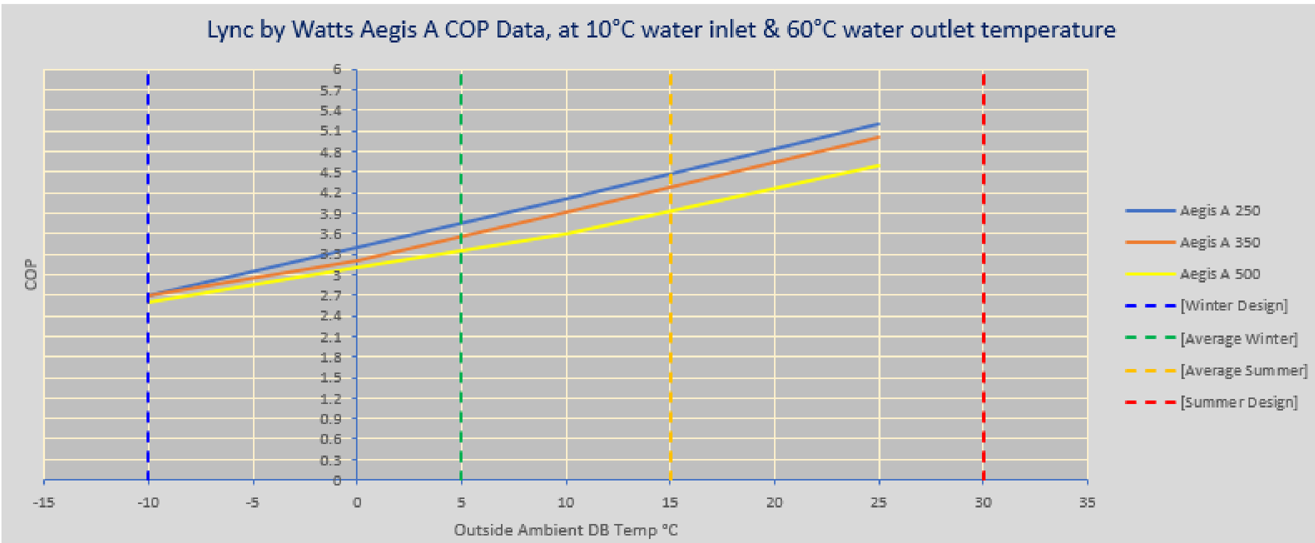


Image 4-12. Lync Extracted COP Chart

This demonstrates the COP improving as the outside ambient air temperature increases, as would be expected, but please note the performance chart is drawn considering fixed inlet and outlet water temperatures as given by the manufacturer and listed in the data table above. We consider the inlet water temperature to be a relatively accurate estimate of incoming water temperature in Vancouver.

4.2 Product Performance Comparison

Performance data is available for all of the products included within this study, but as is demonstrated in the sections above the manufacturers have presented their performance data using varying inlet and outlet water temperatures and across slightly different outside ambient air temperature ranges. Therefore, it is important to understand that the comparison data is not absolute.

With that in mind the drawn COP curves of the products being compared have been overlaid onto the below comparison chart.

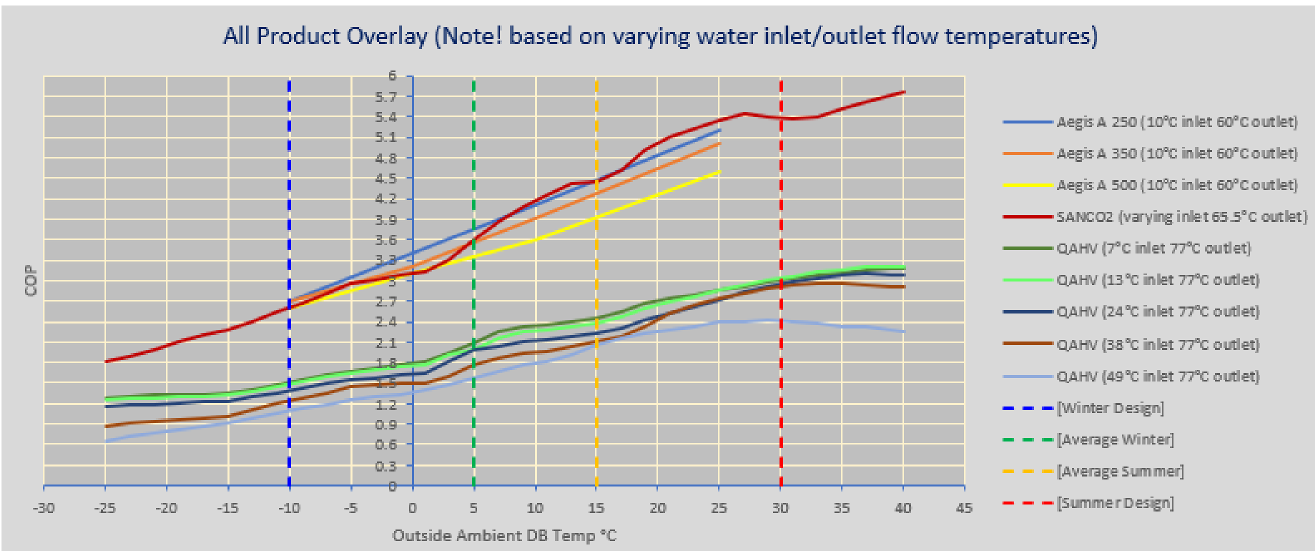


Image 4-13. Product Comparison COP Chart

The chart demonstrates performance similarities between the SANCO2 and the Lync by Watts Aegis A products with the performance of the Mitsubishi QAHV unit somewhat lower. As mentioned previously, due to a lack of standardized performance testing procedures for this type of equipment we cannot be sure if this variation is a result of the higher outlet water temperature used, a simple inefficiency in the components and internal systems of the product or if some manufacturers have included inherent lower performance periods expected during typical 'real world' use in their testing regimes, such as defrost or initial cold start-up cycles.

5 System Sizing

To assess the products suitability specifically for the Vienna House project an initial sizing calculation has been performed to estimate the required storage volume and heat input needed to satisfy the buildings predicted hot water usage. The suppliers have then been invited to provide advice on their proposed system sizing and arrangement(s) based on the building type, size, and occupant count.

5.1 Baseline Sizing

To produce a baseline figure of the expected domestic hot water storage volume and CO_2 heat pump heat supply requirement the following calculation method has been used.

Using the available architectural building layouts at the time of performing this study the overall unit count is 108, which is a mix of studio, 2 bed and 3 bed units with some amenity rooms with the quantity split as listed below.

Apartment Type	Unit Count	Occupant/Unit Type
Studio	49	2
1 Bedroom	0	2
2 Bedroom	42	3
3 Bedroom	17	4
Amenity Room	5	-
-	**Total Occupants**	**292 (+28 amenity)**

Therefore, the peak occupancy is 292 residential occupants with the possibility of 28 additional occupants using the amenity space if visiting the development for a party or event, including some building management staff. The amenity occupants would create some additional lavatory and kitchen sink usage which would create only a minor additional hot water load.

The water flow rates used for the supply fittings to calculate the daily hot water consumption are taken from the Vancouver Plumbing Code 2019, as per the extract below. To calculate the volume of daily hot water consumption daily quantities of supply fitting use and duration per use figures are needed. Though the Vienna House development does not qualify as a 'Sustainable Large Development' under the City of Vancouver Rezoning Policy we have used the baseline indoor potable water use duration and daily use figures from that policy for the purpose of this calculations as this set of data is the most relevant to the site location. An extract of the data used is also included below.

Table 2.2.10.6.
Water Flow Rates from Supply Fittings
Forming Part of Sentence 2.2.10.6.(2)

Supply Fittings	Maximum Water Flow Rate, L/min
Kitchen faucet (non-residential)	8.3
Kitchen faucet (residential)	6.8(1)
Lavatory faucet (for *private use*)	5.7
Lavatory faucet (for *public use*)	1.9(2)
Pre-rinse spray valve	4.8(3)
Shower head	7.6(4)
Wash fountain, per *plumbing fixture* fitting	6.8(5)

Notes to Table 2.2.10.6.:

(1) May be temporarily increased to a maximum flow rate of 8.3 L/min but must default to the lower flow rate upon release of the activation mechanism or closure of the faucet valve.

(2) A *metering fixture* faucet is limited to 1.0 L per cycle.

(3) Each *pre-rinse spray valve* shall be equipped with an automatic shut-off.

(4) Emergency and safety *shower heads* are exempted from this requirement.

(5) A maximum flow rate of 6.8 L/min is permitted for each 500 mm of circumference. For a wash fountain with *metering fixture* faucets, a maximum of one *metering fixture* faucet is permitted for each 500 mm of circumference. *A metering fixture* faucet is limited to 1.0 L per cycle.

Image 5-1. Extract from Vancouver Plumbing Code 2019

4.1.1.1 Indoor Potable Water Use Baseline

The indoor potable water use baseline shall be calculated using the specified fixtures, baseline flow rate / water use per flush values, duration and daily uses specified in Table 1 for the estimated occupancy. Where sufficient justification is provided, daily uses can be modified based on the proposed occupancy type(s) proposed for the building(s) or site. Occupancy shall be based on projected occupancy figures, or where not available, estimated based on floor area using the following:

- Detached Dwellings: 55 m^2/capita
- Apartments: 35 m^2/capita
- Commercial: 23 m^2/capita

The indoor potable water use for the proposed scenario shall utilize the same number of occupants, fixture types, duration and daily uses as the baseline scenario. Potable water use reduction shall be demonstrated through the use of more efficient fixtures with a reduced baseline flow rate / water use per flush and/or supplementing toilet and urinal flushing with non-potable water.

Note: Calculations must be provided to quantify the volume of non-potable water sources collected and utilized to demonstrate compliance with the potable water reduction target.

Table 1: Indoor Potable Water Use Baseline

Only applies to sustainable large developments

Fixture Type	Baseline Flow Rate & Water Use per Flush[1]	Duration	Daily Uses[2]
Lavatory Faucet (for private use)	5.7 L/min	0.25 min	5
Lavatory Faucet (for public use)	1.9 L/min	0.25 min	3
Kitchen Faucet (non-residential)	8.3 L/min	0.25 min	1
Kitchen Faucet (residential)	6.3 L/min	1 min	4
Shower Head	7.6 L/min	8 min	1
Water Closet (Tank Type and Direct Flush) – Male	4.8 L/flush	1 flush	1 male
Water Closet (Tank Type and Direct Flush) – Female	4.8 L/flush	1 flush	3 female
Urinal (Tank Type and Direct Flush) - Male	1.9 L/flush	1 flush	2 male

1 Baseline Flow Rates and Flush Cycle figures from the City of Vancouver Plumbing By-law.

2 Note that daily use can vary based on type of occupant (i.e. Employees, Visitors, Retail Customers, Students and Residential). Daily uses may be adjusted as appropriate based on type of occupant.

Image 5-2. Extract from Sustainable Large Developments Bulletin 2018, 2020 amendment

The domestic hot water consuming fittings are lavatory faucets, kitchen faucets and showers. The water delivery to each fitting is a mixture of hot and cold water to suit the user's temperature preference, and a ratio of 70% hot water to 30% cold water has been used as a reasonable estimate for the purpose of this calculation.

For the number of building occupants stated in the table above and considering the fitting flow rates, hot water ratio, duration per use and the number of uses per day the total daily domestic hot water consumption is calculated as **19625** liters (~67 L/occupant) or **~5200** gallons (~18 gallon/occupant) plus laundry use. Laundry use is expected to take place outside of the most demanding morning peak and will therefore not have a significant affect on plant size selected to deal with that highest demand.

To efficiently size the domestic hot water plant to suit the building demand the peak periods of usage and the demand profiles within those periods need to be considered. This is because a variable usage profile with concentrated peaks of usage creates a larger demand on the hot water plant and will regularly result in a higher storage volume or heat requirement when compared to a less variable and more constant domestic water use. As the use profile is dictated by the behaviour of the occupants a reasonable variability profile needs to be used to robustly calculate a plant arrangement that will satisfy the buildings needs at the highest use times. The plant is selected to meet the requirement of the most demanding peak and is designed to be able to recover so that is can then also meet the requirements of lesser demanding periods.
With this in mind both morning and evening peak periods have been considered, with the morning peak taking place over a shorter duration and the evening peak being spread over a longer duration to represent typical morning showering and breakfast routines seen before the occupants leave for the day, and slightly more relaxed dinner preparation and showering after exercise or before bed routines seen in the evening. The extract below is taken from the ASHRAE Handbook and illustrates a typical hourly use distribution profile for domestic hot water use in residential buildings.

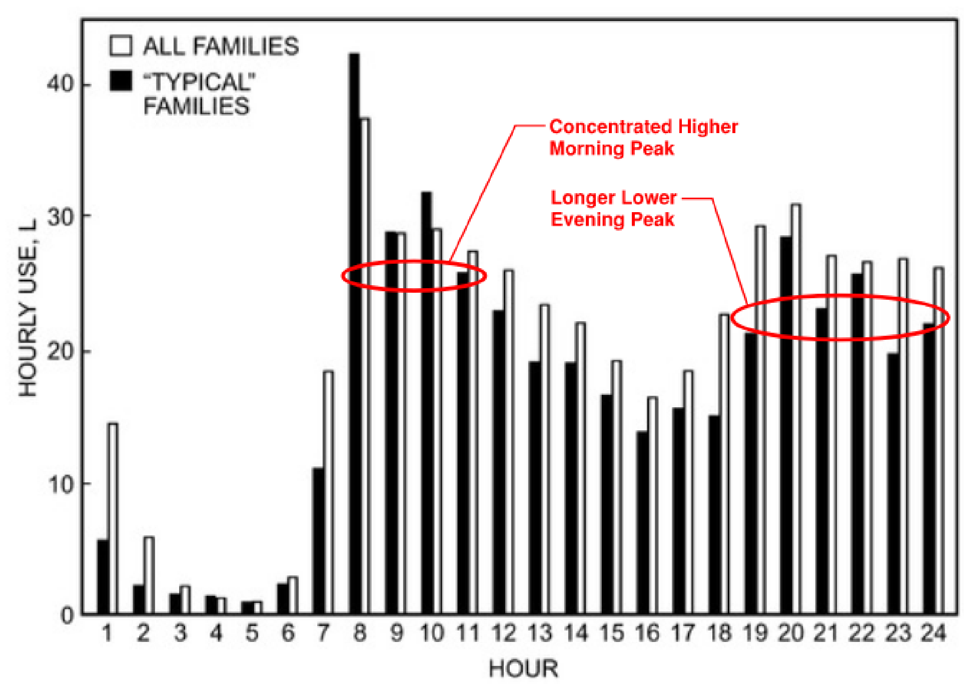


Figure 12. Residential Hourly Hot-Water Use, 95% Confidence Level

Image 5-3. Extract from ASHRAE Handbook 2019, Section 51

The specific peak periods used for this calculation at Vienna House are a morning peak between 6.30-8.00am to represent showering and breakfast before regular working hours and an evening peak between 6.00-8.30pm to represent hot water use after returning from work.
The morning peak considers 45% of the daily showering demand, 25% of the daily lavatory faucet demand and 20% of the kitchen faucet demand, giving a total peak demand volume of 7130 liters (~1900 gallons). This volume is broken down and spread in to 5-minute use periods with a gradual increase in use from 6.30 am to 7.25am and a decline down to 8am.
The evening peak considers 30% of the daily showering demand, 50% of the lavatory faucet demand and 60% of the kitchen faucet demand, giving a total peak demand volume of 7870 liters (~2080 gallons). This volume is broken down and spread in to 5-minute use periods with a flatter profile between 6.00pm and 8.30pm peaking at 7.00pm.
The remaining 25% of daily showering demand, 25% of lavatory faucet demand and 20% of kitchen faucet demand are considered to occur at other times of the day outside of the morning and evening peak periods.

A semi-dynamic calculation method has been used to assess the storage volume temperature variance through 5-minute steps as differing combinations of storage volume and heat input are applied, with an aim to identify a suitable arrangement that maintains a high water storage temperature for at least the top 20% of the storage volume available to ensure adequate hot water availability at all times. The target storage volume temperature used is 70°C as the CO_2 heat pumps are able to achieve this delivery temperature comfortably. This also allows more energy to be stored in the storage vessels which slightly reduces the volume required.

The storage vessel assembly proposed and dictated by all of the suppliers/manufacturers of the equipment being reviewed is a cascade thermal store arrangement. This arrangement connects the vessels in series and fills the connected volume from the same point as the hot water is drawn from to serve the system, allowing the heat pumps to charge the vessels with hot water whilst keeping the water coming from the vessels to be heated at a low temperature for longer, thus maximising the large ΔT and therefore the heat pump COP over a greater period. Below is a representation of a typical thermal store assembly.

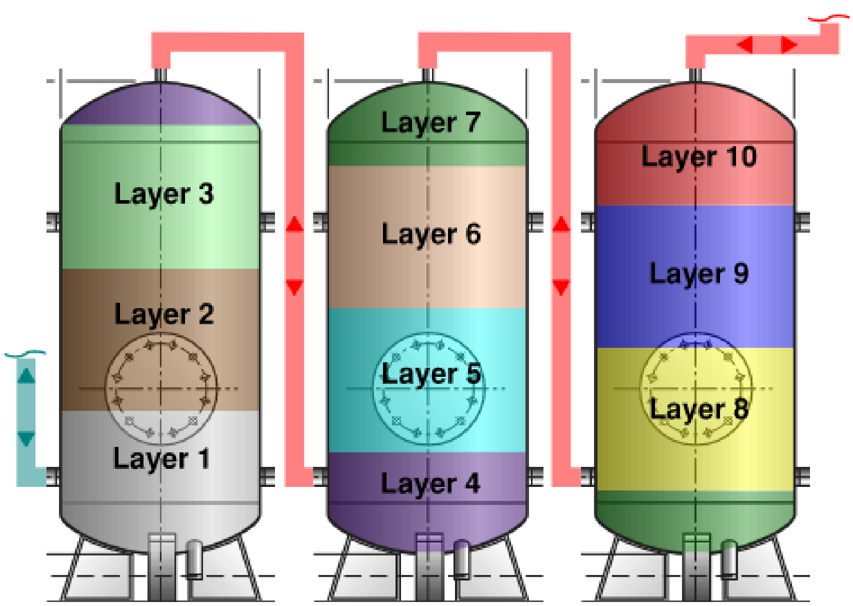


Image 5-4. Typical Cascade Thermal Store Arrangement

The semi-dynamic calculation method records the water temperature of each layer of the overall storage volume at 5-minute intervals as hot water is drawn from the storage and heat is added back into the storage simultaneously.

As the heat pumps represent the highest cost item(s) within these domestic hot water plant arrangements and they require outdoor space and need to be considered from an acoustic perspective it is prudent to approach the plant sizing with a view to minimise the required heat input (heat pump size) by maximising the storage volume and allowing for a longer recovery time period to get the stored water back to full target temperature. Therefore, a large storage to heat ratio has been used. This is very different to how gas fired systems are sized, where the larger heat input gas burners are lower cost than the tanks.

Below is a chart illustrating the morning and evening peak use profiles and the resultant water temperature of each layer of the storage volume throughout the typical peak use day. The overall storage volume and heat input selected and demonstrated with this chart are **6500 liters** (**~1720 gallons**) and **100 kW** (**341,520 BTU/h**).

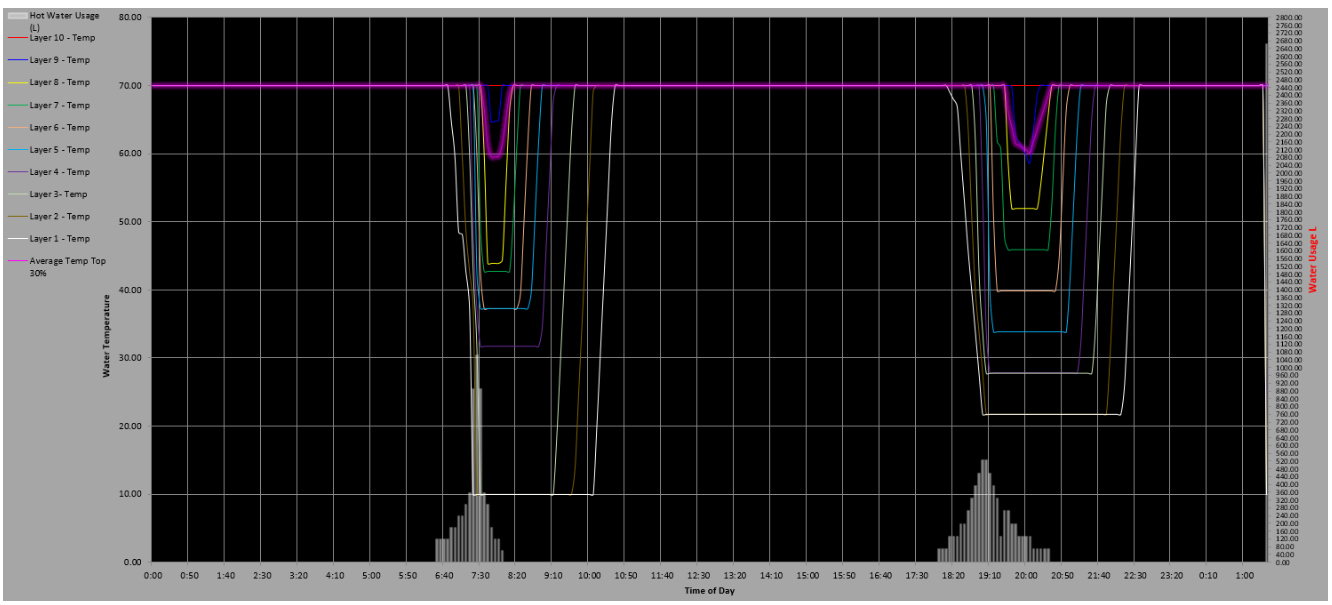


Image 5-5. Water Storage Dynamic Temperature Chart

The chart illustrates that the top two layers (top 20%) of the storage volume remains predominantly above 60°C with the top 10% remaining at 70°C through both peak use periods giving a reasonable margin of comfort that a system sized this way can meet the building demand even if slightly heavier use patterns are experienced on limited occasions.

The chart also shows that after the morning peak period between 6.30-8.00am the 100kW heat input can recover 50% of the storage volume by ~8.45am and 100% of the storage volume by ~10.40am to the target 70°C temperature.

Also, after the evening peak period between 6.00-8.30pm the 100kW heat input can recover 50% of the storage volume by ~9.00pm and 100% of the storage volume by ~10.40pm to the target 70°C temperature.

5.2 Manufacturer Sizing

Following the invitation for the manufactures to provide their sizing recommendations the following proposals were received.

5.2.1 Riada, Lync by WATTS

In providing the system sizing and selection for Vienna House Riada have expressed that they have performed 'some fairly intensive comparisons of different sizing applications both internal and external'. With their strong experience in reviewing sizing methodology to suit the CO_2 heat pump systems they supply to the market their view is that the EcoSizer online application generally produces good results for their applications.

The EcoSizer application is an online tool for sizing heat pump water heater systems for residential buildings, and was designed and built by Ecotope Inc. Further information is available at the EcoSizer website which can be accessed via the link below.

https://ecosizer.ecotope.com/

Riada apply some customized options to the EcoSizer tool to suit their piping recommendations and the building type in question, and they then check the outputs against PVI and Hubbell sizing applications which are based on ASHRAE and ASPE data respectively. Below are extracts from the Riada EcoSizer results that they kindly shared along with the system selections.

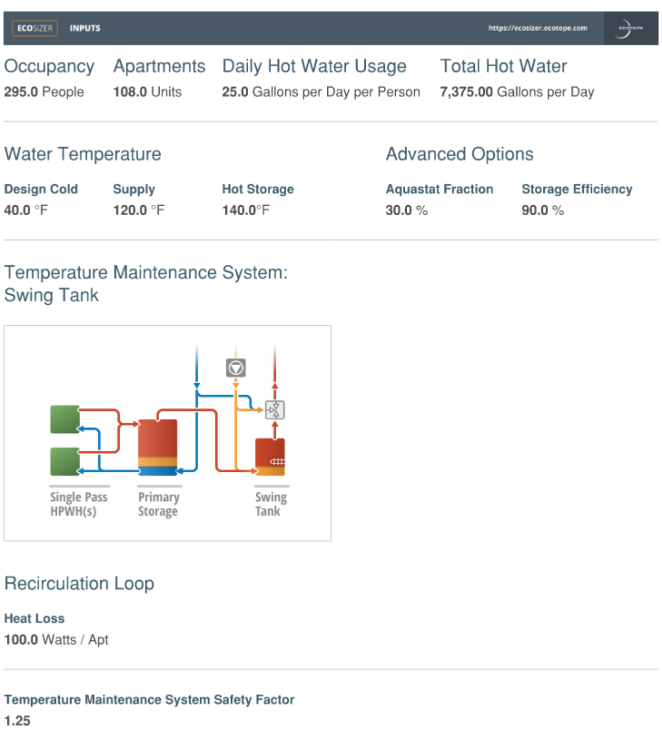


Image 5-7. Riada EcoSizer Inputs

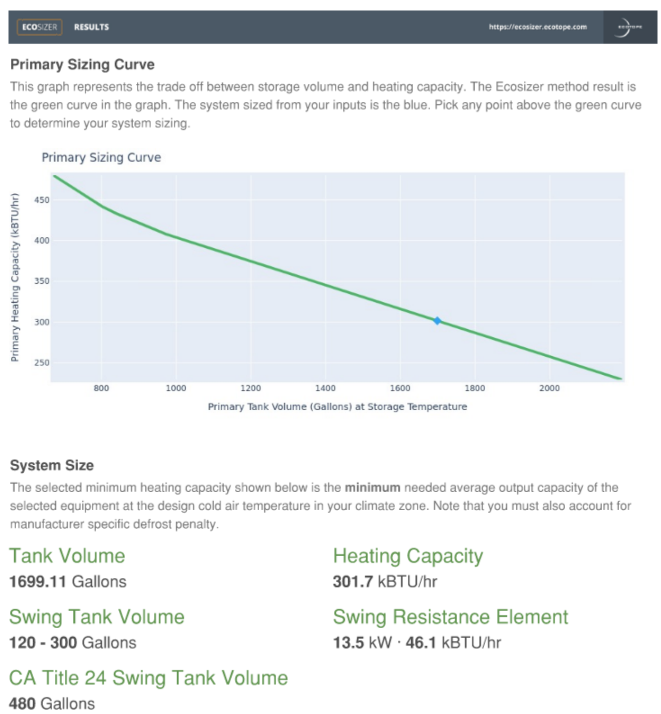


Image 5-6. Riada EcoSizer Results

Based on these outputs Riada have provided two plant arrangement options. The first consists of the following components:

1 x Lync Aegis A 500, CO_2 Heat Pump, 89kW @ -10°C outside ambient air
1 x Aegis Pump and Heat Exchanger Skid
3 x PVI L 600A-TR Thermal Store Vessels, 600 gallon (2270L) each, 1800 gallon (6810L) total
1 x PVI 830 L 600A-VE Electrically Heated Swing Tank, 600 gallon (2270L), 162kW Heat Element

The swing tank is typically used within CO_2 heat pump systems to provide heat input and storage to cover heat losses from the pipework distribution system throughout the building which are returned to the plant arrangement via the traditional domestic hot water recirculation pump. Handling the heat to supplement these losses in a separate tank avoids the recirculation return being fed back to the heat pumps, as this would result in the heat pumps handling the small ΔT of the flow/return circuit which would operate the heat pump inefficiently.

The EcoSizer tool suggests a small 13.5kW swing tank heat element, though Riada have used the swing tank as a full redundancy back-up for the CO_2 heat pump in this instance as they feel this provides good resilience in systems where only one heat pump is used. Hence the swing tank element being sized at 162kW.

Below is an image showing the Riada option 1 plant arrangement.

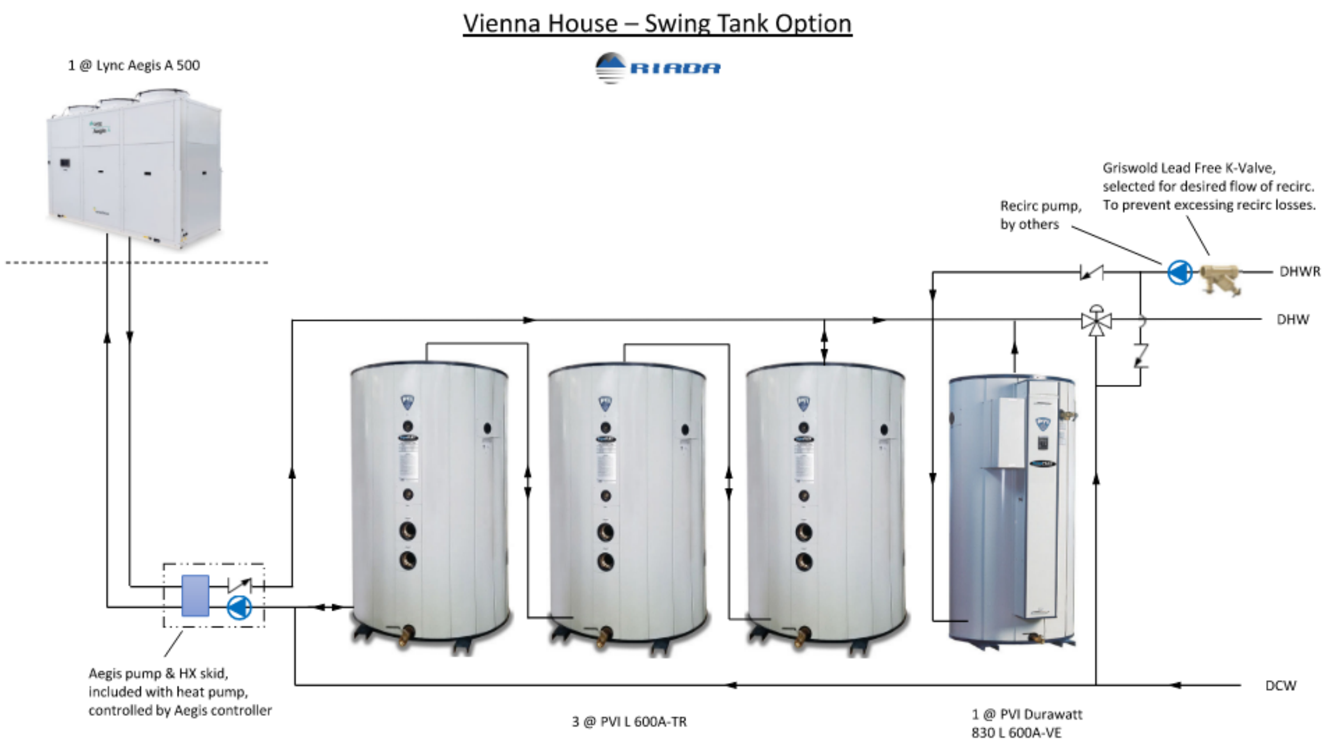


Image 5-8. Riada Plant Arrangement, Option 1

The second plant arrangement option consists of the following components:

1 x Lync Aegis A 500, CO_2 Heat Pump, 89kW @ -10°C outside ambient air
1 x Aegis Pump and Heat Exchanger Skid
3 x PVI L 600A-TR Thermal Store Vessels, 600 gallon (2270L) each, 1800 gallon (6810L) total
1 x Hubbell TXA In-Line Electric Heater, 108kW Heat Element

Instead of utilising a swing tank that is detached from the CO_2 heat pumps this second option uses an in-line electric heater that is piped to handle the hot water recirculation return losses directly. It can also supplement or replace the heat pump to heat the thermal store cascade assembly directly, which removes the need for the swing tank storage volume. This creates a lower cost and smaller space take arrangement which has obvious benefits.

Again, the in-line electric heater is sized at 108kW which is larger than the EcoSizer suggested 13.5kW swing tank heat requirement, but this is also selected to allow the electric in-line heater to replace the heat pump if it is out of use for servicing etc.

Below is an image showing the Riada option 2 plant arrangement.

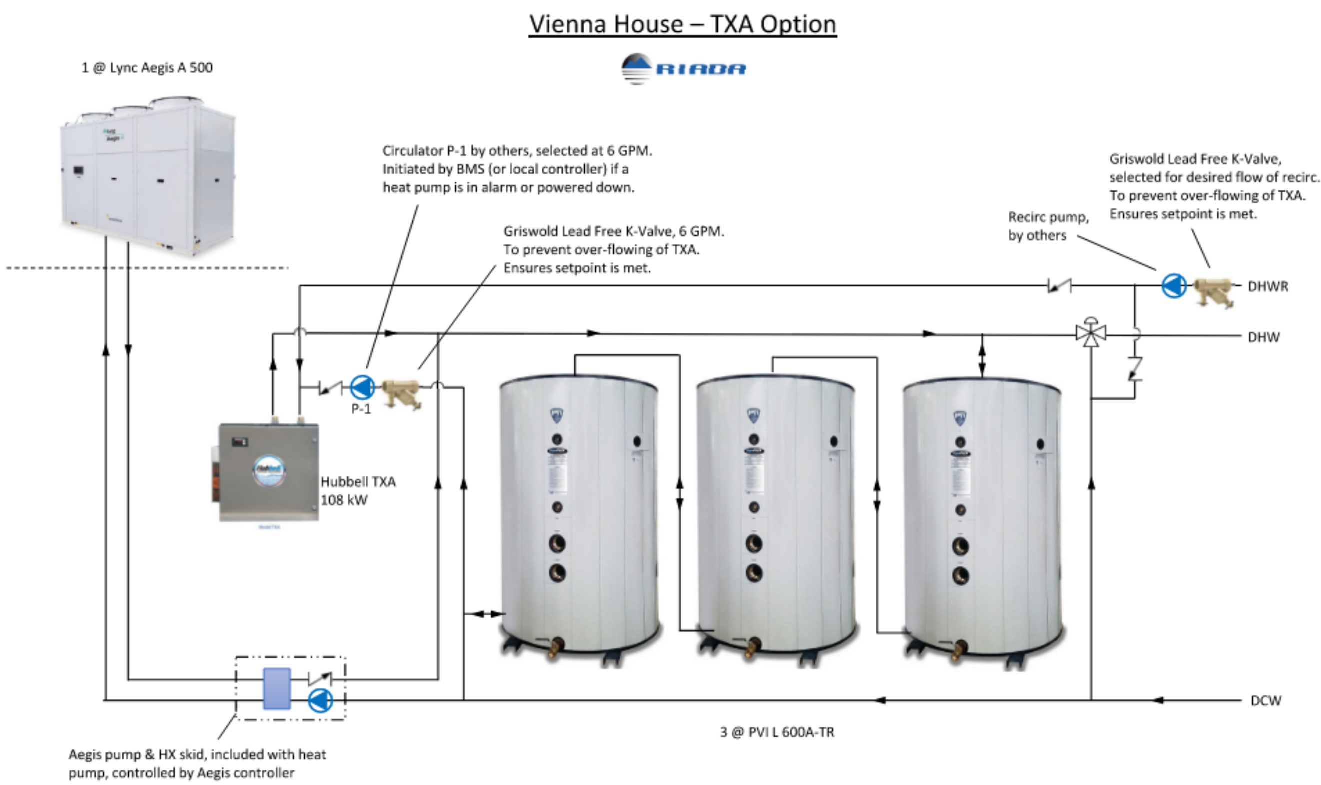


Image 5-9.Riada Plant Arrangement Option 2

For both plant options Riada have said that the single Lync Aegis A 500 could be replaced with 2 x Lync Aegis A 250 heat pumps to provide further resilience in case of break downs or scheduled servicing which could then allow for a slightly smaller electric back-up heat requirement.

5.2.2 Small Planet Supply, SANCO2

In providing the system sizing and selection for Vienna House Small Planet Supply have also used the EcoSizer online application, though they have performed two calculations varying the hot water usage volume per person per day, first calculating for 20 gallons and then for 25 gallons.

Below are extracts from the Small Planet Supply EcoSizer results that they have kindly shared along with the system selections.

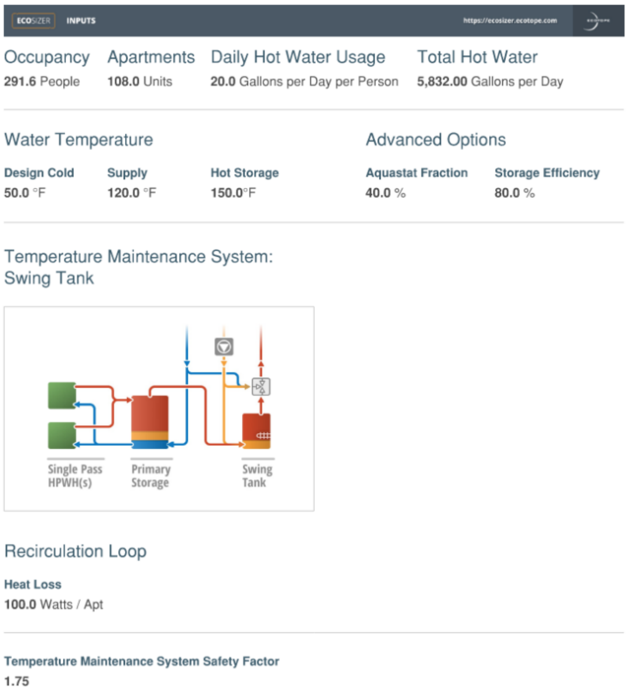


Image 5-10. Small Planet Supply EcoSizer Inputs, Option 1

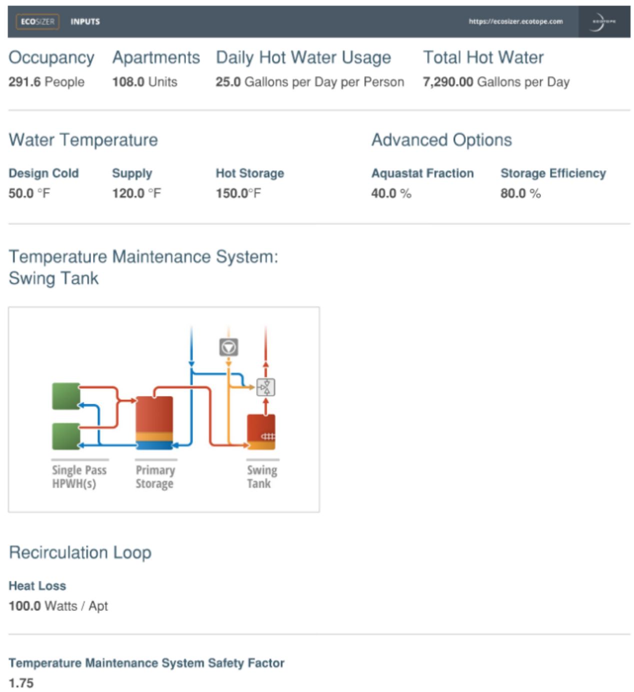


Image 5-11. Small Planet Supply EcoSizer Inputs, Option 2

Image 5-12. Small Planet Supply EcoSizer Results, Option 1

Image 5-13. Small Planet Supply EcoSizer Results, Option 2

Based on these outputs Small Planet Supply have provided two plant arrangement options consisting of the following components:

Option 1 (20 gallons per person per day)

17 x SANCO2 GS4-45HPC, CO_2 Heat Pump, 4.5kW each (76.5 kW total) @ -10°C outside ambient air
3 x Thermal Store Vessels, 455 gallon (1720L) each, 1365 gallon (5160L) total
1 x Electrically Heated Swing Tank, 200 gallon (760L), 30kW Heat Element

Option 2 (25 gallons per person per day)

21 x SANCO2 GS4-45HPC, CO_2 Heat Pump, 4.5kW each (94.5 kW total) @ -10°C outside ambient air
3 x Thermal Store Vessels, 505 gallon (1910L) each, 1515 gallon (5730L) total
1 x Electrically Heated Swing Tank, 200 gallon (760L), 30kW Heat Element

Small Planet Supply have also provided diagrams of the system arrangement as shown below, though the heat pump piping arrangement would need to be upscaled to suit the 17 or 21 unit assembly. Note that the SANCO2 unit can handle potable water directly and a heat exchanger is not included with the plant arrangement.

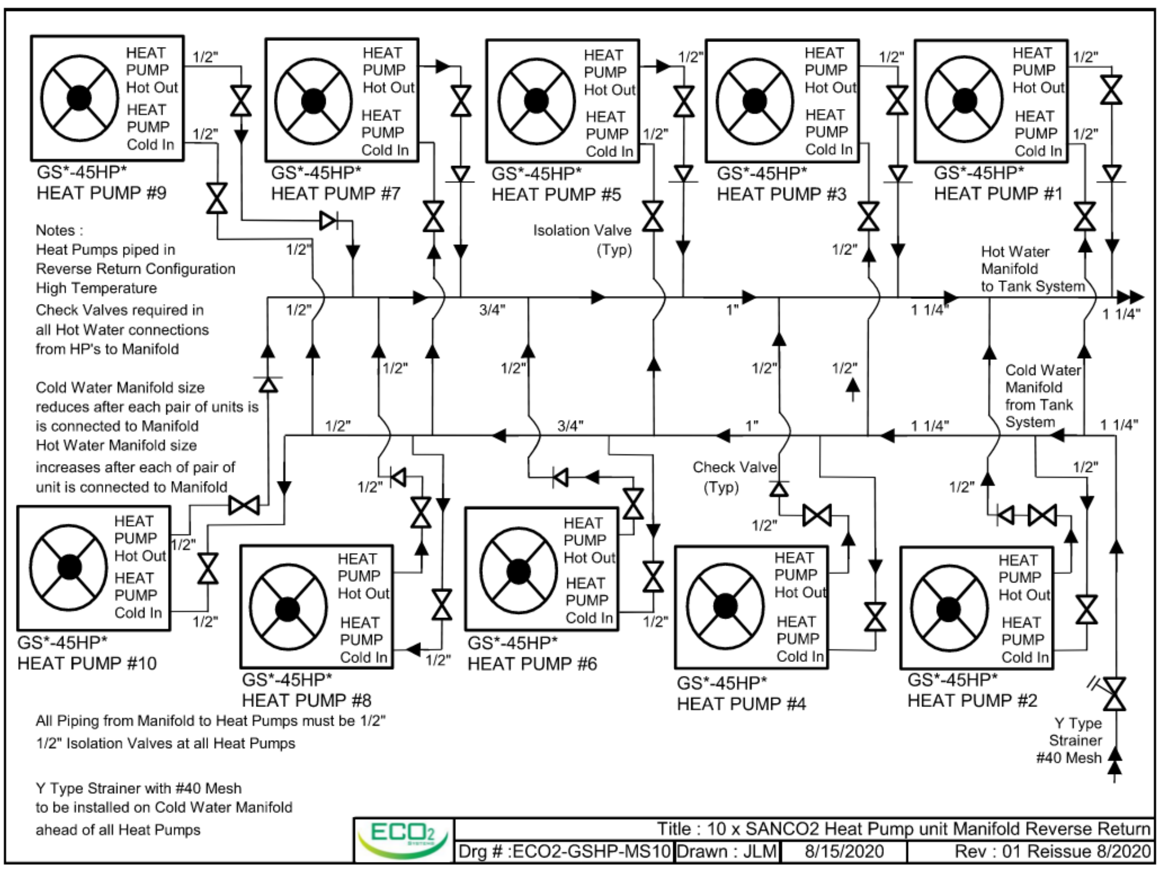


Image 5-14. Small Planet Supply Typical Heat Pump Arrangement

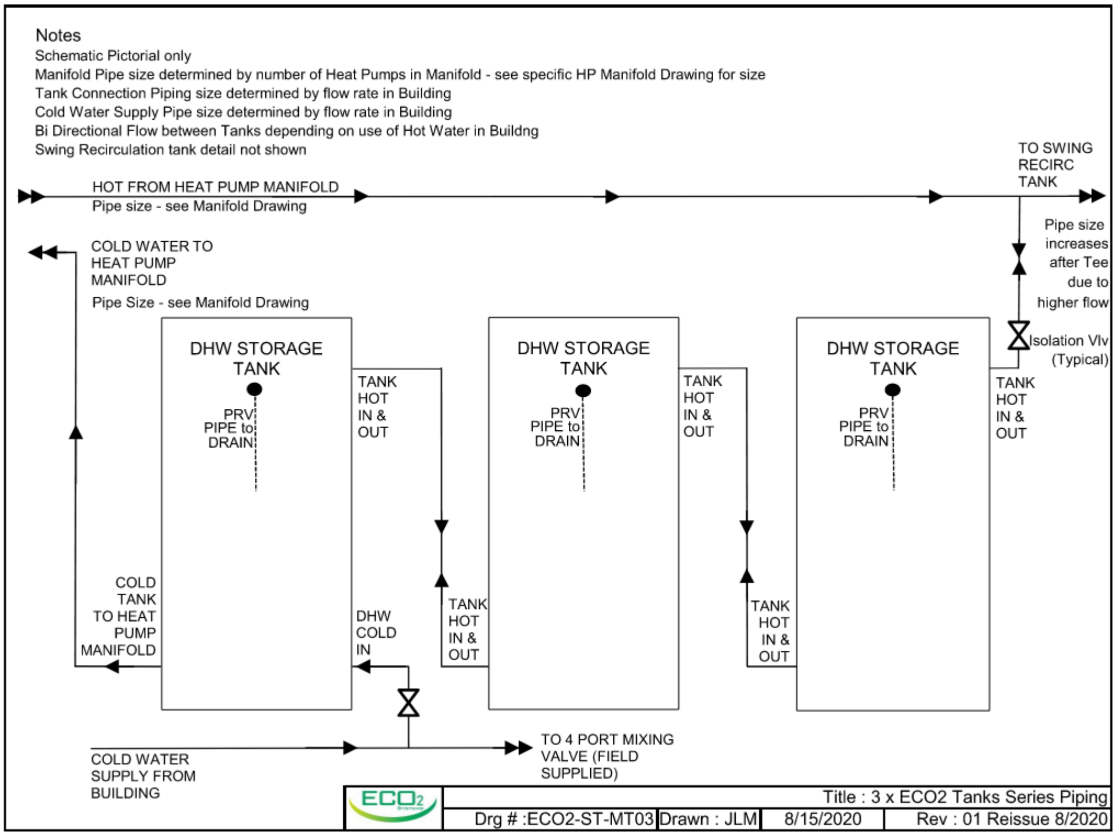


Image 5-15. Small Planet Supply Typical Storage Vessel Arrangement

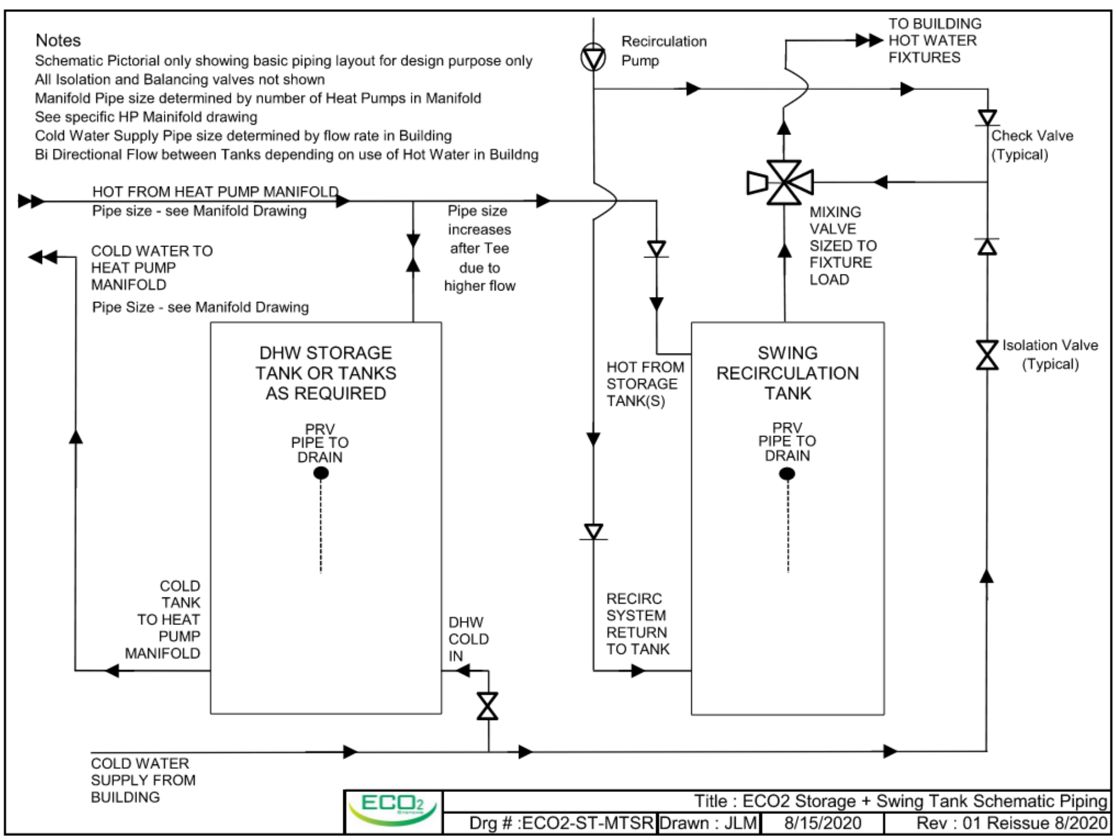


Image 5-16. Small Planet Supply Typical Swing Tank Arrangement

5.2.3 Mitsubishi, QAHV

Due to this product not yet being available to the US and Canada markets the sales and support team do not have access to supporting design information and were therefore unable to provide a full system selection for this study.

The product will become part of the Mitsubishi Diamond Designer program once launched which will include it within Mitsubishi's seminar sessions and support program allowing designers to receive Mitsubishi advice on system selections.

Mitsubishi could only provide generic hot water use per day figures for different building types based on European studies which are not directly relevant to this comparison. However, based upon the baseline calculations and the Mitsubishi piping advice we would suggest the below arrangement.

3 x Mitsubishi QAHV, CO_2 Heat Pump, ~31kW each (93 kW total) @ -10°C outside ambient air
3 x Pump and Heat Exchanger Assembly (1 per heat pump)
3 x Thermal Store Vessels, 600 gallon (2270L) each, 1800 gallon (6810L) total
1 x ~100kW In-Line Electric Water Heater

5.3 Sizing Comparison

The below table illustrates the various system overall sizing options for comparison purposes.

Option	Primary Heat (heat pump)	Primary Storage	Swing Tank Heat (recirc load)	Swing Tank Volume
Baseline	100kW	6500L (1720 gallon)	18kW	450L (120 gallon)
Riada/Lync: 01	89kW	6810L (1800 gallon)	162kW	2270L (600 gallon)
Riada/Lync: 02	89kW	6810L (1800 gallon)	108kW In-Line	-
SANCO2: 01	76.5kW	5160L (1365 gallon)	30kW	760L (200 gallon)
SANCO2: 02	94.5kW	5730L (1515 gallon)	30kW	760L (200 gallon)
Mitsubishi QAHV*	93kW	6810L (1800 gallon)	100kW	-

**Mitsubishi data is estimated based on heat pump unit capacity and baseline sizing*

6 Annual Energy & Carbon

To demonstrate the comparable annual performance in terms of energy, energy costs and carbon emissions, calculations using the City of Vancouver energy modeling guideline, CO_2 emission factors, CWEC weather data, BC Hydro electrical charges and Fortis BC gas charges have been produced.

6.1 Annual Performance Comparison

6.1.1 Baseline Energy

For an annual performance calculation the City of Vancouver Energy Modelling Guideline domestic hot water volume per person per average day figure of 11 gallons (41.64 liters) is used. Considering the 292 residential occupants at Vienna House the daily domestic hot water volume for energy use is 3212 gallons or 12159 liters.

To heat the daily volume from 10°C to 60°C we use the following equation.

$$Energy, Q = \frac{\text{Water Mass, m} * \text{Specific Heat Water, Cp} * \text{ Temp Rise, } \Delta\text{T}}{\text{1 hour}}$$

$$Q = \frac{12159\text{kg} * 4.18\text{kJ/kg} * (60°\text{C} - 10°\text{C})}{3600 \text{ sec}}$$

$$Q = 705.89\ kWh/\text{day}$$

Therefore, the seasonal energy needed to heat the domestic hot water considering four 91-day seasons is **64,263** kWh/season, and the annual energy needed is **256,944** kWh.

6.1.2 Equipment Efficiencies

To show a comparison to the CO_2 heat pump options a typical electric water heater and gas fired water heater have been assumed at 98% and 88% efficiency respectively, which represent realistic performance figures for those systems.

The COP of the various CO_2 heat pump options have been considered by taking average dry-bulb outside air temperatures between a 6am-11pm operating range from the CWEC 2016 weather file for each season, as illustrated below. Though we note that the COPs stated for each product are based on differing test water and ambient air temperatures, so are not accurately comparable.

Season		Winter	Spring	Summer	Fall
Average Dry-Bulb 6am-11pm operating range		5.86°C	13.17°C	18.09°C	7.1°C
Lync by WATTS	**COP**	3.61	4.13	4.49	3.70
SANCO2	**COP**	3.58	4.42	4.62	3.85
Mitsubishi QAHV	**COP**	2.08	2.40	2.53	2.25

6.1.3 Seasonal and Annual Energy Consumption

Considering the energy needed to heat the domestic hot water and the system efficiencies the following energy inputs are required for each system.

System	Winter kWh	Spring kWh	Summer kWh	Fall kWh	Annual kWh	Annual Contribution to TEUI, kWh/m²
Electric Resistance	65,547	65,547	65,547	65,547	262,188	33.9
Gas Fired	72,996	72,996	72,996	72,996	291,982	37.7
Lync by WATTS	17,793	15,544	14,296	17,375	65,008	8.4
SANCO2	17,943	14,533	13,904	16,685	63,065	8.2
Mitsubishi QAHV	30,943	26,735	25,344	28,594	111,616	14.4

For reference a step 4 low-rise residential building total energy use intensity (TEUI) is 100 kWh/m² and the Passive House primary energy renewable (PER) limit is 60 kWh/m², which is equivalent to an approximate TEUI of 45 kWh/m²

6.1.4 Energy Costs

The following electrical energy unit charges have been taken from the BC Hydro Residential Service rate considering that the equipment will be landlord owned and operated.

Basic Charge	$0.2218 per day
Energy Charge	$0.1127 per kWh

For the gas fired option the following natural gas unit charges have been taken from the Fortis BC Rate 2 tariff considering the usage will be less than 2000 GJ annually.

Basic Charge	$0.9616 per day
Delivery Charge	$3.8820 per GJ / $0.01398 per kWh
Storage and Transport Charge	$1.4200 per GJ / $0.00511 per kWh
Natural Gas Unit Charge	$2.8440 per GJ / $0.01024 per kWh

The BC Carbon Tax has also been applied at the following rate (note this tax is steadily increasing which will inflate the gas fired energy costs over time).

Natural Gas Carbon Tax	$0.0882 per m³ / $2.30 per GJ / $0.00829 per kWh

Using these rates the table below illustrates comparison energy costs for each option.

System	Winter	Spring	Summer	Fall	Annual	Annual $/m²
Electric Resistance	$7,407	$7,407	$7,407	$7,407	$29,629	$3.83/m²
Gas Fired	$2,833	$2,833	$2,833	$2,833	$11,333	$1.46/m²
Lync by WATTS	$2,025	$1,772	$1,631	$1,978	$7,407	$0.96/m²
SANCO2	$2,042	$1,658	$1,587	$1,901	$7,188	$0.93/m²
Mitsubishi QAHV	$3,507	$3,033	$2,876	$3,243	$12,660	$1.64/m²

6.1.5 Carbon Emissions

The following CO_2 emission factors are used to calculate the equivalent carbon emissions for each option.

Electricity 0.011 $kgCO_2e/kWh$
Natural Gas 0.185 $kgCO_2e/kWh$

With the results illustrated below.

System	Winter $kgCO_2e$	Spring $kgCO_2e$	Summer $kgCO_2e$	Fall $kgCO_2e$	Annual $kgCO_2e$	Annual Contribution to GHGI, $kgCO_2e/m^2$
Electric Resistance	721	721	721	721	2884	0.37
Gas Fired	13504	13504	13504	13504	54017	6.98
Lync by WATTS	196	171	157	191	715	0.09
SANCO2	197	160	153	184	694	0.09
Mitsubishi QAHV	340	294	279	315	1228	0.16

For reference the VBBL greenhouse gas intensity (GHGI) emissions whole building annual limit for low-rise residential buildings is 5 $kgCO_2e/m^2$, or 8511 $kgCO_2e$ for Vienna House.

6.1.6 Refrigerant Leakage Considerations

As one of the main benefits in using CO_2 heat pumps is the very low GWP when compared to more common modern heat pumps, the carbon emission equivalent caused by a refrigerant leak should be considered.

An equivalently sized ASHP to the Vienna House system options using a more traditional refrigerant is a Colmac CxA-25 sized at 94.5 kW. This unit uses the refrigerant R-134a in a single circuit with a charge of 19.25 lb (8.73 kg) and a GWP of ~1300.

Therefore, a single refrigerant leak from the circuit of this ASHP would result in equivalent carbon emissions of (8.73 x 1300) **11,349** $kgCO_2e$ or an annual GHGI emission of 1.47 $kgCO_2e/m^2$, which is approximately the same carbon emissions as 11 years operation of the average of the CO_2 heat pump options.

6.1.7 Energy Summary

The initial capital cost of the CO_2 heat pump options are indicated in section 8 of this report, and they are considered to be significantly higher than more traditional gas fired and electrical resistance options and marginally higher than similar multi-pass ASHPs using more environmentally harmful refrigerants.

However, the annual energy consumption and operating costs show an improvement over the traditional gas and electric options with the annual CO_2e emissions indicating a clear benefit, especially when considering potential refrigerant leaks from more common equivalently sized ASHPs. These longer-term benefits should be considered carefully when choosing appropriate domestic hot water systems.

7 Electrical Requirements

The various plant options and arrangements require differing electrical power requirements, so the variations have been investigated to demonstrate the space and electrical plant required to support each option.

7.1 Electrical Comparison

Option 1: 2 x Lync Aegis A (250) Arrangement

The Lync Aegis A unit requires a 480V 3phase electrical connection. As the building will be powered via a 600V 3ph service from BC Hydro, a 75kVA 600V : 480V step down autotransformer and 480V distribution panel will be required to provide power to the Lync Aegis A units. This autotransformer and distribution panel will require additional space within the main electrical room which needs to be considered when sizing the space.

Option 2: 3 x Mitsubishi QAHV Arrangement

The Mitsubishi QAHV unit required a 208V 3phase electrical connection. A 208V electrical distribution panel is already envisaged for the building to facilitate other mechanical loads so no additional electrical equipment will be required to provide power to the Mitsubishi QAHV units.

Option 3: 17 x SANCO2 GS4 Arrangement

The SANCO2 GS4 unit required a 208V 1phase electrical connection. A 208V electrical distribution panel is already envisaged for the building to facilitate other mechanical loads so no additional electrical equipment will be required to provide power to the SANCO2 GS4 units. It should be noted that as there are 17 units, a larger electrical distribution panel may be required to facilitate the quantity of circuits required to power the equipment, but additional floor space is not expected for this at present.

Summary

Table 1 below compares a traditional gas fired water heating arrangement (Baseline), compared to modern CO_2 heat pump water heaters (Options 1, 2 & 3). The electrical load requirements for mechanical options 1-3 are larger than the baseline load as illustrated in the table below. At this time it is not expected that any of the mechanical options will require an above the normal electrical service from BC Hydro with only Option 1 requiring additional electrical equipment to facilitate the 480V electrical connection requirement.

It should be noted that this analysis is project specific and should not be used as an assumption for other projects. An example of this is primarily for the increase in power requirement; as this project requires a customer owned substation, the increase in electrical demand is less impactful than if there was a BC Hydro PMT where the increase in electrical load may require a customer owned substation as opposed to a BC Hydro PMT.

	Baseline	Option 1	Option 2	Option 3
	3 x Gas Fired Water Heaters	**2 x Lync Aegis A (250) Arrangement**	**3 x Mitsubishi QAHV Arrangement**	**17 x SANCO2 GS4 Arrangement**
Amps	-	37.81	32.2	7.2
Volts	-	480	208	208
Phase	-	3	3	1
kW/unit	0.2	31.4	11.6	1.5
Total kW	0.6	62.9	34.8	25.5

Table 1 – Electrical Load Comparison

Note: The total power listed is based on the manufacturer stated currents used for breaker and cable sizing, and does not represent normal operating conditions and power consumption.

8 Budget Cost

The suppliers were also asked to provide budget costs for the system selections made to allow an initial high-level comparison.

8.1 Cost Comparison

The below tables illustrate the various system arrangement budget costs received from each supplier.

Small Planet Supply, SANCO2: The budget cost information provided is for the 20 gallon/person/day, 17 no. heat pump option 01

Item	Qty	Unit Price	Total Price (includes 8% discount, does not include BC PST or GST)
SANCO2 G4 CO_2 Heat Pump c/w Thermistor Cable	17	$4,014	$62,779
455 Gallon Storage Tank Carbon Steel Enamel Lined	3	$15828	$43,684
200 Gallon 30kW EWH Swing Tank	1	$15,856	$14,587
Tank Sensor Replacement for Controlled Systems	17	$42	$658
Multi System Control - Basic	1	$3,514	$3,233
Commissioning and Start-up Service	1	$1,650	$1,650
		Subtotal	**$126,591**
		Total (including BC PST 7%, GST 5%)	**$141,782**

This cost does not include piping of the heat pump array which is more excessive than the competitors arrangements with fewer heat pump units.

Mitsubishi QAHV: As this product was only launched in late July 2021 in Canada Mitsubishi were only able to provide a budget cost for the heat pump alone. Mitsubishi are planning to offer a packaged plant arrangement in future, but they do not currently have a preferred line of buffer tanks to offer along side the CO_2 heat pumps.

Item	Qty	Unit Price
Mitsubishi QAHV CO_2 Heat Pump	1	$71,555

The unit price provided is a list price and does not include PST, GST or contractor discounts.

For the proposed plant arrangement 3 no. heat pumps are suggested, therefore the heat pump only cost of that plant assembly is (3 x $71,555) **$214,665,** plus storage tank, electrical back-up and ancillaries.

Riada, Lync by WATTS: The budget cost information provided is for both plant options 01 & 02 and the price of the other smaller heat pump units have also been provided for comparison purposes.

Option 01

Item	Qty	Unit Price	Total Price (does not include BC PST or GST)
Lync Aegis A 500 CO_2 Heat Pump inc. HX skid	1	$254,000	$254,000
600 Gallon Storage Tank Unlined Duplex Alloy	3	$34,000	$102,000
600 Gallon 162kW EWH Swing Tank	1	$65,000	$65,000
		Total	**$421,000**

Option 02

Item	Qty	Unit Price	Total Price (does not include BC PST or GST)
Lync Aegis A 500 CO_2 Heat Pump inc. HX skid	1	$254,000	$254,000
600 Gallon Storage Tank Unlined Duplex Alloy	3	$34,000	$102,000
In-Line EWH 108kW	1	$16,000	$16,000
		Total	**$372,000**

Lync Aegis A Range

Item	Qty	Unit Price
Lync Aegis A 500 CO_2 Heat Pump inc. HX skid	1	$254,000
Lync Aegis A 350 CO_2 Heat Pump inc. HX skid	1	$181,000
Lync Aegis A 250 CO_2 Heat Pump inc. HX skid	1	$147,000

Summary: The Lync by WATTS system option costs are significantly higher than both the SANCO2 and Mitsubishi QAHV system options. The Lync by WATTS heat pumps do however take less space and have the option to provide simultaneous cooling, though these features are unlikely to offset the price difference in many projects unless plant space is extremely valuable in certain instances.

For system costing in-line with industry standard metrics and area rates, and to provide cost estimates of related elements, such as plant screening, power requirements, system piping, insulation, labour rates etc the proposed system designs are to be reviewed by a cost consultant as described within the report scope of works.

9 Plant Arrangement

Space requirements and suitable locations have been reviewed to integrate the CO_2 heat pump systems into the Vienna House building design.

9.1 Indoor Plant

The indoor plant space allocation has been made at the lower ground level neighbouring the buildings parkade, as shown in the image below. Certain elements are not required for all arrangements as previously described. The heat exchanger arrangement is not required for the SANCO2 heat pumps and the swing tank can be replaced by a smaller wall hung in-line electric water heater as described in the Lync by WATTS option 02 arrangement previously. The plant space indicated allows a reasonable allowance for all three CO_2 heat pump options to be installed within Vienna House with adequate room for future servicing and maintenance.

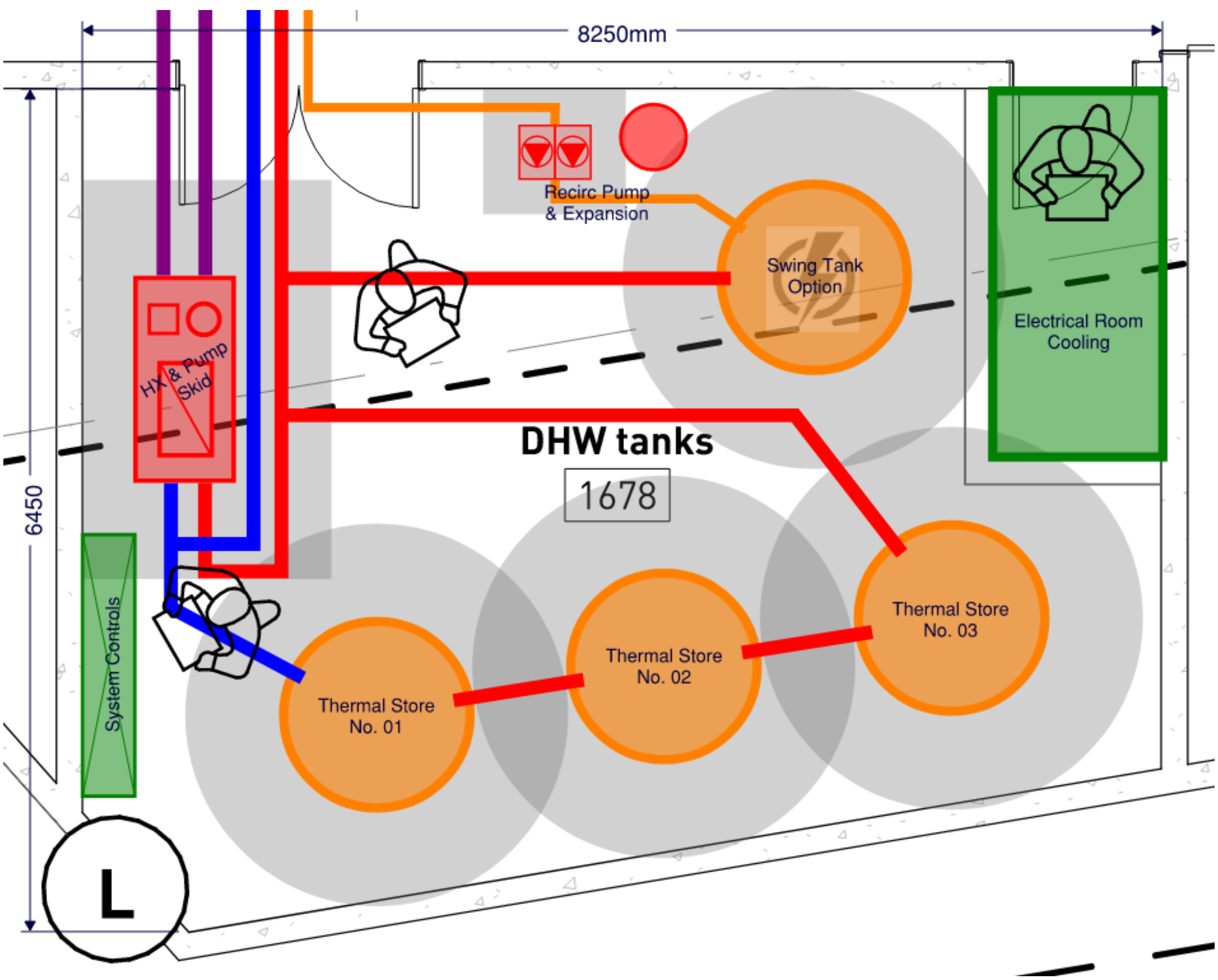


Image 9-1. Vienna House Indoor DHW Plant Arrangement

9.2 Outdoor Plant

The CO_2 heat pumps used in these systems absorb heat from the outside air and are therefore required to be located where they can receive an easy flow of outside ambient air and be able to discharge the cooled air they produce without creating problems of 'short circuiting' that cooled air back into their intake which would result in a loss of performance and efficiency.

Following a review with the architect the best initial space allocation for the outdoor units was the building roof, as no amenity space is currently planned to neighbour the roof plant allocation. In all three options initial anticipated acoustic/architectural screening has been indicated, though this is to be reviewed in more detail as the building design progresses.

The Mitsubishi and Lync by WATTS system options utilize a primary hydronic circuit to transfer heat from the outdoor units to the thermal store vessels via heat exchangers. This circuit is required to be protected from freezing when the system is not operational or during a power outage either by using trace heating on the pipework outside of the buildings thermal line to maintain a minimum 4°C or with a glycol solution in the circuit.

The SANCO2 system flows the domestic hot water directly through the heat pumps so it is not possible to use glycol and because of the extent of manifold pipework to connect the multiple heat pump array trace heating would be expensive. During normal operation the heat pumps can circulate the hot water produced to prevent freezing, but this is not possible during a power outage. Therefore, the SANCO2 system would require a solenoid-valve controlled drain down system with anti-vacuum valves to remove the water from the outdoor circuit in case of a power loss during a cold weather period to protect against freezing and burst pipework.

Riada, Lync by WATTS: To provide resilience to the system and to allow the possibility for the in-line electric heater size to be reduced the 2 x Aegis A 250 CO_2 heat pump arrangement has been used to illustrate the outdoor space required.

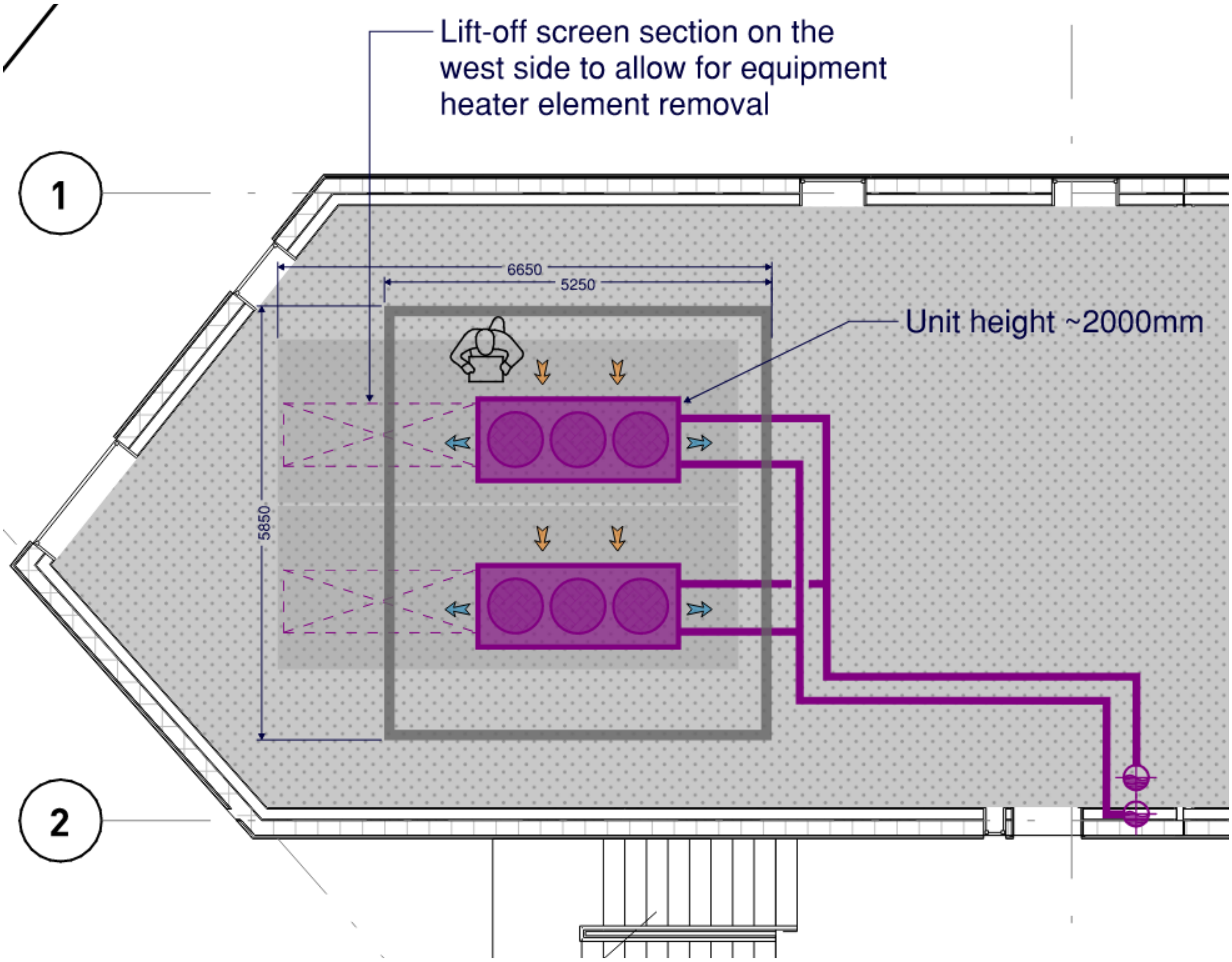


Image 9-2. Vienna House Outdoor CO_2 Heat Pump, Lync Aegis A 250

Mitsubishi, QAHV: To meet the baseline domestic hot water calculation requirement the 3 x QAHV CO_2 heat pump arrangement has been used to illustrate the outdoor space required.

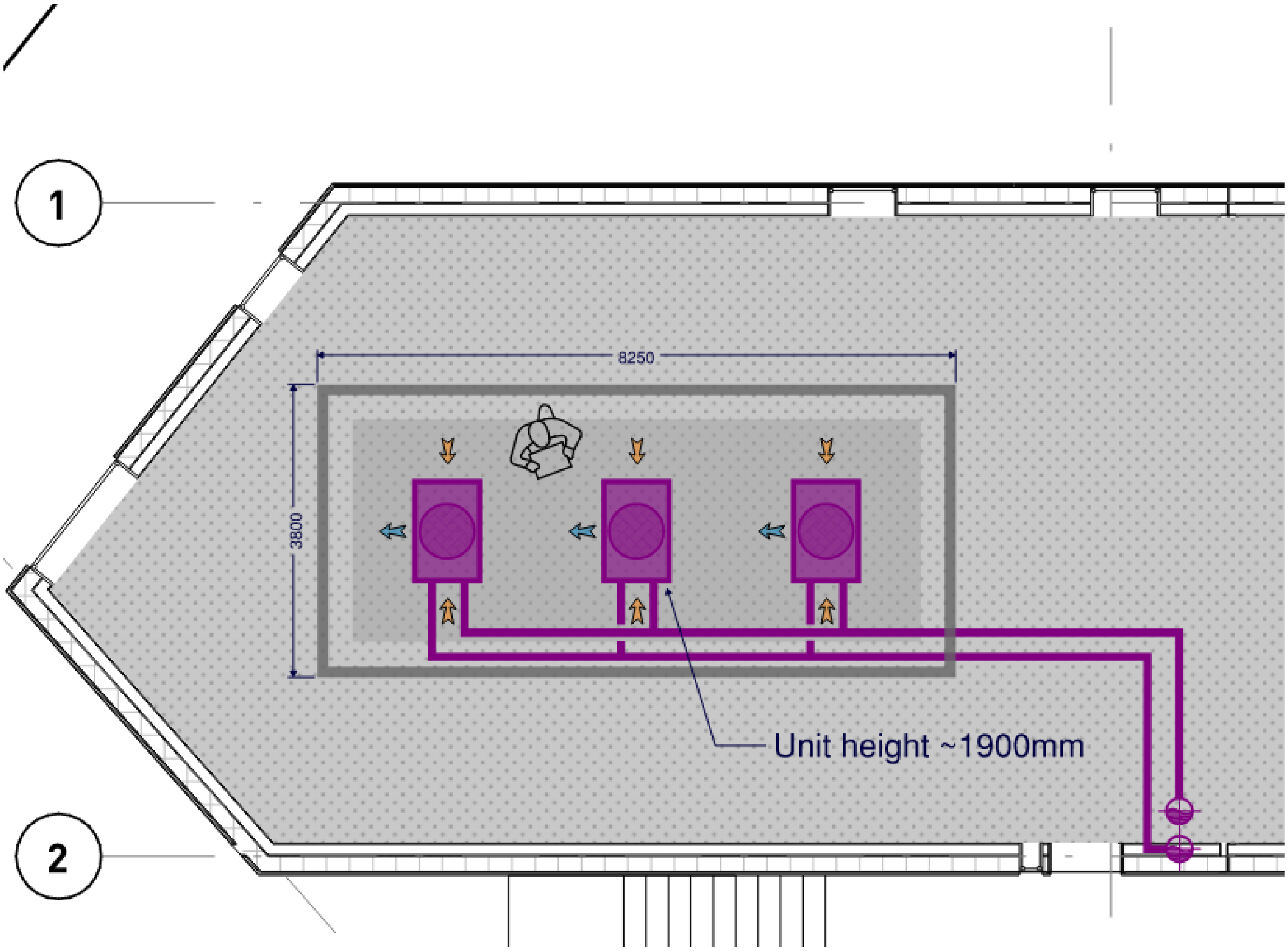


Image 9-3. Vienna House Outdoor CO_2 Heat Pump, Mitsubishi QAHV

Small Planet Supply, SANCO2: Due to the SANCO2 heat pump units being smaller in power output and physical size they are typically double stacked to minimise the overall footprint of the array. The 17 x QAHV CO_2 heat pump arrangement has been used to illustrate the outdoor space required.

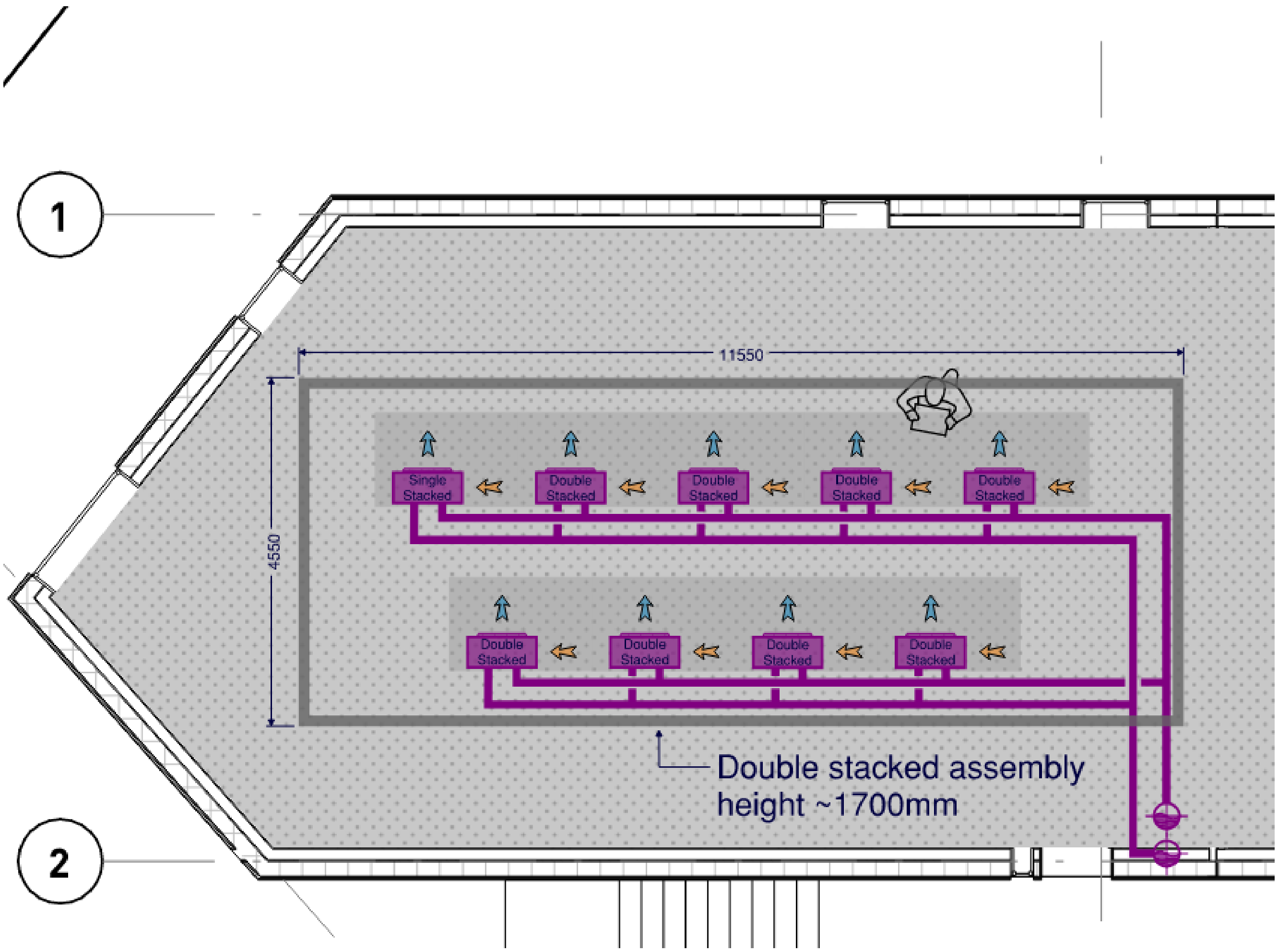


Image 9-4. Vienna House Outdoor CO_2 Heat Pump, SANCO2

10 Supplementary Technology

As residential building fabric performance improves, especially when working to Passive House standards, and as electrical system loads reduce when using LED lighting etc the overall heating and cooling loads become smaller and the domestic hot water load emerges as a more significant proportion of the overall energy usage. Therefore, increasing the efficiency of domestic hot water production with technology such as the CO_2 heat pumps currently under review is an obvious and vital step to improving building energy usage further. However, methods to reduce the domestic hot water volume usage in buildings can also help to provide energy savings and reduce the size of the water heating equipment needed which helps with space saving and minimizing costs of often expensive modern technology.

10.1 Drain Water Heat Recovery

As an example, a showers domestic hot water usage with an overall flow rate of ~7.6L/min (2.0 gpm) is dependant on the temperature of the cold water supplied to the system, the temperature of the hot water in the system (typically 60°C) and the desired temperature that the user likes to shower with, as the cold and hot water are mixed at a suitable proportion to achieve the desired outlet temperature. If the temperature of the cold water is raised then less hot water is needed to achieve the same outlet temperature. Obviously, the cold water needs to be kept low throughout the system to be suitable for drinking and other uses and to prevent bacterial growth, but if the cold water temperature can be raised local to the shower delivery then the hot water volume required can be reduced.

This saving can be achieved using shower drain waste heat recovery technology such as the PowerPipe product by RenewABILITY Energy inc. Products of this type use a wound copper heat exchanging pipework system to extract heat from the shower drain water to elevate the temperature of the cold water flowing through the outer pipe. That cold water can typically be lifted from ~10°C to ~25°C using these products which in turn reduces the required hot water flow to the shower mixing valve which reduces the overall hot water usage per peak period and potentially allows the plant to be smaller and use less energy to meet the daily demand.

Below is a link to a PowerPipe video explaining and demonstrating the product.

https://youtu.be/cvweRHEvBOo

The introduction of shower waste heat recovery does require well planned coordination of the plumbing system pipework to ensure there is a suitable vertical space to fit the drainage pipe and wound heat exchanger on the floor below each shower tray. And the cold water supply to each shower then needs to drop down to run through the heat exchanger on the floor below before rising back up to serve the shower mixer.

Alternatively, a single larger drain water heat recovery unit can be used at the base of the drainage stack on the bottom floor with the cold feed to multiple showers above running through it.

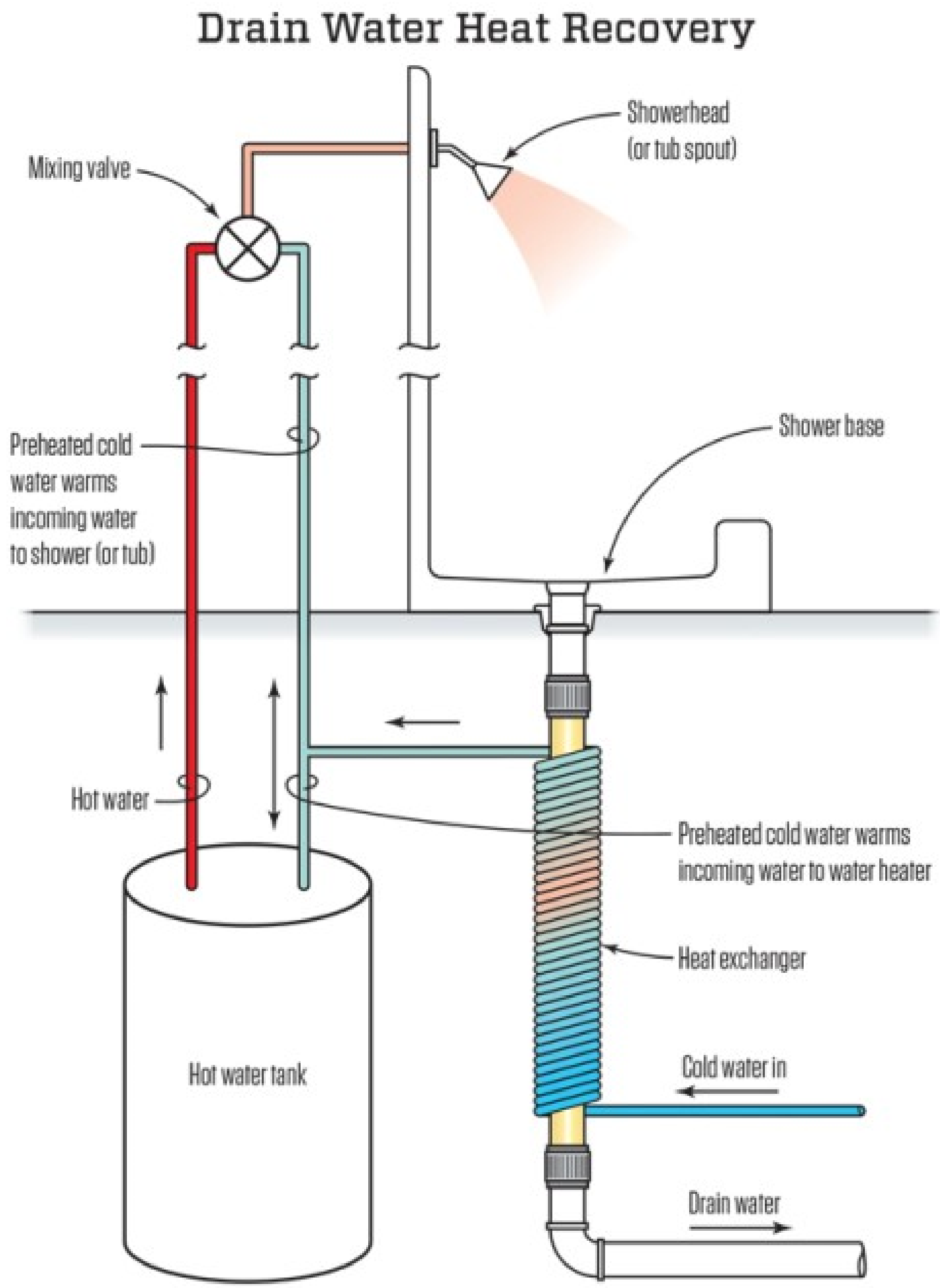


Image 10-1. Shower Water Heat Recovery Diagram, source (https://www.jlconline.com/how-to/plumbing/wastewater-heat-recovery-systems_o)

The use of this technology would obviously carry some additional cost with a slightly more complex design coordination and construction process, but this could be offset by the potential to reduce the domestic hot water plant size and the overall hot water energy consumption.

By using the same baseline domestic hot water calculation method but adjusting the hot water component of the mixed shower use when considering the 'cold' water to the mixer will be 25°C instead of 10°C, the overall daily hot water usage is reduced by ~12%. The domestic hot water plant arrangement can then be adjusted to allow for this difference. As the domestic water storage vessels are the lower cost components of the plant assembly the baseline 6500L (1720 gallon) is left unchanged, but the heat input required from the heat pumps can be reduced from 100kW to 80kW and still achieve suitable temperatures within the storage volume.

For the product options under review this would mean the following;

Lync by WATTS: As the plant assembly is made up of either a single Aegis A 500 unit or two Aegis A 250 units, a 20% reduction in heat requirement would not result in the ability to use less heat pumps. Moving to a single Aegis A 350 (rated at ~65kW at -10°C outside ambient) in lieu of the Aegis A 500 could only be achieved by simultaneously increasing the storage volume and/or the supplemental electric heating to compensate.

SANCO2: As the SANCO2 plant assembly is made up of multiple smaller 4.5kW heat pumps this plant arrangement offers the most flexibility to take advantage of load reductions. This reduction would allow ~4 less heat pumps to be used when maintaining the same storage volume and electrical backup, which would mean using 13 heat pumps in lieu of the recommended 17 unit array.

Mitsubishi QAHV: As the QAHV heat pump is sized at ~31kW at -10°C outside ambient temperatures, moving from 3 to 2 units would result in an undersized heat input and therefore could only be achieved by simultaneously increasing the storage volume and/or the supplemental electric heating to compensate.

With that in mind we would suggest that this type of drainage heat recovery technology at least be considered alongside domestic hot water heat pumps. If this option were to be pursued additional information would be required from the chosen drain heat recovery supplier to ensure an accurate estimate of achievable heat gain is used for domestic hot water calculations, and this information would then need to be passed back to the heat pump suppliers for accurate re-selections to take place.

11 Summary

For residential buildings in particular, domestic hot water loads are emerging as a clear target for improved efficiency as the heating, cooling, electrical etc. loads are reducing due to improved building fabric design and construction methods and improving technology in those systems.

CO_2 Heat pumps offer a very good solution to achieve that improved efficiency for domestic hot water heating while using a lower impact refrigerant, which creates a refrigeration cycle that is ideally suited to heating cold mains water to typical domestic hot water storage temperatures and maintaining efficiencies up to 500% during ideal conditions and consistently above 100% even during cold Vancouver winter weather.

The three products under review for this study all offer solutions to achieve efficient hot water production for residential developments similar to Vienna House.

The SANCO2 product is a smaller unit originally designed for single family homes, but it can be used for larger applications by upscaling to larger multi-unit arrays. Though it perhaps becomes less suitable as the building load gets larger due to the larger space take, more intricate piping requirements with higher opportunity for fitting failures and more complicated control sequencing to manage around 20 or more single units. The supplier sizing of this system came back as the smallest, though we are aware of a previous project where additional electric water heating was required after the original heat pump array was not quite meeting the peak requirement. Therefore, it may be advisable to increase the suggested selection slightly to be closer to the baseline calculation and sizing of the competitors, perhaps by increasing the storage volume and with additional electrical heating, this may also allow a reduction in the CO_2 heat pump number needed.

The Lync by WATTS Aegis A products are larger commercial sized units, meaning fewer larger units can be used for medium to large scale residential applications. This helps to minimize the required outdoor unit space take and allows more concentrated acoustic treatment. These units do however appear to carry a cost premium which clearly needs to be considered, and if only a single unit is used it may become a single point of failure for the system which needs additional electric heating back-up. The ability for the product to provide simultaneous cooling gives potential benefits over the competitors and could be used to offset specific cooling equipment and/or energy requirements with careful application considering cooling and hot water production profile matching and/or cooling thermal stores.

The Mitsubishi QAHV products size sits in-between the other two products under review, which sizes it more favourably for medium to large scale residential applications. Meaning it would be common to use 3-4 units in an array which can be more efficient for space take, compact enough for reasonable acoustic treatment but still have resilience if one unit was down for servicing. The product performance in terms of efficiency appears lower than the comparable products, though it is unclear if this may be caused by inconsistent testing and reporting methods as described previously in this report. Unfortunately, as the product has only been launched in Canada very close to the submission of this report we have limited information of the suppliers suggested sizing and plant arrangement, and only product costing for the heat pump unit itself, though additional information will hopefully be available in the not to distant future.

12 Recommendation

Considering the information gathered and reviewed the Small Planet Supply SANCO2 option appears the most favourable for this project application.

In terms of cost the overall package is the lowest even considering some additional allowance for the heat pump array piping. In terms of simple payback and assuming the thermal store vessels, supplemental electric heating and ancillaries are approximately equal in all options the payback for the heat pump unit packages alone would be as follows.

Baseline traditional electric resistance annual operating cost	$29,629
SANCO2 annual operating cost	$7,188
Annual operating cost saving	$22,441
17 x SANCO2 Heat Pump arrangement	$62,779
Payback period (not offsetting traditional water heater costs)	2.8 years
Lync by WATTS annual operating cost	$7,407
Annual operating cost saving	$22,222
1 x Lync Aegis A 500 Heat Pump arrangement	$254,000
Payback period (not offsetting traditional water heater costs)	11.4 years
Mitsubishi annual operating cost	$12,660
Annual operating cost saving	$16,969
3 x Mitsubishi QAHV Heat Pump arrangement	$214,665
Payback period (not offsetting traditional water heater costs)	12.7 years

*The simple payback periods stated consider only the heat pump equipment costs, and not the additional elements of the domestic hot water system.

In addition to cost and payback some other benefits of the SANCO2 system include.

- Multiple units in the array offers resilience if one or a small number are down for maintenance
- The acoustics and vibrations from the smaller units would be simpler to mitigate
- The system has a BC track record of installed packages on similar slightly smaller multi-unit residential developments
- There are no special electrical requirements as the units run on 208/230v single phase supply which do not require transformers and allows the wiring to be low cost
- As the single units are designed for single family homes, they offer simple maintenance, though obviously require a different skill set and experience level when compared to maintaining more traditional gas fired and electric resistance water heaters.

Some disadvantages that need to be considered are the requirement for drain-down freeze protection as the heat pump units handle the domestic water directly. Also, though the system offers simple maintenance and resilience with multiple smaller heat pumps it is effectively an upscaled single family residence system that wasn't specifically designed for larger applications, though example installations are demonstrating adequate performance.

We would however recommend an alternate system arrangement using a lower number of heat pumps with a higher storage volume (approx. 600 gallon vessels instead of 455 gallon) with a higher electrical backup of approx. 100kW instead of the suggested 30kW to offer higher resilience. The supplier is developing an option to provide the heat pumps in pre-piped skid mounted racks containing 6 heat pumps each, so utilizing two of these rack arrangements would potentially satisfy the requirement when used in conjunction with drain water heat recovery, and by increasing the storage and electrical back-up.

INTEGRAL