Greenhouse Gas Emissions of Refrigerants in Residential Heat Pump Based Mechanical Systems

SUMMARY REPORT

September 21st, 2021

INTEGRAL

Issue	Description	Date (MM.DD.YY)	Prepared By	Signed Off
Draft 1	Initial draft for COV review	07/05/2021	VM	VM
Final Report	-	07/30/2021	VM	VM
Final Report	Reissued with added content	09/21/2021 (dated) 11/26/2021 (issued)	VM	VM / JC

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1 Study Summary

1.1 Introduction

This report summarizes the methodology, key input assumptions, and results of a comparative analysis conducted to review the Greenhouse Gas Emission Intensity (GHGI) of refrigerants (GHGI-R) used in a selection of typical heat pumps systems used in multi-units residential buildings (MURBS) in Lower Mainland climate. The results of this analysis are intended to inform the City of Vancouver's policy development to include impact of refrigerants used in heat pump based mechanical systems on buildings' overall GHG emissions.

1.2 Objectives

The objectives of this study were to:

- Develop one low-rise and one high-rise residential archetype building and conduct an equipment inventory of selected vapour compression cycle-based heat pump types that would be typically installed in similar buildings.
- Assign equipment sizing to the archetype buildings to calculate the GHGI-R for a range of selected heat pump system options.
- Calculate and compare GHGI-R between the selected heat pump system types with sensitivity analysis on key input assumptions for leakage rates, system life, sizing, and Global Warming Potential (GWP) of refrigerants.
- Conduct GHGI-R calculations using the formula and reference information in the City of Vancouver Green Buildings Policy for Rezoning – Process and Requirements (GBP) Section 6.1 and conduct sensitivity analysis on key inputs with reference to the CIBSE Technical Memoranda 65.

1.3 Scope

This study reviews the GHGI-R of selected heat pump systems and building archetypes during their useful service life use and deconstruction stages only. In the framework of a complete Life Cycle Assessment of the refrigerant, this represents the GWP of modules B1 and C1 of the calculation method in standard EN 15804/15978. The analysis does not include production stages A1-A3, end of life stages C2-C4, and recovery stage D. As discussed in CIBSE TM65 section 2.4, use stage B1 presents the majority of refrigerant impact even with proper management and recovery upon end of system life.

1.4 Study Methodology and Assumptions

The study was conducted in the following steps.

1. Each building archetype was reviewed under two scenarios, compliance with the BC Energy Step Code Step 3 and Step 4. The step code performance limits are placed on annual energy use, whereby the GHGI-R of the mechanical system is a function of the equipment size which is determined by the peak load conditions. Measures that reduce building annual energy use by a relatively small margin do not always affect the thermal load under peak conditions. However, for the purpose of this study (based on our other Passive House project energy models) the Step 4 archetypes, which are essentially same

as Passive House, are assumed to have a higher cooling load and lower heating load that the Step 3 archetypes. In all scenarios considered, all heat pump systems are sized to the greater of the building heating or cooling load.

- Archetype Low Rise is 6 storeys, 47 suites, and 4,700 m^2
  - Step 3 equipment sized to peak heating load of 36 W/m^2
  - Step 4 equipment sized to peak cooling load of 25 W/m^2

- Archetype High Rise is 26 storeys, 250 suites, and
  - 21,250 m^2 for Step Code 3 with equipment sized to peak heating load of 48 W/m^2 and
  - 18,000 m^2 for Step Code 4 with equipment sized to peak cooling load of 27 W/m^2. The area difference was included on the basis that future construction will be have higher occupant density in this building sector

2. Heat Pump equipment requirements were estimated for the archetype buildings with the following system types:
   - Central Air Source Heat Pump (ASHP) – R410a, 2 pipe or 4 pipe by archetype
   - Central Water Source Heat Pump (WSHP) – R410a
   - Central WSHP - R513a
   - VRF – R410a, 2 pipe or 3 pipe by archetype
   - VRF Hybrid – R410a, refrigerant to water heat exchange, 75% of distribution pipework is hydronic and 25% refrigerant
   - Packaged Water Source Heat Pumps – R410a
   - DHW HP - R410a
   - DHW HP - CO_2
3. Shop drawings from existing projects and sample equipment technical data were used to calculate the refrigerant charge for each equipment type.

4. GHGI-R was calculated for each archetype and heat pump system combination following the formula in the GBP, Section 6.1, adapted for variable leakage rates, as shown below.

$$GHGI\text{-}R = \frac{kgCO_{2e}}{m^2 a} = \frac{GWP_r \times R_c \times (LR_a \times L + LR_{eol})}{L \times A}$$

Where:

a	SI symbol for year
GWP_r	Global Warming Potential of the refrigerant, in $kgCO_{2e}/kg_r$
R_c	Total refrigerant charge in the system, in kg_r
L	Life of the system, in years
A	Modelled Floor Area, in m^2
LRa	Annual Leakage Rate
LReol	End of system life leakage rate

System equipment life, annual and end of life leakage rates, GWP of refrigerant, and equipment sizing were input in the following scenarios. Unless otherwise noted, leakage rates and GWP of refrigerants are as follows:

LRa = 2%, LReol = 10%

GWP100yr = 410a 1,890 kgCO2e/kg, 513a 573 kgCO2e/kg, CO_2 1 $kgCO_2e/kg$

- As per the GBP Section 6.1, results in Section 2.1.

  LRa = 2%, LReol = 10%

  GWP100yr = 410a 1,890 kgCO2e/kg, 513a 573 kgCO2e/kg, CO_2 1 $kgCO_2e/kg$

- Leakage rates as per CIBSE Technical Memoranda 65 Table 4.4 recommended values per equipment type, as shown below , results in Section 2.2.

TM65 Product	Archetype Assumptions	TM65 Annual leakage rate	TM65 End of life recovery rate
Type 1: Packaged heat pump or chiller, where no refrigerant is managed on site	Packaged heat pumps, DHW HPs	2%	99%
Type 2: Heat pump or chiller where some works to refrigerant piping are carried out on site	Central ASHP, WSHP, VRF--Hybrid	4%	98%
Type 3: VRF systems where a large amount of refrigerant pipework is installed and filled on site	VRF	6%	97%

- Sensitivity analysis of the equipment sizing was conducted by oversizing factors of 30% in heating and 10% in cooling, following NECB Part 8 Section 8.4.4.8, results in Section 2.3

- Sensitivity analysis of the GWP of refrigerants using GWP20year values as follows, results in Section 2.4

  GWP20yr = 410a 4,400 kgCO2e/kg, 513a 1,700 kgCO2e/kg, CO_2 1 $kgCO_2e/kg$

- Sensitivity analysis of input assumptions was conducted using the high-rise 3-pipe VRF archetype, showing the resulting GHGI with
  - Range of annual leakage rates,
  - Range of end of life leakage rates, and
  - System life.

  Results are presented in both GHGI-R and total GWP at year 20 in Section 2.5

  Results in the sensitivity analysis are plotted with reference to the GHGI (in kgCO2e/m^2a) performance limits prescribed in the GBP Table B.1.2a, as well as those for a Low Carbon Energy System (LCES) Type 3, as per the City of Vancouver Low Carbon Energy Systems Policy section 7.

Low Rise	GHGI=5
Low Rise with User-Owned On-Site LCES	GHGI=3.35
High Rise	GHGI=6
High Rise with User-Owned On-Site LCES	GHGI=4.02

5. The results are plotted and compared in the results Section 2 of this report.

2 Results

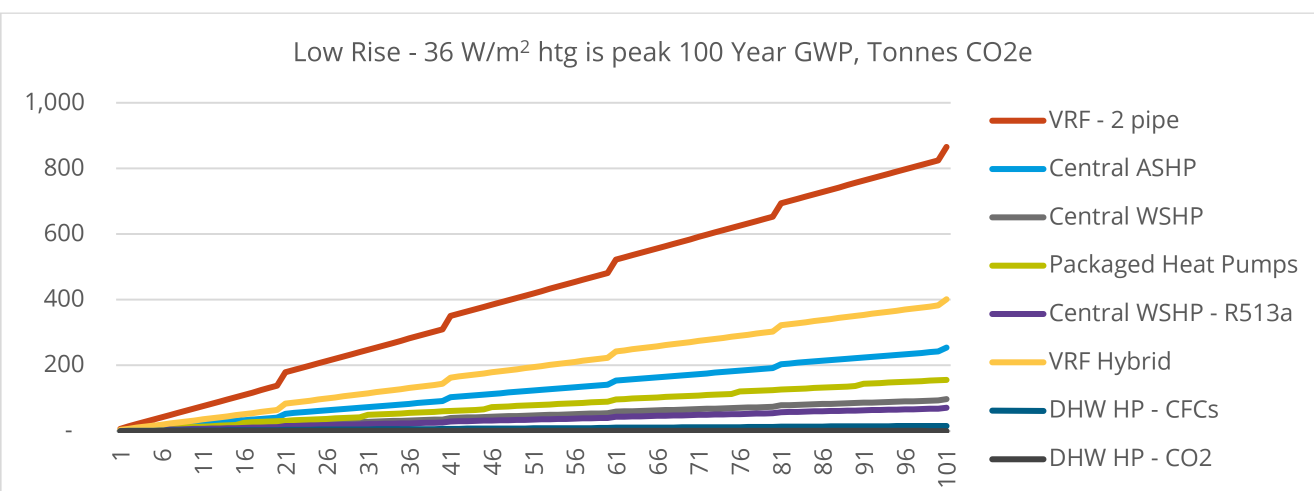
2.1 CoV GBP Section 6.1 Leakage Rates

The following results tables apply leakage rates from the City of Vancouver GBP Section 6.1.

Annual leakage rate = 2%, End of life leakage rate = 10%

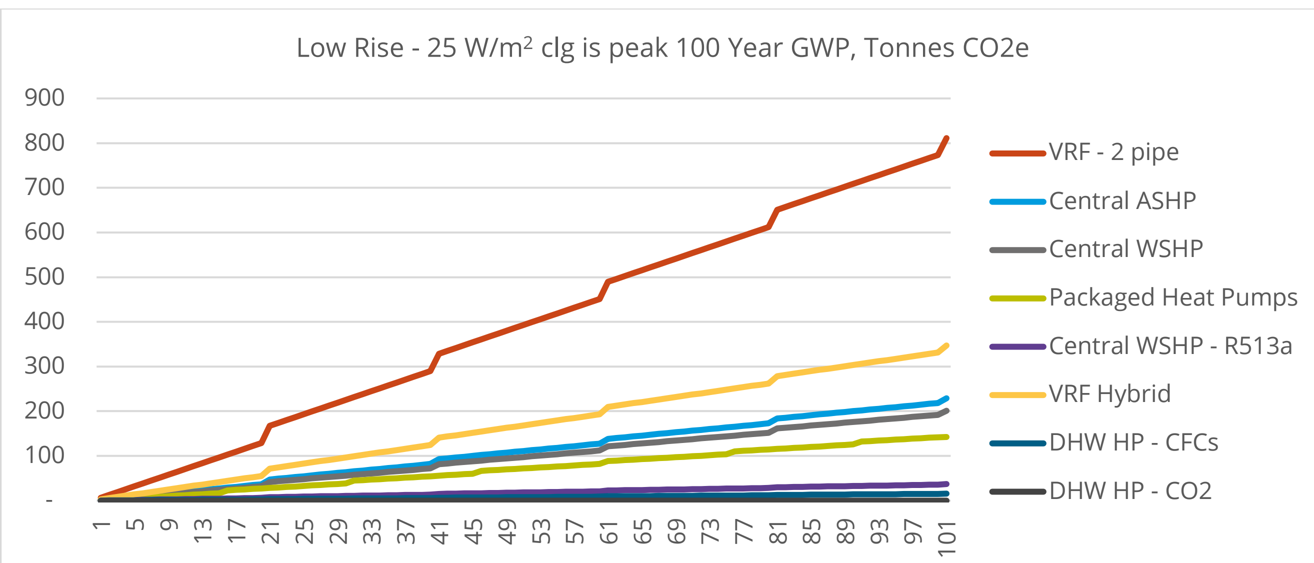
2.1.1 Low Rise Archetype ~ Step 3

GWP of Refrigerants for Archetype Building: Low Rise		**Low Rise MURB - higher heating scenario**							
		Central ASHP	**Central WSHP**	**Central WSHP - R513a**	**VRF - 2 pipe**	**VRF Hybrid**	**Packaged Heat Pumps**	**DHW HP - CFCs**	**DHW HP - CO2**
Number of Floors		6	6	6	6	6	6	6	6
Number of Suites		47	47	47	47	47	47	47	47
Cooling Capacity	kW	89	89	89	89	89	89	-	-
Heating Capacity	kW	170	170	170	170	170	170	11	11
Refrigerant		R-410A	R-410A	R513a	R-410A	R-410A	R-410A	R-410A	C02
GWP of refrigerant	kgCO2e/kg	1890	1890	573	1890	1890	1890	1890	1
Total refrigerant charge of system	kg	53	20	49	182	84	31	3	3
Life of the system	years	20	20	20	20	20	15	20	20
Modelled floor area	m^2	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700
Leakage rate	%	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
End of life leakage	%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GWP of refrigerants per floor area	**kgCO2e/m²a**	**0.5**	**0.2**	**0.2**	**1.8**	**0.8**	**0.3**	**0.0**	**0.0**
GWP of refrigerants per capacity	kgCO2e/kWa	15	6	4	51	23	9	14	0
GWP at year 1	Tonnes CO2e	2	1	1	7	3	1	0	0
GWP at year 20	Tonnes CO2e	52	20	15	179	83	31	3	0
GWP at year 60	Tonnes CO2e	153	59	43	522	242	96	10	0
GWP at year 100	Tonnes CO2e	254	97	71	865	401	155	16	0



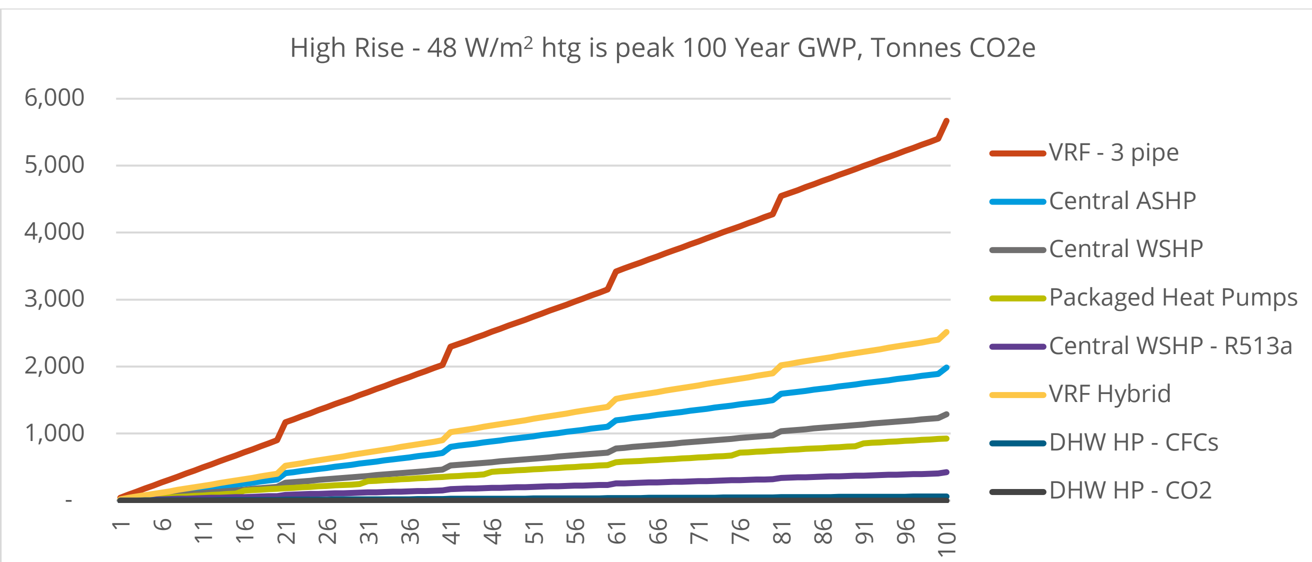
2.1.2 Low Rise Archetype ~ Step 4

GWP of Refrigerants for Archetype Building: Low Rise		**Low Rise MURB - higher cooling scenario**							
		Central ASHP	**Central WSHP**	**Central WSHP - R513a**	**VRF - 2 pipe**	**VRF Hybrid**	**Packaged Heat Pumps**	**DHW HP - CFCs**	**DHW HP - CO2**
Number of Floors		6	6	6	6	6	6	6	6
Number of Suites		47	47	47	47	47	47	47	47
Cooling Capacity	kW	119	119	119	119	119	119	-	-
Heating Capacity	kW	82	82	82	82	82	82	11	11
Refrigerant		R-410A	R-410A	R513a	R-410A	R-410A	R-410A	R-410A	C02
GWP of refrigerant	kgCO2e/kg	1890	1890	573	1890	1890	1890	1890	1
Total refrigerant charge of system	kg	48	42	26	170	73	29	3	3
Life of the system	years	20	20	20	20	20	15	20	20
Modelled floor area	m^2	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700
Leakage rate	%	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
End of life leakage	%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GWP of refrigerants per floor area	**kgCO2e/m²a**	**0.5**	**0.4**	**0.1**	**1.7**	**0.7**	**0.3**	**0.0**	**0.0**
GWP of refrigerants per capacity	kgCO2e/kWa	19	17	3	68	29	12	14	0
GWP at year 1	Tonnes CO2e	2	2	0	6	3	1	0	0
GWP at year 20	Tonnes CO2e	47	42	8	167	72	28	3	0
GWP at year 60	Tonnes CO2e	138	122	23	490	210	88	10	0
GWP at year 100	Tonnes CO2e	229	201	37	812	348	143	16	0



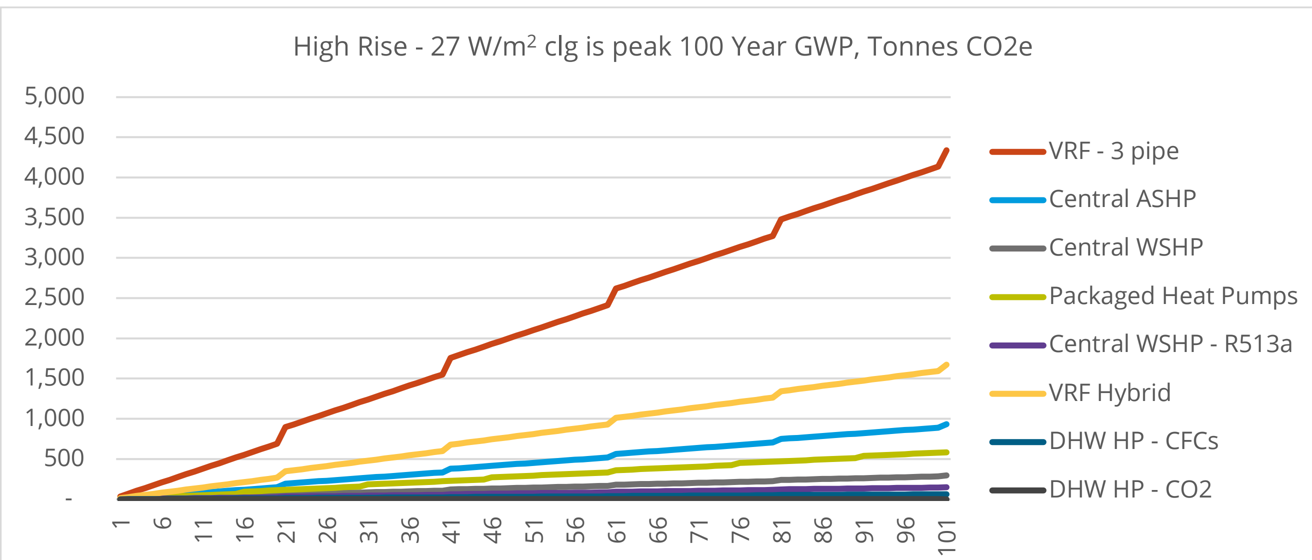
2.1.3 High Rise Archetype ~ Step 3

GWP of Refrigerants for Archetype Building: High Rise		**High Rise MURB - higher heating scenario**							
		Central ASHP	**Central WSHP**	**Central WSHP - R513a**	**VRF - 3 pipe**	**VRF Hybrid**	**Packaged Heat Pumps**	**DHW HP - CFCs**	**DHW HP - CO2**
Number of Floors		26	26	26	26	26	26	26	26
Number of Suites		250	250	250	250	250	250	250	250
Cooling Capacity	kW	533	533	533	533	533	533	-	-
Heating Capacity	kW	1,012	1,012	1,012	1,012	1,012	1,012	46	46
Refrigerant		R-410A	R-410A	R513a	R-410A	R-410A	R-410A	R-410A	C02
GWP of refrigerant	kgCO2e/kg	1890	1890	573	1890	1890	1890	1890	1
Total refrigerant charge of system	kg	417	271	294	1,190	529	187	13	13
Life of the system	years	20	20	20	20	20	15	20	20
Modelled floor area	m^2	21,250	21,250	21,250	21,250	21,250	21,250	21,250	21,250
Leakage rate	%	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
End of life leakage	%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GWP of refrigerants per floor area	**kgCO2e/m²a**	**0.9**	**0.6**	**0.2**	**2.6**	**1.2**	**0.4**	**0.0**	**0.0**
GWP of refrigerants per capacity	kgCO2e/kWa	19	13	4	56	25	9	14	0
GWP at year 1	Tonnes CO2e	16	10	3	45	20	7	1	0
GWP at year 20	Tonnes CO2e	410	267	88	1,169	520	184	13	0
GWP at year 60	Tonnes CO2e	1,198	779	256	3,418	1,520	573	38	0
GWP at year 100	Tonnes CO2e	1,986	1,292	424	5,667	2,520	926	64	0



2.1.4 High Rise Archetype ~ Step 4

<u>GWP of Refrigerants for Archetype Building:</u> High Rise		**High Rise MURB - higher cooling scenario**							
		Central ASHP	**Central WSHP**	**Central WSHP - R513a**	**VRF - 3 pipe**	**VRF Hybrid**	**Packaged Heat Pumps**	**DHW HP - CFCs**	**DHW HP - CO2**
Number of Floors		26	26	26	26	26	26	26	26
Number of Suites		250	250	250	250	250	250	250	250
Cooling Capacity	kW	484	484	484	484	484	484	-	-
Heating Capacity	kW	335	335	335	335	335	335	46	46
Refrigerant		R-410A	R-410A	R513a	R-410A	R-410A	R-410A	R-410A	C02
GWP of refrigerant	kgCO2e/kg	1890	1890	573	1890	1890	1890	1890	1
Total refrigerant charge of system	kg	196	62	105	911	352	118	13	13
Life of the system	years	20	20	20	20	20	15	20	20
Modelled floor area	m^2	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Leakage rate	%	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
End of life leakage	%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GWP of refrigerants per floor area	**kgCO2e/m²a**	**0.5**	**0.2**	**0.1**	**2.4**	**0.9**	**0.3**	**0.0**	**0.0**
GWP of refrigerants per capacity	kgCO2e/kWa	19	6	3	89	34	12	14	0
GWP at year 1	Tonnes CO2e	7	2	1	34	13	4	1	0
GWP at year 20	Tonnes CO2e	192	61	31	896	345	116	13	0
GWP at year 60	Tonnes CO2e	563	179	92	2,618	1,010	360	38	0
GWP at year 100	Tonnes CO2e	933	297	152	4,340	1,674	582	64	0

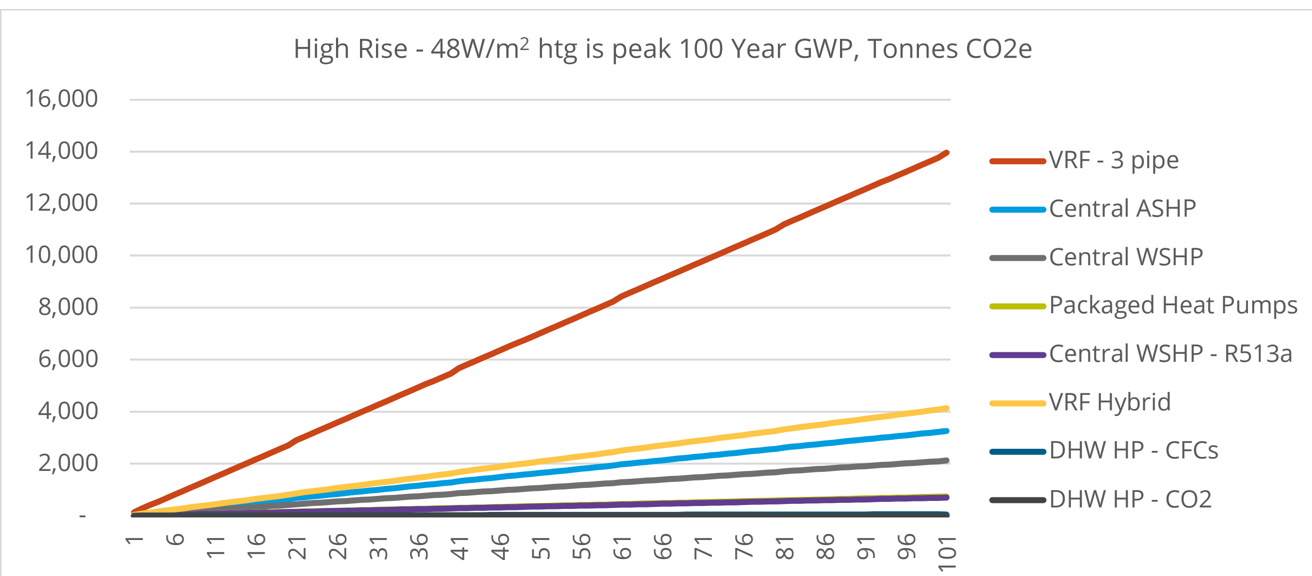


2.2 CIBSE TM65 Leakage Rates

TM65 Table 4.4 leakage rates vary by system type. Rates and product type are shown in the tables below.

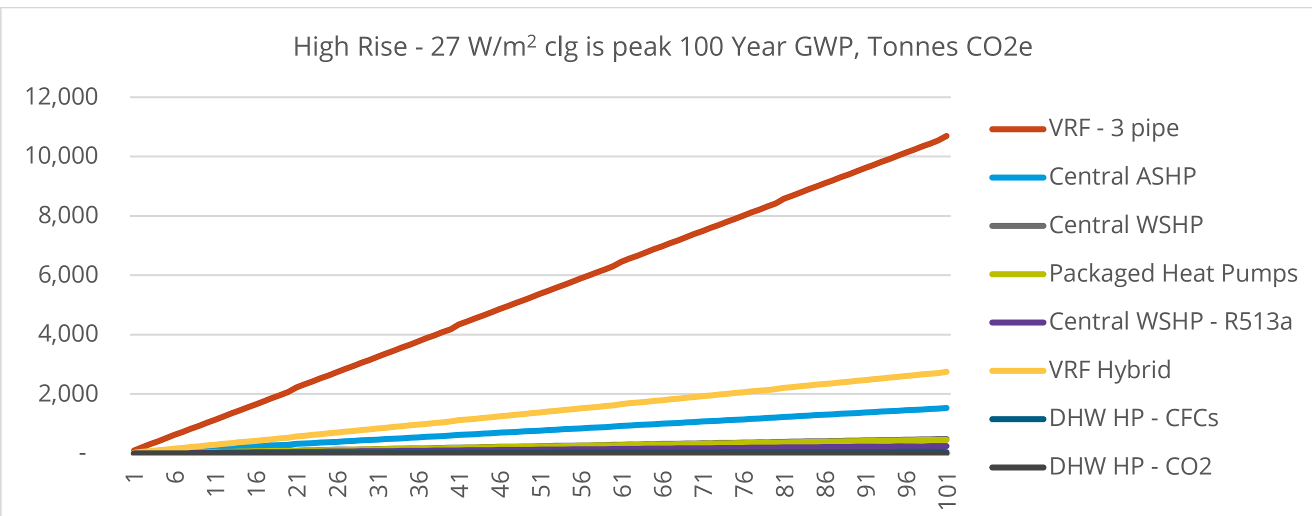
2.2.1 High Rise Sensitivity: TM65 Leakage Rates Step ~ Step 3

GWP of Refrigerants for Archetype Building: High Rise with refrigerant leakage rates as recommended in CIBSE TM65		**High Rise MURB - higher heating scenario**							
		Central ASHP	**Central WSHP**	**Central WSHP - R513a**	**VRF - 3 pipe**	**VRF Hybrid**	**Packaged Heat Pumps**	**DHW HP - CFCs**	**DHW HP - CO2**
Number of Floors		26	26	26	26	26	26	26	26
Number of Suites		250	250	250	250	250	250	250	250
Cooling Capacity	kW	533	533	533	533	533	533	-	-
Heating Capacity	kW	1,012	1,012	1,012	1,012	1,012	1,012	46	46
Refrigerant		R-410A	R-410A	R513a	R-410A	R-410A	R-410A	R-410A	C02
GWP of refrigerant	kgCO2e/kg	1890	1890	573	1890	1890	1890	1890	1
Total refrigerant charge of system	kg	417	271	294	1,190	529	187	13	13
Life of the system	years	20	20	20	20	20	15	20	20
Modelled floor area	m^2	21,250	21,250	21,250	21,250	21,250	21,250	21,250	21,250
Leakage rate	%	0.04	0.04	0.04	0.06	0.04	0.02	0.02	0.02
End of life leakage	%	0.02	0.02	0.02	0.03	0.02	0.01	0.01	0.01
TM65 Product Type	TM65:Table4.4	Type2	Type2	Type2	Type3	Type2	Type1	Type1	Type1
GWP of refrigerants per floor area	**kgCO2e/m²a**	**1.5**	**1.0**	**0.3**	**6.5**	**1.9**	**0.3**	**0.0**	**0.0**
GWP of refrigerants per capacity	kgCO2e/kWa	32	21	7	137	41	7	11	0
GWP at year 1	Tonnes CO2e	32	21	7	135	40	7	1	0
GWP at year 20	Tonnes CO2e	678	441	145	2,901	860	152	11	0
GWP at year 60	Tonnes CO2e	1,970	1,282	421	8,433	2,500	445	32	0
GWP at year 100	Tonnes CO2e	3,262	2,122	697	13,966	4,140	735	52	0



2.2.2 High Rise Sensitivity: TM65 Leakage Rates Step ~ Step 4

GWP of Refrigerants for Archetype Building: High Rise with refrigerant leakage rates as recommended in CIBSE TM65		**High Rise MURB - higher cooling scenario**							
		Central ASHP	**Central WSHP**	**Central WSHP - R513a**	**VRF - 3 pipe**	**VRF Hybrid**	**Packaged Heat Pumps**	**DHW HP - CFCs**	**DHW HP - CO2**
Number of Floors		26	26	26	26	26	26	26	26
Number of Suites		250	250	250	250	250	250	250	250
Cooling Capacity	kW	484	484	484	484	484	484	-	-
Heating Capacity	kW	335	335	335	335	335	335	46	46
Refrigerant		R-410A	R-410A	R513a	R-410A	R-410A	R-410A	R-410A	C02
GWP of refrigerant	kgCO2e/kg	1890	1890	573	1890	1890	1890	1890	1
Total refrigerant charge of system	kg	196	62	105	911	352	118	13	13
Life of the system	years	20	20	20	20	20	15	20	20
Modelled floor area	m^2	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Leakage rate	%	0.04	0.04	0.04	0.06	0.04	0.02	0.02	0.02
End of life leakage	%	0.02	0.02	0.02	0.03	0.02	0.01	0.01	0.01
TM65 Product Type	TM65:Table4.4	Type2	Type2	Type2	Type3	Type2	Type1	Type1	Type1
GWP of refrigerants per floor area	**kgCO2e/m²a**	**0.8**	**0.3**	**0.1**	**5.9**	**1.5**	**0.3**	**0.0**	**0.0**
GWP of refrigerants per capacity	kgCO2e/kWa	31	10	5	219	56	9	11	0
GWP at year 1	Tonnes CO2e	15	5	2	103	27	4	1	0
GWP at year 20	Tonnes CO2e	318	101	52	2,222	571	96	11	0
GWP at year 60	Tonnes CO2e	925	295	151	6,459	1,661	280	32	0
GWP at year 100	Tonnes CO2e	1,533	488	250	10,696	2,750	462	52	0



2.3 Input Sensitivity: Equipment Sizing

GWP of Refrigerants, kgCO2e/m²-year

Leakage rates per CoV GBP Section 6.1

	Low Rise MURB - higher heating scenario – 36 W/m²							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 2 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Equipment sized to peak load	0.5	0.2	0.2	1.8	0.8	0.3	0.0	0.0
Oversizing 30% heating and 10% cooling	0.7	0.3	0.2	2.0	1.0	0.4	0.0	0.0

	Low Rise MURB - higher cooling scenario – 25 W/m²							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 2 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Equipment sized to peak load	0.5	0.4	0.1	1.7	0.7	0.3	0.0	0.0
Oversizing 30% heating and 10% cooling	0.6	0.5	0.1	1.8	0.8	0.3	0.0	0.0

	High Rise MURB - higher heating scenario – 48 W/m²							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 3 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Equipment sized to peak load	0.9	0.6	0.2	2.6	1.2	0.4	0.0	0.0
Oversizing 30% heating and 10% cooling	1.2	0.8	0.3	2.9	1.4	0.6	0.0	0.0

	High Rise MURB - higher cooling scenario – 27 W/m²							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 3 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Equipment sized to peak load	0.5	0.2	0.1	2.4	0.9	0.3	0.0	0.0
Oversizing 30% heating and 10% cooling	0.7	0.2	0.1	2.4	1.0	0.4	0.0	0.0

Equipment oversizing increased the GHGI-R by a maximum of 0.3 kgCO2e/m²-year in the case of the high rise central ASHP and VRF systems.

Sizing of DHW heat pumps can be optimized/ downsized by complementing it with ample DHW storage volume.

2.4 Input Sensitivity: GWP of Refrigerant

GWP of Refrigerants, kgCO2e/m^2-year

Leakage rates per CoV GBP Section 6.1

	Low Rise MURB - higher heating scenario							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 2 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Refrigerant GWP 100 year value	0.5	0.2	0.2	1.8	0.8	0.3	0.0	0.0
Refrigerant GWP 20 year value	1.2	0.5	0.4	4.3	2.0	0.8	0.1	0.0

	Low Rise MURB - higher cooling scenario							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 2 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Refrigerant GWP 100 year value	0.5	0.4	0.1	1.7	0.7	0.3	0.0	0.0
Refrigerant GWP 20 year value	1.1	1.0	0.2	4.0	1.7	0.7	0.1	0.0

	High Rise MURB - higher heating scenario							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 3 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Refrigerant GWP 100 year value	0.9	0.6	0.2	2.6	1.2	0.4	0.0	0.0
Refrigerant GWP 20 year value	2.2	1.4	0.6	6.2	2.7	1.0	0.1	0.0

	High Rise MURB - higher cooling scenario							
	Central ASHP	Central WSHP	Central WSHP - R513a	VRF - 3 pipe	VRF Hybrid	Packaged Heat Pumps	DHW HP - CFCs	DHW HP - CO2
Refrigerant GWP 100 year value	0.5	0.2	0.1	2.4	0.9	0.3	0.0	0.0
Refrigerant GWP 20 year value	1.2	0.4	0.2	5.6	2.1	0.8	0.1	0.0

2.5 Input Sensitivity: High Rise VRF 3-pipe

The following sensitivity analysis was conducted using the scenario with the highest GHGI-R, which was the high rise with 3-pipe VRF system with higher peak load (Step 3).

The sensitivity of the annual leakage rate, end of life leakage rate, and equipment service life inputs were tested individually by holding constant the other two variables.

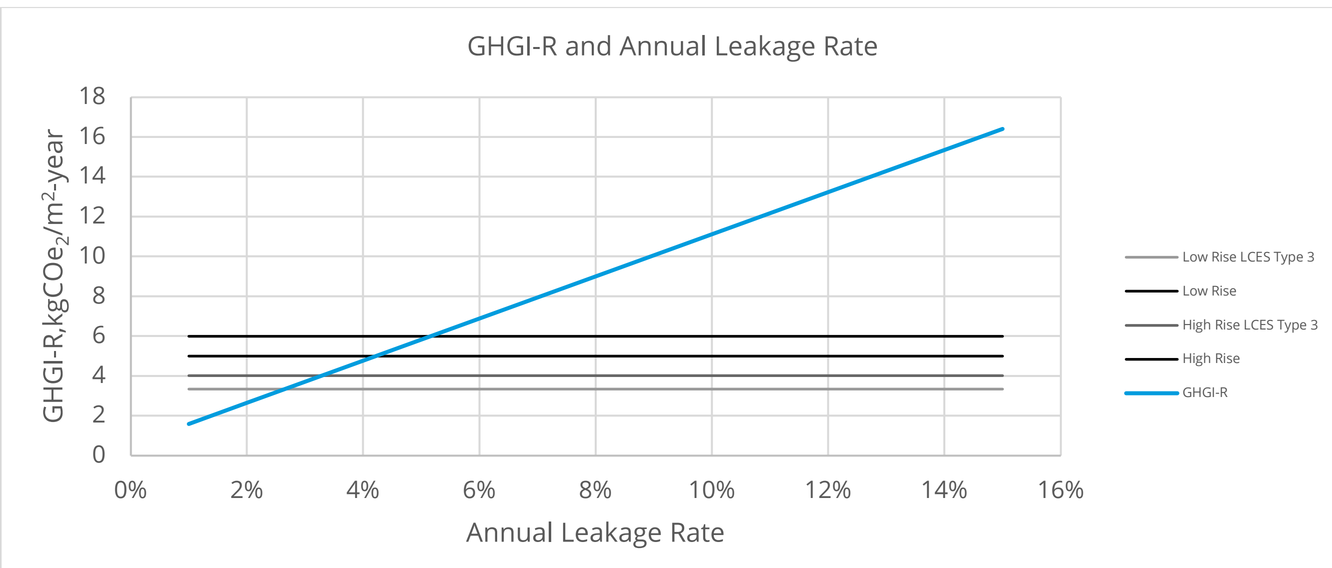
To help gauge the refrigerant results, they are plotted with the GHGI performance limits for operating energy use at the different building typologies. Ranging from 3.35 kgCO2e/m^2 for a low-rise with on-site owner-operated LCES to 6 kgCO2e/m^2-year for a standard high rise.

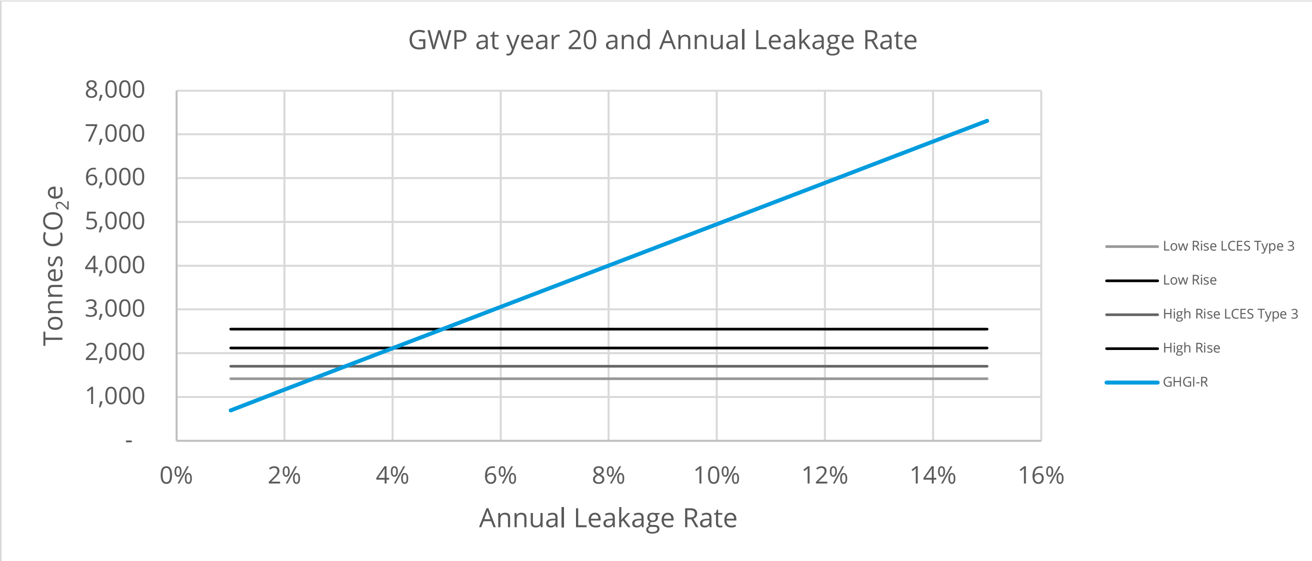
The two leakage rate analysis results are plotted over a range of values selected from the most extreme values cited in the literature review provided in CIBSE TM65 Table D.12, with annual leakage rates ranging from 1% to 15% and end of life leakage rates ranging from 5% to 50%.

Results are presented in GHGI-R as well as in total GWP at year 20.

2.5.1 High Rise VRF 3-pipe Sensitivity Annual Leakage Rates

Constants in the following analysis are service life 20 years, and end of life leakage rate 10%. The annual leakage rate was tested between 1% and 15%.



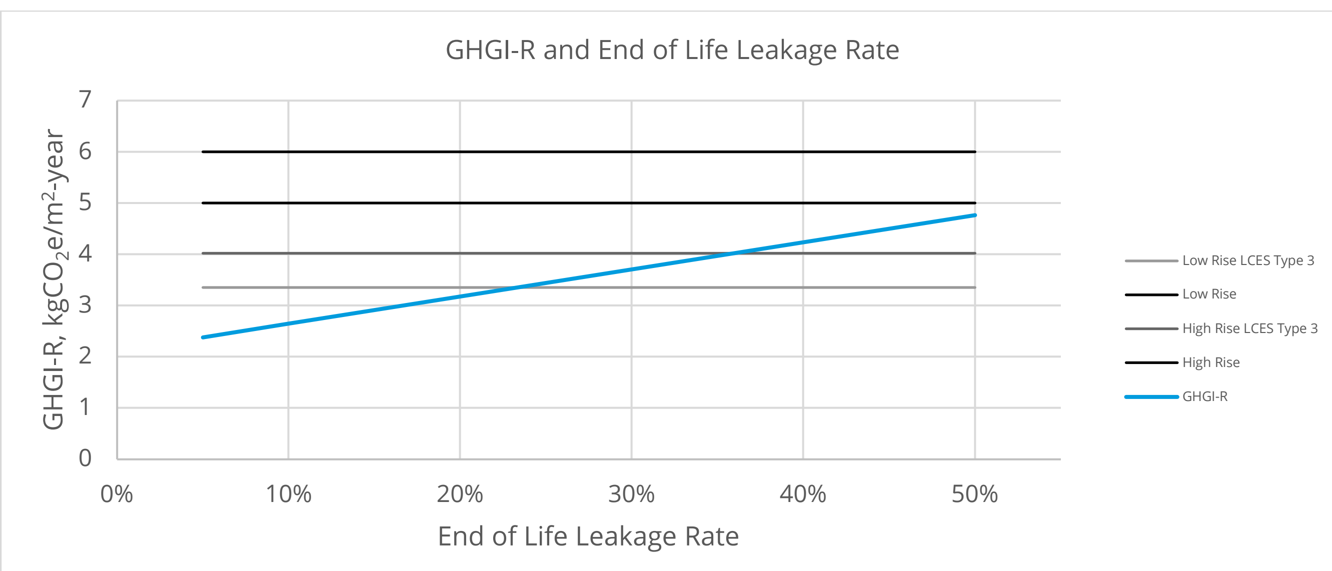


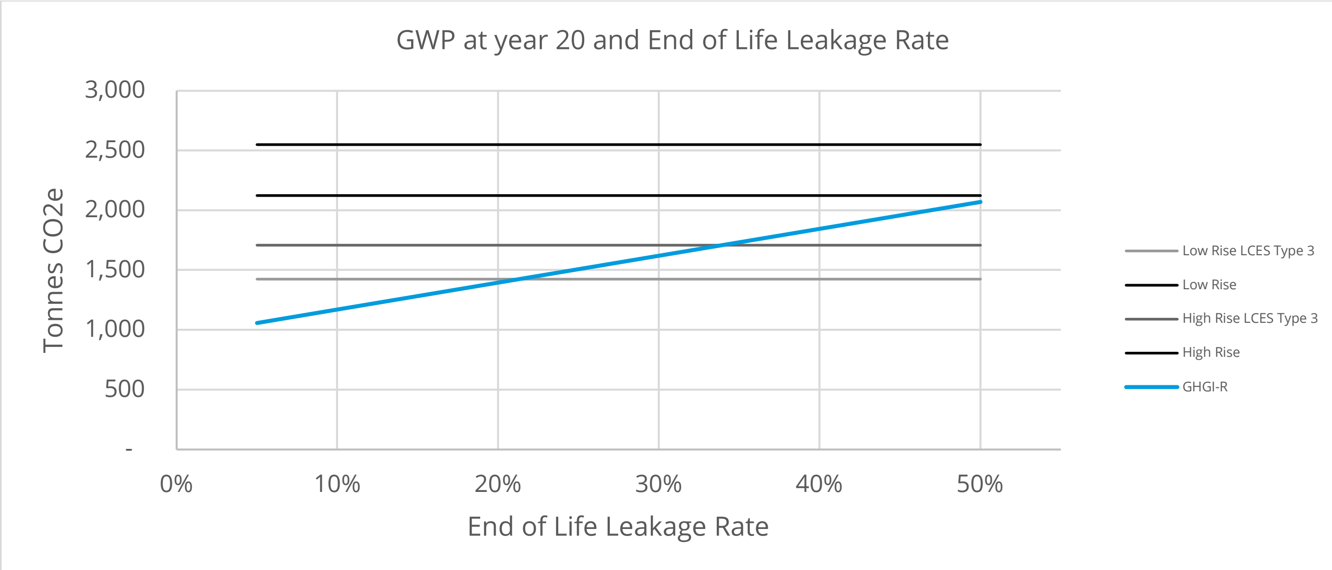
The results show that with an annual leakage rate of 5% or greater, the GHGI-R of the high rise archetype with 3-pipe VRF would be as great or greater than the ongoing energy use performance limit GHGI for all residential building types.

Even at the lowest leakage rate of 1%, the GHGI-R was 1.6 kgCO2e/m^2-year, which is 27% of the ongoing energy use performance limit GHGI for the standard high rise archetype.

2.5.2 High Rise VRF 3-pipe Sensitivity End of Life Leakage Rates

Constants in the following analysis are service life 20 years, and annual leakage rate 2%. The end of life leakage rate was tested between 5% and 50%.

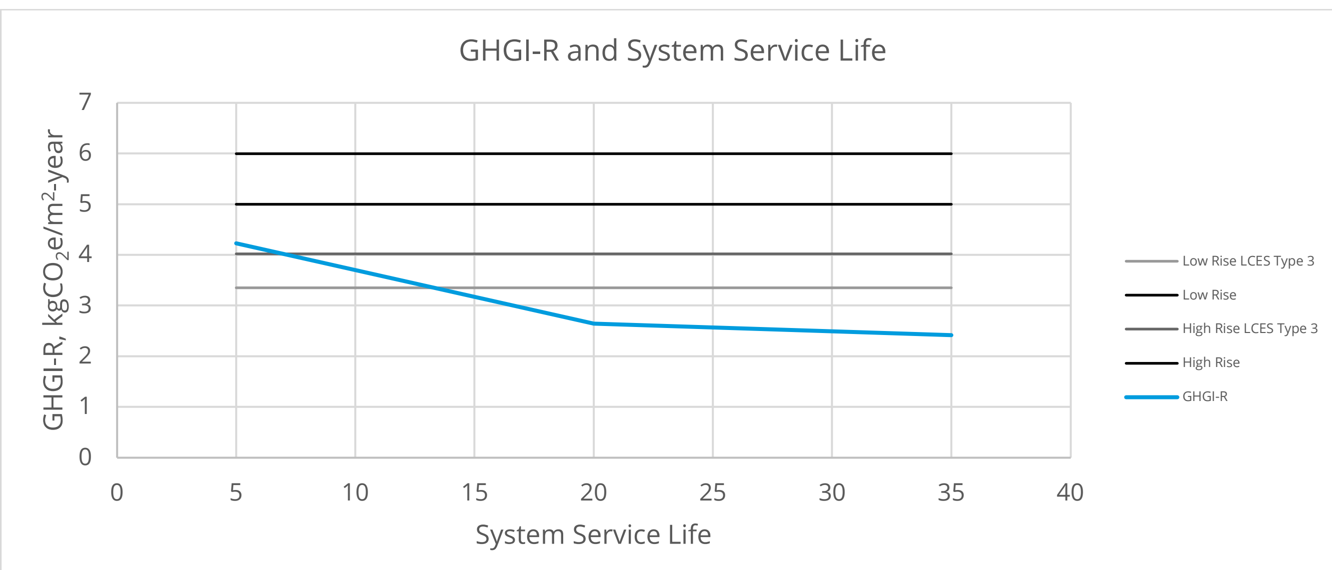


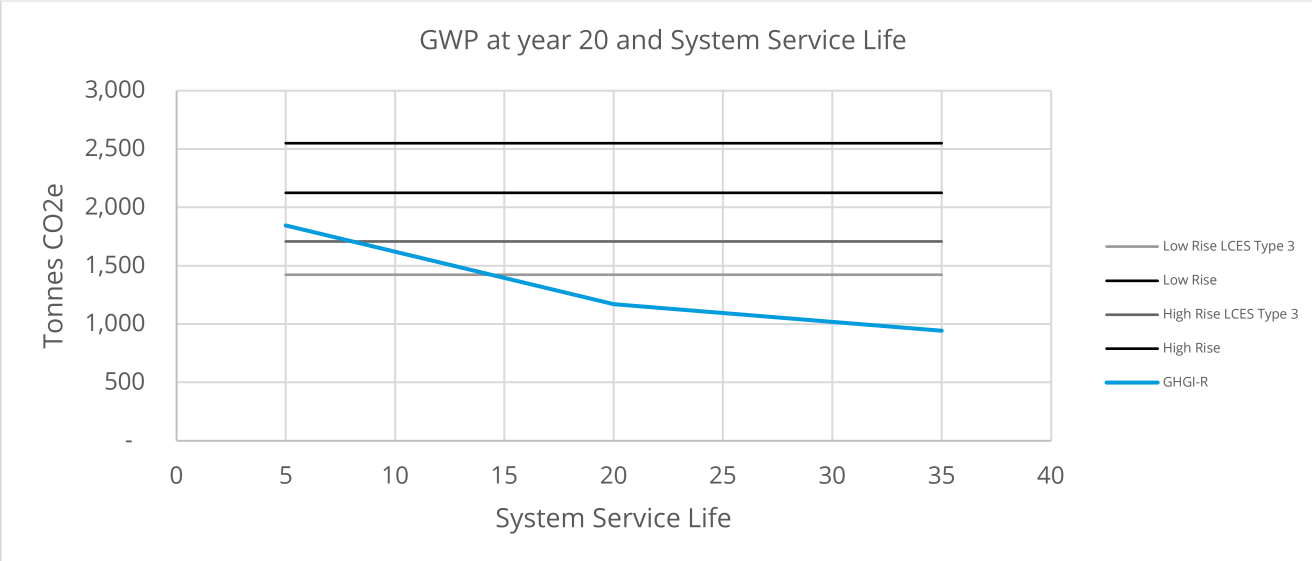


The results show that the end of life leakage rate can have a significant impact on the GHGI-R. Leakage rates of 5% at end of life are 2.4 kgCO2e/m^2-year, which is 40% of the ongoing energy use performance limit GHGI for the standard high rise archetype. This result also implies that the overall environmental impact of the system can be significantly increased by a singular event.

2.5.3 High Rise VRF 3-pipe Sensitivity Equipment Service Life

Constants in the following analysis are annual leakage rate 2% and end of life leakage rate 10%. The equipment service life was tested between 5 and 35 years.





The results show that with very short equipment service life the GHGI-R is quite high at 4.2 $kgCO_{2e}/m^2$-year at 5 years. As the service life increases the GHGI-R reduces. The results imply a non-linear relationship between service life and GHGI-R.

With a 35 year service life the GHGI-R is 2.4 kgCO2e/m^2-year, or 40% of the ongoing energy use performance limit GHGI for the standard high rise archetype.

3 Discussion of Standards

Environmental risk of refrigerant use is addressed in LEED Canada 2009 and TM59. The following provides a brief summary of each methodology.

3.1 LEED Canada 2009

The scope of the LEED program is the entire building site and addresses refrigerants in the Energy and Atmosphere (EA) category with one prerequisites and one credit.

EA prerequisite 3 requires that applicants comply with the more stringent of provincial, federal or EPA regulations on subjects such as the equipment management; refrigerant reclaim, recovery, and disposal, and technician certification. EAp3 also restricts NC applicants to non-CFC refrigerants and addresses CFC refrigerant phase-out in existing systems.

EA credit 4 documentation briefly outlines approaches to reduce the GWP and Ozone Depletion Potential (ODP) of refrigerants such as eliminating their use completely with passive cooling, use of natural refrigerants, use of low impact refrigerants, minimizing leakage, and selecting equipment with long service life.

A calculation is provided with a threshold to limit the combined GWP and ODP. Current market availability of appropriate equipment operating with alternative refrigerants is limited, and this calculation would be similarly limited in range between projects and system types. The calculation assumes constant annual and end of life leakage rates for all system types.

Calculations are required submission to LEED at occupancy, but the methodology does not include any follow-up after occupancy and depends on the integrity of service contracts.

LEED calculations omit HVAC equipment with less than 0.23kg of refrigerant, which although individually small, perhaps should be included in refrigerant accounting considering some MURB equipment could fall in this category.

3.2 CIBSE TM65

The scope of CIBSE TM65 is a calculation methodology for the embodied carbon of Mechanical Electrical and Plumbing (MEP) systems and includes the GWP of refrigerants in life cycle stages B1 and C1.

The calculation methodology applies different leakage rates for different system types based on CIBSE literature review of documented cases.

The document is a calculation methodology and encourages participates to register their results to further research. There are no obligatory reporting protocols in the memoranda.

3.3 Key Features

The following lists features of both methodologies that are critical to support the management of the environmental risk of refrigerants.

- Compliance to most stringent of provincial, federal, EPA
- Encouragement of demand reduction with passive measures
- List of acceptable refrigerants

- Leak mitigation management through service contracts
- Calculation methodology with different leakage rates by system type
- Collection of results for research database.

3.4 Discussion of Standards Takeaways

The following lists features that would support the management of the environmental risk of refrigerants.

- Clear submission requirements at occupancy, during use, and end of system life
- Annual submission requirements for leakage documentation, with mandatory remediation when rates exceed thresholds set in both percent of total charge (%) and absolute mass value (kg/year).
- End of service life documentation by certified refrigerant professional to include recovered mass value and expected next use
- Literature review and documented cases in current local industry to advise range of leakage rates per system type similar to those in TM65.
- Support to research and development industry to develop alternative refrigerants and equipment that is economically and technically viable for range of market applications

4 Key Takeaways

The following observations were made during the analysis:

- Refrigerant charge per output capacity varied between manufacturer and heat pump equipment type. Of the heat pump types reviewed, those with heat recovery had slightly higher refrigerant charge per unit output capacity (per kW maximum output).

  ❖ System refrigerant charge should be minimized with passive building design features to reduce peak loads and avoid equipment oversizing. DHW heat pump heating capacity can be reduced with increased storage volume.

- VRF systems with refrigerant distribution piping had higher GHGI-R results than other system types.

  ❖ System refrigerant charge can be reduced with efficient piping configuration.
  ❖ The new “Hybrid VRF” system type has significantly smaller extent of refrigerant piping and refrigerant charge. It will offer significantly improved GHGI_R performance once available in the local market.

- GHGI-R is most sensitive to annual leakage rate, and in VRF systems, modest leakage rates can result in GHGI-R greater than the acceptable GHGI of operating energy use by the current building bylaw.

  ❖ Operational leakage should be controlled and minimized with proper installation and commissioning of pipework system, along with ongoing monitoring and maintenance with attention to not over pressurize.

- The performance of refrigerants does not degrade over time or after use and can be reused if handled properly at the end of the system service life. If not handled properly, the resulting GHGI-R could reach or even exceed the ongoing energy use GHGI limits for residential buildings.

  ❖ The environmental risk of refrigerant use is sensitive to singular events, such as failure to reclaim the majority at the end of the system service life. Smaller system types such as mini-split units may be at higher risk to end of life leakage than centralized equipment, especially in the multiples required for MURB applications. Without meticulous decommissioning, multiple small leaks could result in significant total mass leakage.

- The construction document review stage of this study found that each VRF manufacturer had unique documentation pertaining to the total refrigerant charge of the system, and in some cases it was not clear.

  ❖ Industry should work to improve the rigor and consistency by which refrigerant charge and leakage rates are specified and accounted for on site during construction, ongoing operation, and end of system service life.

- Policy measures could manage leakage rates by implement recharge limits as part of building operations and maintenance agreement, and mandatory recovery at end of system service life.

- ❖ If leakage rate thresholds are set, they should be in terms of both percent of total charge and absolute mass value. Thresholds could alternatively vary by system capacity and impose lower % thresholds for larger systems.

- Currently there are few alternative refrigerants approved and available in the local market. Practical limitations, such as the large temperature differential (dT) required on the condenser side for CO_2 heat pumps limit their application to DHW heating. Discussion with local VRF system suppliers suggest that there are currently no alternative refrigerants that could directly replace the currently common R410a in those systems.

  - ❖ Support to the research and development sector should be a priority.

Not reviewed in this study but presents potential for future consideration is the embodied carbon of the mechanical system as discussed in the CIBSE TM65. The difference between central and distributed systems in material mass of equipment, distribution piping, pipe insulation would also contribute to the differences in environmental impacts between systems.