University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Climate-Conscious Cooling and Heating

Using Life Cycle Assessment to Determine the Carbon Impact of Heating and Cooling System Alternatives at UBC Ponderosa North

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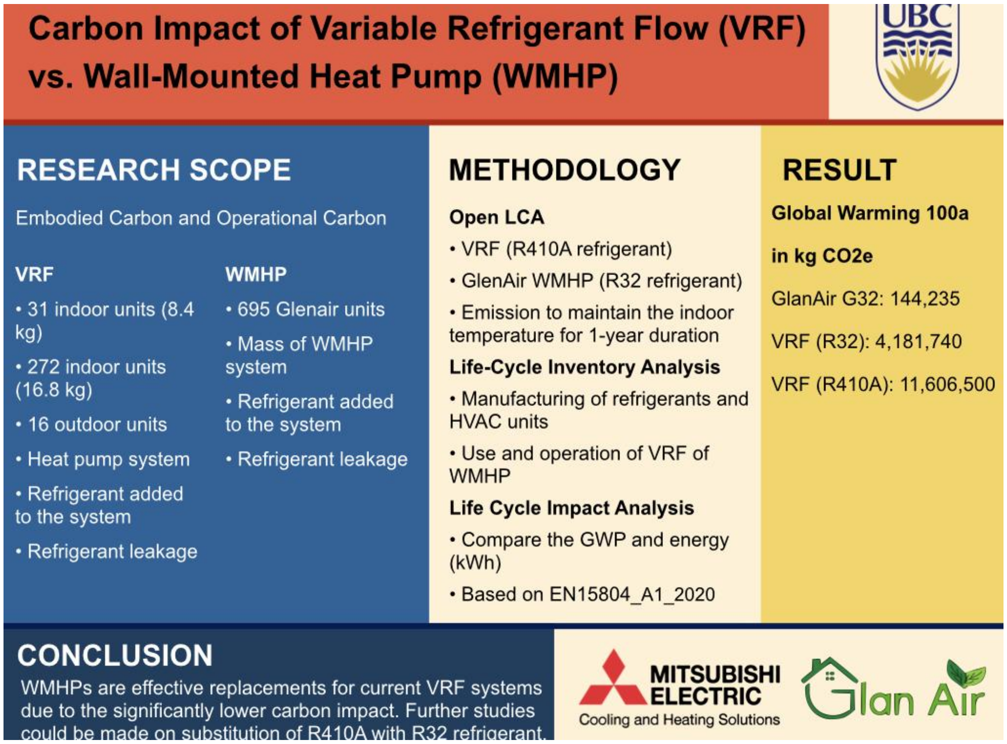
Abstract



The Green Building Action Plan at UBC aims to achieve a net positive impact on human and natural systems within the campus buildings. A significant challenge involves reducing the total carbon emissions in the built environment, emphasizing both operational and embodied carbon emitted throughout the building's life cycle. This project specifically focuses on the heating and cooling systems at UBC Ponderosa North. The carbon impact of Variable Refrigerant Flow (VRF) and Wall-Mounted Heat Pump (WMHP) systems is evaluated and compared using a life cycle assessment approach. By utilizing OpenLCA software and ecoincent 3.8 database, the study compares the global warming potential (GWP) of the WMHP system using R32 refrigerant against the VRF systems using R410A and R32 refrigerants. The results are calculated for a one-year span, showcasing 144,235 kg CO2e for WMHP, 11,606,500 kg CO2e for VRF with R410A, and 4,181,740 kg CO2e for VRF with R32. Ths comparative analysis provides insights into the environmental implications of HVAC choices and refrigerant types, contributing to the improvement of more sustainable building practices at UBC.

Keywords: VRF, Wall-Mounted Heat Pump (WMHP), LCA, Refrigerants, Carbon Impact

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1. Introduction

On a global scale, building operations constitute a significant portion of both energy consumption and greenhouse gas emissions. According to the International Energy Agency (IEA), building operations contribute to 30% of the world's total energy consumption and 26% of global energy-related emissions. Among these emissions, 8% are from direct emissions while 18% result from indirect sources (Delmastro et al., 2023). One component that is often overlooked when considering building operation emissions are the impacts from heating and cooling systems. In recent years, these systems are becoming an essential component to implement in all buildings, especially when considering the changing climate conditions. However, it is important to consider the total environmental impacts of these systems prior to implementation.

One of the more notable concerns regarding these systems are fugitive emissions. Fugitive emissions are often associated with Scope 1 direct greenhouse gas emissions (GHGe), as it results from the direct release of GHG compounds into the atmosphere from various equipment types and processes (United States Environmental Protection Agency, 2014). Discussion revolving around these emissions is a more prominent concern especially when it comes to refrigeration and air conditioning systems. This is due to the usage of Hydrofluorocarbon (HFC) refrigerants in these systems, which often have very high global warming potentials (GWPs) (United States Environmental Protection Agency, 2014; United States Environmental Protection Agency, n.d.).

Asides from the fugitive emissions, it is also important to consider the full scope of emissions from these systems, making it important to look beyond the operational and embodied carbon emissions and address their full life cycle.

1.1. Project Background

By 2035, the University of British Columbia (UBC) aims to ensure their buildings are not only net positive, but also contribute to the sustainability and well-being of the campus community through their Green Building Action Plan (University of British Columbia, n.d.). However, a significant challenge in meeting these climate goals revolves around accounting for the total carbon emissions linked to the buildings – specifically focusing on the operational and embodied carbon from heating and cooling systems. For building emissions, focus is often centered around the energy consumption of buildings. This approach often leads to gaps when addressing the full scope of carbon emissions throughout a building's entire life cycle. Meanwhile, the discussion surrounding heating and cooling systems, in particular, have been gaining traction in recent years due to an increase in the availability of data and methodologies, which were lacking in the past. The usage of Hydrofluorocarbons (HFCs) in these systems adds an extra layer of concern, as it introduces the potential for leakages and fugitive emissions from refrigerant usage.

Currently, numerous student housing buildings across the UBC campus encounter challenges due to the absence of adequate heating/cooling systems to provide students with comfortable temperatures in their dormitories; which is particularly noticeable during the summer months. This makes it necessary to find a system that can efficiently meet the demands of students and staff in these buildings while still minimizing their environmental impacts.

Using Ponderosa Commons North as a case study, this report will focus on the exploration of the overall environmental impacts of two heating and cooling systems. Especially given that fugitive emissions can significantly increase a building's lifetime emissions, it is imperative we examine the full life cycle of heating and cooling systems. By conducting a life cycle assessment (LCA) to understand the total carbon impact of the two heating and cooling systems, this project aims to provide decision makers at UBC with valuable insight to assist them in making an informed decision on which system will better align with UBC's climate goals.

1.2. Variable Refrigerant Flow (VRF) vs. Wall-Mounted Heat Pump (WMHP)

The two systems being considered in this report for implementation at Ponderosa Commons North are the Variable Refrigerant Flow (VRF) system and the Wall-Mounted Heat Pump (WMHP).

Variable Refrigerant Flow (VRF)

To provide a brief overview, the Variable Refrigerant Flow (VRF) system is a type of heating, ventilation, and air conditioning (HVAC) system that consists of an outdoor unit connected to multiple indoor units, as seen in figure 1 (Swegon, 2020). For the implementation of VRF systems on a larger scale, such as in Ponderosa Commons North, the building would be split into zones, with each zone having its own outdoor unit supplying heating/cooling to the individual indoor units within their zone (Jankovic, 2016). This allows for the effective regulation and customizable adjustment of temperature in each of the different zones.

The VRF system proposed in the floor plans are from the manufacturer LG Electronics, with Mitsubishi noted as an equivalent manufacturer, and would be employing the use of the R410a refrigerant.

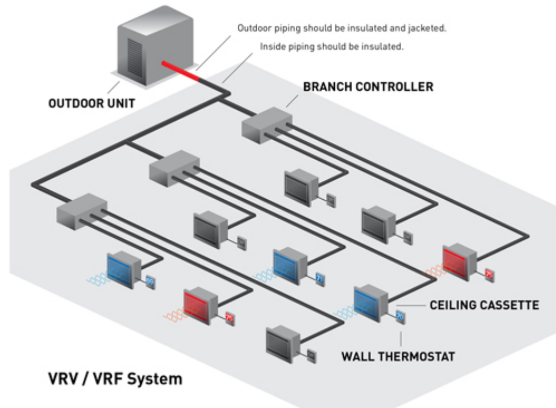

Figure 1. A simplified diagram depicting components of the VRF system and providing a brief overview on how they are set up (Armacell, n.d.).

Wall-Mounted Heat Pump (WMHP)

Unlike the VRF system, the wall-mounted heat pump consists of individual units, which would need to be installed in each room, and does not require the connection of an outdoor unit to multiple indoor units. The wall-mounted heat pump (WMHP) being proposed for this study is manufactured by GlanAir (figure 2) and is a packaged wall-mounted twin duct heat pump air-conditioning unit that employs the use of the R32 refrigerant. Unlike other WMHPs, the GlanAir model does not require an outdoor unit, which can be more cost-efficient and simplify the installation process.

Figure 2. An image illustrating the proposed GlanAir wall-mounted heat pump system.

1.3. Research Questions

The following are some research questions that have been considered while conducting the research and producing this report:

(1) How do heating and cooling systems contribute to the overall carbon emissions of buildings, considering both operational and embodied phases?

(2) How does the proposed Variable Refrigerant Flow (VRF) system compare, in terms of both operational and embodied carbon, to the alternative packaged wall mounted heat pump system?

(3) In addition to specific system recommendations, how can the process of determining carbon impact be improved, and what potential avenues for future research exist in the broader context of sustainable building design, construction, and operation at UBC?

The report will attempt to address these research questions through conducting a Life Cycle Analysis (LCA) on the two heating and cooling systems of interest, the VRF and WMHP. Consequently, the results will be analyzed, from which the limitations of the study will be discussed as well as the recommendations and potential areas for future work.

2. Methods and Materials

Modeling questions to be considered were derived from the research questions prior to beginning the study. These modeling questions considered the objective, measure of success/failure, factors that will influence success, translation of factors into variables, and the link between the variables to the objective.

(1) What is the overall carbon emission from Ponderosa Commons North? How much emissions do heating and cooling systems produce on a yearly basis? What is the energy consumption of each system? How does the energy consumption vary on a yearly basis?

(2) What are the operational and embodied carbon emissions of each system? How does the use of each refrigerant impact the carbon emissions? What is the energy efficiency of each system? How do fugitive emissions play a part? How much do fugitive emissions contribute to the operational/embodied carbon of each system? How does the manufacturing process/material used of each system impact the emission produced?

(3) Can the refrigerant type be changed for each system? What alternative refrigerant types are there and what difference in operational/embodied carbon emissions would that make? Are there any alternative HVAC systems that can be used instead? If so, what are their impacts or how much embodied/operational carbon emissions do they produce in their lifetime? How can the study be scaled to estimate the full scope of carbon emissions for each product's lifetime?

2.1. HVAC System and Building Specifics

Ponderosa North is situated on UBC's Point Grey campus, where an average summer temperature of 20 degrees Celsius and a winter range of 0-5 degrees Celsius are experienced (University of British Columbia, n.d.). With a total building area of 27189 m^2 Ponderosa North is presently equipped with a variable refrigerant flow (VRF) system utilizing the refrigerant R410A for heating and cooling. The VRF system operates by employing multiple fans connected to an outdoor unit, facilitating power provision and assisting refrigerant flow to indoor units (Carrier Corporation, 2013). Energy efficiency is achieved as each indoor unit's sensors activate only when the room temperature falls above or below the desired level (Carrier Corporation, 2013). Ponderosa North currently has 303 indoor units and 16 outdoor units as part of the existing VRF system. To align with UBC's new green action building plan, there is a need to implement heating and cooling systems with lower emission levels not only in new constructions but also by retrofitting existing buildings. A proposed alternative to the VRF system is the utilization of wall-mounted heat pumps, which employ the low-emission refrigerant R32 (Yasaka et al., 2022) and demonstrate comparable heating and cooling capacities to the current VRF systems. An LCA was conducted to compare the overall environmental impacts of the two HVAC systems, analyzing emissions associated with the heating and cooling of each unit.

2.2. Goal and Scope

The LCA aimed to compare the overall embodied and operational carbon of the VRF system, utilizing R410A, and the GlanAir wall-mounted heat pump, using R32 as a refrigerant. Additionally, a sensitivity analysis was performed to determine the emissions impact when substituting R32 for R410A in the VRF system. The scope of the project followed a cradle-to-gate approach, examining the embodied emissions from unit production to their functionality in the building over a yearly period. The functional unit was used to compare the overall heating and cooling capabilities of the two HVAC systems, with the study focusing on assessing the CO2 emissions released during system use. Figure 3 provides a detailed description of the LCA scope, outlining the environmental impacts of variable refrigerant flow systems and wall-mounted heat pumps.

FUNCTION:	To provide heating and cooling to maintain indoor thermal comfort in the building.
UNIT:	kWh/year
MAGNITUDE:	Total area of the building
DURATION:	1 year
LEVEL OF QUALITY:	Maintenance of indoor temperature within a specified range (e.g., 20°C - 25°C) with a certain system efficiency

Figure 3. Summary of the scope of the Life Cycle Analysis to compare emissions from a variable refrigerant flow system and a wall-mounted heat pump.

In this study data points that were difficult to obtain due to lack of resources and time were excluded. Information readily available from public sources such as manufacturing brochures, academic journals, and details provided by UBC Campus + Community Planning was utilised.

Data Points that are excluded from the scope of the study:

- Specific materials used in the construction of the HVAC units both for VRF and wall mounted heat pumps
- Transportation of the HVAC units to Ponderosa North as well as the material being transported to the manufactures of the VRF and wall mounted heat pumps
- The installation of the two different HVAC systems in Ponderosa North
- Packaging associated with any materials pre-manufacturing and post manufacturing
- End of life treatments and disposal

Data points that were included in the scope of the study are:

- The total mass of the individual VRF and wall mounted heat pumps unit that are to be manufactured
- The embodied emissions related to the manufacturing of RF and wall mounted heat pumps unit
- The embodied carbon associated with the production of 1 kg of R410A and R32 refrigerant
- Amount of energy required for the operation of the overall VRF and and wall mounted heat pump systems (for the whole building)

2.3 Data Collection & Assumptions

For both heating and cooling systems, we looked at the operational and embodied carbon associated with the system. This section will breakdown where major data points are sourced from, as well as some of the assumptions made in our analysis.

2.3.1 VRF System

For the VRF system, we were provided with the original design for the system, including the specs associated with each device in the building. In this manner, an example of the data we were provided can be seen below in figure 4. As can be seen from this, the main usable

VRF INDOOR FAN COIL UNIT-SCHEDULE

					COOLING						HEATING							NOTES
TAG #	MANUFACTURER	MODEL	AIR FLOW (L/S)	ESP (Pa)	TOTAL COOLING Btu/hr	SENSIBLE COOLING Btu/hr	EWT (F)	LWT (F)	EAT (F)	LAT (F)	HEATING Btu/hr	EWT (F)	LWT (F)	EAT (F)	LAT (F)	POWER REQ.	ELE. MCA	
AC−3105, AC−3107, AC−3109, AC−3111, AC−3113, AC−3115, AC−3226A, AC−3226B, AC−4105, AC−4107, AC−4109, AC−4111, AC−4113, AC−4115, AC−4226A, AC−4226B, AC−5105, AC−5107, AC−5109, AC−5111, AC−5113, AC−5115, AC−5226A, AC−5226B, AC−6105, AC−6107, AC−6109, AC−6111, AC−6113, AC−6115, AC−6226A, AC−6226B, AC−7105, AC−7107, AC−7109, AC−7111, AC−7113, AC−7115, AC−7226A, AC−7226B, AC−8105, AC−8107, AC−8109, AC−8111, AC−8113, AC−8115, AC−8226A, AC−8226B, AC−9105, AC−9107, AC−9109, AC−9111, AC−9113, AC−9115, AC−9226A, AC−9226B, AC−10105, AC−10107, AC−10109, AC−10111, AC−10113, AC−10115, AC−10226A, AC−10226B, AC−11105, AC−11107, AC−11109, AC−11111, AC−11113, AC−11115, AC−11226A, AC−11226B, AC−12105, AC−12107, AC−12109, AC−12111, AC−12113, AC−12115, AC−12226A, AC−12226B, AC−13105, AC−13107, AC−13109, AC−13111, AC−13113, AC−13115, AC−13226A, AC−13226B, AC−14105, AC−14107, AC−14109, AC−14111, AC−14113, AC−14115, AC−14226A, AC−14226B, AC−15105, AC−15107, AC−15109, AC−15111, AC−15113, AC−15115, AC−15226A, AC−15226B, AC−16105, AC−16107, AC−16109, AC−16111, AC−16113, AC−16115, AC−16226A, AC−16226B, AC−17105, AC−17107, AC−17109, AC−17111, AC−17113, AC−17115, AC−17226A, AC−17226B, AC−18105, AC−18107, AC−18109, AC−18111, AC−18113, AC−18115,	LG	ARNU053SJA4	98~113	–	5,500	–	–	–	75	55	6,100	–	–	70	102	208/1/60	0.31	1,2,3,4,5,6,7,8,10

Figure 4. Example of the data input for a single VRF unit in the system.

information provided by this is the manufacturer, number of units, as well as heating / cooling capacity. Thus the scope for our LCA as it related to the VRF system, consisted of three components: refrigerant leakage, manufacturing emissions, and operational energy use. For the refrigerant leakage portion, we largely relied on literature values for both the amount leaked, as well as the carbon intensity of the leakage. Using literature for this was a decision taken by the team that we all felt confident in as many different studies suggested similar numbers for the refrigerant R410A; a potential drawback of relying on these values rests more on the amount of refrigerant used in the system. We did our best to use literature and the overall size of the system, to get an estimate of the amount of refrigerant, but without specific data this number could be inaccurate. Next for manufacturing emissions, we initially tried looking through LG (the listed manufacturer) to find if they had performed an analysis, but they did not. On the plans, however, they did list Mitsubishi as an "equal manufacturer", so we were able to use Mitsubishi's internal life cycle analysis in order to get precise numbers. Lastly, for the operational energy use we relied on several data points, both provided and found, to attain a reasonable number. The first step in this process was to attain the total heating / cooling area of the building, which was taken from the architecture firm which designed the building, from which we could attain the area covered by each unit, then generate the amount of heating demand per unit in kW/m^2. One consideration here is that there will be a differing heating demand between the two systems, but given that we were not given the COP for the VRF system, the resulting number for energy input to heating output would be completely reliant on our assumed COP (i.e. if same COP as WMHP is assumed, the final numbers would be the same). As such, the assumption underlying our equation is that when the temperature drops below a certain range, the heating system will heat at its maximum capacity until the desired heat is reached, this is the same assumption for the cooling system; this equation can be seen on figure 5.

VRF - Energy Usage

Demand per unit

$$\text{Total Energy (kWh) / yr} = \frac{\left(\dfrac{\text{Heating / Cooling capacity}}{64.2\ \text{m}^2}\right) \times \text{Hours} \times \text{Days}}{\text{COP; assumed } 1.75}$$

Figure 5. Equation for calculating energy usage of the VRF system. Note: 64.2 m^2 came from the total heatable area divided by number of VRF units

Overall, the assumptions that went into the VRF system calculations are mainly from the refrigerant usage and operational energy usage portions, with literature being used for refrigerant usage, and a mixture of given data, found data, and assumptions to generate a realistic number for energy usage. One last note is that generally, the heating / cooling demand per unit was lower for the VRF system, which can largely be attributed to the larger space covered by each unit. This issue could be fixed by conducting a more thorough analysis on what specific areas of the building are covered by which kind of unit, as the different units had different heat / cooling capacities.

2.3.2 WHMP System

For the wall mounted heat pump system, we assessed the carbon impact based on the brochure provided to us by Glan Air. This brochure detailed the energy requirements, heating and cooling capacity, and the applicable space per unit, as well as other minor data points (see figure 6)

SPECIFICATION	U.M	GA32
Output	BTU/h	12000
Cooling/Heating Capacity	W	3500 / 2930
Power Supply	V-V-Hz	115/1/60
Rated input (Cooling / Heating)	W	1250 / 945
EER / COP	kW	3.1/3.6
Moisture Removal	(L/h)	1.4
Air circulation	m^3/h	520
Sound Pressure(Cooling+High Speed Fan)	dB	47
Sound Pressure (Silent Mode)	dB	39
Body Size (Height/Width/Length)	mm	575 x205 x 1000
Package Size (Height/Width/Length)	mm	665 x 335 x 112
Net Weight	Kg	43.5
Gross Weight	Kg	49.5
Typical Application Area (guide only)	m^2	25-30

Figure 6. Data provided by GlanAir brochure. (Glan Air, 2023).

To find the embodied carbon of the system, we found separate data points for the carbon emissions for the heat pump materials, as well as the refrigerant production. In a scholarly article by Finnegan et al. (2018), the researchers synthesized many reports and found that a typical

WMHP has an embodied carbon of 260 kg CO2e/unit. We used this as our best approximation, as we did not have specific details on the materials in the Glan Air specific unit. The WMHP system utilizes R32 refrigerant, which we found from the Mitsubishi study has an approximate embodied carbon of 10.9 kg CO2e /kg R32 (Mitsubishi, . Per each unit, specifics were not given on how much refrigerant is used, so we found another scholarly article that estimates approximately 5.34 kg of refrigerant per unit. Another important consideration in our study is the amount of refrigerant leakage. We approximated that 2% of the total refrigerant needs to be replenished yearly, based on a study by Leiper et al. (2023). Lastly, we needed to approximate how many total units would be needed to provide sufficient heating and cooling to the building, so we used the total assignable area divided by the manufacturer unit area estimate. We chose 28m^2, the midpoint value provided, because Vancouver has a moderate climate.

Determining the operational carbon requires a few further data points. Namely, it requires the energy usage for heating and cooling, the emission factor of electricity from the grid, the R32 annual leakage, and the emission factor of R32. The energy usage was determined using the equation in figure 7.

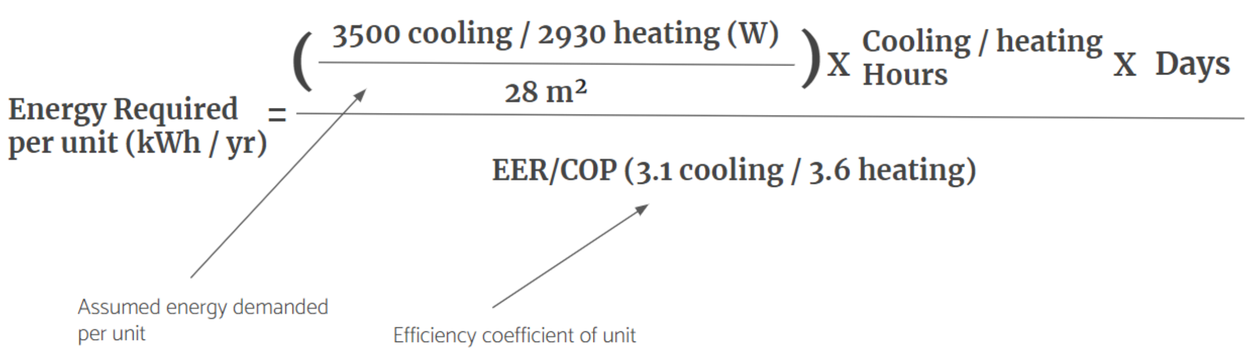

Figure 7. Equation for calculating the energy usage of the WMHP system.

Number of heating and cooling days were extracted from historical Vancouver weather data. We assumed that any day with an average temperature above 18°C was a cooling day, and any day below °C was a heating day. The energy intensity of the electricity grid was specified in our OpenLCA model.

The leakage was the other primary component of our operational carbon emissions. Using the total amount of units, the approximate leakage percentage, and the refrigerant in each unit we could calculate an approximate amount of leakage annually. We found the emission factor of R32 to be 675 kg CO2e through a scholarly article (Leiper, 2023).

Some critical assumptions were used throughout our WMHP analysis. On heating days, we assumed an average use of 10h, and on cooling days an average use of 6h. This was based on approximations based on how far above and below 18 degrees temperature got on average over the amount of days. We also made the assumption that only assignable areas will require heat pumps, which means wall space and corridors are not included.

2.4. Life Cycle Inventory Analysis (LCIA) Modeling

To complete the LCA, sensitivity analysis, and assess environmental impacts for VRF systems vs. Wall-mounted heat pumps and VRF using R410A vs. VRF using R32, OpenLCA software and the ecoinvent 38 database were used. Due to a lack of existing process flows for refrigerants and insufficient data on materials used in the production of individual heat pump units, new processes were created to calculate overall impacts of VRF and wall-mounted heat pump systems. Figure 7 illustrates the processes and data utilized in the LCIA comparing the environmental impacts of a VRF system versus the retrofitting of wall-mounted heat pumps in Ponderosa North, while Figure 8 presents a visualization of the overall scope and boundary of the LCA, including general inputs, outputs, and expected products.

1. Manufacturing	Refrigerants	1 kg of refrigerant, embodied carbon from refrigerant manufacturing
	HVAC units	Mass of units, manufacturer added refrigerant, embodied carbon for unit production, fugitive refrigerant emission
2. Use and operation	VRF and WMHP	total number of units in the building, refrigerant leakage, electricty usage, site added refrigerant, fugitive emissions from refrigerants

Figure 8. Processes used in LCIA for VRF systems versus wall-mounted heat pumps in Ponderosa North.

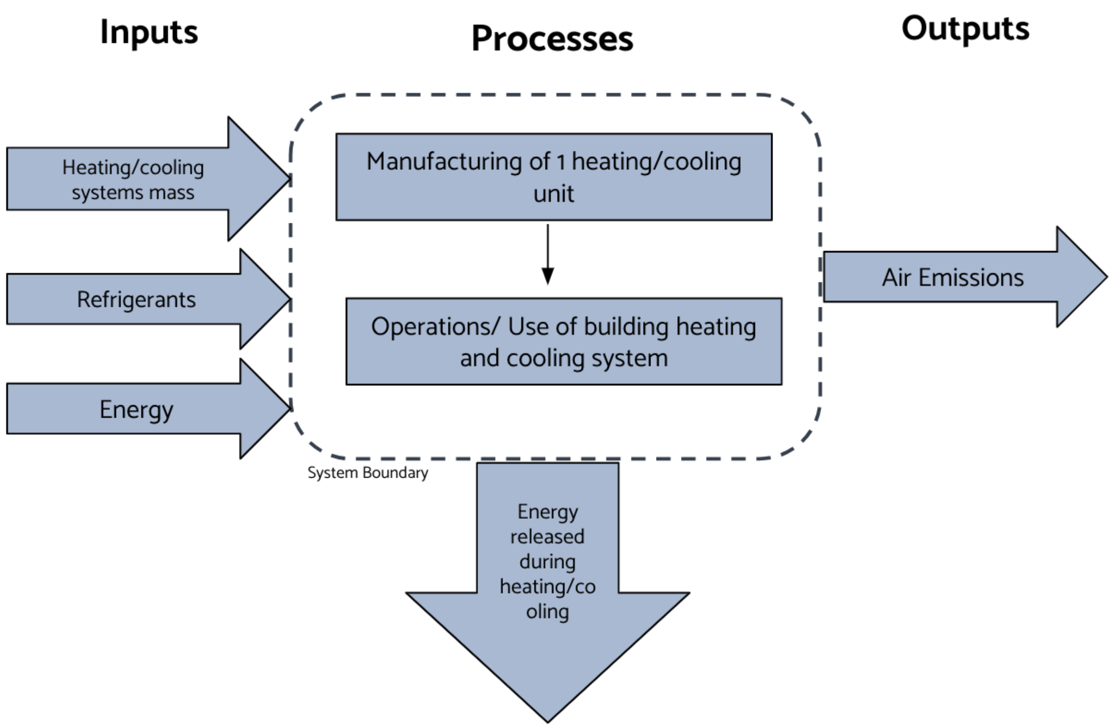

Figure 9. System boundary diagram for LCIA conducted between a VRF system and wall-mounted heat pumps.

The electricity provider was designated as medium voltage, with the power grid selected for British Columbia. Additionally, unspecified carbon dioxide emissions were assumed to be the source of carbon dioxide emissions, given the unknown direct source of CO2 emissions.

2.5. Life-Cycle Impact Analysis

Upon completing the two separate product systems for the VRF system and wall-mounted heat pump system in Ponderosa North, their environmental impacts were compared using the EN15804_A1_2020 impact assessment method. Global warming potential (kgCO2eq) and total heating and cooling output (kWh) served as indicators to evaluate environmental impacts.

2.6. Sensitivity Analysis

A sensitivity analysis was performed for the existing VRF heating/cooling system in Ponderosa North to assess how emissions would change if R32 refrigerant were used instead of R410A. The environmental impacts of the two systems were compared using the EN15804_A1_2020 method, with global warming potential (kgCO2eq) and total heating and cooling output (kWh) serving as indicators to evaluate environmental impacts.

3. Results

HVAC Systems	EI - Global warming 100a (kg CO2e)
GlanAir G32	144,235
VRF (R32)	4,181,740
VRF (R410A)	11,606,500

Figure 10. Results from LCIA demonstrating emissions in kgCO2e for proposed GlanAir G32 units, VRF systems using R32 refrigerant, and the existing VRF system at Ponderosa North using R410A refrigerant.

The results of the study indicate a substantial difference in carbon emissions among the evaluated heating and cooling systems. The existing VRF system using R410A refrigerant exhibits the highest emissions, while switching to R32 refrigerant reduces emissions by more than half. The GlanAir unit shows significantly lower emissions compared to the existing system. Based on the scope studied and the data collected, transitioning to GlanAir units would decrease the carbon impact by a factor of 80.

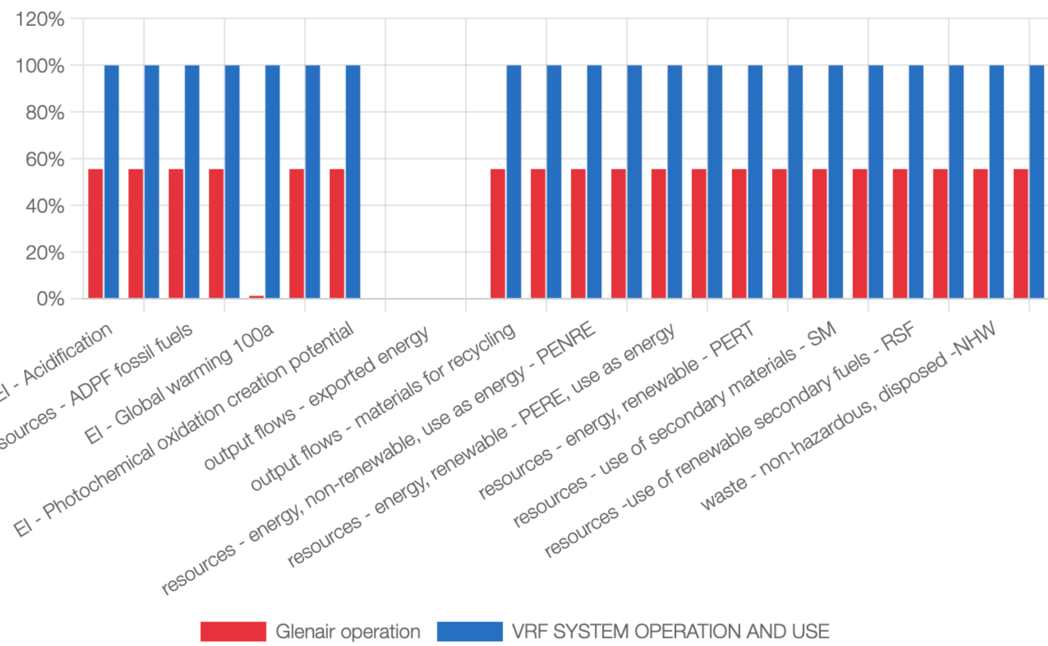

Figure 11. Detailed impact assessment comparisons in percentage from LCIA between proposed GlanAir G32 units and existing VRF system (R410A).

The environmental impacts of GlanAir operation and the existing VRF system across various sectors are illustrated in Figure 11. The GlanAir unit consistently demonstrates a lower percentage of impacts in all sectors, particularly in GWP, constituting only ~1.2% of that emitted by the VRF system. This indicates significantly lower carbon impacts from the GlanAir system during operation, which is a crucial factor in evaluating the feasibility of replacing existing systems. Considering the ~44% reduction in GWP and considerably lower impacts compared to both VRF systems, the WMHP system could be a more suitable and greener alternative to the existing systems.

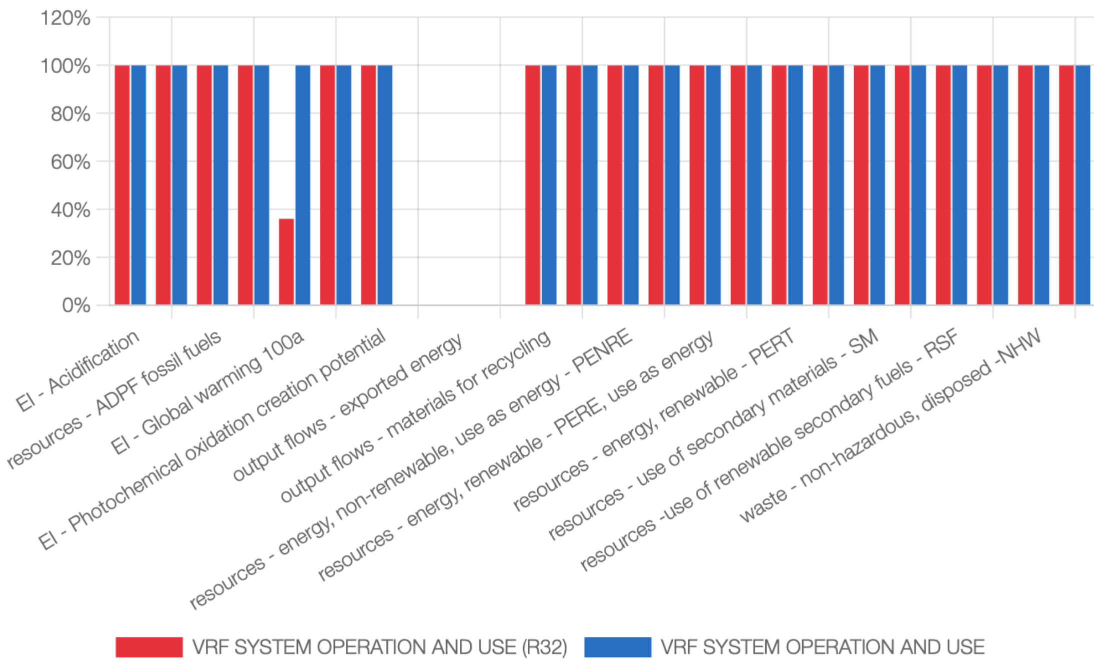

Figure 12. Detailed climate impact assessment comparisons in percentage from LCIA between VRF system (R32 refrigerant, red) and existing VRF system (R410A refrigerant blue).

Figure 12 compares the environmental impacts in various sectors between the two VRF systems utilizing different refrigerants. The impacts in all categories are assumed to be the same since the same production system VRF was used, except for the GWP. As shown in figure 10, the GWP of R32 is around 35% of R410A in result, supporting the argument that R32 has lower impact, especially in fields directly related to emission. The result suggests that using R32 would be a more environmentally friendly alternative for VRF systems using R410A refrigerant.

4. Discussion

4.1. Limitations of Study

Several limitations were discovered during the research, which should be considered when interpreting the results and preparing for future studies. Data accuracy emerged as a significant limitation affecting the reliability of our results during LCA model building. For example, the leakage rates, assumed to be 2% and 6% for WMHP and VRF respectively, were derived from online sources rather than from direct data. This suggests potential inaccuracies particularly for fugitive emissions, which constitute a large portion of the overall emissions. Consequently, the results may not accurately reflect the true carbon impact due to the reliance on these estimated leakage rates. This highlights the importance of precise data, preferably obtained directly from existing HVAC or wholesalers.

The study also holds uncertainty regarding the application of individual heat pumps in large spaces. While the systems are efficient in smaller areas, the performance and effectiveness in larger areas requires further research, The variance in efficiency and energy consumption based on room size would significantly affect the calculation for emissions. It is critical to assess the adaptability of heat pump cross rooms with various scales to determine the scalability of replacing.

Besides the above limitations, the excluded data points as discussed in 2.2 brought up a major challenge in establishing a cradle-to-grave LCIA of the systems. These gaps include aspects such as end-of-life management, emissions from specific material during production, emission generated from transportation and unit installation, the frequency of maintenance and the respective emission, etc. The resulting emissions from these activities are absent due to the complexity involved in data collecting and calculation. As a result, the study may under-estimate the real impact on the environment.

4.2. VRF with R32 Feasibility

From the results of our comparison study, we found that a large share of emissions in the VRF system are coming from R410A leakage. While the heat pump system utilizes R32, which is considered a much greener alternative having a significantly lower emission factor. Further, we found that the producers of the VRF system (LG, Mitsubishi, etc), have started to produce VRF systems that utilize R32 over R410A. While we conducted a brief sensitivity analysis in this study, we suggest that a VRF system that utilized R32 be explored further prior to making a decision. R32 has very credible backing as a greener refrigerant, as well as possibly more efficient. Additionally, our study did not include the installation and retrofit emissions, nor the individual unit lifespan and replacement requirements for the systems, which would be valuable data prior to making a formal decision.

We were not able to find specific cases where R32 is being used or has been used at UBC, however, there are plenty of scholarly articles supporting the transition from R410a to R32. For example, a study by Mota-Babiloni et al., (2017) studied R32's performance in the EU and USA, and found that R32 has similar performance, or improved performance, for both heating and cooling over R410a. This is in addition to a significantly improved GHG impact. The cost of both refrigerants is comparable, with some sources even citing that the cost of R32 is lower (THS, 2023). From our initial research, there are no apparent downfalls to using R32 over R410a.

5. Conclusion

In conclusion, this study conducted a comparative life cycle assessment of VRF systems using R410A and R32 refrigerants and WMHP at UBC Ponderosa North. The results demonstrate that WMHP systems using R32 refrigerant release significantly lower carbon emissions, suggesting their potential as a sustainable alternative to current VRF systems. The transition to the lower-impact systems would align with UBC's climate action goals. However, the study faced limitations, including data accuracy for refrigerant leakage rates and the scale of application for individual heat pumps in large spaces.

For future study, it is suggested to focus on calculating the emissions resulting from recycling and disposal. Given that VRF systems are currently installed and in use, it is especially important to calculate the end-of-life equipment disposal if they were to be replaced by WMHP. Furthermore, conducting a more in-depth analysis of the specific materials used in the production of VRF and WMHP units would provide more accurate data on embodied emissions. The financial perspective should also be investigated to provide a reasonable estimation. The feasibility of VRF systems using R32 refrigerant was also evaluated in the study; more research can be done on upgrading and adapting current equipment. Acknowledging these limitations and uncertainties, the study proposed an inspirative step towards a more sustainable heating and cooling infrastructure at UBC, contributing to broader environmental sustainability efforts.

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