University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

AMS Nest: Net Zero Carbon Emissions by 2025

Direct Emissions Assesment

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List of Abbreviations

ADES → Academic District Energy System

AMS → Alma Mater Society

ASO → Automated System Optimization

BMS → Building Management System

BRDF → Biomass Research and Demonstration Facility

CAD → Canadian dollars

CEC → Central Energy Center

GHG → Greenhouse Gas

HW → Hot water

HVAC → Heating, Ventilation, and Air Conditioning Systems

$kgCO_2e$ → Kilograms of carbon dioxide equivalents

LEED→ Leadership in Energy and Environmental Design

RNG→ Renewable Natural Gas

tCO_2e → Tonnes of carbon dioxide equivalents

UBC → University of British Columbia

Executive Summary

The Alma Mater Society (AMS) student Nest is a LEED (Leadership in Energy and Environmental Design)-platinum certified building located on the University of British Columbia's (UBC) Vancouver campus. The AMS recognizes the impacts of climate change on current and future generations and the urgency to operate in a manner which is sustainable. As a result, the AMS aims to emit net zero direct carbon emissions from the Nest by the year 2025. This project provides an avenue to reach this goal by analyzing Greenhouse Gas (GHG) emissions from the Nest through an emissions inventory report and developing a 5-year management plan. The emissions studied in this project are scopes 1 and 2 emissions, which account for all direct emissions related to building operations and emissions released from the purchase of energy.

The data presented in this report was collected from Skyspark and through communications with building operations, UBC energy and water services, and other UBC/AMS groups. An inventory report of GHG contributors at the Nest was compiled and details emission from the following sources: electricity use, thermal energy from the Academic District energy system (hot water (HW) & steam), natural gas consumption, Heating, Ventilation and Air Conditioning systems (HVAC), and AMS-owned catering vehicle use. Total emissions from 2016, 2017, 2018, and 2019 are calculated to be 643,594, 82,099, 466,139, and 483,301 kgCO2e, respectively. Reconstruction of the Academic District Energy System (ADES) from steam-powered to hot water-powered explains the drastic shift downward in emissions during 2018. In 2019, the percent of emissions from hot water ADES (43%) and natural gas (36%) account for the majority of total emissions. The remaining percent of emissions are from electricity (19%), HVAC (2%), and AMS-owned vehicles (<1%). In analyzing the emissions data over the four years, total emissions appear to increase with the number of students attending UBC and the amount of UBC faculty and staff. Variables, like day of the week and monthly seasonality, were examined and it was found that emissions are significantly lower on the weekends (Friday-Sunday) and during summer months. Also, the amount of biomass relative to natural gas used to power the hot water ADES increases during the summer, which can help explain lower emissions during these months. Seasonality can also be related to the number of people using the Nest, as there may be times of low student/faculty activity

A 5-year management plan for reducing and compensating the Nest's emissions to net zero is presented. Short-term strategies, to be implemented within the next two years, and long-term strategies, implemented within the next five years are discussed. Short-term reduction strategies consist of WiFi heating and cooling, light shelves, smart plugs, and wind turbines. Long-term reduction strategies involve installing an upgraded building management system, doubling the amount solar thermal panels, switching to renewable natural gas, and converting to electric catering vehicles. Employing all reduction strategies is projected to reduce approximately 65% of the total building emissions in 2025 when compared to 2019. It is recommended that the remaining emissions not captured by reduction strategies are compensated by offsets, which are already instituted by UBC but can be further investigated for the Nest specifically. The total capital cost of all strategies is $2,272,446 Canadian dollars (CAD). Strategies that can yield high emissions reductions relative to capital cost and short implementation time are recommended to be prioritized, i.e., Wi-Fi controlled heating and cooling, smart plugs, and switching to renewable natural gas (RNG). Visual strategies, including the wind turbines and solar panels, may have lower emissions reduction potential compared to the strategies aforementioned. However, they can also act as social initiatives to garner interest in the AMS's sustainability goals and inspire change across campus.

1 Introduction

1.1 Background

Each year, the effects of climate change have become more significant, driven largely by the constant emissions of greenhouse gases (GHGs). The greenhouse gas effect is explained by the radiative abilities of GHGs such as carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons, and hydrofluorocarbons which trap heat in the atmosphere [1]. Enhanced greenhouse gas effects are those contributed by human activity, which is responsible for the large shift upward in GHG concentrations in the atmosphere and the associated global temperature increase over the last 100 years [2]. Higher concentrations of GHGs not only affect global temperatures, but also influence sea levels, storm severity and frequency, and precipitation patterns, among others.

GHG management plans are critical for organizations at every level, working towards carbon footprint reduction. A management plan, as discussed in this report, can include two types of strategies: GHG reduction and GHG compensation. GHG reduction strategies are changes to the system that will result in fewer GHGs emitted, which can include strategies such as switching to renewable energy, increasing energy efficiency, and changing old appliances. GHG compensation consists of strategies that counterbalance GHGs already emitted, such as creating carbon sinks or purchasing carbon offsets. Prior to conducting a management plan, a GHG inventory should be taken to assess current and past emissions. A GHG inventory can be taken for a locality, organization, or household to quantify and evaluate the source of GHG emissions. Standards used for generating a GHG inventory discussed in this report are the Greenhouse Gas Protocol, published by the World Resources Institute and the World Business Council for Sustainable Development, and ISO 14064-1:2018, published by the independent, non-governmental International Organization for Standardization (ISO) [3,4]. The purpose of utilizing these standards is to ensure that assumptions, boundary conditions, and methodologies meet standard requirements.

Picture of the AMS Nest building reproduced from the UBC AMS website [5]

Founded in 1915, the Alma Mater Society (AMS) is Canada's oldest student association. The AMS is student-run and advocates for student interests at the university and federal level. Within the University of British Columbia (UBC), the AMS is involved in student services, clubs, and advocacy work. The UBC AMS is centred in the Nest building on campus. In addition to facilities for student services and clubs, the Nest houses numerous dining facilities, student lounges, study spaces, a rock-climbing wall, and more. The building was designed by DIALOG and B+H Associated Architects and construction was completed in 2015.The Nest is LEED-platinum certified, the highest rating for green buildings, and was design with a number of high energy performance strategies and environmental health considerations [5]. However, even as a LEED certified building, the Nest still contributes to global GHG emissions each year. Students at UBC, through initiatives such as the Climate Strike, Climate Emergency Declaration, and Divestment initiatives, have demonstrated that sustainability and climate-friendly action is of critical importance to them. The prioritization of sustainability at the AMS Nest is the driving force behind the creation of the project detailed in this report.

1.2 Problem Statement

The UBC AMS recognizes its contribution to climate change and is actively working to reduce its GHG emissions. By 2025, the AMS would like to achieve net zero carbon emissions for the Nest building. UBC AMS goal of net zero emissions by 2025 is currently hindered by a lack of analysis of emissions and potential strategies to mitigate them. To date, there has not been a thorough investigation or inventory of the GHG emissions generated by AMS at the Nest. Therefore, clear action and management plans have not been able to be established or implemented to effectively reach their goal.

1.3 Objectives

This project aims to provide the UBC AMS with an inventory of direct GHG emissions generated at the Nest and develop strategies to help them achieve carbon neutrality through a 5-year GHG management plan. Specifically, this report will detail the major findings and analyses from the GHG direct emissions inventory and present the data. The 5-year management plan will include benchmarks, emission reduction targets, GHG emission reduction and compensation strategies, and tools for monitoring the results. In addition, this report will include relevant literature on GHG emissions, a systematic mapping, the scope and objective of the study, the methodology used, key assumptions and uncertainties. Finally, this report will provide the UBC AMS with additional communication material in the form of an infographic and poster.

1.4 Scope

The physical boundary of this project is the Nest building and includes only the activities conducted at the Nest, whether they are run by the AMS or outside organizations/companies. Scope 1 and 2 emissions are included in this project which would consist of direct emissions related to building operations and activities as well as emissions related to the production of energy used by the Nest. The emissions from these sources will ultimately be measured as the kilogram of CO_2 equivalents ($kgCO_2e$). What is outside of the bounds of this project are AMS activities run outside of the nest, scope three indirect emissions, environmental impacts not related to GHG emissions, and health impacts of the emissions. The boundaries of this project can be visualized in Figure 1. The inventory report will follow the guidelines set forth in The Greenhouse Gas Protocol and ISO 14064-1:2018.

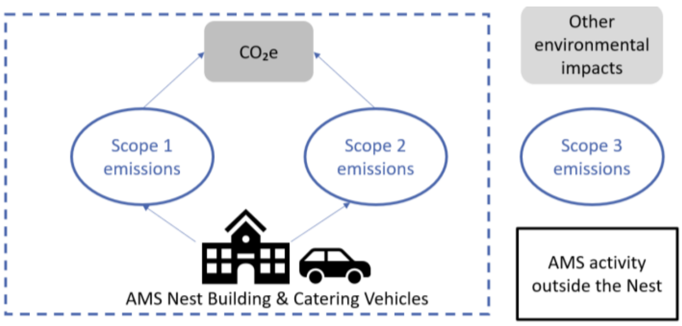


Figure 1 – Project boundaries and scope

1.5 Nest Energy Background

To provide context to the Greenhouse Gas inventory and management plan, a brief overview of the current energy consumption systems at the Nest is given. Figure 2 depicts sources of the major energy inputs to the Nest, including thermal, electrical, and natural gas.

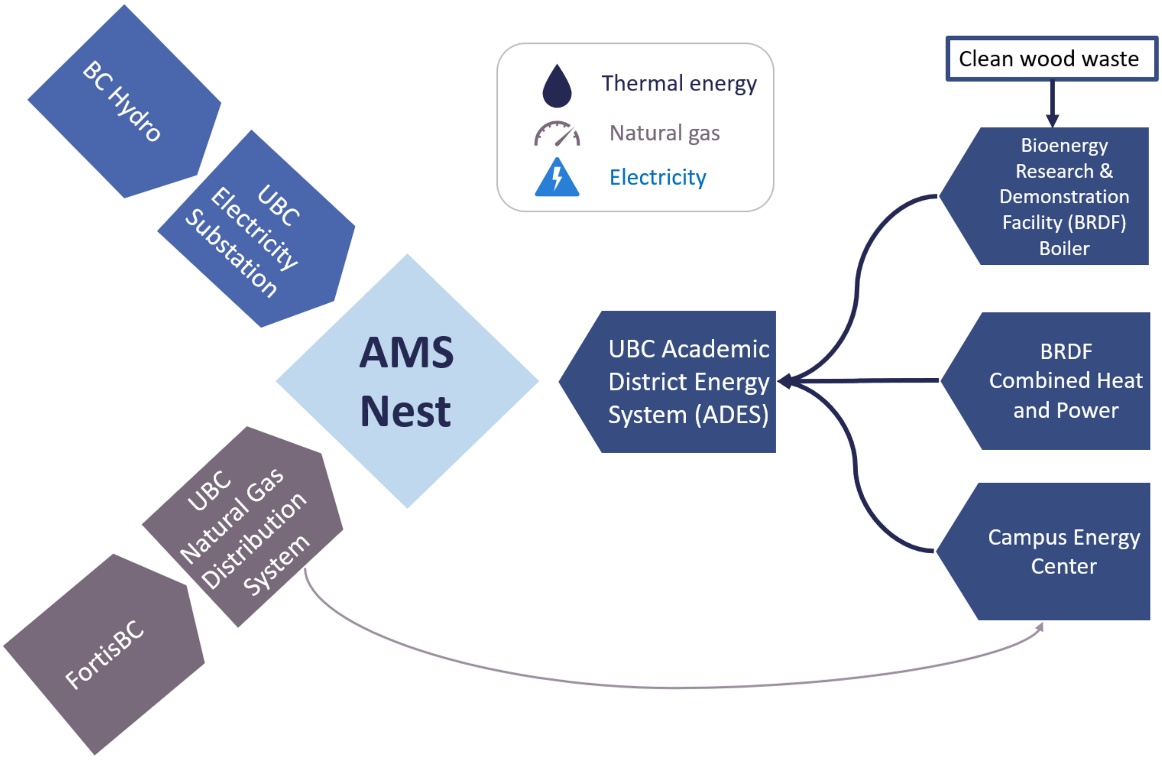


Figure 2 – Energy sources to the AMS Nest Building

Electricity at UBC is primarily generated by BC hydro (97%) and is delivered to the Nest through the UBC North Campus Sub-Station [6]. The remaining 3% of electricity is generated at the on-campus Combined Heat and Power facility [7]. Within the Nest, electricity is used to operate kitchen refrigeration, computer/office equipment, ventilation, and lighting. Electricity also helps power numerous heat pumps, which are partly responsible for the building's heating and cooling. UBC's natural gas is purchased from Shell Energy and is distributed by Fortis BC through the UBC-owned natural gas distribution system on campus [8]. The Nest utilizes this natural gas for operating food and beverage facilities, including the Central food commissary, PR2, Taco and Pit, Honour Roll, The Grand Noodle Emporium and the Gallery Lounge [9]. In addition, natural gas is used to heat internal hot water boilers for domestic hot water (used for sinks, showers, and more). The UBC hot water Academic District Energy System (ADES) is made up of the Biomass Research Demonstration Facility (BRDF), Combined Heat and Power, and Central Energy Center (CEC). These facilities generate thermal energy for water and building heating. Hot water distribution piping circulates the thermal energy across campus and to the Nest. The hot water ADES replaced a 90-year-old steam district energy system in 2017, increasing its energy efficiency by 24% while reducing water usage by 2000% (270 million liters annually) [7]. A breakdown of the energy used within the Nest can be visualized in Figure 3.

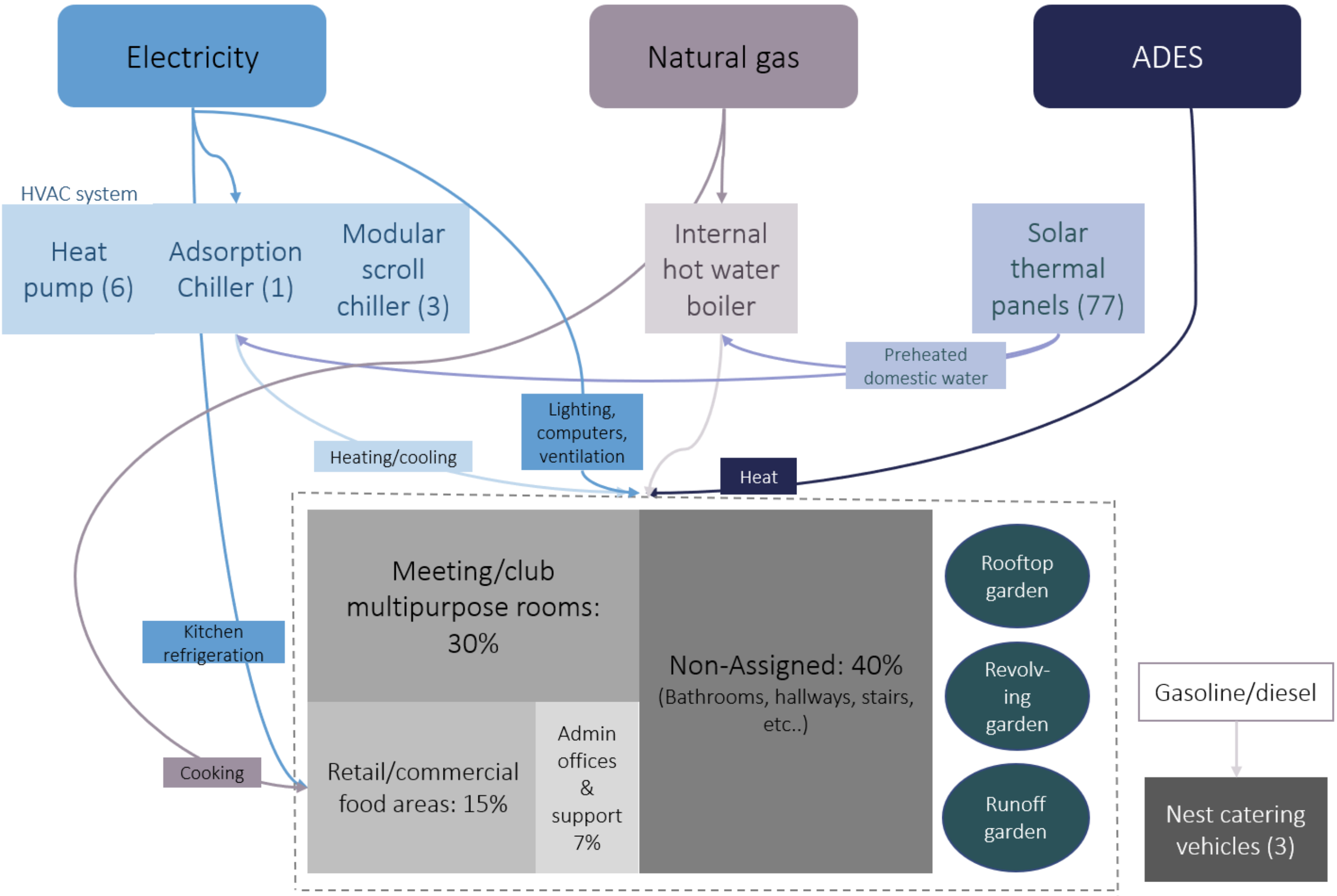


Figure 3 – Energy Utilization within the AMS Nest Building

Electricity within the Nest is used to power the HVAC system, comprised of six heat pumps, an adsorption chiller, and three modular scroll chillers. In addition, electricity is utilized by the retail/commercial food areas for kitchen refrigeration and for lighting, computers, and ventilation throughout the entire Nest. Natural gas is utilized for the internal hot water boilers and for cooking appliances within the dining facilities. Seventy-seven solar thermal panels located on the Nest's roof generate pre-heated water that can be used in the internal hot water boilers and the adsorption chiller. Thermal energy from the hot water ADES provides heat for the building. There are three different gardens within the Nest, the rooftop garden, revolving garden, and runoff garden. All gardens act as GHG sinks, meaning they uptake carbon dioxide and offset the Nest's overall GHG emissions. A rainwater collection system provides water for the rooftop garden, which does not have direct impacts on emissions within the scope of this project but is another sustainability initiative within the Nest. The proportion of area types within the Nest is also illustrated in Figure 5 [10]. Most of the Nest's space is taken up by non-assigned facilities such as bathrooms, hallways, closets, stairs, and elevators. Meeting and club multi-purpose spaces also take up a large portion of the overall area. Although retail and commercial food areas only account for 15% of the Nest's area, they may have a significant impact on energy use, as refrigeration and cooking appliances are used in these spaces. Unfortunately, data is not currently available to allow for an investigation of the independent energy consumption of these spaces.

2 GHG Inventory Methodologies

2.1 Emissions Methodology

To estimate the GHG emissions of the Nest it is necessary to link the activity generating the emission with its emission factor. By simple terms:

$$E = A * EF * (1 - ER/100) \qquad Eq.\ 1$$

Where, E is the GHG emissions, A is the activity rate, EF the correspondent activity emission factor, and ER the overall emission reduction.

For the AMS Nest building, the following sources of emissions were considered:

- Electricity use
- Hot water ADES use
- Natural gas consumption
- Heating, Ventilation and Air Conditioning systems (HVAC)
- Vehicle use (AMS-owned catering vans)

These sources are encompassed in Scope 1 and 2 of the Greenhouse Gases Protocol [11] were discussed with clients to validate their relevance. The following sections (2.1.1 – 2.2.3) will discuss the key methodologies, equations, and assumptions made to calculate GHG emissions from each source. Calculated GHG emissions and analysis are presented in section 3, GHG inventory & analysis.

2.1.1 SkySpark data

SkySpark (https://skyspark.energy.ubc.ca/) is an online tool that can be used to evaluate building energy performance. It tracks energy and facilities resource consumption, which can be used to compare building efficiency.

Energy data was collected from SkySpark from 2016 to 2019. It details energy and power usage from the electricity main meter, hot water main meter, natural gas main meter, and hot water (HW) main meter. Tables 1-4 summarize yearly and monthly energy consumption of electricity, hot water ADES, and natural gas gathered from SkySpark.

Table 1 – Yearly values of variables of interest from SkySpark

Energy profile	**2016**	**2017**	**2018**	**2019**
AMS Nest Elec Main Meter Energy	3389052.1kWh	3939791.5kWh	3270379.0kWh	3179576.5kWh
AMS Nest Elec Main Meter Power	141210.7kW	164146.0kW	136268.3kW	132530.6kW
AMS Nest HW Main Meter Energy	-	-	690210.0kWh	1335750.0kWh
AMS Nest HW Main Meter Power	-	-	47510.2kW	56045.1kW
AMS Nest Gas Main Meter Consumption	84341.6m^3	148052.6m^3	141313.2m^3	90852.3m^3
AMS Nest Water Main Meter Consumption	17932.9m^3	22193.8m^3	22062.9m^3	24136.8m^3

Equation 2 was used to estimate the GHG emissions by electricity consumption at the Nest. Eq. 2 uses the energy profile of the British Columbia grid and their corresponding emission factor (available by the Government of British Columbia) [12]. Table 2 indicates the energy use by month at the Nest.

$$E\ (KgCO_2e/year) = Energy\ use\ (KWh/year) * EF\ (KgCO_2e/MWh)/1000 \qquad Eq.\ 2$$

Table 2 – Monthly sum of AMS Nest Elec Main Meter Energy from SkySpark

Month	2016	2017	2018	2019
January	280993.5kWh	337036.0kWh	279083.0kWh	255621.5kWh
February	264075.4kWh	295976.5kWh	246417.0kWh	228926.5kWh
March	278177.6kWh	347193.0kWh	278629.0kWh	270696.8kWh
April	262083.6kWh	296178.0kWh	261019.0kWh	250882.0kWh
May	251667.3kWh	303068.5kWh	277438.0kWh	265262.3kWh
June	255092.8kWh	322814.5kWh	272019.5kWh	270686.8kWh
July	284344.5kWh	351774.0kWh	308755.7kWh	291691.5kWh
August	289687.3kWh	356991.0kWh	308205.9kWh	293896.3kWh
September	279944.0kWh	366310.5kWh	276660.4kWh	279391.5kWh
October	308799.5kWh	349902.0kWh	279688.4kWh	270934.5kWh
November	320967.8kWh	334366.0kWh	259558.0kWh	261817.0kWh
December	313219.0kWh	278181.5kWh	222905.1kWh	239770.0kWh

Equation 3 was used to estimate the GHG emissions from natural gas consumption at the Nest. Eq. 3 applies the corresponding emission factor for non-marketable natural gas for British Columbia according to the BC Best Practices Methodology for Quantifying Greenhouse Gas Emissions [13]. Table 3 indicates the consumption of gas by month at the Nest.

$$E\ (KgCO_2e/year) = Gas\ use\ (m^3/year) * K\text{-}factor\ (GJ/m^3) * EF\ (KgCO_2e/GJ) \qquad Eq.\ 3$$

Table 3 – Monthly sum of AMS Nest Gas Main Meter Energy from SkySpark

Month	2016	2017	2018	2019
January	368.2m³	35509.5m³	7450.2m³	17785.9m³
February	336.0m³	20810.2m³	6600.7m³	7928.8m³
March	334.3m³	23188.8m³	11307.0m³	8993.5m³
April	183.2m³	21523.8m³	21031.1m³	7362.4m³
May	75.5m³	5921.1m³	10293.2m³	6798.9m³
June	4422.1m³	9217.2m³	6835.7m³	5572.8m³
July	10293.2m³	4901.7m³	6147.6m³	6252.4m³
August	7393.6m³	4564.7m³	5476.5m³	5923.9m³
September	13283.5m³	7382.3m³	10992.7m³	8829.3m³
October	11856.3m³	5722.8m³	18069.1m³	10276.3m³
November	8888.7m³	5646.4m³	19445.3m³	5128.2m³
December	26906.8m³	3664.2m³	17664.2m³	0.0m³

The biomass gasifiers at the BRDF provide heat for the district energy systems hot water, which is then sent to the Nest. The emission factor for HW ADES is a function of the amount of natural gas vs.

biomass used. The future CO_2e are projected to decrease due to the BRDF expansion which is scheduled to be completed in 2021. Twenty-five percent of hot water from the ADES is currently powered by biomass. The remaining seventy five percent remaining comes from the burning of natural gas or renewable natural gas (renewable is only a small portion) [19]. In the future, biomass use is expected to increase to 70%. The emission factors pre-2021 and post-2021 expansion were provided by building operations [19]. Therefore, Equation 4 was used to estimate the emissions related to this source. Table 4 gives the hot water energy use by month at the Nest and the emission factors used.

$$E\ (KgCO_2e/month) = Energy\ use\ (MWh/month) * EF\ (KgCO_2e/MWh)$$

Table 4 – Monthly sum of AMS Hot Water Main Meter Energy from SkySpark

Month	2016	2017	2018	2019	EF pre-2021 (kg CO2e/MWh)	EF post-2021 (kg CO2e/MWh)
January	-	-	0.0kWh	130720.0kWh	206.36	206.00
February	-	-	0.0kWh	210349.8kWh	206.36	206.00
March	-	-	141180.0kWh	170250.0kWh	206.36	206.00
April	-	-	40600.0kWh	129550.3kWh	206.36	12.00
May	-	-	33230.0kWh	70470.0kWh	206.36	12.00
June	-	-	45310.0kWh	44729.8kWh	206.36	12.00
July	-	-	30030.0kWh	35560.3kWh	11.52	12.00
August	-	-	34429.8kWh	31350.0kWh	11.52	12.00
September	-	-	73140.3kWh	53170.0kWh	206.36	12.00
October	-	-	106599.8kWh	136990.0kWh	206.36	206.00
November	-	-	90210.3kWh	137789.8kWh	206.36	206.00
December	-	-	95480.0kWh	184820.3kWh	206.36	206.00

2.1.2 Steam energy

The main use of hot water in the Nest is for heating. From 2012-2018, the building was heated by steam generated from the combustion of natural gas in campus boilers and biomass from the BRDF. Prior to the conversion of the UBC pipeline from steam to hot water, the major GHG emitter, accounting for almost 80% of the emissions at UBC, was the natural gas use for steam generation [14]. However, SkySpark had no data collection of building heating from steam. This explains the increase in GHG emissions in 2018, as it accounts for emissions from the hot water heating system.

To estimate the potential emissions of the steam use (before the switch to hot water), it was assumed that the average temperature each month could be correlated with the energy required to heat the building. To validate this assumption the temperature and hot water energy of each month in 2019 was used to build a scatter plot and perform a regression analysis. The Pearson correlation test found was -0.94 thus validating the assumption (see Figure 4).

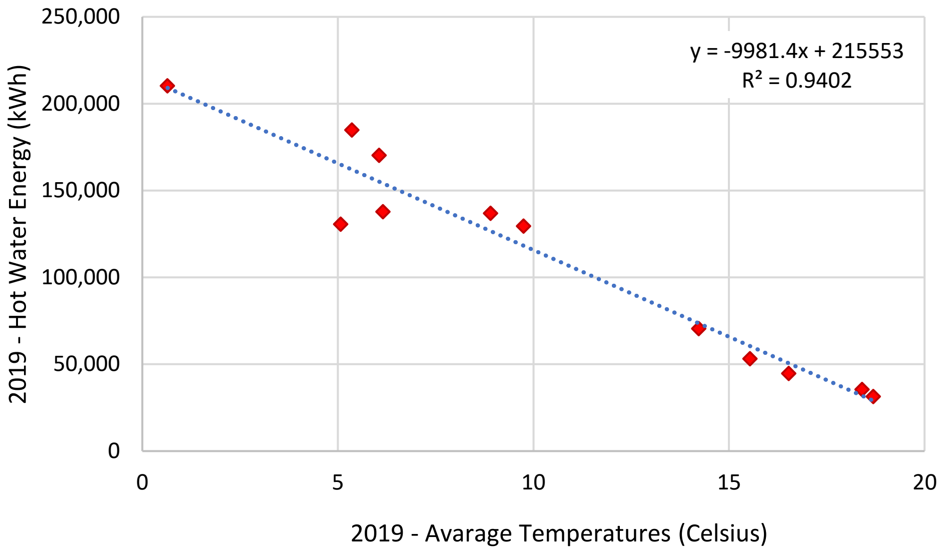


Figure 4 - Linear regression analysis of temperature and energy required for heating at the Nest

Based on the 2019 data, the regression equation showed it was possible to estimate the steam energy from the monthly temperature in 2016 – March/2018. Table 5 gives the energy required to heat the Nest each month and year based on this analysis. Furthermore, UBC states that the steam system had an overall efficiency of 60% while the hot water increased this to 86% [14]. Both percentages are considered in the estimations.

Table 5 – Calculated estimations of steam use for heating at the Nest

Steam/Hot Water Energy	2016 (Steam)	2017 (Steam)	2018 (up to Feb: Steam)	2019 (Hot Water)
January	167137.8kWh	194666.2kWh	158997.9kWh	130720.0kWh
February	146635.4kWh	185592.4kWh	180601.7kWh	210349.8kWh
March	132579.9kWh	151048.7kWh	141180.0kWh	170250.0kWh
April	97145.9kWh	121981.5kWh	40600.0kWh	129550.3kWh
May	73485.8kWh	86213.4kWh	33230.0kWh	70470.0kWh
June	57008.4kWh	58545.4kWh	45310.0kWh	44729.8kWh
July	34878.9kWh	32291.0kWh	30030.0kWh	35560.3kWh
August	32488.2kWh	26948.8kWh	34429.8kWh	31350.0kWh
September	72493.2kWh	54950.9kWh	73140.3kWh	53170.0kWh
October	105011.7kWh	116610.2kWh	106599.8kWh	136990.0kWh
November	121974.9kWh	145952.3kWh	90210.3kWh	137789.8kWh
December	204777.7kWh	187830.8kWh	95480.0kWh	184820.3kWh

2.1.3 HVAC System

The HVAC system in the AMS consists of the equipment given in Table 6. This information was provided by building operations staff [15].

Table 6 – HVAC system installed at the AMS Nest Building [15]

Quantity	Tag	Type	Refrigerant	Charge
1	CHILLER 1	Water to Water Modular Scroll	R410A*	27.5 lbs
1	CHILLER 2	Water to Water Modular Scroll	R410A*	27.5 lbs
1	CHILLER 3	Water to Water Modular Scroll	R410A*	27.5 lbs
1	CHILLER 4	Adsorption	SILICA	1000 lbs
3	HP	Heat pump – 10 ton	R410A*	10.38 lbs
4	HP	Heat pump – 5 ton	R410A*	82 oz
4	HP	Heat pump – 3 ton	R410A*	50 oz
16	HP	Heat pump – 2 ton	R410A*	40 oz
2	HP 10 & 12	Heat pump L2 art storage L3 AMS archive	R407c**	Not listed
2	HP 18a & B	Heat pump	R410A*	40 oz

*R410A = 50% HFC-32 and 50% HFC-125; **R407c = 23% HFC-32, 25% HFC-125 and 52% HFC-134a

The GHG Protocol [11] dictates that the global emissions of the HVAC system are a function of its assembly (installation), operation, and disposal. For this report, only the operational emissions were estimated because: i) no installation information was available; and ii) the HVAC system is not expected to be disposed of during the timeline evaluated. Equation 5 was used to calculate the emissions of the HVAC system

$$OE\ (kgCO_2e) = Sum\ (1\ to\ m)\ of\ [Ni\ *\ Ci\ *\ ALRi\ *\ T\ *\ GWP] \qquad Eq.\ 5$$

Where, OE is the emissions from the HVAC at operation, "i" is the HVAC type, Ci the original refrigerant charge in each equipment (kg), ALR the annual leakage from equipment type "i" (%), GWP the 100-year global warming potential of the refrigerant used, "T" the number of years in use and "m" the number of different types of equipment.

2.1.4 Vehicle use

The emissions, in $kgCO_2e$, from vehicle use of the AMS Nest staff excluding (personal vehicles) were estimated and summarized below. The Nest owns and operates three catering vans that deliver catering to clients, usually on the UBC campus, and commute weekly to Westbrook village [16]. Nest catering provided values for average weekly kilometers (km) driven by each vehicle and their fuel efficiencies [16]. Fuel use in liters (L) per week was calculated from the given values.

Table 7 summarizes the make and model of the catering vehicles, the average weekly distance driven, fuel efficiency, and weekly fuel usage.

Table 7 – Vehicles operating at the AMS Nest Building [16]

Vehicles	**Km/Week**	**Fuel Type**	**Fuel efficiency (Km/L)**	**L/week**
 Ford Transit Connect	15	Gasoline	10.2	1.47
 Ford Econoline	5	Gasoline	7.2	0.69
 Mercedes Sprinter	5	Diesel	12.0	0.42

The GHG emissions from the vehicle use were estimated by Eq. 6, where the emission factor is a function of the fuel type (F).

$$E\ (kgCO_2e/year) = L\ (km/year) * EF\ (kgCO_2e/km) \quad Eq.\ 6$$

For the Ford Transit Connect and Ford Econoline an emission factor of 2342.98 $kgCO_2e/L$ was adopted using the emission factor from the ANNEX 6 EMISSION FACTORS of Canada's GHG inventory [3]. The Mercedes Sprinter EF from the same source was 2705.08 $kgCO_2e/L$.

2.2 Carbons sinks methodology

2.2.1 Rooftop Garden

The Rooftop Garden has 192m² of fenced gardening space and grows produce which is sold to food outlets and the community [17]. A recent Life Cycle Assessment review study showed that Rain Gardens have a net carbon footprint of 12.6 $kgCO_2e/m^2$ over 30 years and a mean carbon sequestration of 75.5 $kgCO_2e/m^2$ over 30 years [18]. Based on this study, the Rooftop Garden would have a carbon sequestration potential of 2.5 $kgCO_2e/m^2/year$ from Eq. 7.

$$E\ (kgCO_2e) = A\ (m^2) * (-1)*EF\ (kgCO_2e/m^2) \quad Eq.\ 7$$

2.2.2 Revolving Garden

The Revolving Garden, designed by mechanical engineering students at UBC, consist of several, large wooden pods with hanging plants positioned along windows in the foyer of the Great Hall. According to information shared by building operations [9], the following plants are part of the garden:

- Pothos 'Marble Queenn'/'Pearls of Jade' (x3)

- Golden pothos (x2)
- String of hearts (x7)
- Spider plant (x6)
- Polka Dot Plant (x3)
- Croton (x6)

At total 27 plants, from varying species and native regions around the globe are part of the garden. In communication with building operations [9], the total area was determined to be 31.5 ft^2 (or 2.93 m^2). This area was then converted to a fictional correspondent diameter (76 in) and Equations 8 to 12 used to estimate the total carbon capture. Plant heights were assumed to be 1.5 ft max and plant age was estimated at two years. With this info, it was possible to estimate the dry weight of carbon stored by each plant, and giving their age, the total carbon sequestration per year[1].

$$Weight\ (W) = 0.25 * (d^2) * h \qquad Eq. 8$$

$$W_{green} = 1.2 * W \qquad Eq. 9$$

$$W_{dry} = 0.725 * W_{green} \qquad Eq. 10$$

$$C_{content} = 0.5 * W_{dry} \qquad Eq. 11$$

$$CO_2 = 3.67 * C_{content} \qquad Eq. 12$$

2.2.3 Runoff Garden

The Runoff Garden consists of young plants distributed in a fashion stairway architecture descending from the ceiling. The garden was designed in such way that excess water in one space drops to the next (below) feeding all plants. Similar to the Revolving Garden it includes a variety of plants species—namely:

- Pothos 'Silver Satin' (x5)
- Polka Dot Plant (x4)
- Nerve Plant (x6)
- Wandering jew (x4)
- Coleus (x6)
- Croton (x6
- Peace Lily (x2)

The total area was determined to be 11.25 ft^2 (or 2.93 m^2). The same methods and equations as for the Revolving Garden were used to estimate the total carbon sequestration each year.

3 GHG Inventory & Analysis

3.1 Annual emissions (Electricity, Gas, Hot Water)

For the annual emissions, the trend of GHG emissions against the annual headcount of students and staff were compared in Figures 5 and 6, respectively. Headcount information was

[1]EcoMatcher gives the closest method to estimate the carbon sequestration in this case: https://www.ecomatcher.com/how-to-calculate-co2-sequestration/

obtained using the Fact Sheet Winter 2020 University of British Columbia, Vancouver Campus. It was not possible to obtain information regarding visitor frequency to perform a granular analysis for monthly, weekly, or daily occupancy. This is suggested for further analysis in future.

The combined emissions from natural gas consumption and electricity use were 270.80 tCO_2e in 2016, 411.67 tCO_2e in 2017, 356.46 tCO_2e in 2018, and 271.05 tCO_2e in 2019. Since 2018, there has been a constant decrease in the emissions. In 2019 the levels were as similar to those in 2016 even though there has been a steady increase of students and faculty at UBC. This trend might indicate an expected decrease of the combined emissions for the following years. The switch to a hot water energy heating system may explain the drastic drop in emissions between those years, of approximately 74% less carbon dioxide equivalent emissions to the atmosphere.

The relationship between the annual emissions and the number of students and staff appears to be segmented between the years of 2016/2017 and 2018/2019. In other words, for the first two years there is a proportional relationship, and then the heating system switch reduces the emissions in 2018. However, even though the type of heating is changed the proportional relationship remains in the following year (2019), i.e., the emissions increased with student/staff increase. The relationship is stronger for student headcount.

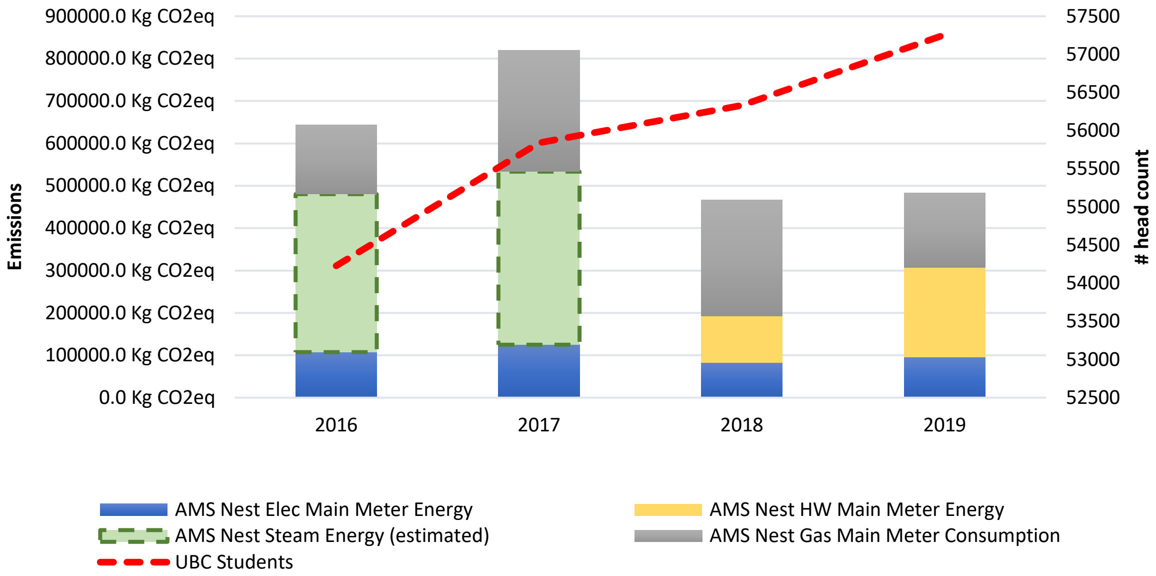


Figure 5 – GHG Emissions apportionment by year in contrast to UBC student population growth

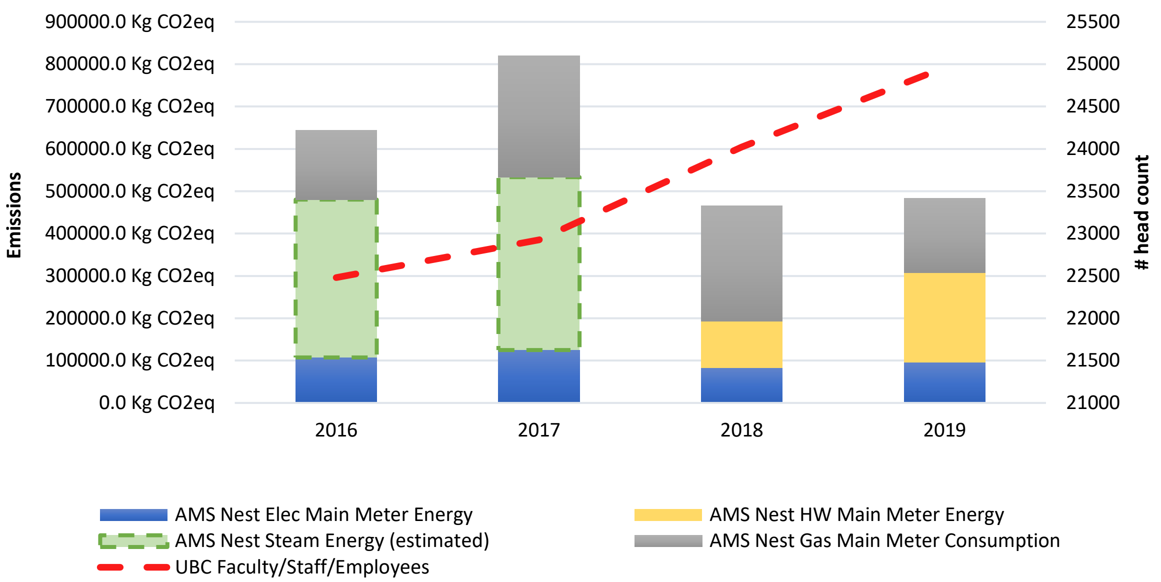


Figure 6 – GHG Emissions apportionment by year in contrast to UBC staff population growth

3.2 Monthly emissions (Electricity, Gas, Hot Water)

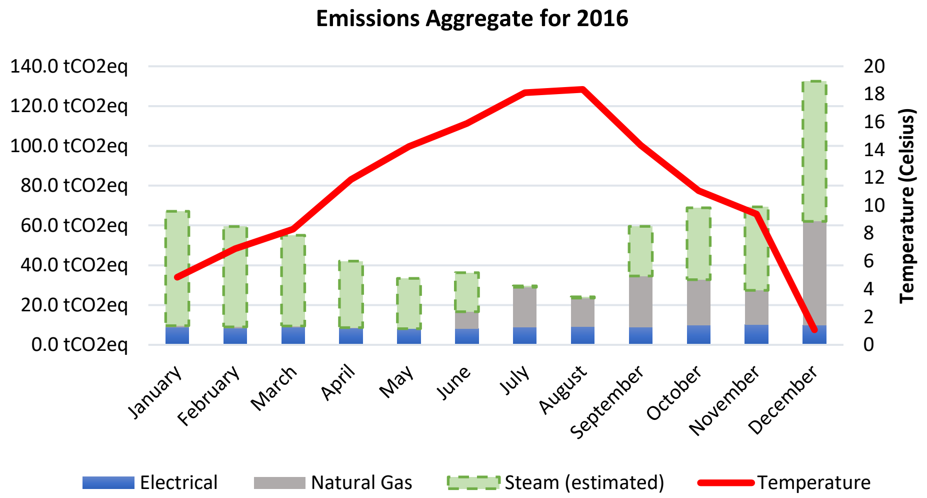
The emissions by month were analyzed to determine if a pattern would emerge. The results were matched to the meteorological variables mean temperature and accumulated precipitation for the respective months – obtained from BC Station Data Vancouver Airport.

For 2016 (see Figure 7), an increase in emissions appears after June with the accounting of the natural gas consumption at the Nest. A slight variance of natural gas emissions occurs between July to November. In December 2016, a peak in emissions is attributed to natural gas and steam energy consumption, i.e. emissions from natural gas and steam were higher in December than any other month of 2016. The meteorological variables do not explain this peak, but the overall correlation was strong for temperature (R -0.85) and fair (R 0.66) for precipitation. Further investigation is necessary to determine the reason. The emissions generated by the electricity consumption remained steady to low for the entire year. Without counting for natural gas consumption, the steam required to heat the building was the highest contributor for the period of January to June.

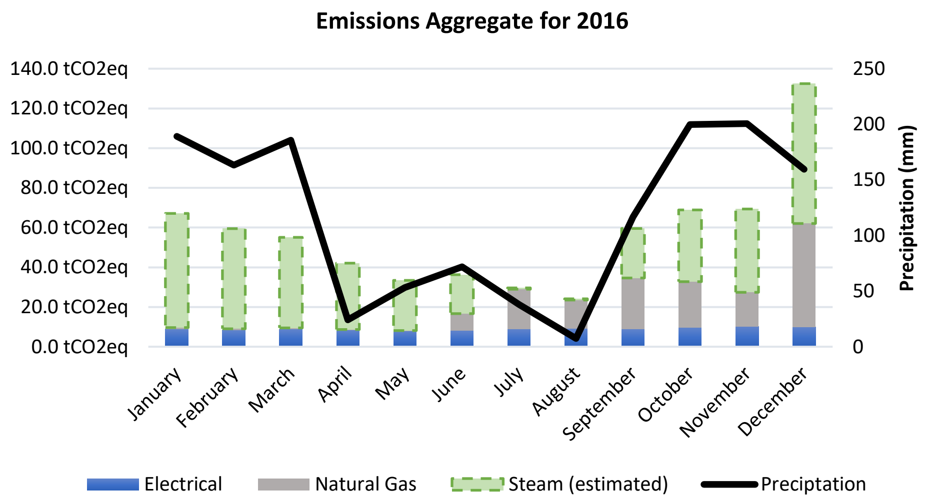
In 2017 (see Figure 8), unlike in 2016, the emissions started high and decreased until May. They briefly rose in June and then continued to decreased, reaching the lowest levels in August before starting to increase again. The natural gas consumption was responsible for the largest percentage of emissions at the Nest from July to August. The electricity usage remained steady most of the year. The meteorological variables seem to relate to emissions more than the previous year. The overall inverse correlation was strong for temperature (R -0.90) and fair correlation (R 0.61) for precipitation.

In 2018, after March, the hot water use entered the balance of emissions (see Figure 9). Since then, a clearer seasonal pattern has appeared, with the months of May – September (summer terms) having the lowest emissions and October – April (winter terms) having the highest. Electricity use accounts for the least emissions and for the majority of 2018, natural gas consumption remained the main emitter of GHGs. The overall inverse correlation was strong for temperature (R -0.96) and fair (R 0.64) for precipitation.

In 2019, the situation changed with hot water use generating more GHGs than natural gas (see Figure 10). This change in the emissions profile is rather important because illustrates less dependency of the Nest on natural gas with time. With the plan for hot water generation to change from 25% t0 70% powered by biomass in the next few years, the emissions are also expected to decrease. The overall inverse correlation was strong for temperature (R -0.93) and fair (R 0.55) for precipitation.

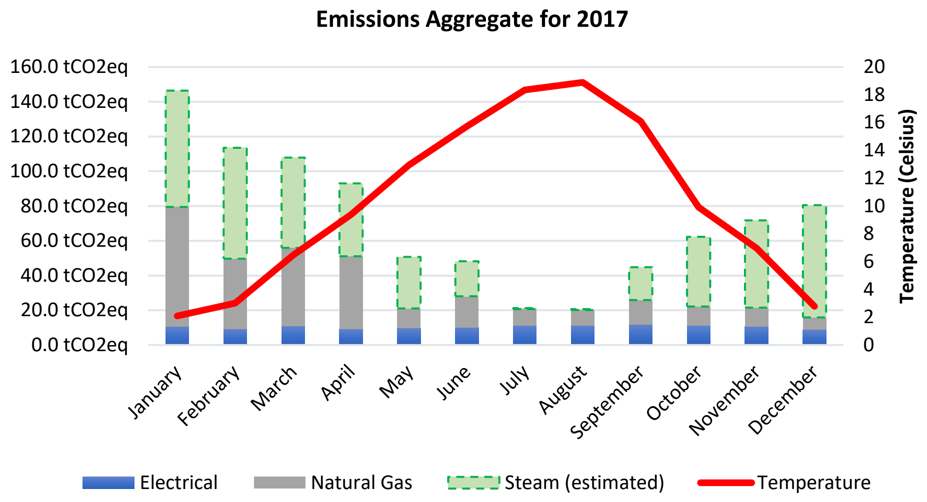


(a)

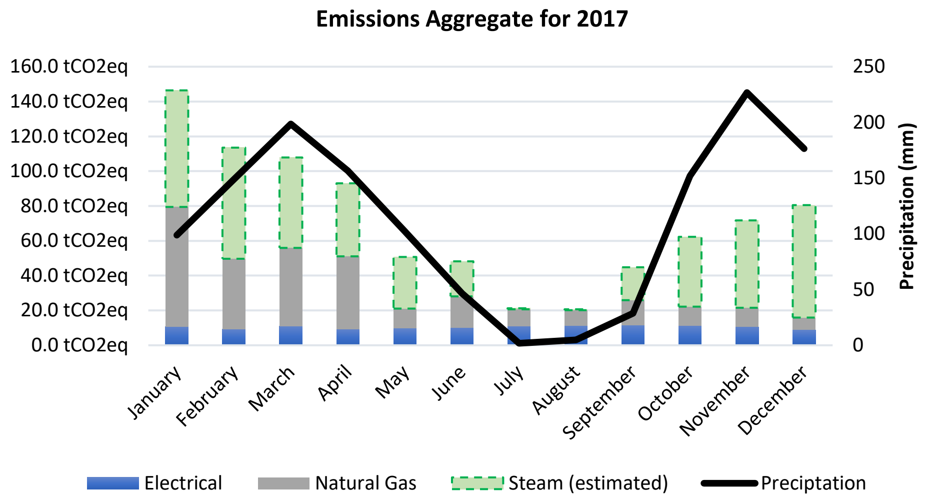


(b)

Figure 7 – GHG Emissions apportionment by month of 2016 in contrast to temperature (a) and precipitation (b) in Vancouver.

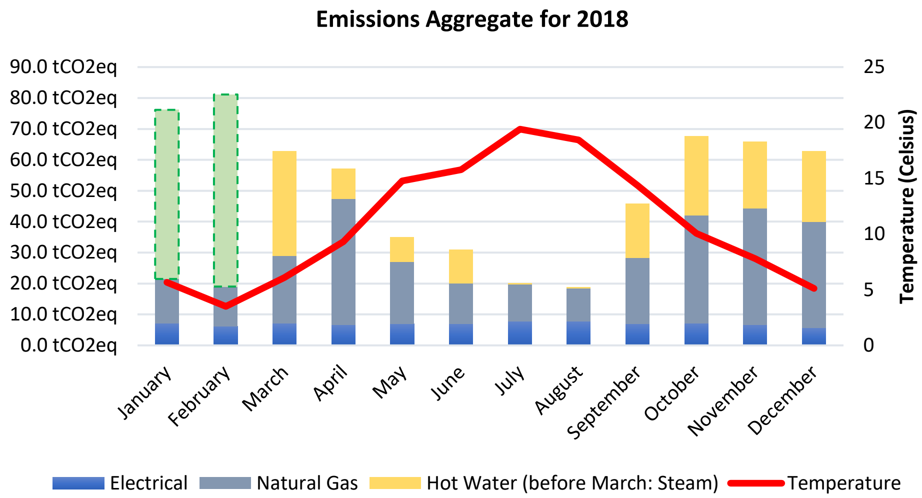


(a)

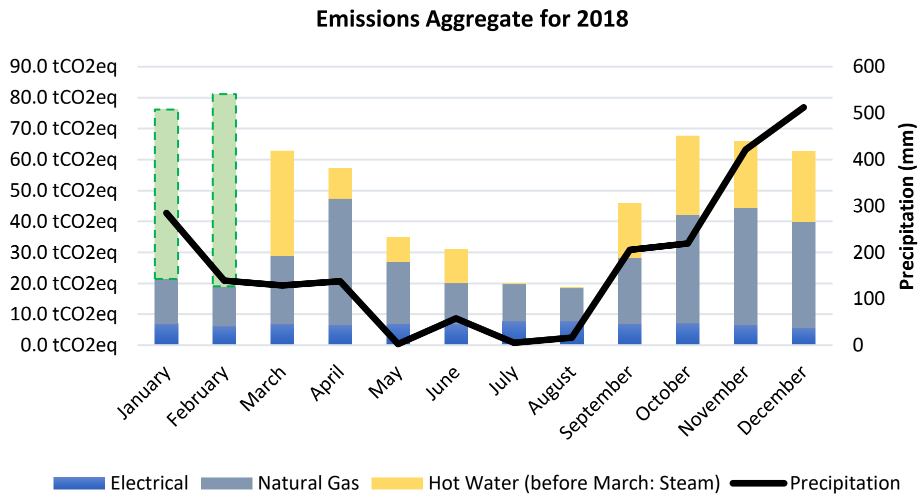


(b)

Figure 8 – GHG Emissions apportionment by month of 2017 in contrast to temperature (a) and precipitation (b) in Vancouver.

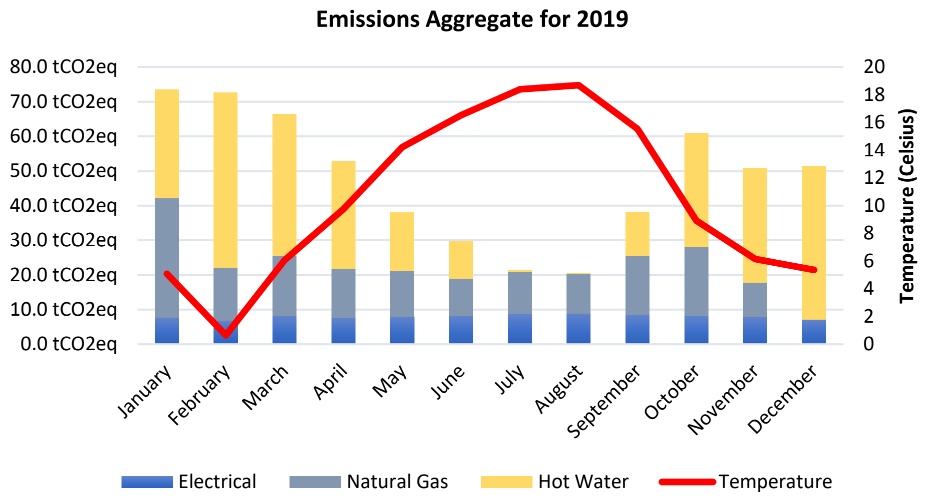


(a)

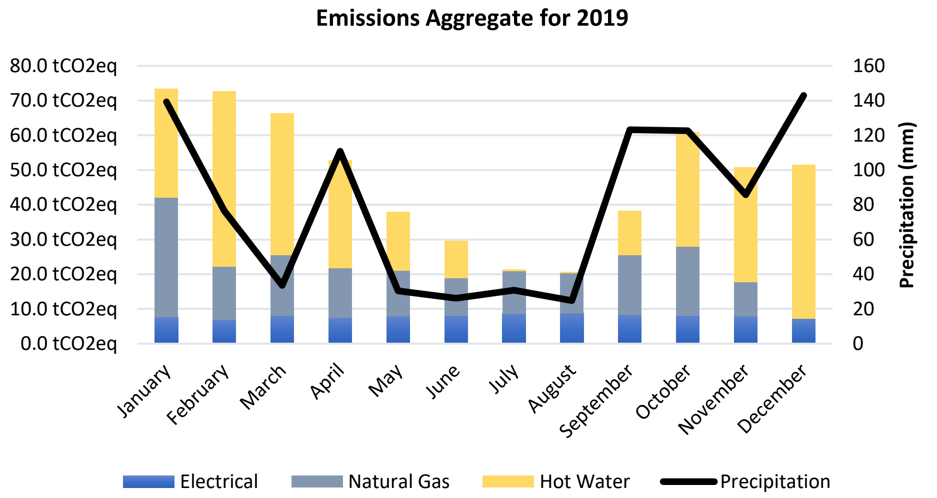


(b)

Figure 9 – GHG Emissions apportionment by month of 2018 in contrast to temperature (a) and precipitation (b) in Vancouver.



(a)



(b)

Figure 10 – GHG Emissions apportionment by month of 2019 in contrast to temperature (a) and precipitation (b) in Vancouver.

In conclusion, the emissions at the Nest appear to have a seasonality factor and are inversely correlated to temperatures in the Vancouver region. The building design favors a lower use of energy per m^2 than other buildings of the same size and range of facilities. Additionally, the emission factor of the grid in British Columbia is lower than other sources provinces which may explain the overall low emissions. In addition, reducing the amount of natural gas consumed by the Nest would greatly mitigate the buildings net emissions.

3.3 HVAC System

To calculate the HVAC emissions under operation conditions, a leakage of 5% was assumed for each piece of equipment. From all equipment in use at the Nest, the emissions of Chiller 4 are inexistent due to the silica technology applied [20]. The Heat Pump (HP) 10 and 12 could not be estimated due to lack of detailed information about the refrigerant and charge, respectively. All other systems use the same refrigerant, R410A, which is a mix of 50% HFC-32 (677 CO_2e GWP 100y) and 50% HFC-125 (3170 CO_2e GWP 100y). The different charges of refrigerant are responsible for the variance in emissions. The HP 10 and 12 use a different refrigerant, R407c, which is a mixture of 23% HFC-32, 25% HFC-125 and 52% HFC-134a (1300 CO_2e GWP 100y). Proportionally, R407c impact less climate change than R410A. However, an investigation of different alternatives and refrigerant capacity is necessary before indicating a substitution. A list of several refrigerant and their GWP 100y values is given in the Appendix. For comparison purposes, the refrigerant charge assumed of HP 10 and 12 was the same of HP 18a & B.

It should be noted that the time component used in the equation was assumed to be the four years investigated. Furthermore, that only one charge per year is necessary. For a more precise emissions report, is necessary to know which equipment is in use during each day, week, or month of the year and additionally, how many refrigerant replacements occur per year. Figure 11 gives the total emissions accounting for the period of 2016 to 2019. In looking at the emissions from each piece of equipment over a four-year period, an approximation of the monthly emissions of natural gas, electricity and hot water use at the Nest was calculated. In looking at this data, it is important to consider that assumptions were made in collecting this data and its interpretation may reflect inaccuracies in these assumptions.

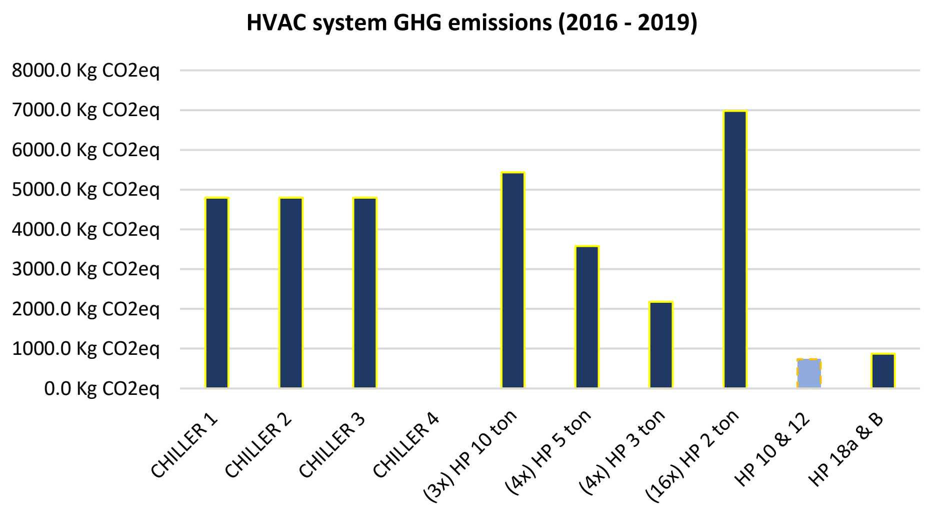


Figure 11 – Emission apportionment type of HVAC equipment

3.4 Vehicles use

The annual emissions found for years with 52 weeks (non-leap years) for the Ford Transit Connect was 179.2 KgCO_2e, for the Ford Econoline 84.6 KgCO_2e and finally for the Mercedes Sprinter 58.6 KgCO_2e. In terms of overall emissions compared to other sources, the vehicles are of less concern due to the low kilometers travelled per week. If possible, using the Mercedes Sprinter more than the Ford models would reduce the carbon footprint of this source. Alternative ways of delivering services could be investigated as well or investing in Natural Gas vehicles that have low emission factors. The drawback of the last option is that natural gas vehicles often have less space due to the gas tank installed.

3.5 Current carbon captures at the Nest

The carbon sink from the Rooftop Garden is estimated to be 921.6 $kgCO_2e$. The Runoff Garden has a carbon sequestration potential of 279.75 $kgCO_2e$/year (or 8.47 $kgCO_2e$/year/plant). The Revolving Garden, on another hand, sequestrates 783.31 $kgCO_2e$/year (or 29.01 $kgCO_2e$/year/plant). All combined they can capture approximately two tCO_2e/year. This is less than a quarter the total emissions from the HVAC system. However, it compensates the emissions from vehicles use almost six times.

The total energy saved from the cooling effect of the carbon sinks is already accounted for by the energy meter in SkySpark. As a result, only carbon sequestration is considered as a GHG sink.

3.6 Projections

To project the emissions of greenhouse gases of the AMS Nest, a few assumptions/considerations were made:

- HVAC system continues to emit the same amount (if no more info about its frequency use is disclosed)
- The HW Meter presented a strong relationship with temperature, thus, the expected temperature for each month for 2022 to 2025 was estimated based on observations from 1938 to 2021 (obtained at - https://vancouver.weatherstats.ca/charts/temperature-monthly.html). More information is available at the Appendix.
- No clear pattern for Electricity consumption could be established, thus the same emissions for the base year (2019) are assumed.
- No clear pattern for Natural Gas consumption could be established, thus the same emissions for the base year (2019) are assumed.
- The forecasted emission factor for Electricity Emissions was kept 29.9 $KgCO_2e$/kWh, the same as the base year 2019.
- The forecasted emission factor for Natural Gas Emissions was kept 0.04987 $KgCO_2e$/kWh, the same as the base year 2019.
- The forecasted emission factor for Hot Water Emissions was 206 $kgCO_2e$/MWh for the months of January to March and October to December, and 12 $kgCO_2e$/MWh for April to September, as disclosed by Building Operations.
- All scenarios (2022 to 2025) consider that the effects of the global COVID-19 pandemic will be restricted to the year of 2021, treated as an abnormal year in terms of emissions.

Figures 15 to 18 show the results for the monthly projected emissions for 2022, 2023, 2024, 2025, respectively. Based on the analysis, the AMS Nest is projected to cumulatively emit 1872.5 tCO_2e between 2022 and 2025. As a result, those emissions must be accounted for in the management plan.

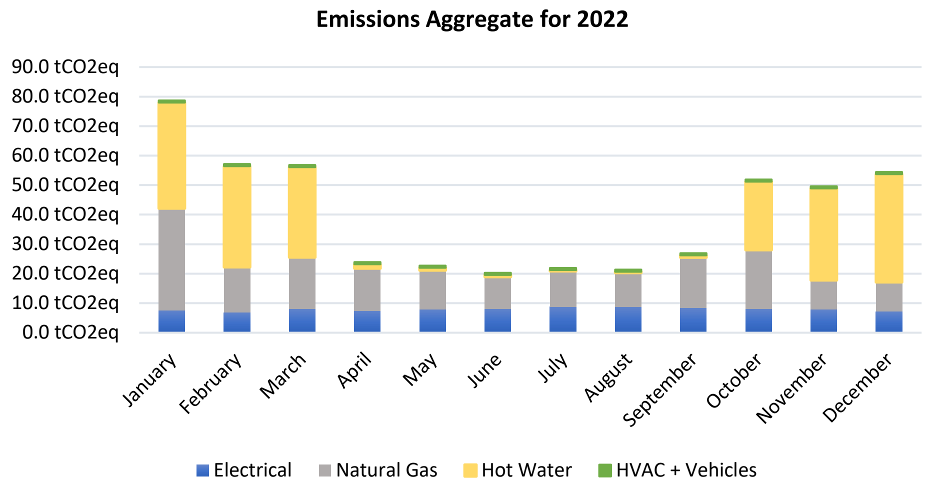


Figure 12 – GHG emissions apportionment by month for 2022

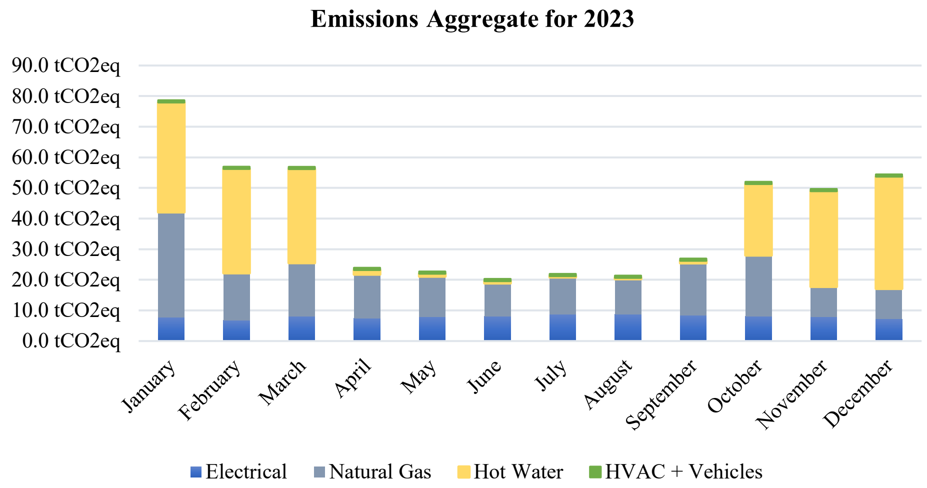


Figure 13 – GHG emissions apportionment by month for 2023

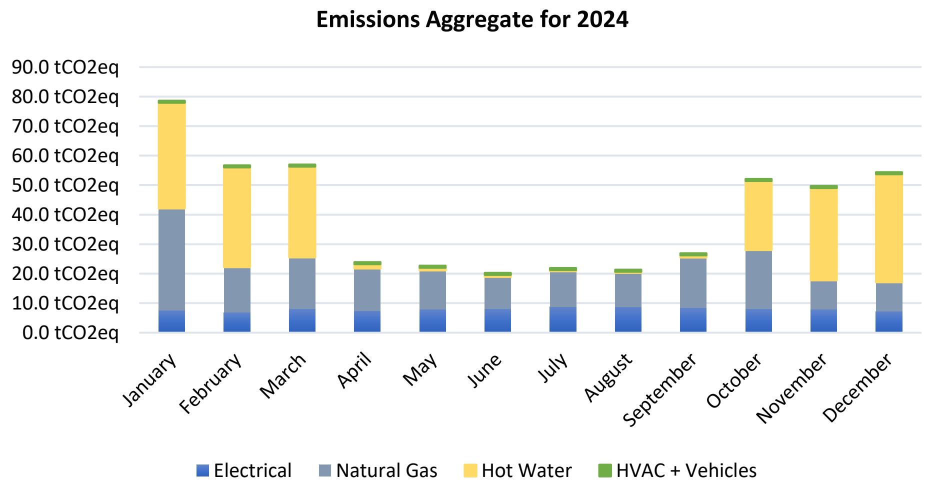


Figure 14 – GHG emissions apportionment by month for 2024

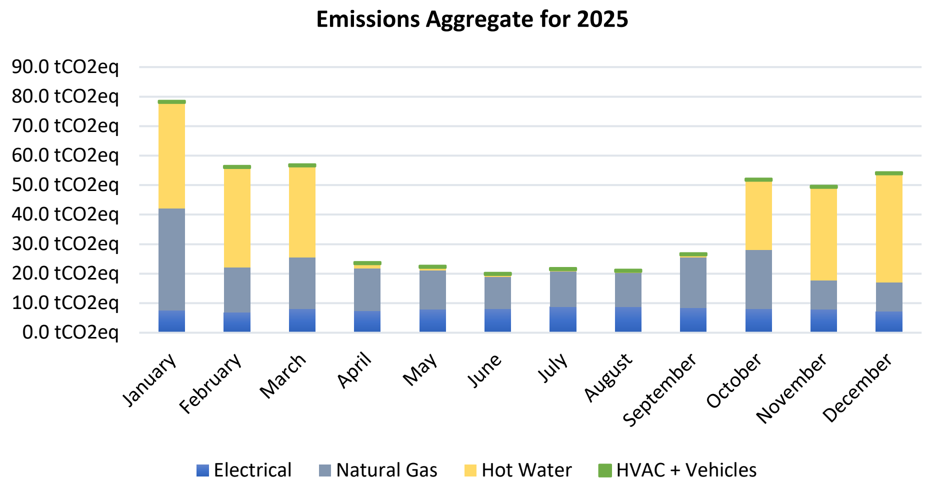


Figure 15 – GHG emissions apportionment by month for 2025

3.7 Putting into perspective

In 2019, the total GHG emissions at the Nest was close to 492 tCO_2e. To put things in perspective, it was estimated the carbon sequestration of a typical Red Maple tree using the methods of [21] and EcoMatcher (same as Revolving/Runoff gardens). Assumptions made were:

- Adult trees of 25 years old
- 6 in diameter
- 29 feet tall

The estimated carbon sequestration of a Red Maple tree is then:

$$Weight\ (W) = 0.25 * (d^2) * h = 0.25 * (6^2) * 29 = 224\ lbs$$

$$W_{green} = 1.2 * W = 269\ lbs$$

$$W_{dry} = 0.725 * W_{green} = 195\ lbs$$

$$C_{content} = 0.5 * W_{dry} = 98\ lbs$$

$$CO2 = 3.67 * C_{content} = 358\ lbs$$

This is equivalent to 6.49 $kgCO_2$ captured each year. If comparing to the AMS Nest emissions of 2019, it would require 75886 adult Red Maple trees to compensate the environment. Figure 16 shows the area required to do this.

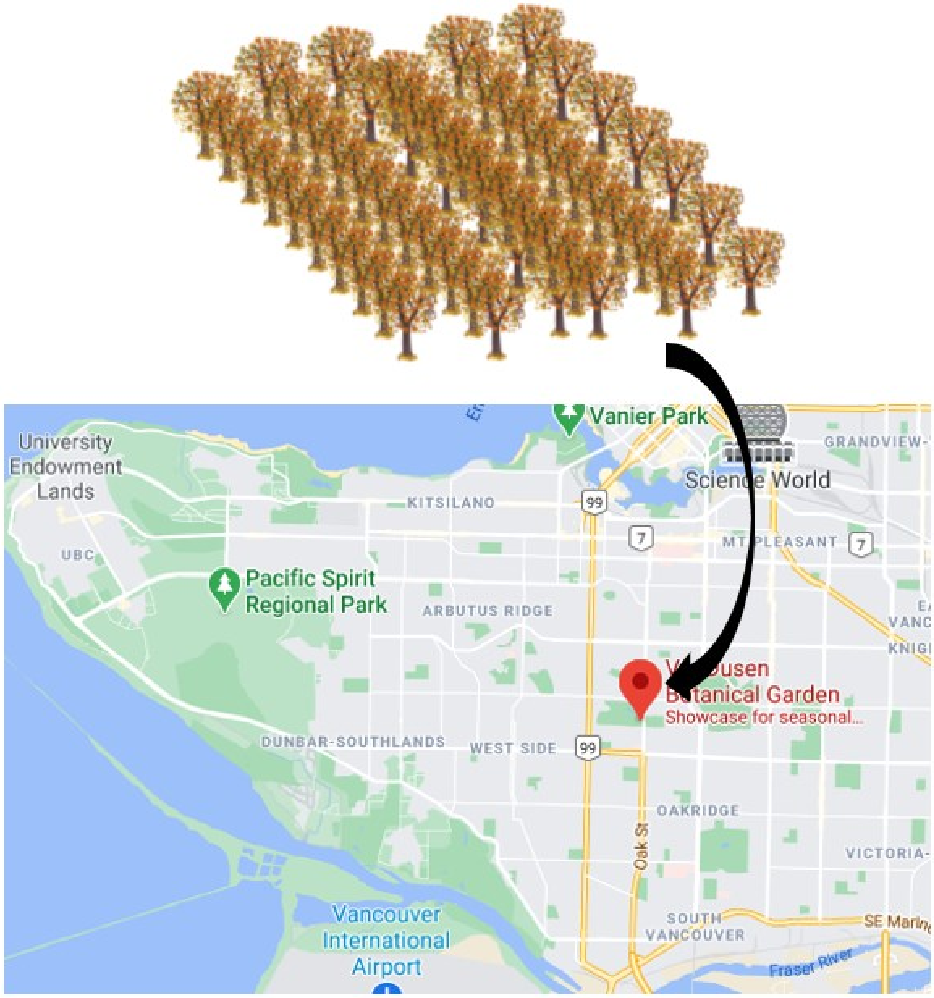


Figure 16 – Green area required to compensate AMS Nest 2019 Emissions

4 GHG Reduction Strategies

4.1 Current GHG Reduction Strategies

Construction of the Nest building, which was completed in 2015, included numerous green energy considerations in order to qualify as a LEEDs platinum building. Accordingly, we have chosen to focus on GHG reduction strategies which requires minimal deep retrofitting and instead look to minor retrofits and remediations/compensation base initiatives. Additionally, based on the GHG Emissions analysis it was determined that the largest contributors to emissions are hot water and natural gas consumption, therefore, proposed strategies to low GHG emissions in these areas will have the largest impact. Strategies to lower GHG emissions due to electricity consumption are also proposed as they still contribute to overall emissions and illustrate current state-of-the-art energy saving measures.

Current GHG reduction strategies in the Nest (see Figure 17) include a high-performance envelope featuring rain screened fiber reinforced cladding and R-25 insulation (above the recommended R-23), energy efficient windows with low emissivity coated triple glazed windows, translucent panels, external shading panels and an envelope which allows for passive airflow [22]. There are 77 solar thermal plates on the roof which supplement water heating in the building and current energy saving measures include a high-efficient hydronic heat recovery system, room occupancy sensors, LED lighting, rainwater recovery, and a building energy management system [22]. Current carbon sinks in the building include the rooftop garden, runoff garden, revolving garden, and the installation of an Aquaphor system on the roof is planned for 2021.

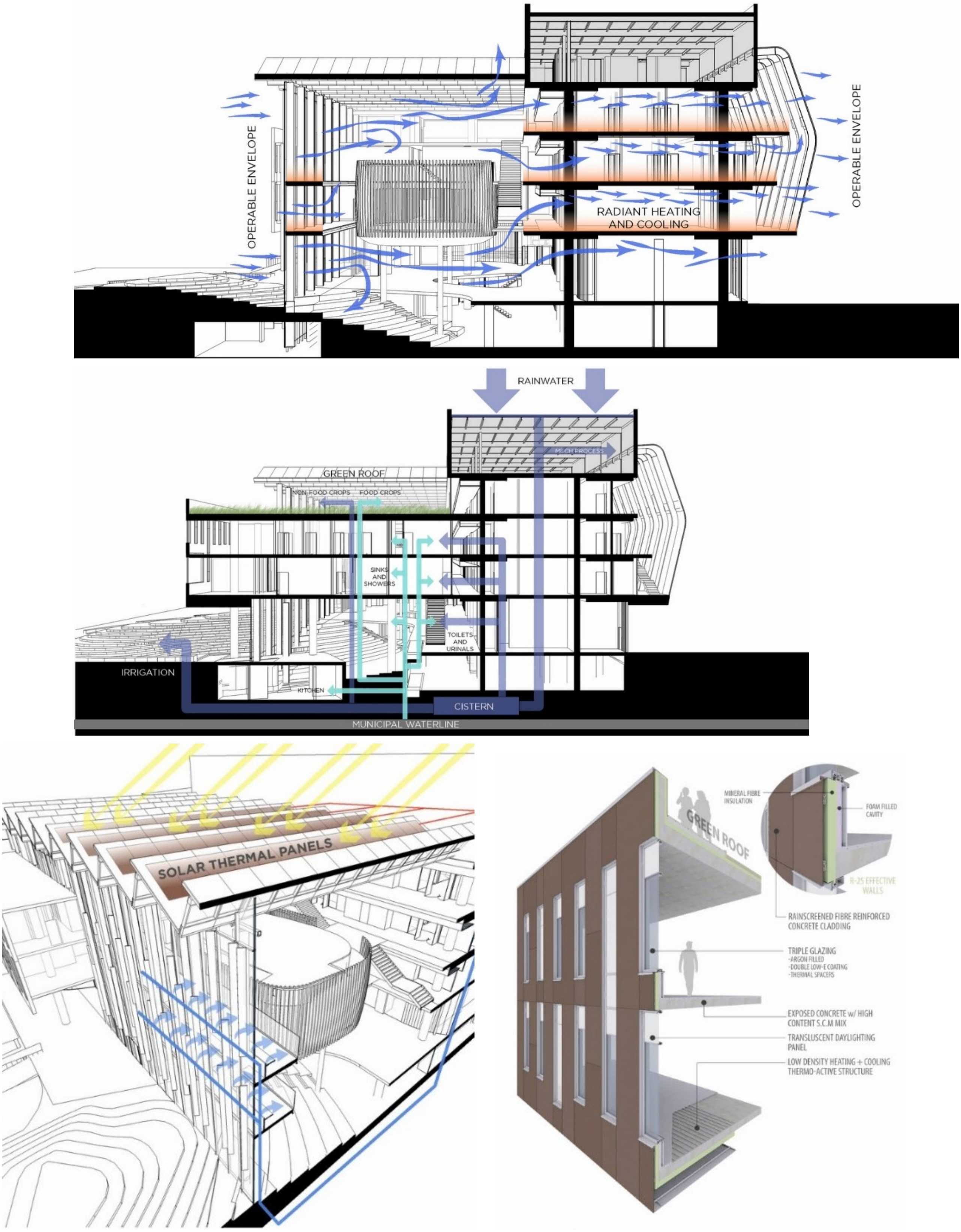


Figure 17 - Current GHG emission strategies in The Nest [Images from B+H Architects][22]

4.2 Proposed strategies to reduce GHG Emissions

Achieving a net zero building requires a multi-pronged approach to tackling GHG emissions which includes:

- Reducing current energy demands
- Switching to renewable energy
- Offsetting emissions

The following sections will describe short- and long-term recommendations, summarized in Table 8, for strategies to reduce AMS GHG emissions. The unit price, capital cost, and GHG reduction percentage of each strategy will be discussed. General assumptions made when determining this information are detailed bellow.

- The total cost of each strategy is calculated based on capital cost only. The installation and operational cost estimates are not included as they would require additional consultations and/or feasibility studies to be performed on the building which are out of the scope of this report.
- GHG reductions are described as a percent reduction of component of the building resource use (electrical, heating, whole building, and more). To determine the projected GHG reductions from 2022-2025 for each strategy the percent reduction was multiplied the projected estimate of that resource for that year. For example, the Wi-Fi controlled heating and cooling is projected to reduce heating use by 5%. The forecasted emissions from hot water heating in 2022 are 179646.3 $kgCO_2e$. Therefore, the calculated reduction is 10612.54 $kgCO_2e$ (5% of 179646.3 $kgCO_2e$).
- The estimated GHG reduction per year of each strategy is based on the 2019 data.

Table 8 – Summary of GHG reduction strategies including unit price, calculated capital cost and GHG reduction percentage (%)

Strategy	Unit Price ($ CAD)	Capital Cost ($ CAD)	GHG Reduction %
Short Term			
Wi-Fi Controlled Heating and Cooling	n/a	n/a	5% of heating
Carbon Offsets	$10-34/$tCO_2e$	$10,922.60	Offsetting all emissions
Smart Plugs and Advanced Power Strips	$50-$250	$ 186,198.00	25-60% of electrical
Light Shelves	$100/shelf	$38,000.00	10% of electrical
Wind Turbine and Controller	$718.00	$718.00	0.03% of electrical
Long Term			
Upgraded Building Management System	$2.50-$7/ sq ft	$1,205,312.50	10-25% whole building
Solar Panels	$2.54-$2.69 /installed watt	$60,000.00	1.5% of heating

Strategy	Unit Price ($ CAD)	Capital Cost ($ CAD)	GHG Reduction %
Switching to Renewable Natural Gas	$606,954.96	$606,954.96	100% of gas usage
Internal Carbon Pricing	$5-$20/tonne	$2,415.00	n/a
Electric Catering Vehicles	$57,855 CAD/ vehicle	$173,565.00	100% of vehicles emissions

4.3 Short Term Strategies

Wi-Fi Controlled Heating and Cooling is an energy saving building control strategy, based on research by a PhD student at UBC. Using real-time anonymized location data provided by the campus Wi-Fi network, the number of people in campus spaces can be approximated. This information can be passed to UBCs building management system which can adjust the ventilation and heating/cooling depending on the population density in different areas of a building. This system was piloted in late 2015 at the Irving. K. Barber Library on UBC campus, a building similar in size to The Nest, at 279,861 ft^2 compared to 253,750 ft^2, respectively. The results showed a 5.2% overall annual reduction in building energy used for heating [23]. This would translate to a reduction of 10,612 kgCO2e GHG emissions per year. During this time, indoor air quality remained within the normal variability range and "no comfort complaints were reported to building staff" [23]. This is a potential energy reduction strategy for The Nest as a building management system already exists and implementing this control method would only require synchronizing real-time data from existing IT infrastructure.

Carbon Offsets are a tool for balancing the amount of GHG emissions that individual buildings, industries, or countries emit. They act as a credit for a specified amount of carbon reduction and are measured in tonnes of carbon dioxide-equivalent (tCO_2e). This approach looks at GHG emissions as a global problem by allowing carbon dioxide emissions in one area to be compensated for elsewhere. This is one of the cheapest and easiest options requiring little upfront financing and no new infrastructure development. Using carbon offsets to balance emission is something that UBC has been doing since 2010 under the Climate Change Accountability Act. In 2019, the university bought 44,490 tCO_2e of offsets at a price of $25 per tCO_2e investing a total of $1,112,250 in carbon offsets [24].

In purchasing carbon offsets there are many important considerations to take into account: the broker is reputable; the portfolio of offsets is diversified; and the funded projects are domestic or international [25]. The most common offsets project types are renewable energy, energy efficiency, fuel switching, methane recovery, and biological carbon sequestration [25]. In 2009, the David Suzuki Foundation and The Pembina Institute published a guide to purchasing carbon offsets for Canadian consumers, businesses, and organizations. It detailed the results of an offset vendor survey, which ranked 20 offset vendors [25]. The offset options from the recommended vendors in the report, if their rating was above 65%, were compiled. An overview of potential offsets, including project, location, and offset cost, and hypothetical a purchase scenario is presented in Appendix B.

Smart Plugs and Advanced Power Strips are two types of technology that are targeted at reducing the "plug load", i.e. the amount of energy drawn by a device plugged into an electrical outlet, of the building. Smart plugs, also known as automatically controlled receptors, are devices which replace existing plugs with receptacles that can communicate with a controller. Advanced power strips are similar to standard power strips but can be programmed to cut the power to a single or combination of plugs. The installation of a combination of these two technologies addresses phantom load, which is when devices unnecessarily draw electricity even after they are turned off. Both technologies can connect to the building management system and can be programmed to schedule plug load usage based on a timer or occupancy data. It is estimated, see Appendix B, that the building has around ~ 1675 plugs in total. The cost of smart plugs ranges from $125-$250 depending on plug voltage capacity. The cost of advanced power strips is $50-$62 each. Smart plugs and advanced power strips have been shown to have an energy saving potential of 50%-60% and 25-50%, respectively, of the building electricity load [26]. It is recommended that a combination of these two technologies (50/50) be installed on 80% of the plugs in the building. This number was chosen as the building occupancy is of the Nest is 300 people. It is assumed that the plugs that students use for portable electronic devices are not drawing a phantom load and so these plugs are omitted. The remaining 1375 plugs account for ~ 80% of plugs in the building. The capital cost of replacing 1375 plugs, calculation shown in Appendix B, is $186,198. The reduction in GHG emissions from this strategy per year is 40,879 kgCO2e.

Light Shelves are passive architectural devices used to reflect sunlight into a building. They are horizontal panes, which can be installed on the exterior or interior of windows, that serve to distribute light more evenly within a space. The advantages of this technology include lowering energy consumption by reducing the need for artificial light and reduced solar heat gains/cooling loads. This strategy can be implemented on sun facing wall and on pole facing walls, however, on the later it would only serve to reduce solar heat gain and cooling loads. This is a proactive strategy as the building does not currently have air-conditioning units but will be installing them within the next year. Exterior light shelves are more effective than internal light shelves as they radiate less heat into the space, however, they are more difficult to install and maintain. The cost of a light shelf is around $100/window but this is subject to variation. The building currently has some external shading; however, light shelves are proposed as they would also reduce electricity use in the building by approximately 10% [27]. This would translate to a reduction of 9,506 kgCO2e GHG emissions per year. A study in Korea which evaluated a light shelve based on energy consumption and lighting and air conditioning found up to a 10.5% reduction in lighting consumption [27]. A calculation showing how this might translate to The Nest can be found in Appendix B, where the capital cost of their implementation is estimated to be $38,000.

Wind Turbines act by harnessing wind to turn propellor like blades around a rotor, spinning a generator and creating electricity. This strategy is being proposed as discussion with Michael Kingsmill revealed that the AMS has a wind turbine in storage. Thus, this would be a low-cost option, requiring only installation, to generate additional renewable electricity for the building. The wind turbine is a vertical wind turbine by Wuxi Fengteng New Energy Co. Ltd. It has a rated power of 500W, is 1.2 m high, and is constructed from aluminum alloy. It was purchased with a controlled compatible with turbines up to 600W power. After looking into the average wind speeds in Vancouver over the past 5 year, it was determined that the energy savings from implementations of this wind turbine would be minimal [28]. However, its installation is still recommended because of the positive potential social implications of having a visible renewable energy system present on the building.

4.4 Long Term Strategies

Building Management System Retrofit involves upgrading the current building management system to an automated system optimization (ASO) system. The current BMS system is a network of computer-based controlled which are connected to the HVAC, heating, and ventilation system in the Nest. Currently, the array of sensors in the building can provide graphics-based monitoring, real-time conditions feedback, and trending/alarming for systems. It currently needs set conditions to be manually inputted and schedules to be set based on historical data [29]. An ASO system would use building system operational data in addition to occupancy patterns, weather forecasts, and utility rates. This approach to building management has the potential to save 10-25% of completely building energy costs [26]. This would translate, conservatively, to a reduction of 48,330 kgCO2e GHG emissions per year. In 2017, Stanford in partnership with Johnson Controls implemented a campus-wide ASO system that uses more than 1220 variables to best run the campus's heat recovery, heating and cooling equipment on autopilot. This solution is projected to save Stanford $12 million per year for the next 30 years due to the significant energy savings. [26]. If implemented at the Nest the price of ASO systems ranges from $2.50-$7 per square foot [26]. As there is already and existing BMS system in place this solution was projected using the average unit cost of $4.75 per square foot. The projected capital cost of this recommendation is $1,205,312.

Solar Panels function by converting solar radiation to thermal energy, a system already in use by the Nest. There are 77 solar panels on the Nest roof, taking up approximately 2% of the roof area. The solar thermal panels used by the Nest utilize water to capture and retain the thermal energy, which can then supplement domestic hot water sources in the building. Heated water from the solar panels can be sent to preheat water in the internal hot water boilers and can also supplement hot water needed in the adsorption chiller. This reduces reliance on electricity and natural gas needed to power these technologies. From the initial building plans, only half of the solar panels proposed were implemented. The cost of implementing solar thermal panels is $2.54-$2.69 CAD per installed watt [30]. To implement a 23.1 kW system, the size necessary to double the current system, the total cost of this strategy is $60,000 CAD [30]. This strategy is projected to decrease the emissions related to building heating by 1.5% of the total emissions which is a reduction of 3,183 kgCO2e GHG emissions per year.

Switching to Renewable Natural Gas is a strategy targeted at reducing the natural gas GHG emissions of the Nest. A study performed in Switzerland in 2017 on the "necessity of improving the environmental impacts of furniture and appliances in net-zero energy buildings" showed that appliances can account for 25% or more of the building's overall energy impact in term of global warming and non-renewable energy indicators [31]. Understandably, this number is going to vary from building to building depending on the type and number of appliances in use. However, this spotlights an area to focus on when looking to reduce the buildings long term GHG emissions. The direct uses of the natural gas are difficult to pinpoint as the natural gas meters only measures consumption for the whole building. Nonetheless, a strategy to reduce overall consumption would be switching to renewable natural gas (RNG), also called biomethane, which is derived from biogas and is a green fuel alternative. It is produced by collecting emissions from decomposing organic waste matter, agricultural waste, and wastewater from treatment facilities [32]. The captured and cleaned "biogas" is a carbon neutral alternative to natural gas produced from fossil fuels. This strategy can use existing infrastructure and only requires sourcing the fuel from a provider like Fortis BC. The cost per year of switching to RNG calculated on the Fortis BC website using their RNG annual premium calculator is $606,954 and this result in a 175,980 kgCO2e reduction of GHG emissions per year [33].

Electric Catering Fleet Vehicles have the potential to eliminate all GHG emissions because of catering vehicle usage. Currently, the three catering vehicles are a Ford Transit Connect, a Ford Econoline, and a Mercedes Sprinter. In 2022 Ford will be releasing the E-Transit, a fully electric cargo van. It is prices at $57,855 CAD and has a battery life of 677kWh or 203 Km [34]. Additionally, a percentage of the cost of purchasing new catering vehicles can be supplemented by the sale of the old vehicles. Although, the overall emissions from the catering vehicles are low this is also a recommendation which also touches on the social aspects of sustainability. It is recommended that the usage of the vehicles be studied to determine if their usage is optimized. However, it is unlikely that catering vehicles usage can be eliminated completely. The purchase and use of electric catering vehicles are a visible signal of the AMS's commitment to reducing fossil fuel emissions and using green alternatives.

Internal Carbon Pricing is similar to a tax which functions to discourage the use of high carbon consumption activities and works to fund green initiatives. This strategy is recommended as a climate-friendly policy and is not assigned a GHG reduction %. The implementation of internal carbon pricing can contribute to the reduction of GHG emissions at the Nest encouraging the use of a "taxed" amount of funding for sustainability initiatives. This concept has been implemented around the world in many industries as it helps corporations get ahead of legislation providing an easier and smoother transition when reducing carbon usage. This strategy would be best implemented over a period of four to five years as a gradual increase in the price on carbon will aid with stakeholder endorsement and for the collect money to accumulate to be put towards larger green initiatives. An internal carbon price places a monetary value on GHG emissions. Observed price for companies that have implemented this is $5-$20/ metric ton [35]. This would serve as a social campaign to encourage the AMS to continue working to lower their GHG emissions.

5 GHG Management Plan

5.1 Year Management Plan

With the goal of achieving Net Zero GHG Emissions by 2025, this report suggests a management plan to implement the suggested strategies that would lead to carbon neutrality of the AMS Nest Building by the year 2025.

As shown in Table 9, implementing all the reduction strategies would lead to the reduction of 1,178,805 kgCO_2e accumulated until 2025. This calculation was made considering 2025 as a final period of evaluation. However, all the suggested strategies are retrofitting projects into the building. This means that any improvement done to the infrastructure will continue to contribute to the GHG emissions reduction even after 2025 as it would be a permanent change in the building. From the strategies suggested, switching to Renewable Natural Gas is the strategy with the biggest benefits, followed by the installation of smart plugs.

Table 9 – Potential GHG emission reduction from each suggested strategy

Short Term	**2022**	**2023**	**2024**	**2025**	**TOTAL**
Wifi Controlled Heating and Cooling	8,982	8,973	8,965	8,956	35,876
Smart Plugs and Advanced Power Strips	43,341	43,341	34,591	40,880	162,152
Light Shelves	10,079	10,079	8044	9507	37,710
Wind Turbine and Controller	30	30	24	29	113
Long Term	**2022**	**2023**	**2024**	**2025**	**TOTAL**
Upgraded Building Management System	47,490	47,472	45,419	46,864	187,245
Solar Panels	2695	2692	2689	2687	10,763
Switching to Renewable Natural Gas	185,914	185,914	185,914	185,914	743,656
Electric Catering Vehicles	322	322	322	322	1,290
	TOTAL REDUCTION POTENTIAL (kgCO_2e)				**1,178,805**

Implementing the suggested strategies will approximately 65% of total building tCO_2e forecasted emissions. Figure 18 shows the comparison of the emissions if none of the strategies were implemented (Business as Usual) and with all of the strategies being implemented. This calculation was done assuming all retrofitting projects would take place at the same time and at the beginning of the Management Plan.

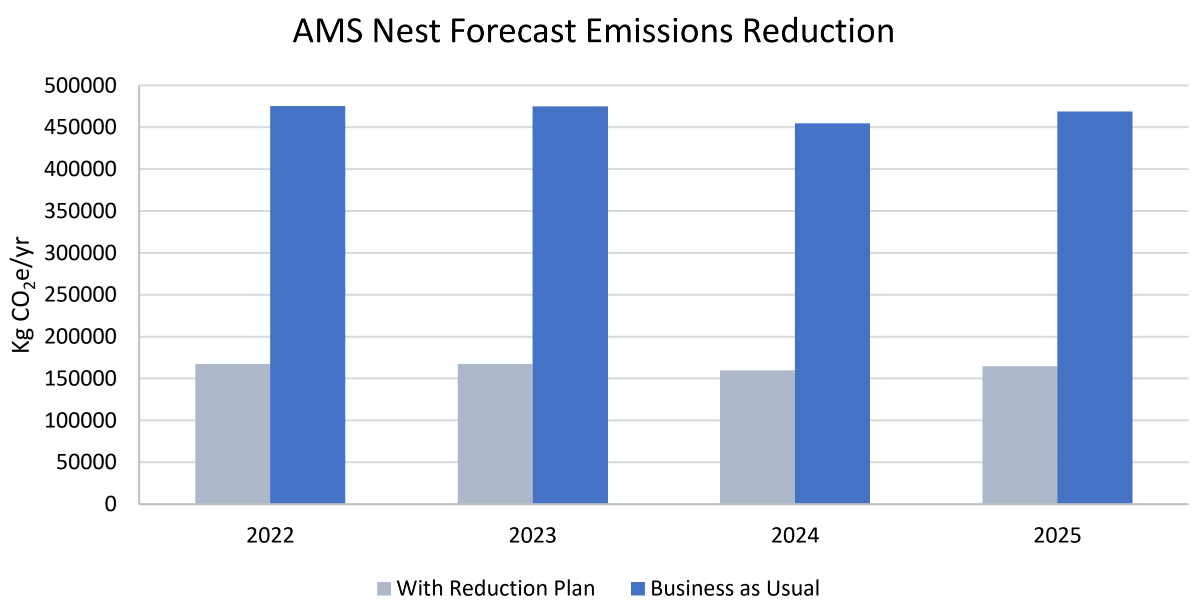


Figure 18 – Compared scenarios of GHG emissions – Business as usual and With Reduction Plan

To achieve the proposed GHG emission reduction, a total investment of $2,272,446 would be needed to implement all the suggested strategies. Table 10 summarizes the total cost of each strategy. As mentioned before, this cost only includes the capital cost associated with the acquisition of the materials or technology needed. A more detailed price including operation costs and installation would need a more detailed feasibility assessment.

Table 10 – Total Capital Cost of Implementation

Short Term	Total Capital Cost
Wifi Controlled Heating and Cooling	n/a
Smart Plugs and Advanced Power Strips	$186,198
Light Shelves	$38,000
Wind Turbine and Controller	$0
Long Term	**Total Capital Cost**
Upgraded Building Management System	$1,205,313
Solar Panels	$60,000
Switching to Renewable Natural Gas	$606,955
Internal Carbon Pricing	$2,415
Electric Catering Vehicles	$173,565
TOTAL CAPITAL COST (CAD)	**$2,272,446**

In order to develop a roadmap for the implementation of all the strategies suggested in this report, a prioritization based on Unit Cost (Figure 19) and a cost-benefit assessment (Figure 20) was made. Unit Cost calculations show how much it would cost to reduce 1 $kgCO_2e$ for each strategy. The strategies that have a lower unit cost are the installation of light shelves, switching to renewable natural gas, and installing smart plugs. The strategies that have a higher unit cost are upgrading the building management system and the installation of solar panels. In the case of the wind turbine and Controller, total capital cost reported in Table 10 is $0 because the turbines have already been purchased by the AMS for a prior SEEDs project. Therefore, its cost was omitted from the budget needed for the implementation of this strategy. The cost of the wind turbine was $718 and this is accounted for in the unit cost presented in Figure 19.

Switching to electric vehicles is not shown in Figure 19 because it is much more expensive than the other strategies. The unit cost is 134.6 CAD/$KgCO_2e$ which is significantly higher than the other strategies listed in this report. However, this cost could be recouped in part by selling the previous internal-combustion vehicles to reduce the investment needed. Furthermore, the benefits of using electric vehicles will continue after 2025, reducing its unit cost each year as long as benefits are maintained.

Finally, unit cost of the strategies listed in this report were compared to the price of carbon offsetting. Considering an average value of 25$ per tCO_2e [24] offsetting GHG emissions is still the cheapest option for carbon compensation. However, carbon offset would need to be paid on yearly basis, whereas, retrofitting the building with energy efficiency features is a one-time investment that leads to permanent benefits in terms of GHG emissions.

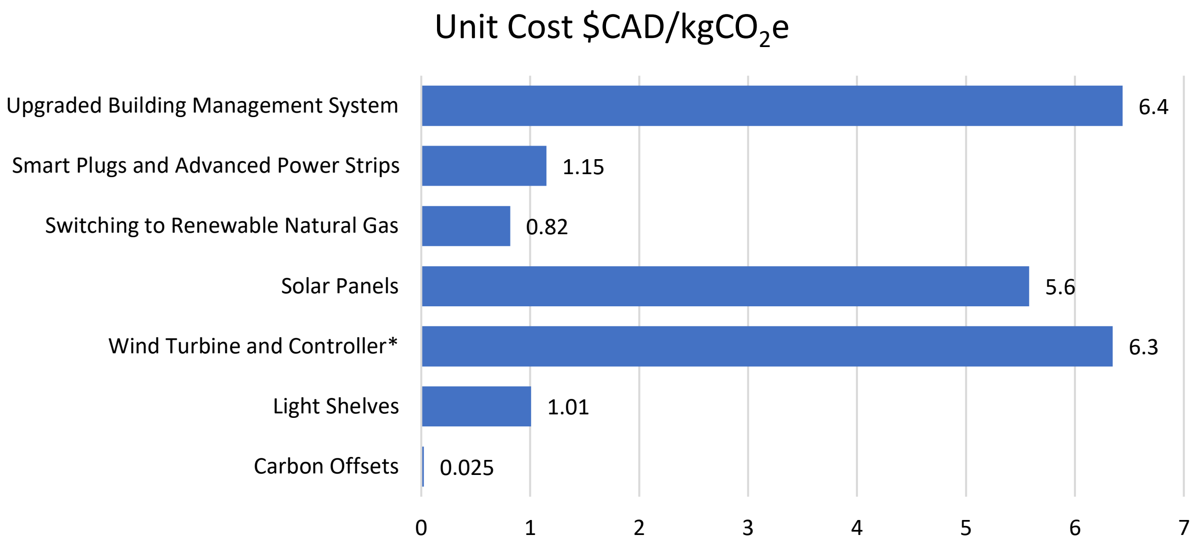


Figure 19 – Unit Cost of GHG Emission Reduction of each proposed strategy

It is recommended also that strategies are prioritized according to the total benefit they can bring. Figure 20 shows the total reduction potential assessed withing the 5-year plan and the total capital cost of each strategy. Based on this evaluation we would recommend the implementation of the proposed GHG strategies in three different phases

1. Phase 1: Implementing the strategies that have the greatest potential even if they require a high capital cost. In this phase the strategies of Wi-Fi controlled heating and cooling, smart plugs, and advance power strips, and switching to renewable natural gas would be implemented.
2. Phase 2: Implementing the strategies that have are cheaper but also have a smaller benefit. In this phase, the light shelves, the solar panels, and the wind turbine would be implemented.
3. Phase 3: Implementing the strategies that require a bigger financial effort and contribute less to GHG emission reduction. In this phase the building management system would be updated, and catering vehicles would be changed from internal combustion to electric ones.

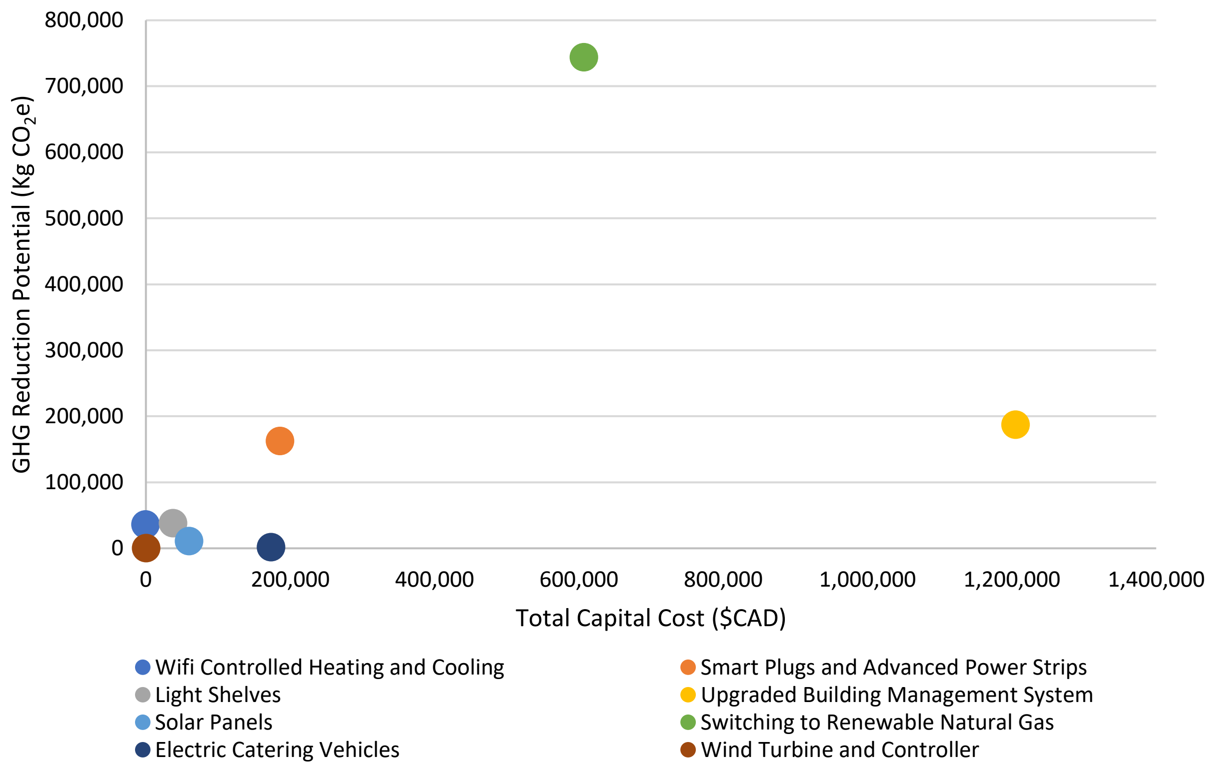


Figure 20 – Cost-Benefit Evaluation of GHG Reduction Strategies

Nevertheless, all the proposed strategies alone will not result in the Nest reaching Net Zero emissions. It is recommended that the remaining GHG emissions be offset. Table 11 summarizes the annual budget needed to offset carbon emissions from the AMS Nest Building after the implementation of all the proposed strategies. It is worth to mention that the total value calculated for carbon offsets represents about 74% less (accumulated) than the budget needed to offset all the GHG emission in a Business-as-Usual scenario. Also, total prices may vary depending on the distribution of offset emissions to each initiative. For this report, it was assumed that emissions to be offset would be equally distributed in each of the mapped initiatives.

Table 11 – Carbon Offset Budget 2022-2025

	Offset Cost per tCO2e	2022	2023	2024	2025
Total Emissions to Offset ($KgCO_2e$)	-	167383.9	167244.7	159582.4	164850.5
Energy Efficiency	$20.00	$669.54	$668.98	$638.33	$659.40
Fuel Switching	$20.00	$669.54	$668.98	$638.33	$659.40
Methane Recovery	$25.00	$836.92	$836.22	$797.91	$824.25
Biological Carbon Sequestration	$20.00	$669.54	$668.98	$638.33	$659.40
Water	$28.00	$937.35	33.44894946	$893.66	$923.16
	TOTAL ($CAD)	**$3,782.88**	**$2,876.61**	**$3,606.56**	**$3,725.62**

6 Recommendations

The recommendations to reduce GHG emissions were categorized into short- and long-term strategies. It is anticipated that the short-term strategies can be implemented within the next two years and will result in a reduction of 62,433 $KgCO_2e$ emissions per year—based on the 2022 emissions data. It is advised that during this period the remaining emissions be offset by purchasing carbon offsets. It is anticipated that the long-term strategies be implemented within the next four years which will result in a reduction of 236,099 $KgCO_2e$ emissions per year—based on the 2022 emissions data. The coupled impact of both the short- and long-term emissions recommendations will result in approximately a 65% total reduction in building emissions comparing 2019 emissions to 2025 forecasted emissions. The remaining emissions can be eliminated will offsets at a cost of ~$3700 per year if all recommendations are implemented, reducing the carbon offsetting costs by 74% compared to if all the emissions were offset. Currently, UBC already purchases carbon offsets to offset total campus total emissions. However, we are not able to determine which portion of the offset account for GHG emissions by the Nest. Prior to the AMS purchasing carbon offsets, it is recommended that the AMS meet with representatives from UBC to determine what emissions are already offset. Additional important considerations are quantity of emissions being offset and the type of offsets being purchased.

Several of the strategies proposed in the management plan act as both tools for GHG reductions and examples that can promote sustainability and environmental awareness. Harnessing the visual elements of strategies such as the wind turbine and solar panels, students can become more aware of the choices the AMS is taking in lowering its carbon footprint. Additionally, these visual elements can provide a simple and effective way to inspire change across campus that will have long-lasting impacts. In conjunction with implementing the strategies as discussed in the management plan, it is recommended that the Nest continues to promote information on the importance of sustainability and the ways in which it can be achieved. Infographics, social media campaigns, smart labels on the strategies demonstrating GHG reduction in real time, and tours of the sustainability initiatives in place at the Nest are some ideas to create a learning environment and include students in the net zero process. An infographic and poster describing the results from this project are included in Appendix C and can be utilized for this purpose. The AMS Nest can serve as an example to the rest of the campus, and to other campuses in general, that strategies for achieving net zero can be achieved.

Recommended next steps include contacting companies for cost estimates of the proposed strategies to consider installation and maintenance costs. Prioritization of strategies should also be discussed in future works with set budgetary considerations and restrictions. The management plan provides a general recommendation for strategy prioritization consisting of three phases: implementing strategies with the highest emissions reductions at higher capital costs, implementing strategies with low cost but relatively lower emissions reductions, and finally implementing strategies with high cost but relatively lower emissions reductions.

Lastly, the Zero Carbon Building - Performance Standard, Version 2, published by the Canada Green Building Council in 2020, requires an annual verification of achievement of zero carbon operations. Therefore, it is also recommended that the progress towards these reduction targets be reviewed on a yearly basis.

7 Conclusions

This report details the GHG emissions from The AMS Nest building and includes only the activities conducted at the Nest, whether they are run by the AMS or outside organizations/companies. Scope 1 and 2 emissions were included in the GHG emissions inventory which consist of direct emissions related to building operations and activities as well as emissions related to the production of energy used by the Nest. The emissions from these sources was measured as the kilograms of CO_2 equivalents ($kgCO_2e$) and forecasted until 2025. Through the emissions inventory report, it was found that a large percentage of emissions can be attributed to energy from the hot water ADES and natural gas consumption. Short-term and long-term emissions reduction strategies were proposed in a 5-year management plan which is forecasted to result in a reduction of 65% of the Nest's total emissions in 2025 compared to total emissions from 2019 with a total capital cost of $2,272,446. Remaining emissions are recommended to be compensated by purchasing carbon offsets. UBC already offsets the Nest's emissions; however, further investigation is needed to ascertain the amount and type of offsets utilized by UBC. Carbon offset options are included in the management plan for future reference. The findings and recommendations from this report provide a pathway for the AMS Nest to achieve their goal of having net zero carbon emissions from the Nest by 2025.

7.1 Limitations & Indications for future assessments

Throughout this investigation, some information was not made available, which could compromise results. As a result, the following consists of a compiled list of limitations and recommendations for future studies that could enhance what was described in this report. They are:

Visitor head count:

- For future works on the AMS Nest GHG inventory, having a way to count the number of visitors and which services they used could improve the capacity to create links between variables and emissions

HVAC system:

- No data was available on how long they are used each day, or if there are any other data on the use frequency
- If there is info about the leakage percentage at the installation and operation
- How many charge replacement are performed each year (if any)

Steam-related emissions:

- Because no data was available for the steam use at AMS Nest, the results associated with this source for the years of 2016, 2017, January and February of 2018 should be interpreted carefully

Carbon sinks:

- No study was found addressing the specific carbon sink of each plant at the Rooftop, Revolving and Runnoff gardens. Therefore, the carbon sequestration here reported is to be interpreted as an approximate estimation based on average values from literature

Carbon offsets:

- It is known that BC currently offsets its emissions. It is meant to encourage the integration of internal carbon pricing into procurement policies within the AMS organization. As it is an internal initiative, it would not be related/ apply to provincial carbon tax

8 References

1. Kyoto Protocol greenhouse gases and the Canadian Environmental Protection Act: chapter 1 - Canada.ca. 2015 May. [cited 2021 Apr 23]. Available from: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/kyoto-protocol-greenhouse-gases/chapter-1.html

2. Bernstein L, Bosch P, Canziani O, Chen Z, Christ R, Davidson O, et al. Climate Change 2007 Synthesis Report. Vol. 104. 2007. [cited 2021 Apr 23]. Available from: https://www.ipcc.ch/report/ar4/syr/

3. Ranganathan J, Corbier L, Schmitz S, Oren K, Dawson B, Spannagle M, et al. Greenhouse Gases Protocol. 2004. [cited 2021 Apr 23]. Available from: https://www.wri.org/research/greenhouse-gas-protocol-0

4. ISO - ISO 14064-1:2018 - Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals [Internet]. International Organization for Standardization. 2018. [cited 2021 Apr 23]. Available from: https://www.iso.org/standard/66453.html

5. LEED® Certification Process [Internet]. Canada Green Building Council. [cited 2021 Apr 23]. Available from: https://www.cagbc.org/CAGBC/Programs/LEED/LEED_Certification_Process.aspx

6. High-Voltage Electricity [Internet]. [cited 2021 Apr 23]. Available from: http://energy.ubc.ca/ubcs-utility-infrastructure/high-voltage-electricity/

7. Hot Water District Energy System [Internet]. [cited 2021 Apr 23]. Available from: http://energy.ubc.ca/ubcs-utility-infrastructure/district-energy-hot-water/

8. Natural Gas [Internet]. [cited 2021 Apr 23]. Available from: http://energy.ubc.ca/ubcs-utility-infrastructure/natural-gas/

9. Personal Communication with Michael Kingsmill. March 2021.

10. Personal Communication with Vince Markarian. March 2021.

11. Ranganathan J, Corbier L, Schmitz S, Oren K, Dawson B, Spannagle M, et al. Greenhouse Gases Protocol. 2004. [cited 2021 Apr 23]. Available from: https://www.wri.org/research/greenhouse-gas-protocol-0

12. Government of British Columbia. Electricity Emission Intensity Factors for Grid-Connected Entities [Internet]. 2019. [cited 2021 Apr 23]. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/reporting/quantify/electricity

13. Ministry of Environment & Climate Change. B.C. Best Practices Methodology For Quantifying Greenhouse Gas Emissions. 2017. [cited 2021 Apr 23]. Available from: http://dx.doi.org/10.1016/j.enbuild.2012.09.008%5Cnhttp://dx.doi.org/10.1016/j.buildenv.2011.09.028%5Cnhttp://link.springer.com/10.1007/s12273-013-0159-y%5Cnhttp://dx.doi.org/10.1016/j.eneco.2010.12.012%5Cnhttp://www.scopus.com/inward/record.url?eid=2-s2.

14. Holt P. UBC Steam to Hot Water Conversion The University of British Columbia. 2016;(June). [cited 2021 Apr 23]. Available from: http://energy.ubc.ca/projects/district-energy/

15. Personal Communication with Stephen Li. March 2021.

16. Personal Communication with Sophorn Kong. March 2021.

17. Personal Communication with Anna Leckie. March 2021.

18. Kavehei E, Jenkins GA, Adame MF, Lemckert C. Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure. Renewable and Sustainable Energy Reviews. 2018;94(March):1179–91. [cited 2021 Apr 23].

19. Personal Communication with James Montgomery. March 2021.

20. Sah RP, Choudhury B, Das RK. Study of a two-bed silica gel–water adsorption chiller: performance analysis. International Journal of Sustainable Energy. 2018;37(1):30–46. [cited 2021 Apr 23].

21. Toochi EC. Carbon sequestration: how much can forestry sequester CO2? Forestry Research and Engineering: International Journal. 2018;2(3):148–50. [cited 2021 Apr 23]. Available from: https://nph.onlinelibrary.wiley.com/doi/full/10.1111/j.1469-8137.2004.01201.x

22. Castro F. AMS Nest / DIALOG + B+H Architects [Internet]. ArchDaily. 2020 [cited 2021 Apr 23]. Available from: https://www.archdaily.com/773797/ams-nest-dialog-plus-b-plus-h-architects

23. UBC Pilot Study Summary Case Study: Real-time Occupancy-based Building Controls. 2016. [cited 2021 Apr 23]. Available from: http://energy.sites.olt.ubc.ca/files/2017/06/2016-02-18-Case-Study-3-UBC-pilot-study-results.pdf

24. UBC Sustainability. 2019 Carbon Neutral Action Report. 2020. [cited 2021 Apr 23]. Available from: https://sustain.ubc.ca/sites/default/files/2019CNAR-WEB.pdf

25. Carlson D, Lingl P, Wong R. Purchasing Carbon Offsets: A Guide for Canadian Consumers, Businesses and Organizations. 2009. [cited 2021 Apr 23]. Available from: https://davidsuzuki.org/wp-content/uploads/2019/10/purchasing-carbon-offsets-guide-for-canadians.pdf

26. King J, Perry C. Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings. American Council for an Energy-Efficient Economy. 2017. [cited 2021 Apr 23]. Available from: https://www.aceee.org/sites/default/files/publications/researchreports/a1701.pdf

27. Lee H, Kim S, Seo J. Evaluation of a light shelf based on energy consumption for lighting and air conditioning. Indoor and Built Environment. 2018;27(10):1405–14. [cited 2021 Apr 23]. Available from: https://journals.sagepub.com/doi/10.1177/1420326X17719954

28. Wind Speed and Direction - Quarterly Data for Vancouver. [cited 2021 Apr 23]. Available from: https://vancouver.weatherstats.ca/metrics/wind_speed.html

29. Building Management Systems [Internet]. Energy & Water Services UBC. [cited 2021 Apr 23]. Available from: https://energy.ubc.ca/ubcs-utility-infrastructure/building-management-systems-bms/

30. Complete Guide For Solar Power British Columbia 2020 [Internet]. energyhub. 2020 [cited 2021 Apr 23]. Available from: https://www.energyhub.org/british-columbia/#:~:text=According to data from Natural Resources Canada%2C the,the solar irradiance potential map for British Columbia%3A. Tsoutsos T, Frantzeskaki N, Gekas V. Environmental impacts from the solar energy

31. Hoxha E, Jusselme T. On the necessity of improving the environmental impacts of furniture and appliances in net-zero energy buildings. Science of the Total Environment. 2017 Oct 15;596–597:405–16. [cited 2021 Apr 23]. Available from: https://www.sciencedirect.com/science/article/pii/S0048969717306216

32. About Biogas [Internet]. Canadian Biogas Association. [cited 2021 Apr 23]. Available from: https://biogasassociation.ca/about_biogas

33. Renewable Natural Gas Rates [Internet]. Fortis BC. [cited 2021 Apr 23]. Available from: https://www.fortisbc.com/services/sustainable-energy-options/renewable-natural-gas/renewable-natural-gas-rates

34. Comparing Transit Vans: Ford vs. Lightning [Internet]. Lightning eMotors. [cited 2021 Apr 23]. Available from: https://lightningemotors.com/transit-vans-ford-vs-lightning/

35. Internal Carbon Pricing [Internet]. Centre for Climate and Energy Solutions. [cited 2021 Apr 23]. Available from: https://www.c2es.org/content/internal-carbon-pricing/#:~:text=The observed price range for, and prepare for future regulation

Appendix A GHG Emission Inventory Supplementary Information

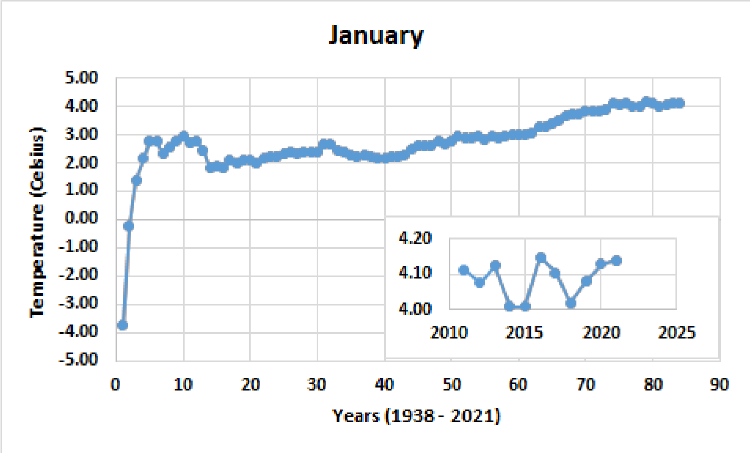
- **Conversion factors of common refrigerant and GHG to carbon dioxide equivalents**

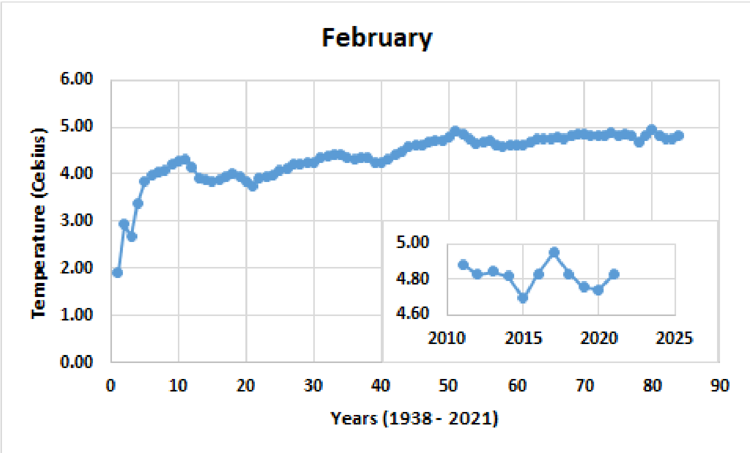
Global Warming Potential (GWP) values - IPCC (2006) – Part 1		
Compound name	**Chemical formula**	**GWP (100y)**
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
CFC-11	CCl_3F	4,660
CFC-12	CCl_2F_2	10,200
CFC-13	$CClF_3$	13,900
CFC-113	CCl_2FCClF_2	5,820
CFC-114	$CClF_2CClF_2$	8,590
CFC-115	$CClF_2CF_3$	7,670
Halon-1301	$CBrF_3$	6,290
Halon-1211	$CBrClF_2$	1,750
Halon-2402	$CBrF_2CBrF_2$	1,470
Carbon tetrachloride	CCl_4	1,730
Methyl bromide	CH_3Br	2
Methyl chloroform	CH_3CCl_3	160
HCFC-21	$CHCl_2F$	148
HCFC-22	$CHCLF_2$	1,760
HCFC-123	$CHCl_2CF_3$	79
HCFC-124	$CHClFCF_3$	527
HCFC-141b	CH_3CCl_2F	782
HCFC-142b	CH_3CClF_2	1,980
HCFC-225ca	$CHCl_2CF_2CF_3$	127
HCFC-225cb	$CHClFCF_2CClF_2$	525
HFC-23	CHF_3	12,400
HFC-32	CH_2F_2	677
HFC-41	CH_3F_2	116
HFC-125	CHF_2CF_3	3,170
HFC-134	CHF_2CHF_2	1,120
HFC-134a	CH_2FCF_3	1,300
HFC-143	CH_2FCHF_2	328

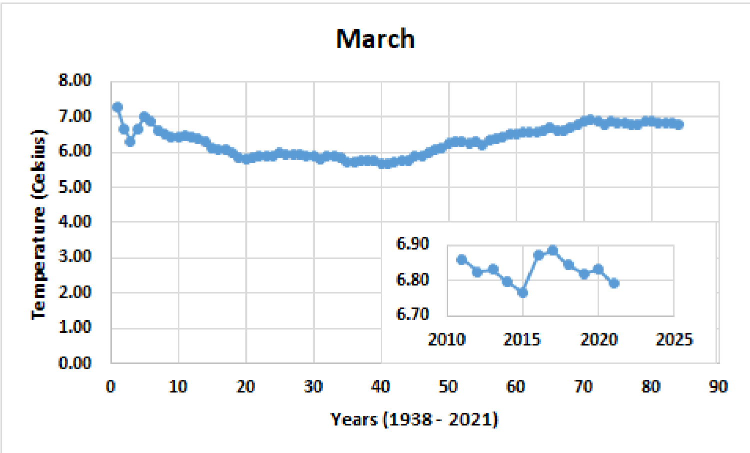
Global Warming Potential (GWP) values - IPCC (2006) – Part 2		
Compound name	**Chemical formula**	**GWP (100y)**
HFC-143a	CH_3CF_3	4,800
HFC-152	CH_2FCH_2F	16
HFC-152a	CH_3CHF_2	138
HFC-161	CH_3CH_2F	4
HFC-227ea	CF_3CHFCF_3	3,350
HFC-236cb	$CH_2FCF_2CF_3$	1,210
HFC-236ea	CHF_2CHFCF_3	1,330
HFC-236fa	$CF_3CH_2CF_3$	8,060
HFC-245ca	$CH_2FCF_2CHF_2$	716
HFC-245fa	$CHF_2CH_2CF_3$	858
HFC-365mfc	$CH_3CF_2CH_2CF_3$	804
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,650
Sulfur hexafluoride	SF_6	23,500
Nitrogen trifluoride	NF_3	16,100
PFC-14	CF_4	6,630
PFC-116	C_2F_6	11,100
PFC-218	C_3F_8	8,900
PFC-318	$c\text{-}C_4F_8$	9,540
PFC-31-10	C_4F_{10}	9,200
PFC-41-12	C_5F_{12}	8,550
PFC-51-14	C_6F_{14}	7,910
PCF-91-18	$C_{10}F_{18}$	7,190
Trifluoromethyl sulfur pentafluoride	SF_5CF_3	17,400
Perfluorocyclopropane	$c\text{-}C_3F_6$	9,200
HFE-125	CHF_2OCF_3	12,400
HFE-134	CHF_2OCHF_2	5,560
HFE-143a	CH_3OCF_3	523
HCFE-235da2	$CHF_2OCHClCF_3$	491
HFE-245cb2	$CH_3OCF_2CF_3$	654
HFE-245fa2	$CHF_2OCH_2CF_3$	812
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	530
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	889

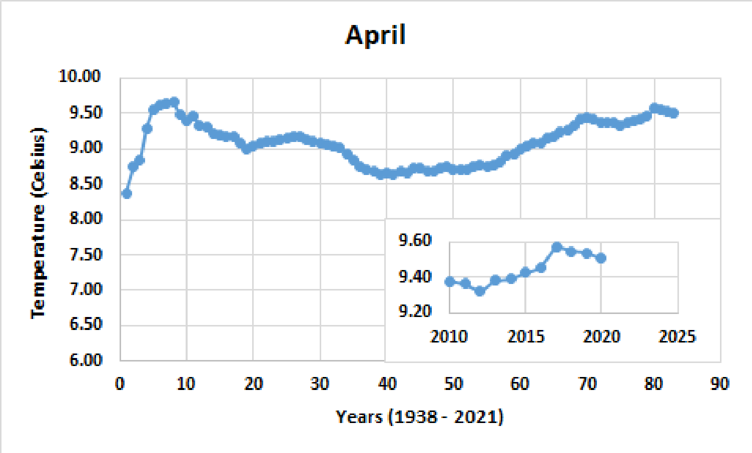
Global Warming Potential (GWP) values - IPCC (2006) – Final		
Compound name	**Compound name**	**Compound name**
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	413
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	421
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	57
HFE-43-10pccc124 (H-Galden1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	2,820
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	5,350
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	2,910
HFE-227ea	$CF_3CHFOCF_3$	6,450
HFE-236ea2	$CHF_2OCHFCF_3$	1,790
HFE-236fa	$CF_3CH_2OCF_3$	979
HFE-245fa1	$CHF_2CH_2OCF_3$	828
HFE-263fb2	$CF_3CH_2OCH_3$	1
HFE-329mcc2	$CHF_2CF_2OCF_2CF_3$	3,070
HFE-338mcf2	$CF_3CH_2OCF_2CF_3$	929
HFE-347mcf2	$CHF_2CH_2OCF_2CF_3$	854
HFE-356mec3	$CH_3OCF_2CHFCF_3$	387
HFE-356pcf2	$CHF_2CH_2OCF_2CHF_2$	719
HFE-356pcf3	$CHF_2OCH_2CF_2CHF_2$	446
HFE-365mcf3	$CF_3CF_2CH_2OCH_3$	<1
HFE-374pc2	$CHF_2CF_2OCH_2CH_3$	627
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	9,710
Chloroform	$CHCl_3$	16
Methylene chloride	CH_2Cl_2	9
Methyl chloride	CH_3Cl	12
Halon-1201	$CHBrF_2$	376

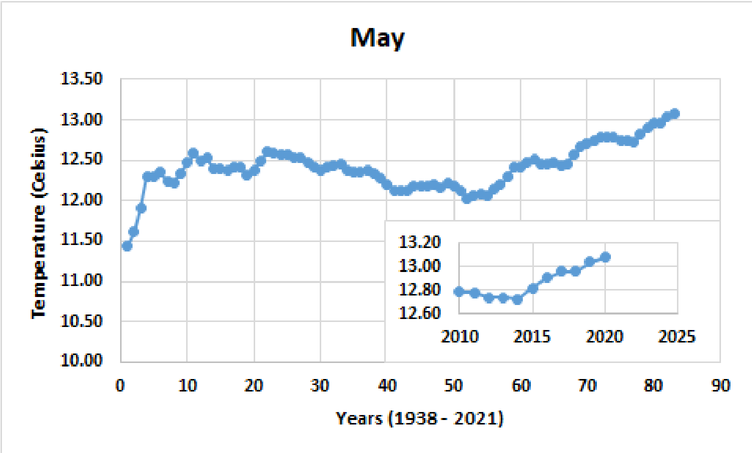
- **Temperature measurements at Vancouver from 1938 – 2021**

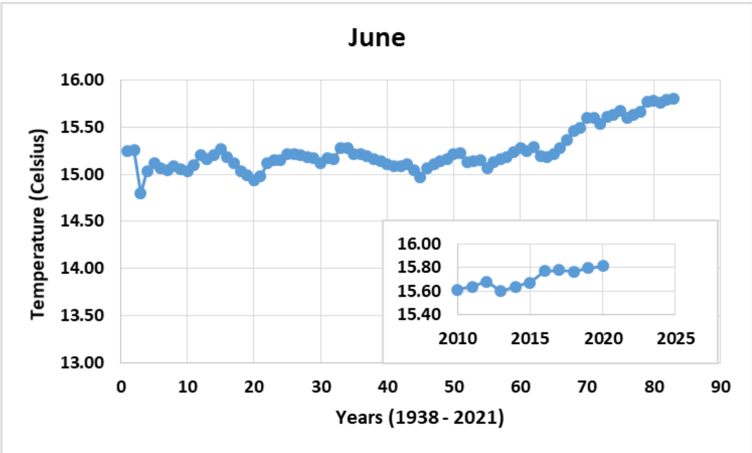


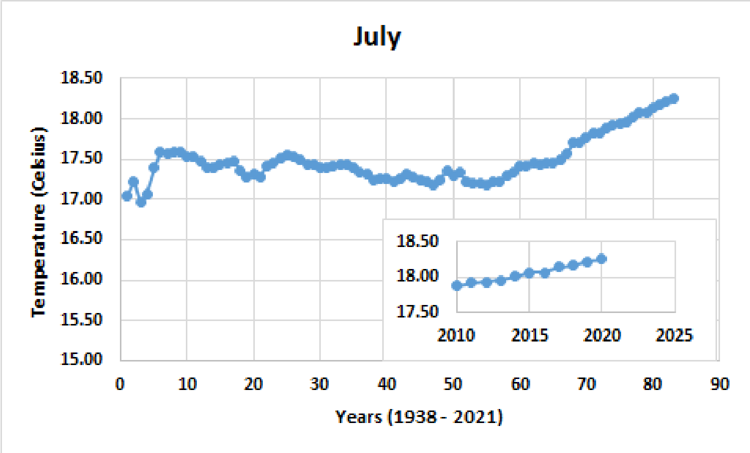


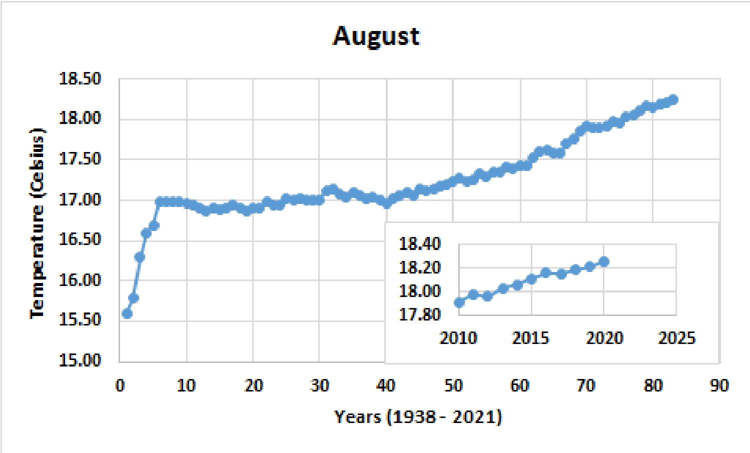


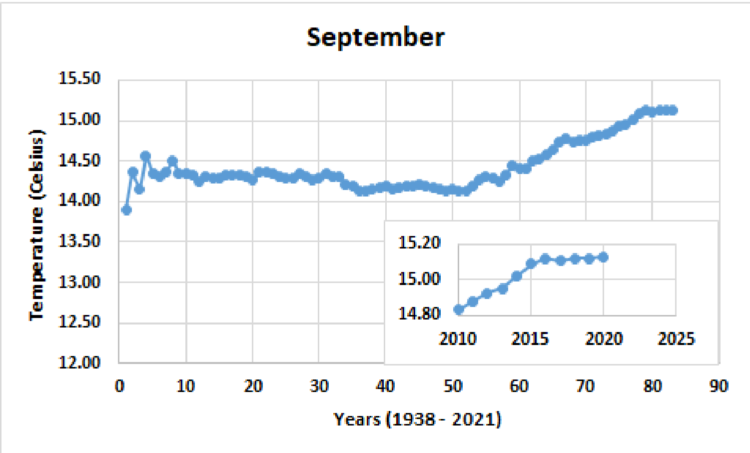

April
10.00
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
Years (1938 - 2021)
9.60
9.40
9.20
2010
2015
2020
2025

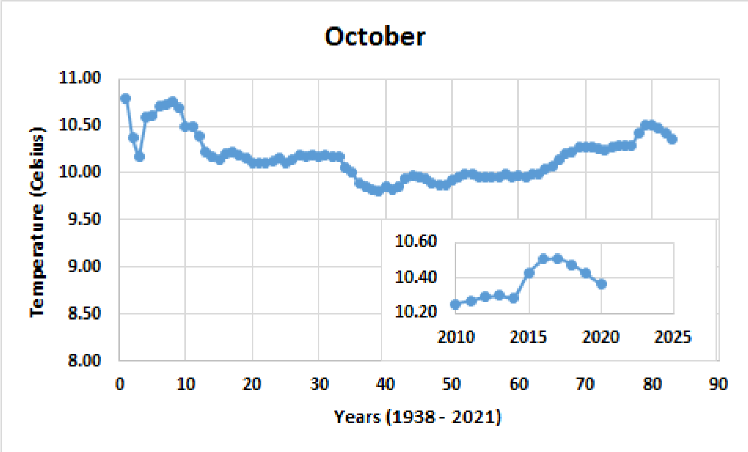

May
13.50
13.00
12.50
12.00
11.50
11.00
10.50
10.00
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
Years (1938 - 2021)
13.20
13.00
12.80
12.60
2010
2015
2020
2025

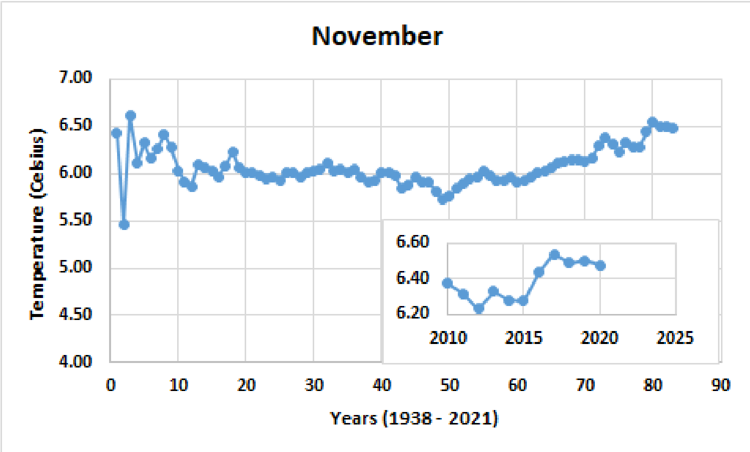

June
16.00
15.50
15.00
14.50
14.00
13.50
13.00
Temperature (Celsius)
0
10
20
30
40
50
60
70
80
90
Years (1938 - 2021)
16.00
15.80
15.60
15.40
2010
2015
2020
2025

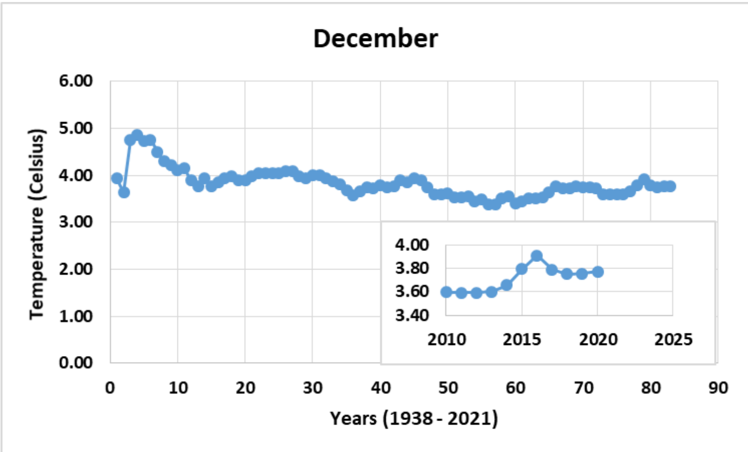

July
Temperature (Celsius)
18.50
18.00
17.50
17.00
16.50
16.00
15.50
15.00
0
10
20
30
40
50
60
70
80
90
Years (1938 - 2021)
18.50
18.00
17.50
2010
2015
2020
2025


August
Temperature (Celsius)
18.50
18.00
17.50
17.00
16.50
16.00
15.50
15.00
0
10
20
30
40
50
60
70
80
90
Years (1938 - 2021)
18.40
18.20
18.00
17.80
2010
2015
2020
2025


September
Temperature (Celsius)
15.50
15.00
14.50
14.00
13.50
13.00
12.50
12.00
0
10
20
30
40
50
60
70
80
90
Years (1938 - 2021)
15.20
15.00
14.80
2010
2015
2020
2025


October
11.00
10.50
10.00
9.50
9.00
8.50
8.00
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90
Years (1938 - 2021)
10.60
10.40
10.20
2010 2015 2020 2025


November
7.00
6.50
6.00
5.50
5.00
4.50
4.00
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90
Years (1938 - 2021)
6.60
6.40
6.20
2010 2015 2020 2025


December
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Temperature (Celsius)
0 10 20 30 40 50 60 70 80 90
Years (1938 - 2021)
4.00
3.80
3.60
3.40
2010 2015 2020 2025

Appendix B Reduction Strategies Supplementary Information

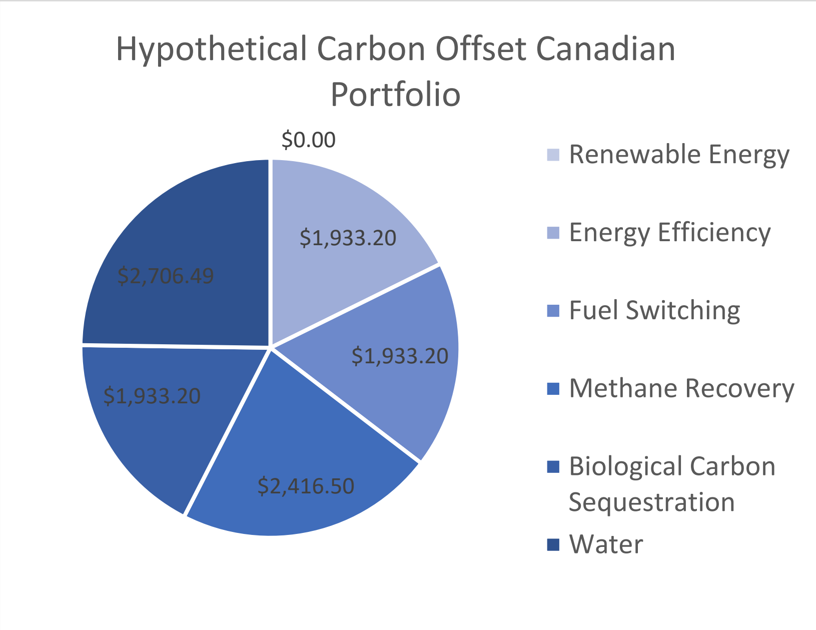
- **Carbon Offset Vendor Information**

Vendor	Vendor Location	Location of Project	Projects	Type of Project	Sub Type	Cost (1 tCO_2e)
Less	Canada	International	Solid Municipal Waste Treatment Plant in Vietnam	Methane Recovery	Landfill Methane Recovery	$24.00
		International	San Miguel Biogas Project in Thailand	Renewable Energy	Biomass	$24.00
		Canada	Essex-Windsor Regional Landfill Gas Capture and Destruction	Methane Recovery	Landfill Methane Recovery	$20.00
Climate Care	UK	International	Water Purification in Kenya	Water	Water management	$13.00
			Wind in Maharashtra India	Renewable Energy	Wind	$13.00
			Efficient Cookstoves in Ghana	Energy Efficiency	Energy efficient technologies and investments	$13.00
			14Trees Sustainable Building in Malawi	Fuel Switching	switching to lower-carbon fuels	$13.00
			Gola Rainforest Protection	Biological Carbon Sequestration	Forest protection	$13.00
Atmosfair	Germany	International	Efficient Cookstoves : Nigeria, Lesotho, Rwanda, India, Ethiopia	Energy Efficiency	Energy efficient technologies and investments	$34.44
			Senegal: Clean Energy from Solar Panels	Renewable Energy	Solar	$34.44

Vendor	Vendor Location	Location of Project	Projects	Type of Project	Sub Type	Cost (1 tCO_2e)
			Nepal: Biogas plants for household energy	Renewable Energy	Biomass	$34.00
			Honduras: Small hydropower plant	Renewable Energy	Hydro	$34.44
			Nicaragua: clean electricity from wind power	Renewable Energy	Wind	$34.44
Planetair	Canada	Canada	Canada Reforestation Portfolio	Biological Carbon Sequestration	Reforestation	$27.50
		Canada	Canada Nature Potfolio	Biological Carbon Sequestration	Forest protection	$25.00
		International	Antai: waste gas recovery	Renewable Energy	Biomass	$28.00
		International	Thailand: wastewater treatment	Water	Water management	$32.50
		International	Taiwan: Wind Farm	Renewable Energy	Wind	$26.50
		International	Rwanda: Accesible drinking water	Water	Water management	$33.50
CarbonZero	Canada	Canada	Nanaimo landfill gas capture project	Methane Recovery	Landfill Methane Recovery	$25.00
		Canada	Newfoundland climate & ecosystem conservancy project	Water	Water management	$28.00
		Canada	Southern Quebec Afforestation Project	Biological Carbon Sequestration	Afforestation	$28.00
		Canada	Ontario Biodiversity afforestation project	Biological Carbon Sequestration	Afforestation	$28.00
		Canada	Thermal Residential heating aggregation project (Canada-wide	Energy Efficiency	Energy efficient technologies and investments	$20.00

Vendor	Vendor Location	Location of Project	Projects	Type of Project	Sub Type	Cost (1 tCO_2e)
		Canada	Niagra escarpement forest carbon project	Biological Carbon Sequestration	Forest protection	$30.00
		Canada	Greenhouse co-op energy efficiency project	Fuel Switching	Switching to lower-carbon fuels	$25.00
LivClean	Canada	Canada	British Columbia Forest Conservation	Biological Carbon Sequestration	Forest protection	$18.00
		Canada	Alberta Tree Planting	Biological Carbon Sequestration	Reforestation	$18.00
TerraPass	USA	International	Virginia Landfill gass capture	Methane Recovery	Landfill Methane Recovery	$10.98
		International	Oklahoma:wind power	Renewable Energy	Wind	$10.98
		International	California: community forest	Biological Carbon Sequestration	Forest protection	$10.98
Offsetters	Canada	Canada	Great Bear Forest, BC: carbon project	Biological Carbon Sequestration	Forest protection	$20.00
		Canada	Chilliwack, BC: Quik's Farm Biomass Conversion project	Fuel Switching	Switching to lower-carbon fuels	$20.00
		Canada	Quadra Island, BC: Reforestland conservation project	Biological Carbon Sequestration	Forest protection	$20.00
		International	Florida: municipal waste methane capture	Methane Recovery	Landfill Methane Recovery	$20.00
		Canada	Selkirk Mountains, BC: Improved Forest management	Biological Carbon Sequestration	Forest protection	$20.00
ative Energy	USA	International	Tanzania: REDD in the Yaeada Valley	Biological Carbon Sequestration	Forest protection	$20.00

- **Hypothetical Carbon Offset Portfolio**



Type of Project	Total Cost
Renewable Energy	$0.00
Energy Efficiency	$1,933.20
Fuel Switching	$1,933.20
Methane Recovery	$2,416.50
Biological Carbon Sequestration	$1,933.20
Water	$2,706.49
Total	**$10,922.60**

Using the 2019 emissions, a portfolio of diversified Canadian offset options was chosen. One offset type from each category, except for renewable energy as there were no Canadian projects at this time, was chosen to account for 20% of the total offsets being purchased. The amount of money to be put towards each offset project type is summarized in the table on the right. To offset all the 2019 emissions, it would cost $10 922.

- **Smart Plugs and Advanced Power Strips: Number Estimate and Cost Calculation**

<u>Assumptions</u>
- The occupancy of the Nest (300) is the number of plugs which don't draw phantom load as the plugs are either in use or not plugged into any electronics
- It is most effective to do a combination of the two plug load reduction strategies. Therefore, a replacement with 50% smart plugs and 50% advanced power strips is proposed
-A power strip accounts for 3 plugs
- To provide a conservative estimate the highest value of the cost range is used for each technology
-The total building electricity reduction is estimated to be 43% which is the mean of the GHG reduction estimates of both strategies from the literature.

<u>Estimate of Number of Plugs in the Nest</u>

Lower Level including and the tenant spaces which I think would be (5 CRUS x 30 plugs) = 150 plugs
CITR, the PIT, and AMS Food Outlets there is another 250 plugs and 50 in the public realm = 450 plugs
Main floor has eight food and service outlets with avg. of 25 plugs + 100 in the public realm and in other operations 75 plugs = 375 plugs
Second floor bookable rooms, resource ct. art gallery and public area = 350 plugs
Third floor business office, service center, club rooms = 300 plugs
Fourth floor Gallery Lounge, club rooms 200 plugs

Total Plugs all floors = 1,675+/-plugs

<u>Number of Plugs Corrected</u>

Based on assumption that certain plugs do not draw phantom load
1675 – 300 = 1375
New total plugs = 1375
Total plugs being replaced with smart plugs = 688
Total plugs being replaced with power strips
686/3 = 229

<u>Cost Calculation</u>

Cost of replacing 688 plugs with smart plugs at $250 a plug = $172 000
Cost of replacing 229 plugs with advanced power strips = $14 198
Total capital cost = $186 198

- **Light Shelves: Calculations based on paper by Lee *et al.* (2018)**

<u>Information from Study</u>
Room Size: 668 ft^2
Room Window Size: 1.9 m (w) x 1.7 m (h)
Results: 0-10.5% decrease in electricity consumption by the room

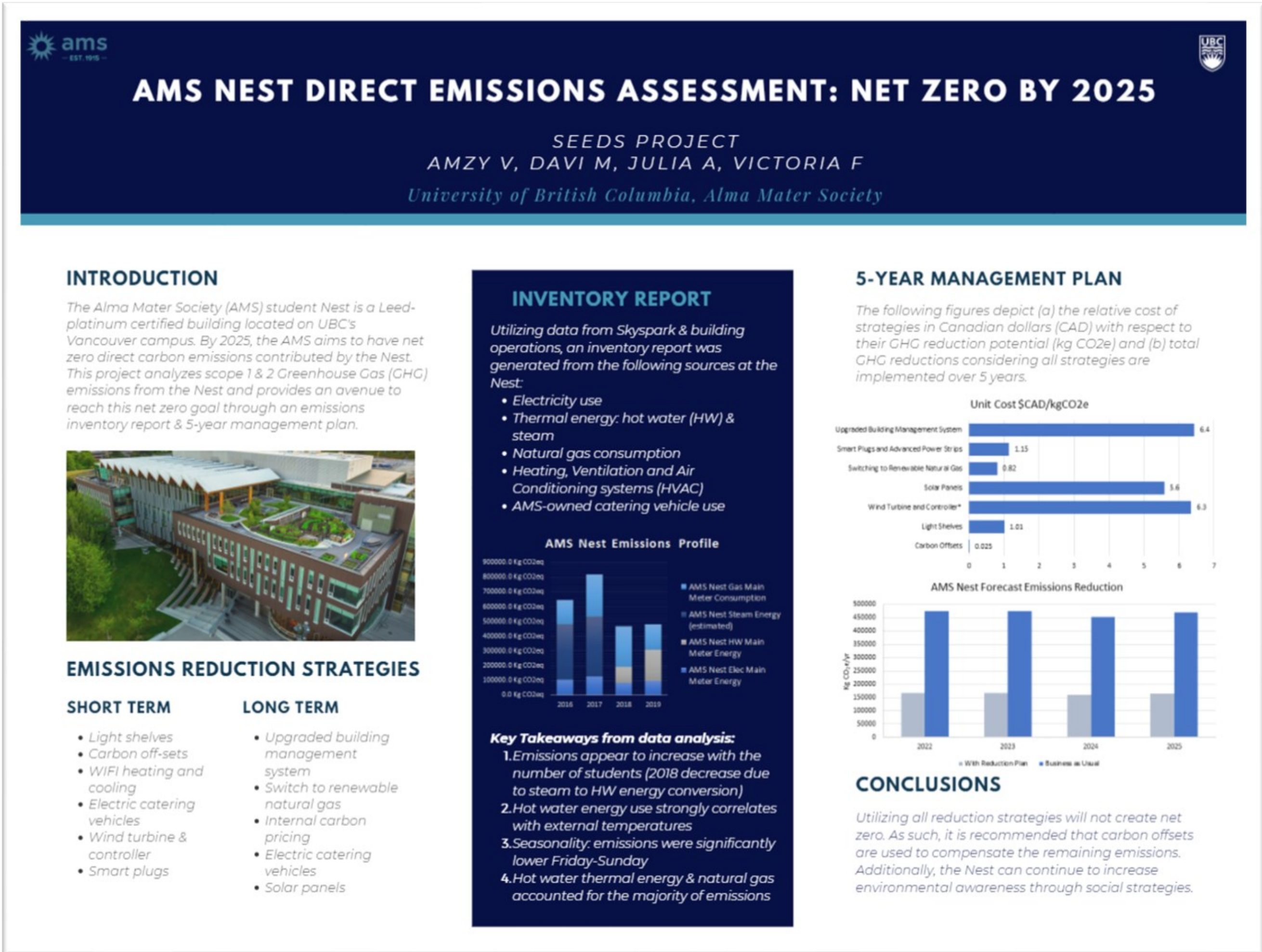
<u>Information about The Nest</u>
Building Size: 253 750 ft^2

$$\frac{253750}{668} = 380$$

Therefore, to have a 10.5% decrease in electricity consumption of the building, 380 light shelves would need to be installed. The GHG reduction of one light shelf is 0.02%.

Appendix C Info Graphic Posters

Online version for download/adjustment found here:
https://www.canva.com/design/DAEZybNi5wc/share/preview?token=NtPKWAEIi7jZIYra7Ow4GA&role=EDITOR&utm_content=DAEZybNi5wc&utm_campaign=designshare&utm_medium=link&utm_source=sharebutton



Online version for download/adjustment found here:

https://www.canva.com/design/DAEaqJ_mwDI/share/preview?token=B8VVze3tRKrUmbrFxOvubg&role=EDITOR&utm_content=DAEaqJ_mwDI&utm_campaign=designshare&utm_medium=link&utm_source=sharebutton