Electric School Bus Energy Assessment:

A Calgary Demonstration Case Study

Implementing Partners:

Pollution Probe

RFS ENERGY

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The project team extends its gratitude to Southland Transportation Ltd. for their valuable contributions, including leasing the electric school bus, providing administrative support to the project, and providing resources related to the ongoing maintenance and operation of the bus.

The Calgary Board of Education (CBE) also played a supportive role by involving the electric school bus on their routes and contributing funding for the bus charger..

LAND ACKNOWLEDGEMENT

With a focus on mobility in what is now known as Alberta – subject to Treaties 6, 7 and 8 – this project is inherently land-based. The project team recognizes the true history of these lands and the injustices that First Nations, Métis, and Inuit peoples continue to experience through colonial systems and structures. We acknowledge these lands as the traditional and ancestral territory of many peoples – the Blackfoot Confederacy– Kainai, Piikani, and Siksika – the Cree, Dene, Saulteaux, Nakota Sioux, Stoney Nakoda, the Tsuu T'ina Nation, and the Métis People of Alberta.

We encourage readers to learn about the Indigenous history of where they live and work and the Truth and Reconciliation Committee of Canada's Calls to Action. We invite you to reflect on your own relationship with the lands you occupy and what meaningful actions you can take toward reconciliation.

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Pollution Probe

Pollution Probe is a Canadian charitable environmental organization that is a leading agent of change at the intersection of communities, health and environment. Since 1969, we have been defining environmental problems through research, promoting understanding through education and pressing for practical solutions through advocacy. Pollution Probe has a proven track record of working in successful partnership with industry and government to develop practical solutions for shared environmental challenges.

Pollution Probe is one of Canada's leading independent transportation solution providers. Our work supports aggressive actions to address climate change and reduce air pollution while promoting job creation and economic growth. In addition to projects we actively contribute to expert transportation committees and working groups at local, regional, national and global levels. We are technology neutral and work collaboratively with a wide variety of stakeholders to develop transportation decarbonization solutions across all modes.

Mobility Futures Lab

Mobility Futures Lab

Mobility Futures Lab is a leading sustainable transportation consulting firm that is at the forefront of innovation and research in the field of mobility. The firm's services are designed to help clients navigate the complex landscape of sustainable transportation, with a focus on proprietary software tools and data-driven solutions. Our approach is based on a deep understanding of the interconnections between transportation, energy, and the environment.

RFS ENERGY

RFS Energy

RFS Energy brings people together to propel planning, research, and climate change policy into the marketplace.

With 50+ years of combined experience working with non-profits, think tanks, 25+ utilities and government agencies across Canada, the RFS Energy team draws from unique experience rooted in on-the-ground program implementation to support clients and bring innovation to life.

SOUTHLAND safely home

Southland Transportation

Founded in 1971, Southland Transportation is a leader in student transportation throughout Canada and a trailblazer in forward-thinking transportation solutions. Operating over 3500 routes daily, Southland understands the GHG impact of the transportation industry and is actively reducing emissions in the communities we serve. With Canada's largest alternative fuel fleet and a growing zero emissions fleet, Southland is creating a sustainable future for the students we deliver Safely Home each day.

Executive Summary

In Canada, the vast majority of school buses, more than 90% of the total fleet, run on diesel fuel, resulting in greenhouse gas (GHG) and harmful pollutant emissions throughout their lifespan. These emissions have direct effects on human health. Electric school buses (ESBs) present a valuable opportunity to reduce GHG emissions associated with the school bus industry and mitigate the detrimental health impacts of diesel exhaust on children and the general population.

While recent reductions in ESB costs, supported by federal and provincial financial incentives, have led to increased adoption across Canada, fleet operators still harbor concerns about the technology's readiness, particularly regarding its performance in winter conditions. To address these concerns, Pollution Probe partnered with RFS Energy and the Mobility Futures Lab, with funding from the Alberta Ecotrust Foundation and the ScotiaBank Zero Emission Fund, to conduct an ESB demonstration in Calgary, Alberta. The demonstration involved deploying a single Blue Bird Vision ESB in collaboration with local fleet operator Southland. The project aimed to monitor the operational performance of the ESB and its associated charger over the course of a school year. This is the first electric school bus demonstration in Canada in which the collected real world operational data is shared publicly.

This technical report presents the operational lessons learned, and the results of the data analysis conducted based on the energy consumption monitoring of the ESB and associated charger. The analysis explores the performance of the ESB under different operating conditions, including the impact of outside temperature and regenerative braking. The energy consumption of trips completed by the ESB is evaluated based on a measure of efficiency called energy intensity. Energy intensity, expressed in kilowatt-hours per kilometer (kWh/km), refers to the amount of electrical energy consumed by an ESB to travel a distance of one kilometer. It is a measure of the efficiency of the vehicle's energy usage and represents the energy required to move the bus a specific distance. Lower energy intensity values indicate higher efficiency, meaning the bus can travel longer distances on the same amount of energy.

This report's findings are crucial for fleet operators as they help identify viable routes in their fleet for electrification, particularly during winter conditions. Moreover, the results assist in determining whether specific routes require ESBs with a larger battery, leveraging the availability of multiple battery sizes by some manufacturers. Reliable estimates of yearly energy consumption from charging and required battery capacity for ESBs are also essential elements to consider in the financial assessments related to deploying ESBs.

Executive summary

Key findings from the report include:

- The range of the ESB on a single charge varied from 73 km to 213 km based on the 155-kWh battery depending on the operating conditions across 81 runs conducted between December 2022 and June 2023. The range of the ESB on a single charge gradually increases from December to June in parallel to warming temperatures. School bus operators can increase their range in winter conditions by installing an auxiliary diesel heater and not relying on electrical heating, which consumes a significant amount of energy.

- Regenerative braking reduces energy intensity by an average of 22%, improving vehicle range. School bus operators should explore driver training programs that generate useful data and maximize regenerative braking to improve vehicle range and reduce charging costs.

- In winter conditions, the use of the bus electrical heating system increases energy intensity by an average of 33%, decreasing vehicle range. Fleet operators should explore bus pre-heating in advance to runs and logistical planning for mid-day charging in between runs to ensure sufficient range capabilities on certain routes.

- Energy transfer losses and energy consumption while plugged to the charger increases the energy intensity of ESBs by an average of 41% relative to the energy intensity estimated based on the energy consumption of the bus only while in operation. This increase is more pronounced during winter conditions and relatively smaller during warmer months. ESB manufacturers are continuously improving their battery management systems to minimize this disparity.

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A Calgary Demonstration Case Study

1. INTRODUCTION

Over 90% of Canada's 50,000 school buses are diesel, emitting 110 tonnes of carbon dioxide (CO_2) each over their lifetime.

Diesel exhaust also includes harmful air pollutants that have direct effects on human health. Electric school buses (ESBs) provide an opportunity to reduce greenhouse gas (GHG) emissions associated with the school bus industry and mitigate the harmful health impacts of diesel exhaust children and the general population are exposed to. [1]

While recent cost reductions of ESBs supported by federal and provincial financial incentives have increased adoption across Canada, fleet operators remain cautious about the technology readiness of ESBs, particularly when it comes to their range in winter conditions. Pollution Probe, in partnership with RFS Energy and the Mobility Futures Lab, was funded by the Alberta Ecotrust Foundation and the ScotiaBank Zero Emission Fund to conduct a demonstration of an ESB in Calgary, Alberta. The demonstration involved the deployment of a single ESB in collaboration with local fleet operator Southland. The project involved monitoring the operational performance of the ESB and associated charger across a school year. Telematics equipment was installed on the bus to collect energy consumption data between December 7, 2022 and June 28, 2023. This is the first electric school bus demonstration in Canada in which the collected real world operational data is shared publicly.

This technical report presents the operational lessons learned, and the results of the data analysis conducted based on the energy consumption monitoring of the ESB and associated charger. The analysis explores the performance of the ESB under different operating conditions, including the impact of outside temperature and regenerative braking. The energy consumption of trips completed by the ESB is evaluated based on a measure of efficiency called energy intensity. Energy intensity, expressed in kilowatt-hours per kilometer (kWh/km), refers to the amount of electrical energy consumed by an ESB to travel a distance of one kilometer. It is a measure of the efficiency of the vehicle's energy usage and represents the

1 Pollution Probe (2022). Opportunities for Accelerating School Bus Electrification in Ontario. Retrieved from: https://www.pollutionprobe.org/wp-content/uploads/2022/05/White-Paper-Opportunities-for-accelerating-school-bus-electrification-in-Ontario.pdf

1 Introduction

energy required to move the bus a specific distance. Lower energy intensity values indicate higher efficiency, meaning the bus can travel longer distances on the same amount of energy.

This report's findings are crucial for fleet operators as they help identify viable routes in their fleet for electrification, particularly during winter conditions. Moreover, the results assist in determining whether specific routes require ESBs with a larger battery, leveraging the availability of multiple battery sizes by some manufacturers. Reliable estimates of yearly energy consumption from charging and required battery capacity for ESBs are also essential elements to consider in the financial assessments related to deploying ESBs.

Deployment planning

2.1 Vehicle and charging station specifications

The project was launched in September 2022 in partnership with local fleet operator Southland.

A 2022 model year Blue Bird ESB with a battery capacity of 155 kWh was leased to operate until June 2023. The ESB was fitted with air brakes, a braking system more commonly found in electric vehicles due to their higher weight compared to diesel vehicles. Drivers need to undergo a one-day training to obtain certification for operating air brake equipped vehicles.

Multiple charging station models were considered for the demonstration with a focus on level 2 AC chargers to limit installation costs. Following discussions with various EVSE providers, a level 2 19 kW Nuvve PowerPort station was selected.[2] The vehicle and charger specifications are presented in **Table 1.**

Table 1: Vehicle and charger specifications

Procurement Item	Specifications	Standards and codes
Blue Bird Vision Electric	Type C, Up to 77 passengers, 155 kWh NMC battery[3]	Level II (AC) - J1772 & Level III (DC) – CCS-Combo
Nuvve charging stations	19 kW level 2 (1 Phase)[4]	J1772

2. Multiple EVSE providers had lead times of above 6 weeks, highlighting some of the supply chain issues and high demand in the industry during that period.
3. Blue Bird (2023). Vision Electric Bus. Retrieved from: https://www.blue-bird.com/buses/vision/vision-electric-bus
4. Nuvve (2023). Nuvve PowerPort. High-Power AC charging station. Retrieved from: https://nuvve.com/wp-content/uploads/2022/01/nuvve-powerport-single-phase-spec-sheet-jan2022.pdf

2 Deployment planning

2.2 Deployment and maintenance

The first step of the demonstration consisted in the selection and installation of the charging station and vehicle telematics equipment.

The charging station was shipped to the yard and installed by a local technician. A DataHub vehicle telematics device from ChargePoint was selected to install on the ESB and shipped to the yard.[5]

The installation of the telematics device required an electrical technician to be contracted to conduct the installation. ESB manufacturers do not all have direct partnerships with telematics device providers, which results in the bus models not always having easily accessible ports to connect with energy consumption monitoring devices. Partnerships are however quickly evolving in the industry, with certain OEMs launching their own telematics monitoring software services.

Following the installation of the charging station hardware and software, and vehicle telematics, data collection covered the period of December 7, 2022, to June 28, 2023, with a number of interruptions to operations resulting in bus downtime. **Table 2** presents the maintenance and weather-related incidents that resulted in bus downtime. Vehicle malfunction events included the 12V battery of the bus having to be replaced and two coolant related issues. The vehicle also had a one-day downtime because of the charger's unplugging handle being frozen.

Table 2: Demonstration maintenance events

Issue	Failure Date	Downtime	Required Dealership Servicing
Coolant leak due to loose clamp	November 21, 2022	14 days	Yes
Frozen charging handle	February 27, 2023	1 day	No
12V battery failure	April 10, 2023	2 days	No
Thermal management system coolant error	April 21, 2023	13 days	Yes

5 ChargePoint (2023). Telematics. ChargePoint Hardware. Retrieved from: https://www.chargepoint.com/fleet/telematics

Evaluation of bus operations

3.1 Importance of ESB energy consumption monitoring

Several studies have investigated how driving behavior affects fuel consumption in diesel buses, and some fleet operators utilize real-time telematics to optimize driving behavior to reduce fuel usage.

Similarly, ESBs exhibit variations in energy consumption based on driving conditions, but these fluctuations tend to be more significant than those in diesel technology. The energy consumption fluctuations in ESBs primarily stem from two factors. Firstly, the electrical HVAC (Heating, Ventilation, and Air Conditioning) systems consume higher power compared to traditional internal combustion engines, particularly in winter when they cannot benefit from the excess heat generated by an internal combustion engine. Secondly, regenerative braking technology enables ESBs to recover energy under certain driving conditions, further impacting energy consumption patterns.

Furthermore, different battery chemistries entail trade-offs in cost, range, charging speed, longevity, safety, and performance.[6] Over the next decade, the considerable investments made in battery manufacturing are anticipated to lead to the availability of diverse battery chemistries in the market, each offering different performance characteristics.

In this context, a better understanding of energy consumption of ESBs using real time monitoring is of greater importance with this new technology for both fleet routing planning and right sizing. Gaining a deeper insight into the range of ESBs helps alleviate fleet operators' range anxiety. This also enables them to avoid purchasing an ESB with a larger, more expensive battery than what is required for their operations, thus enhancing the economics of ESBs. Presented in **Figure 1** are the main factors that impact the energy consumption of ESBs.[7] This report explores how some of these factors affect the range of ESBs.

3

6 National Academies of Sciences, Engineering, and Medicine (2020). Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report. Washington, DC: The National Academies Press. https://doi.org/10.17226/25542.

7. ICCT (2023). Operational analysis of battery electric buses in Sao Paulo. Retrieved from: https://theicct.org/publication/brazil-hvs-zebra-operational-analysis-electric-bus-sao-paulo-feb23/

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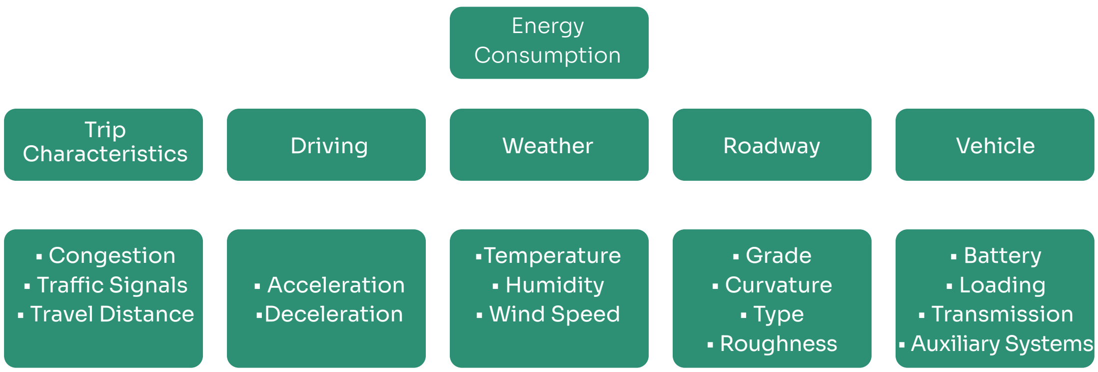
Figure 1: Factors that impact ESB energy consumption



3.2 Routes and data sample size

A total of 81 runs were conducted between December 7, 2022 and June 28, 2023.

The ESB was operated on three different routes presented in **Figure 2**.

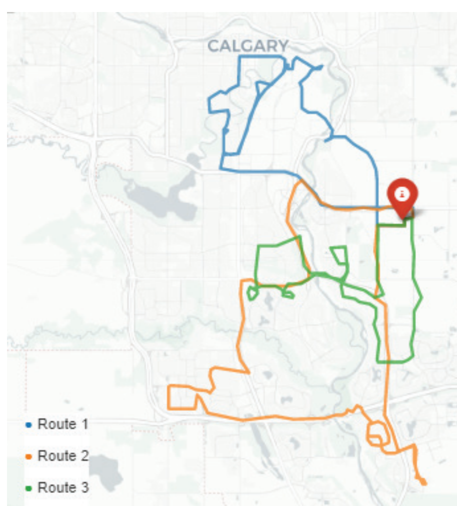


Figure 2: Routes evaluated during demonstration

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Table 3: Characteristics of ESB routes evaluated

Routes	Number of runs	Average distance (km) [min,max]	Average Speed (km/hr) [min,max]
1	13	54 [47,59]	28 [26,31]
2	8	61 [60,62]	42 [39,45]
3	60	41 [34,51]	37 [32,41]
Total	81	45 [34,62]	36 [26,45]

Table 3 presents the total number of runs conducted on each route, along with the average distance and speed of the runs. The number of runs is limited relative to the number of days of operations in the school year due to logistical challenges that had to be overcome. Additionally, the project team faced delays during the demonstration whenever the ESB was handed over to a new driver, as each driver needed to complete the air brake training.

During the initial stages of the demonstration in winter conditions, the bus was only sporadically operated during either the morning or afternoon run to evaluate its range capabilities. The operation of the bus in cold weather showed high energy consumption mainly due to the energy intensive electrical heating system and the ESB was only able to complete a single run (morning or afternoon) on a single charge. The bus was required to return to the yard to be charged in between the morning and afternoon run to ensure enough range. However, it is common practice in the school bus industry for drivers to keep the bus with them throughout the day and only return it to the yard after their afternoon run. Drivers expressed some dissatisfaction with these logistical changes that were required, and delays were incurred to allocate the ESB to drivers that could return to the yard in between the morning and afternoon runs.

Over the course of the demonstration, operational staff from Southland in partnership with the project team gradually tested the use of an auxiliary diesel heater instead of the electrical heating system of the bus to improve the ESB range. Pre-heating of the bus in the morning while it was still plugged into the charger was also added to the operational practices to limit the usage of the electrical heating system during operations. During these tests, the bus system was operated solely with an

3 Evaluation of bus operations

auxiliary diesel heater, without using the bus electrical heating system, in temperatures ranging from -5°C to 5°C. However, it was observed that the diesel heater alone was inadequate to maintain the internal bus temperature at outside temperatures lower than -5°C without the assistance of the bus electrical heating system.[8] The impact of these tests on the energy intensity of the bus is presented in the following sections.

3.2.1 Energy consumption and role of regenerative braking

Figure 3 presents the energy intensity of the bus in kWh/km and associated bus range on a single charge based on the 155-kWh battery on each of the dates in which the ESB was operated between December 2022 and June 2023. Throughout the length of the demonstration, a minimum and maximum energy intensity of 0.67 kWh/km and 1.31 kWh/km respectively were observed. In other words, the range of the ESB on a single charge varied from 73 km to 213 km depending on the operating conditions of the ESB.

A high energy intensity is observed in the winter months of operations followed by varying energy intensity between February and April as HVAC usage varied depending on daily temperature. The energy intensity of the bus subsequently decreased from April to June 2023 as temperatures increased. The energy consumption of an ESB can be impacted by the ambient temperature due to the usage of the electrical HVAC system for heating or cooling, as well as a variation in the performance of the battery itself depending on its chemistry.

Figure 3: Energy intensity of trips and range implications across days of operations

8 This finding is based on the size of the diesel heater available in this project. A larger diesel heater could allow ESB operation by entirely relying on a diesel heater without using the electrical heating system for heating at lower temperatures.

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Table 4 presents the average energy intensity and associated vehicle range on a single charge based on the 155-kWh battery for each of the months in which the ESB was operated. The range of the ESB on a single charge gradually increases from December to June in parallel to warming temperatures. Fleet operators should consider addressing these range variations either by utilizing auxiliary systems (such as diesel heaters) to limit them or by factoring them into their route planning and ESB charging strategies during deployment.

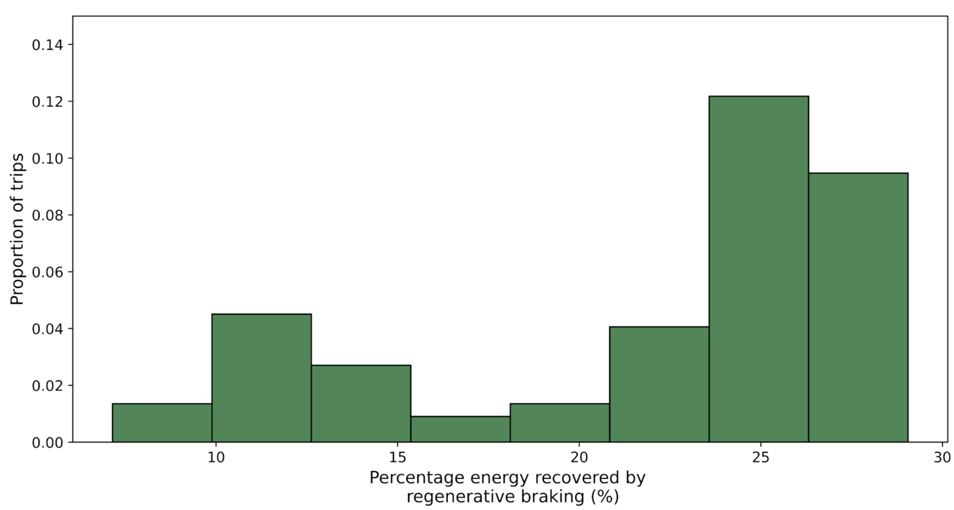
Figure 4 presents the percentage of total energy consumption recovered with regenerative braking for all runs conducted throughout the demonstration. An average proportion of 22% of total energy consumed was recovered through regenerative braking across all runs, with a minimum of 7% and a maximum of 29%.

Table 4: Average energy intensity and range by month

Month	Average Energy Intensity (kWh/km)	Average Single Charge Range (km)
December	1.25	83
January	1.14	93
February	0.99	114
April	0.83	156
May	0.75	189
June	0.75	189

Regenerative braking energy recovered varies based on the characteristics of a route and the driving behavior of individual drivers. The number of runs conducted on Routes 1 and 2 as part of this demonstration were significantly lower than Route 3, making a comparison across routes not statistically significant. However, the limited observations show that Route 3 had a significantly higher proportion of energy recovered through regenerative braking. Further exploration on the conditions in which the proportion of energy recovered with regenerative braking increases is needed. School bus operators should explore driver training programs that generate useful data and maximize regenerative braking to improve vehicle range and reduce charging costs.

Figure 4: Proportion of energy recovered through regenerative braking across trips



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3.2.2 Impact of temperature on energy intensity

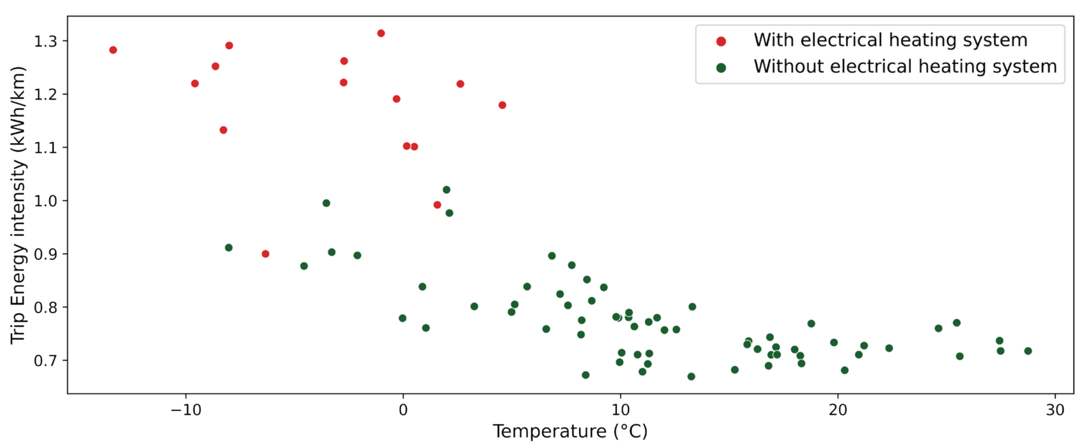
As mentioned earlier, the energy consumption of an ESB can be impacted by the ambient temperature due to the usage of the electrical HVAC system for heating or cooling, as well as a variation in the performance of the battery itself depending on its chemistry.

Figure 5 presents the energy intensity of trips conducted relative to the outside temperature on the day of each run, distinguishing between runs conducted with the electrical heating system turned on and off. Runs conducted in winter conditions at less than -10°C with the electrical heating system on had an average intensity of 1.18 kWh/km, which translates to a range of 95 km on a single charge based on the 155-kWh battery size.

Between -5°C and 5°C, Southland staff were able to test operations with and without the electrical heating system by relying on an auxiliary diesel heater as well as pre-heating of the bus prior to the start of a run while plugged to the charger. These tests showed that operations in winter conditions with the electrical heating system active increased the energy intensity of trips by an average of 33%, thereby reducing vehicle range.[9]

At a temperature of 10°C and above, the energy intensity of the bus decreases to reach an average of 0.73 kWh/km, which translates to a range of 210 km based on the 155-kWh battery size. It is in these 'optimal' conditions that the ESB can reach the highest ranges advertised by manufacturers.

Figure 5: Impact of HVAC electrical system and outside temperature on trip energy intensity



9 It is important to note that these findings are based on a limited number of runs, and need to be validated by a larger scale data collection effort

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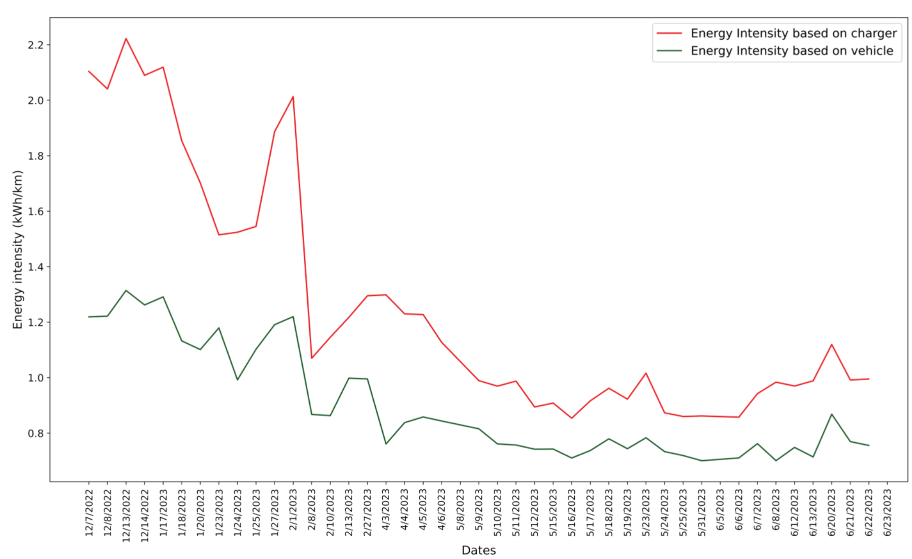
3.3 Charger energy consumption

The ESB was charged daily in between runs or after the afternoon run. The charging power was consistent at 12.5 kW, lower than the 19.2 kW the Nuvve charger is capable of. This difference is likely due to the ESB hardware that does not allow AC charging above 12.5 kW. Under a 12.5 kW charging speed, the ESB can be fully charged in 11-12 hours. Developments are taking place in the manufacturing realm of ESBs to enhance the charging power capacity of newly developed ESB models.

Charging stations require energy to power their own operations and experience energy losses during the charging process when supplying energy to the vehicles. Consequently, the charger's daily energy consumption tends to be higher compared to the energy consumed by the ESB during operations.[10] Additionally, in cold weather conditions, ESBs consume energy and require charging while parked to ensure that the battery management system keeps the battery at an optimal temperature for starting. This precaution is taken because extreme cold can affect battery performance and reduce its ability to provide sufficient power for the bus to start and operate effectively. Lastly, pre-heating the bus prior to a run while the vehicle is still plugged to the charger results in energy consumption that is not accounted for when looking exclusively at operational energy consumption of the ESB.

Figure 6 presents the energy intensity in kWh/km based on the charger and the ESB for each of the dates of operations for which data was available for extraction from the charger software. The energy intensity based on the charger is calculated by dividing the total energy consumption of the charger on that day by the total distance travelled by the ESB. The energy intensity based on the vehicle is calculated by dividing the total energy consumption of the bus during operations on that day by the total distance travelled by the ESB.

Figure 6: Net Energy Used for charging relative to energy consumed by vehicle on days of operation



10 Vermont Energy Investment Corporation (2018). Electric School Bus Pilot Project Evaluation. Retrieved from: https://www.mass.gov/doc/mass-doer-electric-school-bus-pilot-project-evaluation/download

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The energy intensity based on the charger is found to be on average 41% higher than the one based on the vehicle. This additional energy consumption can be attributed to bus pre-heating while it is plugged to the charger prior to runs, top up energy consumption to maintain adequate battery temperature, energy losses during charging, and energy consumed to power the charger hardware.

In winter months, the disparity between the energy intensity of the charger and the vehicle is at its greatest due to vehicle pre-heating and battery temperature preservation heating. However, during warmer months, this gap decreases significantly, accounting for only energy losses during charging and the energy consumed to power the charger hardware (**Table 5**).

Table 5: Average energy intensity based on vehicle and charger by month

Month	Energy intensity based on ESB (kWh/km)	Energy intensity based on charger (kWh/km)	Percent increase (%)
December	1.25	2.11	69
January	1.14	1.74	52
February	0.99	1.35	36
April	0.83	1.22	48
May	0.75	0.92	24
June	0.75	0.98	30

Lessons Learned

- The range of the ESB on a single charge varied from 73 km to 213 km based on the 155-kWh battery depending on the operating conditions across 81 runs conducted between December 2022 and June 2023. The range of the ESB on a single charge gradually increases from December to June in parallel to warming temperatures. School bus operators can increase their range in winter conditions by installing an auxiliary diesel heater and not relying on electrical heating, which consumes a significant amount of energy.

- Regenerative braking reduces energy intensity by an average of 22%, improving vehicle range. School bus operators should explore driver training programs that generate useful data and maximize regenerative braking to improve vehicle range and reduce charging costs.

- In winter conditions, the use of the bus electrical heating system increases energy intensity by an average of 33%, decreasing vehicle range. Fleet operators should explore bus pre-heating in advance to runs and logistical planning for mid-day charging in between runs to ensure sufficient range capabilities on certain routes.

- Energy transfer losses and energy consumption while plugged to the charger increases the energy intensity of ESBs by an average of 41% relative to the energy intensity estimated based on the energy consumption of the bus only while in operation. This increase is more pronounced during winter conditions and relatively smaller during warmer months. ESB manufacturers are continuously improving their battery management systems to minimize this disparity.

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