Program Record (Vehicle Technologies Office)		
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Title: Impact of Cold Ambient Temperature and Extreme Conditions on Electric Vehicles		
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Background

A battery electric vehicle (BEV) is an efficient and clean personal transportation solution that eliminates tank-to-wheel (downstream) greenhouse gas (GHG) emissions and tailpipe criteria pollutant emissions while reducing petroleum dependency. As renewable energy sources increase as a share of total grid electricity production,[1] the associated well-to-tank (upstream) emissions of BEVs will also steadily decrease. In short, a BEV purchased today will get cleaner over the full useful life of the vehicle as the electric grid becomes less carbon-intense over time. Along with energy and environmental benefits, BEVs feature quieter operation, equal or better acceleration performance, fewer moving parts, and lower operating and maintenance costs compared to their conventional counterparts. Despite these benefits, mainstream consumers have concerns about BEVs—as is often the case with new technologies as the product adoption life cycle expands beyond early adopters.

The Vehicle Technologies Office (VTO) funds extensive research in BEV battery and electrification technologies and has performed significant modeling, testing, and data analysis of these vehicles. These activities provide important information that speaks to addressing consumer concerns, driving down costs, and increasing accessibility and utility of clean vehicle technologies. Through federal investment, congressional legislation, and market forces, BEVs have become more prevalent on the roads, with sales reaching over 8% of the light-duty fleet at the end of 2023,[2] up from 1.6% annually in 2020. Recent cost reductions, particularly in batteries, and improvements in vehicle range[3] have led to significant market adoption increases in recent years.

This Program Record speaks to one particular concern for BEV shoppers and owners: vehicle range and potential impacts on range caused by extreme ambient temperatures and weather events. This document presents key performance and technical characteristics of modern BEVs, such as range and energy consumption, across a spectrum of ambient temperature conditions, based on an analysis of laboratory test data as well as real-world data.

[1] Pieter Gagnon, An Pham, Wesley Cole, et al., *2023 Standard Scenarios Report: A U.S. Electricity Sector Outlook*, National Renewable Energy Laboratory, revised January 2024, nrel.gov/docs/fy24osti/87724.pdf.
[2] Argonne National Laboratory, "Light Duty Electric Drive Vehicles Monthly Sales Updates," accessed 2024, https://www.anl.gov/esia/light-duty-electric-drive-vehicles-monthly-sales-updates.
[3] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, "FOTW #1344, May 27, 2024: Nineteen Model Year 2023 Light-Duty EVs Have a Driving Range of 300 Miles or Greater," May 27, 2024, https://www.energy.gov/eere/vehicles/articles/fotw-1344-may-27-2024-nineteen-model-year-2023-light-duty-evs-have-driving.

Introduction

BEVs have higher powertrain efficiency than conventional internal combustion engine vehicles (ICEVs)[4] and therefore require less onboard stored energy. As a result, BEV energy consumption and range are more sensitive to significant ambient temperature changes than comparable conventional vehicles. This sensitivity to extreme cold is due in large part to the power required for heating, ventilation, and air conditioning (HVAC) systems, as well as the reduced chemical performance in the battery cells.

Conventional ICEVs are considerably less energy-efficient, losing most of the energy stored in the fuel to heat, with only a small portion going to vehicle tractive effort. These vehicles carry significantly more stored energy on board, owing to petroleum-based fuels' volumetric and gravimetric energy density, and are therefore less sensitive to increased cabin heating needs in cold temperatures. Heat from the hot engine coolant—heat that would otherwise be wasted—can be used to heat the cabin via an interior heat exchanger, or heater core. ICEVs therefore see a proportionally smaller increase in energy consumption in cold ambient conditions.

Given these key differences between the two powertrain architectures, specific concerns have been raised about the ability of BEVs to maintain cabin temperature for extended periods of time during extreme cold temperatures, such as when a vehicle becomes stranded on a congested highway during a blizzard.

In this Program Record, chassis dynamometer and on-road vehicle test data are both referenced to show that BEVs commercially available today, while more sensitive to cold ambient temperatures than ICEVs, are capable of meeting driving requirements under extreme weather conditions and can maintain cabin comfort for extended periods of time in such conditions. A range of ICEVs and BEVs were tested in a broad spectrum of temperatures and operating conditions to draw energy consumption and range trends based on driving conditions, heater technologies, and vehicle features currently available. This document also addresses the statistical significance of getting caught in a blizzard on a highway for several hours.

VTO anticipates that future advancements to vehicle technologies will improve cold weather performance and range for BEVs. Lower-cost battery chemistries, as well as battery technologies that enable higher energy density, will both provide for additional stored energy on board at lower financial, mass, and packaging cost. Battery thermal system design may also improve battery performance in cold temperatures. Improvements to the broader vehicle HVAC system design and efficiency will also play a role in reducing vehicle HVAC load and its outsize impact on cold weather performance.

Impacts of Ambient Temperature on Energy Consumption and Vehicle Range across Powertrains

Changes in Range due to Ambient Temperature

Government and industry have both been addressing BEV range challenges by working to increase battery energy density, drive down battery and electrified powertrain costs, and improve vehicle system, glider, and aerodynamic efficiency. Since 2010, estimated BEV range has more than tripled,

[4] U.S. Department of Energy and the U.S. Environmental Protection Agency, "Where the Energy Goes: Electric Cars," FuelEconomy.gov, accessed 2024, https://www.fueleconomy.gov/feg/atv-ev.shtml

achieving 300 miles as an average of available models in 2022.[5] Though significant progress has been made in BEV performance and range, current BEVs still exhibit more sensitivity to ambient temperature than ICEVs, and these sensitivities are worth characterizing.

To shed light on changes in energy consumption and range due to different ambient temperatures, this analysis relies both on controlled tests conducted in a laboratory environment and on real-world data collected on-road from several sources, including research supported by VTO and partners, as well as external studies and reports. A detailed analysis of the powertrain components contributing to range loss was performed on three model year 2019–2020 BEVs using U.S. Environmental Protection Agency (EPA) standard driving cycles on a vehicle chassis dynamometer at Argonne National Laboratory's Advanced Mobility Technology Laboratory (AMTL). In addition, real-world data collected on a larger number of vehicles across a wide range of driving conditions was sourced from various organizations to complement the controlled dynamometer test data. Data was analyzed from the sources, as shown in Table 1. The real-world data from these organizations demonstrated similar trends to the ones measured on dynamometers during controlled tests.

Table 1. Data Sources Referenced

Sources	Data type
Argonne National Laboratory (ANL)	Dynamometer tests at temperatures from 0°F to 95°F
American Center for Mobility (ACM)	Cold temperature impact on powertrain losses
American Automobile Association (AAA)	Range tests at hot and cold conditions
Recurrent[6]	Estimated and verified range loss at freezing conditions
EV WATTS[7]	Energy consumption estimates at various ambient temperatures
Geotab[8]	Estimated trip efficiency at various ambient temperatures
Autocar[9]	Range tests in hot and cold conditions

To determine vehicle range, ANL performed dynamometer testing from 0°F to 95°F ambient on EPA standard drive cycles as prescribed in the SAE J1634[10] test procedure, measuring energy consumption and usable battery energy content over different driving cycles. The test vehicles in question had interior temperature thermostatically maintained at 72°F by the vehicle HVAC system. Results in Figure 1 show that, compared to a reference vehicle range tested at 72°F ambient, BEV range decreased by an average of 14% in 95°F ambient, which is an identical proportional decrease to that of an ICEV in the same

[5] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, "FOTW #1290, May 15, 2023: In Model Year 2022, the Longest-Range EV Reached 520 Miles on a Single Charge," May 15, 2023, https://www.energy.gov/eere/vehicles/articles/fotw-1290-may-15-2023-model-year-2022-longest-range-ev-reached-520-miles.
[6] Recurrent, "Winter & Cold Weather EV Range 10,000+ Cars," January 2, 2024, https://www.recurrentauto.com/research/winter-ev-range-loss.
[7] Energetics, "EV WATTS: Electric Vehicle Widescale Analysis for Tomorrow's Transportation Solutions, accessed 2024, https://www.energetics.com/evwatts-vehicle-dashboard.
[8] Geotab, "To what degree does temperature impact EV range?," last updated on November 30, 2023, https://www.geotab.com/blog/ev-range/.
[9] Autocar, "Electric vehicle range test reveals up to 20% drop in winter," News by Move Electric, March 17, 2022, https://www.autocar.co.uk/car-news/move-electric/electric-vehicle-range-test-reveals-20-drop-winter.
[10] SAE International, "Battery Electric Vehicle Energy Consumption and Range Test Procedure J1634_202104," revised 2021, https://www.sae.org/standards/content/j1634_202104/.

conditions. In typical cold conditions (20°F), BEV range decreased 41%, compared to 10% for an ICEV. Test data from a comparable hybrid electric vehicle (HEV) is also shown for reference.

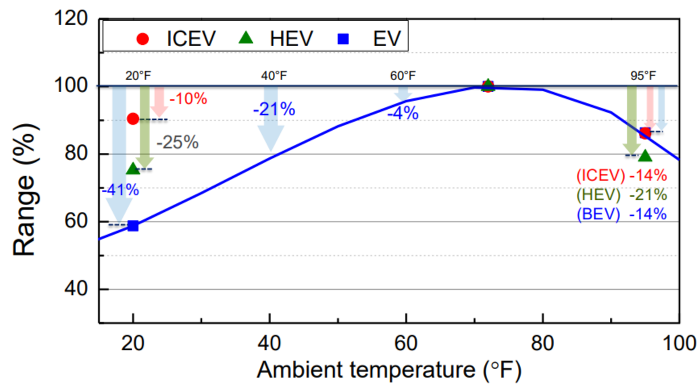

Figure 1. Average ambient temperature impact on midsize conventional ICEVs, HEVs, and BEVs, based on weighted city and highway driving cycles. Vehicle cabin temperature set to 72°F. Source: ANL AMTL

Changes in Energy Consumption due to Ambient Temperature

The primary reason for these BEV range differences is the power consumed by onboard HVAC systems, whose power use increases as the ambient temperature diverges from temperatures ideal for human comfort (assumed to be 72°F in this study). A secondary reason is changes to battery chemistry. Cold and extreme cold conditions affect battery chemistry, resulting in less usable battery energy.

The "hot weather" conditions of 95°F ambient used in these tests are only 23°F from the ideal temperature, whereas the range of "typical cold weather" and "extreme cold weather" conditions (20°F and 0°F ambient, respectively) represent a much wider range of temperatures and a larger magnitude of temperature difference from the defined ideal. As the ambient temperature decreases, the power consumption of BEV HVAC systems increases in response to both battery chemistry impacts and power requirements for the battery to power an electric resistance heater or heat pump. In hot weather, range impacts are not as significant because of the smaller temperature difference, reduced mechanical powertrain losses, and negligible battery chemistry impacts for BEVs. While BEVs and ICEVs respond similarly to hot weather conditions, the latter are less sensitive to cold temperatures because otherwise wasted heat from the engine is used to heat the cabin, so there is less of an increase in heating loads.

Figure 2 shows energy consumption impacts for BEVs and ICEVs using both normalized (left) and absolute (right) methods. The normalized method shows the percentage change in energy consumption compared to the baseline for the respective powertrains. As the baseline energy consumption for the two powertrains is not equivalent, absolute energy consumption results (in kilowatt-hours) are shown at right. Using absolute energy consumption to compare the two powertrains illustrates that, while a BEV is subject to more proportional impact from ambient temperature conditions, the magnitude of energy in question is significantly less than that of an ICEV because the BEV powertrain is significantly more energy-efficient.

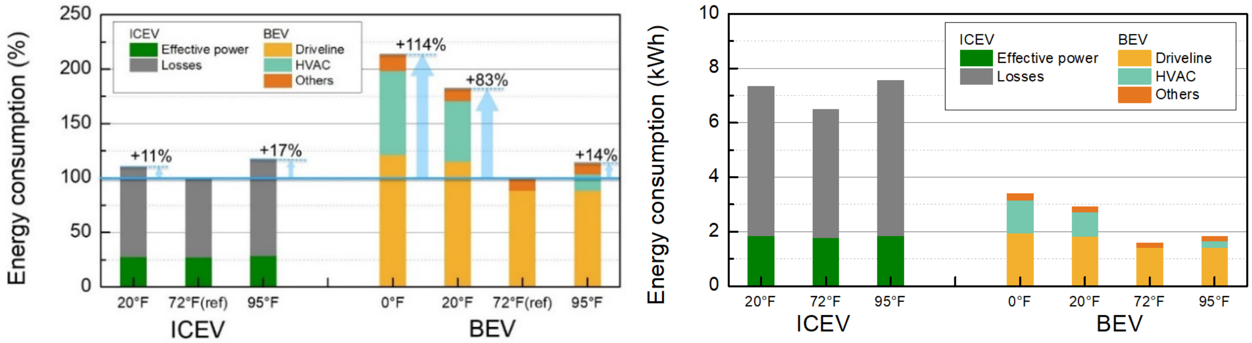

Figure 2. Ambient temperature impacts on conventional and electric vehicle energy consumption (normalized: left, absolute: right) based on weighted city and highway driving cycles. Source: ANL AMTL

Usable Battery Energy

Low ambient temperature reduces the efficiency of the chemical reactions in a BEV battery, which in turn reduces output voltage and available capacity, resulting in a lower amount of usable battery energy (UBE). This effect is more pronounced in extreme cold conditions (i.e., 0°F and colder). However, this effect can be partially mitigated through the use of an onboard battery heater. As shown in Figure 3, at 0°F, a BEV equipped with a battery heater (blue line) maintains significantly more UBE than a BEV without a battery heater (red line). Most modern BEV batteries have built-in heating and cooling elements powered by electricity supplied by either the charger or the battery itself.[11]

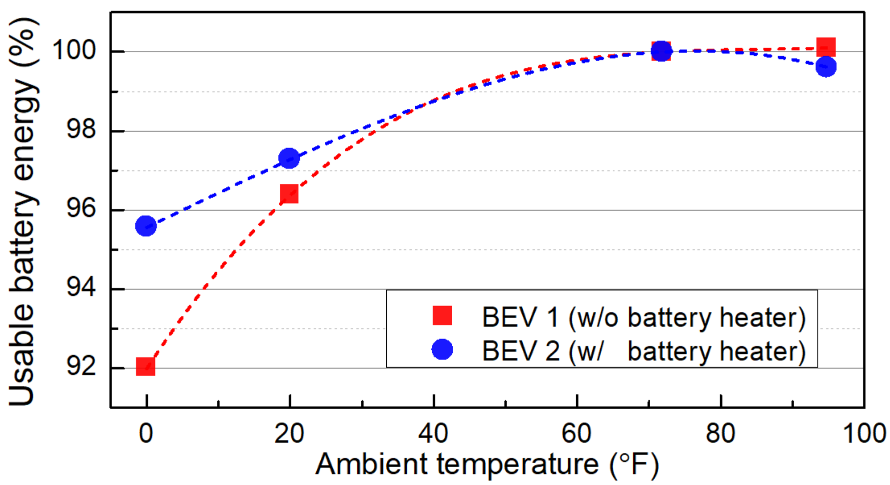

Figure 3. BEV UBE in various ambient temperatures with and without a battery heater. Source: ANL AMTL

Impacts of Vehicle Technologies and Operating Conditions

BEV range loss and energy consumption increases due to ambient temperature are variable across different models and are dependent on a given vehicle's battery thermal management strategy and HVAC technology. As Figure 4 shows, the energy consumption of one of the test vehicles ("BEV 3") at low temperatures increased significantly compared to the others ("BEV 1" and "BEV 2"), which can be attributed to these technological differences. The ICEV data shows a similar trend of increased energy

[11] Rick Cotta, "When Should I Precondition an EV?", Cars.com, November 12, 2023, https://www.cars.com/articles/when-should-i-precondition-an-ev-2-474356/.

consumption due to ambient temperatures, albeit lower proportionally.[12] Once again, the left plot shows a normalized method, and the right plot shows an absolute method. Real-world BEV data collected from EV WATTS shows similar trends to the test results obtained by Argonne.

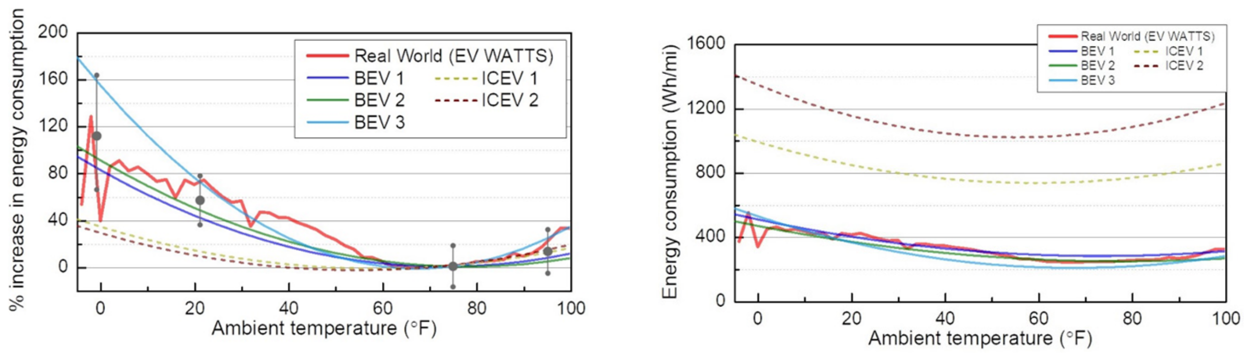

Figure 4. Comparison of real-world (EV WATTS) and dynamometer (Argonne) test data. Error bars show +/- one standard deviation of Argonne test results (accounting for test-to-test variation).

Operating Conditions

Vehicle energy consumption and range, whether for a BEV or an ICEV, is also affected by a wide range of factors, including driving patterns such as vehicle speed, acceleration, deceleration, idle time, and road grade. As shown in Figure 5, under extremely cold temperatures (0°F), the additional HVAC energy consumption for a BEV leads to an average of approximately 50% range loss, with a maximum of 59% in urban driving conditions (with ample idle time) and a minimum of 39% under highway driving conditions (with no idle time). In this case, the testing performed at 72°F serves as the baseline case, assuming no range loss. Real-world BEV data at 25°F (collected from Recurrent) shows similar trends to the test results obtained at Argonne.

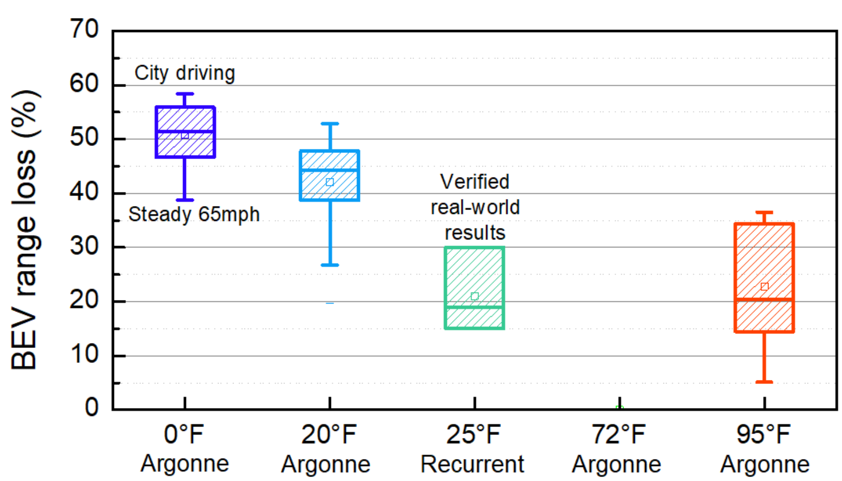

Figure 5. Comparison of real-world (Recurrent, in green) and dynamometer (Argonne) range losses tests for BEVs. Argonne results include the EPA Urban Dynamometer Driving Schedule (UDDS), EPA Highway Fuel Economy Test Cycle (HWFET), US06, and 65 mph steady-state. Error bars show maximum and minimum percentage range loss.

[12] As discussed earlier, ICEVs consume significantly more energy than BEVs, which should be considered alongside the relatively smaller percentage change in energy consumption for ICEVs.

As noted above, driving patterns and other conditions can play an important role in determining BEV range. Further analysis shows that when looking at the net impact of vehicle speed and ambient temperature, BEV range impacts begin to converge as speed increases over 40 mph across a range of temperatures, further indicating that temperature has less of an effect on BEV range at highway speeds.[13]

HVAC System Technology

As previously noted, vehicle HVAC systems consume significantly more power when heating the vehicle cabin in cold ambient conditions than when cooling the cabin in hot ambient conditions. While the power consumed from HVAC systems is the biggest contributor to reduced BEV range in winter conditions, HVAC systems that incorporate heat pump technology typically consume notably less power than those that are equipped solely with electric resistance heaters. However, heat pumps become less effective (due to a lower coefficient of performance [COP]) in extreme cold ambient conditions (e.g., 0°F), as there is no ambient heat outside the vehicle to absorb. Heat pumps have been adopted by BEV original equipment manufacturers, including Tesla, Ford, BMW, Hyundai, and Kia. Much like a residential heat pump, a BEV heat pump draws in ambient air, compresses it, and then uses the heat generated in the condenser to increase the temperature in both the cabin and the BEV's high-voltage battery. BEVs equipped with heat pumps are 3–4 times more efficient than BEVs equipped with radiant heating, equating to less range loss in cold conditions. Some modern BEVs are equipped with both electric resistance heaters and heat pumps, such that all heating loads are met as efficiently as possible, even in extreme ambient conditions.

Figure 6 shows HVAC power consumption, including thermal management of the battery, needed to maintain 72°F cabin temperature at both 0°F and 20°F ambient. BEV 1 ("Vehicle 1" in the figure) can use a combination of a heat pump and an electric resistance heater for heating, whereas BEV 2 is equipped only with an electric resistance heater. The use of a heat pump can reduce the total HVAC system power draw by 38% at 20°F, which would have a significant mitigating effect on cold-weather range loss, particularly in city driving. As heat pumps do become less effective in extreme cold ambient conditions, BEV 1 must use the electric resistance heater to meet most of the heating load at 0°F, while the heat pump can contribute only a small portion because of limited COP.

[13] Geotab, "Digging deeper into how temperature and speed impact EV range," last updated on November 30, 2023, https://www.geotab.com/blog/ev-range-impact-of-speed-and-temperature/.

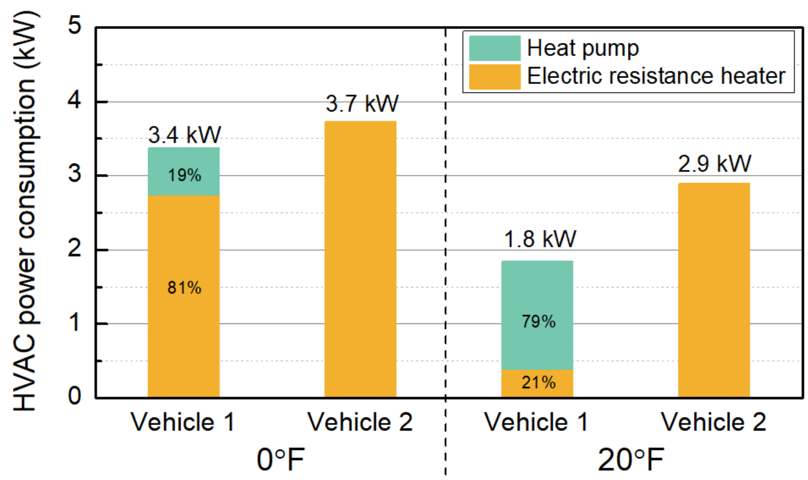

Figure 6. Power consumption by HVAC technology for two BEVs in cold temperatures. Source: ANL AMTL

Figure 6 shows power consumption ranging from 1.8 to 3.7 kW, depending on the cabin heating technology and ambient air conditions. For comparison using non-lab testing, real-world BEV testing was conducted at 15°F ambient while maintaining a cabin temperature of 65°F using resistance heating, resulting in a power consumption of only 1.6 kW[14]; the vehicle in question received even more efficient heat pump technology in subsequent model years.[15]

Other Technologies

Waste Heat Recovery

Waste heat recovery (WHR) can capture the heat generated by the powertrain and other components that would otherwise be lost to the environment.[16,17]

Radiant Heating, Heated Seat and Steering Wheel (Conductive Heat)

These technologies provide near-instant warmth and consume less energy than convection-based HVAC systems by focusing on heating a small zone of the vehicle or by directly heating the occupants. Heated seats, which warm the occupants via conduction, consume approximately 50 W per seat, whereas convection-based HVAC systems typically require 2,000 to 4,000 W. A radiant heater[18] can provide near-instant heat at a faster rate than convection-based HVAC systems while using less than 150 W, and heat is effectively supplied to areas that are difficult to reach with heated air, such as the front of the thighs, shins, and ankles.

[14] Connor Hoffman, “How Long Can an EV Keep the Cabin Warm When It's Cold Out? We Found Out,” *Car and Driver*, January 21, 2022, https://www.caranddriver.com/news/a38807463/tesla-model-3-climate-control-cold-weather-test/.
[15] Fred Lambert, “A comparison of a Tesla Model 3 with a heat pump to one without shows impressive results,” *electrek*, December 3, 2020, https://electrek.co/2020/12/03/tesla-model-3-heat-pump-comparison-results/.
[16] Zhen Tian et al., "Investigation on an integrated thermal management system with battery cooling and motor waste heat recovery for electric vehicle," *Applied Thermal Engineering* 136 (2018): 16-27, https://doi.org/10.1016/j.applthermaleng.2018.02.093.
[17] PR Newswire/Hyunday Motor Group, “Recycling More Heat: Hyundai and Kia Turn Up EV Efficiency with New Heat Pump Technology”, accessed 2024, https://www.prnewswire.com/news-releases/recycling-more-heat-hyundai-and-kia-turn-up-ev-efficiency-with-new-heat-pump-technology-301072517.html
[18] Paul Weissler, “Electric radiant heat for EV cabin comfort,” *SAE International*, May 19, 2022, https://www.sae.org/news/2022/05/electric-radiant-heat-for-ev-cabin-comfort

Cabin Preconditioning

The "remote start" feature in ICEVs is commonly used to warm up the cabin and engine before driving. A similar feature is often included in modern BEVs: the cabin is preconditioned, and the battery is brought to ideal temperature while the vehicle is still plugged into the electric grid. This feature allows the energy required for preconditioning to be drawn directly from the grid, preserving battery energy for vehicle operations and avoiding significant energy losses on the trip due to startup temperature transients. For short, city-like trips at 20°F, for example, cabin preconditioning can save up to 20% battery energy, as shown in test data highlighted in Figure 7. Additionally, a BEV can be preconditioned while inside an enclosed garage, as the vehicle has no harmful tailpipe emissions.

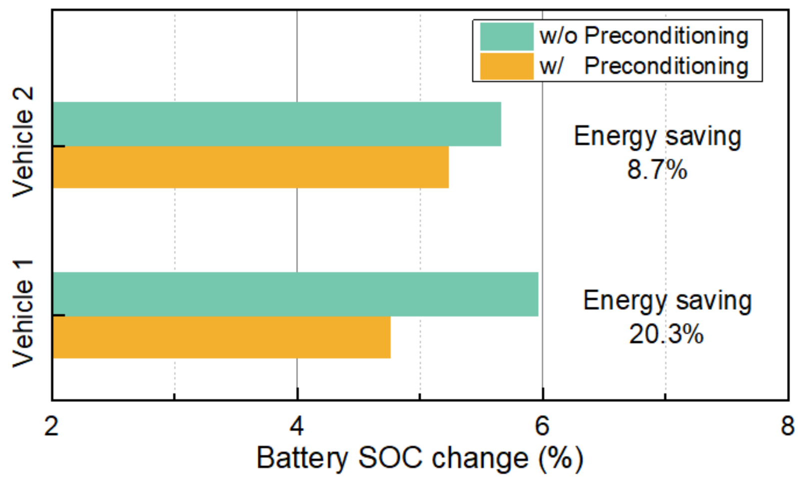

Figure 7. Preconditioning can reduce energy consumption by 9%–20% in a regulatory city driving cycle (7.5 miles) at 20°F ambient temperature. Source: ANL AMTL

Cabin Temperature Maintenance During Emergency Conditions

Statistical Significance of Traffic Events due to Blizzards

An extensive literature review was conducted to better understand extreme winter weather across the Unites States and the corresponding statistical significance of a driver experiencing extended delays as a result of severe winter weather. Blizzards are defined as winter snowstorms with sustained winds of 35 mph or greater and visibility of one-quarter mile or less for an extended period of time (three hours or more).[19] Research indicates an annual blizzard probability of 0%–76.4% for the contiguous United States (Figure 8), with the highest annual probability (61.6%–76.4%, or about one blizzard every 1.5 years) occurring in North Dakota, South Dakota, and Minnesota.[20] The research showed that, outside the regions of the Central Plains and Upper Midwest, the probability of a blizzard occurrence diminishes substantially. Parts of New England were shown to have a regionally high blizzard probability of about one blizzard every 5 years. However, other research estimates a gradual decline in the number of

[19] National Weather Service, "Winter Storms and Blizzards, accessed 2024, https://www.weather.gov/fgz/WinterStorms.
[20] J.S.M. Coleman and R.M. Swartz, "An Updated Blizzard Climatology of the Contiguous United States (1959-2014): An Examination of Spatiotemporal Trends," *Journal of Applied Meteorology and Climatology* (2017).

blizzards relative to their frequency in the near future (from 2030–2059) in the Great Plains, Upper Midwest, and New England.[21]

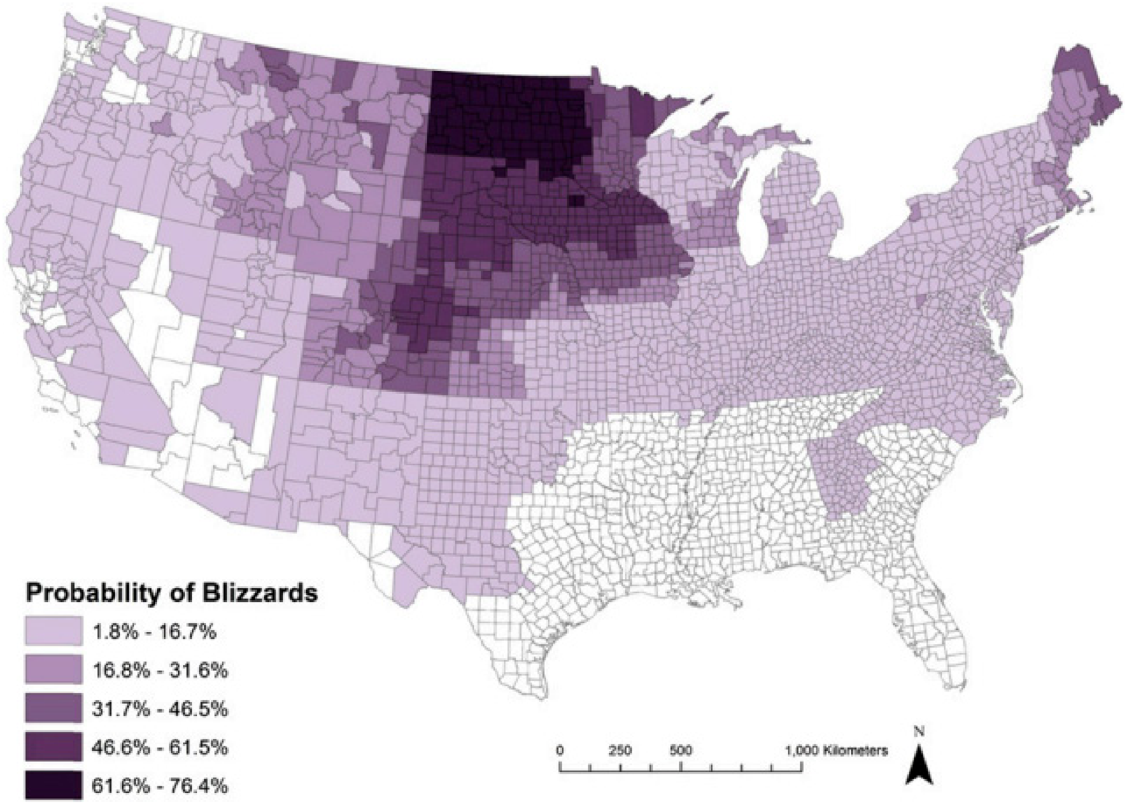

Figure 8. Annual blizzard probability by county (1959–2014). Source: Coleman and Swartz

In Iowa, researchers found that for snowstorms lasting four hours or more with a snowfall of 0.2 inches per hour, an average of two vehicle crashes that could cause significant traffic jams were reported.[22] Other work reported on the duration of traffic jams caused by freeway crashes and vehicle disablements in California.[23] The report indicates a mean duration of 37 minutes for all incidents, with just over half of the sample having a duration of 30 minutes or less and 82% of the durations lasting one hour or less. Only 2% of the incidents were longer than two hours.

For the Washington, DC, metropolitan area, the mean probability of blizzard occurrence is one blizzard every 11 years (9.1%), two accidents per blizzard (200%), and a 2% chance of an accident lasting two hours or more, resulting in a 0.36% probability of all events occurring simultaneously. In January 2022, snowfall in northern Virginia resulted in a major crash that shut down a stretch of the interstate for several hours. The preceding data indicates a 0.36% chance that this type of event would occur, i.e., the statistical likelihood of being stranded on a highway in a blizzard for a significant amount of time is very

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[21] A. Browne and L. Chen, "Investigating the occurrence of blizzard events over the contiguous United States using observations and climate projections," *Environmental Research Letters* (2023).
[22] K.K. Knapp, L.D. Smithson, and A.J. Khattak, "The Mobility and Safety of Winter Storm Events in a Freeway Environment," *Mid-Continent Transportation Symposium Proceedings, 2000*.
[23] G. Giuliano, *Incident Characteristics, Frequency, and Duration on a High Volume Urban Freeway*, UCI-ITS-WP-88-7, University of California, Irvine, 1988.

remote. Nonetheless, even the remote possibility is potentially concerning to BEV adopters, so the outcome for BEVs in such situations should be examined. Analysis was conducted accordingly; the following section discusses the results.

BEV Performance in Extreme Weather Conditions

Test results show that BEVs can maintain cabin temperature for long periods, even in extreme cold conditions. For comparison, a typical idling gasoline vehicle will lose approximately 6 miles of range per hour at 20°F, i.e., the vehicle can maintain cabin temperature for over two days when starting with a full tank of fuel (assuming an approximately 16-gallon fuel tank capacity). As shown in Figure 9, a fully charged BEV with a conservatively small 60 kWh usable battery[24] can maintain a 72°F cabin temperature for 27 hours with an outside temperature of 20°F. This equates to a range loss of approximately 8–10 miles of range per hour. In the more extreme 0°F case, a fully charged 60 kWh usable battery BEV could maintain cabin temperature for approximately 15 hours, losing approximately 9–12 miles of range every hour. While data is not available for the ICEV at 0°F, other detailed test data from this portion of the study can be found in Table 2. This data shows nearly identical performance for the BEV and ICEV in long, hot-weather soak conditions. The efficiency of the BEV powertrain and HVAC system allow the BEV to perform nearly as well, if not as well, as the ICEV.

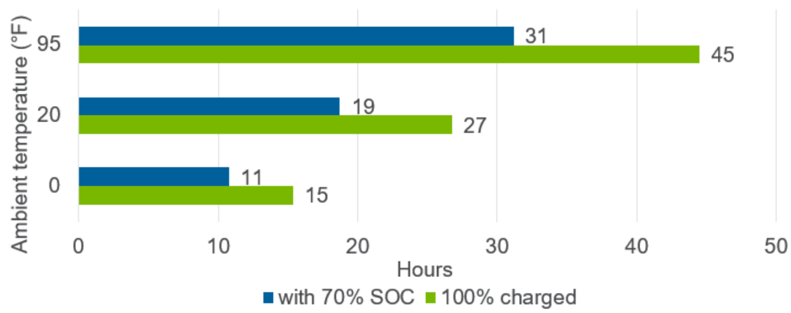

Figure 9. BEV runtime (60 kWh usable), at idle, to maintain a 72°F cabin temperature at various ambient temperatures.

[24] 60 kWh is a conservative estimate of usable battery energy for a modern BEV. EV Database shows an average of 68 kWh (Useable battery capacity of full electric vehicles cheatsheet - EV Database (ev-database.org)); as of April 2022, according to EVStatistics, "Across the BEVs currently available (or that will be in the next few months) in the US, they average (mean) 82.8 kWh and the median battery size is 78 kWh." (BEV Batteries Average 83 kWh Versus 15 kWh For PHEVs – EVStatistics)

Table 2. BEV and ICEV Stationary Runtime to Maintain 72°F Cabin Temperature at Various Ambient Temperatures (ANL AMTL)

Ambient temperature (Cabin target temperature setting: 72°F)	ICEV 1 (Fuel tank: 16 gallons, *535 kWh)		ICEV 2 (Fuel tank: 16 gallons, *535 kWh)		BEV 1 (Battery energy spec: 62 kWh)				BEV 2 (Battery energy spec: 66 kWh)			
	Idle fuel consumption (gal/h, *kW)	Available operating time (Idle fuel / Tank)	Idle fuel consumption (gal/h, *kW)	Available operating time (Idle fuel / Tank)	UBE (A1)	HVAC power consumption (B1)	Other power consumption (C1)	Available operating time (A1)/(B1+C1)	UBE (A2)	HVAC power consumption (C2)	Other power consumption (B2)	Available operating time (A2)/(B2+C2)
0°F	-	-	-	-	54.5 kWh	3376 W	390 W	14.5 h	61.6 kWh	3732 W	390 W	15.0 h
20°F	0.20 gal/h 6.7 kW	79.5 h	0.22 gal/h 7.8 kW	68.5 h	57.1 kWh	1848 W	479 W	24.5 h	62.7 kWh	2898 W	253 W	19.9 h
72°F	0.19 gal/h 6.5 kW	81.9 h	0.21 gal/h 7.3 kW	73.6 h	59.2 kWh	0 W	226 W	262h	64.5 kWh	0 W	144 W	447.8 h
95°F	0.33 gal/h 11 kW	48.6 h	0.34 gal/h 11.7 kW	45.8 h	59.3 kWh	956 W	544 W	39.5 h	64.2 kWh	755 W	239 W	64.6 h

As the results show, initial battery state of charge (SOC) makes a significant difference in such situations. Statistically, BEV owners are more likely to keep their vehicle batteries charged than ICEV owners are to keep their fuel tanks full. BEV drivers in general tend to be more conscious about recharging their vehicles, even after short trips, and tend to maintain a higher available range on a regular basis. As a result, BEVs tend to be recharged more frequently per mile driven and are more likely to have a higher available charge at the beginning of a given trip. A Transportation Research Board study found that "the typical [conventional vehicle] refueler reported the tank to be 'nearly empty' (66% of drivers) or less than one-third full (93% of drivers)"[25]—whereas most BEV drivers have access to residential charging and use it almost every day.[26] EV WATTS data suggests that most BEV trips are conducted, on average, at approximately 70% battery SOC. Between the statistical insignificance of being stranded in a snowstorm on an interstate for hours and the generally acceptable heating performance of modern BEVs in such conditions, this office finds the particular concern to be so remote that it should not impact adoption of BEVs for the vast majority of drivers.

Conclusion

BEVs available for purchase today are capable of meeting typical driving requirements, even under extreme weather conditions, and can maintain cabin comfort for extended periods of time. Analysis results show ambient temperature impacts on range and energy consumption for various powertrains; this document provides the reasons for those impacts and further examines various driving conditions and vehicle technologies. Findings do show that BEVs are more sensitive, in terms of range and energy consumption, to cold weather conditions than conventional vehicles, as cold affects electric HVAC loads and current battery chemistry properties. Nonetheless, the data indicate that BEVs can serve the vast majority of light-duty vehicle driving needs, even in the most extreme temperature conditions, while maintaining comfortable cabin temperatures. In addition, currently available vehicle technologies such as heat pumps, heated seats, and cabin pre-conditioning can limit the impacts of cold weather conditions on range loss and energy consumption.

[25] Dennis Dingemans, Daniel Sperling, and Ryuichi Kitamura, "Mental Maps and the Refueling Behavior of Vehicle Drivers," Transportation Research Record 1092-001, 1986, https://onlinepubs.trb.org/Onlinepubs/trr/1986/1092/1092-001.pdf.

[26] Idaho National Laboratory, "Plugged In: How Americans Charge Their Electric Vehicles: Findings from the largest plug-in electric vehicle infrastructure demonstration in the world," INL/EXT-15-35584, 2015, https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf.