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Are Heat Pumps Helpful in EVs in the Arctic?

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Executive Summary

Thermal management of electric vehicles (EVs) impacts battery range, especially in cold temperatures. EV manufacturers, such as Tesla, have started transitioning from using resistive heating to heat pumps for thermal management; these are generally considered to be more energy efficient than resistive heating systems, and are reported to increase winter range in EVs. However, there is a temperature below which the heat pump will not operate more efficiently than resistive heating. Crowdsourced data from eight Teslas operated in extreme cold temperatures in Alaska show mixed results. This indicates that the performance benefit of heat pumps may be muted and obscured by other factors that affect vehicle efficiency in extremely cold climates.

1 Introduction

Cold weather introduces a number of difficulties for EVs. It reduces the efficiency of lithium-ion batteries, which in turn can reduce the efficiency and range of EVs directly through the use of energy to thermally condition the batteries to optimize performance [1]. In addition, vehicles must heat the cabin in cold weather. While gas vehicles have access to waste heat from the engine to heat the cabin, EVs do not and must expend energy to heat the cabin. EVs can achieve this through a number of methods, two popular options being resistive heating and heat pumps. Despite a history of resistive heating being the standard, some EV manufacturers, such as Tesla, have begun implementing heat pumps in their vehicles. Heat pumps have increased energy efficiency compared to resistive heating across a temperature range determined by the specific heat pump design [2].

Starting in October 2020, Tesla began integrating heat pumps into their vehicle models [3]. According to Tesla's heat pump patent [4], the heat pump can extract heat from multiple sources in the vehicle and can combine or isolate sources depending on the circumstances. Anecdotal evidence and discussions indicate that these heat pumps can efficiently operate down to -10 °C [5, 6]. These claims are supported in Tesla's certificate of conformity application to the U.S. Environmental Protection Agency's (EPA), which states that the 2021 Model 3's heat pump can operate like a resistive heater when it is unable to satisfy the heating load [7]. Efficiency benefits have been reported due to the use of heat pumps in EVs with a reduction in energy consumption and an increase in driving range by 20% to 31% at -20 °C depending on the refrigerant used [8]. Some regions, such as Alaska, experience temperatures colder than -10 °C for a large percentage of the year, potentially affecting the overall benefit of installing the heat pump [9]. Initial data analysis of crowdsourced data for EVs in Alaska seemed to show little difference in the energy use vs. temperature for vehicles known to have heat pumps and those without [10]. In this study, crowdsourced energy use data from eight Tesla EVs driven in Alaska in temperatures ranging between -40 °C to 20 °C were analyzed to investigate the effectiveness of heat pumps in reducing vehicle energy use in cold regions.

2 Methodology

2.1 Crowdsourced Data

To analyze the effectiveness of heat pumps, data was crowdsourced from eight Teslas from the Anchorage and Fairbanks areas of Alaska, three with heat pumps and five with positive-temperature-coefficient (PTC) heaters, with model years ranging from 2016 to 2021. PTCs are a self-regulating form of resistance heating. At least one year of driving data was collected from each vehicle, two of which had more than two years of data available. Information on each Tesla vehicle is presented in Table 1. Some owners, as indicated from the de-identified names, own multiple vehicles used in the study. These may be regularly driven by the same family members, although this is unknown, and they may also have different regular drivers from the household. If they were operated by the same person, it would remove a potential variable in this analysis, as driver behavior (including comfort set points) has a large effect on energy consumption, including the temperature-dependent coefficient of energy consumption [11, 12].

Table 1: Information about Tesla vehicles used in this study

Car Name	Type	Drive Type	Wheel Size (in)	Rated EPA Consumption (kWh/100 mi)	Heat Pump	Location (Alaska)
owner1_car1	2020 Model 3	Dual Motor	18	28	no	Fairbanks
owner1_car2	2020 Model 3	Single Motor	19	28	no	Fairbanks
owner2_car1	2020 Model Y	Performance	19	28	yes	Fairbanks
owner2_car2	2018 Model 3	Single Motor	19	26	no	Fairbanks
owner 3_car1	2018 Model 3	Dual Motor	18	29	no	Anchorage
owner3_car 2	2020 Model Y	Dual Motor	20	30	yes	Anchorage
owner4_car1	2021 Model X	Dual Motor	20	35	yes	Fairbanks
owner5_car1	2016 Model S	Dual Motor	19	35	no	Fairbanks

Trip level data for eight of the cars was gathered through the third party app, TezLab, a software that collects and compiles driving data from vehicles via Tesla's application programming interface (API) [13], containing trip start and end times, trip duration and distance, start and end odometer, estimated energy consumption, and average ambient temperature. With this app, trip level data was gathered from eight Teslas. Owner5_car1's data was collected from a different app, TeslaFi. Similar to TezLab, this app collects data from Tesla's API, providing raw telemetry data, summarized trip data, as well as charging summaries [14]. TeslaFi provides telemetry data at a 60 second resolution. This data, which was collected in raw telemetry format, was synthesized to create summarized trip data with the same data fields mentioned above.

Driving speed and temperature are two of the biggest factors affecting EV efficiency [15]. To reduce the effect of different speeds on trip efficiency, data was pruned to use a range of 20 to 60 miles per hour (mph) average trip speed, this speed range is based on the EPA city and highway road test simulations, each test having an average speed of 20 mph and 48 mph[16]. Although compounding the sparseness of available data, a further analysis was also carried out breaking the data into sub-ranges of 20-45 and 45-60 mph. As this analysis focuses on the heating regime, only trips below 20 °C were used. Lastly, data was pruned to trips longer than 6 minutes. Figure 1 illustrates the distribution of trips across the temperature range.

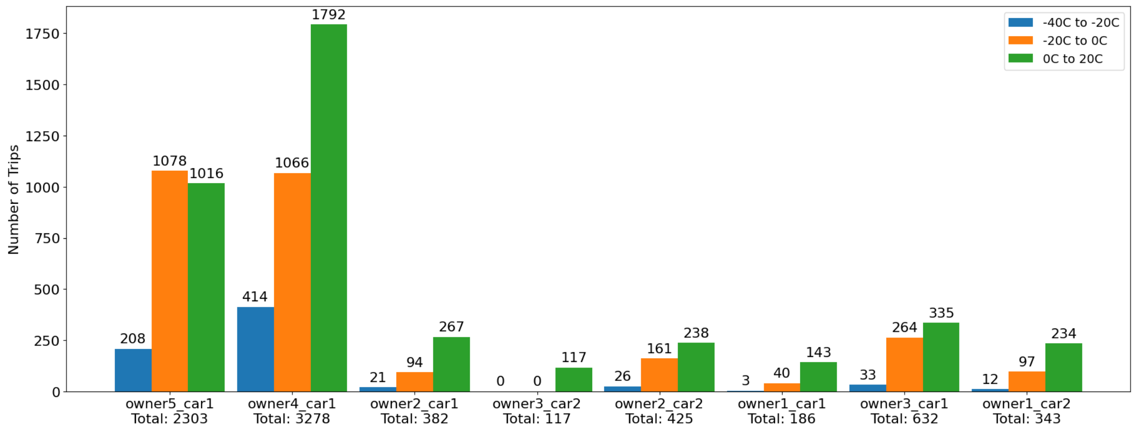

Figure 1: The distribution of each Tesla's total trips across three temperature regimes.

As seen in Figure 1, a majority of the trips for each car fall between 0 °C and 20 °C, owner5_car1 being the only exception. Owner5_car1, a non-PTC Tesla, and owner4_car1, a PTC Tesla, have the most trip data points compared to the rest of the cars.

2.2 Estimating the Factors Affecting Heat Load of the Passenger Cabin

It is assumed that the heat load of the passenger cabin is the largest component of temperature dependency in the trip energy use. This heat load will be highly dependent on outside air exchange as well as conduction through the cabin shell and solar gain through windows. Conduction through the shell is dependent on inside and outside temperatures, thermal resistance (or insulation value) of the shell, and shell surface area. Air exchange, solar gain, inside air temperature, and thermal resistance of the shell are unknown with the data available. Some information related to passenger cabin volume, which can be used to roughly estimate shell surface area, is available from owner's manuals [17, 18, 19, 20]. Every model of Tesla is represented in this study, each with a different passenger volume. As the heat transfer rate is proportional to the surface area of the heated passenger cabin, which in turn is proportional to the volume, each model's passenger volume was calculated. The total passenger volume was estimated by using the reported passenger measurements of the front and the cargo volumes of the back row, front trunk and trunk in Equation 1.

$$PV = \frac{fhr \times flr \times fsr}{1728} + (CV - FT) \tag{1}$$

Where **PV** is the estimated passenger volume (cf), **fhr**, **flr** and **fsr** are front head, leg, and shoulder room measurements (cubic inches) respectively, **CV** and **FT** are cargo volume and front trunk measurements (cf) respectively.

Equation 1 is only applicable for the Models X, Y and S. A different equation is required for the Model 3, as its owner's manual lacks the needed cargo volume measurement. The passenger volume can be found using the front and second row passenger measurements in Equation 2.

$$PV = \frac{(fhr \times flr \times fsr) + (bhr \times blr \times bsr)}{1728} \tag{2}$$

Where **PV** is the estimated passenger volume (cf), **fhr**, **flr** and **fsr** are front head, leg, and shoulder room measurements (cubic inches) respectively, **bhr**, **blr** and **bsr** are back head, leg, and shoulder room measurements (cubic inches) respectively.

This calculated volume is an estimation used for a comparison of estimated surface area of the different models. The estimated passenger volumes of each model of Tesla calculated using Equation 1 and 2 are presented in Table 2, along with an estimated surface area assuming a cube, and the ratio of these surface areas to that calculated for the Model 3.

Table 2: Estimated size parameters of Tesla models.

Tesla	Estimated Passenger Volume (cf)	Estimated Surface Area (sf)	Ratio of Surface Area to Model 3
Model S	113	140	1.1
Model 3	98	128	1.0
Model X	145	166	1.3
Model Y	128	152	1.2

Using the values from Table 1, the Model X, Y and S have approximately a 10, 20 and 30% higher estimated surface area for heat loss than the Model 3 respectively. An increase in surface area should lead to higher temperature dependence of energy use, all else equal, while the use of a heat pump in its effective regime should lead to lower temperature dependence.

3 Anlaysis

In this analysis each car's estimated energy consumption data is split into three heating regimes and an independent linear fit is performed in each regime (Figure 2, Table 3). The boundaries of the three heating regimes were chosen to capture one in which a heat pump should be functioning with much greater efficiency than resistive heating (10 °C to 20 °C), a colder regime where the heat pump is still expected to operate more efficiently than resistive heating (-10 °C to 10 °C), and an extreme cold regime where the heat pump is not expected to be effective (-40 °C to -10 °C). These regimes are different from the temperature distribution ranges used in Figure 1 in order to better reflect temperature ranges of interest to the operation of the heat pump, rather than an even division of the overall range.

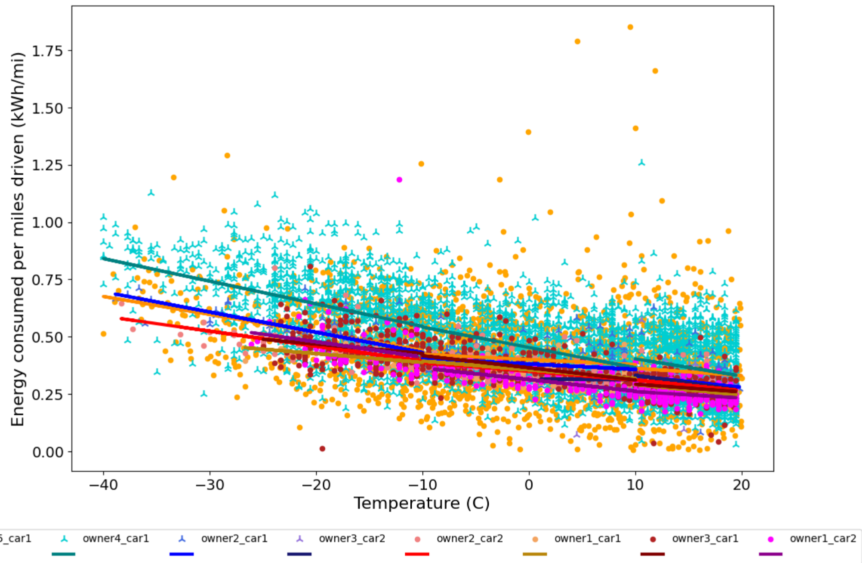

Figure 2: Energy consumption per mile as a function of temperature broken down by three heating regimes (10 °C to 20 °C, -10 °C to 10 °C, and -40 °C to -10 °C). Cool colors (violet, blue and cyan) indicate cars with heat pumps, while warm colors (red, orange, yellow, brown and magenta) indicate cars without heat pumps.

To help separate the effect of driving speed on the energy efficiency, the data was split into two speed categories, low speed (20 - 45 mph) and high speed (45 - 60 mph), the analysis of which can be seen in Figure 3 and Figure 4, respectively. Because this split further reduces the amount of data in each regime, negatively affecting the statistical significance of the fit to the data, linear fits are no longer performed for each vehicle, but instead for all vehicles with heat pumps and, separately, all vehicles without heat pumps.

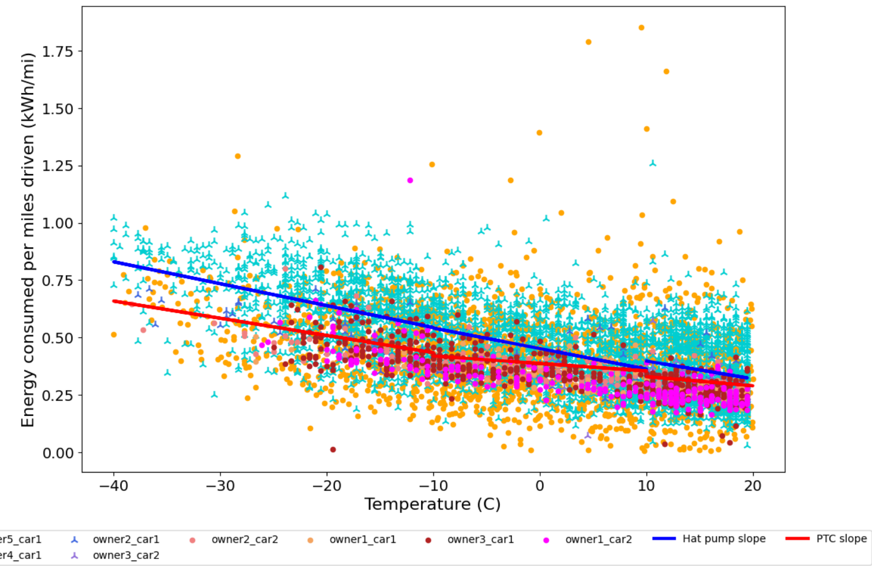

Figure 3: Low speed (20-45 mph) energy consumption per mile as a function of temperature broken down by three heating regimes (10 °C to 20 °C, -10 °C to 10 °C, and -40 °C to -10 °C). Trip-level data points shown are trips with an average speed between 20 and 45 mph. Blue fit line is fit to all data from Heat pump Teslas, red fit line is fit to all data from non-heat pump Teslas.

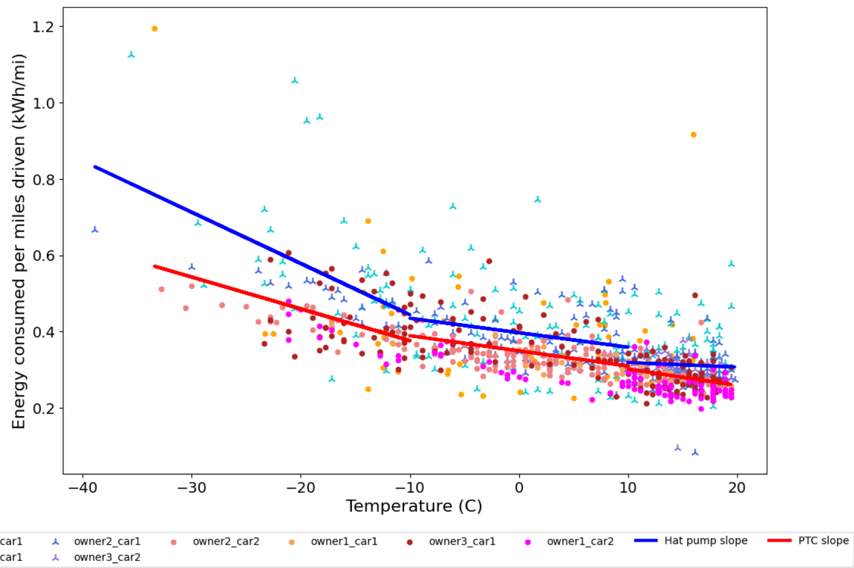

Figure 4: High speed (45-60 mph) energy consumption per mile as a function of temperature broken down by three heating regimes (10 °C to 20 °C, -10 °C to 10 °C, and -40 °C to -10 °C). Trip-level data points represented have an average speed of 45 - 60 mph. Blue fit line is fit to all data from heat pump Teslas, red fit line is fit to all data from non-heat pump Teslas.

4 Results and Discussion

The slopes of each Tesla's fit lines from Figure 2 are presented in Table 3. These slopes, with units of kilowatt hour per mile per degree Celsius (kWh/mi/°C), are the coefficients of temperature dependence and are expected to be greater in absolute magnitude the greater the effect of temperature on the energy use of the vehicle. There are various factors that could lead to a larger absolute magnitude of this slope as discussed in the Methodology section, including larger surface area of the heated cabin, higher cabin heater setting used by the occupant, lower insulation value in the cabin shell (perhaps due to sun roofs, etc.), more air exchange with the outside, lower solar gain through windows, and lower efficiency of the heater. Although all vehicles in our dataset are passenger car Teslas, unfortunately there are no models represented in both of the heat pump and non-heat pump subsets. All HP Teslas are Model X and Y and all PTC Teslas are Model 3 and S. The X and Y are larger cars, which are estimated to have heated space surface areas 10-30% larger than the Model 3 and S. This would be expected to increase the magnitude of the slope, while more efficient heating would be expected to decrease the magnitude of the slope.

Table 3: Coefficients of temperature dependence of each vehicle over various temperature ranges.

Car	Heat pump?	Cool (10 °C to 20 °C)	Cold (-10 °C to 10 °C)	Extreme (-40 °C to -10 °C)
Owner4_car1 Model X	yes	-0.0075	-0.0089	-0.0099
Owner2_car1 Model Y	yes	-0.0049	-0.0023	-0.0088
Owner3_car2 Model Y	yes	-0.0067	-	-
Owner2_car2 Model 3	no	-0.0047	-0.0038	-0.0066
Owner1_car1 Model 3	no	-0.0046	-0.0038	-0.0039
Owner3_car1 Model 3	no	-0.0034	-0.0053	-0.0041
Owner1_car2 Model 3	no	-0.0028	-0.0051	-0.0066
Owner5_car1 Model S	no	-0.0032	-0.0022	-0.0078
Average of HP Teslas	yes	-0.0064	-0.0056	-0.0094
Average of PTC Teslas	no	-0.0037	-0.0040	-0.0058

The slopes of owner3_car2 in the Cold and Extreme regimes were excluded from the table due to a lack of data. In the Extreme heating regime (-40 °C to -10 °C) the heat pump is not expected to be operational and able to provide any efficiency benefit over the vehicles only equipped with PTC heating, therefore the larger vehicles with heat pumps are expected to have a higher coefficient of temperature dependence in this temperature regime, all other factors equal. In this regime HP Teslas had slopes that averaged 1.5 times higher than the averaged slopes of the PTC Teslas, somewhat higher than the estimated ratio of surface area in the two groups.

In Cold regime (-10 °C to 10 °C) the heat pump is expected to be operating with a coefficient of performance (COP) greater than 1, however heat pump COPs decrease with decreasing temperature and at the lower cutoff of -10 °C the COP likely approaches 1. Only two of the HP Teslas have enough data in this regime to be included in this analysis, and the results are mixed with one HP Tesla's slope higher in magnitude than the PTC Tesla and one lower in magnitude than all but one of the PTC Teslas. On average, the HP Tesla slopes are of higher magnitude, again by a ratio of approximately 1.5.

When comparing the Teslas in the Cool regime (10 °C to 20 °C), where the heat pump is expected to have the highest COP values and the most efficiency benefits, the HP Teslas again had slopes that were higher in magnitude than the PTC Teslas. On average, this ratio is still approximately 1.5.

Owner5_car1 of the PTC Tesla group and owner4_car1 of the HP Tesla group had the most data collected of the respective groups. When comparing the slopes of these two Teslas in the three temperature regimes, it can be seen that the PTC Tesla has a lower magnitude temperature-dependent coefficient (slope) than the HP Tesla in each regime, as is the general trend from the analysis. In the Cool and Cold temperature regimes, the slopes of the HP Teslas are 2.3 and 4.5 times greater than that of the PTC Tesla, respectively. The ratio in slopes between the two cars decreases in the extreme regime, below the effective temperature of the heat pump where both vehicles would be expected to be heating with a COP of 1, with the PTC Tesla's slope only 1.3 times greater than that of the HP Tesla's slope. The behavior, which is opposite that expected due to the efficiency gains of the heat pump, implies that factors other than the heat pump are dominating the temperature dependency of the energy use.

The coefficients of temperature dependence of the HP Teslas and PTC Teslas from the analysis by low (20-45 mph) and high speed (45-60 mph) are presented in Table 4. In this case, due to the smaller, split data sets of each speed range, a single linear fit was performed to each group (HP and PTC Teslas) in each temperature regime, as shown in Figures 3 and 4. This is instead of the individual fits to each vehicle's trip data in Figure 2 and Table 3.

Table 4: Coefficients of temperature dependence from a fit to all heat pump Teslas and all PTC Teslas over various temperature ranges split into low and high speed categories.

Category	Low Speed			High Speed		
	Cool	Cold	Extreme	Cool	Cold	Extreme
Heat Pump	-0.0077	-0.0089	-0.0096	-0.0012	-0.0038	-0.0134
PTC	-0.0040	-0.0033	-0.0075	-0.0042	-0.0040	-0.0083

As can be seen in Table 4, in the low speed data, the relationship between the coefficients of temperature dependence of the PTC Teslas and the HP Teslas is similar to that seen in the full dataset. This is not surprising as this speed range contains the bulk of the data of the entire set and is dominated by the two Teslas with significantly larger amounts of data available, owner5_car1 and owner4_car1. In the Cool and Cold regimes, the HP Teslas' slopes were 1.92 and 1.62 times greater than the PTC Teslas', respectively. The difference in slope between the two groups is smaller in the Extreme regime, with the HP Teslas slope 1.28 times greater than the PTC Teslas slope.

The coefficient of temperature dependence in the high speed analysis shows the same behavior as previous analyses in the Extreme regime, where HP Teslas have a much higher magnitude slope than the PTC Teslas. As discussed previously, the heat pump is not expected to provide benefits in this temperature regime, so this result is expected for the larger vehicles with heat pumps. However, the slope of the fit is of lower magnitude for the HP Teslas than their PTC counterparts in the Cool and Cold regimes. The HP Teslas also saw larger increases in absolute magnitude between their slopes from Cool to Cold to Extreme than the PTC Teslas. This is consistent with the efficiency gains expected from heat pumps, which are expected to be highest in the Cool temperature regime.

There are many factors that can affect thermal management that cannot be determined from the data available. Some of these factors, like the existence of sunroofs, may be specific to the vehicle, and some are dependent on driver behavior. Settings such as the seat heaters, air flow, and defrost can affect thermal demand, and in turn affect energy usage. One major factor is the variability of Tesla's climate control system, which allows for independent adjustment of thermal management of the front and back of the car [17, 18, 19, 20]. Thermal management of the driver and passenger side of the front can be adjusted independently as well. These factors, among others, can lead to variability in the energy efficiency among the vehicles used in this study. Data from TezLab did not contain any information about settings from the climate system or other settings that could affect energy management. TeslaFi does record some of these settings, but this software was used for only one Teslas and was therefore not used for this analysis for consistency. Because of this, there are a number of factors that cannot be adequately accounted for in this study and may play a large role in the relative temperature dependence of energy use of the individual vehicles.

This is a very small data set, with even greater limitations in the amount of data from vehicles with heat pumps. This limitation, as well the unobservable factors mentioned above, can lead to diminishing statistical significance of the results and conclusions. Despite this, it can be seen that the apparent effectiveness of heat pumps in Teslas can become obfuscated by other factors in cold and extremely cold climates. Ongoing data collection is expected to expand the dataset and allow better analysis, however, it appears that in extremely cold climates, the performance benefit of heat pumps may not be enough to provide clear energy efficiency gains.

References

[1] J. Jaguemont, L. Boulon, and Y. Dubé, "A comprehensive review of lithium-ion batteries used in hybrid and electric vehicles at cold temperatures," *Applied Energy*, vol. 164, pp. 99–114, Feb. 2016. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0306261915014841

[2] I. Cvok, I. Ratković, and J. Deur, "Optimisation of Control Input Allocation Maps for Electric Vehicle Heat Pump-based Cabin Heating Systems," *Energies*, vol. 13, no. 19, p. 5131, Oct. 2020. [Online]. Available: https://www.mdpi.com/1996-1073/13/19/5131

[3] Tesla, "Tesla Parts Catalog," 2025. [Online]. Available: https://epc.tesla.com/en-US/catalogs/9678bc03-3011-4c95-9620-bb32d391cac0/categories/f570428b-c08d-4935-9b4c-718c8c9722f8/subcategories/d86f7011-89ef-472b-ba5d-62328c28fbca?autoscroll=true

[4] Nicholas Mancini, Joseph Stratford Maxwell Mardall, Jan Kopitz, Curt Raymond O'Donnell, Daniel F. Hanks, and Huize Li, "Optimal source electric vehicle heat pump with extreme temperature heating capability and efficient thermal preconditioning," U.S. Patent US10 967 702B2, Apr., 2021.

[5] G. Bower, "Tesla Model Y Heat Pump Details Infrequently Discussed By The Media," *InsideEV*, Nov. 2020. [Online]. Available: https://insideevs.com/news/452464/tesla-model-y-heat-pump-system-details/

[6] "What heat pump?!" [Online]. Available: https://www.reddit.com/r/TeslaModel3/comments/1977yc6/what_heat_pump/

[7] S. Nagaraj, "Request for issuance of a new Certificate of Conformity – Initial application," Oct. 2021.

[8] B. Yu, J. Yang, D. Wang, J. Shi, and J. Chen, "Energy consumption and increased EV range evaluation through heat pump scenarios and low GWP refrigerants in the new test procedure WLTP," *International Journal of Refrigeration*, vol. 100, pp. 284–294, Apr. 2019. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0140700719300490

[9] M. Wilber, "ACEP EV Map," Jun. 2020.

[10] ——, "Alaska Electric Vehicle Calculator," 2020. [Online]. Available: https://mmwilber-ak-ev-calculators-ev-emissions-3c5aff.streamlit.app/

[11] M. Steinstraeter, T. Heinrich, and M. Lienkamp, "Effect of Low Temperature on Electric Vehicle Range," *World Electric Vehicle Journal*, vol. 12, no. 3, p. 115, Aug. 2021. [Online]. Available: https://www.mdpi.com/2032-6653/12/3/115

[12] X. Wu, D. Freese, A. Cabrera, and W. A. Kitch, "Electric vehicles' energy consumption measurement and estimation," *Transportation Research Part D: Transport and Environment*, vol. 34, pp. 52–67, Jan. 2015. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S1361920914001485

[13] Tezlab, "Tezlab." [Online]. Available: https://tezlabapp.com/

[14] TelsaFi, "TeslaFi Software Tracker." [Online]. Available: https://about.teslafi.com/

[15] C. Argue, "Digging deeper into how temperature and speed impact EV range," Nov. 2023. [Online]. Available: https://www.geotab.com/blog/ev-range-impact-of-speed-and-temperature/

[16] US Department of Energy, "Detailed Test Information." [Online]. Available: https://www.fueleconomy.gov/feg/fe_test_schedules.shtml

[17] Tesla, "Tesla Model S Owner's Manual."

[18] ——, "Tesla Model Y Owner's Manual."

[19] ——, "Tesla Model X Owner's Manual."

[20] ——, "Tesla Model 3 Owner's Manual."

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