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How Temperature Affects Electric Vehicle Range

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Executive Summary

The topic of electric vehicle (EV) range in cold weather comes up often and is one of the major concerns or even barriers for prospective EV buyers. This paper highlights the effects of ambient temperature on EV range, backed up by on-road testing. Consumer Reports auto engineers took four popular EVs on the same section of highway, at the same speed, same cabin temperature settings and with the same drivers during frigid, mild, and warm ambient temperatures. The effect of temperature was consistent for all four cars. We found that during frigid winter temperatures the range was slashed by 25% to 31% compared to the range found during mild and warm temperatures, respectively. Surprisingly, we found that the range was the longest during typical warm, humid summer weather conditions.

Keywords: Light duty vehicles, Battery electric vehicles (BEVs), Consumer demand growth, including education, demonstration and motivation analysis, Fleet vehicle deployment case studies, Rural driving needs.

1 CR tested EVs from Ford, Hyundai, Tesla, and Volkswagen in cold, mild, and warm weather

It is well established that cold weather takes a toll on the range for electric vehicles, because the car must manage both battery and cabin temperatures, causing a significant drain. The question is: by how much? And what about warm weather? Between winter and summer 2022, Consumer Reports sought to answer these questions by conducting seasonal testing on popular dual-motor (all-wheel-drive) EVs: the Ford Mustang Mach-E Extended Range, Hyundai Ioniq 5 SEL, Tesla Model Y Long Range, and Volkswagen ID.4 Pro S.

Each car was tested in the exact same manner, by the same drivers, driven in a caravan on three different days: a frigid one, a mild one, and a warm one. We found that cold weather saps about 25 percent of range when cruising at 70 mph compared with the same conditions in mild weather. Compared to the warm weather, the range gets slashed by 31 percent.

Unlike an internal combustion engine (ICE) car, where the heat is a byproduct of the engine, an EV has to produce cabin heat and manage an optimal battery temperature with energy that comes from the battery, in turn reducing range.

We had an expectation that mild weather in the mid 60°s F (around 17° Celsius) would provide the greatest range, but actually, the warm temperatures of the mid 80°s F (around 30° C) temps provided the longest range of the three tested environmental conditions.

This test shows that EV range is not an absolute metric. In general, weather, hills, speed, traffic, cargo, passengers, and climate settings can have an impact. That said, this particular experiment provides key insights into the role weather plays with range.

2 What We Found

This test series underscores the importance of taking range claims as general guides and being mindful of the "moving target" nature of EV range. Another difference between ICE (internal combustion engine) cars and EVs is that during constant cruising, an ICE car attains its best fuel economy. An EV, on the other hand, is not at its optimal efficiency when cruising on the highway, with limited opportunity to benefit from regenerative braking—energy that's recouped from braking and coasting that gets directed back into the battery. Note also that EV motors tend to spin at high rpm at highway speeds, compromising efficiency, whereas ICE vehicles cruise at low rpm and in a tall gear ratio. This notion is a paradigm shift for many prospective EV buyers. Because the Environmental Protection Agency (EPA) range is based on a mix of city and highway driving, the expectation for a test like this was that the vehicles would underperform their rated range at a constant highway speed. That expectation did not pan out in all scenarios.

We found a clear trend among these models showing that under different seasonal temperatures, as predictable, winter cold results in the shortest range, followed by mild temperatures. It was on a typical summer day of sunny, humid, mid-80-degree Fahrenheit (30-Celsius) weather that we saw the longest range, despite using air conditioning.

More detailed findings showed:

- The Mustang Mach-E stood out for having the most accurate range prediction—the indicated range used vs. the actual miles driven. Its real-world range also came within 1 or 2 miles of the Model Y on every run, even though the Model Y has a higher official EPA range. Note that the Mach-E has the largest battery of the bunch, at 88 kWh of usable capacity.

- The Ioniq 5's cold-weather range ended up being only 3 miles short of the Model Y's, which probably should not be a surprise because they have similar-sized batteries, but the Ioniq 5 is almost 200 pounds heavier than the Tesla.

- It is interesting to note that the Model Y is the lightest vehicle of the quartet, differing by more than 500 pounds from the ID.4, which is the heaviest.

- On the mild run the Ioniq 5 matched its its EPA rating almost exactly.

- The Mach-E and ID.4 exceeded their EPA rating on the warm day.

3 How We Tested

We began testing in frigid February 2022, repeating the procedure in balmy April and in August heat. Originally, we tested only the trio from Ford, Tesla, and VW in the winter of 2022 because the Hyundai Ioniq 5 was still tied up with its regular regimen of testing. We've since closed the loop and ran the Ioniq 5 on the same route in February 2023 with nearly identical ambient conditions. Like the other three EVs, it followed the familiar trend, showing the same 25 percent loss of range compared with the mild weather run.

The EVs were fully charged overnight before each of the runs and were allowed to precondition the cabin to 72° F (22° C) for fifteen minutes while still plugged in outdoors. At the same time, we checked and verified the tire pressure and cleared snow and ice. Heated or cooled seats or heated steering wheels were not used.

On the very cold day, the temperature averaged 16° F (-8° C), meaning that considerable energy was needed to keep the cabin comfortable and the battery pack in its ideal operating condition. The mild spring day was 65° F (18° C) during most of the drive, and the warm summer day was 85° F (29° C) during the drive. Each test day was clear and sunny.

The cars were taken on the road concurrently and driven on the same 142-mile round-trip route that consisted of Connecticut Route 2 and I-91 northbound. We used adaptive cruise control set to 70 mph (112 km/h) and the widest gap to prevent any aerodynamic trailing effect or sudden decelerations and accelerations due to surrounding traffic. The regenerative braking mode was set to its lowest setting for each car in order to level the playing field since regenerative braking strategy is different among manufacturers. We paused for 10 minutes with the cars off at the midpoint.

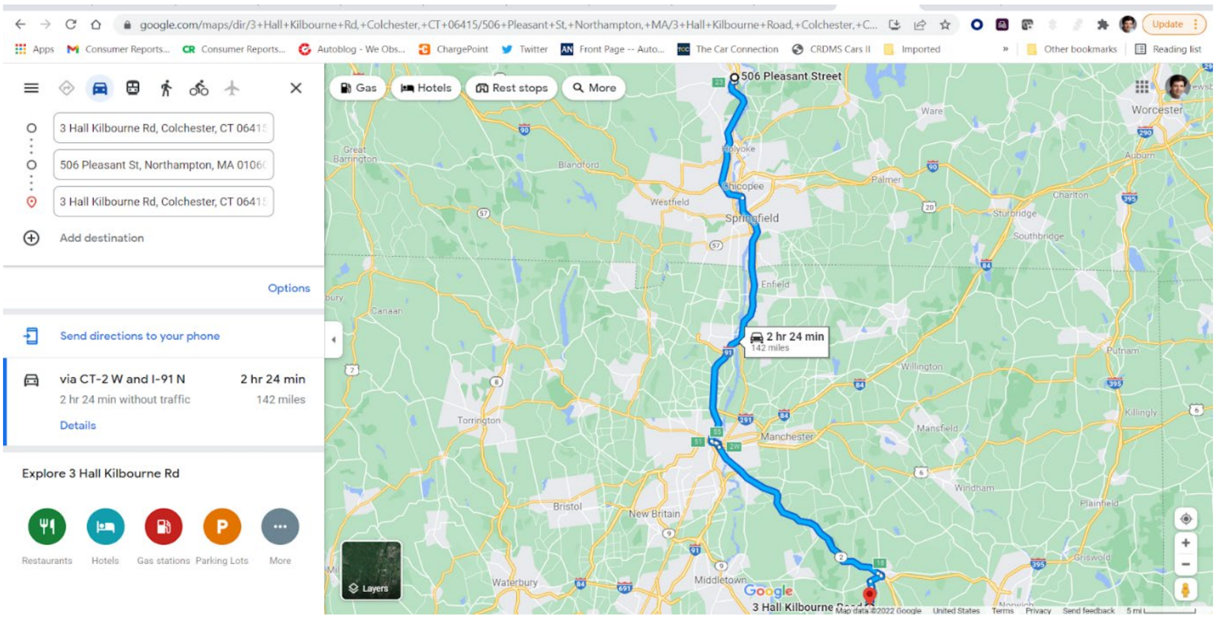
Once back at our Auto Test Center, we didn't just record the remaining range indicated in the cars. We applied the ratio of miles of range used vs. miles driven throughout the trip to extrapolate what would be the total range for each specific trip.

We also checked that ratio against the miles driven per each percent of state of charge (SOC) as extra validation of our results. The difference between the two methods amounted to single digits percentage-wise. The average miles driven per SOC was 1.9 on the cold day, 2.7 on the warm day.

We intentionally didn't drain the batteries until totally empty to reflect the typical owner experience and avoid any reduced propulsion power that manufacturers program into their vehicles to varying degrees. We don't drive regular gasoline cars until they are bone dry, either.

4 The Driving Route

The original plan called for a longer driving route but the precipitous drop of predicted range half way through the outbound drive in the winter dictated a shorter trip that ensured returning to our base with sufficient buffer. The 142-mile route originated in Colchester, Connecticut and continued to Northampton, Massachusetts using Route 2 and Interstate-91 and back.



5 Figures, Tables and Equations

a. Figures

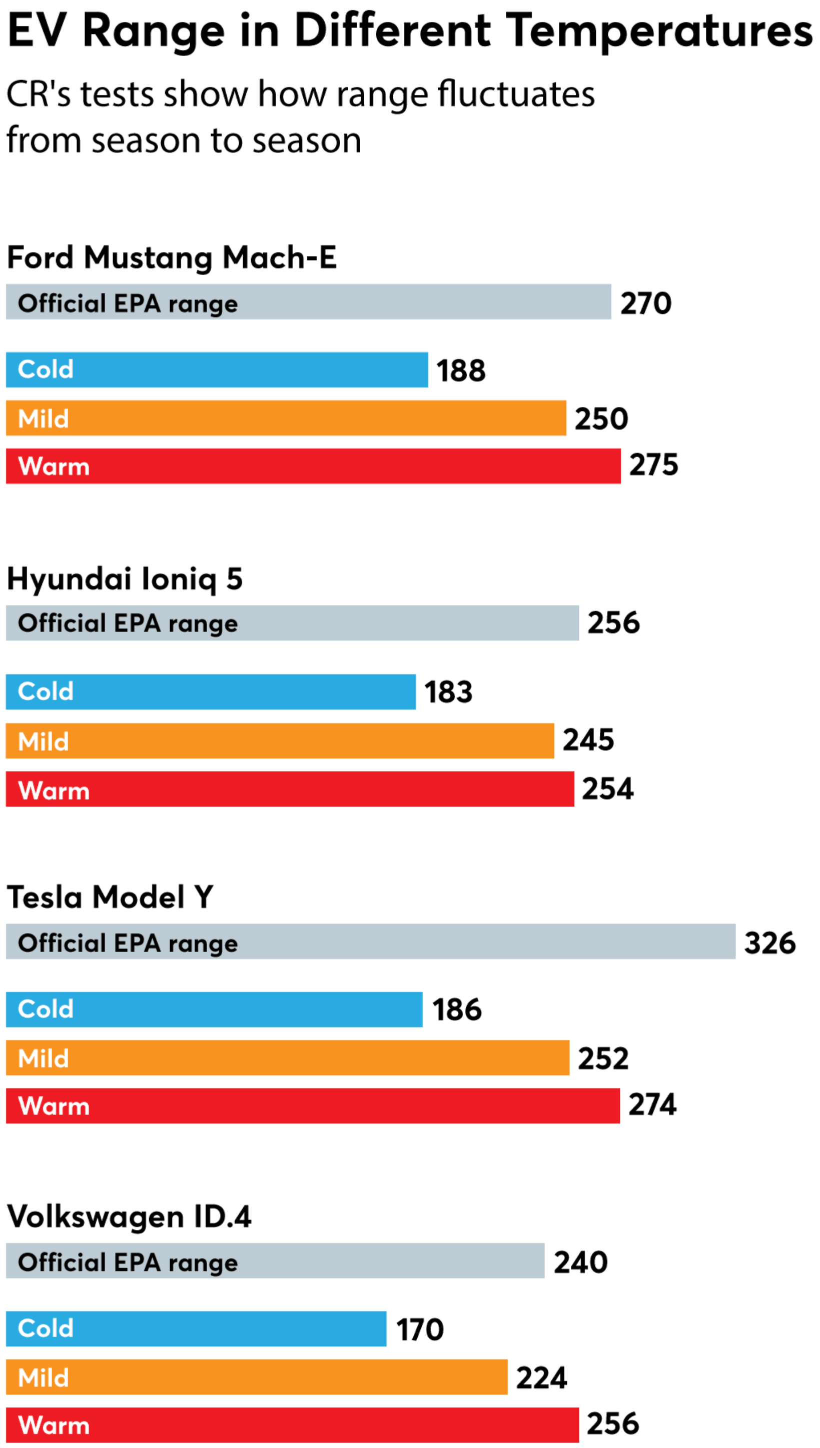


Figure 1: EV Range Fluctuations in Different Temperatures

Figure 2: The four EVs before setting off on the frigid day

b. Tables

Table 1: Extrapolated range for the cold, mild, and warm runs

	Model Y	Mach-E	ID.4	Ioniq 5
Official EPA range, mi	326	270	240	256
Cold extrapolated	186	188	170	183
Mild extrapolated	252	250	224	245
Warm extrapolated	274	275	256	254

Table 2: Percent loss cold vs. mild (average: 25.1%)

Model Y	Mach-E	ID.4	Ioniq 5	
186	**188**	**170**	**183**	**Extrapolated range in cold weather**
66	**62**	**54**	**62**	**Delta range bet mild & cold (mi)**
26.07	**24.88**	**24.04**	**25.41**	**% loss due to cold temp**

Table 3: Percent loss cold vs. warm (average: 31.4%)

Model Y	Mach-E	ID.4	Ioniq 5	
186	**188**	**170**	**183**	**Extrapolated range in cold weather**
88	**87**	**86**	**71**	**Delta range bet warm & cold (mi)**
32.19	**31.64**	**33.72**	**28.05**	**% loss due to cold temp**

c. Equations

Definitions of terms:

Total miles driven = Mi_driven

Predicted range at end = Mi_Pred_end

Miles of predicted range used for trip = MoR used

Miles of predicted range "vanished" = MoR vanished

Ratio between miles of range used vs. miles of range "vanished" = MoR vanished / MoR used

Range prediction percent deviation = MoR% dev

Extrapolated range = Range (extp)

SOC_end = % State of Charge at end of trip

Equation used to arrive at the extrapolated range based on the ratio between miles predicted and miles driven

$$\text{Range (extp)} = (1-\text{MoR\% dev}) \times \text{Mi\_Pred\_end} + \text{Mi\_driven} \tag{1}$$

Equation used to arrive at "miles driven per % battery"

$$\text{MoR/\%SOC} = \text{Mi\_driven} / [(1-\text{SOC\_end}) \times 100] \tag{2}$$

$$\text{MoR estimate for 100\% battery} = \text{MoR/\%SOC} \times 100 \tag{3}$$

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References

[1] Jeff S. Bartlett, Gabe Shenhar, *How Temperature Affects Electric Vehicle Range*, https://www.consumerreports.org/cars/hybrids-evs/how-temperature-affects-electric-vehicle-range-a4873569949/ published August 22, 2022, updated March 1, 2023

Presenter Biography

Gabriel Shenhar is an Associate Director at Consumer Reports' Auto Test Center in Colchester, Connecticut. He has been the point person for all alternative fuel vehicle testing since 2007 and spearheaded the introduction of CR's electric vehicle testing, including its on-site charging infrastructure. He leads a team of auto testers and evaluators and oversees the purchasing of all test vehicles for CR. He is a regular panelist on CR's Talking Cars podcast. Shenhar holds a degree in Mechanical Engineering from the New Jersey Institute of Technology.