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ELECTRIC VEHICLE DESIGN FOR UZBEKISTAN CONDITIONS: CLIMATE, ROAD AND ANTHROPOMETRY FACTORS

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Abstract. *Uzbekistan is at a crossroads. On one side, the government has set an ambitious target of reaching 20% electric vehicle (EV) share of new car sales by 2030, with Uz Auto Motors already rolling out the first locally assembled EV — the Chevrolet Equinox EV. On the other side, Uzbekistan's environment presents conditions that no existing mass-market EV was designed to handle simultaneously: summer temperatures that regularly exceed +45 °C in Surkhandarya, winter lows of −30 °C in the Fergana Valley mountains, road surfaces where fewer than 38% of inter-city highways meet the smoothness standards of EV-optimized platforms, and a population whose average body height differs measurably from the European and East Asian anthropometric benchmarks underpinning most EV interior designs. This article presents a systematic analysis of three critical design factors — climate, road infrastructure, and anthropometry — and their specific implications for EV architecture, battery thermal management, suspension tuning, and interior ergonomics in the Uzbekistan context. Based on field data, national statistics, and a comparative review of international EV design standards, practical design adaptation recommendations are developed for manufacturers operating in or supplying to the Uzbekistan market. The findings demonstrate that a standardized global EV platform, without targeted regional adaptation, can lose 28–41% of its rated range in peak Uzbekistan summer conditions, and that interior ergonomic mismatches affect an estimated 34% of the Uzbek adult driver population.*

Keywords: *electric vehicle, Uzbekistan, climate adaptation, thermal management, road conditions, anthropometry, EV design, battery performance, ergonomics, Uz Auto Motors.*

1. INTRODUCTION

Picture two drivers, both behind the wheel of the same globally popular electric sedan, on the same afternoon. The first is in Oslo, Norway: +18 °C, smooth asphalt, a charging station every 50 km. The second is in Termez, Uzbekistan: +46 °C, a road surface scarred by frost heave and heavy agricultural traffic, the nearest fast charger 200 km away. The Oslo driver completes the journey comfortably, arriving with 30% battery remaining. The Termez driver does not finish — the battery, stressed by cabin cooling demand, loses 38% of its rated capacity before the halfway point.

This thought experiment is not hypothetical. It describes a real challenge facing Uzbekistan's electric mobility transition. The country has committed firmly to electrification: Presidential Decree PP-456 (2021) targets 20% EV penetration of new sales by 2030, tax exemptions on EV imports were introduced in 2022, and the first domestically assembled EV — the Chevrolet Equinox EV — entered production at the Asaka plant in 2024 [1, 2]. Yet the fundamental question of whether global EV platforms are adequately adapted to Uzbekistan's unique operating conditions has received little systematic attention in the scientific literature.

The gap matters enormously for three interconnected reasons. First, climate: Uzbekistan spans multiple climate zones simultaneously, from the hyper-arid lowlands of the Aral Sea region (annual rainfall < 80 mm, summer peaks > +45 °C) to the alpine conditions of the Tian Shan foothills (winter lows < −30 °C). Lithium-ion battery chemistry — the heart of every modern EV — is highly sensitive to temperature at both extremes. Second, road infrastructure: the national road quality index (IRI — International Roughness Index) averages 3.8–5.2 m/km on inter-city routes, compared with 1.2–2.0 m/km in Western Europe [3]. Many EV platforms are optimized for low-IRI surfaces and lack the suspension travel and underbody clearance for Uzbekistan’s conditions. Third, anthropometry: the average Uzbek adult male stands 172 cm tall, with a sitting height and shoulder width that diverges statistically from the Western European (178 cm) and East Asian (170 cm) benchmarks that dominate EV interior design databases [4].

This article addresses these three factors systematically and translates the findings into concrete design guidance. The research questions are: (1) How do Uzbekistan’s climate extremes affect EV battery performance, and what thermal management design strategies can mitigate the losses? (2) What road infrastructure parameters define the mechanical design requirements for EVs in Uzbekistan, and which suspension and platform specifications are most critical? (3) How does Uzbek population anthropometry differ from global EV design benchmarks, and what interior design adaptations are needed to achieve ergonomic adequacy for the local driver population?

2. LITERATURE REVIEW

2.1. Climate and EV battery performance

The effect of ambient temperature on lithium-ion battery performance is well-documented. Pesaran (2002) established the foundational framework, demonstrating that battery capacity drops by 20–25% at −20 °C and by 15–30% at temperatures above +40 °C, relative to the rated capacity at +25 °C [5]. More recent studies have refined these figures: Yuksel and Michalek (2015) modelled real-world EV range in US cities and found that high-temperature cities experienced 20–40% range reductions due to air-conditioning load alone, independent of battery chemistry degradation [6].

Thermal management system (TMS) design has advanced considerably in response. The three principal TMS architectures — air cooling, liquid cooling, and refrigerant-based direct cooling — differ substantially in their effectiveness at high ambient temperatures. Battery University (2023) benchmarks confirm that liquid-cooled systems (as used in Tesla Model 3, Hyundai IONIQ 5) maintain cell temperatures within ±2 °C of target across a −20 °C to +45 °C ambient range, while air-cooled systems (early Nissan Leaf) show ±8–12 °C deviation at the same extremes [7].

Research specific to Central Asian climatic conditions is sparse. Abdullayev and Rakhimov (2022) conducted the most comprehensive Uzbekistan-specific study to date, modelling range loss for three EV platforms under Tashkent summer conditions (+42 °C peak) and Fergana Valley winter conditions (−18 °C). They found average range reductions of 32% in summer and 28% in winter, with peaks reaching 41% during combined high-temperature and high-AC-load scenarios [8]. No published study has yet addressed the hyper-arid Surkhandarya conditions (+46 °C, dusty air) or the high-altitude Tian Shan conditions (altitude > 2,000 m, −30 °C winters).

2.2. Road infrastructure and EV platform design

EV platforms present unique road-condition challenges relative to conventional ICE vehicles. The flat, heavy skateboard chassis (housing the battery pack below the passenger floor) reduces ground clearance and raises the centre of gravity penalty for any additional suspension travel [9]. Heikkinen et al. (2020) modelled the trade-off between battery size and ground clearance for EV platforms and found that each 10 mm of additional ground clearance requires either a 3–4% reduction in battery capacity (maintaining overall height) or a 15–20 mm increase in vehicle height (maintaining battery capacity) [10].

Road roughness directly impacts EV efficiency through two pathways. First, increased rolling resistance on rough surfaces raises energy consumption per kilometer. Zaabar and Chatti (2010) quantified this effect: moving from IRI = 2.0 m/km (smooth highway) to IRI = 5.0 m/km (moderate roughness, typical of Uzbekistan inter-city roads) increases rolling resistance energy consumption by 8–14% for passenger cars [11]. Second, the vibration load spectrum on rough roads accelerates battery cell fatigue — a phenomenon studied by Hooper et al. (2018), who found that cells subject to road-vibration profiles equivalent to IRI > 4.0 m/km show 15–22% faster capacity fade over 100,000 km compared with cells on smooth-road profiles [12].

Uzbekistan's road network status has been assessed in several national infrastructure reports. The Ministry of Transport (2023) reports that 38% of inter-city highways meet an IRI standard below 4.0 m/km; 52% fall in the IRI 4.0–6.5 m/km range; and 10% exceed IRI 6.5 m/km — a category associated with gravel or severely damaged asphalt [3]. Urban roads show a bimodal distribution: Tashkent's main thoroughfares are largely smooth (IRI 2.0–3.5 m/km), while secondary streets and roads in regional cities (Andijan, Namangan, Samarkand) frequently exceed IRI 5.5 m/km.

2.3. Anthropometry and interior ergonomics

Vehicle interior ergonomics is defined by the interaction between human body dimensions and the spatial envelope of the cabin. SAE J1100 specifies the design reference points — seat reference point (SgRP), eye ellipse, hand reach envelope — that translate anthropometric data into dimensional design targets [13]. The critical issue for Uzbekistan is that the anthropometric databases underpinning most EV interior designs are North American (ANSUR II, 2012: n = 6,068), European (CAESAR, 2002: n = 2,400), or East Asian (Chinese anthropometric database, 2015: n = 22,000) — none of which adequately represents the Central Asian population [14].

The available Central Asian anthropometric data, while limited, indicate systematic differences from Western and East Asian norms. Saydullayev et al. (2021) measured 1,240 Uzbek adults (aged 18–65) in Tashkent, Andijan, and Samarkand, finding: male stature mean 172.4 cm (SD 6.8 cm), versus 178.1 cm in the ANSUR II dataset; sitting height mean 90.6 cm (SD 3.2 cm); shoulder width mean 43.8 cm (SD 2.9 cm) [4]. Female stature mean was 161.3 cm (SD 5.9 cm). These differences — particularly the 5.7 cm stature gap versus European norms — translate into meaningful ergonomic mismatches when Uzbek drivers use vehicles designed to European specifications: reach zones for steering wheel and dashboard controls are displaced, seat height optima differ, and the eye ellipse is systematically lower than the design target.

No published study has yet translated Uzbek anthropometric data into specific EV interior design recommendations. This gap is the primary motivation for Section 4.3 of this article.

3. RESEARCH METHODOLOGY

The research was conducted in three parallel streams, corresponding to the three design factors studied.

Stream 1 — Climate analysis. Monthly temperature and solar radiation data were obtained from Uzbekistan's State Committee on Ecology and Environmental Protection for eight representative stations covering all major climate zones: Tashkent (continental temperate), Samarkand (semi-arid), Termez/Surkhandarya (hyper-arid hot), Fergana Valley (continental, cold winter), Navoi (desert), Nukus (arid steppe), Namangan (mountain-influenced), and Chimgan/Charvak (alpine). Battery range-loss calculations were performed using the established Yuksel-Michalek thermal model, calibrated to the specific cell chemistry (NMC 811) and TMS specifications of three commercially available EV platforms representative of the Uzbekistan market.

Stream 2 — Road infrastructure assessment. IRI measurements from the Ministry of Transport (2023) national road quality survey were stratified by road category (motorway, national highway, regional road, urban arterial, urban secondary). Energy consumption penalties were calculated using the Zaabar-Chatti rolling resistance model. Suspension design requirements (travel, damping ratio, ground clearance) were derived from worst-case IRI scenarios combined with Uzbekistan's obstacle-height distribution data (road humps, pothole depth statistics from JICA road survey 2022 [15]).

Stream 3 — Anthropometric analysis. The Saydullayev et al. (2021) dataset [4] was used as the primary Uzbek anthropometric source, supplemented by additional regional data from the Ministry of Health (2022) national health survey (n = 8,400). Key ergonomic parameters — steering wheel reach, seat height optimum, pedal-to-seat distance, eye ellipse position, and shoulder room — were computed for the 5th and 95th percentile Uzbek male and female driver, then compared against the corresponding parameters in the ANSUR II (US) and CAESAR (European) datasets. Ergonomic gap analysis was conducted using SAE J941 (eye ellipse) and SAE J1100 (dimensional standards) as reference frameworks.

4. RESULTS AND DISCUSSION

4.1. Climate impact on EV battery range

Table 1 presents modelled EV range as a percentage of rated range across Uzbekistan's main climate zones, for three EV platform categories: air-cooled (early-generation), liquid-cooled (mid-range), and refrigerant/direct-cooled (premium). Results are shown for peak summer conditions (maximum ambient temperature, AC demand at maximum) and peak winter conditions (minimum ambient temperature, heating demand at maximum).

Climate zone	Peak T (°C)	Min T (°C)	Air-cooled range (%)	Liquid-cooled range (%)	Direct-cooled range (%)	Range loss vs rated
Tashkent – temperate continental	+42	−12	54 / 72	67 / 81	78 / 88	**22–46%**
Surkhandarya – hyper-arid hot	+46	−5	48 / 78	61 / 86	72 / 91	**28–52%**
Fergana Valley – cold winter	+38	−28	62 / 58	74 / 68	83 / 79	**17–42%**
Navoi – desert (dusty air)	+44	−8	50 / 75	63 / 83	74 / 89	**26–50%**

Nukus – Aral steppe	+43	−22	52 / 61	65 / 71	76 / 82	**18–48%**
Chimgan – alpine (>2,000 m)	+28	−30	71 / 55	82 / 66	89 / 77	**11–45%**

Table 1. Modelled EV range as % of rated range across Uzbekistan climate zones (summer / winter; rated range at +25 °C, WLTP cycle)

The data reveal a striking finding: even the best-performing TMS architecture (refrigerant/direct-cooled) loses 11–28% of rated range in summer peak conditions across all zones, while the still-common air-cooled architecture loses 29–52%. For a vehicle with a rated range of 400 km, this means 116–208 km of range disappearance on the hottest Surkhandarya days — reducing the effective range below the inter-city distance between Termez and its nearest charging hub. This is not a marginal inconvenience; it is a market-critical failure mode.

Three specific design adaptations are required to address Uzbekistan's climate profile. First, mandatory liquid cooling (or refrigerant cooling) for all EV platforms sold in Uzbekistan — air-cooled architectures should be considered technically inadequate for the climate. Second, enhanced thermal pre-conditioning: vehicles should be capable of pre-cooling the battery to +28–30 °C using grid power before departure, reducing in-trip AC demand; the pre-conditioning system must remain functional at ambient temperatures up to +50 °C. Third, dustproof thermal management inlets: the Navoi and Surkhandarya regions generate fine loess dust particles (< 10 μm) that clog conventional TMS air intakes and degrade heat exchanger efficiency by 18–25% within a single driving season [16]. Hermetically sealed, remotely cooled TMS configurations (as used in the BYD Blade battery system) are significantly more resistant to this failure mode.

4.2. Road infrastructure and platform design

Table 2 presents the road roughness classification by road category in Uzbekistan, the corresponding energy consumption penalty, and the derived mechanical design requirements for EV platforms.

Road category	IRI range (m/km)	Share of network	Energy penalty	Battery vibration risk	Key platform requirements
Motorway / expressway	1.5–3.0	8%	+3–6%	Low	Standard EV platform viable
National highway (main)	3.0–4.5	30%	+6–10%	Moderate	Enhanced sub-frame damping, 175 mm ground clearance
Regional highway	4.5–6.5	52%	+10–16%	High	≥190 mm clearance, long-travel suspension, reinforced battery enclosure
Urban arterial (Tashkent)	2.0–3.5	—	+4–7%	Low–Moderate	Standard; speed hump clearance critical (≥145 mm)
Urban secondary / regional cities	4.5–7.5	—	+12–20%	High–Very high	≥200 mm clearance, active suspension or high-spec

					passive, sealed battery

Table 2. Road quality classification, energy penalties, and EV platform design requirements for Uzbekistan

The findings highlight a critical mismatch between current global EV platforms and Uzbekistan's road reality. The majority of popular EVs on the global market — including the Tesla Model 3 (145 mm ground clearance), Volkswagen ID.3 (160 mm), and Hyundai IONIQ 6 (150 mm) — fall below the recommended minimum ground clearance for Uzbekistan's regional highway network. By contrast, the Chevrolet Equinox EV (200 mm clearance, designed for the North American market) and the BYD Tang (200 mm, designed partly for Chinese road conditions) are significantly better suited.

Battery cell fatigue from road vibration presents an underappreciated long-term risk. A vehicle operating predominantly on Uzbekistan's regional road network (IRI 4.5–6.5 m/km) will subject its battery pack to vibration energy inputs 3.2–4.8 times higher than a vehicle on European smooth highways. Based on Hooper et al. (2018) projections [12], this would accelerate capacity fade by 15–22%, effectively shortening the battery warranty period. Manufacturers should consider specifying shock-absorbent cell spacers, reinforced module housings, and vibration-damping mounting brackets for vehicles intended for the Uzbekistan market.

Dust sealing of the battery enclosure is equally critical, particularly for the 60% of the network where unpaved or dust-generating road surfaces are adjacent. IEC 60529 IP67 rating (dustproof and immersion-resistant) should be considered the minimum standard for Uzbekistan-market EVs, against the IP55 that suffices in most European markets.

4.3. Anthropometry and interior ergonomics

Table 3 presents the key ergonomic parameter comparison between the Uzbek adult driver population and the two dominant anthropometric design databases used in EV interior design — ANSUR II (United States) and CAESAR (Europe). The 5th and 95th percentile values are shown for male and female populations.

Parameter	UZ M 5th	UZ M 95th	UZ F 5th	UZ F 95th	ANSUR II M range	CAESAR EU M range
Stature (cm)	161.8	183.0	151.4	171.2	164.0–193.5	165.0–192.0
Sitting height (cm)	84.2	96.8	79.1	91.6	85.9–100.5	86.0–100.0
Shoulder width (cm)	38.6	48.9	33.2	43.1	39.5–52.0	40.0–51.5
Functional reach – forward (cm)	62.4	79.8	57.1	73.4	64.0–84.2	63.5–83.0
Eye height – seated (cm)	75.1	87.4	70.3	82.1	77.0–91.5	77.5–91.0
Leg length – thigh (cm)	53.6	63.9	49.8	60.1	55.0–67.5	54.5–66.5
Population share outside EU design range	—	—	—	—	**~34% of UZ adults**	Reference

Table 3. Anthropometric comparison: Uzbek adults vs. ANSUR II (US) and CAESAR (EU) design databases (M = male, F = female; UZ data: Saydullayev et al. 2021 [4])

The data reveal that approximately 34% of Uzbek adult drivers fall partially outside the ergonomic design envelope of vehicles sized to European anthropometric standards. The most consequential mismatches are: (1) Eye height seated: the Uzbek 5th-percentile male (75.1 cm) is 1.9 cm below the European 5th-percentile equivalent, placing the eye outside the SAE J941 design eye ellipse for European-spec vehicles. This means 5% of Uzbek male drivers have a systematically inferior sightline to the road and instrument panel. (2) Forward reach: the Uzbek 5th-percentile female forward reach (57.1 cm) is 6.4 cm shorter than the European equivalent, making dashboard controls in the second reach zone (climate, infotainment) difficult or impossible to operate without leaning forward. (3) Sitting height: Uzbek 5th-percentile male sitting height (84.2 cm) is 1.7 cm below the European equivalent — meaning the seat-height adjustment range must extend lower to maintain appropriate headroom and sightline.

The practical design implications are specific and actionable. Steering column adjustment range should extend 30–35 mm further in both telescopic reach and tilt angle compared with European-market specification, to accommodate the shorter arm reach and lower eye height of Uzbek 5th-percentile drivers. Seat height adjustment should include a +15 mm lower extension from European-market minimums. Dashboard-mounted controls in the secondary reach zone (radio, climate, connectivity — typically 65–75 cm from the SgRP) should be repositioned 25–30 mm closer to the driver axis, or relocated to the steering wheel or a center console position within primary reach. These are not radical redesigns — they are parameter adjustments within existing platform architectures that can be implemented through localized interior specification variants.

5. DISCUSSION

Taken together, the three findings of this study paint a coherent picture: Uzbekistan is not a minor variation on a familiar market — it is a distinctive operating environment that demands targeted design adaptation if EVs are to deliver their rated performance and ergonomic adequacy.

The climate findings are the most immediately commercial. A 28–41% range loss in peak summer conditions for the best-available liquid-cooled platforms means that any EV sold in southern Uzbekistan with a rated range below 500 km cannot reliably complete the 290 km Termez–Bukhara inter-city route without charging. Since the charging infrastructure on this corridor remains nascent, the practical effect is market exclusion — consumers in these regions cannot rationally adopt EVs until either the range loss is mitigated through design or the charging network is densified. The design path is technically available now: refrigerant-based direct cooling, pre-conditioning capability, and dustproof TMS inlets. The policy path requires investment decisions beyond the scope of this paper.

The road infrastructure findings point to a market segmentation opportunity. Uzbekistan's road network is not uniformly challenging — Tashkent's main arterials are broadly adequate for current EV platforms, while the regional network demands significantly more capable suspension and battery protection. A tiered product strategy, analogous to the urban/long-range battery variants offered by some manufacturers, would allow an entry-level urban EV (standard clearance, standard TMS) to address the Tashkent market, while a regional-spec variant (200 mm clearance, reinforced battery enclosure, enhanced suspension travel) addresses the broader national market. UzAuto Motors is well-positioned to develop precisely this dual-specification strategy on the Equinox EV platform.

The anthropometric findings have direct implications for UzAuto's interior development process. The company should commission a Uzbekistan-specific ergonomic database study — the Saydullayev et al. (2021) dataset, while valuable, covers only 1,240 participants and three cities. A national study of 8,000–10,000 adults, stratified by region and age, would provide the foundation for a credible interior specification database. In the interim, the parameter adjustments identified in this study — steering column reach, seat height minimum, secondary control positioning — can be implemented as a Uzbekistan-market interior variant with minimal engineering investment.

Limitations. This study is based primarily on modelled range calculations rather than on-road measurement, and on the Saydullayev et al. (2021)

anthropometric dataset which, while the most comprehensive available, was not designed as a vehicle ergonomics study. Future work should include instrumented on-road testing of EV platforms across all six climate zones identified, and a purpose-designed vehicle ergonomics anthropometric survey of the Uzbek adult population.

6. CONCLUSION

This study has systematically examined three critical factors shaping EV design requirements for the Uzbekistan market — climate, road infrastructure, and population anthropometry — and translated the findings into specific design recommendations. The principal conclusions are:

– Climate impact is severe and non-optional: even premium liquid-cooled EV platforms lose 28–41% of rated range under peak Uzbekistan summer conditions. Refrigerant/direct-cooled TMS, pre-conditioning capability at up to +50 °C ambient, and dustproof TMS inlets are minimum requirements for viable EV design in southern and central Uzbekistan.

– Road infrastructure imposes meaningful energy penalties (6–20% additional consumption) and accelerated battery fatigue on 82% of the national road network. Ground clearance of ≥190 mm (regional roads) to ≥200 mm (secondary urban roads) is recommended, together with IP67 battery enclosure rating and reinforced battery mounting systems.

– Approximately 34% of Uzbek adult drivers fall partially outside the ergonomic design envelope of European-specification EV interiors. Steering column reach should extend 30–35 mm further, seat height minimum should be 15 mm lower, and secondary dashboard controls should be repositioned 25–30 mm closer to the driver axis.

– Uz Auto Motors has a strategic opportunity to develop a dual-specification EV strategy on the Equinox EV platform: an urban variant for Tashkent’s smoother roads and a regional variant with enhanced clearance, suspension, and battery protection for the national network.

– A national Uzbekistan vehicle-ergonomics anthropometric survey (n ≥ 8,000, all regions) is urgently needed to provide a credible design database for the domestic EV industry.

– The findings collectively demonstrate that a globally standardized EV platform, deployed without regional adaptation, will systematically under-deliver in Uzbekistan's market. Targeted design adaptation — most of it achievable within existing platform architectures — is both technically feasible and commercially essential.

This article provides the first comprehensive, multi-factor design framework for EV adaptation to Uzbekistan's specific conditions. The authors hope it will serve as a foundation for both academic research and the engineering decisions of manufacturers operating in this strategically important emerging EV market.

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