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*Original Article*

# A Comparative Study of Electric and Internal Combustion Engine Vehicle Performance Under High Ambient Temperatures: A Case Study of Kuwait

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***Abstract*** - *This research presents a comparative analysis of the impact of high ambient temperatures on the performance of Electric Vehicles (EVs) and Internal Combustion Engine (ICE) vehicles in Kuwait. The study uses real-world data from over 3,000 EV trips and empirical data from ICE vehicles to examine energy consumption, range reduction, and power loss under temperatures between 40°C and 50°C. Results show that EV energy consumption rises by 22% at 40°C and 32% at 50°C due to the increased burden on battery cooling systems. ICE vehicles experience up to a 30% loss in power from engine detonation and overheating. These findings highlight the need for advancements in thermal management technologies for both vehicle types and emphasize the importance of infrastructure improvements, such as expanded charging networks, in extreme climates. The study provides actionable insights for vehicle manufacturers, policymakers, and consumers to enhance vehicle performance in hot regions.*

***Keywords*** - *Ambient, Combustion, Electrical, Vehicle, Kuwait.*

## 1. Introduction

With its desert climate, Kuwait experiences some of the highest ambient temperatures globally, especially during the summer months when temperatures frequently exceed 40°C. These extreme conditions significantly challenge vehicle performance, efficiency, and longevity. Both Electric Vehicles (EVs) and Internal Combustion Engine (ICE) vehicles encounter unique obstacles in such an environment. EVs face issues like increased battery cooling demands and higher energy consumption for air conditioning, which reduces driving range and accelerates battery wear. Conversely, due to the excessively hot weather, ICE vehicles are prone to engine overheating, diminished fuel efficiency, and accelerated wear and tear.

While global interest in electric vehicles as part of sustainable mobility initiatives is gradually making its way into Kuwait, the country remains predominantly reliant on ICE vehicles. This dominance is attributed to low fuel costs and a well-established infrastructure favoring fossil fuel-powered cars. Despite Kuwait's government setting ambitious targets to reduce reliance on fossil fuels and increase the adoption of EVs, significant barriers remain. Chief among these are concerns about the performance of EVs in extreme heat, particularly regarding battery life, range, and overall reliability, which have hampered their widespread acceptance. This presents a critical research gap: existing studies have yet to thoroughly examine and compare the operational performance of EVs and ICE vehicles under Kuwait's extreme heat conditions. Such an analysis is essential for understanding each vehicle type's specific challenges and identifying engineering solutions to address these issues. Bridging this gap is crucial for advancing consumer confidence in EVs and enabling policymakers and manufacturers to make informed decisions about infrastructure investments and design improvements. This study uses real-time performance data from EVs and ICE vehicles to pinpoint areas requiring engineering enhancements to improve vehicle performance and reliability in hot climates. By addressing these challenges, the study will contribute to the sustainable adoption of EVs in regions with harsh environmental conditions, supporting Kuwait's transition toward a more sustainable transportation ecosystem.

## 2. Literature Review

The impact of high ambient temperatures on the performance and efficiency of vehicles, particularly electric vehicles (EVs), has been a growing area of research due to the increasing global focus on sustainable transportation. Studies have examined the challenges faced by vehicles in regions with extreme climates like Kuwait, where temperatures frequently exceed 40°C during summer.

### 2.1. Impact of Ambient Temperature on Electric Vehicle (EV) Performance

High ambient temperatures significantly impact electric vehicles (EVs), particularly in hot climates such as Kuwait, where the effects are more pronounced due to extreme weather conditions. Hamwi et al. (2022) conducted a detailed case study focusing on Kuwait's extreme climate, demonstrating that energy consumption in EVs increases by 22% at 40°C and by up to 32% at 50°C. This increase is mainly driven by the additional power required for air conditioning and battery cooling, which severely reduces driving range, exacerbating range anxiety among EV users.

Liu et al. (2018) also analyzed the effect of ambient temperature on EV energy consumption, concluding that energy consumption spikes sharply as temperatures exceed 23°C. This study pinpointed battery cooling and air conditioning as major contributors to the increased energy demand, aligning with the findings of Hamwi et al. Yuksel and Michalek (2015) extended this analysis by assessing temperature impacts across various U.S. regions, noting that energy efficiency in EVs declines by 15-22% when temperatures rise above 30°C, further confirming the importance of advanced thermal management systems in hot regions like the Southern United States.

Real-world data from Tesla vehicles support these trends. Taggart (2017) found that short trips with heavy air conditioning use cause a significant spike in energy consumption, emphasizing the critical role of optimizing EV thermal management systems. Together, these studies highlight the urgent need for robust battery thermal management and efficient air conditioning to improve EV performance in hot climates like Kuwait.

In response to these challenges, Chang et al. (2023) developed an energy-saving battery pre-cooling system that uses a secondary liquid cooling loop to reduce the cooling load on EV air conditioning. This system significantly improves battery cooling efficiency during extreme temperatures, reducing energy consumption and extending battery life. Similarly, Garud et al. (2023) reviewed advanced cooling strategies, emphasizing the superiority of direct liquid cooling and phase change materials over traditional air-cooling systems in managing thermal challenges in high-temperature regions.

### 2.2. Effect of High Ambient Temperature on Internal Combustion Engine (ICE) Vehicle Performance

While EVs face increased energy consumption due to the burden on battery cooling systems, internal combustion engine (ICE) vehicles encounter distinct challenges under high temperatures. Morad and Alrajhi (2014) conducted an in-depth study on ICE vehicle performance in Kuwait, revealing that high temperatures—especially those exceeding 90°C—cause engine overheating, power loss, and increased engine wear due to detonation. These issues are particularly evident when engines operate under heavy loads, further highlighting the inefficiency of traditional cooling systems in extreme climates.

Couetoux and Gentile (1992) emphasized the importance of proper cooling system control in automotive engines, noting that inadequate cooling in high-temperature environments leads to engine damage and decreased fuel efficiency. They stressed the need for advanced cooling solutions, particularly in regions with common high ambient temperatures, such as the Middle East. To mitigate these issues, Washington et al. (1996) investigated organic-based coolants and found that while they improved thermal management, they were insufficient for maintaining optimal engine performance in extreme heat.

Further work by Morad and Alrajhi (2014) recommended using a 25% ethylene-glycol coolant mixture, coupled with larger radiators, to enhance cooling capacity and prevent engine failure in Kuwait's hot climate. These findings emphasize the necessity of optimizing ICE cooling systems for reliable performance in high-temperature environments.

### 2.3. Comparative Studies on EV and ICE Performance in Hot Climates

Morad and Alrajhi (2014) analyzed the effects of high temperatures on ICE vehicles in Kuwait, identifying issues like engine overheating, reduced fuel efficiency, and accelerated wear and tear [4]. In contrast, Taggart (2017) examined real-world EV efficiency and range under varying ambient temperatures, finding that EVs are more sensitive to temperature fluctuations than ICE vehicles [6]. Dost et al. (2015) supported these findings, indicating that high temperatures significantly increase energy consumption in EVs, underscoring the need for robust cooling systems [7].

### 2.4. Infrastructure and Technological Advancements

Both EVs and ICE vehicles require infrastructure improvements to maintain performance in high-temperature environments. Garud et al. (2023) highlighted the importance of expanding EV charging networks with integrated cooling systems to alleviate the energy burden caused by high ambient temperatures. Pre-cooling batteries before charging, as demonstrated by Chang et al. (2023), could significantly improve EV performance in hot regions like Kuwait. For ICE vehicles, improved road infrastructure, such as shaded parking and better air circulation in urban areas, could reduce engine thermal loads, preventing overheating and extending vehicle lifespan.

### 2.5. Battery Thermal Management Challenges

Effective battery thermal management systems (BTMS) are critical in mitigating the effects of high temperatures on EVs. Chang et al. (2023) developed an energy-saving battery pre-cooling system to enhance EV performance under extreme conditions, demonstrating the potential of advanced cooling strategies [8]. Tai et al. (2024) reviewed various BTMS advancements for fast charging, noting that efficient cooling systems can significantly improve battery longevity and performance in hot climates [9].

Garud et al. (2023) further elaborated on advanced cooling strategies, emphasizing the importance of innovative thermal management techniques for maintaining battery health and efficiency [10].

***2.6. Cooling System Innovations for Improved Vehicle Performance***

Couetoux and Gentile (1992) focused on automotive engine cooling system control, providing foundational insights into managing high-temperature impacts on vehicle engines [5]. Building on this, recent studies like those by Chang et al. (2023) and Tai et al. (2024) highlight advancements in cooling technologies tailored for EVs, showcasing how engineering innovations can address challenges posed by extreme climates [8], [9].

*2.6.1. Research Gap and Future Directions*

Despite the growing body of literature, there remains a need for comprehensive studies that compare the real-time performance of EVs and ICE vehicles under extreme heat conditions specific to Kuwait. Existing research often focuses on individual aspects, such as energy consumption or thermal management, without providing an integrated analysis. Addressing this gap is crucial for developing tailored engineering solutions, improving vehicle performance, and supporting the sustainable adoption of EVs in hot climates. This review synthesizes existing knowledge and underscores the importance of innovative cooling strategies and comprehensive comparative analyses to overcome the challenges of operating vehicles in extreme temperatures.

## 3. Methodology

It draws data from performance studies on internal combustion engine vehicles and electric vehicles to compare the effects of high ambient temperatures on vehicle efficiency, energy consumption, and range (for EVs) or power loss (for ICE vehicles). This analysis is based on real-world data pertaining to EV operations in Kuwait and empirical ICE vehicle performance data under analogous conditions.

***3.1. Data Sources***

Two primary datasets were used in this study:

*3.1.1. Electric Vehicle Data*

Real-world data from the study by Hamwi et al. (2022), which collected over 3000 trip records from a Chevrolet Bolt EV in Kuwait. The data captures metrics such as energy consumption (Wh/km), range reduction at different temperatures, and the impact of high temperatures on the vehicle's auxiliary systems, such as air conditioning and battery cooling.

*3.1.2. Internal Combustion Engine Data*

A dataset by Morad and Alrajhi (2014) focuses on ICE vehicle performance in Kuwait's hot climate and empirical information. Therein included is information on engine power loss, effects of detonation, and increased burden on cooling systems as the temperature rises beyond 90°C.

***3.2. Performance Metrics***

The following performance metrics are used to compare the effect of high temperatures on both vehicle types:

*3.2.1. Energy Consumption (EVs)*

Kilowatt-hours per kilometer: a unit of measurement for the amount of electrical energy consumed in powering an EV over a given distance. It questions the increase in energy consumption with rising ambient temperature, majorly due to extra energy required for battery management and air conditioning.

*3.2.2. Range Reduction (EVs)*

A percentage of decrease in driving range as temperatures rise. It focuses on how much the range decreases at different temperature thresholds—indicatively 30°C, 40°C, and 50°C— as opposed to optimal operating temperatures around 22-23°C. The post appeared first on.

*3.2.3. Power Loss (ICE vehicles)*

Engine power loss due to high temperatures, especially due to detonation and pre-ignition. The paper investigates the 90°C plus temperatures and how they affect engine performance, leading to efficiency losses and the possibility of engine damage.

*3.2.4. Cooling System Efficiency (ICE vehicles)*

The efficiency of ICE vehicle cooling systems. In particular, how effective the radiator and fan are with increased heat load. The paper identifies the added burden to these systems with temperature increases as higher fuel consumption and potential overheating risks.

***3.3. Data Analysis***

The analysis includes the following:

*3.3.1. EV Energy Consumption and Range Reduction*

Real-world data from Hamwi et al. 2022 is used in this study for regression analysis modeling of the relationship between temperature and energy consumption (Wh/km) for EVs to estimate how much energy consumption rises as ambient temperatures increase. The following will describe the model estimating how much energy consumption rises as ambient temperatures increase. The model also calculates range reduction percentages by comparing vehicle performance at 40°C and 50°C with the optimal performance at 22-23°C. The model does this, therefore providing more insights into the impact of high temperatures on EV range and user experience. If the model does this, it will provide more insights into the impact of high temperatures on EV range and user experience ( Hamwi et al. (2022)).

Empirical data from Morad and Alrajhi (2014) is used to evaluate how ICE vehicle power decreases with high temperatures. A regression analysis is done to model the power loss, focusing on the risks of detonation and pre-ignition at temperatures above 90°C (Morad and Alrajhi (2014)).

Also, the cooling system efficiency can be assessed by increasing the ambient temperature that further loads on radiators and fans, leading to the total performance of the engine and consumption of the car.

### *3.4. Comparative Approach*

The comparative analysis examines the main differences in the response to high temperatures exhibited by EVs and ICE vehicles based on the above performance metrics. The following aspects are compared:

Energy Consumption and Range (EVs) vs. Power Loss (ICEs): How increasing temperatures lead to higher energy consumption and reduced range in EVs, vis-à-vis power losses and increased fuel consumption in ICE vehicles

Cooling System Performance: Compare the cooling requirements for EV battery management systems with those for ICE radiators and fans.

### *3.5. Limitations*

The study notes some limitations, such as the data being based only on one EV model and ICE vehicles tested in Kuwait. These models may not represent the whole population of vehicle types. Another point is that the evolution of vehicle technology from when this data was obtained up to now may affect the performance of newer models under the same conditions.

## 4. Results and Discussion

### *4.1. Electric Vehicle (EV) Performance*

#### *4.1.1. Increased Energy Consuming*

This real-world data indicates that EV energy consumption rises significantly in Wh/km with rising ambient temperature. At 30°C, energy intensity rises by approximately 6%, 40°C by 22%, and 50°C by 32%. This pattern is visible in Figure 1. energy consumption shows a linear increase with temperature. The increase in energy consumption is mainly attributed to the additional power needed to cool the battery and maintain cabin comfort via air conditioning.

The increased energy demand has its toll on EV efficiency, whereby more energy is channeled to auxiliary systems. In Kuwait, EV drivers will experience efficiency loss due to high temperatures, making the standard daily commute more energy. With temperatures as high as 40°C in Kuwait, an electric vehicle in such a climate will have to be charged more frequently because energy is being consumed at an increased rate, hence the necessary usable infrastructure in this location.

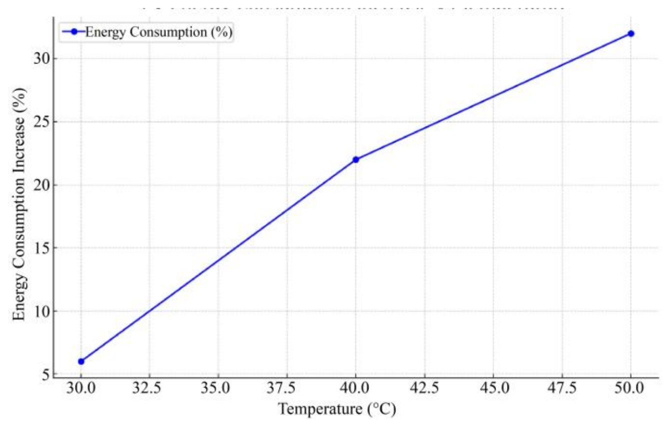


**Fig. 1 EV Range Reduction vs Temperature**

#### *4.1.2. Impact on Range*

Another issue with higher temperatures is higher energy consumption, drastically decreasing EV driving range. As shown in Figure 2, at 40°C, the range reduction is 22%, and it can get up to 32% at 50°C. This is a huge range loss in extreme temperatures; e.g. a vehicle specified for 300 km at standard conditions may take you only 200 km when it is 50°C. For really hot climates, this would be invalid for an EV.

The reduced range also combines with the phenomenon known as "range anxiety" for EV users, especially in regions possibly poorly provided with charging infrastructure. In the case of very hot weather, EV users would have to plan their journeys very accurately due to **a** drastic decrease in the vehicle range. This would make the vehicles unsuitable for extreme climates if infrastructure is unavailable. In Kuwait, the problem of range reduction can be solved by developing a system of recharging stations and explaining to the population how it works in different weather conditions.

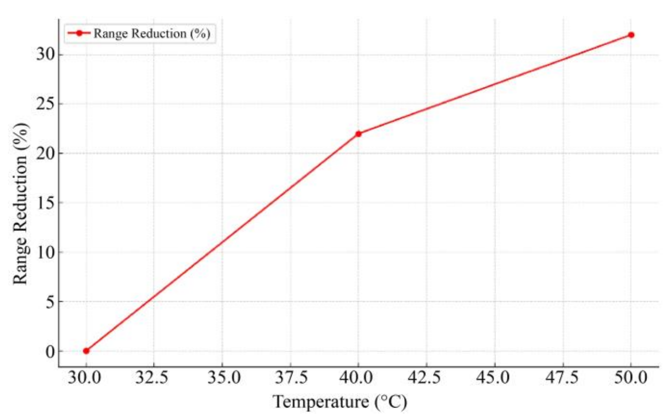


**Fig. 2 EV Range Reduction vs Temperature**

*4.1.3. Cooling System Demands*

EVs rely heavily on battery thermal management systems to prevent overheating. This is essential for both battery longevity and vehicle performance. However, the energy used to cool the battery significantly increases overall consumption. In Figure 6, EV cooling systems account for approximately 30% of total energy use in high-temperature environments. This is compared to 25% in ICE vehicles.

Thus, it is recommended that manufacturers should invest in battery cooling optimization with minimal energy penalty, particularly in places like Kuwait.

***4.2. Internal Combustion Engine (ICE) Vehicle Performance***

*4.2.1. Power Loss and Knock*

Empirical data from Morad and Alrajhi (2014) immediately gives us a clue that ICE vehicles experience notable power losses at high ambient temperatures. As was shown in Figure 3, the power loss may reach up to 30% at temperatures higher than 100°C. The major reason for this is detonation, which takes place when the fuel-air mixture is ignited prematurely because of the high temperature in the combustion chamber. This phenomenon, also called "knocking," results in a decrease in engine efficiency, power loss, and even engine damage if not well controlled.

In ICE vehicles, the high risk of detonation and pre-ignition forces the engine control system to adjust the ignition timing to avoid severe damage to the engine. However, this adjustment reduces the available power output and efficiency. Therefore, vehicle owners are likely to experience decreased engine performance. And high maintenance needs due to engine stress resulting from high temperatures. Manufacturers should be channeling their efforts toward enhancing fuel formulations and engine designs, which are more resistant to detonation under extreme heat.

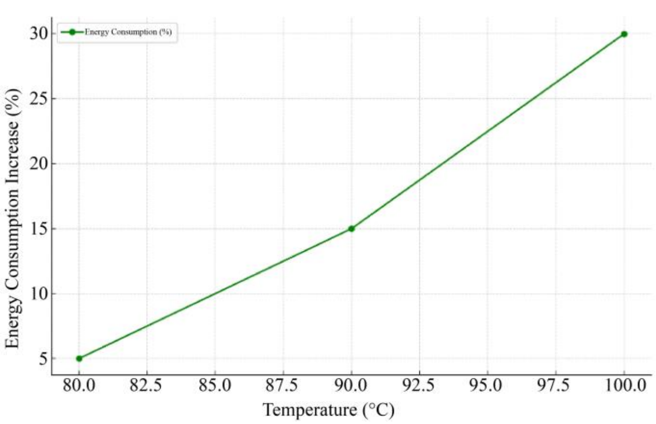


**Fig. 3 ICE Power Loss vs Temperature**

*4.2.2. Cooling System Burden*

In ICE vehicles, increased heat load at high temperatures places substantial demands on the cooling system, comprising radiators, fans, and coolants. The steps involved in managing this increased heat load are shown in Figure 4. An increase in ambient temperature will result in the cooling system expelling heat from the engine to work harder, increasing energy use and fuel consumption.

Cooling systems become less efficient when the temperature differential between engine coolant and ambient air is low. The fans would need to run at higher speed/for a longer duration. This increased workload consumes more vehicle energy and accelerates wear on the cooling components.

The tougher the cooling system works to meet the optimal temperature of the engine, the more ICE vehicles are likely to consume more fuel in hot weather. Impacts on both fuel efficiency and maintenance costs over the long term show the necessity for better cooling technologies in extreme climates.

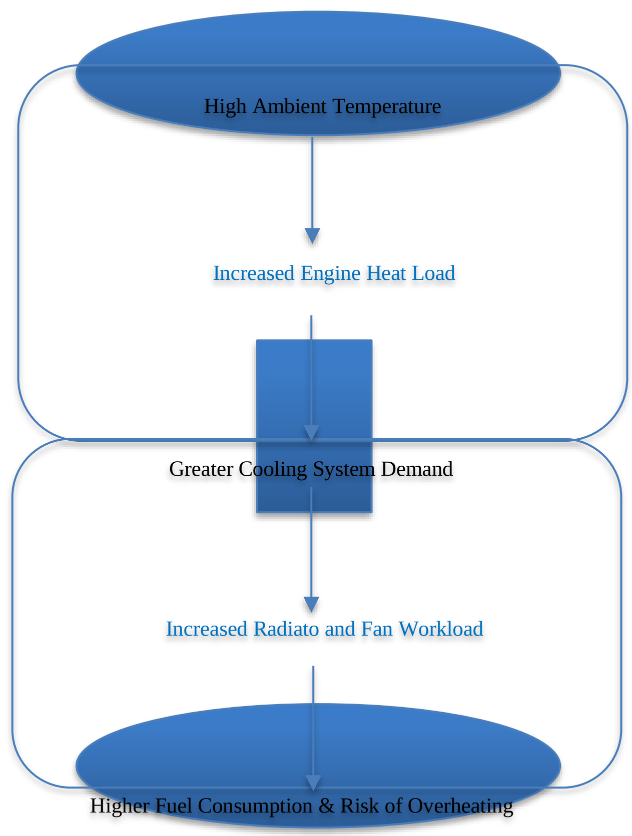


**Fig. 4 Increased cooling system burden for ICE vehicles**

***4.3. Comparative Analysis***

The comparative bar chart in Figure 5 depicts the same, which shows EVs and ICE vehicles responding in different ways to high ambient temperatures. ICE vehicles are likely to experience power loss in this case (up to 30% at 100°C) because of engine detonation and insufficient cooling. Conversely, increased energy consumption for EVs can be noticed at up to 32% at 50°C.

EVs may also suffer from reduced range because cooling systems consume more energy. Direct reduction in power output faces ICE vehicles. Both vehicle types have their performance limited in hot climates, though the essence of limitation is different for each: EV - energy efficiency, battery cooling; ICE vehicles - engine performance degradation cooling system demands.

EVs and ICE vehicles both suffer from performance degradation in high temperatures. The former suffers more from range reduction, which makes EVs less ideal **for** tropical regions. ICE vehicles have more risks of engine inefficiency and overheating**.**

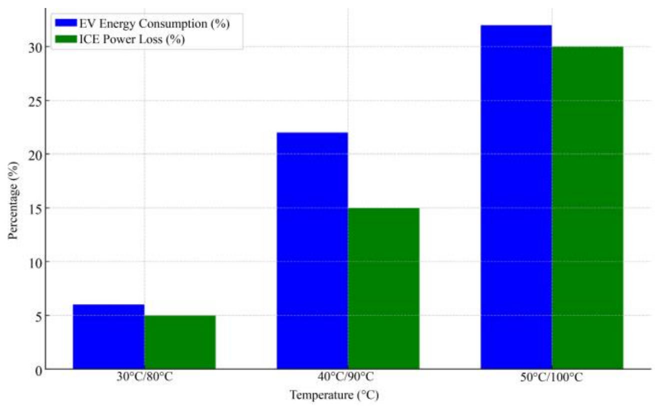


**Fig. 5 EV Energy Consumption vs ICE Power Loss at Similar Temperatures**

### *4.4. Cooling System Comparison*

Figure 6 highlights the energy burden imposed by cooling systems in both EVs and ICE vehicles. EVs allocate ~30% of their energy to cooling systems, while ICE vehicles allocate ~25%. The difference is because EVs need to manage the thermal load of both the battery and the cabin environment, while ICE vehicles focus primarily on engine cooling.

As the ambient temperature increases, cooling demands surge for both types of vehicles, though more prominently for EVs compared with ICE vehicles due to their direct effect on energy consumption. In the case of ICE vehicles, the effect is rather on engine performance and fuel consumption. EVs and ICE vehicles alike require further developments in cooling technologies to derive the best performance under hot conditions. This might sound a bit tricky for EVs because of battery thermal management, and it is not so hard for ICE vehicles due to better engine cooling efficiency.

This detailed review indicated that both EVs and ICE vehicles have notable performance challenges in high-temperature environments, though the nature of the challenge is different between the two. EVs are more seriously challenged by energy efficiency and range reduction compared to ICE vehicles, which suffer from power loss and increased fuel consumption because their cooling systems are struggling. While both types of vehicles would need some innovations in their cooling technologies to address this issue, infrastructure development is very important in countries with very hot climates, such as Kuwait (e.g., expanding charging stations for EVs).

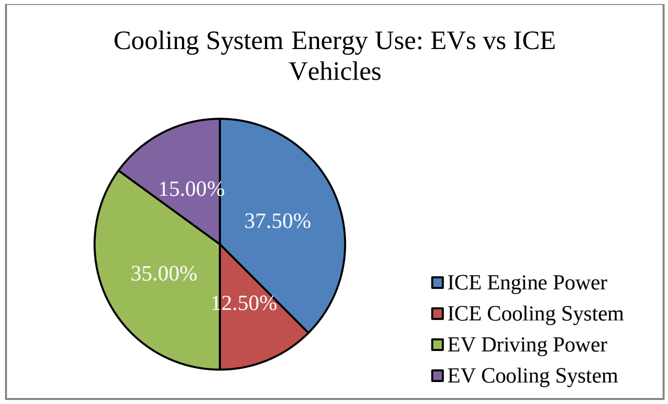


**Fig. 6 Comparative diagram of cooling system energy use for EVs and ICE vehicles.**

## 5. Conclusion

This study presents a comparative analysis of the effects of high ambient temperatures on Electric Vehicles (EVs) and Internal Combustion Engine (ICE) vehicles, focusing on their performance in Kuwait's extreme climate. Both vehicle types face significant challenges in maintaining efficiency and performance under high-temperature conditions, though these challenges differ. EVs experience substantial energy consumption increases due to the additional burden on battery cooling systems, reducing range. On the other hand, ICE vehicles suffer from power loss caused by engine detonation and overheating.

These findings offer critical insights into improving the design and operation of both EVs and ICE vehicles, particularly in extreme climates like Kuwait. Key areas for development include optimizing thermal management systems, enhancing engine and battery designs to handle high temperatures, and incorporating advanced materials and technologies to mitigate the effects of heat. By implementing these innovations, manufacturers can improve vehicle efficiency, safety, and reliability in hot environments, supporting the global demand for resilient vehicle designs.

Moreover, infrastructure improvements, such as expanding EV charging networks and developing cooling technologies, will be essential to support the widespread adoption of EVs and ensure the longevity and performance of ICE vehicles in hot climates. Future research should focus on refining these systems and exploring further technological advancements to meet the unique challenges posed by extreme temperatures.

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