Comparative road performance testing of the Chevrolet Volt PHEV.

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Abstract

The Chevrolet Volt PHEV entered the Australian market badges as the Holden Volt in 2013, and is the first 'long range' or 'extended range' electric vehicle to be sold on the Australian market. Chevrolet state the Volt can drive petrol free up to 87 km on a fully charged battery, with the transmission automatically switching over to the petrol engine for a total range of over 600 km with both a full charge and tank of fuel. However, these performance values are expected under ideal conditions, not 'every day' driving conditions. This research investigates the performance of the Volt under a number of conditions, including ambient temperature and air-conditioning loads, route topography, traffic congestion, passenger load and variable driver behaviour. For comparative purposes the Volt performance was compared against an electric-converted Hyundai Getz under near-identical conditions, to demonstrate differences in road conditions in addition to technical variants of the vehicles, such as manual and automatic gearboxes and regenerative braking systems.

Keywords: Electric vehicle; road test; energy consumption; range; Volt.

Introduction

This research is a collaborative investigation by the University of Western Australia (UWA) and Murdoch University (MU), both in Perth, Western Australia. The aim of investigation one was to analyze the performance of the Chevrolet Volt under real-world conditions, and compare these results with the results with an electric-converted Hyundai Getz, referred to as the 'REV Eco'. The influence of different driving factors including highway driving, peak driving, A/C usage, passenger number etc., have been assessed (Table 1). Two urban routes were used to represent typical city and highway driving. To reduce the influence of varying traffic conditions for each route, each test was repeated five times for the REV Eco and three times for the Volt. When testing the Volt, efforts were made to keep the conditions as consistent as possible to the REV Eco. There were, however some variables that were impossible to control. Firstly, the REV Eco has a manual gearbox with a removed clutch. This is in contrast to the Volt with an automatic transmission. On the Volt, Chevrolet has incorporated a petrol range-extender in case the car runs out of battery charge. This created a difference in results and hence additional tests were made to test the different drive modes of the Volt to compare with the REV Eco. The Volt features 'Normal' (D), 'Low' (L), 'Hold' and 'Sport' modes, where the 'Hold' mode is continuous petrol engine-only enabling the car's petrol motor to power the car and charge the battery.

Table 1: Summary of the tests performed by Assessment 1.

Volt tests	REV Eco tests
City vs. Highway	City vs. Highway
Off-peak vs. Peak	Off-peak vs. Peak
0 passengers vs. driver plus 2	0 passengers vs. driver plus 2
Electric air-conditioning on/off	Electric air-conditioning on/off
'Normal' (D) vs. 'Low' (L) vs. 'Sport' Modes	Headlights & radio on/off
'Hold' Mode (continuous petrol engine usage)	Electric heater on/off
"Long range' test.	

Increased EV adoption is hindered by insufficient vehicle driving range, existing recharge infrastructure, and associated [1-12]. However, EV performance an efficiency road testing is challenging due to variable environmental factors (wind, rain, temperature, topography) and temporal and geographical actors (locations and time of use) [6, 13, 14] in addition to driver influence [15-18] Furthermore, EV batteries are required for both propulsion and auxiliary power, with auxiliary loads (operating brake booster vacuum pumps, power steering, navigation, computers, stereos, and in particular A/C and heating systems) contributing to considerable energy consumption and a reduction in driving range depending on driver preferences [14, 15, 17-24]. Investigations by Sheffield [16, 18] comparing EV energy consumption and range tests using a laboratory chassis dynamometer against equivalent road tests and drivers highlighted major differences in driver behaviour on road tests, and resulting range and energy consumption variations. The EV chassis dynamometer range test results (using a Smart Fortwo EV) was between 105.66 km and 114.68 km for all selected drive cycles. However, the road tests result variations were between 61.2 km and 74.0 km [16]. Further investigations with a larger pool of 25 drivers found even larger variations in EV range between 56 km and 107 km [18].

Method

Accurate readings of energy consumption for the REV Eco were generated by an energy meter from TBS Electronics BV [25], measuring the main battery voltage (V), instantaneous current (A), cumulative ampere hours (Ah), and battery state of charge (SOC) in percentage (%). To approximate the vehicle energy consumption, the main battery voltage was logged, averaged, and multiplied by the Ah.

The energy consumption of the Volt were generated and displayed on the inbuilt LCD display (to a precision of 0.1kWh). All drive mode tests in this research were repeated three times and averaged, and the kWh, speed, time, distance, and ambient temperatures were recorded. All drive mode testing were conducted on the 'city' route to determine differences in energy consumption. Of particular interest was the difference in energy consumption between the driver preset options in the automatic transmission Volt: 'Low' (L) and 'Normal' (D) modes in the Volt. The L mode reduces speed by decelerating using the regenerative braking system (RBS), when the accelerator pedal is released. In D mode the Volt only uses the battery and the car coasts as the driver removes their foot from the accelerator. Driving in the L mode with the use of the RBS suggests that the net energy consumption should be lower than that in D mode. Testing was also carried out using the Volt 'Sports' mode with a significant improvement in acceleration than the D mode, and the 'Hold' mode which is preserve the remaining battery energy by switching to the petrol mode only.

Assessment 1 Method: Comparative Performance of the Volt vs. REV Eco

The 'city' route used was around 27 km, starting at UWA, looping around the campus, and south to North Fremantle before heading back to the origin (Figure 1). The 'city' route involved varying speeds (40 km/h to 70km/h), traffic lights, elevations, and traffic levels to produce a 'real world' representation of an urban commute to work. On all the trials for the Volt, recordings were made via the free smartphone app (MapMyRide, 2014), giving a full analysis of speed and location accessible online to track and measure observations. To maintain consistency with the 'city' route, the 'highway' route was a similar distance and was chosen to represent typical driving on high-speed Australian roads (predominantly 100 km/h). The route starts on Mounts Bay Road and continues down on Kwinana Freeway before turning around at the South Street exit and returning to the origin (Figure 2).

The REV Eco test occurred in the morning peak traffic period at 7am to 9am, and the peak afternoon peak traffic period from 4pm to 6pm (Transperth, 2014). Due to time constraints the Volt was only tested during the morning peak. The Volt testing was carried out during school holidays, which does significantly affect traffic conditions in Perth, whereas the REV Eco testing was undertaken during school periods. The effect on energy consumption of the weight of two additional passengers (totaling 150kg) was also analysed. Similarly, the effect of air-conditioning (A/C) on energy consumption was analysed by setting the thermostat for the climate control to 20 degrees Celsius whilst driving the 'city' route. The Volt has three cabin temperature modes (fan only, ECO, and comfort.) The ECO mode was selected to enable the use of economy control strategies to maintain the set cabin temperature. Due to time constraints, peak 'highway' conditions, headlights and radio tests, and the electric heater tests were not performed on the Volt in Assessment 1. The earlier testing of these parameters on the REV Eco showed that the effect on energy consumption of either 'highway' peak/off-peak, or headlights and radio on/off were not significant. The heater testing was not performed as the test period was in summer with outside temperatures at testing of up to 40 degrees Celsius and deemed inappropriate for heater testing.

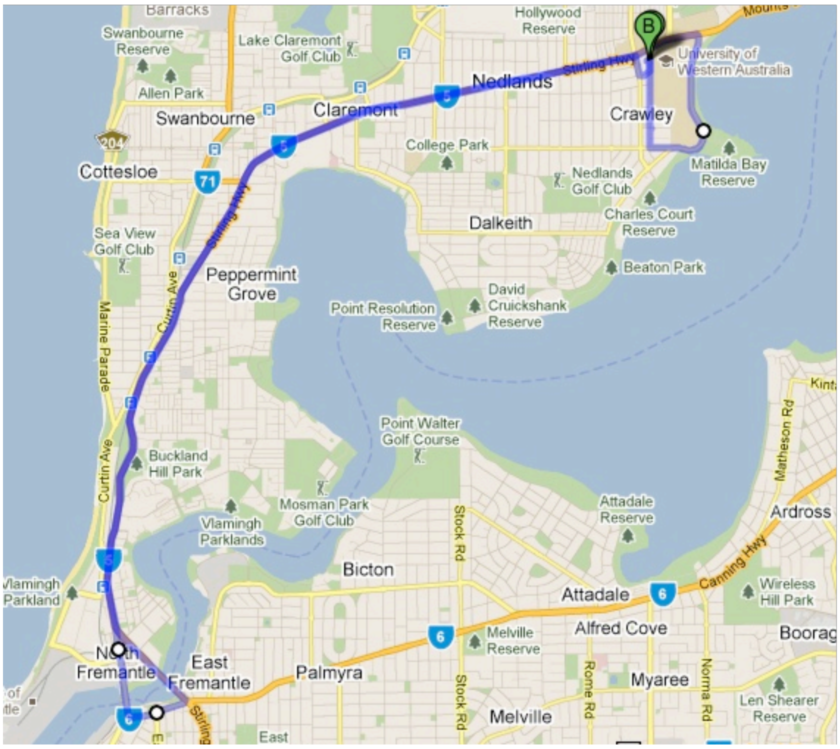


Figure 1 The 'city' route used to test urban driving for the Volt and REV Eco (Google Maps, 2014)

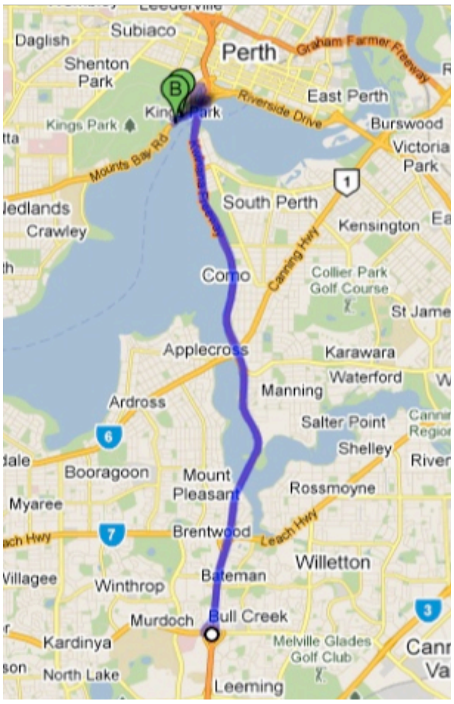


Figure 2 The 'highway' route used to test the Volt and REV Eco (Google Maps, 2014)

Assessment 2 Method: Performance and Range Analysis of the Volt

The objective of Assessment 2 was to analyse differences between vehicle drivers and routes on test results. All test criteria for Assessment 2 with the Volt were identical to Assessment 1, and Table 2 shows the test matrix for Assessment 2, undertaken in summer with the A/C on ECO mode and a cabin temperature set at 22 degrees Celsius with the radio on. The tests with the A/C off involved the front windows being half opened and with the radio off. Two comparable routes were selected for testing the road performance of the Volt for Assessment 2; a ‘city’ route length of 28.3 km with varying traffic congestion, traffic lights, topography, passengers, and speeds (between 40km/h to 70km/h), shown in Figure 5. This route was representative of the average daily distance travelled by most passenger cars in Perth, based on 90% of passenger cars that travel 10,648km per year (ABS, 2012). The ‘highway’ driving route was 30.7km at speeds of predominantly 100 km/h (Figure 6). An iPhone application (BMW Power Meter, 2014) was used to test the Volt acceleration in both D and ‘Sports’ modes from 0-50km/h to determine maximum acceleration differences between the two modes. Assessment 2 also incorporated tests with three passengers (total combined weight of 180kg) to compare EV performance under partial versus full passenger load. The final test was range testing the Volt as a ‘long range’/‘extended range’ vehicle. Chrysler state the Volt is able to drive petrol free up to 87km on a fully charged battery before switching over to the petrol engine under ideal conditions. The test was undertaken under non-peak real-world (non-ideal) driving conditions with performance values expected to be slightly less, although not drastically different from the claims of Chrysler. The Volt battery was fully charged (taking around 9 hours and 30 minutes) from a standard 240V grid connected EV charger at MU. The route started and finished at MU driving under both ‘city’ and ‘highway’ conditions with the midpoint slightly over 30km in Kalamunda near Perth, and a round trip totaling 76.6km using both battery power (70.3 km) and the petrol engine (6.3 km) to complete the test (Figure 7). The test used normal driving “D” mode and only one driver with A/C off and radio off.

Table 2: Testing criteria for the Volt for Assessment 2.

	Mode	**Peak**	**Off-Peak**	**A/C and radio**	**Route**
Battery	Normal (D)	X	X	X	City/Highway
	Low (L)		X	X	City
	Sports	X	X	X	City
Hold Mode (Petrol)	Normal (D)	X	X	X	City
Night Driving	Normal (D)		X	X	City
Acceleration	Normal (D)		X		City
	Sports		X		City
Full Passenger Load	Normal (D)		X	X	City
Long Range	Normal (D)		X		City/Highway

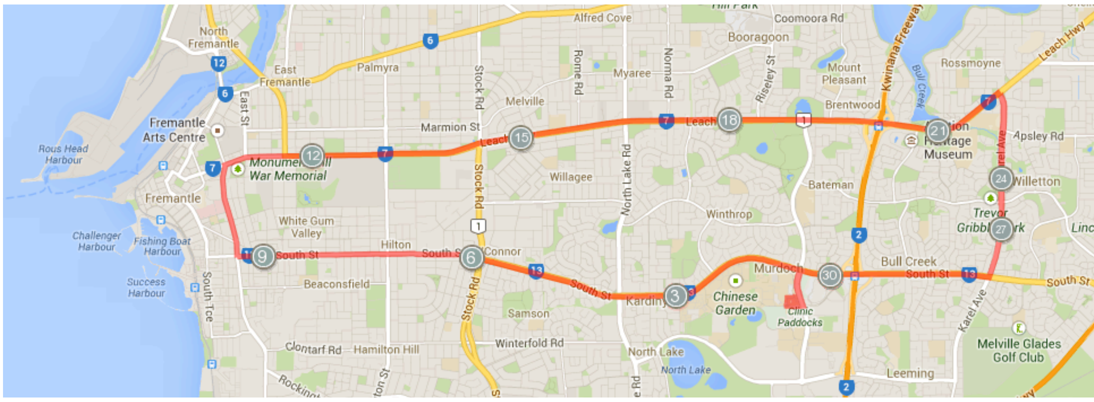


Figure 5: ‘City’ route for testing Volt performance (Google Map, 2014)

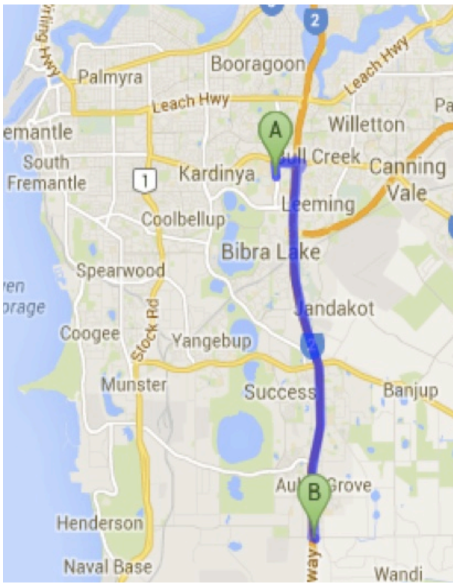
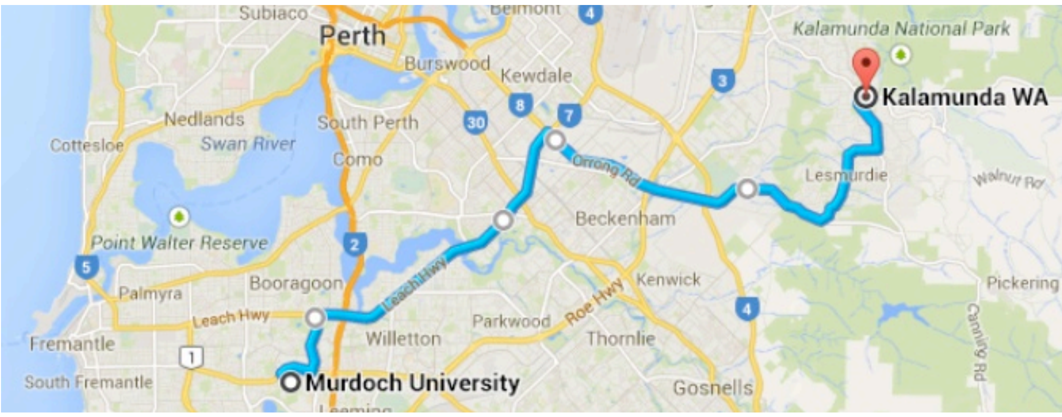


Figure 6: ‘Highway’ route for testing Volt performance (Google Map 2014)



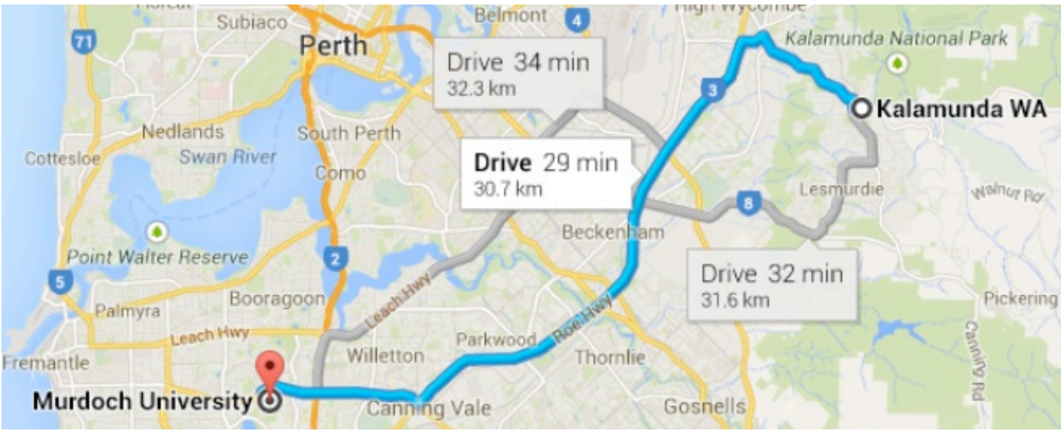


Figure 7: Extended range driving routes from MU to Kalamunda and return.

Results and Discussion: Assessment 1 (Volt vs. REV Eco Performance)

Figure 8 shows the energy consumption of the Volt in comparison with the REV Eco across the range of tests. Figure 9 presents the relative percentage difference of energy consumption in the tests above that of the lowest level of energy consumed in any individual test (i.e. using the ‘city’ off-peak data as a baseline). The results show that the more finely-tuned factory Volt is much more efficient in all tests than the REV Eco. This is most likely due to the Volt engine as well as the RBS (the REV Eco does not have an RBS). The findings show a major impact on energy consumption from the use of A/C. The use of A/C increased energy consumption by 32.14% in the Volt and 29.6% in the REV Eco. (The authors note that A/C test results are heavily dependent on the outside temperatures during testing.) The influence of the RBS can also be seen clearly in the ‘highway’ vs. ‘city’ test - the only test showing a significant difference in energy consumption between the REV Eco and the Volt. The difference in energy consumption between ‘highway’ and ‘city’ driving for the REV Eco was quite small (3.5%), whereas it was much more pronounced in the Volt (13.4%). There are comparable energy consumption differences between extra passengers and ‘city’ off peak traffic between the REV Eco (21.3%) and the Volt (14.3%), implying that the effect of the extra passenger load will always cause a noticeable increase in energy consumption.

A surprising result during the Volt tests was the relative similarity of the ‘Sports’ mode and D mode in terms of energy consumption. The expectation that the ‘Sports’ mode would result in a considerable increase in energy consumption was not confirmed. The results show that ‘Sports’ mode relative to D mode increased energy consumption by only 1.7%, despite the EV exhibiting a noticeable improvement in acceleration from a standing start. Similarly, the L mode caused a decrease in efficiency of 9.8% relative to D mode; an unexpected result as the L mode would be assumed to produce lower energy consumption due to more frequent regenerative braking. The fuel testing in ‘Hold’ mode showed that the Volt was also quite fuel-efficient. The testing involved three drives obtaining an average of 5.4L/100km, which is an excellent value in comparison with internal combustion engine vehicles. However, the results need to be taken in context within the limitations of the study, primarily a limited number of tests and associated result reliability and accuracy.
Additionally, the differences between the Volt and the REV Eco features must also be taken into account when comparing results between the EVs.

Below is a table detailing the specifications of both cars:

	Volt	REV Eco
Max Power	111kW	39kW
Voltage	340V	144V
Capacity	16.5kWh	13kWh
Transmission	Auto – Electronic ratio select	5 speed manual
Curb Weight	1721kg	1160kg

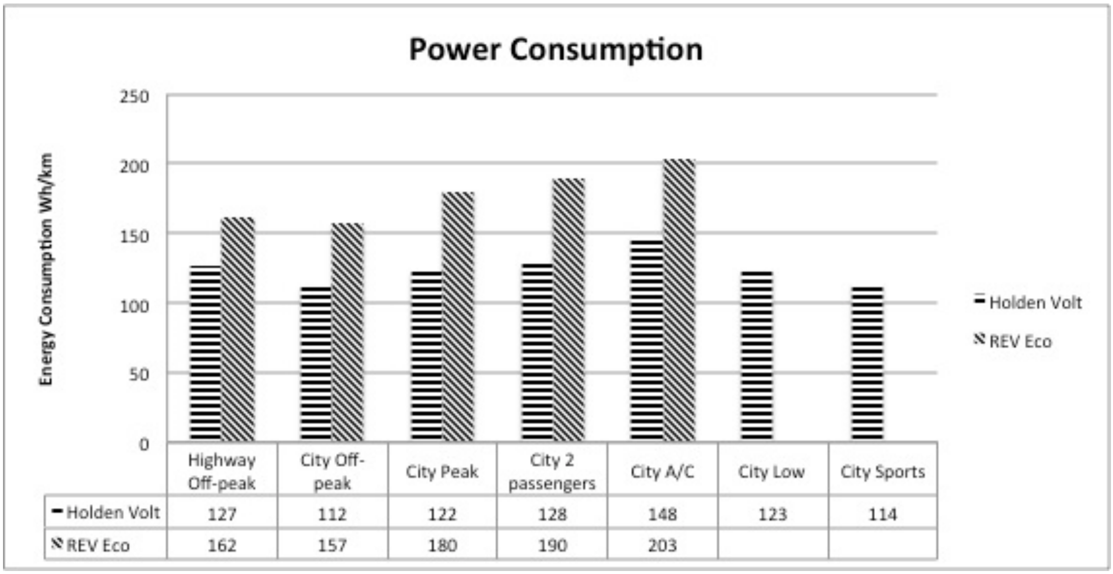


Figure 8 Energy consumption between the EVs for each test; D = Volt's Normal mode, L= Volt's Low mode

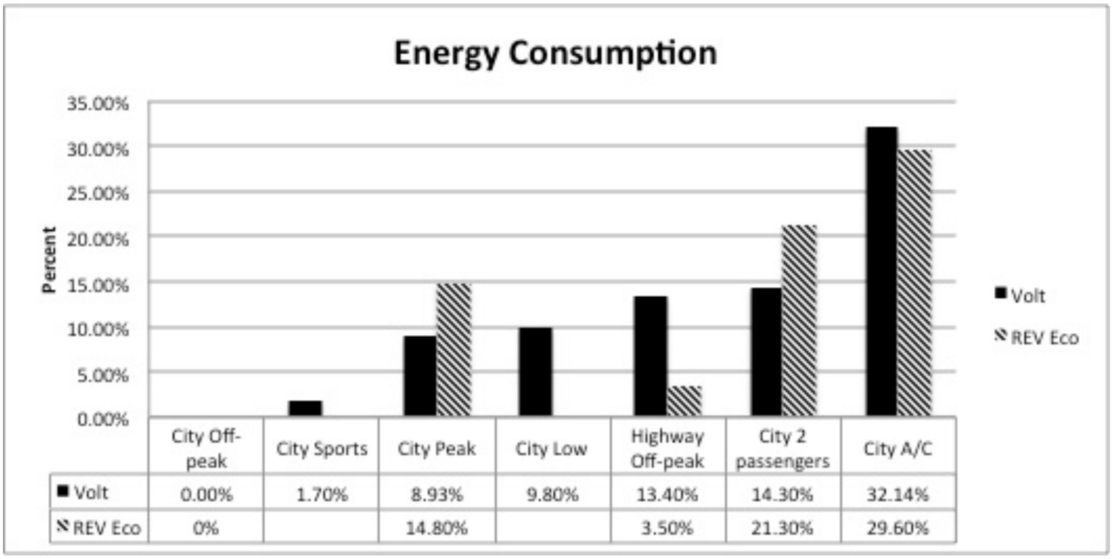


Figure 9 Relative percentage difference of energy consumption compared with city off-peak

Results and Discussion: Assessment 2 (Volt Performance and Range)

Normal (D) vs. Sports Mode in City Route

Figure 10 compares the Volt D and Sports driving modes under different conditions. The findings indicate that the Volt uses between 3%-10% less energy in Sports mode than in D mode when the A/C is on. The possible reason for the difference could be ambient temperature and the driving route; even though the car is in Sports mode, it has no real opportunity within the test route to acceleration greatly. In both driving modes the energy consumption is greater in peak traffic than off-peak traffic as expected, although less than the Assessment 1 trial. The effect of A/C on the average energy consumption in both the D mode (18% off-peak, 21% peak) and Sports mode (3% off-peak, 5% peak) was relatively consistent between modes. The morning peak test temperature range of 20-30 degrees Celsius, lower than the afternoon off-peak test temperature range of 26-39 degrees Celsius. The authors note that the energy consumption in D mode with the A/C on was much higher than Sports mode with the A/C on. However, the energy consumption in D mode with the A/C off was much lower than Sports mode with the A/C off.

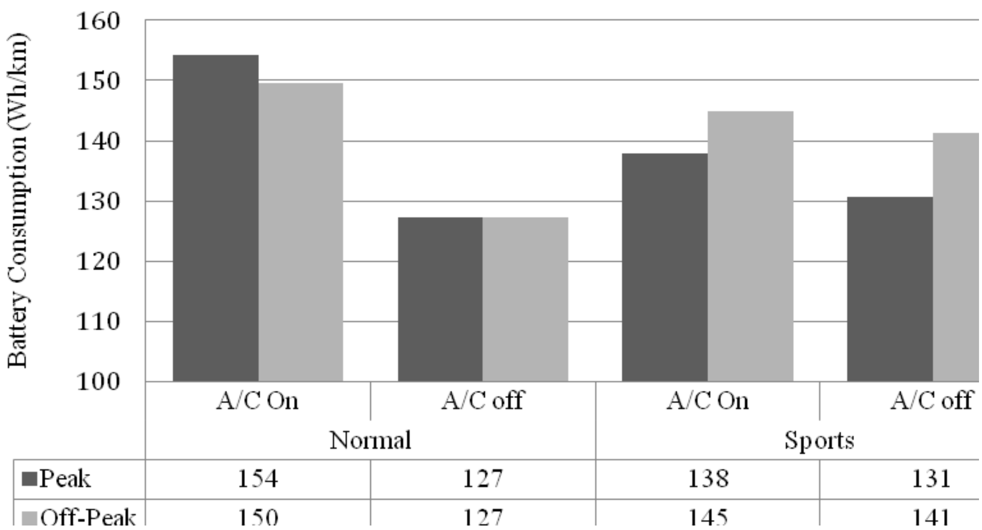


Figure 10: Comparison of Normal (D) and Sports mode in the 'city' route

Battery vs. Petrol in City Route

Figure 11 shows the energy consumption for the Volt from the two different fuel sources. Assuming the energy content value of petrol to be 34.4 MJ/L, the energy used by the car in 'Hold" mode consuming petrol is almost 5 times that when operating from the battery. With the A/C on, there is an increase in the energy consumption in both modes and traffic conditions as expected.

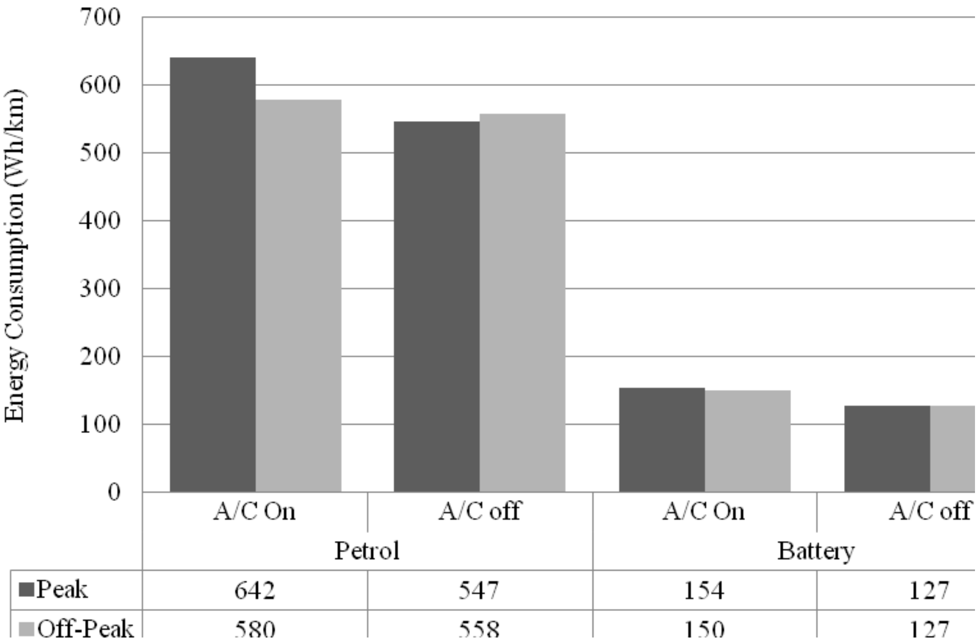


Figure 11: Comparison of battery and petrol energy consumption

Single vs. Full Passenger Load and Day Driving vs. Night Driving

Figure 12 compares the performance of the Volt when the passenger load is increased. Back-to-back driving tests were undertaken with single (74kg) and full (250kg) passenger load, both in D mode with the A/C on. The results show energy consumption increased by 1.1 kWh (24%) for the full passenger load. The results of the comparison between day and night driving in the Volt are shown in Figure 13. The energy consumption during night driving is less than driving, likely to the ambient temperature difference of almost 10 degree Celsius between the day and night drives.

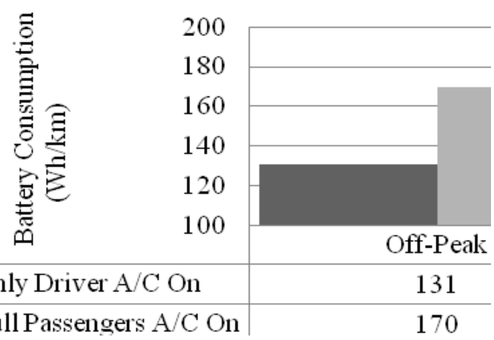


Figure 12: Comparison of single and full passenger loads

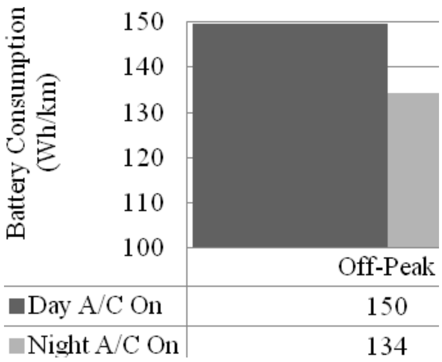


Figure 13: Comparison of day and night driving

Highway vs. City Driving and Battery Charging vs. km

Figure 14 compares the Volt 'city' and 'highway' drive. The A/C was on in both tests and the results show that the energy consumption of the 'highway' drive increased by almost 10% compared to the 'city' drive. The likely reason for this is the amount of energy that can be recovered during the 'city' driving when the regenerative braking is being regularly applied. The energy provided to the battery was recorded every time the Volt was plugged into the charging station. The 32-ampere single phase (240V) charging station normally takes 3-4 hours for the full battery charging. 1kWh on average produced 5.7km to the battery km as indicated by the Volt dashboard meters.

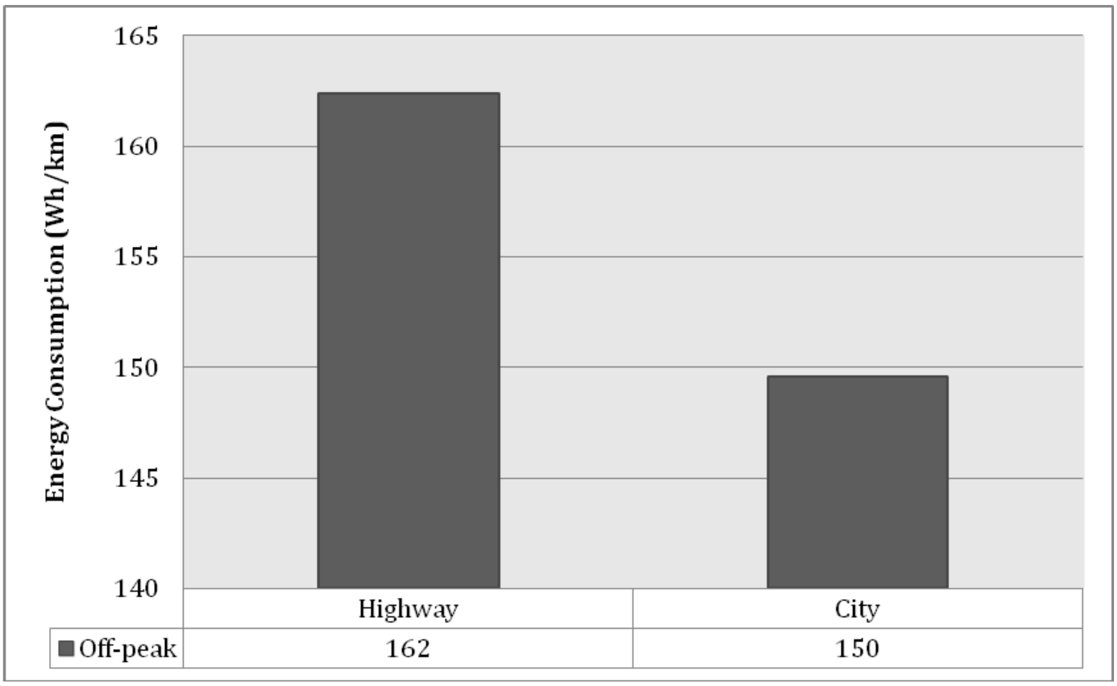


Figure 14: Comparison of 'highway' vs. 'city' driving

Acceleration Test (0-50km/h) and Long Range Tests

The IPhone application 'BMW Power Meter' was used to gauge the acceleration of the Volt in D and Sports mode during 0-50km/h sprints. The average value of three experiments in each case showed that the maximum acceleration in Sports mode was 29% greater than D mode. In the long range test, a total distance of 70.3km was achieved using the Volt battery before the petrol engine was engaged due to a fully discharged battery. The remaining 6.3km of the journey completed powered by the petrol engine. The battery energy consumed was calculated as 10.5kWh, or 149.35Wh/km. Only 0.38L of petrol was consumed during the test.

Comparative Analysis of Assessment 1 vs. Assessment 2

The objective of Assessment 2 was to take into account driver behavior and route differences to Assessment 1 tests. Figure 15 shows a summary of the differences in energy consumption under the test criteria. Figure 15 shows that energy consumption is highest with the A/C on and a full passenger load, as expected. In both cases of A/C on and A/C off there was very little difference in energy consumption between 'city' driving during off-peak traffic and 'city' driving during peak driving. This may purely be a feature of the route selected and the times that the tests were carried out. Using the A/C was the single criterion that had the highest impact on energy consumption, increasing it by around 20%. Note, however, that the trials were conducted in peak summer, and the increase in energy consumption due to using the A/C would be lower in other months of the year.

Figure 16 compares the performance of the Volt under different driving routes of similar length and with different drivers. For 'city' peak driving, either with A/C on or off, the differences between the trials were less than 4%, suggesting that any differences in length of routes, driver behaviour, or comfort control settings, were not critical factors under D mode. Greater variation was observed when driving in different modes in Assessment 1, using around 15% and 20% of the total energy consumption for the Sports and L modes, respectively. Differing driver behaviour is likely to be a major factor in the different Volt mode test results for Assessment 1 and 2. An interesting result was the Volt L mode was found to not reduce driving energy consumption in both Assessment 1 and 2 results as would be expected, and will require further investigation. The results show the greatest difference between the trials occurred for the 'highway' tests (28% difference) and the passenger load tests (32% difference). In the 'highway' tests both trials used similar length sections of the Kwinana Freeway; however, the driver in Assessment 1 achieved the lower energy consumption while using a busier section of the Kwinana Freeway, including a section with a speed limit decrease from 100km/h to 80km/h. It is possible that more energy was recovered through regenerative braking for Assessment 1 'highway' test. In terms of passenger load, Assessment 2 included a full car (driver plus 3 passengers), whereas Assessment 1 had one less person (driver plus 2 passengers). The increase in inertia of the Volt for Assessment 2 is likely to be the reason for the increase in energy consumption.

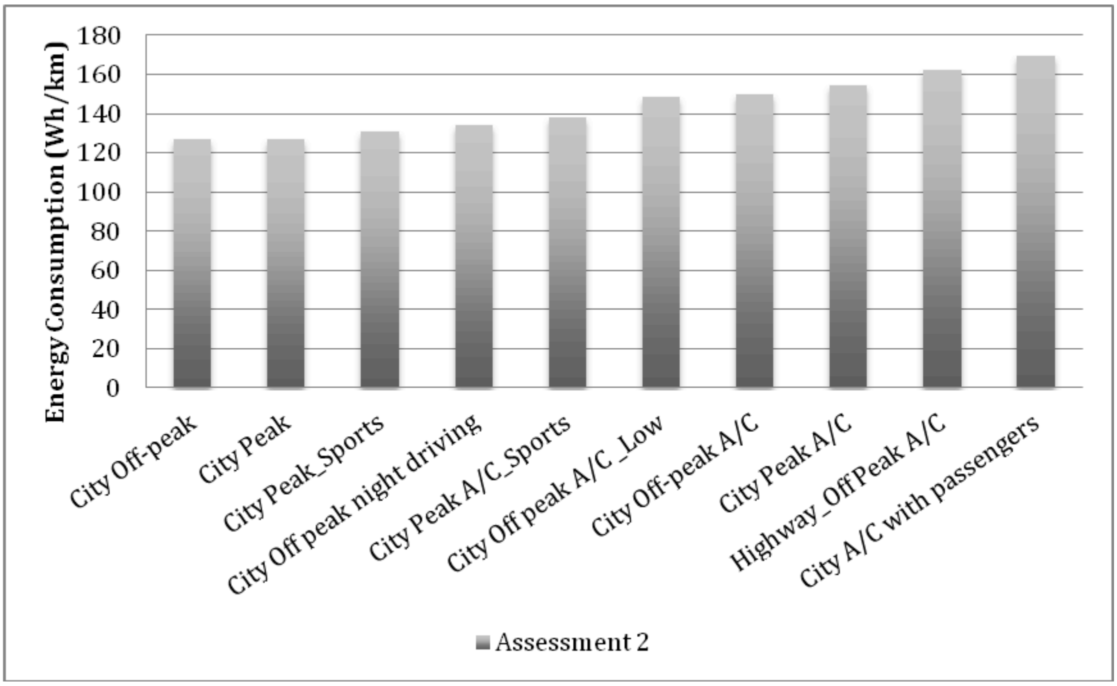


Figure 15: Assessment 2 results summary of the Volt tests

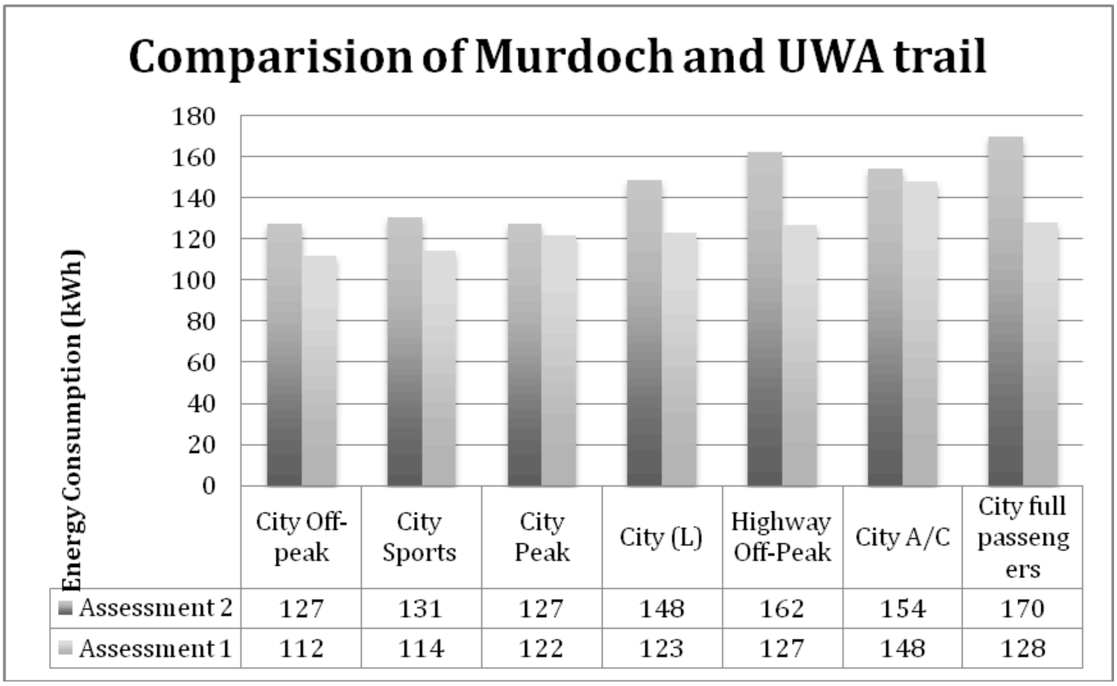


Figure 16: Comparison of Assessment 1 and 2 Volt energy consumption.

Conclusion

The Chevrolet Volt was analysed as a 'long range'/'extended range' PHEV and compared against an electric-converted Hyundai Getz under near-identical conditions. The results demonstrated differences in route and road conditions on EV performance and energy consumption between the technical variants such as manual and automatic gearboxes and regenerative braking systems. This research further investigated the performance of the Volt under different driving modes, ambient temperatures and A/C loads, route topography, traffic congestion, passenger loads, and variable driver behaviours.

Acknowledgements

The authors would like to thank Holden Australia and Shacks Holden Fremantle for providing the Holden Volt vehicle used for our experiments, and John Oakley for performing the REV Eco testing.

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