Performance Evaluation of Battery-Electric Vehicles under Varying Road Conditions and Settings

Jonathan Oakley
and Thomas Bräunl*

Renewable Energy Vehicle Project,
The University of Western Australia,
Crawley, Perth, WA 6009, Australia
Email: Thomas.Braunl@UWA.edu.au
*Corresponding author

Abstract: Conventional road transport is powered by non-renewable hydrocarbon fuels and is a major contributor to greenhouse gas emissions. These factors have raised global interest in electric alternatives. Several large manufacturers are starting production of completely electric cars. Currently the performance and range of these vehicles are measured using standardised tests, adapted from speed profile testing, to measure fuel economy and emission levels in internal combustion powered vehicles. Research suggests that such testing does not accurately describe economy or emissions in real driving conditions. The aim of this study was to assess the performance of an electric vehicle by conducting a number of real-world driving tests under varying conditions. Our results suggest that some standardised tests are underestimating energy consumption, as real-world tests have shown significant energy consumption increases for accessory usage and for high traffic scenarios that are not tested using standard procedures.

Keywords: battery electric vehicle; REV Project; EV conversion; EV energy consumption; on-road drive testing.

Reference to this paper should be made as follows: Oakley, J. and Bräunl, T. (2013) 'Performance Evaluation of Battery-Electric Vehicles under Varying Road Conditions and Settings', Int. J. Vehicle Design, vol. x, no. x, pp. x-x.

1 Introduction

The term *Electric Vehicle* (EV) applies to all means of transportation where propulsion is provided by electric motors. This study will concentrate on automobile battery-electric vehicles (BEV). The threat of climate change caused by the emission from internal combustion engine (ICE) cars has raised global interest in electric vehicle alternatives. Renewable energy sources, such as photovoltaic, wind, tidal, geothermal, hydro, etc., are the preferred methods for recharging battery-powered electric cars.

First generation hybrid electric vehicles have been largely successful with mass production of cars such as the Toyota Prius (Toyota 2013) and the Honda Insight (Honda 2013). While these vehicles have electric drive and storage systems, they are still reliant on petrochemical fuels. These vehicles did not have a 'plug-in' capability, which means any electric energy for driving such a hybrid car has to come from burning petrol in its internal combustion engine. As it is usually not economical to add a plug-in functionality to an existing hybrid car, the largest problem of these hybrids is their very limited battery size. The Toyota Prius only had a 1.3kWh nickel metal hydride battery (Iliaifar 2012) and could drive purely electric for only 90 seconds or 1.5km.

More recent plug-in hybrids have come to the market with a larger battery sizes (but still small compared to battery-electric vehicles), such as the 2012 Toyota Prius Plug-in Hybrid at 4.4kWh for 18km in mixed electric/petrol mode (Wikipedia 2013) or the Chevrolet Volt at 16kWh for 56km pure electric drive (Edsall, Lutz 2010).

Several manufacturers are releasing fully-electric vehicles, which is the next logical step towards emission-free transport. While range is a major obstacle in the acceptance of these automobiles, production cars as well as conversions have ranges in excess of 100km. In our on-road tests with two-thirds city traffic and one-third highway traffic we have established a range of 112km for the Mitsubishi iMiEV and 131km for the converted Ford Focus, used in the Western Australian Electric Vehicle Trial and converted by EV Works in cooperation with REV/UWA and CO2Smart. Mitsubishi's published range for the iMiEV of 160km (Mitsubishi 2013) is based on dynamometer testing and not realistically achievable on the road.

Considering that the average daily driven distance in Australia in 2010 was only 32km (Australian Bureau of Statistics 2011), an EV range in excess of 100km seems to give a quite comfortable safety margin, however, the inability to go on an occasional longer trip with a quick 'refuel' like ICE cars is a concern to electric motorists. Lengthy charging times (three hours for a full recharge on a level-2 intermediate–fast charging system versus ten hours at level-1 slow or home charging) together with a general lack of public recharging infrastructure are the true reasons behind 'range anxiety'.

1.1 Objectives

The primary objectives of this study were to document the influence of driving factors, such as city/highway driving, number of passengers, peak/off-peak driving and the usage of air conditioning, heater, etc. on the energy consumption of an EV, as well as to investigate the relationship between standard testing methods and real-world driving.

Research on ICE vehicles suggests that standard tests do not give an accurate measure of fuel consumption or emissions (Debal, Pelkmans 2006), (Zhihua 2011). The standard testing procedures have been developed for cars with internal combustion engines and may not be suitable for testing electric vehicles. These tests have been designed to be comparable and repeatable, which gives consumers the ability to compare vehicles and make informed decisions based on the rated economy and emissions. Electric vehicles are limited by current battery technology. The result is a much smaller range when compared to conventional vehicles. As such, an accurate measure of performance and range is important. There is already some scepticism about the performance and practicality of electric vehicles, and overstating their range could be damaging to this emerging industry (Hindrue et al. 2011).

All standard tests consist of following a predefined speed profile on a chassis dynamometer. The vehicle sits on the rollers of the dynamometer, which spins a mass to simulate the acceleration forces experienced on the road (Federal Register of Legislative Instruments 2008). An additional braking system is used on this mass to simulate the rolling and wind resistances. For internal combustion vehicles, the fuel consumption and emissions are measured. For electric vehicles the energy consumption is measured and range is calculated using this energy consumption value.

The method used to calculate the range is of concern in a number of ways. The range is calculated by simply dividing the stated capacity of the battery by the power consumption value determined in the speed profile test (Federal Register of Legislative Instruments 2008). If the speed profile tests underestimate realistic energy consumption the result will be an overestimated range value. The rated battery capacity is also of some concern. The manufacturers of the batteries release performance information to portray their products in the best possible light. Most production electric vehicles use lithium-ion cells, which lose capacity with time and use. Deep discharging of these battery cells will result in shortening the life of the battery. This means that the practical range is reduced in order to extend the life of the battery. All manufacturers have systems in place to prevent fully discharging in order to protect the battery. There are multiple testing cycles in use in different countries, which creates some confusion, as performance values are different for each testing procedure (Tzirakis et al. 2006), (Mock et al 2012).

1.2 Motor Vehicle Consumption and Emission Testing

There are a multitude of test cycles in use for a variety of vehicles. For light passenger vehicles there are three methods that are predominantly used, however there is a new initiative in order to harmonize all light vehicle testing procedures by 2014 (UNECE 2013). This study has examined the New European Driving Cycle (NEDC, Wikipedia 2013), which is being used in the European Union. This test cycle is used to perform European emissions standard testing. These standards are an on-going effort to reduce vehicle emissions. The Europe emissions standards have five levels of allowable emissions. Each increasing level introduces more stringent emission limits (European Union 1998). The test cycle features only specific levels of acceleration and speed (modes of operation). The test cycle has been criticised for only containing limited modes of operation (Debal, Pelkmans 2006). Not only do they not accurately reflect real-world driving conditions, there is evidence that car manufacturers have been optimising performance just to comply with standards. This may not reduce the actual level of emissions.

Figure 1 New European Drive Cycle Speed Profile (USEPA 2010)

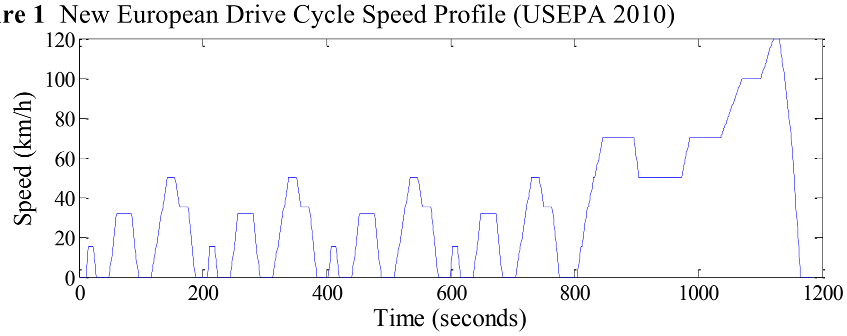


Figure 1 shows the speed profile from the NEDC. The first four sections are comprised of Elementary Urban Cycles which represent low speed city driving. This is followed by the Extra Urban Duty Cycle which represents motorway driving. From these measurements a city, highway and combined fuel consumption figure are generated. This is also the test procedure used in the Australian Design Rules 81/02 Fuel Consumption Labelling for Light Vehicles (Federal Register of Legislative Instruments 2008).

Adopting this test procedure developed with European driving data may not accurately reflect Australian driving conditions.

Figure 2 REV Eco, UWA

The vehicle used for our tests is The University of Western Australia's REV Eco (Renewable Energy Vehicle Project 2008), a BEV conversion of a Hyundai Getz small passenger car, designed and built in 2008 (see Figure 2). This car is a fully battery-electric conversion of a 2008 model Hyundai Getz. It features a 28 kW DC electric motor and 13 kWh lithium-ion-phosphate batteries that give it an 80km range. All of the original accessories are operational including air conditioning, heating and power steering. In related research, we have examined noise level of EVs (Bräunl 2012), optimal traffic dispatching (Lim et al. 2011), as well as the effect of EV charging on the electricity grid (Mullan et al. 2011 and 2012).

2 Performance Evaluation Setup

For the labelling of all new cars sold in Australia, fuel consumption is measured using the test procedures from Australian Design Rule 81/02, which are identical to the New European Drive Cycle (NEDC). These labels indicate economy values for the combined cycle, urban and extra-urban driving. The test consists of four elementary urban cycles and one extra-urban cycle. The combined economy value is calculated from the whole test profile, and the urban and extra-urban values come from the separate cycles. The design rules for electric vehicles state that economy values will be displayed in kWh/km (Federal Register of Legislative Instruments 2008).

After some in initial tests, we found it near impossible to perform an on-road version of the ADR/NEDC drive cycles, maintain the required speeds on the available Western Australian test tracks. Instead, we decided to perform proper road testing with other traffic. Although these tests will exhibit a larger variation, the results will be much more relevant for practical use.

The power consumption readings were taken using the TBS electronics E-Xpert pro high-precision battery monitor (TBS Electronics 2013), which is installed in the REV Eco. The monitor has an accuracy of +/- 0.4% for current and voltage measurements with a refresh rate of 1Hz. These values can be logged on a computer using a USB or serial interface module. For our tests, we recorded amp hour readings and calculated kWh values using the nominal voltage of the battery pack. This introduces some inaccuracy as the voltage of the pack changes with current draw and charge level.

The real-world testing was designed to measure the power consumption of the

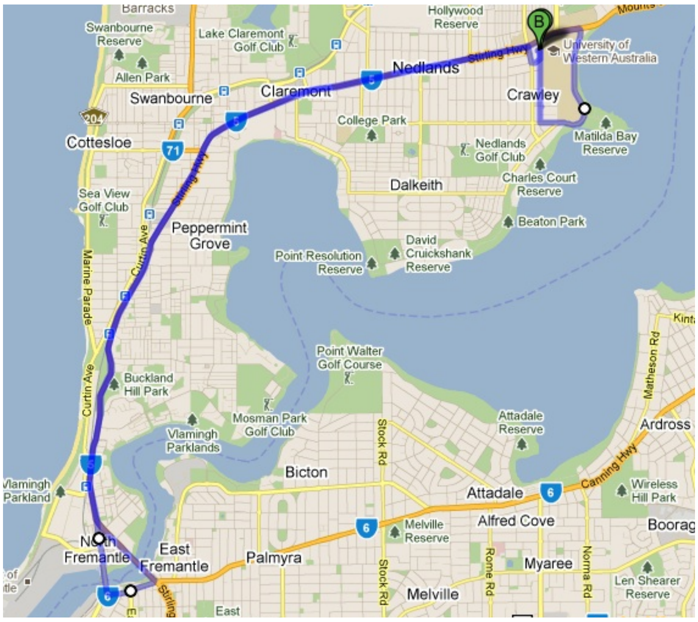
REV Eco in a variety of operating conditions:

- City versus highway
- Off-peak versus peak traffic
- No passengers versus driver with two passengers
- Headlights and radio on/off
- Electric heater on/off
- Electric air conditioning on/off

Two routes were selected to represent city and highway driving. For each condition five trials were completed to find the average power consumption. Multiple trials of each condition were completed so unusual traffic conditions would have less of an impact on the final results. The trials included both peak and off-peak traffic on the city and highway routes. The effect of accessories on power consumption was also measured on the city route at off-peak times. The influences of air conditioning, heating, passenger load, lights and the radio were measured. Amp hour recordings were made using the TBS battery monitor. Position and speed were also logged using a USB GPS mouse (Qstarz 2013) connected to a laptop, as well as our built-in vehicle information system EyeBot (Bräunl 2008) recording at 10Hz sampling frequency.

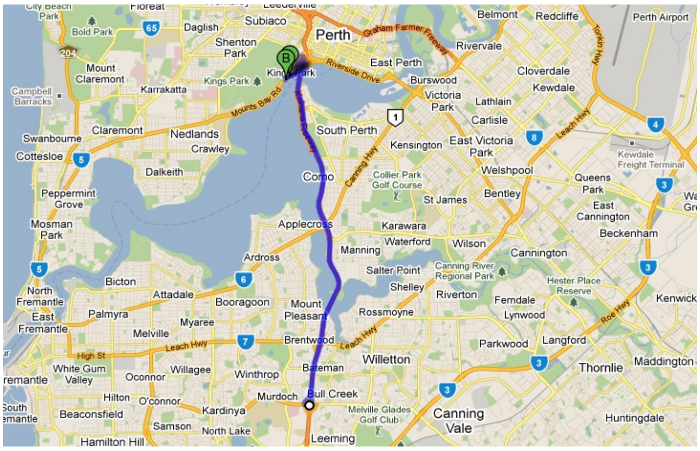
The city route shown in Figure 3 was selected to represent city driving. It includes a loop around the UWA campus then travels down to North Fremantle before returning to the start position. The circuit features different speeds, traffic lights, hills and traffic levels. The route was selected to represent a typical commute of leaving a suburb before entering a more arterial road. GPS recordings were made for peak and off-peak conditions to verify they have a significant effect on the speeds and how the car was driven.

Figure 3 City Test Route 26.6km (using Google Maps)



The highway route shown in Figure 4 was chosen to represent typical driving on high-speed Australian roads. The route runs from near the Perth CBD south bound on the Kwinana Freeway before turning around at the South Street exit and returning to the starting position. The circuit was chosen to have a similar distance to the city route. The average speed during off-peak times is high and it features extended periods at a high constant speed. Again, GPS recordings were taken for the peak and off-peak periods.

Figure 4 Highway Test Route 27.7km (using Google Maps)



Peak period traffic results in higher fuel consumption in ICE vehicles and it has been shown that their fuel consumption is highest when traffic is transitioning between free-flowing and congested (Zhang, Batterman, Dion 2011). Trials were therefore completed to see how traffic impacts the power consumption of the REV Eco. All of the trials were completed on non-holiday weekdays during school periods. Each weekday was divided into three time periods. The first was the morning peak period from 7am to 10am. This was followed by the off-peak period from 10am to 3pm. Finally there was the afternoon peak period from 3pm to 6pm. Starting the afternoon peak period at 3pm was chosen to lessen the impact of school-related traffic. Each test drive had to be conducted within the necessary period, either peak or off-peak.

The use of air conditioning has a significant effect on fuel economy in ICE vehicles (Kassakian et al. 1996). The American FTP-75 testing procedure has specific tests to determine how much this changes fuel consumption. This is something that is lacking in ADR 81/02 and the NEDC testing schemes. In conventional cars the air conditioning compressor is powered from the engine. A clutch mechanism engages the compressor when necessary. This is not the case in the REV Eco. Since the drive motor in the REV Eco does not move when the car is stationary, a separate electric motor has been installed to drive the compressor. A contactor is used to switch the air conditioning motor on.

The heating system in conventional cars does not have much of an effect on the fuel consumption levels. Internal combustion engines produce large quantities of heat and must be cooled using water and radiator systems. This cooling fluid is directed to a heater core through which air is passed to heat the car cabin. The only additional load comes from the electric fan used to generate the airflow. In the electric REV Eco the heat must be produced using an electric PTC heater element (positive temperature coefficient element). This represents a substantial load, which in colder climates could significantly impact power consumption and range.

Headlights and other electrical accessories will also influence the power consumption (Kassakian et al. 1996), although these loads are relatively small. To overcome this, multiple devices were used during a test scenario. The headlights, windscreen wipers, car stereo and EyeBot controller were all expected to influence the consumption. In particular the impact of using the headlights and radio was measured. For every test scenario the EyeBot on-board-controller remained on for the duration of each trial.

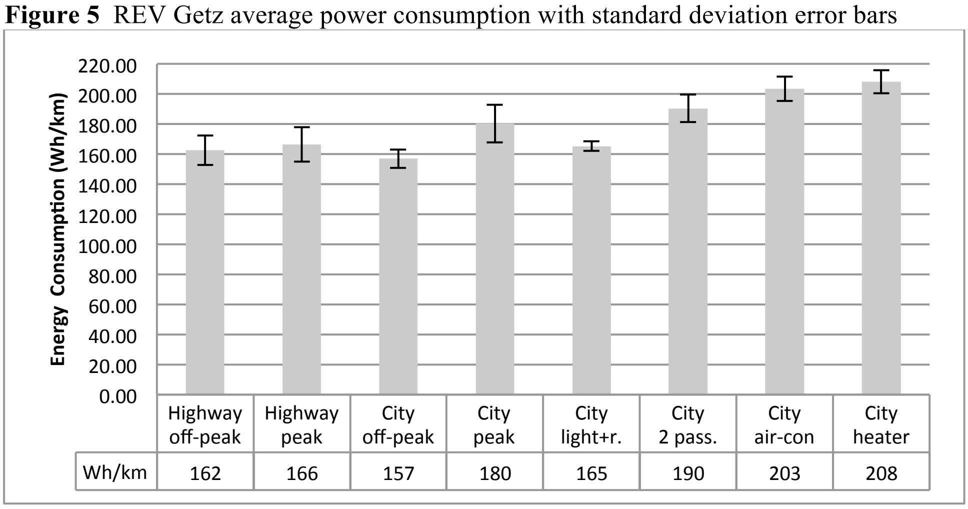
For the other testing conditions only the driver has been present in the vehicle. As the laden vehicle weight obviously affects the power consumption, trials were completed with two additional passengers to gauge the change caused by additional load.

Finally, the charging efficiency of the REV Eco was measured. A power measurement was taken between the mains general power outlet (GPO) and the on-board battery charger. This was achieved using a residential power meter to give energy readings in kWh. The battery was charged over several hours with voltage and current values recorded every five minutes and the instantaneous power was calculated. The ratio between this value and the reading from the power meter gives the efficiency value.

4 Measurements

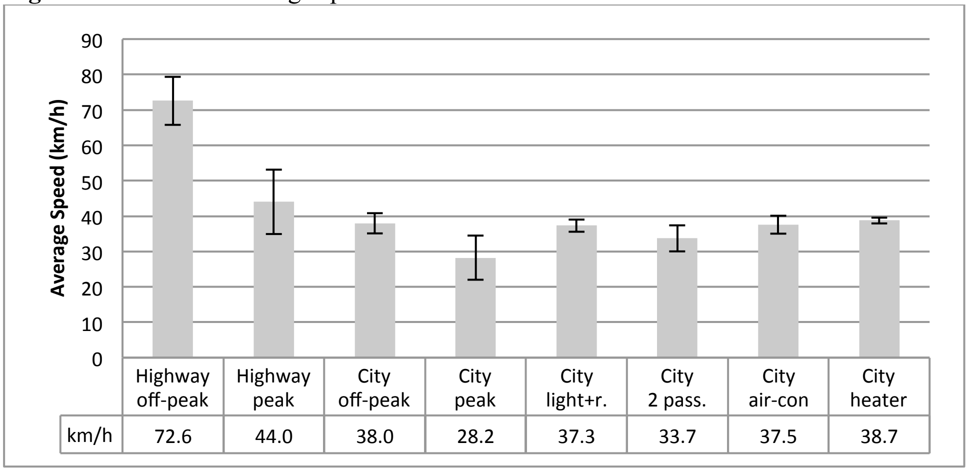
Five trials were completed for each of the eight driving conditions in the real-world testing. GPS data was also recorded for particular trials to demonstrate how traffic conditions change the speed profile of the vehicle being driven. Figure 5 shows the average power consumption recorded for each test condition over five trials. Figure 6 shows the average speed for the five trials for each test condition. The trials for accessory usage were completed on the city route during off-peak times; consequently the average speed values are similar for those conditions.

Figure 5 REV Getz average power consumption with standard deviation error bars



Note that the effects of both air conditioning and heater can be significantly higher in very hot or very cold conditions than shown here in Figures 5 and 6, which had been conducted at an average temperature of 20 degrees Celsius.

Figure 6 REV Getz average speed with standard deviation error bars



Energy consumption tests have been conducted to find the difference between peak and off-peak traffic on the city route as well as on the highway route. In city traffic, the energy consumption increased by 14.8% during peak traffic, while the average speed was reduced by 25.5%. This indicates that acceleration events have a large impact on energy consumption. However, for the highway route the average energy consumption only increased by 1.0% with a 39.3% reduction in average speed. Note that this EV was not equipped with a regenerative braking system.

The use of accessories had a large impact on power consumption. The air conditioning and heating used a surprising amount of energy, with increases over the baseline of 29.6% and 32.6% respectively. Two additional passengers increased power consumption by 21.3%. Combined driving lights and radio usage caused a 5.2% increase.

4.2 Charging

Charging efficiency tests were completed to show the losses in the charging system. The REV Eco was driven until the TBS battery monitor gave a charge percentage reading of 30.0%. It was then charged to 99.1% over five hours. Readings of the current and voltage of the battery as well as the energy supplied to the charging system were taken every five minutes. Figure 7 is a graph of the power charging the battery versus time, power being the product of the voltage and current readings as per Equation 1. Figure 8 shows the cumulative energy supplied to the charging system over time. To calculate the efficiency a reading of the energy supplied to the battery is needed. This is achieved by integrating numerically over time, the values in Figure 7. The trapezoidal rule described in Equation 2 was used for this numerical integration. Finally, the efficiency was calculated in Equation 3 from the energy readings.

Figure 7 REV Getz Power Supplied to the Battery versus Time

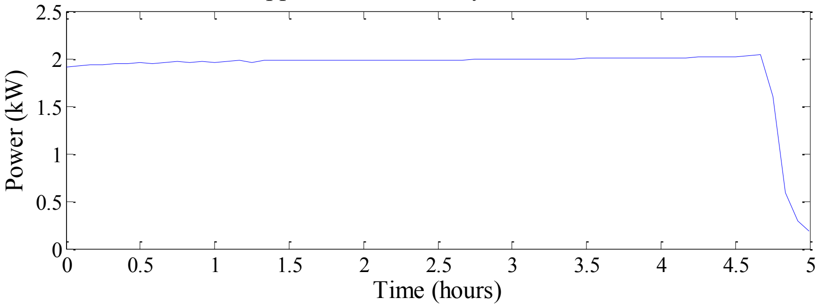
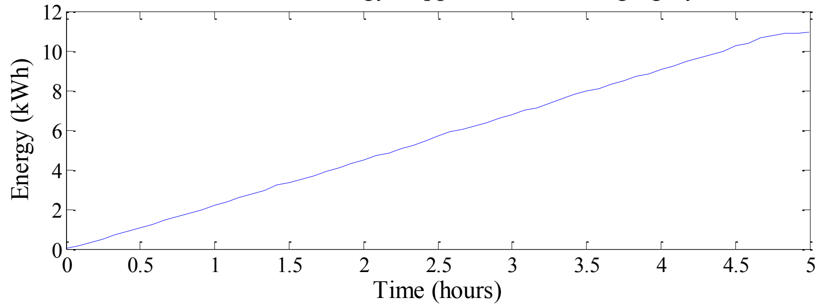


Figure 8 REV Getz Accumulated Energy Supplied to the Charging System



Equation 1 Power Equation

$$P = I \times V$$

Equation 2 Trapezoidal Rule

$$\int_{i}^{i+1} f(t)dt \approx \big((i+1) - i\big)\frac{f(i) + f(i+1)}{2}$$

Equation 3REV Getz Charging Efficiency Calculation

$$\text{Efficiency} = \frac{\text{Useful power ouput}}{\text{Total power input}} = \frac{9.55\ \text{kWh}}{10.95\ \text{kWh}} = \eta \approx 0.87$$

The petrol Getz test was completed in order to gauge the fuel consumption on the city test route. This was done so it could be compared to the figures released by the manufacturers using the ADR 81/02 testing format. During an off-peak period the petrol Getz was driven around the city route three times for a total distance of 79.1km. During this the vehicle used 5.37 litres of fuel. This resulted in the fuel consumption figure calculated in Equation 4. Table 1 shows the fuel consumption values from standard testing.

Equation 4 Petrol Getz City Route Off -peak Fuel Efficiency

$$\text{Fuel Consumption} = \frac{\text{Fuel Used}}{\text{Distance Traveled}} \times 100 = \frac{5.37\text{l}}{79.1\text{km}} \times 100 \approx 6.79\ \text{l/100km}$$

Table 1 Automatic Getz ADR 81/02 Fuel Consumption

Vehicle\Test Cycle	Urban	Extra Urban	Combined
Hyundai Getz	9.5 l/100km	5.4 l/100km	6.9 l/100km

5 Analysis and Discussion

Our testing indicated that accessory usage has a significant impact on power consumption, which is particularly evident with climate control. The charging efficiency testing for the REV Getz has verified the ratings released by the manufacture of greater than 85% (Zivan 2003). Finally, the test completed with the petrol Getz recorded a fuel consumption in line with the ADR 81/02-rated figures for the chosen test route.

Our results suggest that speed profile tests for electric vehicles can overestimate energy consumption compared to real-world driving situations. This is in contrast to Debal and Pelkmans (2006), who found that the NEDC cycle underestimated fuel consumption and emissions by 5–10% compared to real-world testing for ICE cars. It is not clear if the ADR urban test profile typifies urban Australian driving. There are indications that regional traffic is very different and not adequately described by NEDC testing (Alessandrini, Orecchini 2003), (Kamble, Mathew, Sharma 2009). The results are inconclusive; if our real-world city test does accurately describe city driving in Perth as we believe, then the ADR test procedure does not accurately describe energy consumption. The real-world city test route had fewer periods of acceleration, higher levels of acceleration, longer periods of constant speed and a higher average speed than the ADR profile.

The results also highlighted the difficulty in generating test schemes. The test profiles are generated using local road usage data (Lyons et al. 1986). Different locations have very different traffic conditions, which change the typical manner in which vehicles are driven. Determining typical traffic conditions in Perth would require extensive road usage data. While standard test procedures allow for repeatable and comparable testing, these results fail to describe real-world driving adequately. Our real-world testing has demonstrated the drastic differences in energy consumption from different operational conditions.

The lowest energy usage was recorded on the city route during off-peak times, which was used as the baseline to which other test cases were compared. Figure 9 shows the increases in energy consumption for the different scenarios.

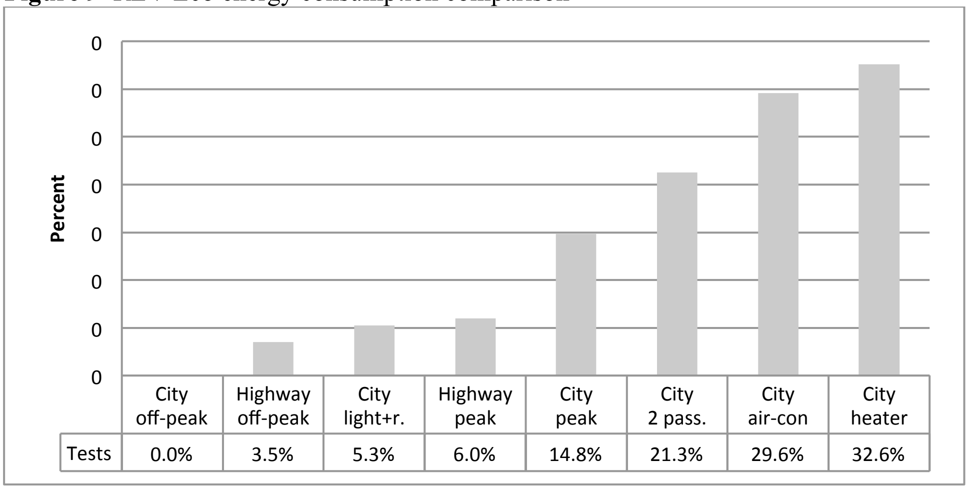
Test drives were completed in two different traffic conditions defined as peak and off-peak traffic. The results have demonstrated that more energy is used in the peak traffic conditions. The way in which increased traffic affects power consumption is complex. Zhang, Batterman and Dion (2011) demonstrated that for conventional cars the largest fuel consumption and emission were recorded during transitional stages, where traffic is changing between free flowing and congested and drivers must accelerate and decelerate frequently. Like internal combustion engines (ICE), electric motors are most inefficient when starting or accelerating and parallel results could be expected for electric vehicles. The speed profiles show more acceleration events and a lower average speed for peak conditions than off-peak conditions, resulting in higher energy consumption.

The majority of the standard testing procedures do not take into account accessory usage. Modern cars include increasing amounts of electrical equipment. In a conventional car these electrical loads lead to increased fuel consumption. Kassakian et al. (1996) have calculated that a 200W electrical load can lead to a 0.4l/100km increase in fuel consumption. The real-world testing has demonstrated that accessory usage causes significant loads. An example is the Mitsubishi i-MiEV which has a range of 160km according to the Japan 10–15 mode test cycle (Mitsubishi 2013). Consumers are finding it difficult to reach the 100km range while using air conditioning and travelling at faster speeds than in the test profile, while our own on-road tests with a two-thirds urban and one-third highway mix have resulted in a range of 112km for the i-MiEV. The current results indicate that air conditioning uses a large amount of power, with about a 30% increase in energy consumption for the cooling system in the REV Eco and even more for a desired more powerful air-conditioning system, as mentioned before.

Heating systems represent a significant power draw in electric vehicles. In conventional cars heat does not need to be generated; waste heat from combustion is used to warm the cabin. The heating system in the REV Getz increased energy consumption by 33% which would be higher in countries with a colder climate than Australia. No standard test procedures consider the impact from heating systems. In colder climates this could lead to a greatly overstated range. Higher temperatures increase the rate of capacity loss over time, but lower temperatures reduce the effective capacity of lithium-ion batteries. The effective capacity is also reduced by higher current draws. The effects of cooler outside temperatures and higher current draws from using heating systems compound to reduce range.

The combined load from the driving lights and radio was about 200W, resulting in a 5% increase in power usage. Designers need to be vigilant of the significant impact that all electrical loads have on range. Finally, loading the vehicle with two additional passengers increased the power consumption by 21%. Although this is a large increase in energy consumption, it still demonstrates the energy savings that can be achieved by reducing single-occupancy traffic.

Figure 9 REV Eco energy consumption comparison



Testing the charging efficiency for electric vehicles is important. It is just one element in assessing their environmental impact. Currently, fossil fuels generate the majority of the world's electricity (Malla 2009). If the energy is generated using fossil fuel sources and the charging and transmission losses are known it is possible to compare the emission of electric vehicles to those of conventional cars.

Comparing tailpipe emissions between conventional cars and electric vehicles is irrelevant. When comparing the emissions from each type of vehicle the whole life cycle needs to be examined. Ideally, emissions necessary for their creation, operation and disposal should also be examined. Emissions are also generated during the gathering and processing of fuel, and in transporting it to fuel distributors and petrol stations. Equally, for electric vehicles emissions come from the generation of electricity and losses incurred from the transmission of this energy. Van Vliet et al. (2011) estimate that electric vehicles emit 155g/km of carbon dioxide when they are powered using electricity generated from older-generation coal power stations. The official figure released for the petrol-powered Getz is 165g/km. This figure is only the tailpipe emissions measured using the ADR testing procedure, so the true on-road emissions from the petrol car would be higher, not even considering the well-to-tank emissions of gathering, processing and transporting hydrocarbon fuels.

6 Conclusions

The results of this study suggest that standard speed profile testing for electric vehicles overestimates energy consumption. This is contrary to research that shows fuel consumption and emissions are underestimated in vehicles powered by internal combustion engines. Validating speed profile testing is difficult; it is not clear if the real-world test cases typify driving conditions in a given city. The testing has shown that acceleration duration, magnitude and frequency have large impacts on energy consumption. Specifically, there are less acceleration events and longer periods of constant speed in real-world testing compared to some speed profiles. This resulted in lower energy consumption and higher average speeds than standard profile tests. The origin of the data used to construct the speed profiles is important, as different driving conditions are experienced in different regions. The real-world tests have shown that accessory usage and passenger loading have significant effects on energy consumption. This is neglected by the standard profile tests, which result in overstated range values when systems such as air conditioning or heating are used. The product life cycle when comparing electric vehicles to conventional cars has been examined. Electric vehicles do not have operational emissions; however construction, electricity generation and transmission can contribute to emissions and must be considered.

Future directions for research could include testing the effects of colder climates on energy consumption. Heating and air conditioning represent large loads that are not considered by any of the standard testing procedures. This, combined with the reduction of lithium-ion battery capacity at lower temperatures, compounds a significant reduction in achievable range.

Acknowledgements

The authors would like to thank all members of the UWA REV team, including all current and former team members, workshop staff, especially Ivan Neubronner and Ken Fogden, as well as our sponsors and research partners Western Australian Department of Transport, Galaxy Resources, CREST, Swan Energy, Huber+Suhner, Altronics, EV Works, Telstra, AEVA, and CO2Smart.

References

Alessandrini, A., Orecchini, F. (2003) *A driving cycle for electrically driven vehicles in Rome*, Proceeding of the Institution of Mechanical Engineers, vol. 217, no. 9, pp. 781-790

Australian Bureau of Statistics (2011) *Survey of Motor Vehicle Use: Data Cubes, Australia, 12 months ended 31 October 2010*, report no. 9210.0.55.001

Bräunl, Thomas (2008) *Embedded Robotics – Mobile Robot Design and Applications with Embedded Systems*, 3rd Ed., Springer-Verlag, Berlin Heidelberg.

Bräunl, T. (2012) *Synthetic engine noise generation for improving electric vehicle safety*, International Journal of Vehicle Safety, vol. 6, no. 1, pp. 1-8

Debal, P., Pelkmans, L. (2006) *Comparison of on-road emissions with emissions measured on chassis dynamometer test cycles,* Transportation Research Part D: Transport and Environment, July 2006

Edsall, Larry, and Lutz, Bob (2010) *Chevrolet Volt: Charging into the Future*, Motorbooks, Minneapolis MN

European Union (1998)*, Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC*, European Parliament and Council of the European Union, Journal of the European Communities, 28.12.98, no. L 350/, pp. 1-56

Federal Register of Legislative Instruments (2008) *Vehicle Standard (Australian Design Rule 81/02—Fuel Consumption Labelling for Light Vehicles) 2008*, Appendix B, United Nations – Economic Commission for Europe, Regulation No. 101, Rev. 2, Amd. 1

Kamble, S., Mathew. T., Sharma, G. (2009) *Development of real-world driving cycle: Case study of Pune, India*, Transportation Research Part D: Transport and Environment, vol. 14, no. 2, pp. 132-140

Hidrue, Michael, Parsons, George, Kempton, Willett, Gardner, Meryl (2011) *Willingness to pay for electric vehicles and their attributes,* Journal on Resource and Energy Economics, no. 33, Feb. 2011, pp. 686-705

Honda (2013) Honda Insight – A very surprising hybrid, online at: https://insight.honda.com.au/ (accessed March 2013)

Iliaifar, Amir (2012) Toyota Prius Plug-in Review, 6 Sep. 2012, online at: http://www.digitaltrends.com/cars/2012-toyota-prius-plug-in-review/ (accessed March 2013)

Kassakian, J., Wolf, H., Miller, J., Hurton, C. (1996) *Automotive Electrical Systems Circa 2005 – Demands for Better Fuel Economy and more Electric Power are Driving Cars to Multiple Higher Voltages*, IEEE Spectrum, Aug. 1996

Lim, C., Mamat, R., Bräunl, T. (2011) *Impact of ambulance dispatch policies on performance of emergency medical services*, IEEE Transactions on Intelligent Transportation Systems vol. 12, no. 2, pp. 624-632.

Liu, Zhihua, Ge, Yunshan, Johnson, Kent, Shah, Asad, Tan, Jianwei, Wang, Chu, Yu, Limxiao (2011) *Real-world operation conditions and on-road emissions of Beijing diesel buses measured by using portable emission measurement system and electric low-pressure impactor,* Journal of the Science of the total environment, March 2011

Lyons, T., Kenworthy, J., Austin, P., Newman, P. (1986) *The development of a driving cycle for fuel consumption and emissions evaluation*, Transportation Research Part A: General. vol. 20, no. 6, pp. 447-462.

Malla, S. (2009) *CO2 emissions from electricity generation in seven Asia-Pacific and North American countries: A decomposition analysis*, Energy Policy, vol. 37, no. 1, pp. 1-9

Mock, Peter, German, John, Bandivadekar, Anup Riemersma, Iddo (2012) *Discrepancies between type approval and "real-world" fuel consumption and CO2 values*, International Council on Clean Transportation, April 2012

Mullan, J., Harries, D., Bräunl, T., Whitely, S. (2011) *Modelling the impacts of electric vehicle recharging on the Western Australian electricity supply system*. Energy Policy vol. 39, no. 7, pp. 4349-4359.

Mullan, J., Harries, D., Bräunl, T., Whitely, S. (2012) *The technical, economic and commercial viability of the vehicle-to-grid concept*, Energy Policy, vol. 48, pp. 394-406.

Mitsubishi (2013) *i-MiEV. Plug into the future,* http://www.mitsubishi-motors.com.au/vehicles/i-miev (accessed March 2013)

TBS Electronics (2013), *High-Precision Battery Monitor e-xpert pro, Owner's Manual*, TBS Electronics BV, Zwaag, The Netherlands

Toyota (2013) *Toyota Prius c*, online at: http://www.toyota.com.au/prius-c (accessed March 2013)

Tzirakis, K., Pitsas, K., Zannikos, F., Stournas, S. (2006), *Vehicle emissions and driving cycles: comparison of the Athens driving cycle (ADC= with ECE-1t and European Driving Cycle (EDC)*, Global NEST Journal, vol. 8, no. 3, pp. 282-290

Qstarz (2013) *GPS Bluetooth Receiver*, online at: http://www.qstarz.com/GPS_products.html (accessed March 2013)

Renewable Energy Vehicle Project (2008) *The REV Project - Economy*, The University of Western Australia, Perth, online at: http://therevproject.com/vehicles/economy.php (accessed March 2013).

UNECE (2013) *The World Forum for Harmonization of Vehicle Regulations*, working party WP.29, Inland Transport Division of the United Nations Economic Commission for Europe

United Nations (2005), *Uniform provisions concerning the approval of passenger cars powered by an internal combustion engine only, or powered by a hybrid electric power train with regard to the measurement of the emission of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range, and of categories M1 and N1 vehicles powered by an electric power train only with regard to the measurement of electric energy consumption and electric range*, addendum 100, regulation no. 101, revision 2

USEPA (2010), *Testing and Measuring Emissions Dynamometer Driver's Aid*, United States Environmental Protection Agency, online at: http://www.epa.gov/nvfel/testing/dynamometer.htm (accessed March 2013)

Vliet, O. van, Brouwer, A., Kuramochi, T., Broek, M. van den, Faaij, A. (2011). *Energy use, cost and CO2 emissions of electric cars*. Journal of Power Sources, vol. 196, no. 4, pp. 2298-2310

Wikipedia (2013) *New European Drive Cycle*, online at: http://en.wikipedia.org/wiki/New_European_Driving_Cycle, (accessed March 2013)

Zhang, K., Batterman, S., Dion, F. (2011) *Vehicle emissions in congestion: Comparison of work zone, rush hour and free-flow conditions*, Atmospheric Environment, vol. 45, no. 11, pp. 1929-1939

Zivan (2003) *Battery Charger NG3 Installation and User Manual*, 2nd Ed., Zivan S.r.l., Sacramento CA, online at: http://www.zivanusa. com/pdf/NG3.pdf (accessed March 2013)