# MAC test results with Korean vehicles based on draft procedure of GRPE-61-21(2011)

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MINISTRY OF ENVIRONMENT

Transportation Pollution Research Center

National Institute of Environmental Research

# Background

- MAC TP in GRPE(Jan. 2011) proposed test procedure for MAC and asked non-EU countries'participation in the pilot test program (Under 1958 Agreement)
  - 'MAC test procedure to be used in a pilot phase (GRPE-61-21)'
  - Mainly estimating additional fuel consumption (or $CO_2$) by MAC operation
  - NIER in Korea tested 5 vehilces based on the draft procedure in Jan. 2011

# Korean Emission and GHG regulation

- Korea has introduced or referred to US and European regulations on vehicle emission
  - Gasoline and Gas LDV: Fleet Average System in CARB (FTP-75)
  - Diesel LDV: Euro-5(NEDC)
  - HDV: Euro-5(ESC, ETC)
- Korean GHG Emission Regulation start in 2012
  - $CO_2$ target is 140g/km in 2015 (combined FTP-75 & US highway)
  - Incentive for Eco-innovation technologies (including MAC)
  - Methods to estimate $CO_2$ reduction of the thechnologies are not determined (manufacturers may need to prove)

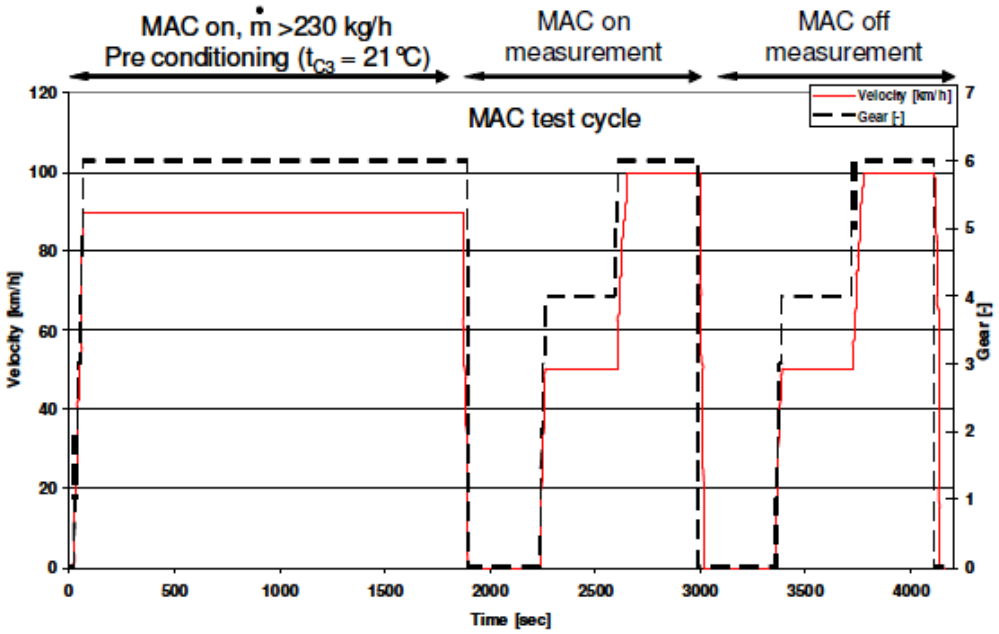
  ☞ Test procedrues established in WP29 could be good references

# Summay of test conditions

- Following up draft procedure GRPE-61-21, but
  - Not perfect test cell temp. and humidity control
  - Setting maximum cabin mass flows
  - No correction for glazing effect
- 5 vehicles tested
  - 3 gasoline(ULEV) and 2 diesel(1 EURO-4, 1 EURO-5)
  - Roughly, different categories in MAC grades
- Test results are presented based on open issues as follows
  - Outlet vent or cabin temperature as target
  - Pre-conditioning
  - Test tolerance
  - Performance for MAC ranking

# MAC test cycle

- Steady state test cycle in MAC on/off



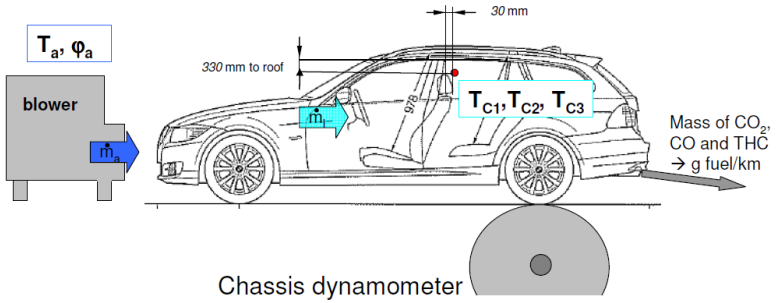

Evaluation periods suggested:

| | |
|---|---|
| 1960 - 2220 | MAC on |
| 2320 - 2580 | |
| 2710 - 2970 | |
| 3090 - 3350 | MAC off |
| 3450 - 3710 | |
| 3840 - 4100 | |

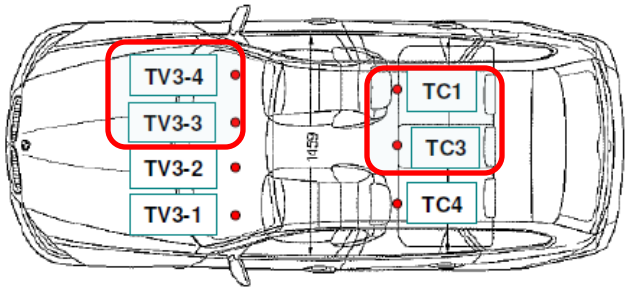
$$FC_{MAC_T} = 0.15 \times FC_{MAC_{idling}} + 0.65 \times FC_{MAC50km/h+} + 0.20 \times FC_{MAC_{100km/h}}$$

# MAC test setup

- Location of temp. and humidity sensors
  - Test cell: measured near blower (cooling fan)




  - Interior: measured TV3-3,4 for vent and TC1,3 for cabin



# MAC test setup

- Cabin Temperature Condition
  - Option 1 Cabin($TC_3$) below 23℃
  - Option 2 vent(TV) below 15℃
- Cabin mass flow
  - Over 230kg/h

  → Maxium setting (difficult to get exact setting data for proposed mass flow)
- Test cell temperature and humidity
  - Humidiy: 45±5% (or over 45%)
  - Temperature: 25±2℃ (or over 25℃)

  → Humidity control is quite challengeable

# MAC emission measurement

- Emission Measurement
  - Using instantaneous signal from CVS for emission
  - Using bag for dilution air: 1 bag for MAC on / 1 bag for MAC off step

- Tolerances for $CO_2$
  - Standard deviation / Average

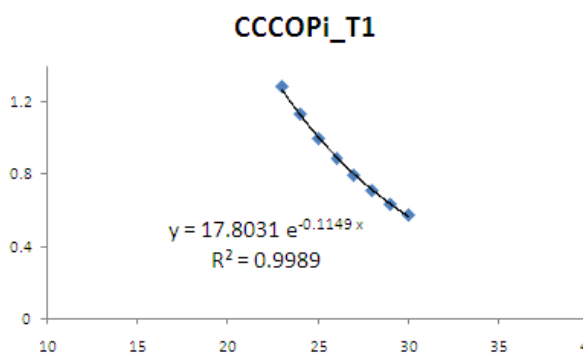
| Test part | MAC status | Start [s] | End [s] | Result [kg/h] | max. $CO_2$ standard deviation (1) |
|---|---|---|---|---|---|
| Precon | On, adjust TV3 | 90 | 1800 | - | Not relevant |
| Idling | On | 1960 | 2220 | FC i-MAC | 10% from average |
| 50 km/h | On | 2320 | 2580 | FC 50-MAC | 5% from average |
| 100 km/h | On | 2710 | 2970 | FC 100-MAC | 5% from average |
| Idling | Off | 3090 | 3350 | FC i | 10% from average |
| 50 km/h | Off | 3450 | 3710 | FC 50 | 5% from average |
| 100 km/h | Iff | 3840 | 4100 | FC 100 | 5% from average |

# MAC correction

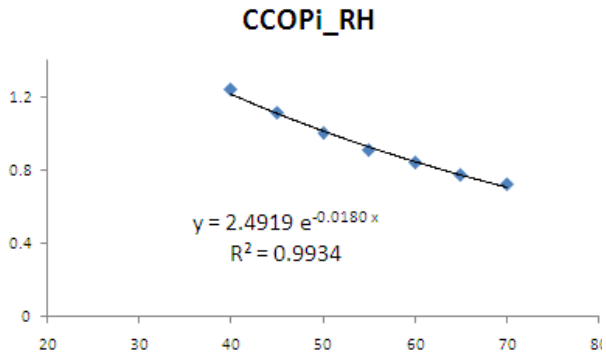
- Correction

$$FC_{MAC_i} = 3.6 \times C_{COP_i} \times (C_{Pe_i} \times FC_{i\,Measured-AC-on} - FC_{i\,Measured-AC-off})$$

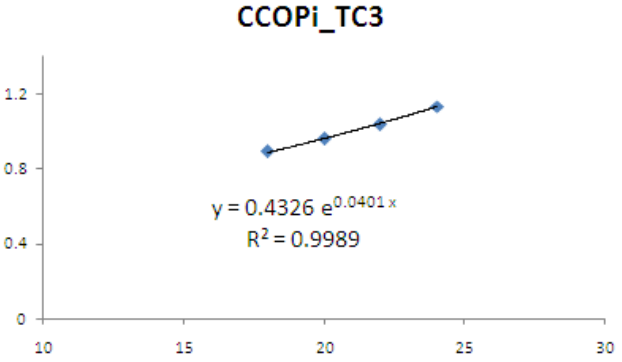
  - Dyno load correction($C_{pei}$): $C_{Pei} = \frac{P_{B_{AC-On\_Speed\_i}}}{P_{B_{AC-Off\_Speed\_i}}}$
  - $C_{copi}$: $C_{COPi} = C_{COPi-T1} \times C_{COPi-RH} \times C_{COPi-TC3}$




Test cell temp.




Test cell humidity




Cabin temp.

  - Glazing effect : N/A in this test (short of related data)

# Test Vehilces

- Test vehicle specification

| Vehicle | fuel | Displacement [L] | Emission level | Curb weight [kg] |
|---|---|---|---|---|
| Vehicle 1 | Diesel | 1.6 | EURO-4 | 1340 |
| Vehicle 2 | Gasoline | 1.6 | ULEV | 1305 |
| Vehicle 3 | Gasoline | 2.0 | ULEV | 1410 |
| Vehicle 4 | Diesel | 2.0 | EURO-5 | 1625 |
| Vehicle 5 | Gasoline | 2.4 | ULEV | 1525 |

# Test vehicles-MAC technologies

- Rough categorization based on TNO report

| techologies | Vehicle 1 | Vehicle 2 | Vehicle 3 | Vehicle 4 | Vehicle 5 |
|---|---|---|---|---|---|
| **Basic/ simple**<br>- VDC(or fixed) with internal control<br>- Orifice tube as expansion device<br>- Accumulator<br>- Manual control (fans, air flow, control flaps)<br>- Simple heat exchangers | | ● | | | |
| **In between/regular**<br>- VDC with internal control<br>- thermal expansion valve<br>- integrated or non-integrated receiver/dryer<br>- IHX/no-IHX<br>- simple control | ● | | | | |
| **Advanced**<br>- VDC with external control<br>- thermal expansion valve/ other type of controlled expansion device<br>- integrated receiver/dryer<br>- IHX, internal heat exchanger<br>- Automated control(PWM fans and blower, air flow control flaps)<br>- More efficient heat exchangers(micro channerl, others) | | | ● | ● | ● |

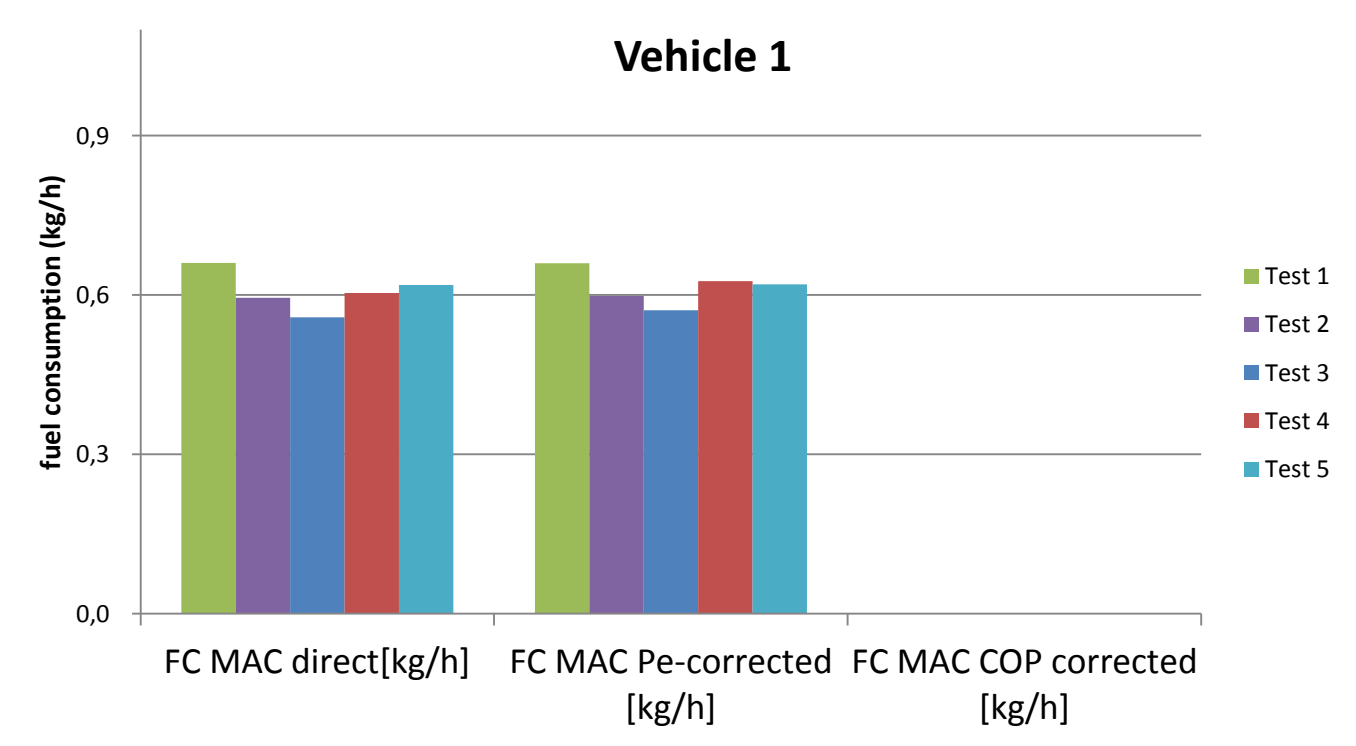
# Test Result Summary

- Additional fuel consumpton by MAC operation

| MAC fuel consumption | vehicle 1 | | vehicle 2 | | vehicle 3 | | vehicle 4 | | vehicle 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | measured | corrected | measured | corrected | measured | corrected | measured | corrected | measured | corrected |
| average [kg/h] | 0.607 | - | 0.829 | 0.559 | 0.594 | 0.270 | 0.467 | 0.270 | 0.554 | 0.220 |
| average [L/100km] | 1.390 | - | 2.128 | 1.434 | 1.524 | 0.694 | 1.069 | 0.610 | 1.421 | 0.564 |
| standard deviation [% from mean value] | 6.2% | - | 16.9% | 11.0% | 2.0% | 1.5% | 2.7% | 7.6% | 9.8% | 2.8% |
| Test numbers | 5 | | 5 | | 3 | | 3 | | 3 | |

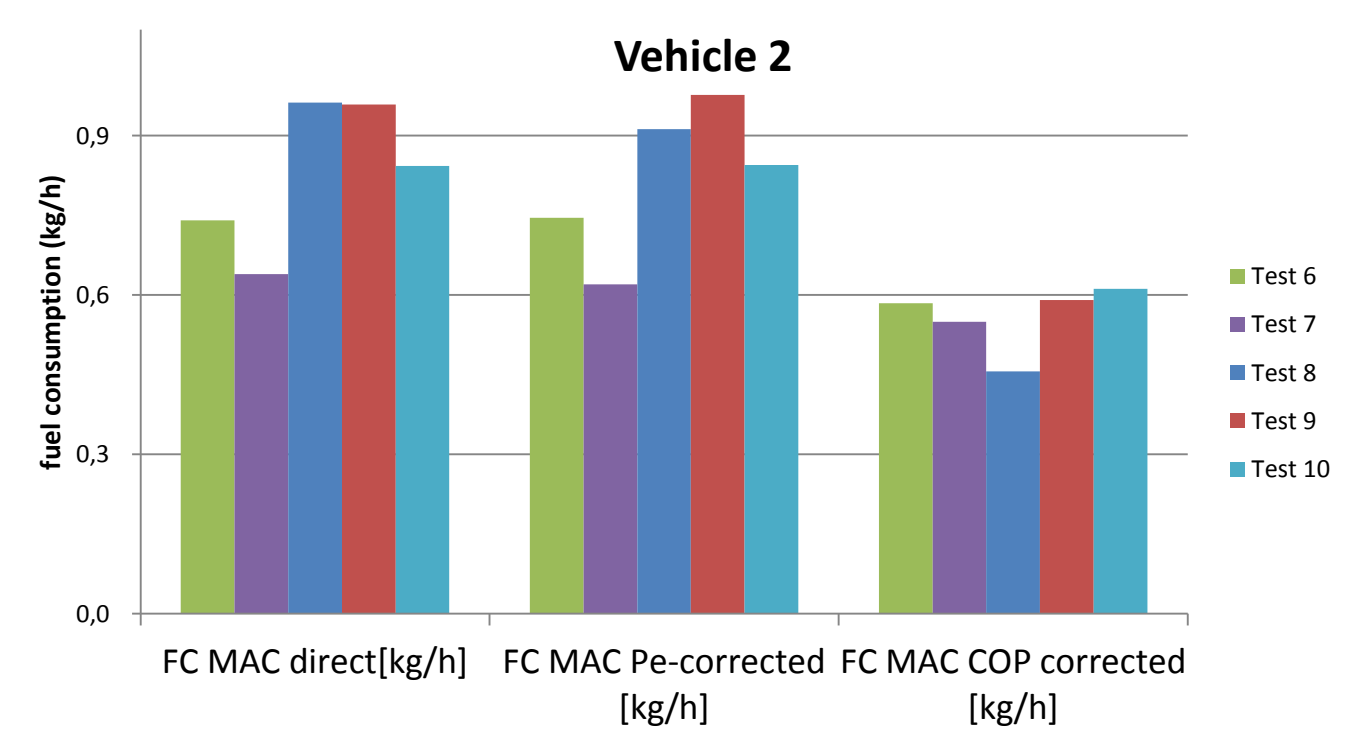
# Test Result

- Test vehicle 1 (diesel 1.6L, EURO-4)



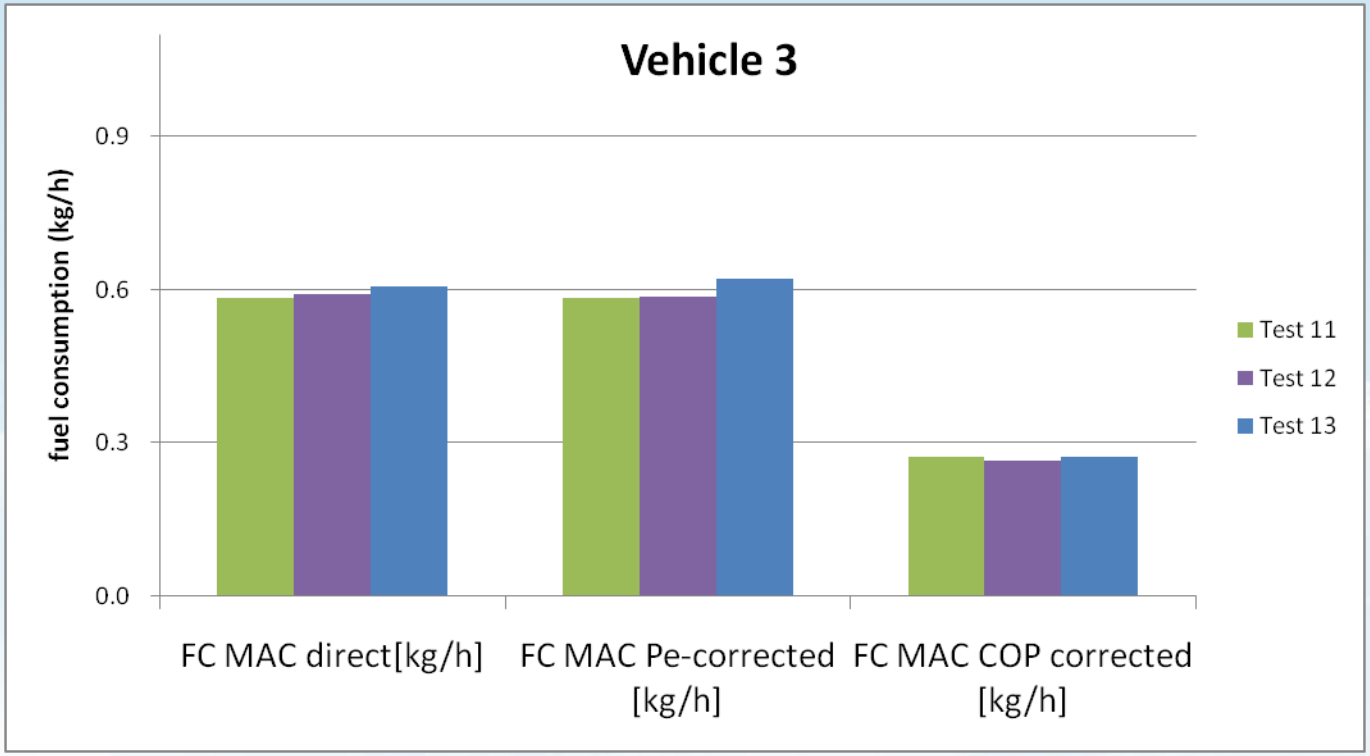
# Test Result

- Test Vehicle 2 (gasoline 1.6L, ULEV)



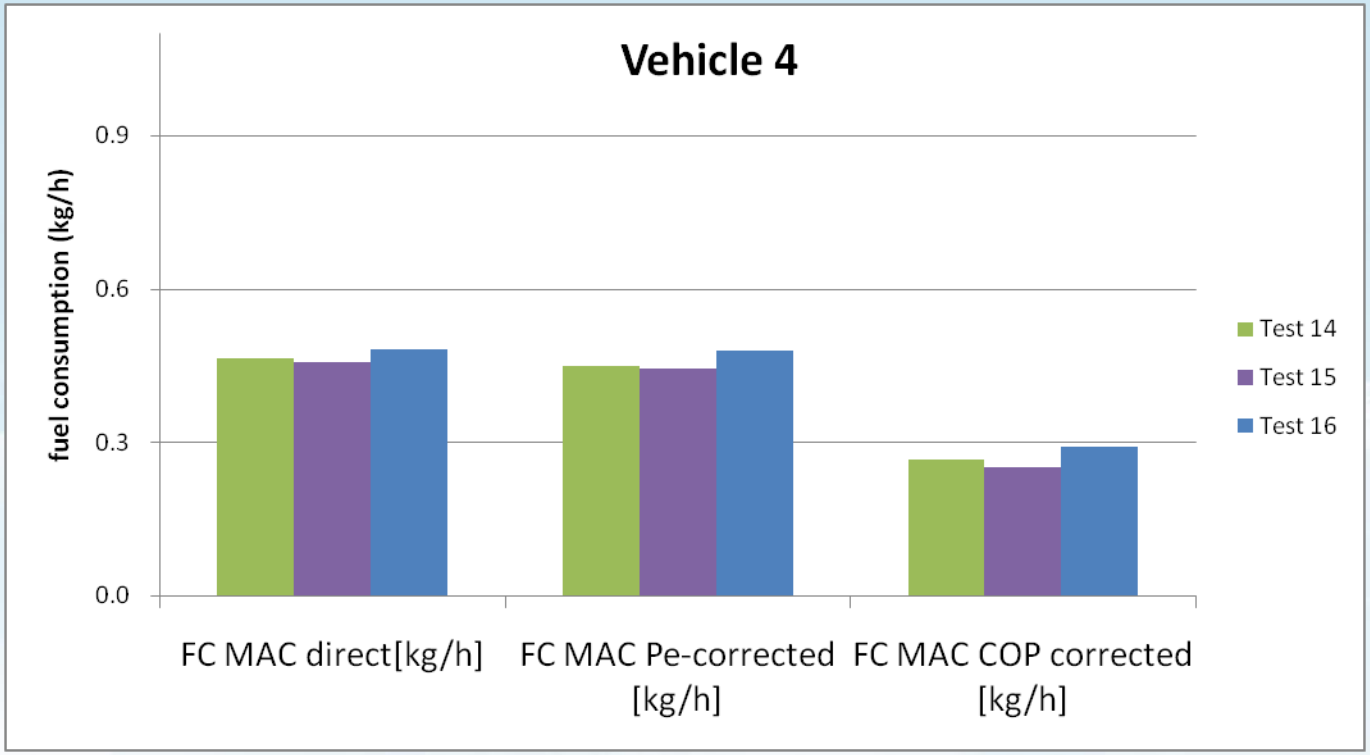
# Test Result

- Test Vehicle 3 (gasoline 2.0L, ULEV)



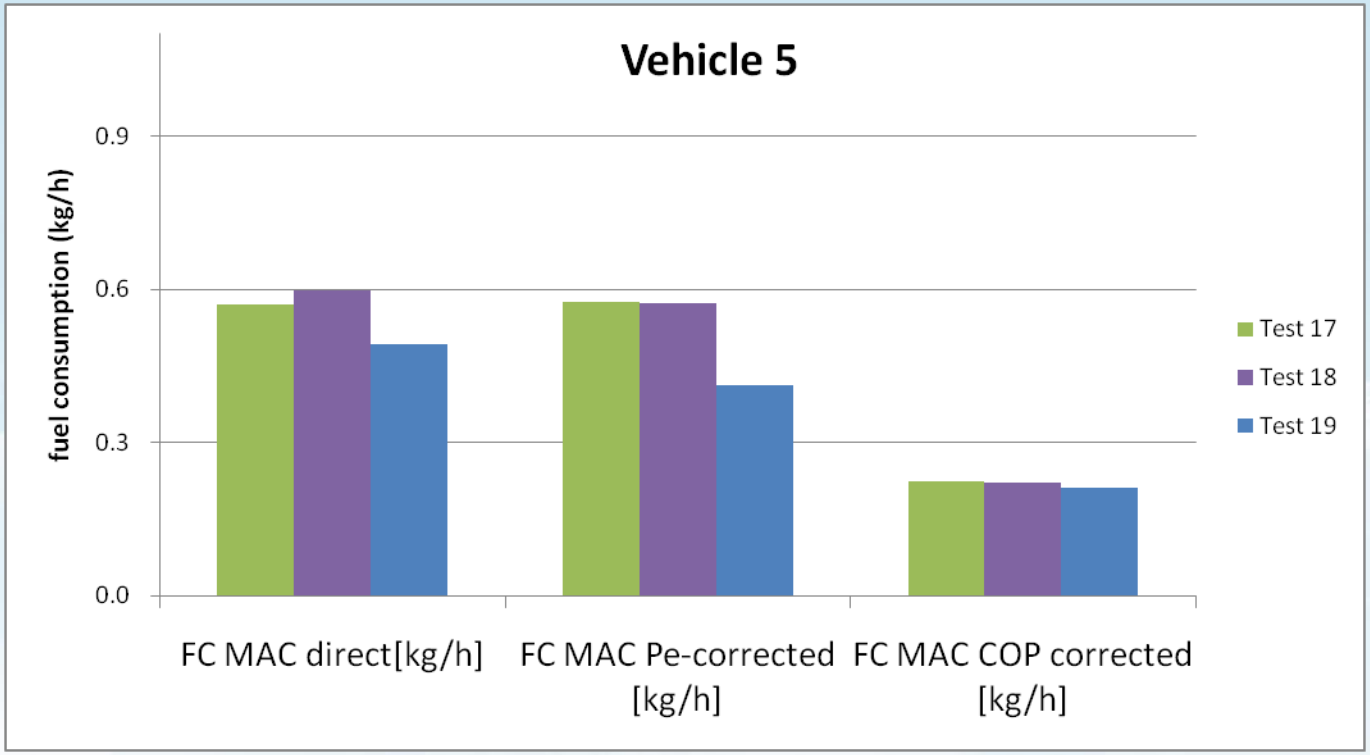
# Test Result

- Test Vehicle 4 (Diesel 2.0L, EURO-5)

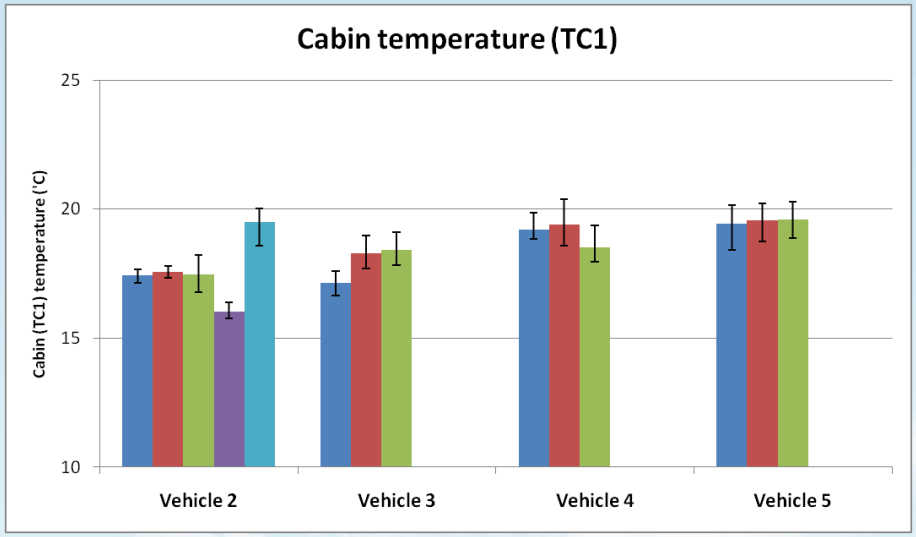


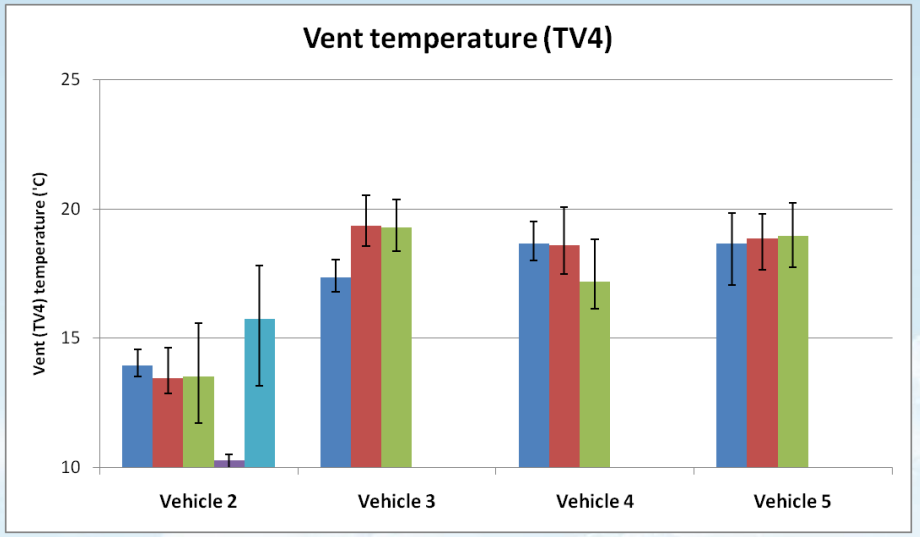
# Test Result

- Test Vehicle 5 (Gasoline 2.4L, ULEV)



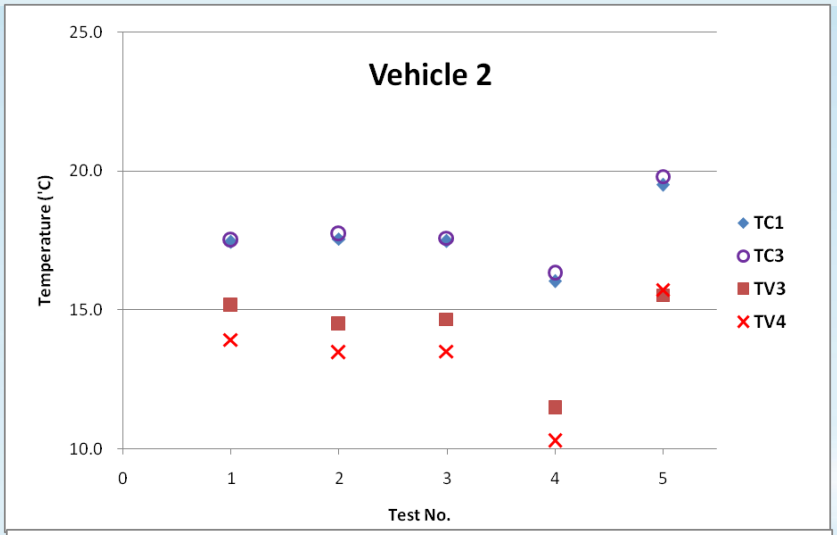
# Cabin & Vent temperature-deviation

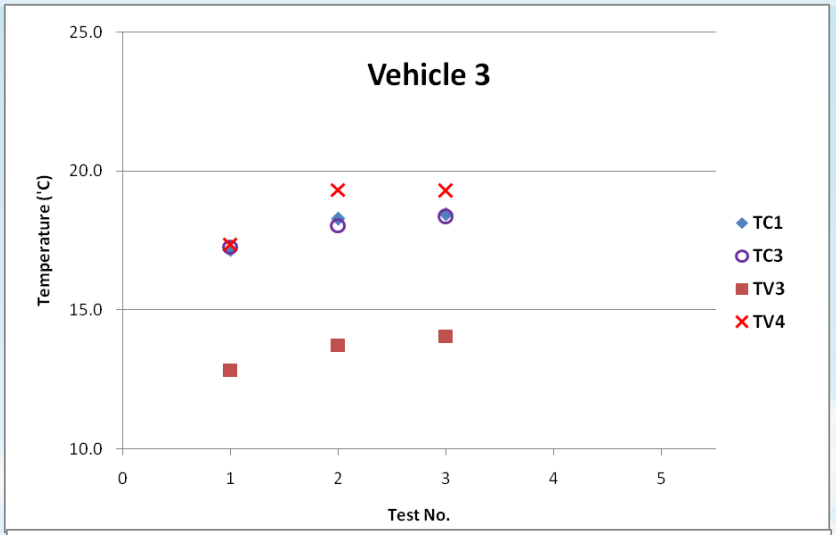


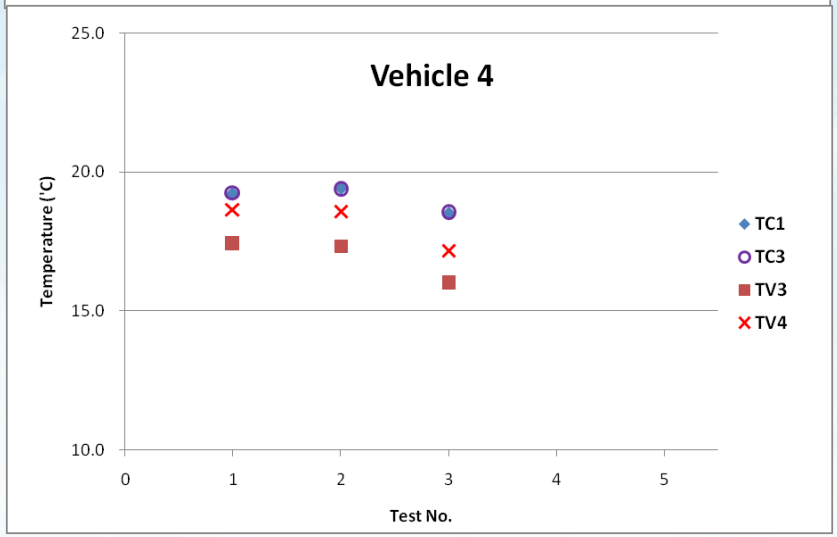



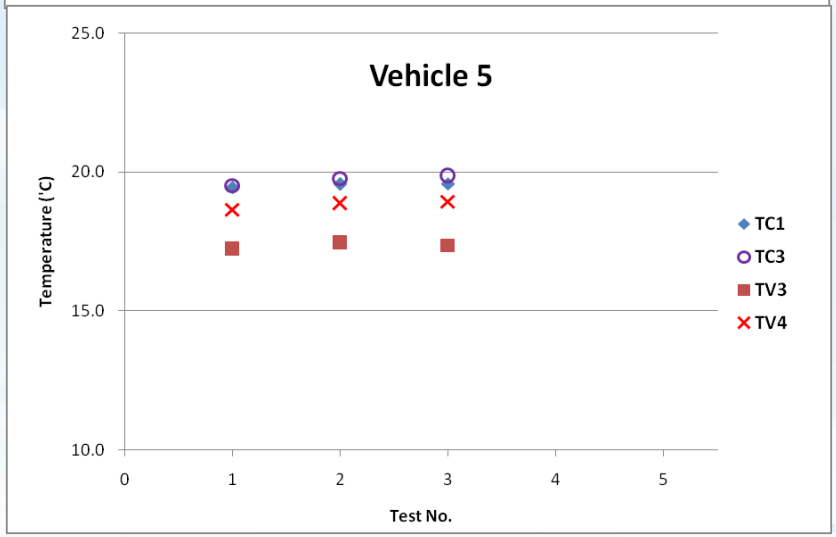

- Deviation of average cabin temperature in speed steps
  - Within +/- 1 ℃ in all tests
- Deviation of vent temperature in speed steps
  - Bigger than deviation of cabin temperature

# Cabin & Vent temp. difference as location



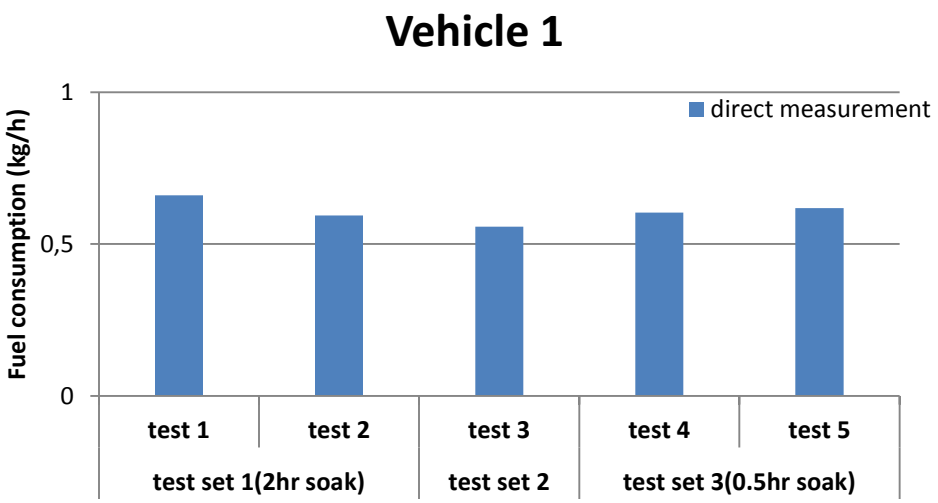



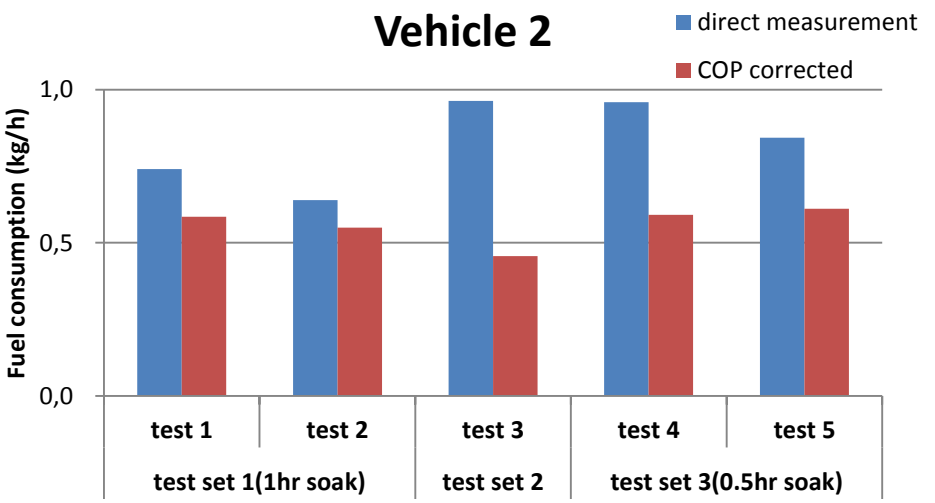



# Pre-conditioning

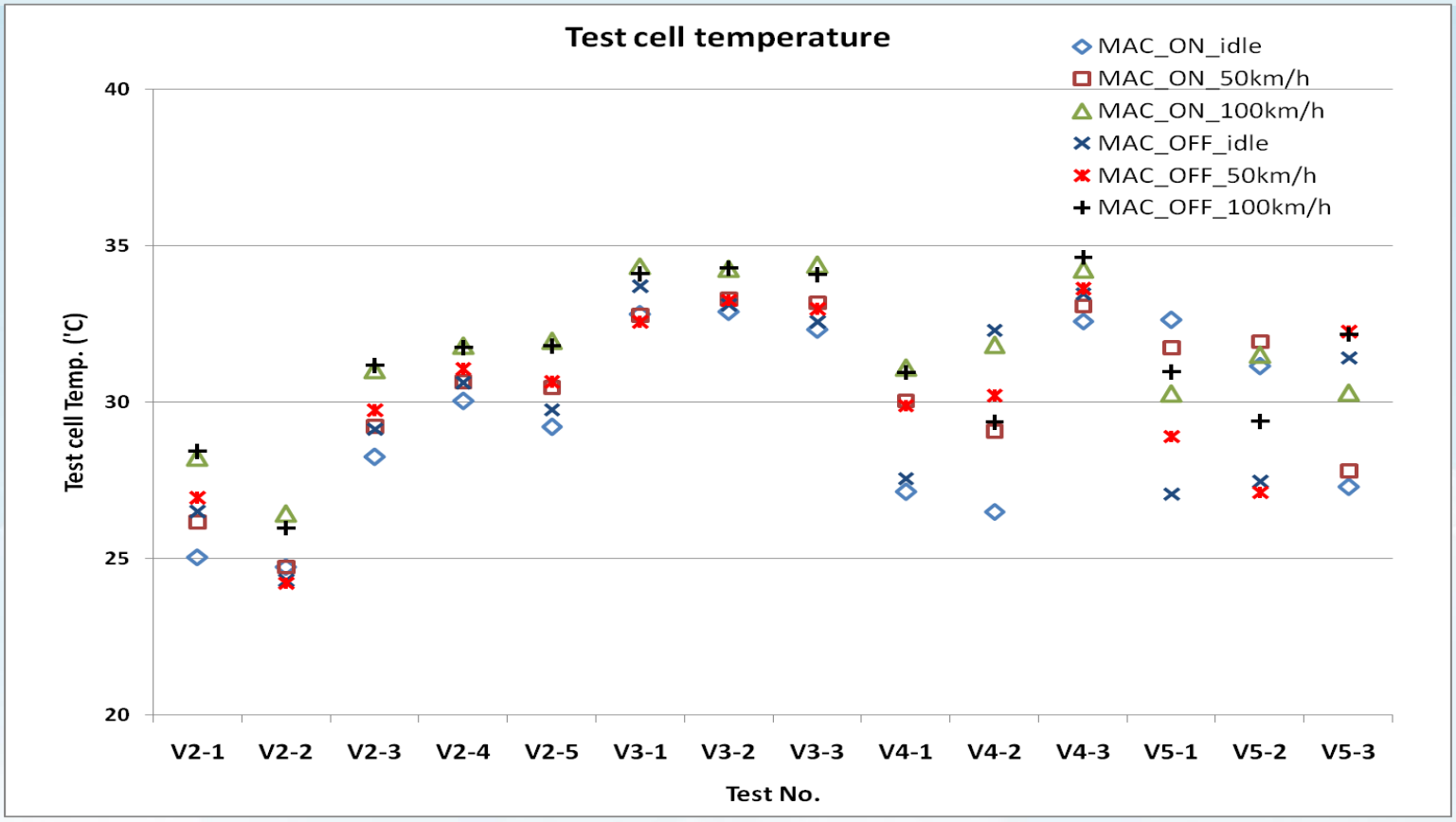
- Repeatability as soaking time between tests



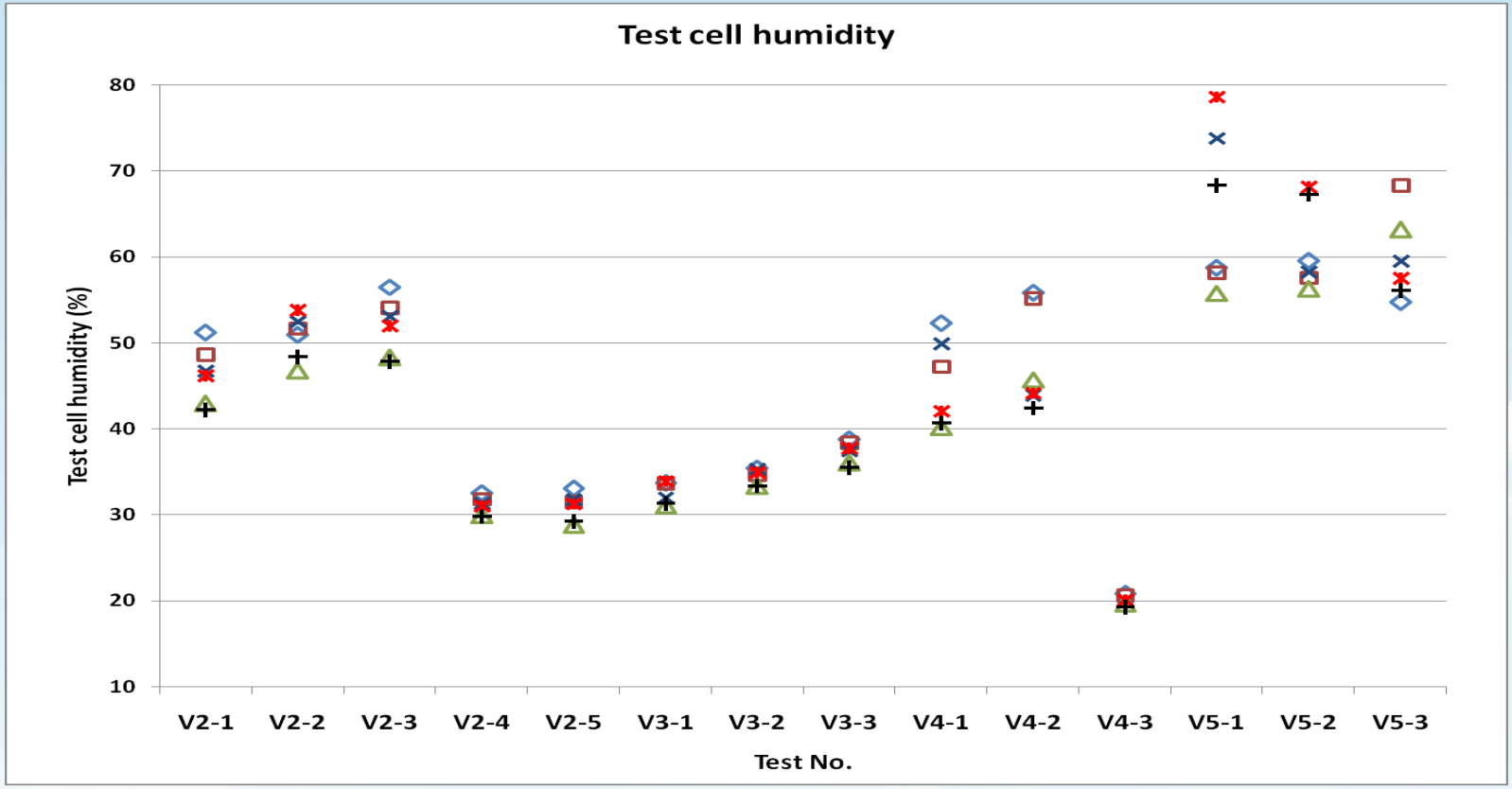

- Soaking time between tests does not big effect on test results
  - 90km/hr preconditiong for 30min. would make the test conditions stable enough
  - Over 30min. soaking is realistic considering time for bag analysis

# Test cell temperature tolerance



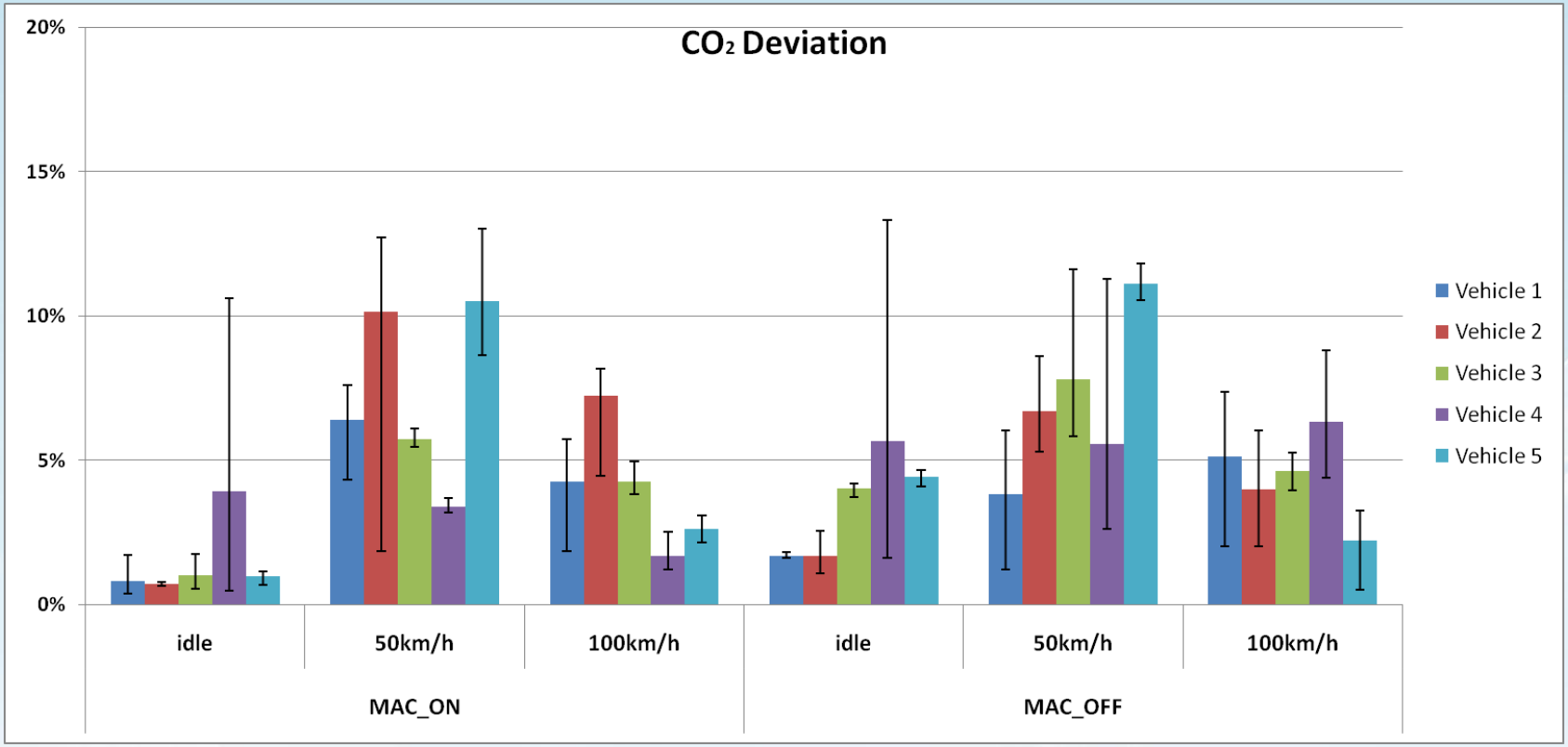

- Deviation of average test cell temperature in speed steps
  - Over +/−2 ℃ in testing vehicle 4, 5

# Test cell humidity tolerance



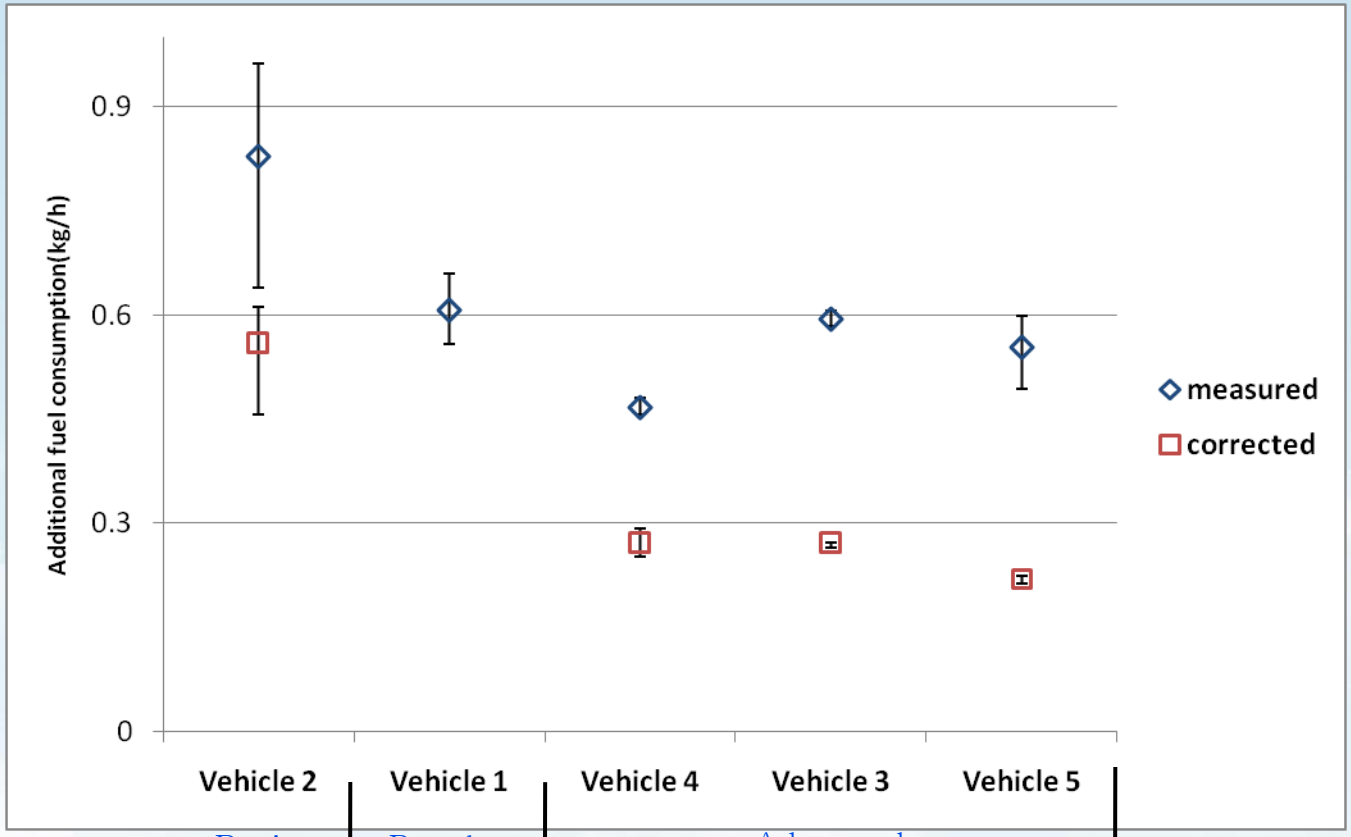

- Deviation of average test cell humidity in each speed step
  - Over +/−5 % in testing vehicle 4, 5

# $CO_2$ tolerance




- 5% $CO_2$ tolerance in 50km/h, 100km/h seems severe to Korean vehicles depending on vehicle type and MAC control
  - 10% tolerance seems realistic

# Performance for MAC ranking



# Comments

- MAC test procedure set up in WP29 will be a good reference to Korea
  - To give $CO_2$ incentive for high efficiency MAC
- COP corrections improve repeatability
- Deviation of cabin temp. is smaller than that of vent temp.
  - depending on speed steps and measuring locations
- Need to review the effect of tolerances on repeatability based on pilot phase results
  - Possibility to extend tolerances for cell temp., humidity and $CO_2$ deviation
- The higher tech. MAC shows the lower additional fuel consumption with draft test procedure