Development of a standard testing method for vehicle cabin air quality index

"A pathway to reduce exposure to MSATs"

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Background

- People experience the highest exposure to particulate matter (PM) while driving or riding.

- Cleaner vehicle cabin air quality. => Less exposure to PM on the road.=>Also less exposure to MSATs.

Background

Recirculation mode

- In cabin particle concentrations decrease.
- Fuel saving due to less compressor work.
- CO_2 and H_2O increase and dehumidification should be better controlled.

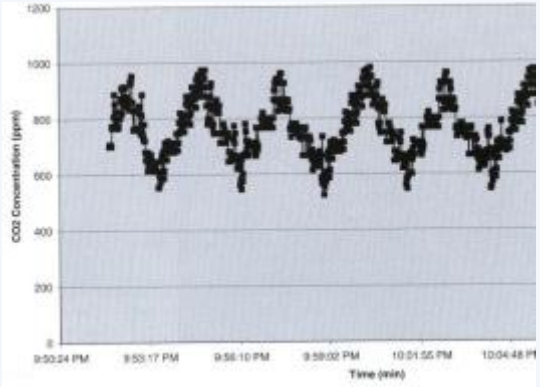
Fresh air mode

- Outside air infiltrates.
- “Fresh” does not mean clean.
- High concentration of roadside particles infiltrates.

Examples

Intermittent on/off, BMW

On/off control



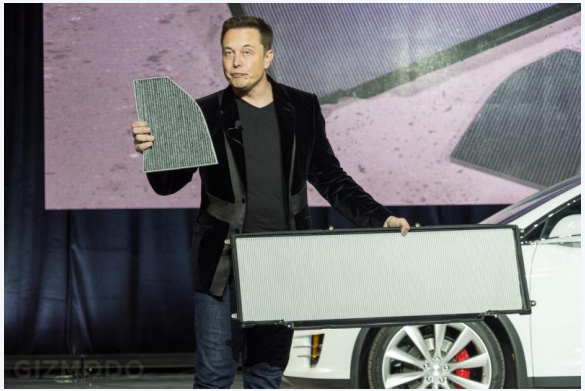
Mathur,2008-01-0829

Fractional control

Grady et al., 2013-01-1494

Examples

Tesla biodefense mode

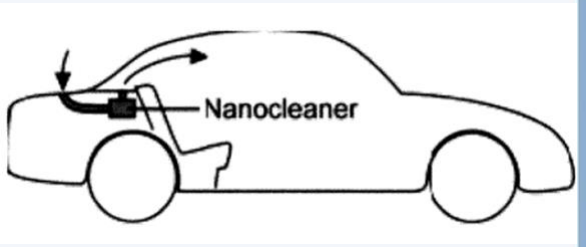


Large HEPA filter

2018 Prius Eco-Driving mode

Aggressive recirculation, PM decrease and fuel economy improves

Auxiliary cabin filter system



Kasper et al. (2008)

Examples

Charcoal lined cabin filter

Adsorption filter to remove gaseous pollutants

- Packed activated carbon bed.

HOW DO WE EVALUATE OR QUANTIFY THEM?

WE PROPOSE
CABIN AIR QUALITY INDEX

Cabin Air Quality Index

Issues

- Cabin air system has a relatively large time constant.
- There is a trade off between CO_2 and particle concentrations.

Proposed

- Integrated (or cumulative I/O ratio) as opposed to instantaneous I/O ratio.

Metrics

- Particle number (PN)
- Particle surface area (PS)
- Particle mass (PM)
- Gases (CO_2, NOx, etc)

Cabin Air Quality Index (CAQI)

- $$CAQI_{pollutant} = \frac{\int_0^t C_{pollutant\_inside}\, dt}{\int_0^t C_{pollutant\_outside}\, dt}$$

- $CAQI_{CO_2} > 1$ Stuffiness Ex) 1000ppm/400ppm=2.5

- $CAQI_{particle} < 1$ Infiltration ratio

Proposed standard test method and conditions

- Fixed parameters
  - Number of passengers (2), Ventilation mode (chest setting), AC ON, test vehicle at rest inside a workshop (no external wind or blower) for static test.

- Varied parameters
  - Fan speed, recirculation ON/OFF

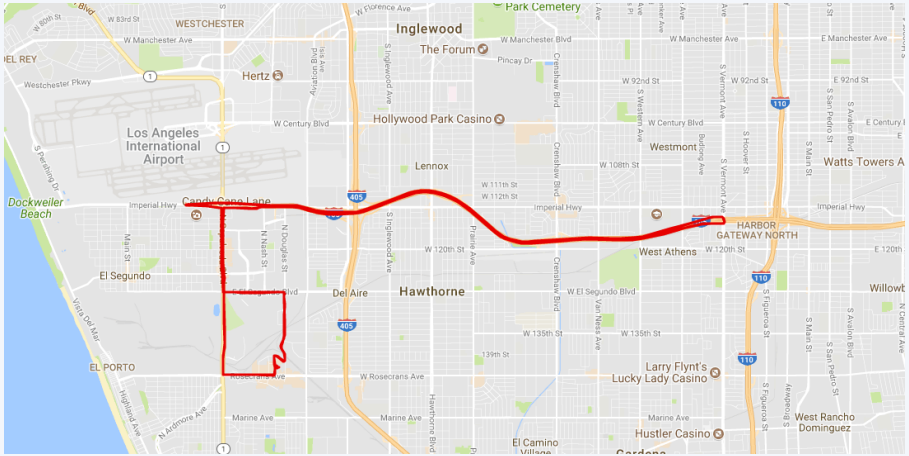
Static test (test vehicle at rest in a workshop)

1. Set data marker
2. Open doors for two minutes to ventilate cabin
3. Close doors and windows
4. Air recirculation on or off
5. Set fan speed
6. Switch on AC at manual setting, 50% of maximum fan speed
7. Deploy CO_2 canister
8. Wait for five minutes
9. Set data marker

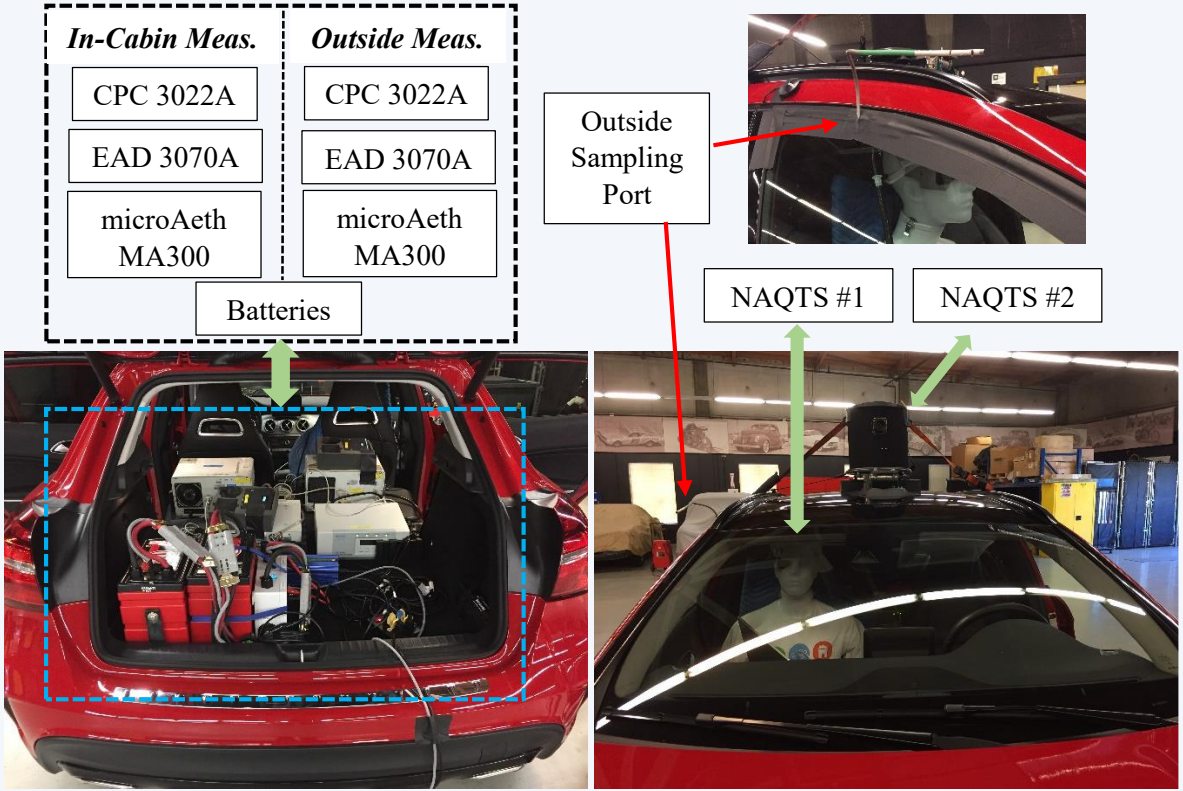
Dynamic test

Driving route

- 30 min drive of urban polluted route
- Low speed range (i.e <30 mph for 90% of time)
- Recirculation ON/OFF
- Two passengers, AC ON, fan speed at mid speed, and chest vent mode.
- Integrated IO ratio over the driving route.



Experimental setup



PN: CPC, NAQTS
PS: EAD
BC: µAeth
Gases: NAQTS

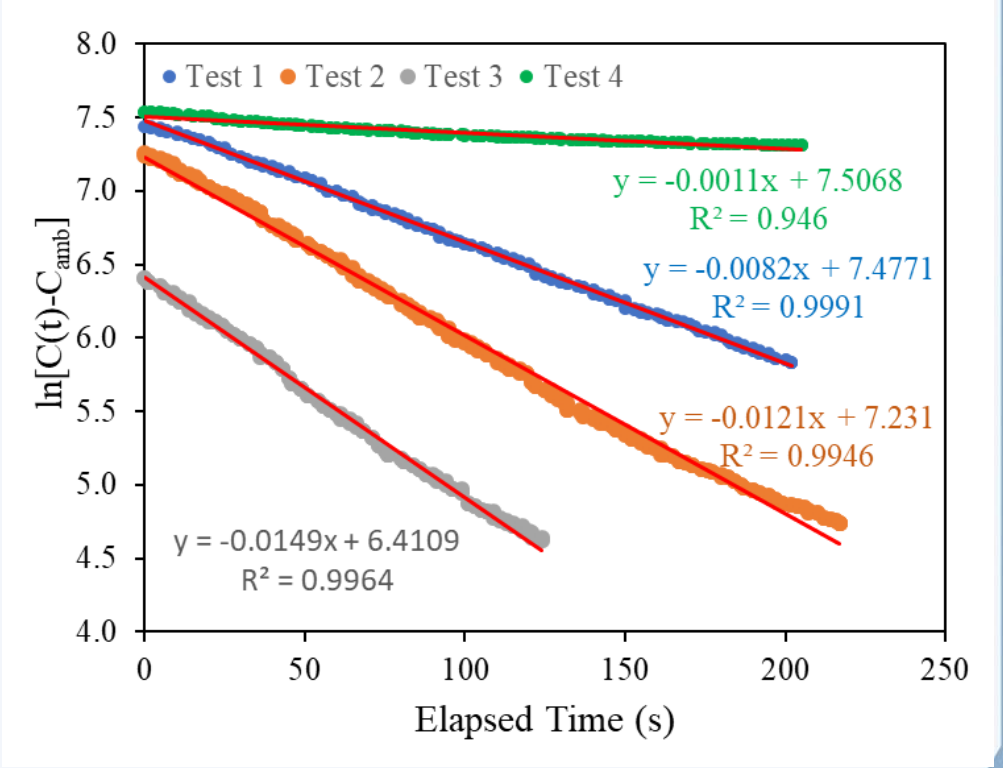
Experimental setup

Pairs of instruments

- TSI CPC 3022 (d50=7nm) => d^0
- TSI Electrical Aerosol Detector (d50=10nm) =>$d^{1.13}$
- MicroAeth MA300=>d^3 or BC mass
- NAQTS (VOC, CO, NO_2, O_3, NH_3, CO_2, and particle count)

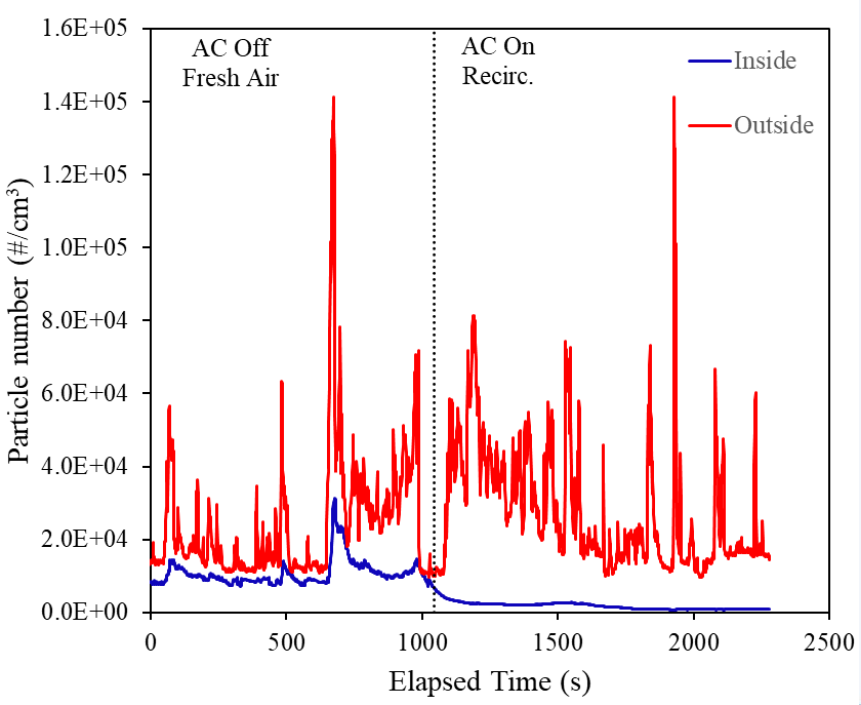
Results from static tests

Test #	Fan Speed	Recir.	AC	AER(h^{-1})
1	1	Off	Off	30
2	3	Off	Off	44
3	5	Off	Off	54
4	3	On	On	4

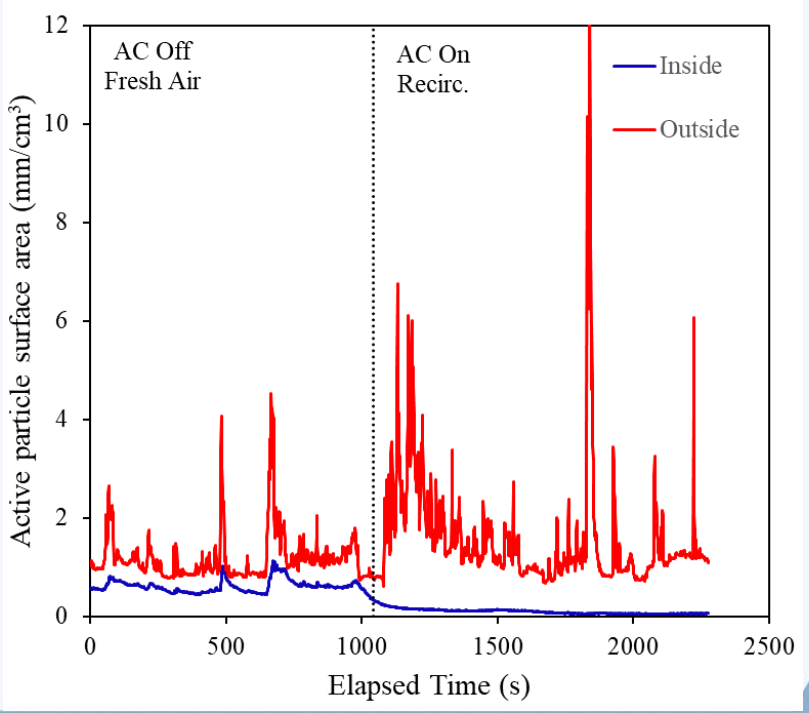


Results from a dynamic test

Particle number

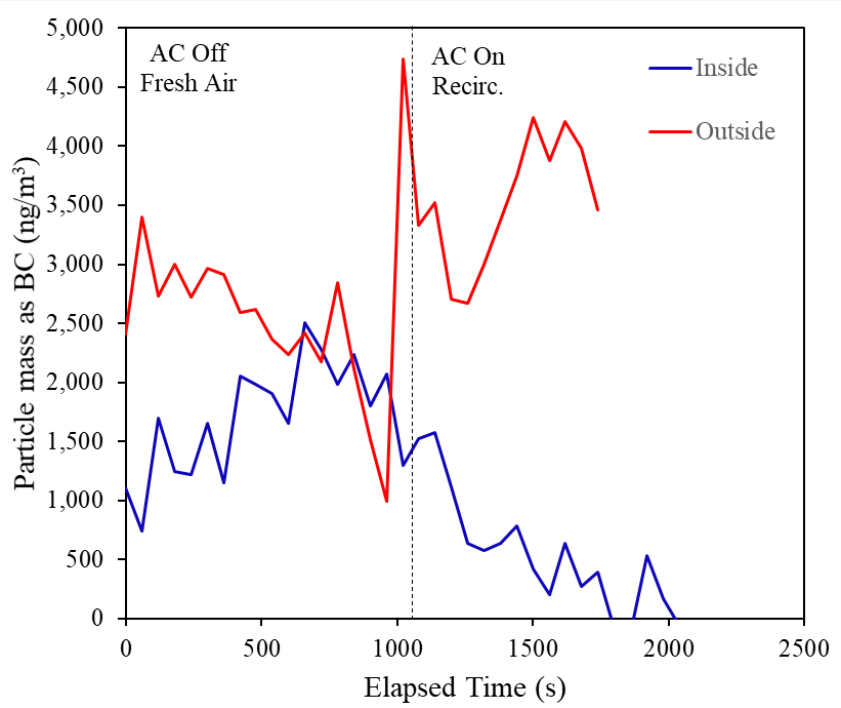


Particle surface area

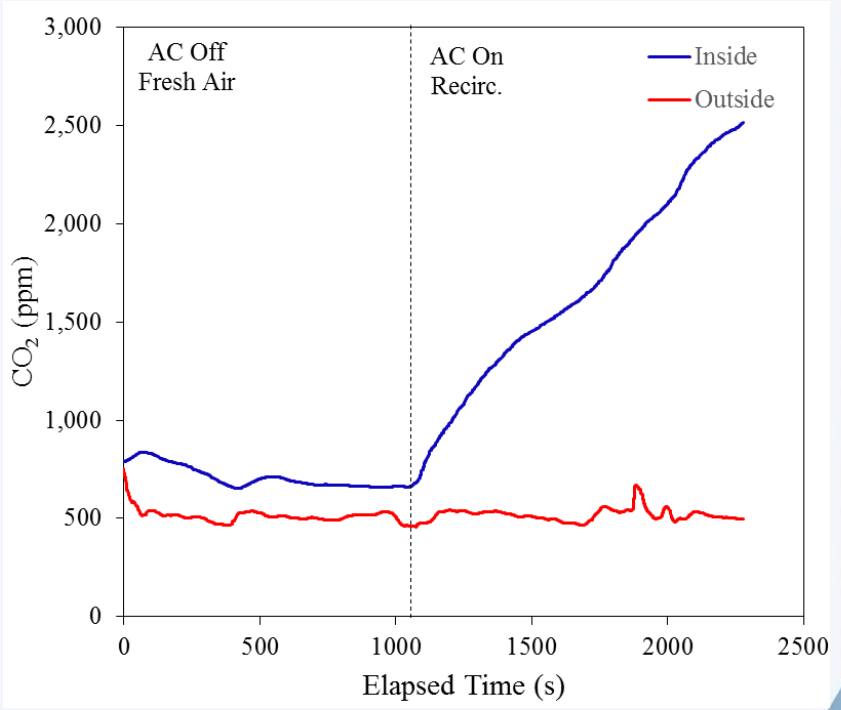


Results from a dynamic test

Particle mass

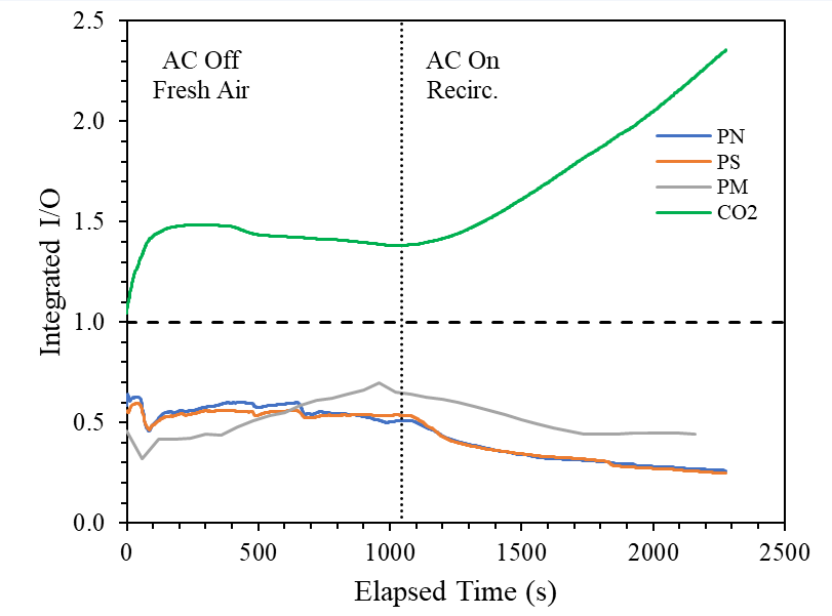


CO_2

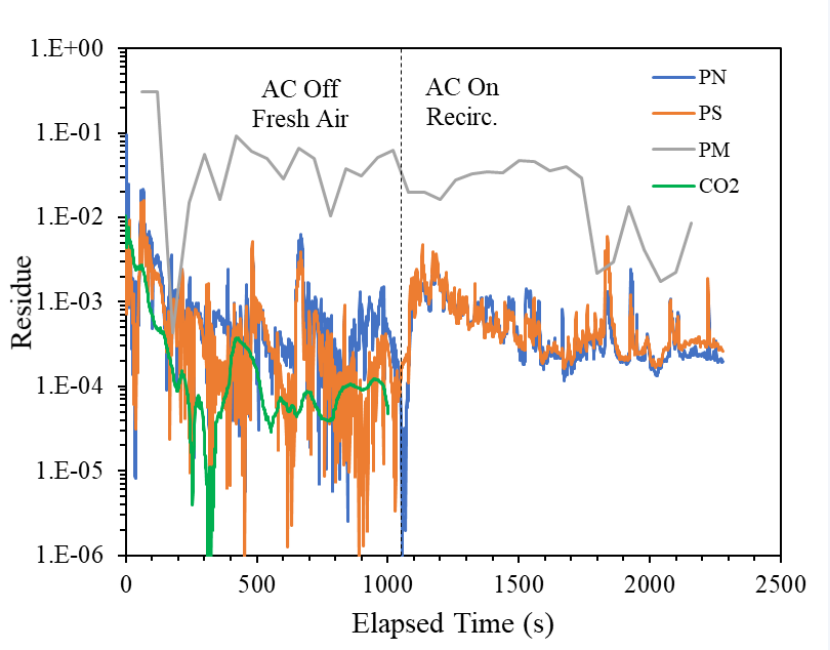


Cabin air quality index

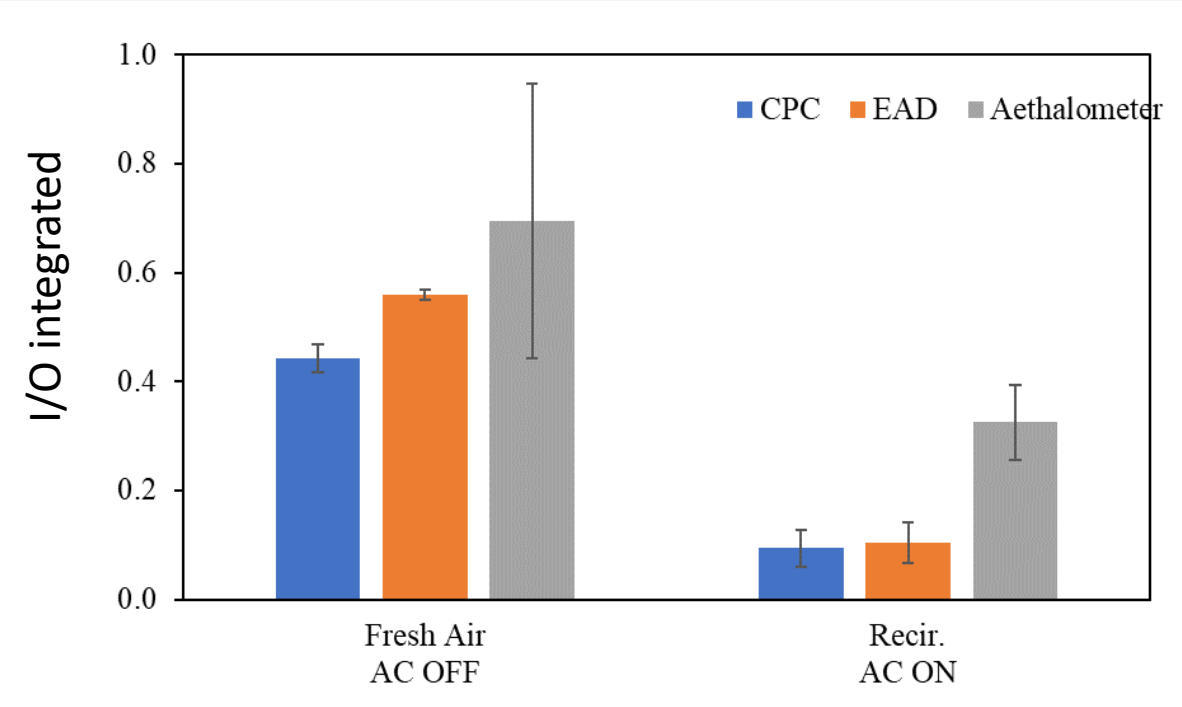
CAQI



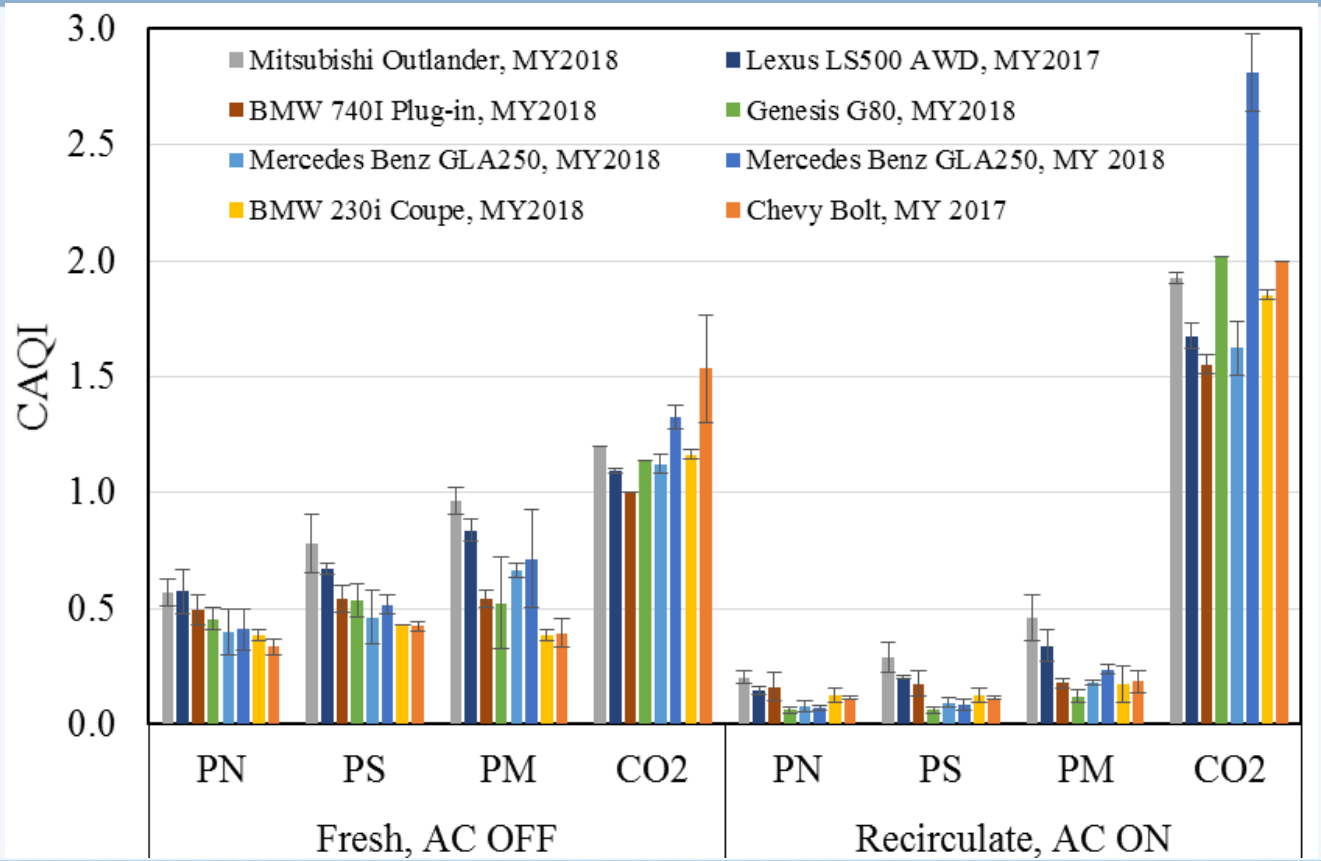
Residue



Results from dynamic tests



Comparison of cabin infiltration among different vehicles



Conclusion

- Calibration of the pair of instruments is important to get accurate results.
- CAQI works to evaluate vehicle HVAC system to control cabin air quality.
- Different metrics gives different CAQI due to their difference in weighing on particle diameter.

Conclusion

- The database which will be widely disseminated to the public will empower customers to choose environmentally friendly designed vehicle HVAC system to reduce their exposure to pollutants on roads.
- The Air Quality Index Database will promote auto manufacturers to design cabin air system to reduce passengers' exposure to air pollutants. => Less exposure to MSATs

Conclusion

- Choose a metric or metrics.
- Test more vehicles and establish data base for all cars in the market
- A longer test duration can reduce measurement uncertainty and improve repeatability but it will require more resources.
- Constrain test conditions such as allowing only certain range of on-road pollutant concentrations to reduce uncertainties or to improve repeatability.

Interesting health study results

Rudell et al. , *Efficiency of automotive cabin air filters to reduce acute health effects of diesel exhaust in human subjects.* Occup Environ Med. 1999 ;56(4):222-31

VOC is potentially as important as PM to reduce adverse health effects.