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Assessment of self-pollution of school buses with various retrofit technologies

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Background

- More than 24 Million children in USA commute by school buses every day
- Studies have shown adverse health effects of traffic exhaust exposure
- Elevated levels of $PM_{2.5}$ and BC inside school buses in Connecticut (Wargo, '05), Los Angeles (Behrentz, '05; Sabin, '05) and Seattle (Adar, '08; Zielinska, '08)

Motivation

- Most diesel exhaust particles on buses are attributable to bus itself - self-pollution. (Fitz 03; Sabin 05)
- Ireson (2004) reported little self-pollution from the tailpipe
- UW's bus self-pollution (SP) study; in year 2005 with 2 Seattle buses without CCV (closed crankcase ventilation)
- Liu (2008) and Zielinska (2008) show crankcase contribution greater than tailpipe

Remaining Questions ??

- Can we generalize these results on bus self-pollution?
- Does CCV reduce the crankcase emissions effectively?
- Does DOC (diesel oxidation catalyst) help at all?
- What is the effect of windows open/ closed on bus self-pollution?

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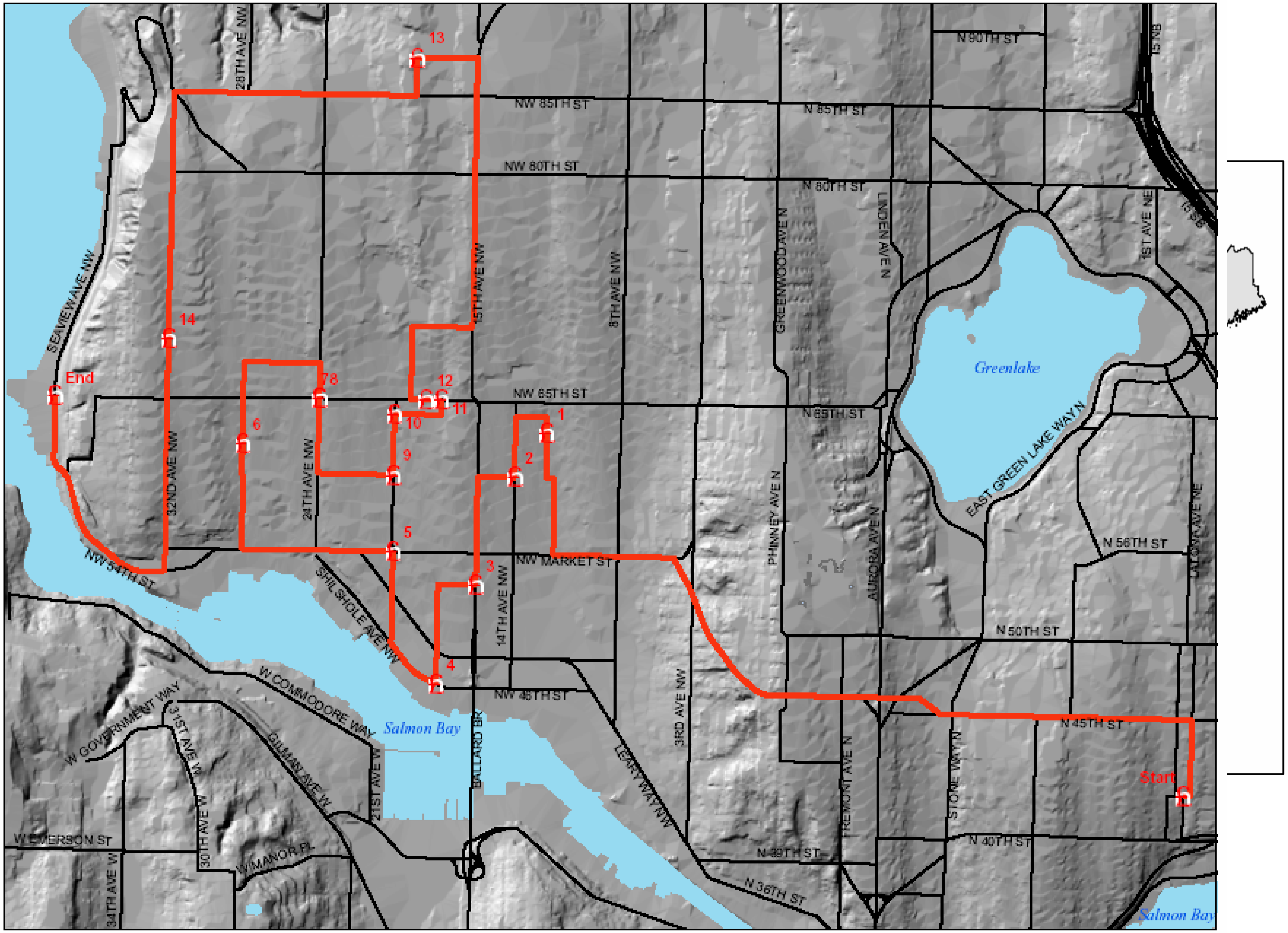
Locations and bus routes



Bus selection

(Null, DOC, CCV, DOC+CCV)

Bus ID	DOC	CCV	Model year	Engine model	Engine location	Mileage
Seattle						
1DC	Y	Y	2002	T444E	F	42,492
1DX	Y	N	2002	T444E	F	42,492
2XC	N	Y	2002	T444E	F	49,550
2XX	N	N	2002	T444E	F	49,550
Tahoma						
5DC	Y	Y	1993	DT360	F	149,605
6DX*	Y	N#	1993	5.9L	R	168,000
7DX**	Y	N#	1993	DT360	F	144,201
8DC	Y	Y	1993	DT360	F	160,200
8DX	Y	N	1993	DT360	F	160,200

Donaldson CCV unit disconnected prior to the tests

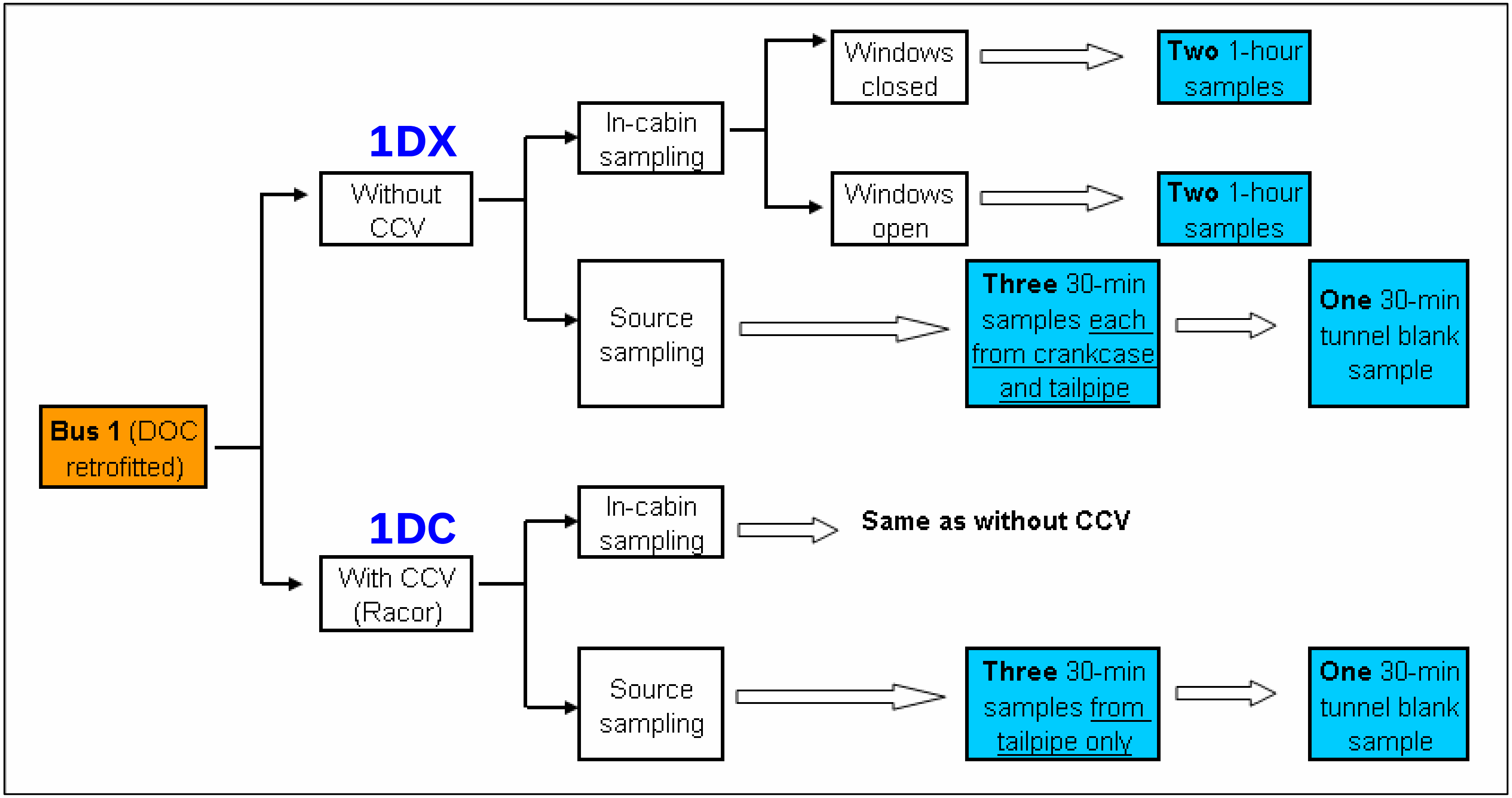
* Strong odors reported coming from rear engine compartment into bus during operation

** Engine failure (turbo seals ??) during emission testing; testing aborted

Study design – In-cabin, Lead Vehicle and Source sampling

- A 3-week study (Aug 14-Sep 1, 2006)
- Sampling on 6 buses with total 9 configurations
- **On bus**: Collocated $PM_{2.5}$ samplers at 120 L/min, and PM_1 sampler at 16.7 L/min
- Simultaneous sampling of tailpipe and crankcase emissions using two parallel dilution tunnels in most runs
- **On bus and Lead Vehicle:** pDR, Ptrak and EcoChem

Sampling Schematic



Chemical Analysis

- $PM_{2.5}$ Teflon filters: gravimetric and INAA for Iridium
- $PM_{2.5}$ quartz filters: detailed organics
  - OC and EC using the TOR-IMPROVE protocol
  - Speciated organic analysis including d-alkane ($C_{36}D_{74}$) with GC/MS
- PM_1 filters: gravimetric and XRF for trace elements

Estimating self-pollution using tracers

$$PM_{2.5,\ SP} = PM_{Tailpipe} + PM_{2.5,\ Crankcase}$$

$$= Ir_{in\text{-}cabin}\,(PM_{TP}/Ir_{\ TP}) + d\text{-}alkane_{in\text{-}cabin}\,(PM_{2.5,\ Ck}/d\text{-}alkane_{Ck})$$

- **Organo-metallic Ir complex added in diesel fuel as tracer for tailpipe emissions**
- **d- alkane ($C_{36}D_{74}$) added in lubricating oil as tracer for crankcase emissions**

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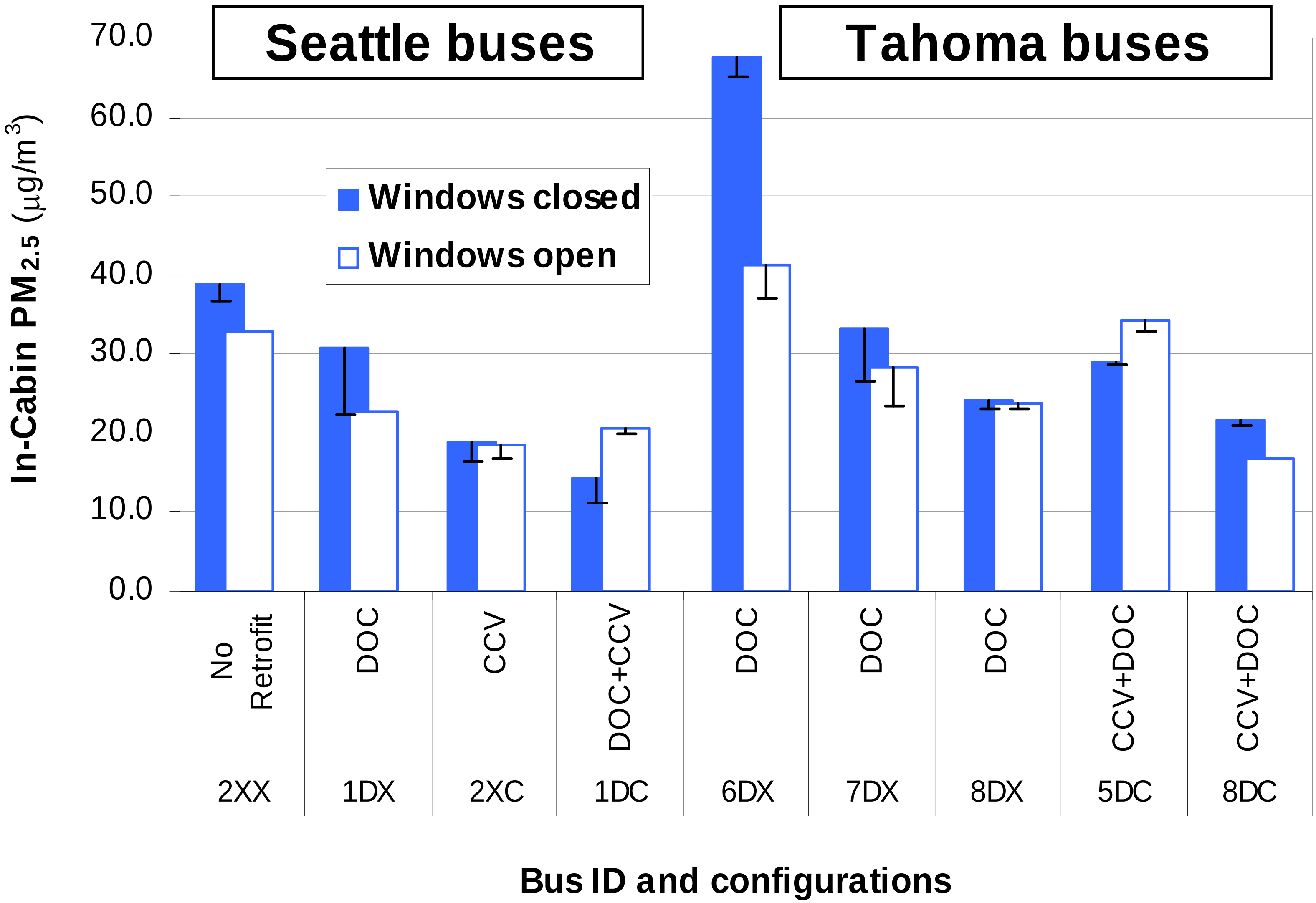
In-cabin total $PM_{2.5}$



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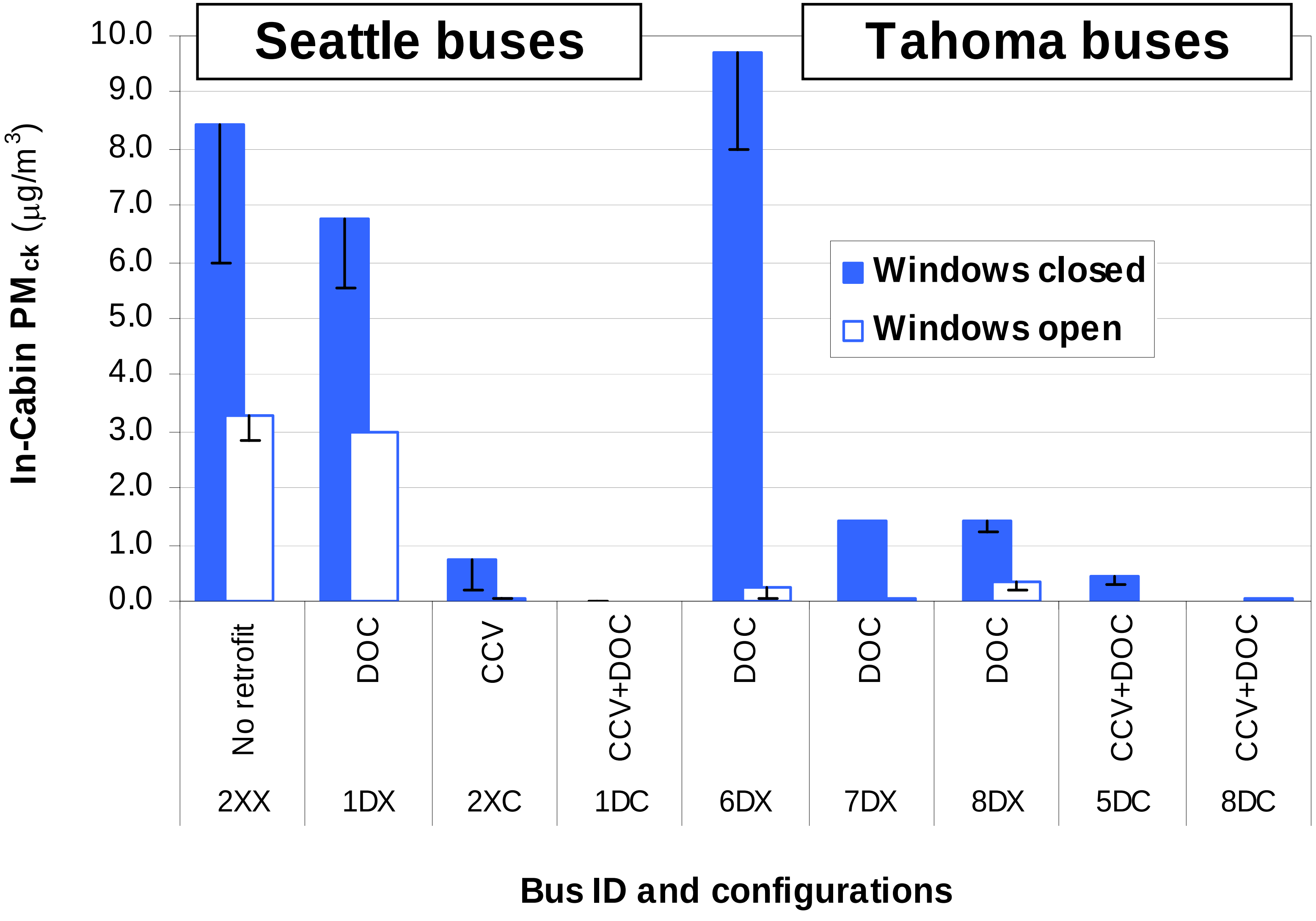
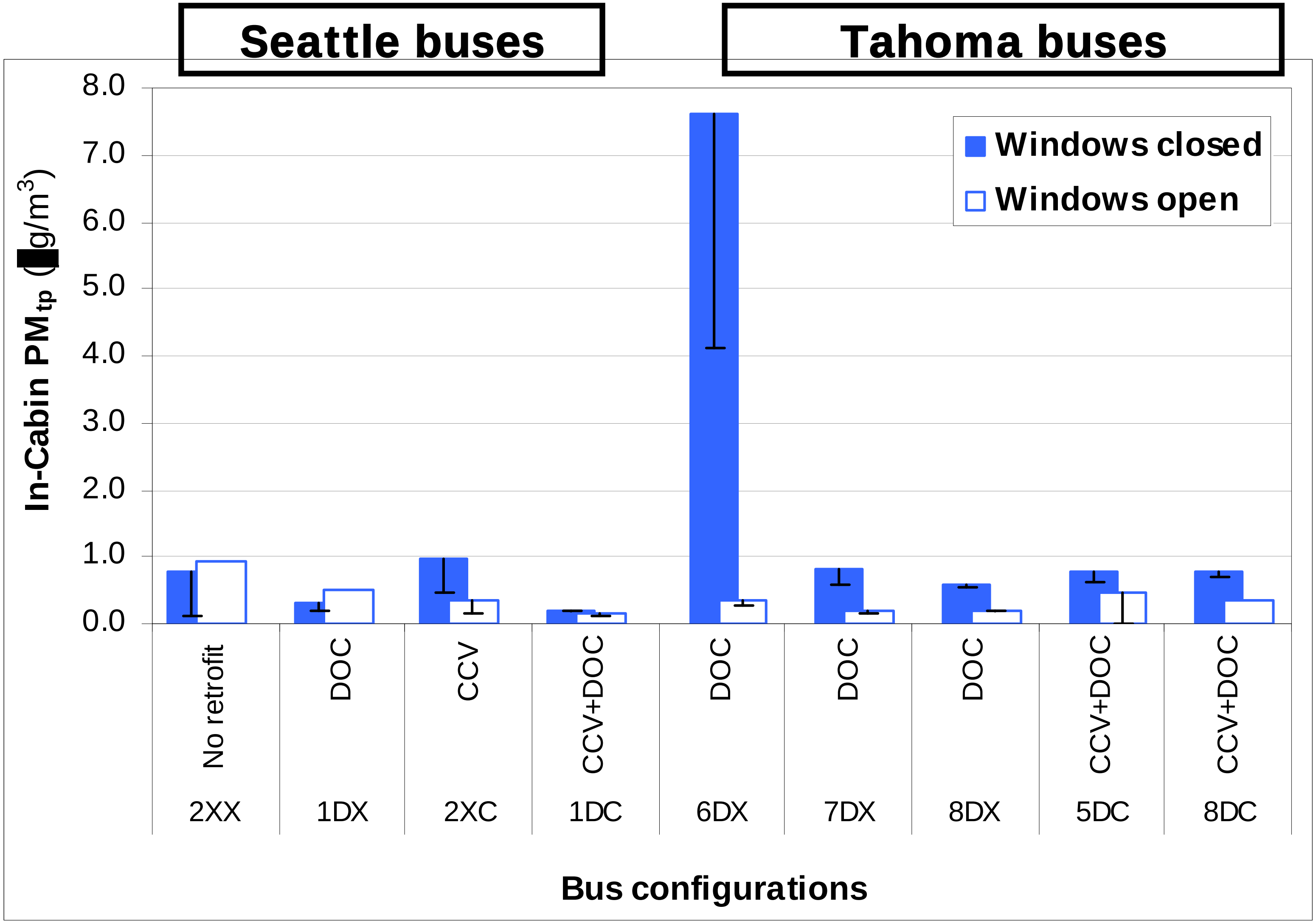
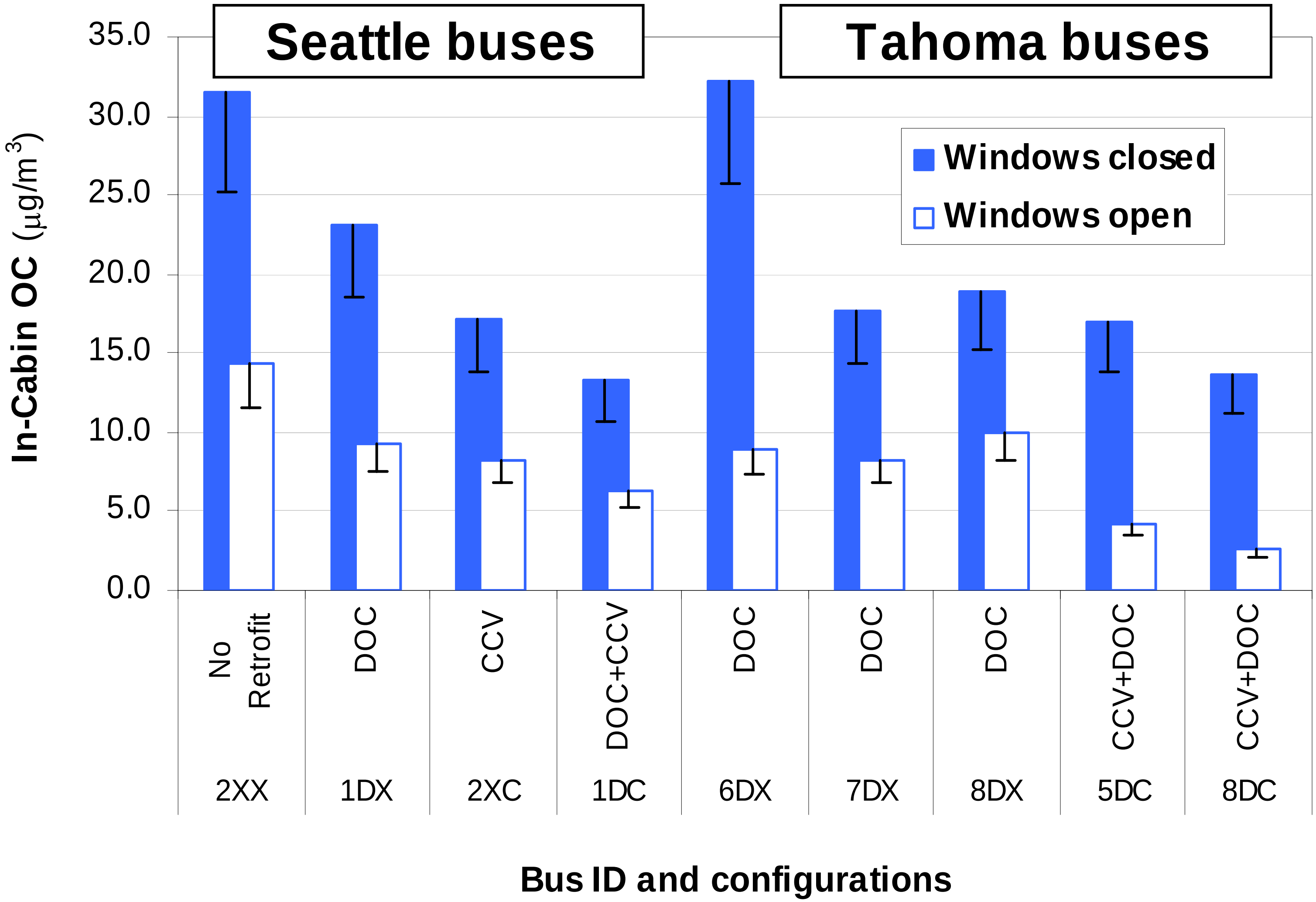
In-cabin crankcase $PM_{2.5}$



In-cabin tailpipe $PM_{2.5}$



In-cabin OC conc.



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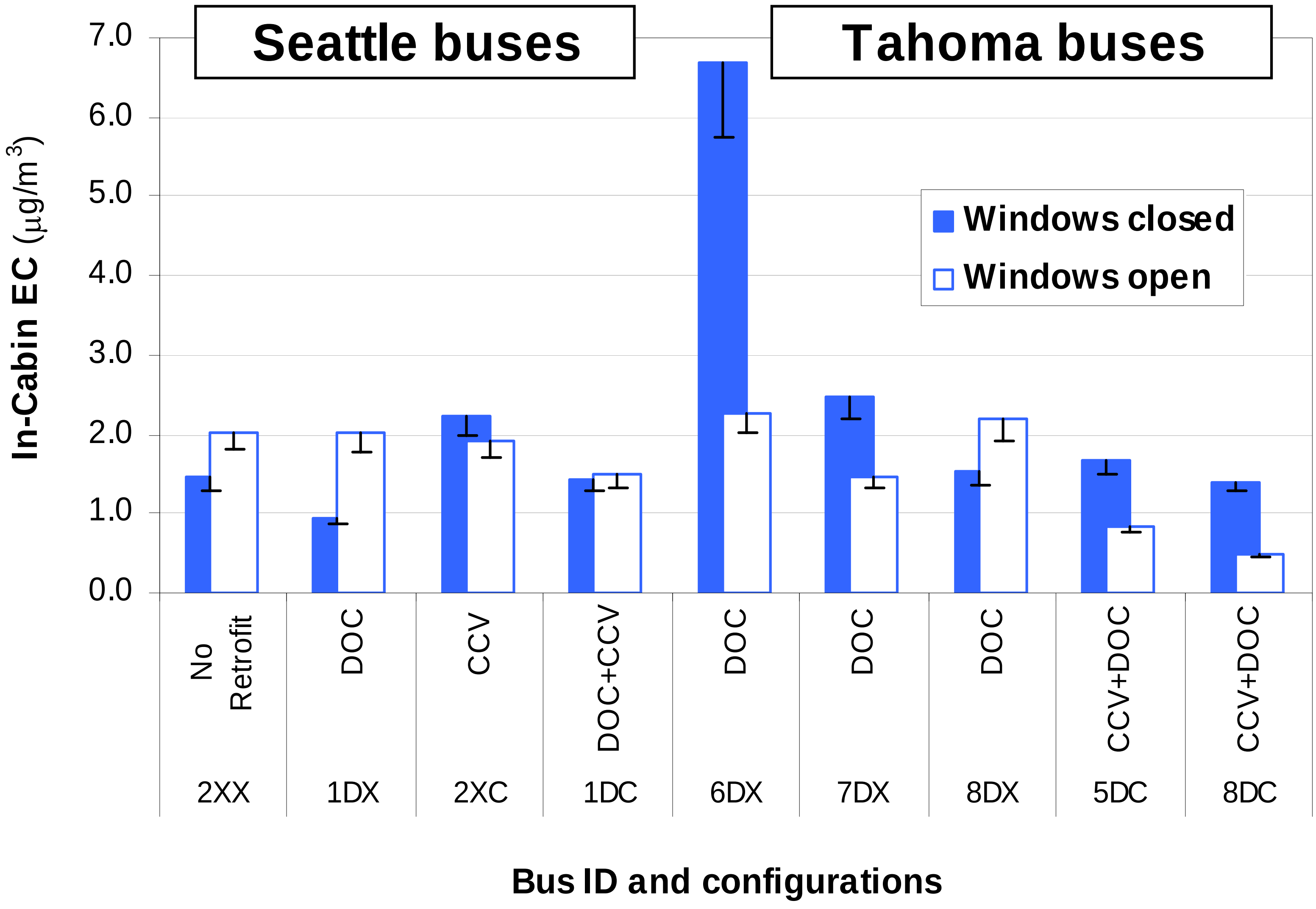
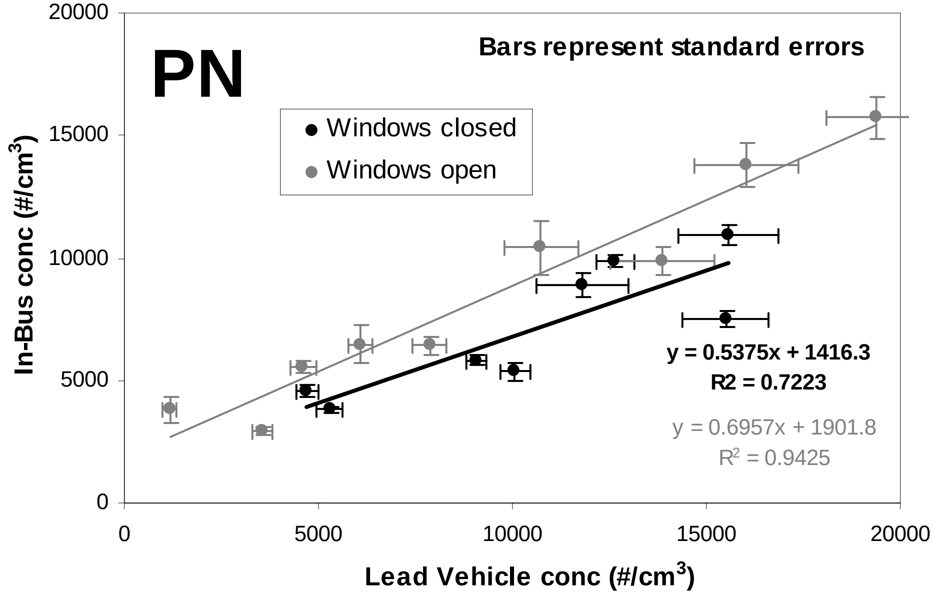
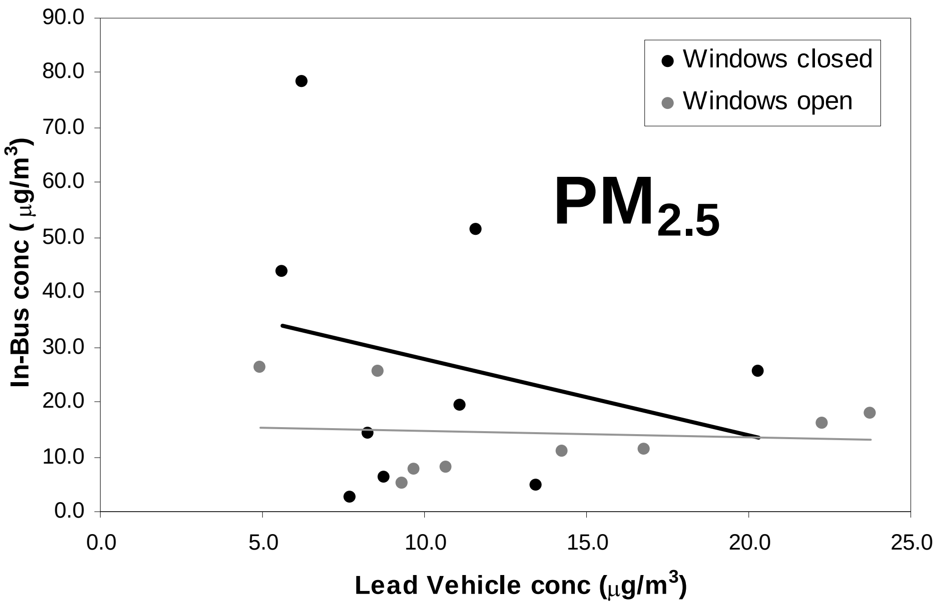
In-cabin EC conc.



Continuous measurements





Comparisons with previous findings

Parameters	This study				Liu et al., 2008
	Seattle		Tahoma		Seattle
	No CCV	CCV	No CCV	CCV	No CCV
Windows closed					
SP ($\mu g/m^3$)	**8.2**	1.0	7.2	1.0	**14.0**
% PMck/SP	**94**	25	63	18	**88**
% SP/PM2.5	**24**	5	13	4	**48**
Windows open					
SP ($\mu g/m^3$)	**3.9**	0.3	0.5	0.4	**1.9**
% PMck/SP	**82**	7	40	6	**66**
% SP/PM2.5	**14**	1	2	2	**20**

- **In our 2005 bus SP study (Liu, 2008), bus model year were 2002 and 1999**
- **Both had DOC and none CCV**

Summary

- Self-pollution ranged 1-8.2 μg/m³ when windows closed ; 0.3-3.9 μg/m³ when windows open (wo)
- In-cabin $PM_{2.5}$ and OC were higher when windows closed (wc)
- In newer (2002) buses, crankcase contribute 77 and 87% of SP (wo,wc), while ~30, 55% of SP (wo,wc) in older (1993) buses
- Crankcase $PM_{2.5}$ ~5-10 times higher than tailpipe PM inside the bus
- Retrofit CCV control effectively reduced in-cabin $PM_{2.5}$ and OC emissions; DOC did not
- In cabin PN track roadway levels very well and about 50% of roadway background (wc) and 70% (wo)

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