UCR College of Engineering- Center for Environmental Research & Technology

UCLA School of Public Health

Evaluation of Methods to Reduce Exhaust Penetration into School Buses

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Introduction

- Children are especially susceptible to air pollutants
- Many children spend significant time commuting in diesel-powered school buses in California
- Diesel exhaust has been designated a toxic air contaminant by the ARB
- Exposure due to exhaust from self-pollution or from following another diesel-powered vehicle has been shown to be significant
- While 2007 and future diesel engines have reduced emissions, many older buses are still in use

Overall Objective

Develop and evaluate methods to minimize exposure to diesel exhaust while commuting on school buses

Approach

- Identify mitigation methods
- Evaluate effectiveness of mitigation methods using tracer gases in the exhaust while
  - Stationary
  - On a test route

Mitigation Methods Evaluated

- Identify and repair exhaust leaks
- Measure and lower the bus air leak rate
- Raise the exhaust release point
- Power ventilate the bus
- Combine the last two methods

Exhaust Leak Identification

- Tracer Method
  - Added dimethyl sulfide to fuel
  - Probed exhaust manifolds and pipes with the inlet of a flame photometric real-time total sulfur analyzer
  - "Calibrated" by monitoring near an "artificial leak" created by flowing gas at expected exhaust SO_2 concentration
  - One bus sampled
- Back Pressure Method
  - Placed stopper with orifice into exhaust pipe
  - Measured pressure before and after orifice
  - Seventeen buses sampled

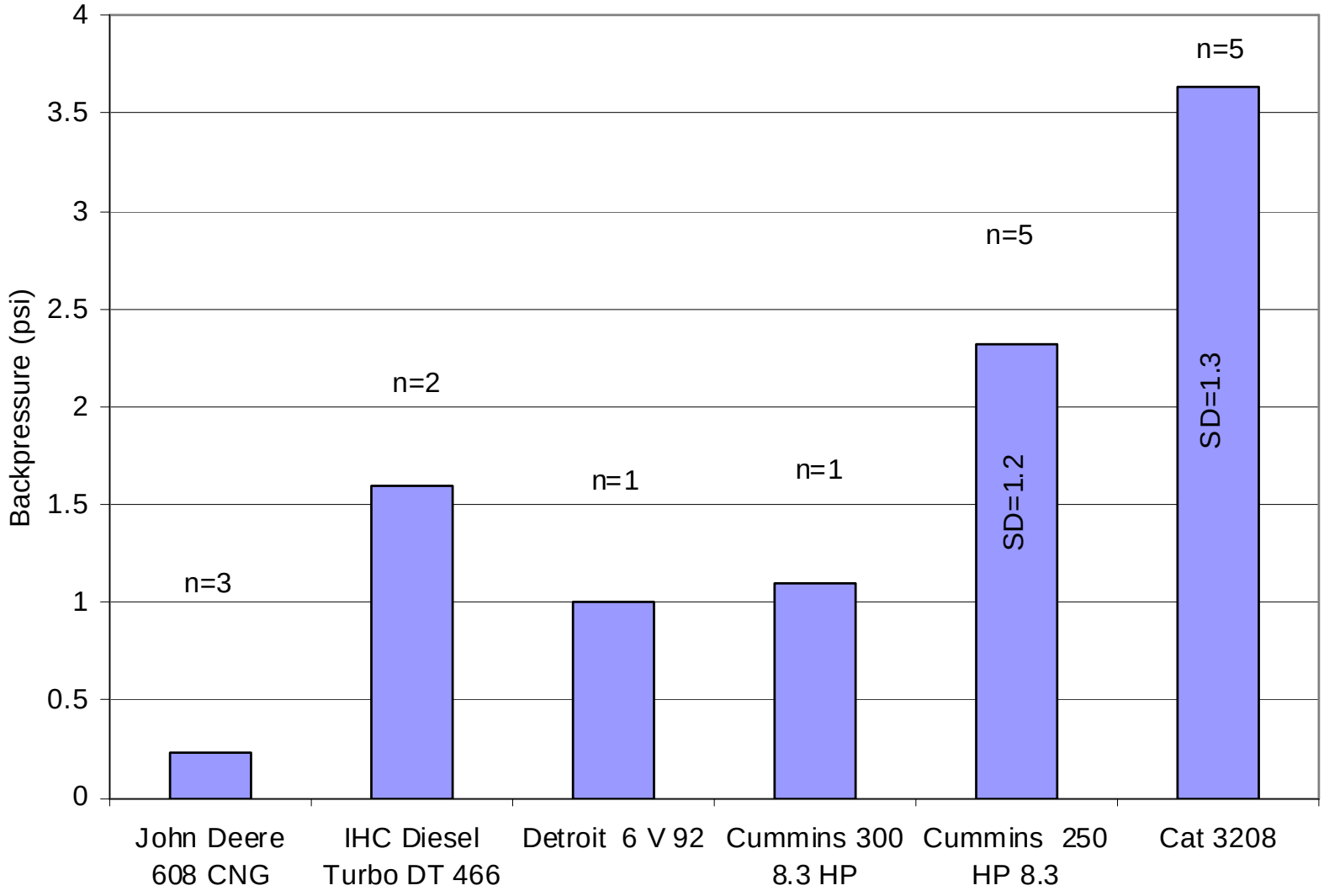
Probing for Leaks with Sulfur Tracer

Sulfur Tracer Probing Results (1 bus)

- Three leaks found in the 50ml/min range
- Less than 0.01% of the exhaust
- Insignificant

Back Pressure Leak Detection

Back Pressure Leak Detection



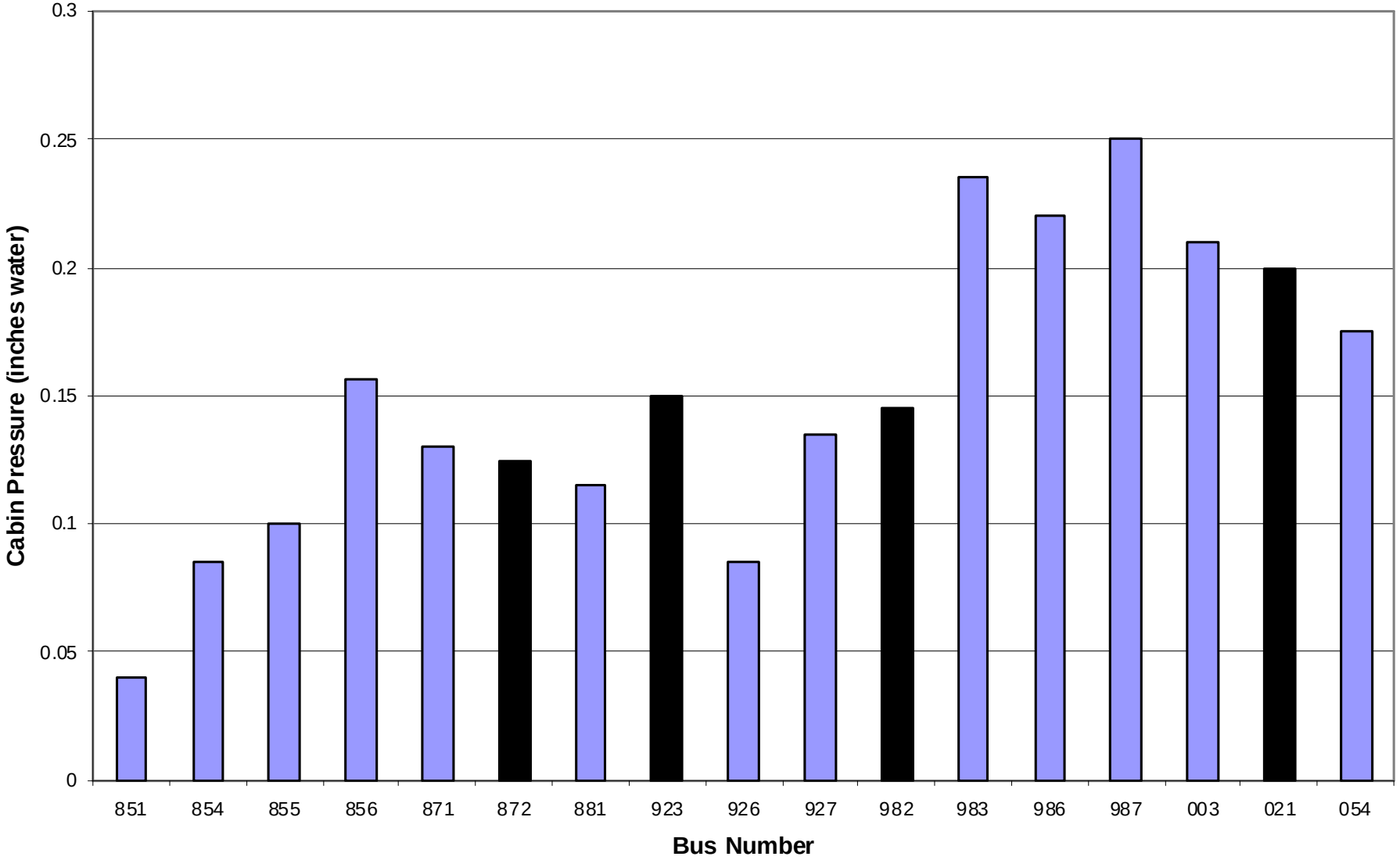
Measurement of Bus Cabin Leak Rate

- "Blower door" method
  - Used extensively for buildings
  - Pressurize with a blower of known flow rate (1200 cfm)
  - Measure pressure drop between inside and outside
- Seventeen buses sampled

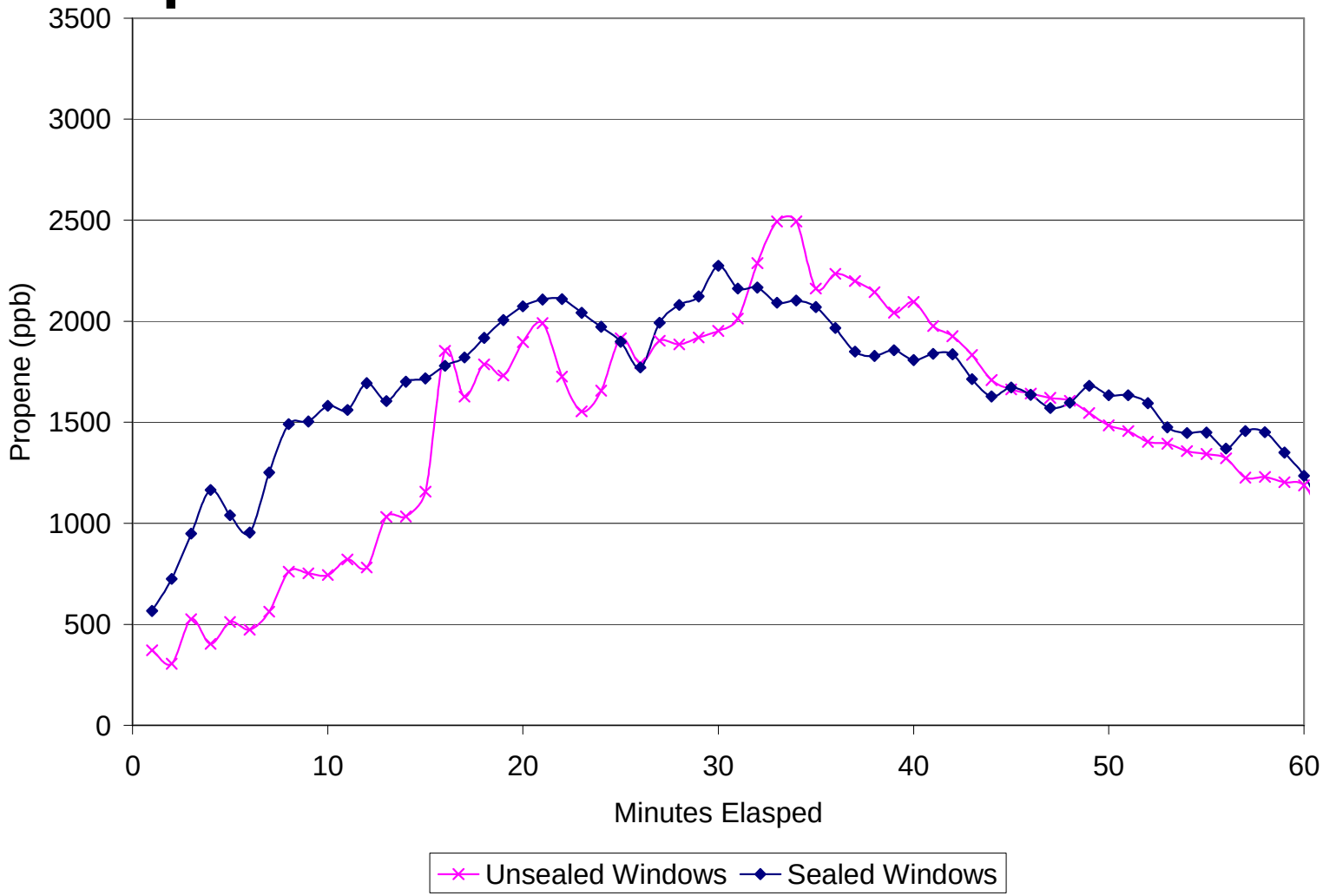
Blower Door Method

Photograph 3.2.2.1 A leak at the bottom of a bus door.

Blower Door Results



Window Sealing Evaluation using Propene Exhaust Tracer Gas



INVESTIGATION OF MITIGATION MEASURES

Raised Exhaust Evaluation

- Four representative buses used
- Tracer gases (SF_6 and propene) at each height
  - Propene measured by photoionization
  - SF_6 measured by electron capture
- Tracer flow rate was controlled by a data logger to maintain constant concentration with engine speed
- Four operational modes
  - Stationary self-pollution
  - Stationary leader-pollution (tracers released from leader)
  - Mobile self-pollution
  - Mobile leader-pollution (tracers released from leader)

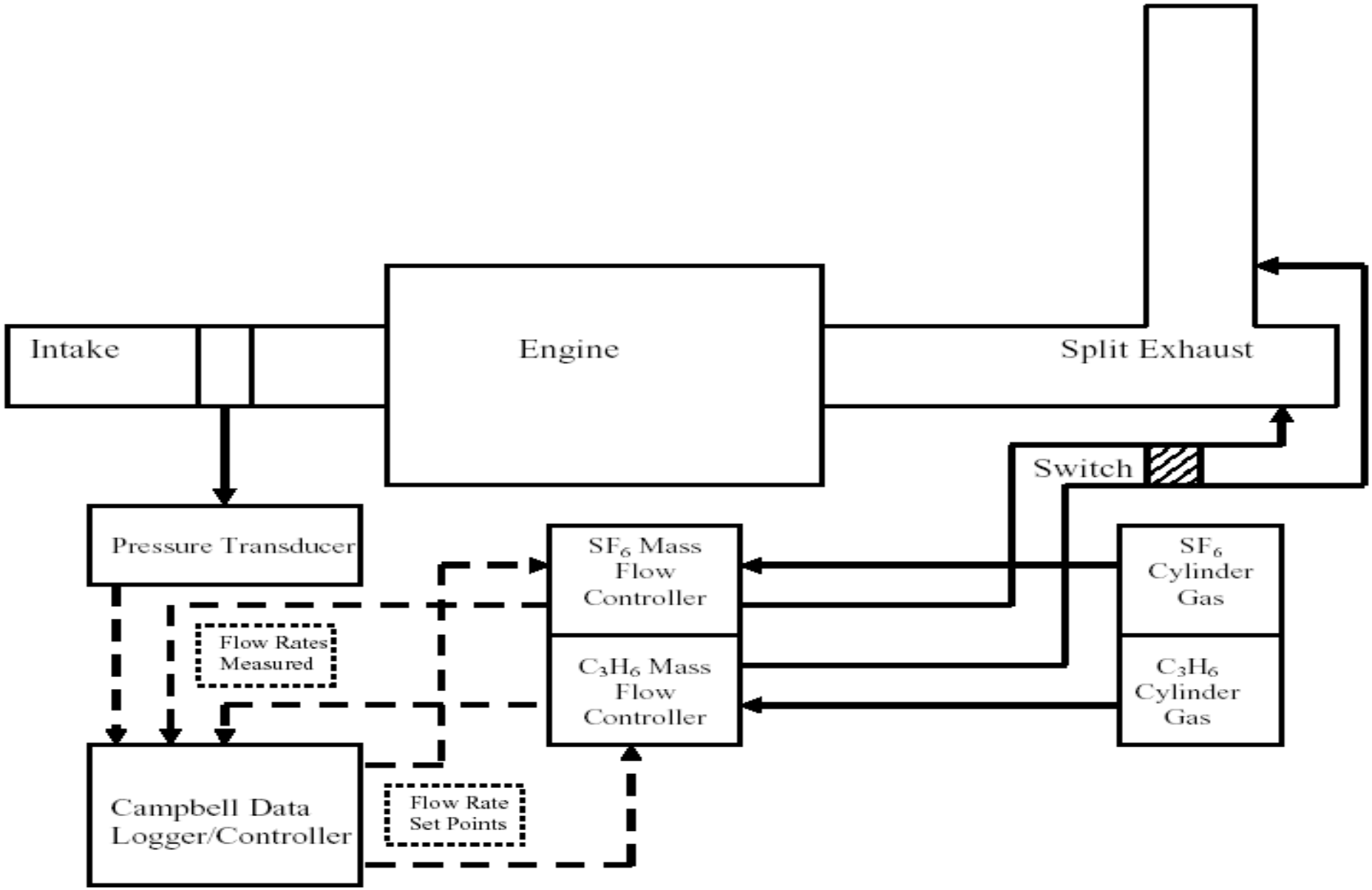


Figure 3.2.3.1 Tracer gas release system used in main study, using two tracer gases. The system was controlled by engine intake flow.

Table 4.2.2.1 Measurement methods utilized in the main study.

Species/Measurement	Instrument/Model	Detection Limit
Sulfur Hexafluoride (SF_6)	AeroVironment CTA 1000	10 ppt
Particle Bound PAH (inside and outside bus)	EcoChem PAS 2000	0.01 $\mu g/m^3$
Particulate Matter Number>7nm	Thermo Systems Inc. Model 3022	1 particle/cm^3
Total Hydrocarbons	ppb RAE	0.05ppm
Bus Location	Garmin Map 76 GPS	3 m
Bus Engine rpm	Engine Alternator Signal	Single pulse
Temperature & Relative Humidity (inside bus)	Rotronics PM101A	0.5°C/5% RH
Exhaust Gas Flow Rate	Omega PX274 Pressure Transducer	0.00" H_2O
Wind Speed, Wind Direction, and Temperature	Climatronics F460	0.1 m/s, 2 deg WD, 0.1°C

Figure 4.1.3.1.1 Map of Route 1 in Riverside, California.

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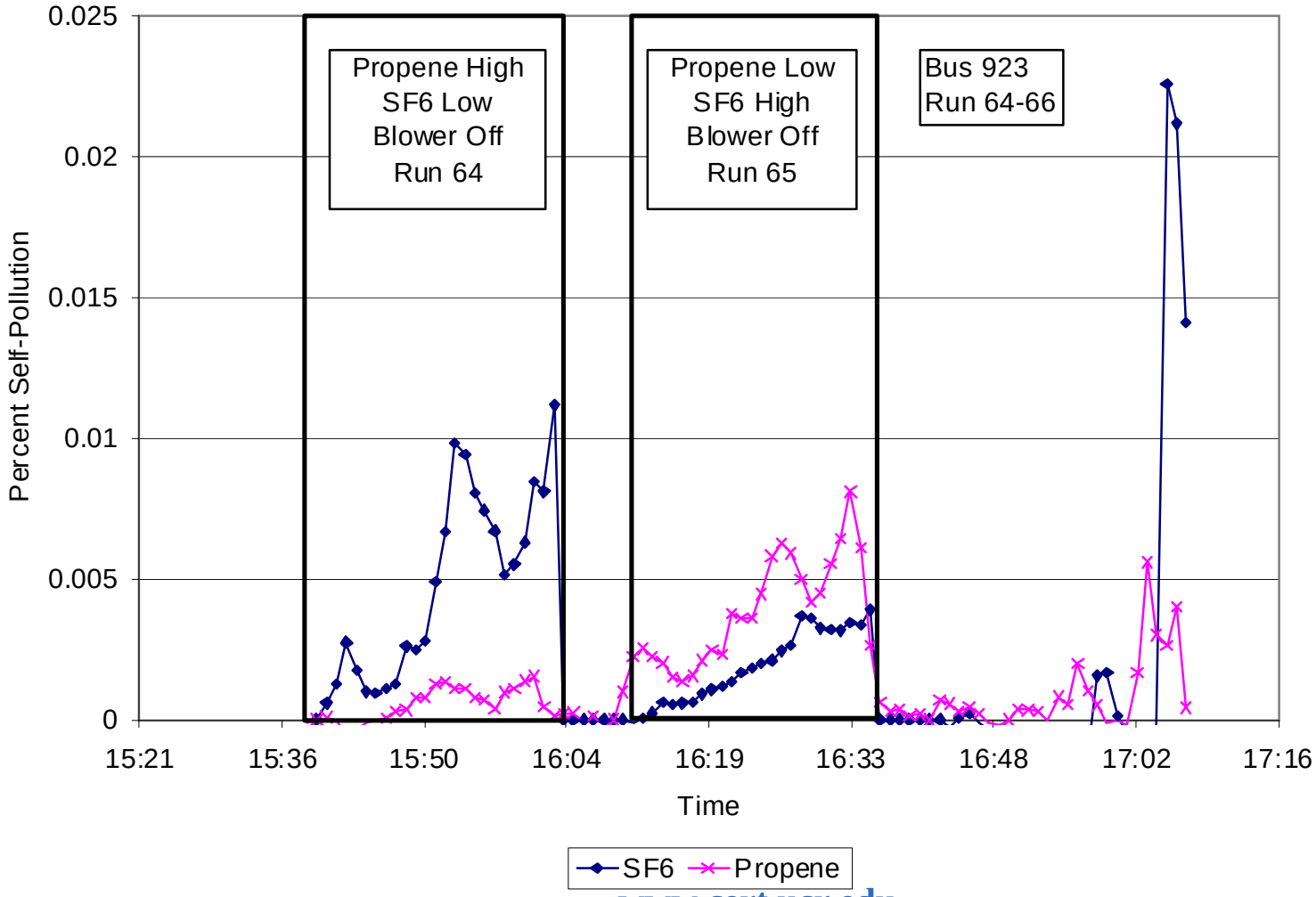
Raised Exhaust

Original exhaust pipe location

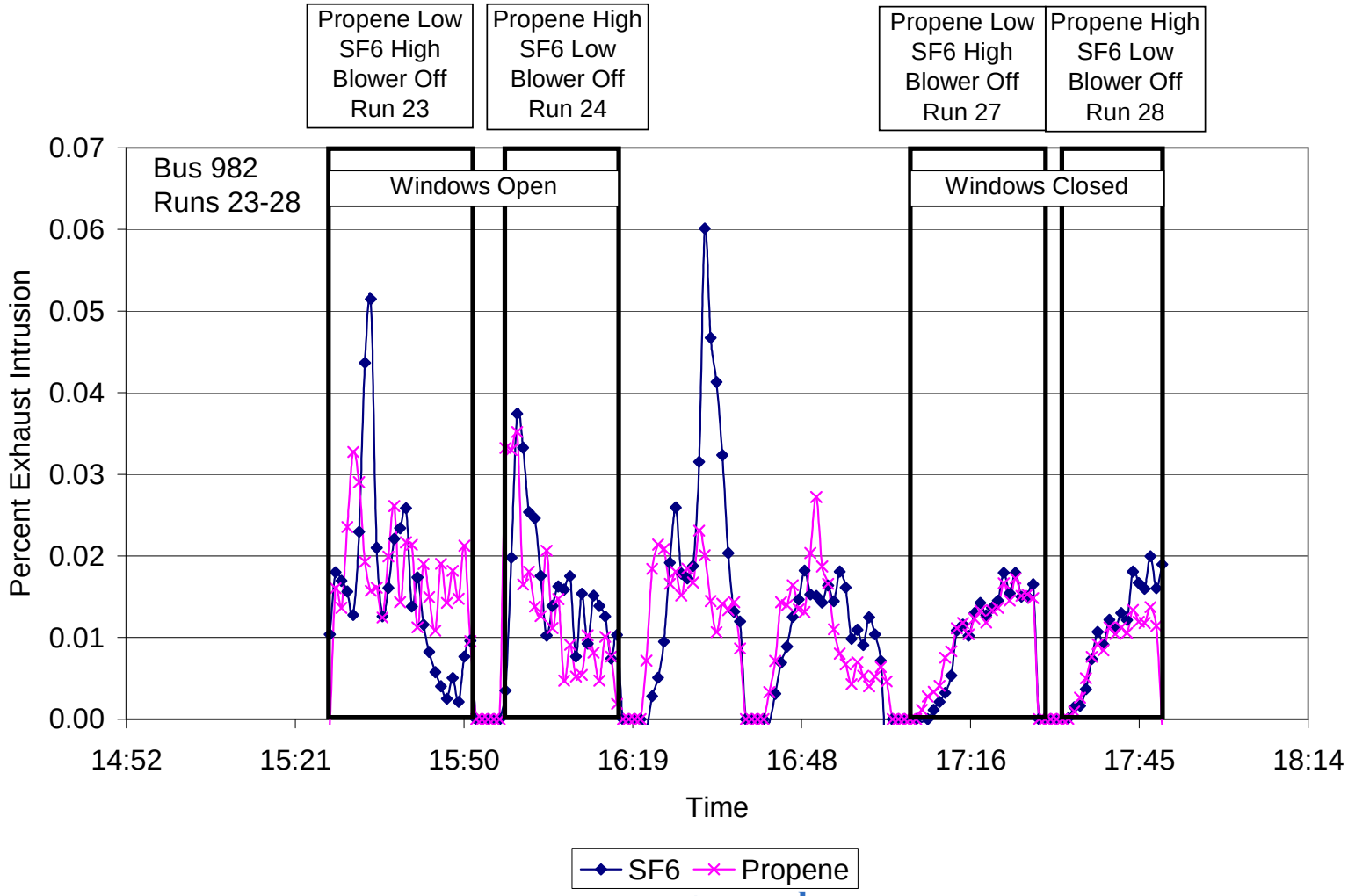
Tracer Study Data Analysis

- Calculated the percentage of air in the cabin that can be attributed to the exhaust as the ratio of tracer concentration in the cabin to tracer concentration in the exhaust (i.e. percent “self-pollution” or percent “leader intrusion”)

High/Low Exhaust Typical Results: Mobile Self-Pollution



High/Low Exhaust Typical Results: Mobile Leader-Pollution

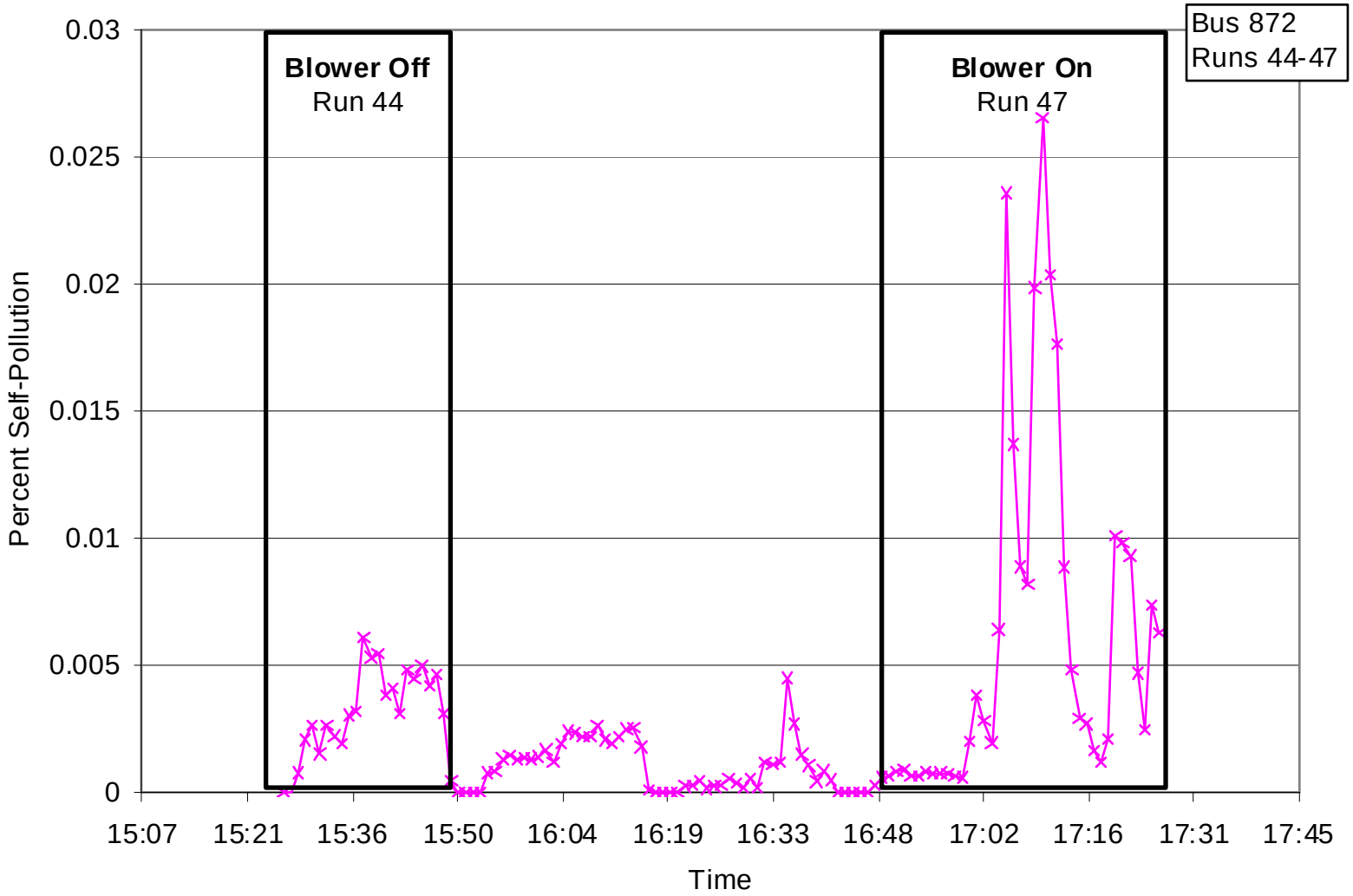


Powered Ventilation

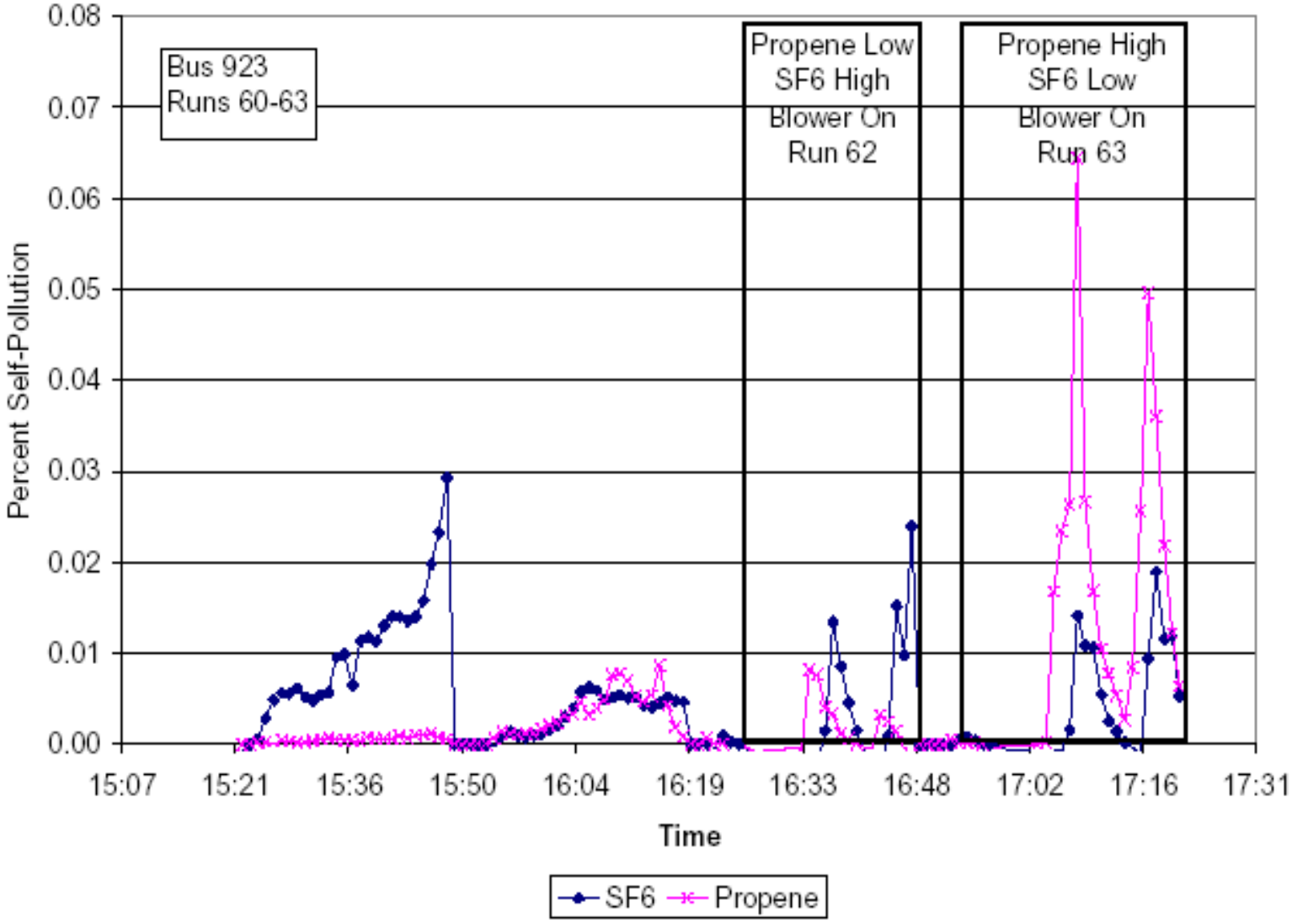
- Constant speed blower used inside the bus at 1200 cfm
- Air inlet at top of bus or at window
- Air outlet near the rear of the bus
- Four modes of operation (windows closed)
  - Stationary self-pollution high/low exhaust
  - Mobile self-pollution high/low exhaust
  - Stationary leader-pollution high/low exhaust
  - Mobile leader-pollution high/low exhaust

Powered Ventilation

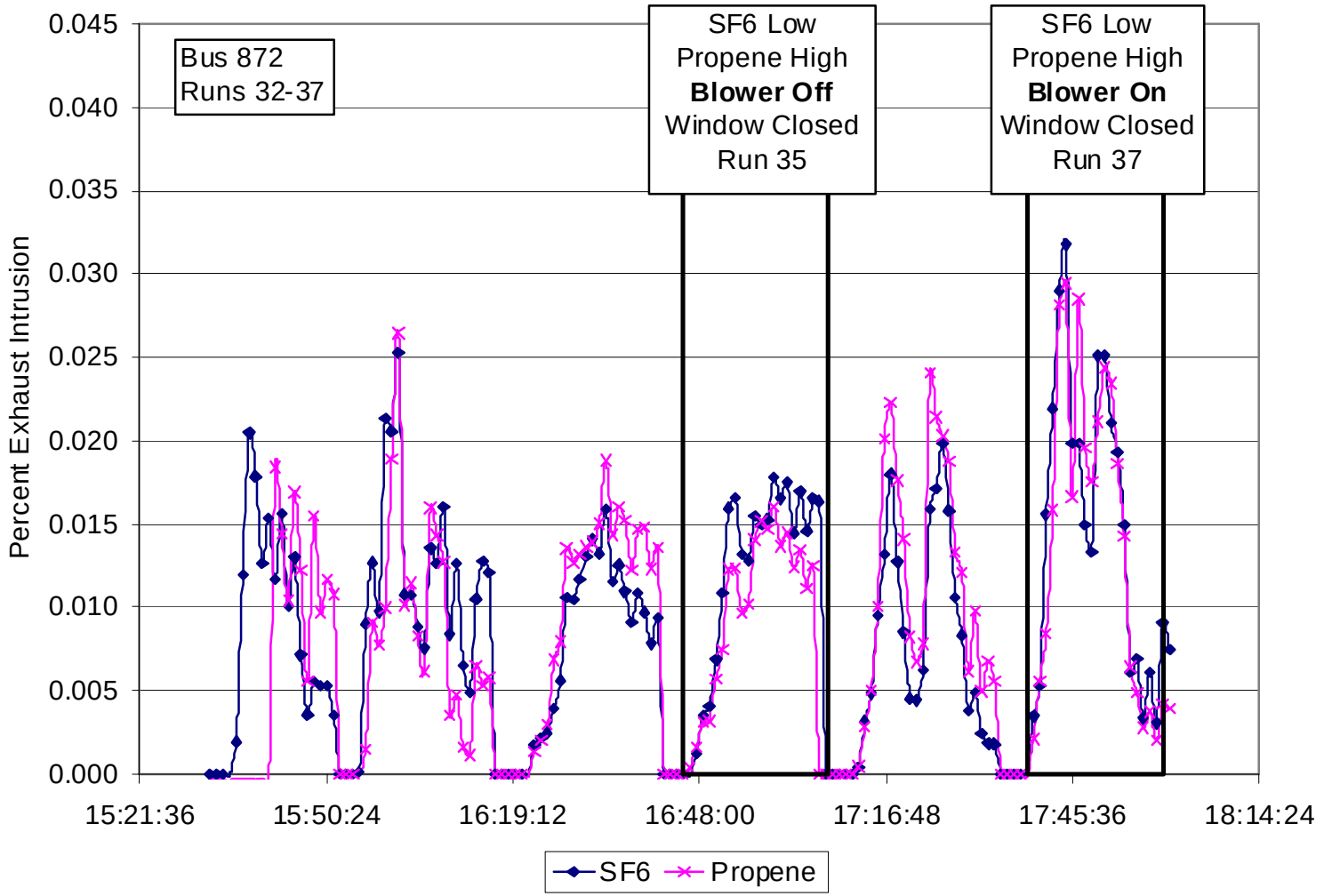
Powered Ventilation Typical Results: Mobile Self-Pollution



Powered Ventilation Typical Results: Mobile Self-Pollution



Powered Ventilation Typical Results: Mobile Leader-Pollution



Summary Results of Combined High-Low Exhaust and Powered Ventilation

MITIGATION METHOD	Exhaust High vs. Low	Blower On vs. Off	
TEST CONDITION	Blower Off	Exhaust Low	Exhaust High
RUN TYPE			
Self-Pollution, Mobile	++/-	++	+/--
Self-Pollution, Stationary	++/-	+/--	+/--
Leader-Follower, Mobile	+	+/-	-
Leader-Follower, Stationary	++	+/--	--

Conclusions

- Exhaust system leaks are minimal in a well-maintained bus
- Bus cabin leak rates varied significantly, but it was not clear that reducing leaks would significantly reduce exposure to exhaust
- Power ventilation reduced exposure in some cases but increased it in others
- Raising the exhaust was the most effective mitigation method
- Leader-pollution was approximately twice self-pollution

Acknowledgements

- California Air Resources Board
- Hemet Unified School District
- UCR Transportation Services

For More Information

- Final report to the California Air Resources Board: arb.ca.gov/research/apr/past/03-343.pdf

A second method for evaluating the performance of the release system was to investigate the concentration of tracer gas in the exhaust. Since conducting direct measurements in the exhaust was not feasible in this study (the high concentrations required were far beyond the range of the high sensitivity analyzers required after dilution), tracer gas concentration in the exhaust was calculated using Equation 5.1 below, as described in detail in Fitz et al. (2003) and Behrentz et al. (2004).

$$Cexh = Ccyl * \frac{Qcyl}{Qexh + Qcyl} \qquad (5.1)$$

where:

Q_{exh} = Exhaust flow ≈ Exhaust intake flow

C_{exh} = Concentration of tracer gas in the exhaust

Q_{cyl} = Tracer gas flow from the compressed gas cylinder

C_{cyl} = Concentration of tracer gas in the compressed gas cylinder

Table 5.1.1 Characteristics of the test buses.

Bus No.	Make/Model	Year	Mileage	Type
982	1998 Thomas Saf-T-Liner	1998	124,000	Diesel (with particle trap)
872	1987 Blue Bird	1987	324,000	Diesel
021	2002 Thomas Saf-T-Liner	2002	66,000	Diesel
923	1993 Carpenter SPT-3908	1992	128,000	Diesel (converted from CNG)

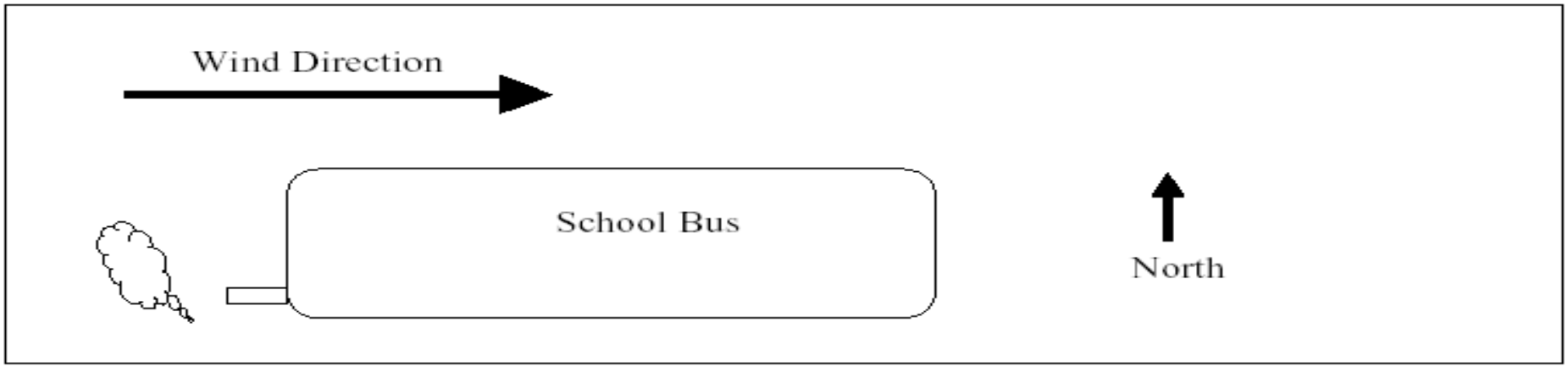


Figure 5.6.1 School bus orientation in relation to wind direction for stationary self-pollution runs.

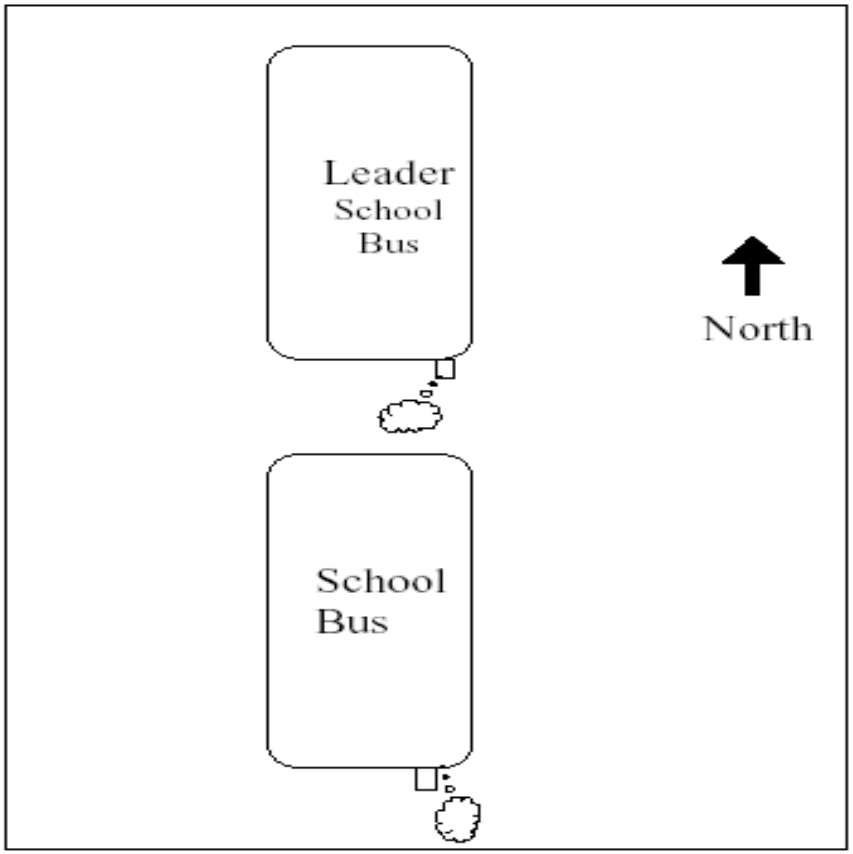


Figure 5.6.2 School bus orientation for leader exhaust testing. Both tracer gases are released from the leader bus from a high exhaust position and low exhaust position.