HIGH PERFORMANCE AIR FILTRATION FOR CLASSROOM APPLICATIONS

Andrea Polidori, Ph.D.
Quality Assurance Manager
SCAQMD Science and Technology Advancement

South Coast Air Quality Management District (AQMD)
21865 Copley Dr, Diamond Bar, CA 91765

PILOT STUDY: Introduction

- School-aged children spend ~30% of their day in classrooms. Minimizing the concentration of PM and other air toxics inside classrooms is important

- Common approach: installation of panel filters inside the HVAC system

- Filters in most classrooms and commercial buildings (e.g. MERV 7) not effective for PM < 0.3 µm (e.g. diesel PM and UFP)

- In-classroom filtration challenges
    - Older HVAC systems
    - Noise regulations
    - Doors and windows are frequently open
    - Indoor generation of PM and other pollutants

PILOT STUDY: Objectives

- Investigate the effectiveness of different air purification systems/solutions in reducing the exposure of children to indoor air contaminants

  - *SCAQMD*
  - *IQAir (air filtration manufacturer)*
  - *Thermal Comfort Systems (an HVAC contractor)*

- Pollutants for which the performance of the installed systems were tested:

  - *UFPs: < 0.1 μm; combustion of fossil fuels*
  - *$PM_{2.5}$: < 2.5 μm; primary and secondary origin*
  - *PM_{10}: < 10 μm); mechanical processes*
  - *BC: incomplete combustion; good indicator of diesel PM*
  - *VOCs: evaporative processes and combustion sources*

PILOT STUDY: Schools & Classrooms Characteristics

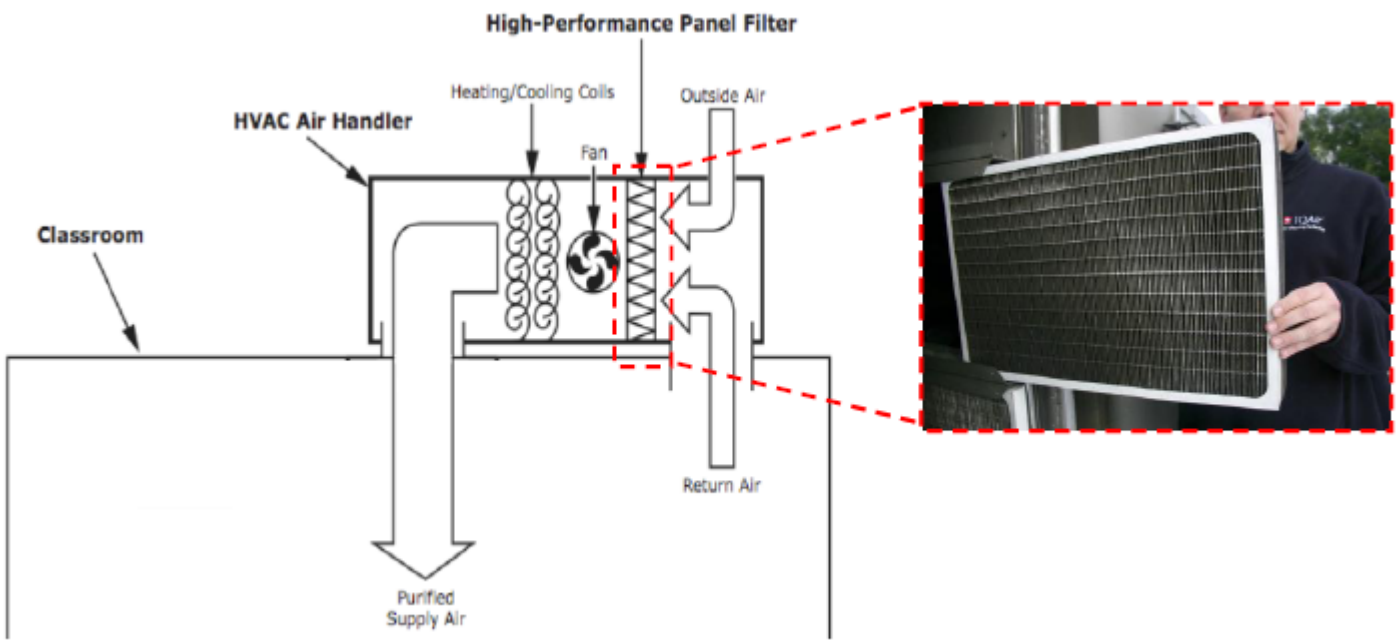
Union Pacific Railroad Intermodal Container Transfer Facility

- Del Amo Elmentary (LAUSD)
- Dominguez Elementary (LAUSD)
- Hudson (LBUSD)

- <u>Pilot Study</u>
  - April - December 2008
  - 3 schools / 9 classrooms
    - *Similar size (7500 to 9200 ft^3)*
    - *Similar ventilation conditions (HVAC)*
    - *MERV 7 (replaced every 3 mo)*

- <u>Major emission sources</u>:
  - *Refineries*
  - *Roadways*
  - *Los Angeles / Long Beach Port*
  - *UPRR ICTF*

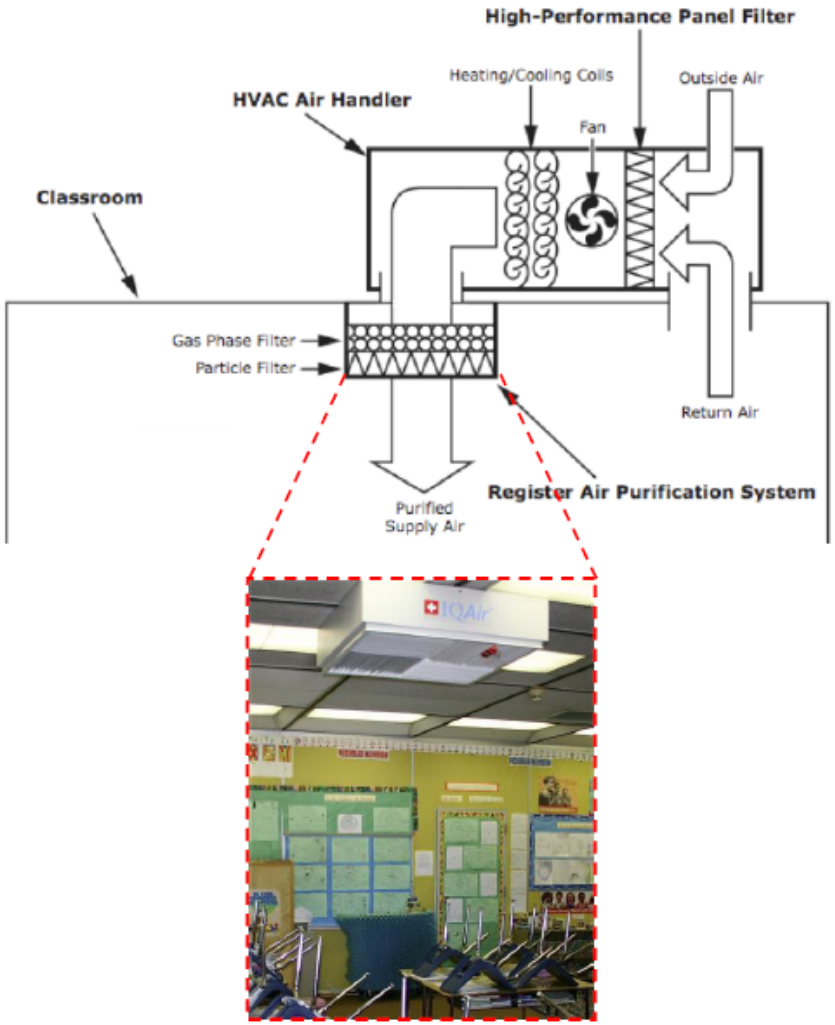
PILOT STUDY: Air Filtration Solutions
High-Performance Panel Filter (HP-PF)



- Compared to standard / conventional filters
  - *Proprietary technology (remove UFPs and BC)*
  - *Twice as thick (2" in depth); larger surface area (5-9 times larger)*
  - *Similar air resistance properties (do not reduce HVAC air flow)*
  - *Longer lifetime (>1 year)*

PILOT STUDY: Air Filtration Solutions

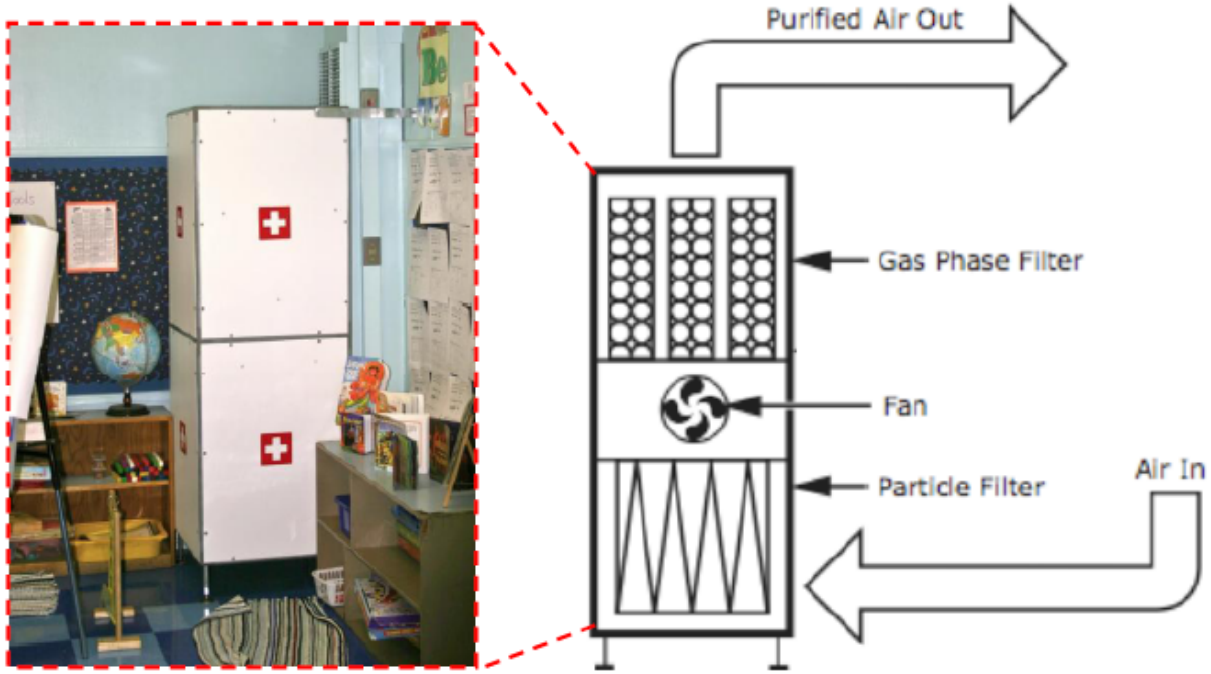
Register System (RS)



- Installed directly on the HVAC register
- Equipped with:
  - *HP-PF*
  - *High-capacity gas phase filter cartridges for VOC removal*
- RS does not reduce the overall HVAC system airflow

PILOT STUDY: Air Filtration Solutions

Stand-alone System (SA)



- Operates independently of a classroom's HVAC
- Height: 6' feet; Footprint: 4 ft^2
- Runs on a standard power circuit
- Ultra quiet operation (<45 db(A) at high airflow)
- Equipped with: HP-PF + 12 high-capacity gas phase filter cartridges

PILOT STUDY: *In-classroom Configurations*

HP-PF

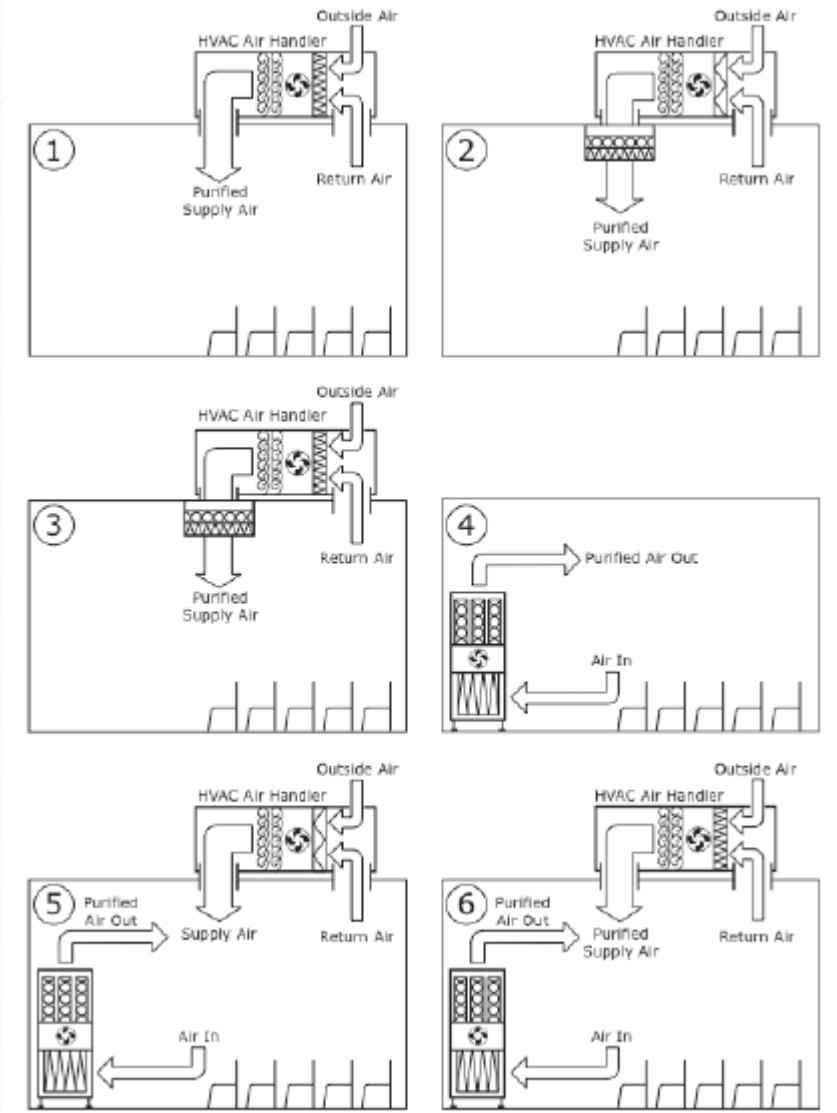
RS + PF

RS + HP-PF

SA
(no HVAC running)

SA + PF
(HVAC running)

SA + HP-PF



PILOT STUDY: *Indoor and Outdoor Measurements*

- Continuous Instruments
  - *UFP; #/cm^3*
  - *BC (µg/m^3)*
  - *$PM_{2.5}$ (#/cm^3)*
  - *$PM_{2.5}$ and PM_{10} (µg/m^3)*

- Integrated measurements
  - *PM_{10} (µg/m^3)*
  - *VOCs (ppbv)*

- Four carts: 1 outdoors + 3 indoors

- Removal efficiency (%) = [(OUT – IN) / OUT] 100

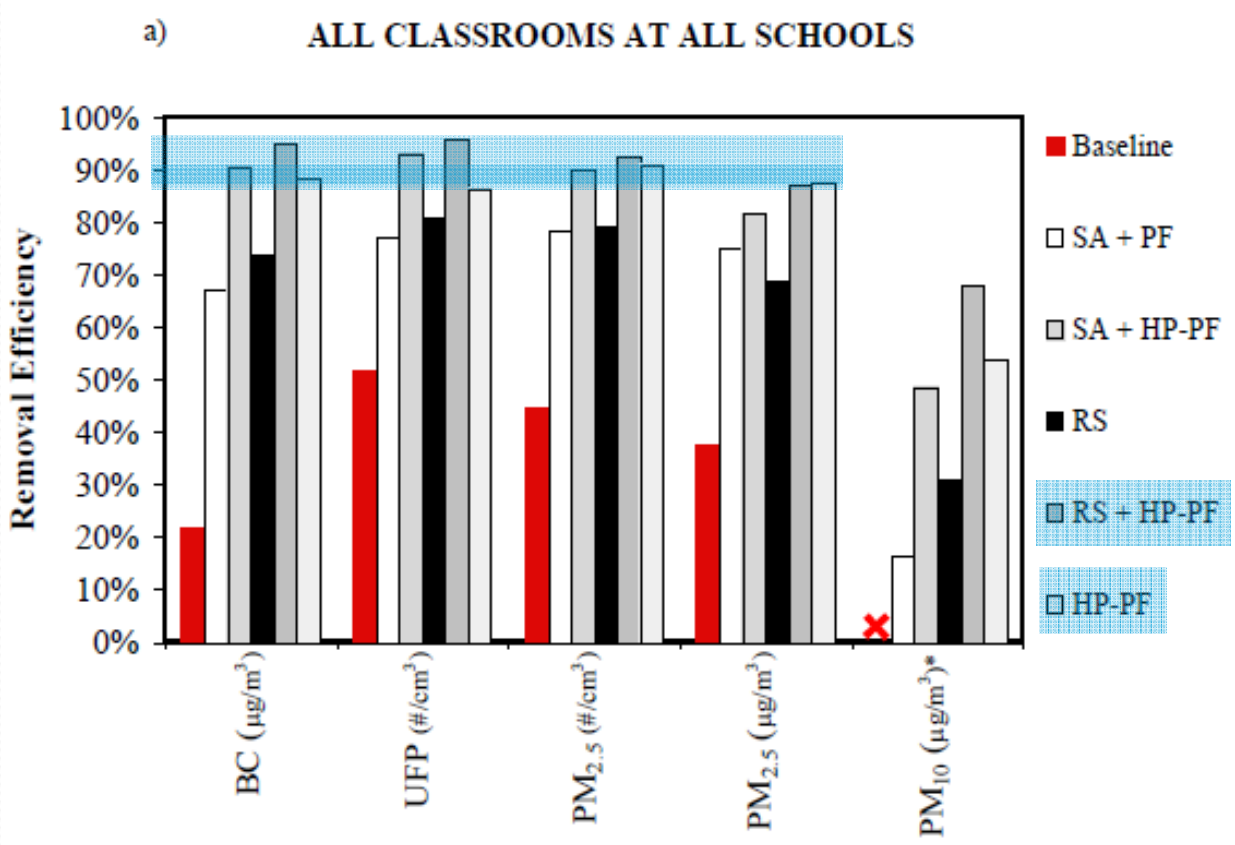
- Baseline measurements (pre-existing removal efficiencies)

- Collocated measurements (QA; precision, potential problems)

- Testing period: during school hours; >150 measurement days

PILOT STUDY: *Results*

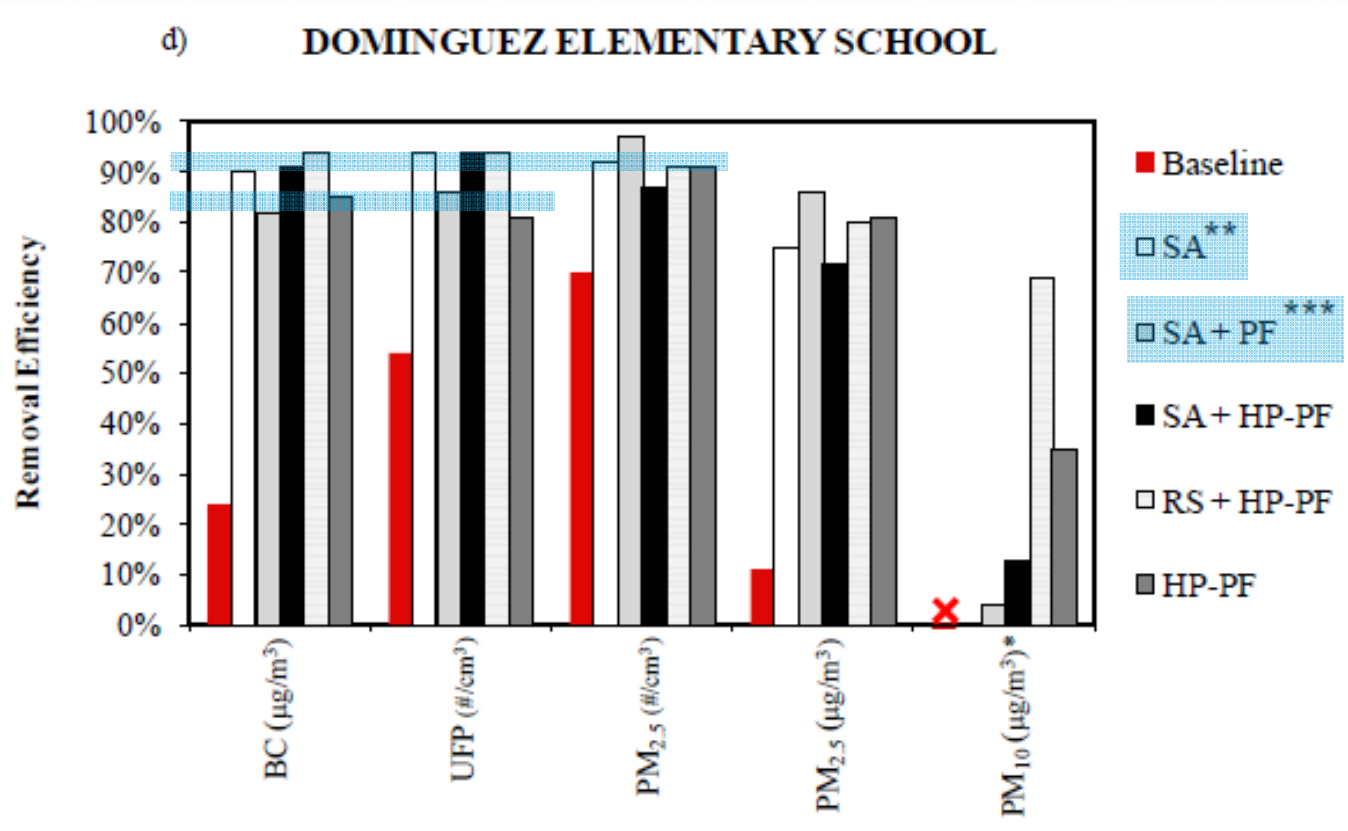
Removal of PM and Other Particle Species



- RS + HP-PF: most effective solution (study average removal efficiency = 87-96%)
- HP-PF: also an effective solution (study average removal efficiencies = 86-91%)

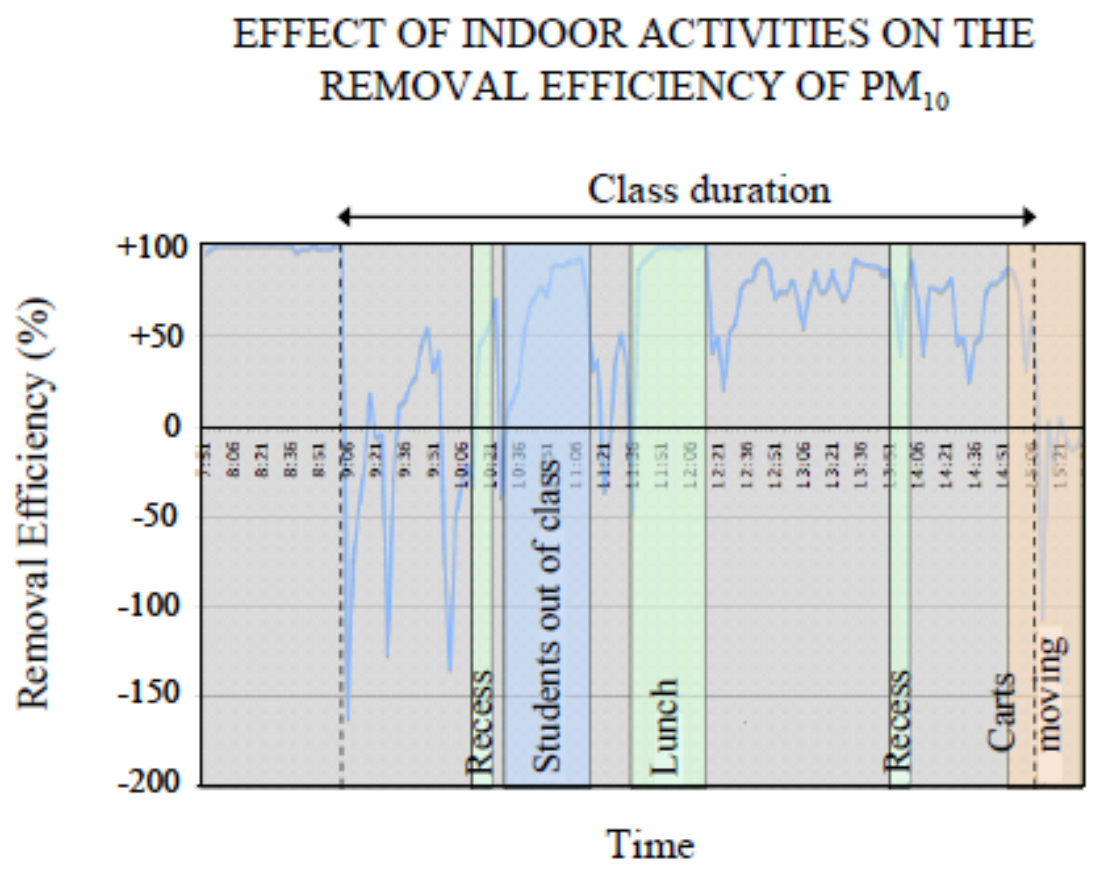
PILOT STUDY: *Results*

Removal of PM and Other Particle Species



- SA (HVAC off): removal efficiencies ~90% for BC, UFP and $PM_{2.5}$ (count)
- SA + PF (HVAC on): removal efficiencies < 90% for BC and UFP

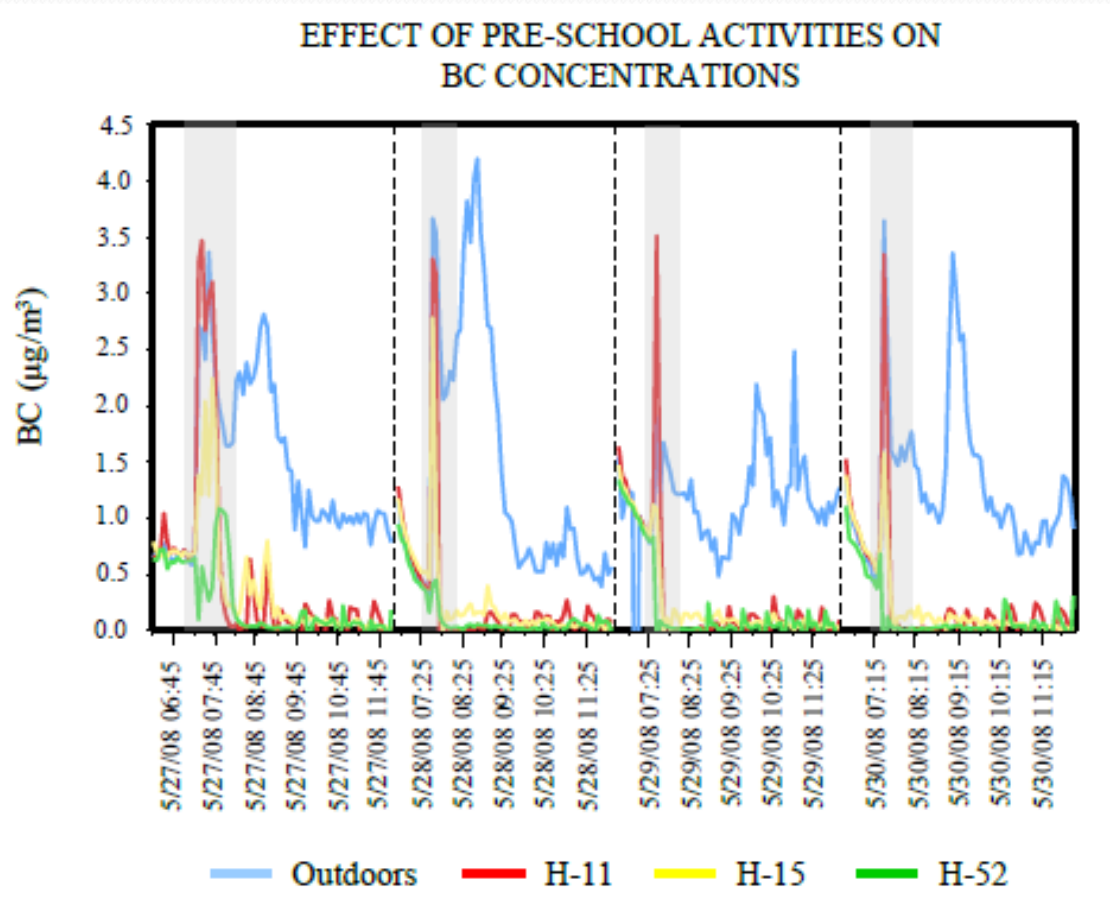
PILOT STUDY: *Results*
Effect of Indoor Activities



Hudson; room H-15
(May 21, 2008)

- Removal efficiency for PM_{10}
  - *High: before the school day started and during lunchtime*
  - *Low: when classes were in session*

PILOT STUDY: *Results*
Effect of Outdoor Activities



- Effect of morning drop-off (doors were open)
  - *BC increase; temporary decrease in removal efficiency*
  - *Relatively small decrease in average removal performance*

PILOT STUDY: *Results*
VOC Removal

	DOMINGUEZ ELEMENTARY SCHOOL			
	Study Days (#)	Total VOCs (%)[1]	Ethanol (%)	Benzene (%)
Baseline	18	-114 ± 731	-1230 ± 982	-11 ± 22
SA (HVAC off)*	3	15 ± 132	-349 ± 276	52 ± 35
SA + PF (HVAC on)**	4	19 ± 198	-587 ± 903	58 ± 33
SA + HP-PF	6	-6 ± 280	-929 ± 853	73 ± 11
RS	N/A	N/A ± N/A	N/A ± N/A	N/A ± N/A
RS + HP-PF	8	-3 ± 345	-534 ± 502	58 ± 49
HP-PF	18	-64 ± 404	-1111 ± 1164	1 ± 38

[1]Sum of 61 known VOCs and 53 unspeciated organic compounds
*Operated with the HVAC system turned off
**Operated with the HVAC system turned on

- Ethanol: from both indoor and outdoor sources
- Benzene: indicator of VOCs of outdoor origin

- Large standard deviations: wide concentration ranges for the different chemicals
- SA: 52-73% removal performance for benzene
- Several measured indoor VOCs are mostly of indoor origin

PILOT STUDY: *Summary and Conclusions*

• RS + HP-PF: most effective solution for BC, UFP, and $PM_{2.5}$ (study average removal efficiencies = 87-96%)

• <u>HP-PF: reductions close to 90%</u>

• Removal performance of PM_{10} was lower due to re-suspension of dust and other indoor activities (e.g. walking and cleaning)

• In all cases, air quality conditions were improved substantially with respect to baseline (pre-existing) conditions

• The effectiveness, lifetime, costs, benefits, and maintenance of the gas removal systems tested in this pilot study must be further assessed before conclusions and recommendations can be made

TESTING PROGRAM: Background and Objectives

• PON2010-02 (AQMD, 2010): "…to solicit a list of qualified air filtration devices to be used in the installation and maintenance of air filtration systems in Wilmington area schools using $5.4 million in funds from the TraPac Settlement Special Revenue Fund."

- Outreach: > 150 manufacturers
- Testing conducted by the University of California Riverside College of Engineering Center for Environmental Research & Technology (CE-CERT)
- PF, RS, and SA submitted between 05/07/10 and 06/30/10
  - *10 PF, 4 SA, 1 RS (9 different manufacturers)*

• Standard MERV rating system for filters do not address particles < 300 nm and fresh diesel PM (< 200 nm). Air filtration technologies are not typically tested for removal of UFP and BC

• Evaluate the efficiency of all received air filtration devices for reducing the outdoor-infiltrated and indoor-generated concentrations of UFP and BC in a typical classroom setting

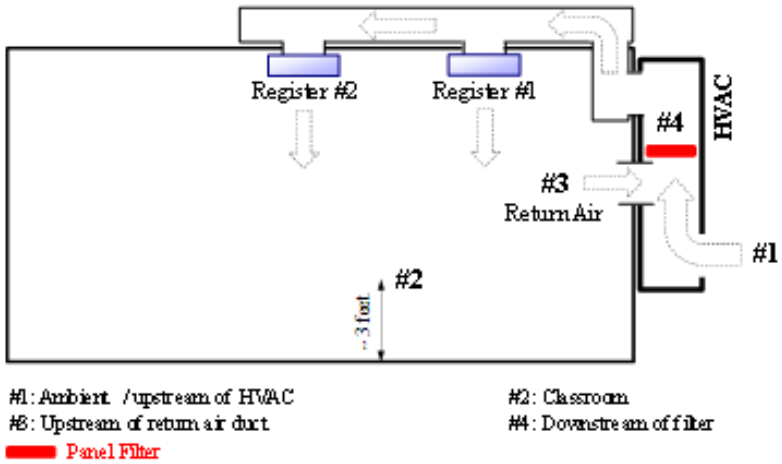
- Minimum requirements: 85% removal efficiency for UFP and BC

TESTING PROGRAM: *Testing Location*

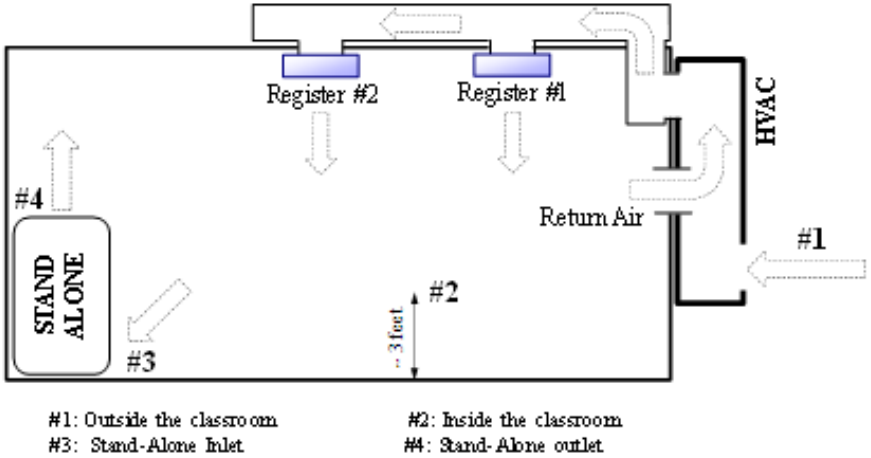
- Sunnyslope Elementary School (Riverside)
- Prefabricated / portable classrooms
- Classroom dimensions: 39’ 23’ 8.5’
- HVAC: BARD Inc. (~1550 cfm)
    - *~15% fresh air; ~85% return air*

TESTING PROGRAM: *Testing Procedure*

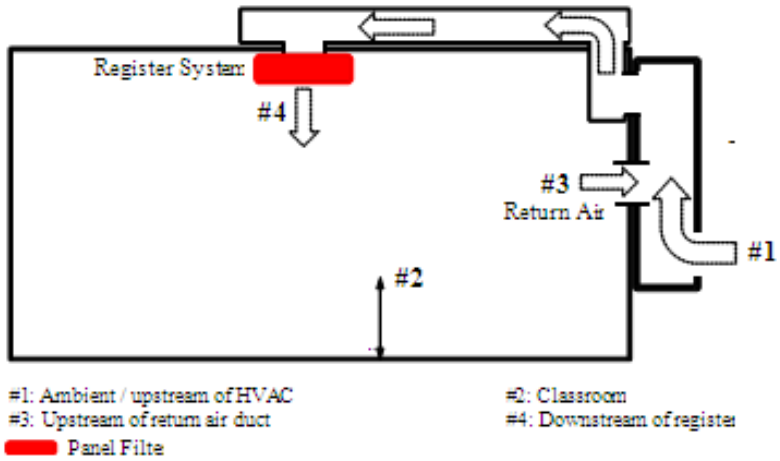
a) PF



c) SA



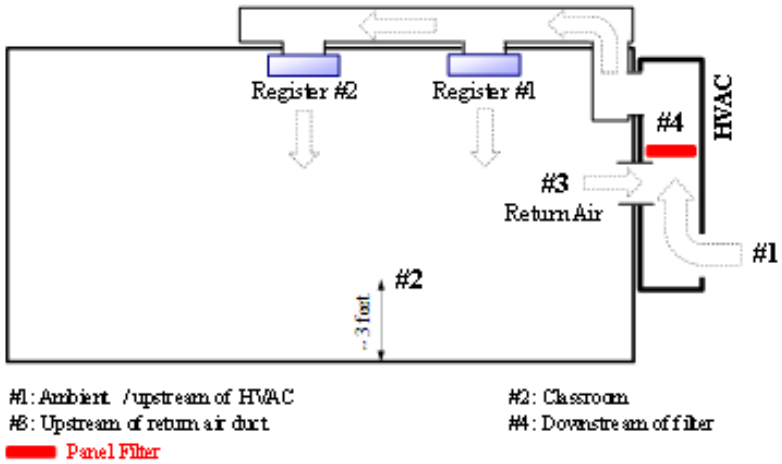
b) RS



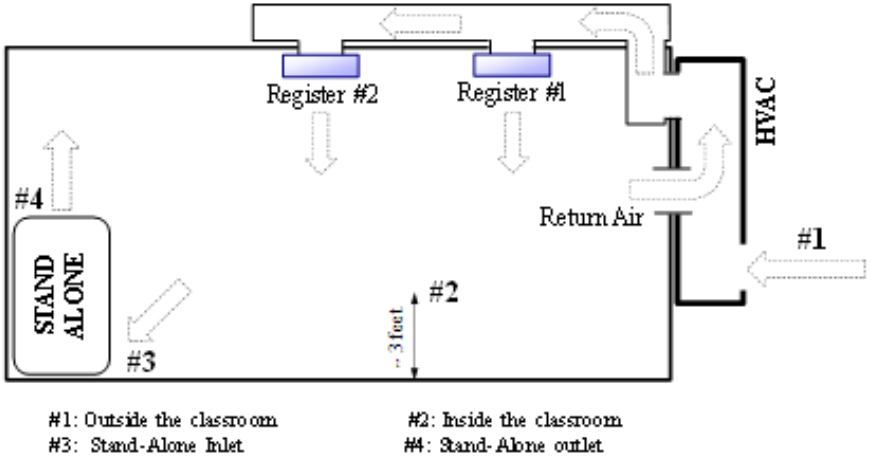
#1: Outside the classroom, upwind of the HVAC intake
#2: Classroom center at about 3' from the floor
#3a: Upstream of the return air intake duct (PF or RS)
#3b: Close to the air intake of the SA with the HVAC system on, and with no filtration device mounted on the HVAC register
#4a: Close to the downstream side of the PF or RS
#4b: Close to the outlet of the SA

TESTING PROGRAM: *Testing Procedure*

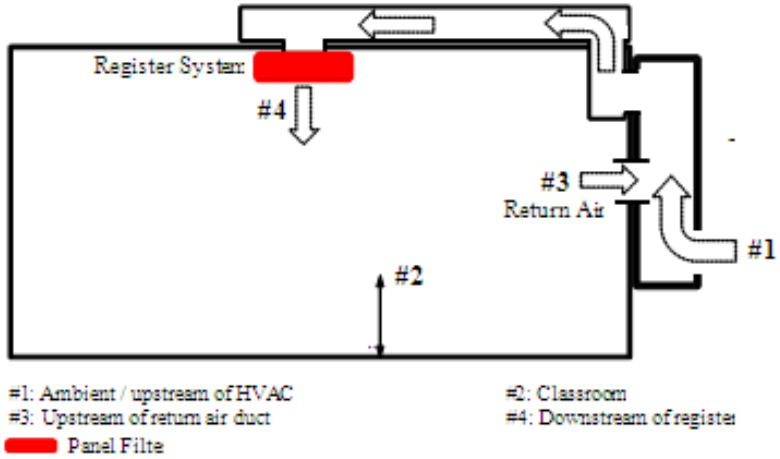
a) PF



c) SA

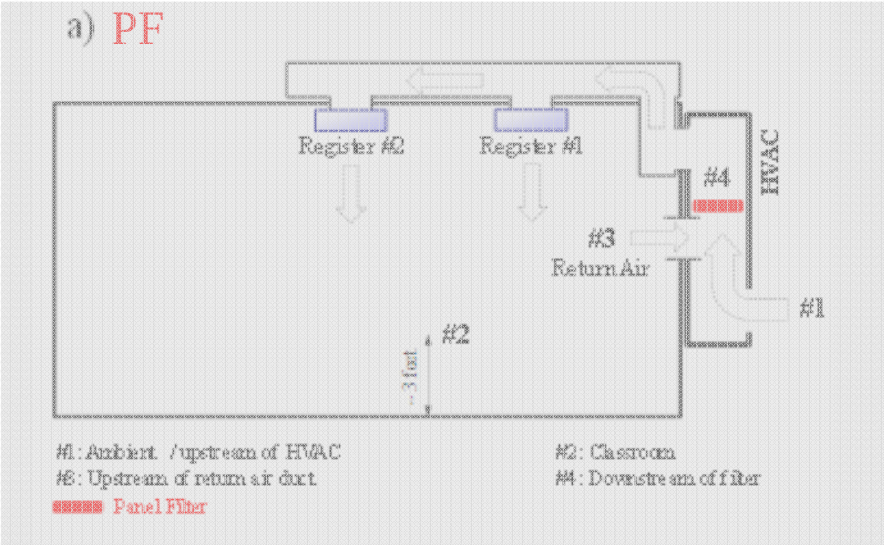


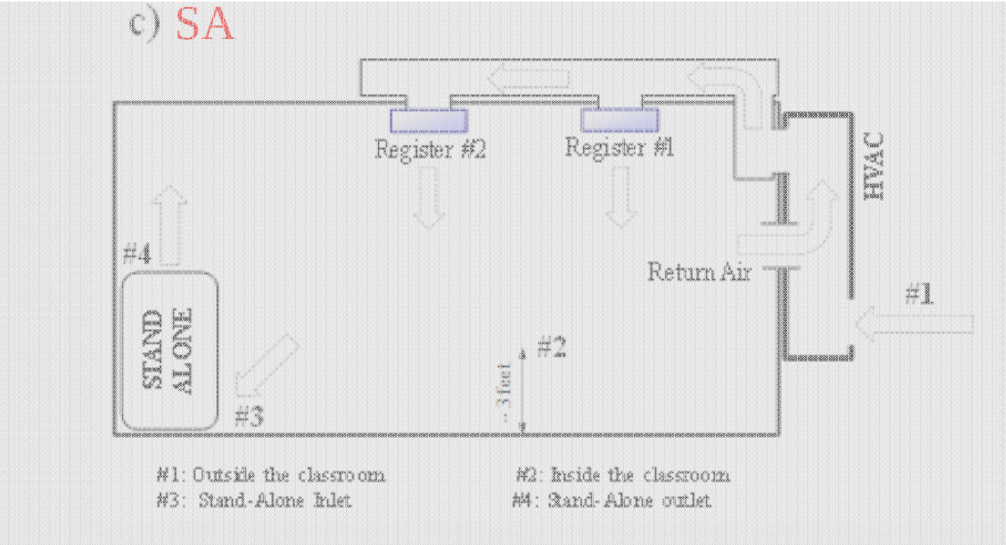
b) RS

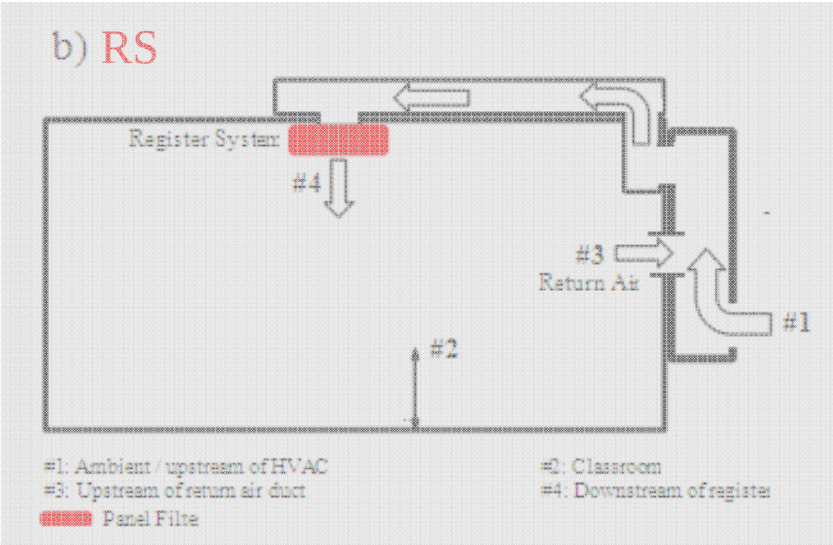


- Sampling was conducted for 6 hr
- Same repeatable conditions: HVAC system on and <u>no students</u>
- For SA: HVAC on but no filter
- Room temperature = 74 ºF
- 4 carts (1 outdoors; 3 indoors):
  - CPC (UFP)
  - Aethalometer (BC)

TESTING PROGRAM: *Testing Procedure*

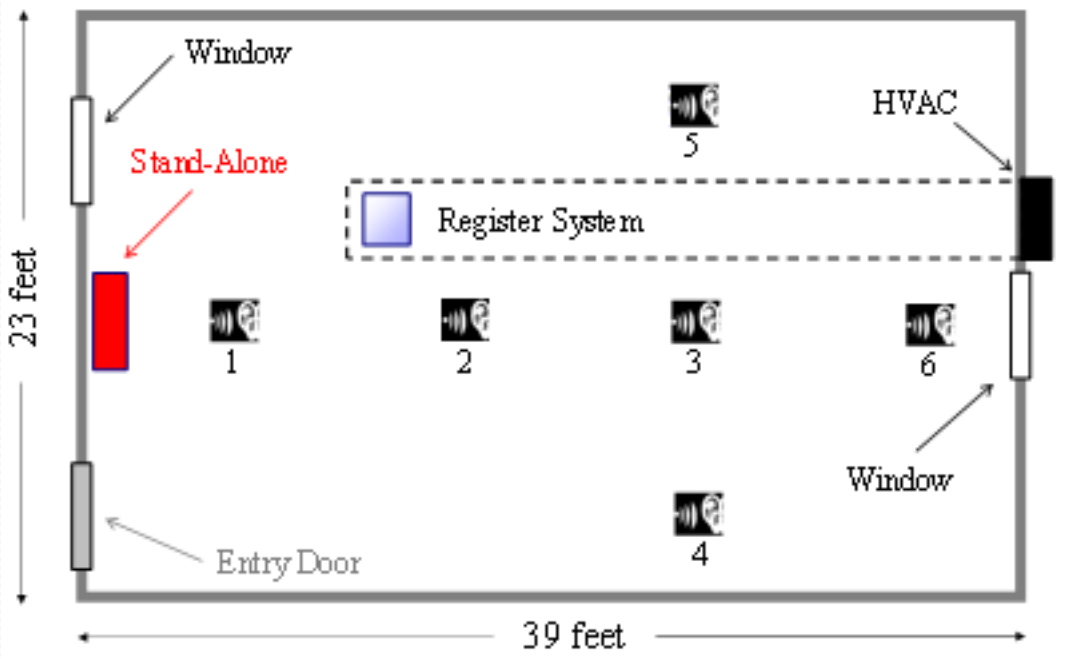






- <u>Baseline measurements</u>
  - 5 days (07/08/10 to 07/14/10); 6 hr/day
  - Pre-existing removal efficiencies before modification
  - Clean "low efficiency" PF mounted inside the HVAC; UFP and BC measured at positions 1-4
  - HVAC system on and <u>no students</u>
  - For SA: HVAC on but no filter

TESTING PROGRAM: *Additional Measurements*



#1 = 40”
#2 = 10’ 40”
#3 = 20’ 40”
#4 = 20’ 40” and 5’ N of #3
#5 = 20’ 40” and 7’ S of #3
#6 = 30’ 40”

- Noise level (for SA only): w/ HVAC off; meter at ~3 feet above the floor
- Pressure drop across the PF in the HVAC
- Ozone generation
- Indoor-outdoor air exchange rate (AER; hr^{-1}):

$$lnC_t = -(AER + k)t + lnC_0$$

TESTING PROGRAM:
Device Tested

Manufacturer	Model	Nominal Size	MERV rating	Delta P (inches water)	ID in report
Existing Filter (Baseline)	NA	20" x 30" x 1"	8	0.14	EF-8
Camil Farr	30/30® – M8	20" x 30" x 1"	8	0.10	CF-8
Air Cleaners, Inc.	Washable Electrostatic	20" x 30" x 1"	7	Not recorded	WE1-7
Air Cleaners, Inc.	Washable Electrostatic	20" x 30" x 2"	7	0.14	WE2-7
Freudenberg Filtration Technologies L. P.	Ultra 1500	20" x 30" x 1"	11	0.13	U-11
Freudenberg Filtration Technologies L. P.	Maxx 2000	20" x 30" x 1"	12	0.14	M-12
eSpin Technologies, Inc.	Exceed	20" x 30" x 2"	11	0.10	E-11
eSpin Technologies, Inc.	Exceed	20" x 30" x 2"	13	0.12	E-13
eSpin Technologies, Inc.	Exceed	20" x 30" x 2"	14	0.24	E-14
IQ Air	IQ Air MERV 13	20" x 30" x 2"	13	0.08	IQ-13
IQ Air	Nanomax S-220	20" x 30" x 2"	16	0.13	IQ-16
IQ Air	CleanZone SL	72" x 29" x 10"	500	NM	CZ
Pure Air	HPS 350	13" x 13" x 21.5"	140 - 350[2]	NM	PA
NQ Industries Inc.	NQ400	32" x 26" x 13"	195 - 545[3]	1.1[4]	NQ-1
NQ Industries Inc.	NQ Clarifier	28" x 15" x 14"	350[5]	NM	NQ-2
Environmental Dynamics Group, Inc.	1V8-4812-291/2	51" x 57" x 14"	NA	NM	EDG

PF

SA

RS

NA = Not applicable
NM = Not measured
[2] Four switchable flow rates between 140 and 350 cfm; tested at 350 cfm
[3] Four switchable flow rates between 195 and 545 cfm; tested at 545 cfm. Also contains one UV lamp
[4] Reading on gage of NQ-1
[5] Variable speed fan up to a maximum flow rate of 350 cfm; tested at 350 cfm. Also contains two UV lamps

TESTING PROGRAM: *Removal Efficiencies and Performance Criteria*

• Relative Removal Efficiency: percentage reduction in the concentration of UFP (or BC) downstream of the device tested (position #4) relative to its concurrent ambient (outdoor) level upstream of the HVAC (position #1)

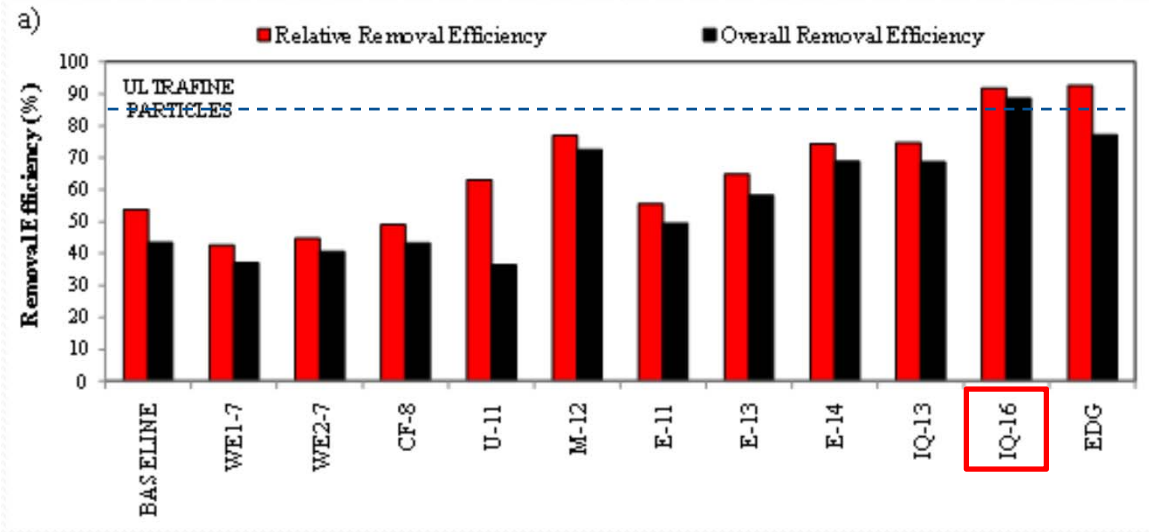
$$RRE = 100 \times (P_{\#1} - P_{\#4})/P_{\#1}$$

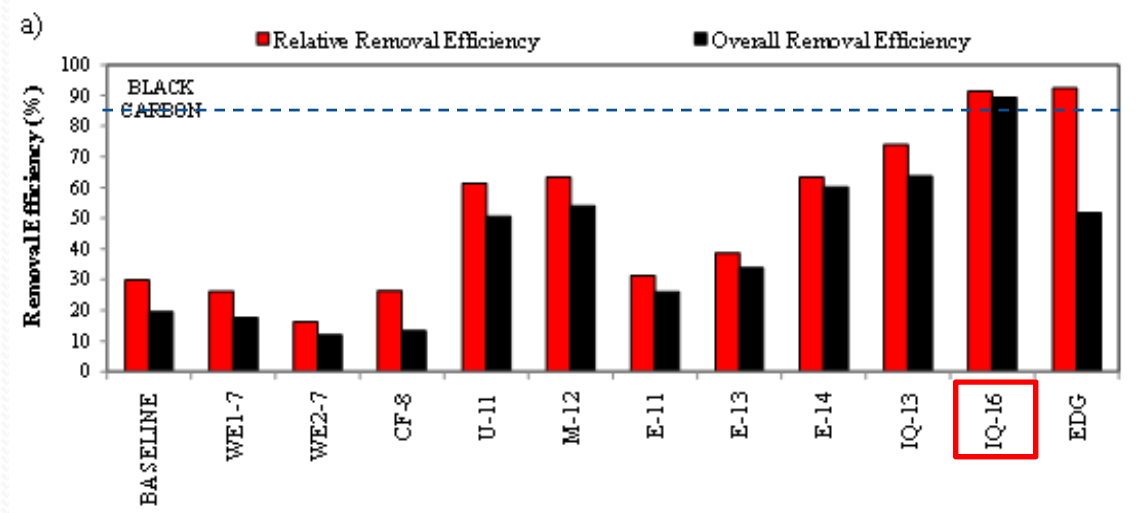
• Overall Removal Efficiency: percentage reduction in the concentration of UFP (or BC) inside the classroom (position #2) relative to its concurrent ambient (outdoor) level (position #1)

$$ORE = 100 \times (P_{\#1} - P_{\#2})/P_{\#1}$$

• Performance Criteria:
- High removal efficiency
  - *PF and RS: Overall removal efficiency for UFP and BC > 85%*
  - *SA: Relative removal efficiency for UFP and BC > 85%*
- Low pressure drop (PF)
- Noise level < 45 decibels [db(A)] (SA)
- Negligible O_3 generation (<5 ppb)

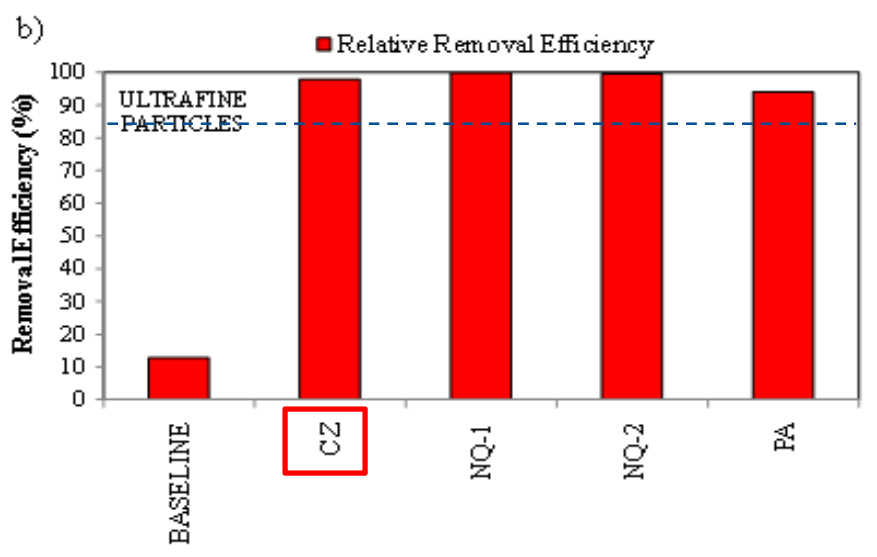
TESTING PROGRAM: *Results (PF and RS)*

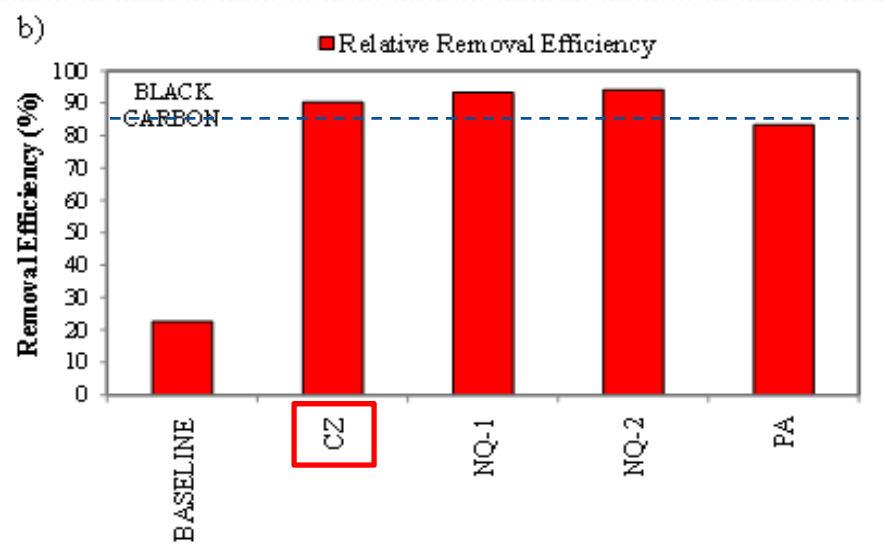




- PF:
  - > MERV rating
    > removal efficiency
  - MERV 7
    - 37-45% removal for UFP
    - 12-26% removal for BC
    - No improvement from baseline
  - MERV 16
    - 89% removal for UFP and BC
    - Only “approved” PF
- RS:
  - Relative removal > 85%
  - Overall removal < 85%

TESTING PROGRAM: *Results (SA)*





- SA:
  - UFP and BC at position #2 affected by
    - Classroom configuration
    - Proximity to supply registers
    - Lower air flow rate
    - Classroom set-up
  - Relative removal efficiency is a better measurement of performance
  - High relative removal efficiencies
    - 94-100% for UFP
    - 83-94% for BC
  - Clear-Zone
    - Noise level = 44.4 dB(A)
    - Only “approved” SA

TESTING PROGRAM: *Summary and Conclusions*

- Over 150 manufacturers contacted by AQMD staff
  - 9 companies participated in this program
  - 15 air filtration devices submitted for testing
    - 10 PF; 4 SA; 1 RS

- PF:
  - Overall (and relative) removal efficiencies increased with increasing MERV rating
  - The "Nanomax S-220" (IQAir; MERV 16) was the only HVAC-mounted device that satisfied the performance requirements set by AQMD

- SA:
  - Relative removal efficiencies is the most robust measurement to evaluate SA performance
  - All SA tested showed high removal efficiencies
  - Only the "CleanZone SL" (IQAir) did not exceed a noise level of 45 decibels [dB(A)]

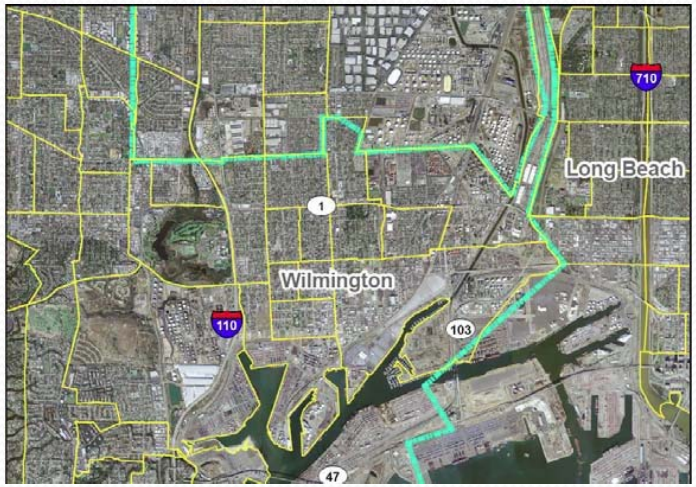
SCAQMD AIR FILTRATION IMPLEMENTATION

- SCAQMD started $1.125M implementation program in Los Angeles-Long Beach Port area schools (2009)
- Air filtration installation at seven Los Angeles and Long Beach schools within 10 mile of Valero Refinery (penalty settlement) (2010-2012)

First installation of air filtration systems completed at Del Amo Elementary (LAUSD) in Jan 2010

TRAPAC AIR FILTRATION PROGRAM

- In Jan 2011 SCAQMD Governing Board approved execution of a $5.4M contract with IQAir North America for installation of air filtration systems in 47 schools
- Selection of contractor involved RFP for air filtration installers and testing of air filtration technologies
- Steering and technical advisory committees
- Installation completed at 27 Phase I schools in 2012-2013; starting Phase II schools



Geographical area of schools in TraPac program

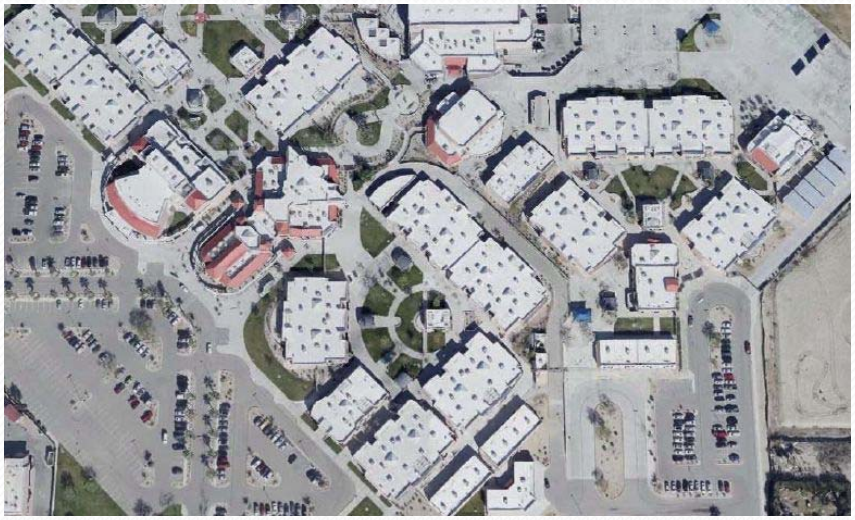
RFG AIR FILTRATION PROJECTS

- MELA and CCAEJ installed air filtration at schools in Boyle Heights and San Bernardino using RFG funds ($950,000 and $1M respectively) (2012-2013)
- Combined with EPA Region 9 CATI, Targeted Air Shed grants, SCAQMD Priority Reserve funding
  - 7 Boyle Heights schools - LAUSD and Archdiocese
  - 6 San Bernardino schools - SBCUSD and JUSD

CCAEJ

CVUSD AIR FILTRATION

- CVUSD and IQAir received grants for $337,200 and $921,000 to install air filtration in at least 10 schools
  - PM filtration to assist with dust and agricultural burning issues
  - Saul Martinez and Mecca ES will demonstrate VOC removal technologies to mitigate odor issues at schools



ACKNOWLEDGEMENTS

The pilot study was funded through the use of mitigation fees collected by the SCAQMD under Rule 1172 for VOC releases by local refineries

The testing program has been conducted by the University of California, Riverside, Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT)

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