Quantitative Methodologies to the Community Air Protection Incentives 2019 Guidelines

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A. OVERVIEW

Assembly Bill (AB) 617 (Chapter 136, Statutes of 2017) directed the California Air Resources Board (CARB or Board), in conjunction with local air quality management districts and air pollution control districts (air districts) to establish the Community Air Protection (CAP) Program. On May 23, 2019, the Board approved the *Community Air Protection Incentives 2019 Guidelines* (CAP Guidelines) intended to support the goals of AB 617.

The purpose of the Quantitative Methodologies is to describe the quantitative methods to calculate emissions reductions and benefits for the project types outlined in Chapters 4 and 5 of the CAP Guidelines. The Quantitative Methodologies document is laid out such that Section B addresses emissions reductions for Hexavalent Chrome Plating projects from Chapter 4 of the CAP Guidelines, and Sections C, D, and E address the calculations for Composite Wood Products, Zero Emissions Lawn and Garden, and Air Filtration project types from Chapter 5, respectively.

Funding for CAP incentives is appropriated from the Greenhouse Gas Reduction Fund (GGRF). Some projects may require greenhouse gas (GHG) emissions reductions calculations, if applicable, which will be noted in the pertinent section. GHG quantification methodologies are developed in accordance with the *Funding Guidelines for Agencies that Administer California Climate Investments* and are published on the following web page: https://ww2.arb.ca.gov/resources/documents/cci-quantification-benefits-and-reporting-materials.

B. CHROME PLATING AND CHROMIC ACID ANODIZING OPERATIONS

Hexavalent chromium has an associated Air Toxic Control Measure (ATCM) and is currently known to be the second most potent carcinogen identified by the Board. Hexavalent chromium electroplating and chromic acid anodizing operations involve the electrical application of a coating of chromium onto a surface for decoration, corrosion protection, or for durability. These processes cause mists containing hexavalent chromium to be emitted from the plating tanks and dispersed into indoor and outdoor ambient air.

The quantitative methodology outlined below aims to quantify the emissions reductions achieved by facilities upgrading their control technologies or switching to a trivalent chromium process. It first establishes baseline emissions for a facility, then the reduced emissions, and then the total emissions reductions.

1. Chrome Plating Methodology

The Baseline Emissions is dependent on local air district permitting and the annual ampere-hour usage that these operations are obligated to report annually per the Chrome Plating ATCM regulation.

Equation 1: Baseline Emissions

$$Baseline\ Emissions\ (mg) = Reported\ Input\ \ (amp - hrs) * Baseline\ Emissions\ Rate\ \left(\frac{mg}{amp - hrs}\right)$$

Table B - 1: Equation 1 Variables

Equation 1 Variables	Variable Description	Units
Baseline Emissions	Annual emissions prior to project implementation	milligram
Reported Input	Annual amp-hours reported by district	ampere-hours
Baseline Emissions Rate	Rate in which emissions occur based on the ATCM Criteria	milligram/ampere-hour

The Baseline Emissions Rate can be determined by consulting Table B-2. For facilities that use chemical fume suppressants, the ATCM Limit is equal to 0.01 mg/amp-hr[1]. The ATCM criteria is used to establish the baseline. However, if a facility has approved source testing data form within a year of application, then the tested rate in units of mg/amp-hr can be used as the Baseline Emissions Rate instead. If limits from a local air district regulation apply, then those limits should be used for determining the Baseline Emissions Rate, provided they are stricter than the ATCM limits.

For the Reported Input, the last three years of reported amp-hours should be used if the data is available. If not, the most recently reported amp-hours should be used instead. In the absence of reported amp-hour data then the permitted amp-hours may be used.

[1] Fact Sheet for Chrome Plater Using Fume Suppressants, California Air Resources Board, https://ww3.arb.ca.gov/toxics/chrome/chrome.htm, 09-23-2015.

Table B - 2: Chromium Plating ATCM Emission Limits[2]

Distance[3]	Ampere-Hours[4]	Emissions Limitation	Start Date
≤ 330 feet	≤ 20,000	Use of specific chemical fume suppressants	4/24/2008
≤ 330 feet	> 20,000 - ≤ 200,000	0.0015 mg/amp-hr with add-on control	10/24/2010
≤ 330 feet	> 200,000	0.0015 mg/amp-hr with add-on control	10/24/2009
> 330 feet	≤ 50,000	Use of specific chemical fume suppressants	4/24/2008
> 330 feet	> 50,000 - ≤ 500,000	0.0015 mg/amp-hr	10/24/2011
> 330 feet	> 500,000	0.0015 mg/amp-hr with add-on control	10/24/2009

Equation 2: Reduced Emissions

$$Reduced\ Emissions\ (mg) = Reported\ Input\ \ (amp - hrs) * Reduced\ Emissions\ Rate\ \left(\frac{mg}{amp - hrs}\right)$$

Table B - 3: Equation 2 Variables

Equation 2 Variables	Variable Description	Units
Reduced Emissions	Annual emissions after to project implementation	milligram
Reported Input	Annual amp-hours reported by district	ampere-hours
Reduced Emissions Rate	Rate at emissions occur based on the ATCM Criteria	milligram/ampere-hour

[2] Title 17, California Code of Regulations, Division 3, Chapter 1, Subchapter 7.5, section 93102.4, https://govt.westlaw.com/calregs/Document/I2B330560D60811DE88AEDDE29ED1DC0A?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default), 12/06/2019

[3] Distance refers to a chrome plating facility's proximity to its nearest sensitive receptor. Distance plays a role in determining the appropriate ATCM criteria but is not an input of the calculations outlined in the methodology.

[4] Permitted annual/ampere-hours.

The CAP Guidelines require source testing to confirm post-technology emissions prior to the payment of grant funds and considers this testing to be eligible for funding. In accordance to the criteria in title 17, CCR, section 93102.07, a minimum of three test runs are necessary to confirm the post-technology emissions. The results of these test runs will provide emissions rates in the units of mg/amp-hr. Test results should either be averaged or the most representative result chosen to determine the Reduced Emissions Rate. Although a trivalent chromium plating process can still result in minimal hexavalent chromium emissions, the Reduced Emissions Rate is assumed to be 0 mg/amp-hr for a facility that has converted to trivalent chromium process.

The Total Emissions Reduction is the difference between the Baseline Emissions and the Reduced Emissions, Equation 3.

Equation 3: Total Emissions Reductions

$$Total\ Emissions\ Reduction\ (mg) = Baseline\ Emissions\ \ (mg) - Reduced\ Emissions\ (mg)$$

Table B - 4: Equation 3 Variables

Equation 3 Variables	Variable Description	Units
Total Emissions Reduction	Total hexavalent chromium emissions reduced	milligram
Baseline Emissions	Annual emissions prior to project implementation	milligram
Reduced Emissions	Annual emissions after to project implementation	milligram

2. Chrome Plating Example Calculations

Example 1 Conditions: A chrome plating facility that is 400 ft. from the nearest sensitive receptor and permitted to run at 100,000 ampere-hours has installed HEPA filters to gain further hexavalent chromium emission reductions. No additional ventilation installation was necessary because there was already existing ducting. Last year this facility reported that their usage was 90,000 amp-hrs and that post-control technology testing has confirmed that they now operate at 0.0001 mg/amp-hr.

Table B - 5: Example 1 Provided Variable Values

Variable	Value	Units
ATCM Limit[5]	0.0015	mg/amp-hr
Permitted Input	100,000	amp-hrs
Reported Input	90,000	amp-hrs
Reduced Emissions Rate	0.0001	mg/amp-hr

Using Equation 1

$$Baseline\ Emissions\ (mg) = 90{,}000\ \ (amp - hrs) * 0.0015\ \left(\frac{mg}{amp-hrs}\right) = \mathbf{135\ (mg)}$$

Using Equation 2

$$Reduced\ Emissions\ (mg) = 90{,}000\ \ (amp - hrs) * 0.0001\ \left(\frac{mg}{amp-hrs}\right) = \mathbf{9\ (mg)}$$

Using Equation 3

$$Total\ Emission\ Reductions\ (mg) = 135\ \ (mg) - 9\ (mg) = \mathbf{126\ (mg)}$$

[5] From Table B - 2

Example 2 Conditions: A chrome plating facility recently switched away from their hexavalent chromium process in favor of a trivalent chromium process. They are located 250 ft. from the nearest sensitive receptor and are permitted for 15,000 amp-hours with the use of chemical fume suppressants. Their most recently reported usage was 12,500 amp-hours.

Table B - 6: Example 2 Provided Variable Values

Variable	Value	Units
ATCM Limit[6]*	0.01	mg/amp-hr
Permitted Input	15,000	amp-hrs
Reported Input	12,500	amp-hrs
Reduced Emissions Rate[7]**	0	mg/amp-hr

Using Equation 1

$$Baseline\ Emissions\ (mg) = 12{,}500\ \ (amp-hrs) * 0.01\ \left(\frac{mg}{amp-hrs}\right) = \mathbf{125}\ (\boldsymbol{mg})$$

Using Equation 2

$$Reduced\ Emissions\ (mg) = 12{,}500\ \ (amp-hrs) * 0\ \left(\frac{mg}{amp-hrs}\right) = \mathbf{0}\ (\boldsymbol{mg})$$

Using Equation 3

$$Total\ Emissions\ Reduction\ (mg) = 125\ \ (mg) - 0\ (mg) = \mathbf{125}\ (\boldsymbol{mg})$$

[6] For facilities that use chemical fume suppressants.

[7] Although it is possible there can be minimal emissions of hexavalent chromium converted during the trivalent chromium plating process, staff assumed 0 mg/amp-hr of hexavalent chromium.

C. COMPOSITE WOOD PRODUCTS

CARB evaluated formaldehyde exposure in California and found that composite wood products containing formaldehyde glues[8] can emit formaldehyde over time as the product off-gases. Once classroom furniture is a few years old, off-gassing is no longer a concern. When classroom furniture is damaged and needs to be replaced, formaldehyde emissions from new furniture can be minimized by replacing damaged furniture and other composite wood equipment with items made with no-added formaldehyde (NAF) or ultra-low emitting formaldehyde (ULEF) furniture, which emit less formaldehyde.

The outlined methodology specifically focuses on quantifying emissions reductions of formaldehyde for the following regulated composite wood products contained in classroom furniture and equipment: hardwood plywood (HWPW), particleboard (PB), and medium and thin density fiberboard (MDF). The methodology will result in a rate reduction of formaldehyde release and will provide guidance in determining composite wood surface area and formaldehyde emissions rates for the various composite wood products.

1. Composite Wood Product Methodology

The formaldehyde emission rate reductions from composite wood products are estimated as the difference between Phase 2 compliant baseline and project scenarios over the project life using Equations 1-4. When the type of composite wood material is unknown, assume the composite wood board is a medium density fiberboard and use the emission factors related to this type of board for the emission rate reduction calculations.

The equations below calculate the emission rates for composite wood boards under standard test conditions. Some of the assumptions with the methodology are:

- Formaldehyde emissions are reduced from surfaces that are laminated; composite wood board material that is laminated, such as the upper surface, seals in emissions.

[8] Battelle (1996). Determination of Formaldehyde and Toluene Diisocyanate Emissions from Indoor Residential Sources. https://ww3.arb.ca.gov/toxics/compwood/implementation/93-315a.pdf?_ga=2.236447553.1740808918.1579641097-1957062033.1571425543

- Formaldehyde emissions from the composite wood products do not exceed the formaldehyde emissions standards established in the ATCM for Phase 2 or NAF/ ULEF products.

Equation 1: Dimensions of composite wood surface

$$SA = lw$$

Table C - 1: Equation 1 Variables

Equation 1 Variables	Variable Description	Units
SA	Surface Area	m^2
L	Length	meters
W	Width	meters

Equation 2A: Phase 2 Compliant ATCM wood product emissions per square meter

$$Phase\ 2\ Board\ Emission\ Rate = \frac{(Form\ ER)(Phase\ 2\ ATCM)(AirExchR)}{Loading\ Ratio}$$

Table C - 2: Equation 2A Variables

Equation 2A Variables	Variable Description	Units
Phase 2 Board Emission Rate	Hourly rate of formaldehyde emissions from the exposed compliant Phase 2 ATCM composite board surface area	mg/m^2hr
Form ER	Formaldehyde Emissions Rate	$mg/m^3/ppm$
Phase 2 ATCM	"Emissions Criteria for Compliance in Parts per Million (ppm)"	ppm
AirExchR	Air exchange rate in testing chamber	exchanges/hr
Loading Ratio	Loading ratio of test material*	m^2/m^3

ASTM E 1333- Standard Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber.

This calculation is based on ASTM E 1333 and the air exchange rate is 0.50 air exchanges per hour for all composite wood board types used in this quantification methodology.

Loading Ratio:

- Hardwood Plywood: 0.43 m^2/m^3
- Particleboard: 0.43 m^2/m^3
- Medium Density Fiberboard: 0.26 m^2/m^3

Equation 2B: Total Emissions from Phase 2 Compliant Board

$$\begin{aligned}&\textit{Total Hourly Rate of Phase 2 Board Emissions}\\&\quad = (\textit{Phase 2 Board Emission Rate})(SA)(\textit{Exposed Surfaces})\end{aligned}$$

Table C - 3: Equation 2B Variables

Equation 2B Variables	Variable Description	Units
Total Hourly Phase 2 Board Emission Rate	Rate of formaldehyde emissions from the compliant Phase 2 ATCM composite board	mg/hr
Phase 2 Board Emission Rate (from Equation 2A)	Hourly rate of formaldehyde emissions from the exposed compliant Phase 2 ATCM composite board	mg/m^2hr
SA	Surface area	m^2
Exposed Surfaces	Number of units of equivalent SA Exposed: Assumed to be 0.5 of the surfaces exposed (*e.g.*, number of desktop surfaces exposed)	NA

Equation 3A: NAF/ ULEF Compliant ATCM wood product emissions

$$\textit{NAF or ULEF Board Emission Rate} = \frac{(\textit{Form ER})(\textit{NAF or ULEF})(\textit{AirExchR})}{\textit{Loading Ratio}}$$

Table C - 4: Equation 3A Variables

Equation 3A Variables	Variable Description	Units
Total Hourly NAF or ULEF Board Emission Rate	Hourly emission rate from the exposed compliant NAF or ULEF Board consistent with ATCM composite board surface area	mg/m^2hr
Form ER	Formaldehyde emissions rate	$mg/m^3/ppm$
Phase 2 NAF or ULEF	NAF or ULEF Emissions Criteria for Compliance in Parts per Million (ppm) in accordance with ATCM	ppm
AirExchR	Air exchange rate in testing chamber	exchanges/hr-
Loading Ratio	Loading ratio of test material	m^2/m^3

ASTM E 1333- Standard Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber.

This calculation is based on ASTM E 1333 and the air exchange rate is 0.50 air exchanges per hour for all composite board types used in this quantification methodology.

Loading Ratio:

- Hardwood Plywood: 0.43 m^2/m^3
- Particleboard: 0.43 m^2/m^3
- Medium Density Fiberboard: 0.26 m^2/m^3

Equation 3B: Total Emissions from NAF or ULEF Compliant Board

$$Total\ NAF\ or\ ULEF\ Board\ Emissions = (NAF\ or\ ULEF\ Board\ Emission\ Rate)(SA)(Exposed\ Surfaces)$$

Table C - 5: Equation 3B Variables

Equation 3B Variables	Variable Description	Units
Total Hourly NAF or ULEF Board Emissions	Emissions from the compliant NAF or ULEF ATCM composite wood board[9]*	mg/hr
NAF or ULEF Board Emission Rate (from equation 3A)	Emissions from the compliant NAF or ULEF ATCM	mg/m^2hr
SA	Surface area	m^2
Exposed Surface	Number of units of equivalent SA Exposed: Assumed to be 1 / 2 of the exposed surfaces (*e.g.*, number of desktop surfaces exposed)	N/A

Equation 4: Emission Rate Reductions from NAF or ULEF to Standard Phase 2 ATCM Compliant Board

$$ER\ Total = (Total\ Phase\ 2\ Board\ Emission\ Rate) - (Total\ NAF\ or\ ULEF\ Board\ Emission\ Rate)$$

Table C - 6: Equation 4 Variables

Equation 4 Variables	Variable Description	Units
ER Total	Total emission rate reduction	mg/hr
Total Hourly Phase 2 Board Emission Rate	Emissions from the compliant Phase 2 ATCM composite wood board	mg/hr
Total Hourly NAF or ULEF Board Emission Rate	Emissions from the compliant NAF or ULEF ATCM composite wood board	mg/hr

[9] Emissions are from Composite Wood Emission Table C – 7.

Table C - 7: CARB ATCM to Reduce Formaldehyde Emissions from Composite Wood Products, Title 17, CCR Section 93120

Type of Wood Product	Emissions Criteria for Compliance in Parts per Million (ppm)	Emission Standards for No-Added Formaldehyde Resin (ppm)[10]	Emission Standards for Ultra-Low Emitting Formaldehyde Resin (ppm)[11]
Hardwood Plywood	0.05	0.05	0.05
Particleboard	0.09	0.06	0.06
Medium Density Fiberboard	0.11	0.06	0.06
Thin Medium Density Fiberboard	0.13	0.06	0.06

[10] CCR § 93120.3. A manufacturer may be exempt from third party certification for two years if the manufacture demonstrates that 90% of its quality control test results during a 3-month period are no higher than 0.04 ppm; all results must be at or below the concentrations listed.

[11] CCR § 93120.3. A manufacturer may be exempt from third party certification for two years if the manufacture demonstrates that 90% of its quality control test results during a 6-month period are no higher than 0.04 ppm; all results must be at or below the concentrations listed. This is restricted to ULEF manufacturers that have been granted an exemption from third-party certification

2. Composite Wood Product Example Calculations

This example calculation is for a new student desk. Only the desktop consists of composite wood product. The calculation is for one piece of equipment; the emission reductions can then be multiplied by the total number of desks being replaced through CAP incentives.

Assumptions:

- Composite wood products are only in desktop
- Desktop consists of high-pressure laminate affixed to platform (core) material consisting of either particleboard (PB), scenario 1, and medium density fiberboard (MDF), scenario 2.
- Assume that the desktop does not contain hardwood plywood
- Assume that the total emissions of a board represent both sides of the board and formaldehyde emissions can only leak out of underside of desk (which is unlaminated). The upper surface of the composite wood platform material is laminated, which seals in most of the emissions from the upper surface.
- Assume emissions are highest allowed by ATCM for Phase 2 and NAF products

(Reference: ASTM E 1333 – Standard Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber)

Example 1

Scenario 1: Phase 2 ATCM Particle Board (PB) replaced with No-Added Formaldehyde Product

Equation 1: Dimensions of Desk Top Surface

$$SA = lw$$

$$SA = 24\ in. \times 48\ in. = \mathbf{0.74\ m^2}$$

Equation 2A: Phase 2 Compliant ATCM Particle Board (PB)

$$Phase\ 2\ Board\ Emissions\ = \frac{(Form\ ER)(Phase\ 2\ ATCM)(AirExchR)}{Loading\ Ratio}$$

Form ER = 1.23 mg/m^3 /ppm

Phase 2 ATCM = 0.09 ppm

AirExchR = 0.5 /hr

Loading Ratio = 0.43 m^2/m^3

$$Phase\ 2\ Board\ Emissions\ = \frac{\left(1.23\frac{mg}{m^3 \times ppm}\right)(0.09\ ppm)\left(\frac{0.5}{hr}\right)}{0.43\frac{m^2}{m^3}} = \mathbf{0.13\frac{mg}{m^2 \times hr}}$$

Equation 2B: Total Emissions from Phase 2 PB Compliant Board

$$*\ Total\ Emissions\ Board\ Phase\ 2 = \ (Phase\ 2\ Board\ Emissions)(SA)(Exposed\ Surface)$$

*Note: Total emissions represent 2 sides of the panel board.

Phase 2 Board Emissions = 0.13 mg/m^{2}hr

SA = 0.74 m^2

Exposed Surfaces = 1 / 2

$$Total\ Emissions\ Board\ Phase\ 2 = \left(0.13\frac{mg}{m^2 \times hr}\right)(0.74\ m^2)\left(\frac{1}{2}\right) = \mathbf{0.048\frac{mg}{hr}}$$

Equation 3A: NAF Compliant ATCM Desk Top Emissions

$$NAF\ or\ ULEF\ Board\ Emissions\ = \frac{(Form\ ER)(Phase\ 2\ NAF\ or\ ULEF)(AirExchR)}{Loading\ Ratio}$$

Form ER = 1.23 mg/m^3 /ppm

Phase 2 NAF = 0.04 ppm

AirExchR = 0.5 /hr

Loading Ratio = 0.43 m^2/m^3

$$NAF\ Board\ Emissions\ = \frac{\left(1.23\frac{mg}{m^3 \times ppm}\right)(0.04\ ppm)\left(\frac{0.5}{hr}\right)}{0.43\frac{m^2}{m^3}} = \mathbf{0.057}\frac{\boldsymbol{mg}}{\boldsymbol{m^2 \times hr}}$$

Equation 3B: Total Emissions from NAF Desk Top

$$Total\ Emissions\ NAF\ or\ ULEF\ Board = (NAF\ or\ ULEF\ Board\ Emissions)(SA)(Exposed\ Surfaces)$$

NAF Board Emissions = 0.057 mg/m^2hr

SA = 0.74 m^2[5]

Exposed Surface = 1 / 2

$$Total\ Emissions\ NAF\ Board = \left(0.057\frac{mg}{m^2 \times hr}\right)(0.74\ m^2)\left(\frac{1}{2}\right) = \mathbf{0.021}\frac{\boldsymbol{mg}}{\boldsymbol{hr}}$$

Equation 4: Emission Rate Reductions from NAF Board and Standard Phase 2 PB

$$ER\ Total = (Total\ Emissions\ Board\ Phase\ 2) - (Total\ Emission\ NAF\ or\ ULEF\ Board)$$

Total Emission Board Phase 2 Board = 0.048 mg/hr

Total Emissions from NAF Board = 0.021 mg/hr

$$ER\ Total = \left(0.048\frac{mg}{hr}\right) - \left(0.021\frac{mg}{hr}\right) = \mathbf{0.027}\frac{\boldsymbol{mg}}{\boldsymbol{hr}}$$

Example 2

Scenario 2: Phase 2 ATCM Medium Density Fiberboard (MDF) replaced with No-Added Formaldehyde Product.

Equation 2A: Phase 2 Compliant ATCM MDF

$$Phase\ 2\ Board\ Emissions\ = \frac{(Form\ ER)(Phase\ 2\ ATCM)(AirExchR)}{Loading\ Ratio}$$

Form ER = 1.23 mg/m³ /ppm

Phase 2 ATCM = 0.11 ppm

AirExchR = 0.5 exchanges/hr

Loading Ratio = 0.26 m²/m³

$$Phase\ 2\ Board\ Emissions\ = \frac{\left(1.23\frac{mg}{m^3\ x\ ppm}\right)(0.11\ ppm)\left(\frac{0.5}{hr}\right)}{0.26\frac{m^2}{m^3}} = \mathbf{0.26}\frac{\boldsymbol{mg}}{\boldsymbol{m^2 \times hr}}$$

Equation 2B: Total Emissions from Phase 2 PB Compliant Board

$$Total\ Emissions\ Board\ Phase\ 2 = (Phase\ 2\ Board\ Emissions)(SA)(Exposed\ Surfaces)$$

Phase 2 Board Emissions = 0.26 mg/m²hr

SA = 0.74 m²

Exposed Surface = 1 / 2

$$Total\ Emissions\ Board\ Phase\ 2 = \left(0.26\frac{mg}{m^2 \times hr}\right)(0.74\ m^2)(\frac{1}{2}) = \mathbf{0.10}\frac{\boldsymbol{mg}}{\boldsymbol{hr}}$$

Equation 3A: NAF Compliant ATCM Desk Top Emissions

$$NAF\ or\ ULEF\ Board\ Emissions\ = \frac{(Form\ ER)(Phase\ 2\ NAF\ or\ ULEF)(AirExchR)}{Loading\ Ratio}$$

Form ER = 1.23 mg/m³ /ppm

Phase 2 NAF = 0.04 ppm

AirExchR = 0.5 exchanges/hr

Loading Ratio = 0.26 m²/m³

$$NAF\ Board\ Emissions\ = \frac{\left(1.23\frac{mg}{m^3 \times ppm}\right)(0.04\ ppm)\left(\frac{0.5}{hr}\right)}{0.26\frac{m^2}{m^3}} = \mathbf{0.095}\frac{\boldsymbol{mg}}{\boldsymbol{m^2 \times hr}}$$

NAF Desk Top Emissions =

Equation 3B: Total Emissions from NAF Desk Top

$$Total\ Emissions\ NAF\ or\ ULEF\ Board = (NAF\ or\ ULEF\ Board\ Emissions)(SA)(Exposed\ Surfaces)$$

NAF Board Emissions = 0.095 mg/m^2hr

SA = 0.74 m^2

Exposed Surface = 1 / 2

$$Total\ Emissions\ NAF\ Board = \left(0.095\frac{mg}{m2Xhr}\right)(0.74\ m^2)\left(\frac{1}{2}\right) = \mathbf{0.035\frac{mg}{hr}}$$

Equation 4: Emission Rate Reductions from NAF Board and Standard Phase 2 MDF

$$ER\ Total = (Total\ Emissions\ Board\ Phase\ 2) - (Total\ Emission\ NAF\ or\ ULEF\ Board)$$

Total Emission Board Phase 2 Board = 0.095 mg/hr

Total Emissions from NAF Board = 0.035 mg/hr

$$ER\ Total = \left(0.095\frac{mg}{hr}\right) - \left(0.035\frac{mg}{hr}\right) = \mathbf{0.060\frac{mg}{hr}}$$

D. ZERO EMISSION LAWN AND GARDEN

A quantitative methodology for the Zero Emission Lawn and Garden category is currently in development. However, GHG emissions reductions can still be quantified for this category. Quantitative methodologies for determining emissions reductions for GHGs are published by CCI and can be found here: https://ww2.arb.ca.gov/resources/documents/cci-quantification-benefits-and-reporting-materials.

E. AIR FILTRATION

Students are exposed to particulate matters with a diameter of 2.5 micrometers and smaller ($PM_{2.5}$) sources from inside the classroom and from outside sources. Outdoor PM can enter the classroom through mechanical ventilation, natural ventilation (open windows and doors), and infiltration through gaps in windows, walls, and doors. Indoor sources of PM2.5, such as particle resuspension, are not considered in this work. This methodology quantifies the reduction of indoor $PM_{2.5}$ levels for school classrooms that have upgraded air filtration, through either higher efficiency air filters in central ventilation systems, stand-alone (portable) air cleaners, or a combination of both. Upgraded air filtration includes replacement of filters with higher efficiency ones, or by increasing the volume of air that is filtered. The methodology applies to both stand-alone (portable) air cleaners and central systems with high efficiency air filters installed.

1. Air Filtration Methodology

Indoor $PM_{2.5}$ exposure concentrations are influenced by both the infiltration level of outdoor $PM_{2.5}$ along with the ability of HVAC/filtration systems to remove $PM_{2.5}$ from within the classroom. The reduction of exposure concentration of $PM_{2.5}$ due to enhanced filtration is estimated as the difference in indoor $PM_{2.5}$ levels with the current system compared to indoor $PM_{2.5}$ levels with an upgraded air filtration or the addition of portable air cleaners.

DISCLAIMER: This quantification methodology is intended to support projects funded with CAP incentives only. There are several assumptions and default values utilized[12] and these parameters may not be representative of all situations.

Some of the assumptions include:

- HVAC systems are constantly utilized in the classroom
- Outdoor $PM_{2.5}$ concentrations are assumed to be a single value based on CalEnviroScreen estimations
- Indoor $PM_{2.5}$ exposure concentrations are based on $PM_{2.5}$ from outdoor origin, indoor sources are not included. Note: This assumption will result in underestimation of indoor $PM_{2.5}$ levels
- Default values of ventilation rates and particle characteristic parameters are used to represent actual conditions

[12] The assumptions and default values used in this methodology, as well as the derivation of the equations used, can be found in Appendix I.

- Filter bypass is ignored in this method

Replacement filters often have a Minimum Efficiency Reporting Value (MERV) rating associated with them. A typical MERV rating will have a number associated with it ranging from 5 to 16 with higher efficiency ratings corresponding with higher values. High-Efficiency Particulate Air (HEPA) filters is another replacement filter option available for use. For portable air cleaners, a Clear Air Delivery Rate (CADR) is used to describe a volumetric rate of air filtration.

Equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms with HVAC system only.

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{(6.4h^{-1}(Filter\ Efficiency) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1})(Outdoor\ PM_{2.5}\ levels)}$$

Table E - 1: Equation 1 Variables

Equation 1 Variables	Description	Units
Indoor $PM_{2.5}$ levels	Ambient $PM_{2.5}$ levels indoors	µg/m^3
Outdoor $PM_{2.5}$ levels	Ambient $PM_{2.5}$ levels outdoors (from CalEnviroScreen)	µg/m^3
Filter efficiency	(% reduction) in $PM_{2.5}$ achieved through filtration MERV 5 (2.0%) = 0.02 MERV 6 (6.9%) = 0.069 MERV 7 (23.6%) = 0.236 MERV 8 (26.4%) = 0.264 MERV 10 (30.5%) = 0.305 MERV 12 (65.6%) = 0.656 MERV 14 (71.0%) = 0.710 MERV 16 (96.3%) = 0.963 HEPA (99.7%) = 0.997	N/A

When a portable air cleaner is implemented in the classroom, Equation 2 can be used to calculate indoor $PM_{2.5}$ levels. The CADR refers to the Clear Air Delivery Rate.

Equation 2: Estimation of indoor $PM_{2.5}$ levels in classrooms with a portable air cleaner.

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{6.4h^{-1}(Filter\ Efficiency) + \frac{CADR}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}(Outdoor\ PM_{2.5}\ levels)$$

Use Equation 2 when portable air cleaning units are utilized. The following equation (Equation 3) can be used to calculate the reduction of indoor PM2.5 concentrations calculated using Equation 1 with the application of new air filters or Equation 2 with the addition of a portable air cleaner.

Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

Table E - 2: Equation 3 Variables

Equation 3 Variables	Description	Units
Indoor $PM_{2.5}$ (current)	Current indoor $PM_{2.5}$ concentration calculated using equation 1	μg/m^3
Indoor $PM_{2.5}$ (new)	New indoor $PM_{2.5}$ concentration calculated using Equation 1 or 2	μg/m^3
Reduction of indoor $PM_{2.5}$ concentrations	Reduction of indoor $PM_{2.5}$ *concentrations* from switching from the current air filter to the new air filter	μg/m^3

2. Air Filtration Example Calculations

Example 1 – Richmond, CA

Scenario 1.1 – Upgrades HVAC Filter Panels Only

Scenario 1.2 – Upgrades to 1 – 2 Portable Air Cleaning Devices

From CalEnviroScreen, range of outdoor ambient $PM_{2.5}$ annual average values for Richmond: 7.86-8.69 μg/m^3

Scenario 1.1: Upgrading HVAC Filters

Outdoor Ambient $PM_{2.5}$ = 8.1 μg/m^3

Current system: MERV 7 (Filter efficiency (23.6%) = 0.236)

New System: MERV 14 (Filter efficiency (71.0%) = 0.710)

Using Equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04h^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{6.4h^{-1}(Filter\ Efficiency) + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}}(Outdoor\ PM_{2.5}\ levels)$$

Calculation of current Indoor $PM_{2.5}$ level (MERV 7):

$$Indoor\ PM_{2.5}\ (current) = \frac{2.04h^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}}\left(8.1\frac{\mu g}{m^3}\right) = \mathbf{3.58\ \mu g/m^3}$$

Calculation of new Indoor $PM_{2.5}$ levels (MERV 14):

$$Indoor\ PM_{2.5}\ (new) = \frac{2.04h^{-1}(1 - 0.710) + 0.147h^{-1}}{6.4h^{-1}(0.710) + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}}\left(8.1\frac{\mu g}{m^3}\right) = \mathbf{0.87\ \mu g/m^3}$$

Using Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

$$Reduction\ of\ indoor\ PM_{2.5}\ levels = 3.58\frac{\mu g}{m^3} - 0.87\frac{\mu g}{m^3} = \mathbf{2.71\frac{\mu g}{m^3}}$$

Scenario 1.2 –_Upgrading with 1 – 2 Portable Air Cleaning Devices

Outdoor Ambient $PM_{2.5}$ = 8.1 μg/m^3

Current system: MERV 7 (Filter efficiency (23.6%) = 0.236)

New System 1.2.1: 1 portable air cleaner (CADR = 680 m^3/h)

New System 1.2.2: 2 portable air cleaners (CADR = 1360 m^3/h)

Using equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms with a HVAC system only

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04h^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{(6.4h^{-1}(Filter\ Efficiency) + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1})(Outdoor\ PM_{2.5}\ levels)}$$

Calculation of current Indoor $PM_{2.5}$ level (MERV 7):

$$Indoor\ PM_{2.5}\ (current) = \frac{2.04h^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}}\left(8.1\frac{\mu g}{m^3}\right)$$

$$= \mathbf{3.58}\frac{\boldsymbol{\mu g}}{\boldsymbol{m^3}}$$

Using Equation 2: Calculation of indoor $PM_{2.5}$ levels in classrooms with portable air cleaners

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{\left(6.4h^{-1}(Filter\ Efficiency) + \frac{CADR}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}\right)(Outdoor\ PM_{2.5}\ levels)}$$

Calculation of new Indoor $PM_{2.5}$ levels (1 portable air cleaner):

$$Indoor\ PM_{2.5}\ (new_1) = \frac{2.04h^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + \frac{\frac{680m^3}{h}}{231m^3} + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}}\left(8.1\frac{\mu g}{m^3}\right)$$

$$= \mathbf{2.03\frac{\mu g}{m^3}}$$

Calculation of new Indoor $PM_{2.5}$ levels (2 portable air cleaners):

$$Indoor\ PM_{2.5}\ (new_2) = \frac{2.04h^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + \frac{\frac{1360m^3}{h}}{231m^3} + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}}\left(8.1\frac{\mu g}{m^3}\right)$$

$$= \mathbf{1.42\frac{\mu g}{m^3}}$$

Using Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

Calculation of new Indoor $PM_{2.5}$ levels (1 portable air cleaner):

$$Reduction\ of\ indoor\ PM_{2.5}\ levels\ (adding\ 1\ portable\ air\ cleaner) = 3.58\frac{\mu g}{m^3} - 2.03\frac{\mu g}{m^3} = \mathbf{1.55\frac{\mu g}{m^3}}$$

Calculation of new Indoor $PM_{2.5}$ levels (2 portable air cleaners):

$$Reduction\ of\ indoor\ PM_{2.5}\ levels\ (adding\ 2\ portable\ air\ cleaners) = 3.58\frac{\mu g}{m^3} - 1.42\frac{\mu g}{m^3} = \mathbf{2.16\frac{\mu g}{m^3}}$$

Example 2 – Long Beach, CA

Scenario 2.1 – Upgrades HVAC Filter Panels Only

Scenario 2.2 – Upgrades to 1 – 2 Portable Air Cleaning Devices

From CalEnviroScreen, range of outdoor ambient $PM_{2.5}$ annual average values for Long Beach: 11.21-12.05 μg/m³

Scenario 2.1: Upgrading HVAC Filters

Outdoor Ambient $PM_{2.5}$ = 12.1 μg/m³

Current system: MERV 10 (Filter efficiency (30.5%) = 0.305)

New System: MERV 14 (Filter efficiency (71.0%) = 0.710)

Using equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms with a HVAC system only

$$(Indoor\ PM2.5\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{6.4h^{-1}(Filter\ Efficiency) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}(Outdoor\ PM2.5\ levels)$$

Calculation of current Indoor PM2.5 level (MERV 10):

$$Indoor\ PM_{2.5}\ (current) = \frac{2.04hr^{-1}(1 - 0.305) + 0.147h^{-1}}{6.4h^{-1}(0.305) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}(12.1\ \mu g/m^3) = \mathbf{4.40\ \mu g/m^3}$$

Calculation of new Indoor PM2.5 levels (MERV 14):

$$Indoor\ PM_{2.5}\ (new) = \frac{2.04hr^{-1}(1 - 0.710) + 0.147h^{-1}}{6.4h^{-1}(0.710) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}(12.1\ \mu g/m^3) = \mathbf{1.30\ \mu g/m^3}$$

Using Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

$$Reduction\ of\ indoor\ PM_{2.5}\ levels = 4.40\frac{\mu g}{m^3} - 1.30\frac{\mu g}{m^3} = \mathbf{3.10\frac{\mu g}{m^3}}$$

Scenario 2.2 –_Upgrading with 1 – 2 Portable Air Cleaning Devices

Outdoor Ambient $PM_{2.5}$ = 8.1 μg/m^3

Current system: MERV 7 (Filter efficiency (23.6%) = 0.236)

New System 2.2.1: 1 portable air cleaner (CADR = 680 m^3/h)

New System 2.2.2: 2 portable air cleaners (CADR = 1360 m^3/h)

Using equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms with a HVAC system only

$$(Indoor\ PM2.5\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{(6.4h^{-1}(Filter\ Efficiency) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1})(Outdoor\ PM2.5\ levels)}$$

Calculation of current Indoor PM2.5 level (MERV 10):

$$Indoor\ PM_{2.5}\ (current) = \frac{2.04hr^{-1}(1 - 0.305) + 0.147h^{-1}}{6.4h^{-1}(0.305) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}\left(12.1\frac{\mu g}{m^3}\right) = \mathbf{4.40\frac{\mu g}{m^3}}$$

Using Equation 2: Calculation of indoor $PM_{2.5}$ levels in classrooms with portable air cleaners

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{\left(6.4h^{-1}(Filter\ Efficiency) + \frac{CADR}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}\right)(Outdoor\ PM_{2.5}\ levels)}$$

Calculation of new Indoor PM2.5 levels (1 portable air cleaner):

$$Indoor\ PM_{2.5}\ (new_2) = \frac{2.04hr^{-1}(1 - 0.305) + 0.147h^{-1}}{6.4h^{-1}(0.305) + \frac{\frac{680m^3}{h}}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}\left(12.1\frac{\mu g}{m^3}\right) = \mathbf{2.61\frac{\mu g}{m^3}}$$

Calculation of new Indoor $PM_{2.5}$ levels (2 portable air cleaners):

$$Indoor\ PM_{2.5}\ (new_3) = \frac{2.04hr^{-1}(1 - 0.305) + 0.147h^{-1}}{6.4h^{-1}(0.305) + \frac{\frac{1360m^3}{h}}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}\left(12.1\frac{\mu g}{m^3}\right) = \mathbf{1.86\frac{\mu g}{m^3}}$$

Using Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

Calculation of new Indoor PM2.5 levels (1 portable air cleaner):

$$Reduction\ of\ indoor\ PM_{2.5}\ levels\ (adding\ 1\ portable\ air\ cleaner) = 4.40\frac{\mu g}{m^3} - 2.61\frac{\mu g}{m^3} = \mathbf{1.79\frac{\mu g}{m^3}}$$

Calculation of new Indoor $PM_{2.5}$ levels (2 portable air cleaners):

$$Reduction\ of\ indoor\ PM_{2.5}\ levels\ (adding\ 2\ portable\ air\ cleaners) = 4.40\frac{\mu g}{m^3} - 1.86\frac{\mu g}{m^3} = \mathbf{2.54\frac{\mu g}{m^3}}$$

Example 3 – Bakersfield, CA

Scenario 3.1 – Upgrades HVAC Filter Panels Only

Scenario 3.2 – Upgrades to 1 – 2 Portable Air Cleaning Devices

From CalEnviroScreen, range of outdoor ambient $PM_{2.5}$ annual average values for Bakersfield: 18.76-19.6 μg/m^3

Scenario 3.1: Upgrading HVAC Filters

Outdoor Ambient $PM_{2.5}$ = 19.2 μg/m^3

Current system: MERV 7 (Filter efficiency (23.6%) = 0.236)

New System: MERV 16 (Filter efficiency (96.3%) = 0.963)

Using equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms with a HVAC system only

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{6.4h^{-1}(Filter\ Efficiency) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}(Outdoor\ PM_{2.5}\ levels)$$

Calculation of current Indoor $PM_{2.5}$ level (MERV 7):

$$Indoor\ PM_{2.5}\ (current) = \frac{2.04hr^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}(19.2\ \mu g/m^3) = \mathbf{8.48\ \mu g/m^3}$$

Calculation of new Indoor $PM_{2.5}$ levels (MERV 16):

$$Indoor\ PM_{2.5}\ (new) = \frac{2.04hr^{-1}(1 - 0.963) + 0.147h^{-1}}{6.4h^{-1}(0.963) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21hr^{-1}}(19.2\ \mu g/m^3) = \mathbf{0.50\ \mu g/m^3}$$

Using Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

$$Reduction\ of\ indoor\ PM_{2.5}\ levels = 8.48\frac{\mu g}{m^3} - 0.50\frac{\mu g}{m^3} = \mathbf{7.98\frac{\mu g}{m^3}}$$

Scenario 3.2 – Upgrading with 1 – 2 Portable Air Cleaning Devices

Outdoor Ambient $PM_{2.5}$ = 19.2 µg/m^3

Current system: MERV 7 (Filter efficiency (23.6%) = 0.236)

New System 3.2.1: 1 portable air cleaner (CADR = 680 m^3/h)

New System 3.2.2: 2 portable air cleaners (CADR = 1360 m^3/h)

Using equation 1: Estimation of indoor $PM_{2.5}$ levels in classrooms with a HVAC system only

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{(6.4h^{-1}(Filter\ Efficiency) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1})(Outdoor\ PM_{2.5}\ levels)}$$

Calculation of current Indoor $PM_{2.5}$ level (MERV 7):

$$Indoor\ PM_{2.5}\ (current) = \frac{2.04hr^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}\left(19.2\frac{\mu g}{m^3}\right) = \mathbf{8.48\frac{\mu g}{m^3}}$$

Using Equation 2: Calculation of indoor $PM_{2.5}$ levels in classrooms with a portable air cleaner

$$(Indoor\ PM_{2.5}\ levels) = \frac{2.04hr^{-1}(1 - Filter\ Efficiency) + 0.7 \times 0.21h^{-1}}{\left(6.4h^{-1}(Filter\ Efficiency) + \frac{CADR}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}\right)}(Outdoor\ PM_{2.5}\ levels)$$

Calculation of new Indoor $PM_{2.5}$ levels (1 portable air cleaner):

$$Indoor\ PM_{2.5}\ (new_2) = \frac{2.04hr^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + \frac{\frac{680m^3}{h}}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}\left(19.2\frac{\mu g}{m^3}\right) = \mathbf{4.81\frac{\mu g}{m^3}}$$

Calculation of new Indoor $PM_{2.5}$ levels (2 portable air cleaners):

$$Indoor\ PM_{2.5}\ (new_3) = \frac{2.04hr^{-1}(1 - 0.236) + 0.147h^{-1}}{6.4h^{-1}(0.236) + \frac{\frac{1360m^3}{h}}{231m^3} + 0.1hr^{-1} + 2.04hr^{-1} + 0.21h^{-1}}\left(19.2\frac{\mu g}{m^3}\right) = \mathbf{3.36\frac{\mu g}{m^3}}$$

Using Equation 3: Calculation of the reduction of indoor $PM_{2.5}$ concentrations

$$Reduction\ of\ indoor\ PM_{2.5}\ concentrations = Indoor\ PM_{2.5}\ (current) - Indoor\ PM_{2.5}\ (new)$$

Calculation of new Indoor $PM_{2.5}$ levels (1 portable air cleaner):

$$Reduction\ of\ indoor\ PM_{2.5}\ levels\ (adding\ 1\ portable\ air\ cleaner) = 8.48\frac{\mu g}{m^3} - 4.81\frac{\mu g}{m^3} = \mathbf{3.67\frac{\mu g}{m^3}}$$

Calculation of new Indoor $PM_{2.5}$ levels (2 portable air cleaners):

$$Reduction\ of\ indoor\ PM_{2.5}\ levels\ (adding\ 2\ portable\ air\ cleaners) = 8.48\frac{\mu g}{m^3} - 3.36\frac{\mu g}{m^3} = \mathbf{5.12\frac{\mu g}{m^3}}$$

APPENDIX I: AIR FILTRATION EQUATION DERIVATION: MODELING INDOOR PARTICLES OF OUTDOOR ORIGIN IN CLASSROOMS

1. Introduction

This appendix describes the derivation of the equations outlined in Section E of the Quantitative Methodologies. The objective of this modeling work is to estimate the reduction of exposure concentrations of fine particles (e.g. $PM_{2.5}$) for students in classrooms with improved air filtration. Two options to improve air filtration in classrooms are considered:

1) Upgrading currently used air filters in the HVAC systems to ones with higher particle removal efficiency, if the HVAC systems can handle the upgraded filters

2) Using portable air cleaners if the classroom does not have a HVAC system or the system cannot handle the upgraded filters.

The following methods estimate indoor levels of $PM_{2.5}$ of outdoor origin in school classrooms, using inputs such as the particle removal efficiency of the air filters in the HVAC systems and the efficiency of portable air cleaners. These methods, especially the values of parameters used, are not applicable to other school spaces, such as libraries and cafeterias. Energy related issues, such as pressure drop of different air filters, are not discussed in this work.

2. Methods

As shown in Figure 1, outdoor particles transport indoors through mechanical ventilation, natural ventilation, and infiltration. Mechanical ventilation refers to the intake airflow of outdoor air through the heating, ventilation, and air-conditioning (HVAC) system; natural ventilation refers to airflow through open windows and doors; and infiltration refers to airflow through the building envelope. The processes that remove particles from the space include ventilation, filtration, and particle deposition. Figure 2 illustrates the air flows through a wall-mount HVAC system in a typical classroom. Air filters installed in HVAC systems (Figure 2) serve as an important air-cleaning device that removes indoor particles. In addition to air filters, portable air cleaners can also work effectively to reduce indoor particle levels.

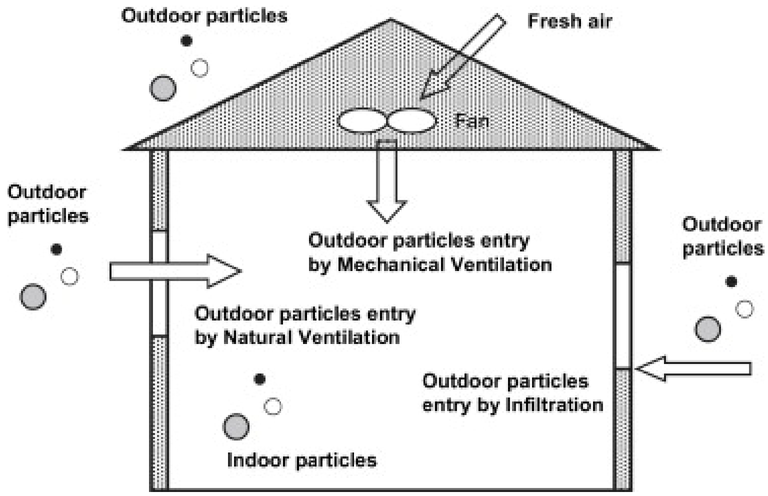

Figure I – 1: Schematic of the processes that affect the indoor proportion of outdoor particles for a generic single-zone room.

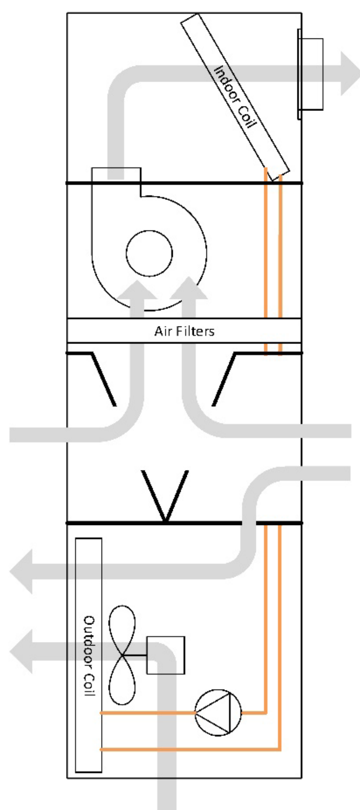

Figure I – 2: Schematic of wall-mount HVAC system in typical classrooms (Source: Western Cooling Efficiency Center, the University of California at Davis).

Assuming that the room is well-mixed and that there is no particle resuspension or coagulation, the mass balance for particle accumulation in the room is described in Equation 1.

Equation 1: Mass balance of particle accumulation in the room

$$V\frac{dC}{dt} = Q_m C_o(1-\eta) + Q_n C_o + PQ_i C_o - Q_r \eta C - VCk_{dep} - (Q_m + Q_i + Q_n)C - Q_p \eta_p C$$

The variables involved in Equation 1 are listed below.

Table I – 1: Equation 1 Variables.

Equation 1 Variable	Variable Description	Units
V	Volume of the classroom	m^3
C	Particle concentration in classroom	$\mu g/m^3$
C_o	Outdoor particle concentration	$\mu g/m^3$
Q_m	Mechanical ventilation rate	m^3/h
Q_n	Natural ventilation rate	m^3/h
Q_i	Infiltration rate	m^3/h
Q_r	Recirculation ventilation rate	m^3/h
Q_P	Air flow rate of portable air cleaner	m^3/h
P	Particle penetration factor	
η	HVAC air filter efficiency	
η_P	Particle removal efficiency of the portable air cleaner	
k_{dep}	Particle deposition loss rate	/h

Equation 1 ignores indoor sources of particles and considers particle removal by ventilation, deposition, HVAC air filters and portable air cleaners. The steady-state indoor particle concentration is expressed in Equation 2.

Equation 2: Steady-state particle concentration in the room

$$C = \frac{\frac{Q_m}{V}(1-\eta) + \frac{Q_n}{V} + P\frac{Q_i}{V}}{\frac{Q_r}{V}\eta + \frac{Q_P}{V}\eta_P + k_{dep} + \frac{Q_m + Q_n + Q_i}{V}} C_o$$

For school classrooms that are capable of upgrading HVAC air filters, no portable air cleaners are needed. In such cases, the term $Q_P\eta_P/V$ in Equation 2 can be dismissed. For the convenience of calculation, the ventilation rates in Equation 2 are usually converted to the corresponding air change rates (ACHs), k (1/h), which are the ventilation rates normalized by the room volume. Following this conversion, the steady-state particle concentration in classrooms upgraded with higher efficiency HVAC filters is represented by Equation 3.

Equation 3: Steady-state particle concentration in the room upgraded with higher efficiency HVAC filters

$$C = \frac{k_m(1-\eta) + k_n + Pk_i}{k_r\eta + k_{dep} + k_m + k_n + k_i} C_o$$

Table I – 2: Equation 3 Variables.

Equation 3 Variables	Variable Description	Units
k_m	Normalized mechanical ventilation rate	hr^{-1}
k_n	Normalized natural ventilation rate	hr^{-1}
k_i	Normalized infiltration rate	hr^{-1}
k_r	Normalized recirculation ventilation rate	hr^{-1}

There can be cases when the air filters installed in HVAC systems of classrooms cannot be upgraded to those with higher particle removal efficiency. Under such situations, portable air cleaners will be implemented to achieve the goal of reducing indoor particle levels. To evaluate the effectiveness of portable air cleaners the most helpful parameter isthe clean air delivery rate (CADR), which is usually expressed in cubic feet per minute (cfm). The CADR is a product of the particle removal efficiency and the airflow rate through the air cleaner (U.S. EPA 2018), or

$$CADR = Q_P\eta_P$$

Because the particle removal efficiency of the portable air cleaner, η_P, is less than 1, the CADR is less than the airflow rate through the air cleaner, Q_p. When a portable air cleaner is implemented in a classroom, the steady-state indoor particle concentration can be expressed by Equation 4.

Equation 4: Steady-state particle concentration in the room with a portable air cleaner

$$C = \frac{k_m(1-\eta) + k_n + Pk_i}{k_r\eta + \frac{CADR}{V} + k_{dep} + k_m + k_n + k_i} C_o$$

It should be noted that the labelled CADR of a portable air cleaner is typically the highest CADR achievable. Therefore, the steady-state particle concentration is underestimated in Equation 4 because the actual CADR of a portable air cleaner is usually less than the labelled CADR. More importantly, the CADR is dependent on the size fractions of particles. For example, the CADR of a portable air cleaner for $PM_{2.5}$ is different from that for PM_{10}. A more detailed discussion on CADRs is presented in the following section.

3. Input Parameters

Some input parameters, such as k_m and k_r, can be difficult to obtain. In such cases, we recommend some default values for rough estimations. These default values are based on previous field studies or modeling results and therefore can result in great uncertainty. A good understanding of the default values for calculations is important.

For portable air cleaners (standalone units), the value of CADR is usually provided by the manufacturer and can be found on the packages or in the users' manuals. If not printed in these places, one can find the value in the Association of Home Appliance Manufacturers (AHAM)'s searchable database (https://www.ahamdir.com/462-2/). To choose the suitable portable air cleaners for a classroom, we need to consider factors including the room size, the noise level, and the CADR. For detailed information on choosing a suitable portable air cleaner, one can refer to a guidance provided by the Indoor Exposure Assessment Section of Research Division of CARB (https://ww3.arb.ca.gov/research/indoor/acdsumm.pdf).

4. Classroom Dimensions

To better evaluate the effectiveness of portable air cleaners, the specific dimensions should be used to calculate the volume of a classroom. If the specific classroom size cannot be obtained, we recommend using the dimensions of a typical re-locatable classroom in the California Portable Classroom study (CARB, 2004) as default values. These values are also adopted by California Department of Public Health (CDPH) as the definition of standard school classroom in standard method for the testing and evaluation of volatile organic chemical emission from indoor sources using environmental chambers (version 1.2) (2017). Detailed values are listed in the following table.

Table I – 3: Classroom Dimensions.

Parameter	Unit of Measure	Parameter Value
Length (40 ft)	m	12.20
Width (24 ft)	m	7.32
Floor (ceiling) area	m^2	89.2
Ceiling height (835 ft)	m	2.59
Volume	m^3	231

5. Mechanical Ventilation Rate

The Building Energy Efficiency Standards adopted by CEC has required that mechanical ventilation rate in classrooms to be no less than the larger of the following:

- 0.15 cfm/ft^2 * floor area
- 15 cfm/person * number of students

The CEC has required these standards for some time now (CEC 2019). However, a study by Chan et al., 2020 found that the mechanical ventilation rates in most California classrooms are ventilated at rates lower than the required 15 cfm/person.

To consider this situation, we use the ventilation rate of 5.2 L per second-person estimated by Chan et al. (2020) in this work. In a typical classroom with 30 students, the resulting ventilation rate is 156 L per second, or 561.6 m^3 per hour. Given that the volume of a typical classroom is 250 m^3 (CARB, 2004), the total air change rate of the classroom is 2.25 per hour. The value of K_m is calculated from the total air change rate minus the value of infiltration rate (K_i) discussed subsequently.

6. Recirculation Ventilation Rate

Data on recirculation ventilation rates in schools are very limited. Chan et al. (2015) suggested that high recirculation rates between 3 and 10 per hour (mean = 6.6/h) were measured in spaces that are about 100 m^2 in floor area. This modeling work uses the value of 6.4 per hour as the recirculation ventilation rate, which was measured as the mean value in Polidori et al. (2013).

7. Natural Ventilation Rate and Infiltration Rate

Natural ventilation rate (opening doors/windows) is assumed to be 0 in this methodology. The value of infiltration rate for classroom is assumed to be 0.21 per hour (Martenies and Batterman, 2018). Given the total air change rate of 2.25 per hour and the infiltration rate of 0.21/h, the normalized mechanical ventilation rate is:

$$\frac{2.25}{hr} - \frac{0.21}{hr} = \frac{2.04}{hr}$$

8. PM Penetration Ratio Through Building Envelope

The penetration ratio through building envelope, P, is dependent on particle size. For PM2.5, we assume the value of 0.7 to estimate the effectiveness of enhanced filtration in classrooms. This assumption is used by a recent modeling study by Martenies and Batterman (2018) and an earlier study by Riley et al. (2002).

9. PM Deposition Rates

The PM deposition rate is assumed to be 0.3 per hour in this modeling work (Martenies and Batterman, 2018 and Riley et al., 2002).

10. Clean Air Delivery Rates

The CADR value of a portable air cleaner is determined experimentally using the Method for Measuring Performance of Portable Household Electric Room Air Cleaners established by AHAM (AHAM AC-1-2019). According to the method, the CADR values of a portable air cleaner are listed for three categories of particles: dust (particle size from 0.50 μm to 3.0 μm), cigarette smoke (particle size from 0.10 μm to 1.0 μm), and pollen (particle size from 5.0 μm to 11.0 μm). In this work, we use the cigarette smoke CADR as the $PM_{2.5}$ CADR.

To select an air cleaner suitable for a given classroom, we use the following equation provided by AHAM:

$$Square\ feet = 1.557 \cdot CADR(cfm)$$

The relationship is based on the objective to provide an 80% reduction in steady-state particle concentrations when the selected air cleaner is implemented. Given the floor area of the standard classroom (960 ft^2), the desirable CADR of the air cleaner is 616.57 cfm (1047.56 m^3/h). If the CADR of an air cleaner is smaller than the recommended value, multiple units can be used simultaneously to achieve the desirable effectiveness.

11. List of Input Parameters

If the data for a specific classroom can be obtained, one should use these data. Otherwise, we recommend using the default values listed in the following table. For portable air cleaners, it is important to note that this work does not recommend any kind of air cleaners for classrooms, and the one listed in the following table only serves as an example for calculation purpose.

Table I – 4: Default Values for Input Parameters.

Variables	Description	Units	Default value
V	Volume of the classroom	m^3	231 [13]
C_o	Outdoor particle concentration	$\mu g/m^3$	~
k_m	Normalized mechanical ventilation rate	1/h	2.04 [14]
k_n	Normalized natural ventilation rate	1/h	0
k_i	Infiltration rate normalized by volume	1/h	0.21
k_r	Normalized recirculation ventilation rates	1/h	6.4 [15]
P	Particle penetration factor	N/A	0.70 [16]
η	Air filter efficiency	N/A	N/A
k_{dep}	Particle deposition loss rate coefficient	1/h	0.10 [4]
CADR	$PM_{2.5}$ CADR of a portable air cleaner	m^3/h	680

When default values of the input parameters listed above are applied, Equation 3 is as follows:

Equation 3.1

$$C = \frac{2.04h^{-1}(1-\eta) + 0.7 \times 0.21h^{-1}}{6.4h^{-1}\eta + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}h^{-1}} C_o$$

When using a portable air cleaner with the CADR of 680 m^3/h in the classroom, Equation S4 is as follows:

[13] CARB 2004 Portable Classroom study.

[14] Calculated using the ventilation rate of 5.2 L/s-person estimated by Chan et al. (2020). The total air change rate of a classroom is 2.25/h, and the normalized mechanical ventilation rate = 2.25/h – 0.21/h = 2.04/h, where 0.21/h is the assumed infiltration rate.

[15] Polidori et al. (2013).

[16] Riley et al. (2002) and Martenies and Batterman (2018).

Equation 4.1

$$C = \frac{2.04h^{-1}(1-\eta) + 0.7 \times 0.21h^{-1}}{6.4h^{-1}\eta + \frac{680m^3h^{-1}}{231m^3} + 0.1h^{-1} + 2.04h^{-1} + 0.21h^{-1}} C_o$$

12. References

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