> nfmt_west_2026.boot( ) · track: efficiency / tech & market trends

Your classroom is running *old code.*

Improving air quality in K–12 schools for compliance and performance

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Wed Nov 4 · 2:10 PM

Bronze 4

> audience.inhale( )

Take a deep breath.

Nice. Now imagine **1 in every 16** of those breaths was secondhand, already secondhand, already exhaled by a classmate.

RM 304 · K. O. Knudson MS · 1:40 PM · 2,726 ppm CO_2 · (2,726 − 420) ÷ 38,000 ≈ 6% rebreathed (Rudnick & Milton, 2003)

// whoami

Hi, I'm Lori. I debug systems.

~40
years in environmental science

1,900+
classrooms monitored in real time

266,545
students in the nation's 5th-5th-largest district

5
kids raised: my first field study of stuffy rooms and and teenage moods

Buildings, water systems, even people: every system runs on code. When the output is wrong, you don't blame the user. blame the user. *You find the old code and correct it.*

We are CCSD

// today's program

An error-correcting code for classroom air

01 detect( )

Find the error

How CO_2 and ventilation drive cognition, instruction and outcomes outcomes

02 debug( )

Manage it with data

Real-time monitoring, protocols and leadership practices

03 deploy( )

Fund and scale the fix

A roadmap and funding models to act act now and modernize later

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01 · detect( )

Error detected.

The air is fine on paper. The students are not.

// 01 detect · the old code

Compliance is code written once. Air is breathed every minute.

spec.md

ASHRAE 62.1 classrooms (age 9+): **10 cfm/person + 0.12 cfm/ft²** of outdoor air, checked at design and commissioning.

In a typical classroom that settles near **1,100 ppm CO_2**.

runtime.log

Dampers drift. Economizers fail. Schedules change. Rooms Rooms fill past design.

CO_2 is invisible and odorless, so **nobody files a bug report.**

Fun fact: K. O. Knudson MS dates to **1961**. Its ventilation code was written before the moon landing.

ppm = parts per million · **cfm** = cubic feet per minute · **ACH** = air changes per hour · **ASHRAE** = HVAC engineering standards body

ASHRAE Standard 62.1-2022, Table 6-1

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// audience poll · hands up

Guess the ppm: a 7th-grade classroom, 1:40 PM, 29 kids, door closed

A

900

"Probably fine"

B

1,500

"A little stuffy"

C

2,726

"Surely not"

Outdoor air ≈ 420 ppm · Code-level classroom ≈ 1,100 ppm

// 01 detect · error log

As CO_2 climbs, thinking crashes

CO_2 level	What the research found	Study
~ 945 ppm	Cognitive scores 15% lower than at ~ 550 ppm	Allen 2016 (adults)
1,000 ppm	6 of 9 decision-making scales 11–23% lower	Satish 2012 (adults)
~ 1,400 ppm	Cognitive scores cut in half vs. ~ 550 ppm	Allen 2016 (adults)
2,000 → 1,000	Halving CO_2: school tasks 12% faster, 3% fewer errors	Wargocki 2020 (children)
2,500 ppm	7 of 9 scales 44–94% lower; some "dysfunctional"	Satish 2012 (adults)
+ 1,000 ppm	10–20% relative increase in student absence	Shendell 2004 (schools)

CO_2 is the marker: effects likely reflect CO_2 plus the other pollutants people give off when ventilation is low.

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// 01 detect · 1,636 classrooms with data, one dataset

Above 1,800 ppm, learning erodes silently

15.2%

of reporting classrooms topped 1,800 ppm at least once in an average full week*

1,312

room-hours per week above 1,800 1,800 ppm during school hours, averaged over full weeks*

470 ppm

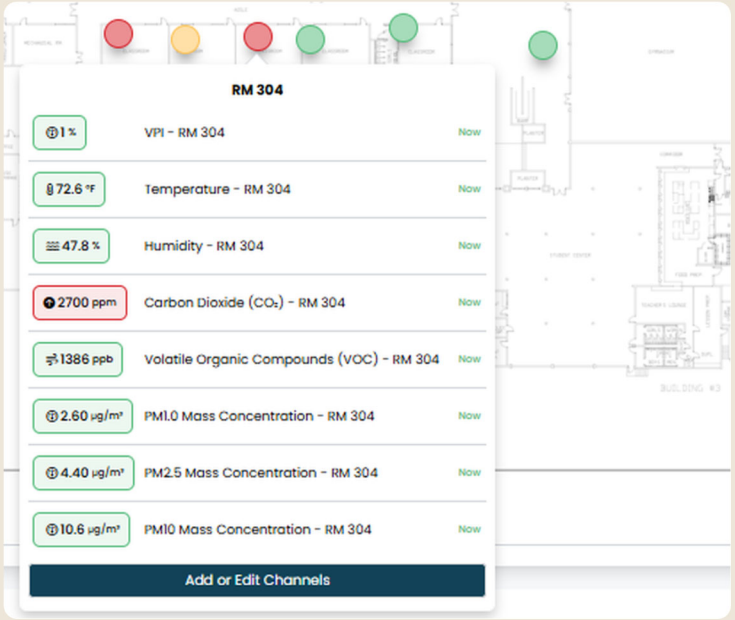
median CO_2 during school hours across reporting classrooms*

*School hours = Mon–Fri, 8 a.m.–3 p.m. Pacific (actual occupancy not verified; school breaks included). Weekly figures: mean of 49 full weeks, Oct 27, 2025–Oct 4, 2026. Total 2025–Oct 4, 2026. Total time above 1,800 ppm: 66,308.5 room-hours (not student-hours). Missing readings excluded; duplicate room sensors averaged.

Source: CCSD CO_2 monitoring network, Oct 23, 2025–Oct 9, 2026 (through 12:15 p.m. Pacific)

// 01 detect · case file: RM 304

The thermostat said "fine." The sensor said otherwise.



temp ..... 72.6°F OK

humidity .. 47.8% OK

PM2.5 ..... 4.4 OK

VOC ..... 1,386 OK

CO_2 2,700

ERROR: fresh air not found

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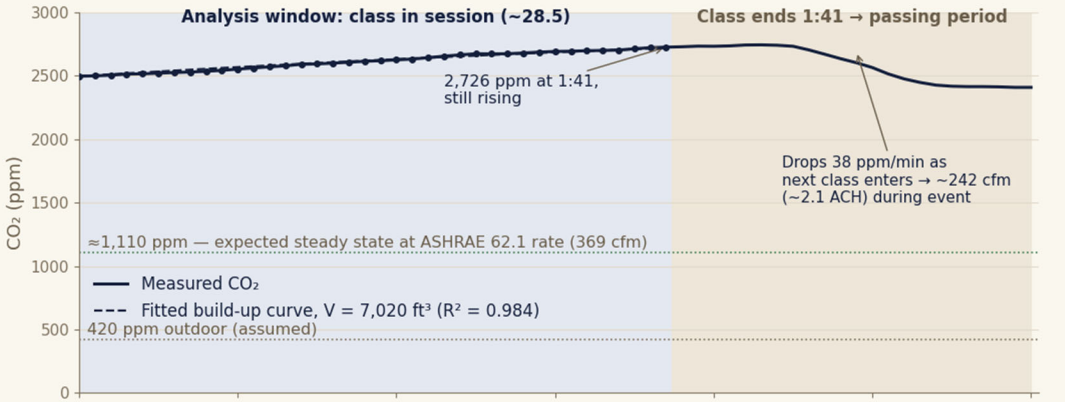
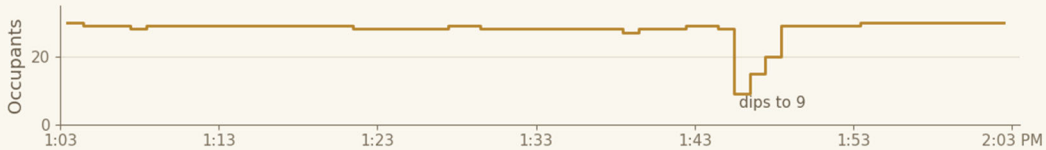
RM 304 · K. O. Knudson MS — Ventilation Rate from CO_2

Transient mass-balance (CO_2 build-up) method · Sept 25, 2026, 1:03–2:03 PM · 1-minute sensor data





3.4 cfm/person
Measured outdoor air (~96 cfm total)

369 cfm needed
ASHRAE 62.1 Vbz (13.0 cfm/person)

~74% short
Delivering ~26% of required outdoor air

0.82 ACH
Outdoor-air changes/hr (7,020 ft³ room)

Show the work

1 · Mass balance on room air

$$V\frac{dC}{dt} = NG - Q(C - C_o)$$

Solution with constant N, G, Q (ASTM D6245 build-up):

$$C(t) = C_{ss} - (C_{ss} - C_0)\,e^{-(Q/V)t}, \quad C_{ss} = C_o + \frac{NG}{Q}$$

2 · Inputs

V = 27 ft × 26 ft × 10 ft ceiling* = 7,020 ft³ (A = 702 ft²)
N = 28.5 occupants (avg, 1:04–1:41) C_0 = 2497 ppm
C_o = 420 ppm outdoor (assumed)
G = 0.0042 L/s/person = 0.0089 cfm/person
(ages 11–16, ~1.2 met; Persily & de Jonge 2017)

3 · Least-squares fit for Q (38 points, R^2 = 0.984)

Q = 96 cfm → C_ss = 420 + (28.5 × 0.0089)/96 × 10^6 = 3,057 ppm
ACH = Q × 60 / V = 96 × 60 / 7,020 = 0.82 /hr
Q / N = 96 ÷ 28.5 = 3.4 cfm/person

4 · ASHRAE 62.1-2022 required (classroom, age 9+)

$$V_{bz} = R_pN + R_aA = 10(28.5) + 0.12(702) = 369 \text{ cfm}$$

Measured ÷ required = 96 ÷ 369 = 26%

5 · Cross-check (volume-independent)

CO_2 still rising at 2,726 ppm ⇒ C_ss > 2,726, so

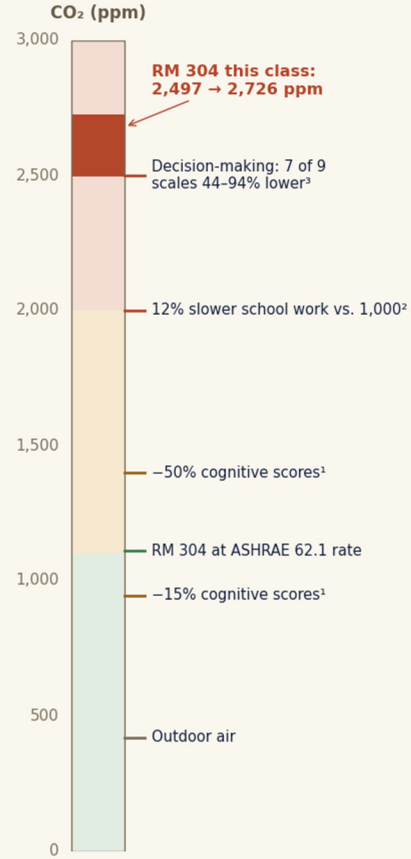
$$Q < \frac{28.5 \times 0.0089}{(2726 - 420) \times 10^{-6}} = 110 \text{ cfm} = 3.9 \text{ cfm/p}$$

*Ceiling 9–12 ft → 3.2–3.4 cfm/person; G ±20% scales Q ±20%.

Data: RM 304 occupancy & CO_2 sensor export. Q = outdoor-air (ventilation) rate; assumes well-mixed room and constant supply during the window. ASHRAE 62.1-2022 Table 6-1, classrooms age 9+: Rp = 10 cfm/person + Ra = 0.12 cfm/ft².

RM 304 at 2,500–2,730 ppm CO_2: What Students Are Experiencing

K. O. Knudson MS · Sept 25, 2026 class period (1:03–1:41 PM) · ~3.4 cfm/person outdoor air vs. 13 cfm/person required



COGNITIVE / LEARNING

Slower, less accurate work

~12% slower on school tasks and ~3% more errors vs. a room at 1,000 ppm[2]

Weaker higher-order thinking

Strategy, information use and crisis response drop most[1] [3]: the skills behind problem-solving and test-taking

Lower test outcomes

Each +1 L/s/person of ventilation ≈ +2.7–2.9% of students passing[4]. RM 304 is ~4.5 L/s/person short

Lost focus late in the period

CO_2 climbed the whole class: the last 15 minutes had the worst air

PHYSICAL

Drowsiness and yawning

Heavy, “stuffy” air; students feel sleepy and sluggish

Headache and fatigue

Most common symptoms reported in poorly ventilated classrooms[5]

Stale air and odors

Body odor and exhaled compounds build up: CO_2 is the marker, not the only pollutant

Breathing each other’s air

~6% of every breath was already exhaled by someone else in the room[6] (vs. ~2% at code rate)

EMOTIONAL / BEHAVIORAL

Restless and irritable

Discomfort plus fatigue shortens patience with peers and tasks

Lower motivation

Harder work feels harder; more off-task behavior and disengagement

Frustration and anxiety

Students may blame themselves when they can’t focus or recall material

Missed school

+1,000 ppm (indoor − outdoor) ≈ 10–20% more absences[7]; RM 304 is ~1,500 ppm above code level

~6%

of each breath was air classmates already exhaled

~12%

slower on school tasks (vs. 1,000 ppm)

+12–13 pts

more students passing if ventilated to code (est.)

15–30%

more absences expected at this CO_2 gap (est.)

Adult studies[1] [3]; classroom meta-analysis[2]

[1] Allen et al. 2016, Environ Health Perspect (COGfx) · [2] Wargocki et al. 2020, Build Environ · [3] Satish et al. 2012, Environ Health Perspect · [4] Haverinen-Shaughnessy et al. 2011, via Wargocki 2020
[5] Muscatiello et al. 2015, Indoor Air · [6] Rudnick & Milton 2003, exhaled CO_2 ≈ 38,000 ppm: (2,726 − 420) ÷ 38,000 · [7] Shendell et al. 2004, Indoor Air
Estimates apply published relationships to RM 304 data; most cognitive-effect studies used adults. Effects are likely driven by CO_2 together with other occupant-generated pollutants that build up when ventilation is low.

02 · debug( )

The students aren't broken.

They're just running on old code. Let's rewrite it.

// 02 debug · diff

Old code vs. new code

	− compliance-based	+ performance-driven
Verification	At design and commissioning	Continuous, every occupied minute
Trigger	A complaint or work order	A data threshold and alert
Metric	Design cfm on the drawings	Delivered cfm/person, time above threshold
Who sees it	Facilities only	Facilities, principals, teachers, leadership
Goal	Avoid violations	Protect instructional time
Budget case	Deferred maintenance	Student outcomes and energy

// 02 debug · the error-correcting loop

Five functions, run on repeat

monitor( )	Real-time CO_2, temp, RH, PM and VOC in every classroom
diagnose( )	Turn CO_2 into delivered cfm/person; rank rooms by the gap
correct( )	Controls first, then repair, then capital
verify( )	Re-run the calculation after every fix
report( )	Share results with schools, leadership and the board

Then loop. An error-correcting code never runs once.

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// 02 debug · log levels

Every level has an owner and a clock

INFO	< 1,100 ppm	At or above code. Carry on.
WARN	1,100–1,800	Site checks schedule, occupancy, doors, dampers
ERROR	> 1,800 ppm	Work order auto-generated; outdoor air verified promptly
FATAL	repeat ERROR	Room joins the capital list with its cfm gap

CO_2 thresholds per the CCSD operating protocol.

// 02 debug · the override

Most patches cost little or nothing

hotfix · $0

- Reset OA minimums
- Pre/post flush
- Door protocol
- Fix DCV setpoints

patch · O&M

- Free stuck dampers
- Repair economizers
- Filters and coils
- Rebalance airflow

release · capital

- Energy recovery
- Rooftop units
- Controls / BAS
- Ranked by cfm gap

RM 304 proof: door open at the bell = **~2.5× the fresh air rate.**

OA = outdoor air · **DCV** = demand-controlled ventilation · **O&M** = operations and maintenance · **BAS** = building automation system system

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// 02 debug · case file #2: the empty portables

Same sensor, opposite bug: cooling empty rooms

01 Utility dashboard flags a Lunt ES portable

02 Site visit: every portable is empty

03 Ask NOVA: which portables sit at outdoor CO_2?

04 **2 minutes later: 235 empty portables, 100 schools**

cooled to 73°F, 6 AM–4 PM
Aug 11 → Oct 7, 2026

~$22.8K

spent cooling rooms nobody was in (est.)
(est.)

~$14.5K

avoidable with one schedule change to
to 86°F unoccupied

Engineering estimate (~171,000 kWh): 41 school days, Las Vegas 1991–2020 normals, actual room sizes from CCSD portable inventory (172,528 ft²), CCSD all-in rate $0.13376/kWh (FY2025-26). Range ~$15.2K–$31.3K.

03 · deploy( )

Ship the fix.

Now: how to pay for it, and how to get a yes.

// 03 deploy · dependencies

Six ways to fund it without waiting for a bond

Energy savings

Reinvest what you stop wasting

Performance contracts

Savings pay for the upgrades

Utility incentives

Rebates for DCV, ERV, controls

One-time funds

Settlements and other one-time time dollars

Capital programs

cfm gaps rank HVAC replacement

Grants

Federal, state and private programs

DCV = demand-controlled ventilation · **ERV** = energy-recovery ventilator · **HVAC** = heating, ventilation and air conditioning

General funding sources; availability varies by state, utility and district.

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// 03 deploy · release plan

Act now, modernize over time

v0.1 · 90 days

Pilot sensors; baseline CO_2; reset controls

v1.0 · 1 year

Scale monitoring; owners; first scorecard

v2.0 · 1–3 yrs

Repair, rebalance; fund by measured gap

v3.0 · 3–5+ yrs

Capital by data; IAQ in design standards

You don't need v3.0 to start. *You need v0.1 and a spreadsheet.*

// 03 deploy · translate( )

Speak superintendent, not HVAC

– before

"RTU-4's outdoor-air damper is stuck at 10%."

Result: polite nod, next agenda item.

+ after

"Room 304 gets a quarter of the fresh air it needs, and every class works ~12% slower."

Result: "How fast can we fix it?"

Tie every request to learning time, attendance and achievement.

// patch_notes.md

Three commits for Monday morning

git commit -m

"Measure one room" room"

Log CO_2 and headcount for one one class. Calculate cfm/person. cfm/person.

git commit -m

"Name a threshold and and owner"

Decide who acts, and when, before the data arrives.

git commit -m

"Tell the learning story" story"

Frame the gap in learning terms terms for leadership.

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> questions.open( )

Your students aren't broken.
They're just coded.

Learning begins with a breath.

Confidence to believe their mind has value. Freedom to imagine. The power to make it real.

Ventilation calculator

Connect on LinkedIn

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