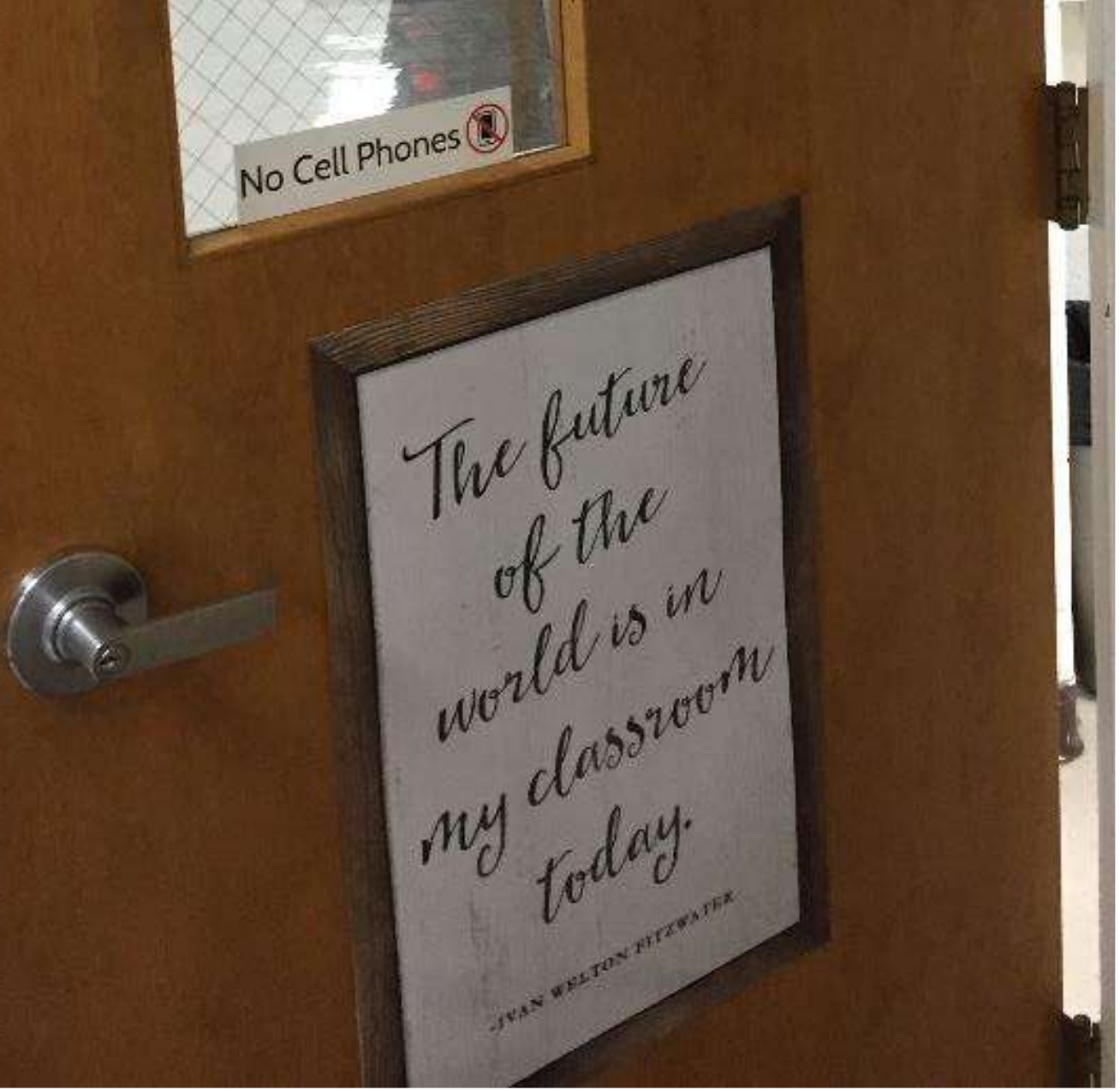


Creating Healthy Decarbonized Classrooms

Ty Newell, PhD, PE
Build Equinox
Urbana, IL 61802
www.buildequinox.com

BUILD EQUINOX

SOLUTIONS FOR A HEALTHY, COMFORTABLE, AND SUSTAINABLE LIFESTYLE

Maine Indoor Air Quality Council

October 30, 2023

Two Healthy Air & Decarbonization School Projects

BRIXHAM MONTESSORI FRIENDS SCHOOL

BMFS
York Maine

Distributed IAQ and Comfort

Mary Miller Junior High School
Georgetown-Ridge Farm CUSD#4
Georgetown Illinois
Unitized Classroom IAQ and Comfort

Health & Comfort Classroom Impacts – Three Studies

Reference 1: IAQ Impacts Class Performance

Reduction of carbon dioxide from 2100ppm to 900ppm increases student task speed by 12%

Reduction of carbon dioxide from 2100ppm to 900ppm improves student test score accuracy by 2%

Reduction of carbon dioxide from 2400ppm to 900ppm improves student performance on standardized test by 5%

Reference 2: Fresh Air Flow & Particulates Impacts Absenteeism

Fresh air flow increase of 1liter/s per person (2 cfm per person) reduces absenteeism 5.6 days/school-year per class

PM2.5 decrease of 1µg/m^3 (average class size of 21.5 students) reduces absenteeism by 7.4 days/school-year per class

Reference 3: Discomfort Impacts Class Performance

Classroom performance decreases by 2% for every 1C (1.8F) increase above comfort temperature

(1) "The relationships between classroom air quality and children's performance in school", P Wargocki, J Ali Porras-Salazar, S Contreras-Espinoza, W Bahnfleth; Building and Environment 173 (2020), https://doi.org/10.1016/j.buildenv.2020.106749

(2) "Associations between illness-related absences and ventilation and indoor PM2.5 in elementary schools of the Midwestern United States", S Deng, J Lau, P Wargocki, Z Wang; Environment International (2023), https://doi.org/10.1016/j.envint.2023.107944

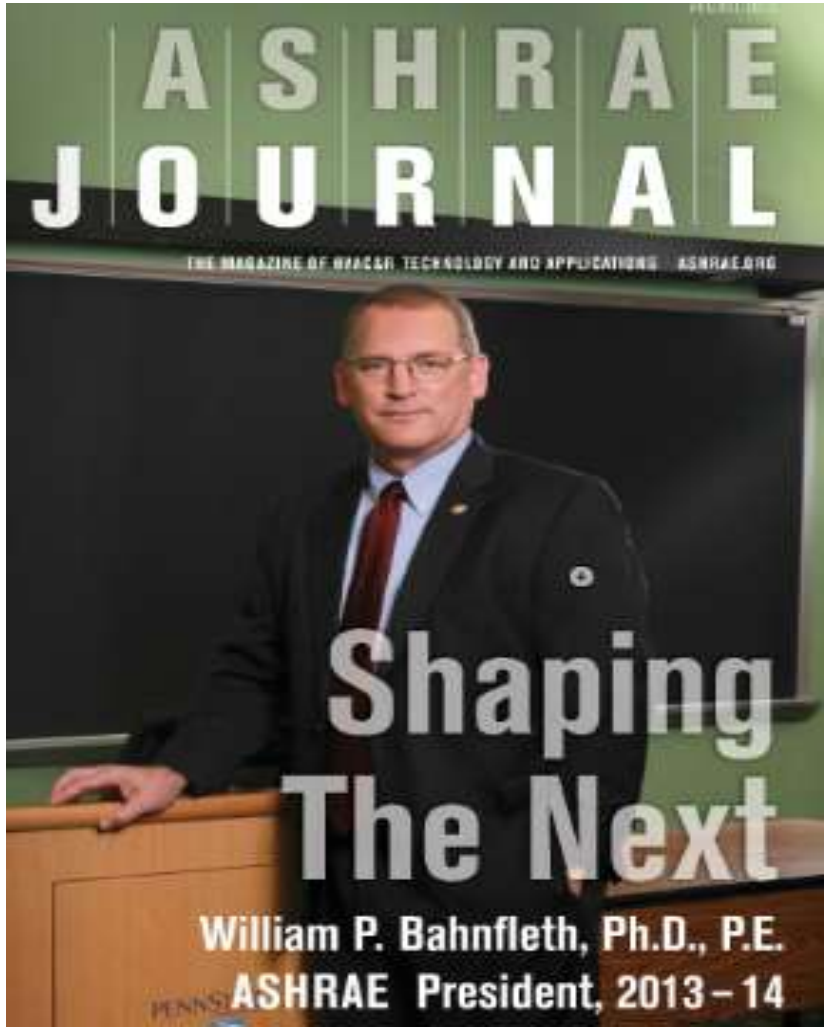
(3) "The relationship between classroom temperature and children's performance in school", P Wargocki, J Ali Porras-Salazar, S Contreras-Espinoza, Building and Environment 157 (2019), https://doi.org/10.1016/j.buildenv.2019.04.046

ASHRAE President Visits Equinox House

Equinox House

"…..a critical shift in thinking from a goal of **indoor environments that are acceptable** to the occupants to those that are **truly healthy and productive.**"

Bill Bahnfleth; 2013-2014 ASHRAE President



Newell – Broken Record on Sustainability, Health & Comfort

2017 NESEA

NESEA
NORTHEAST SUSTAINABLE ENERGY ASSOCIATION

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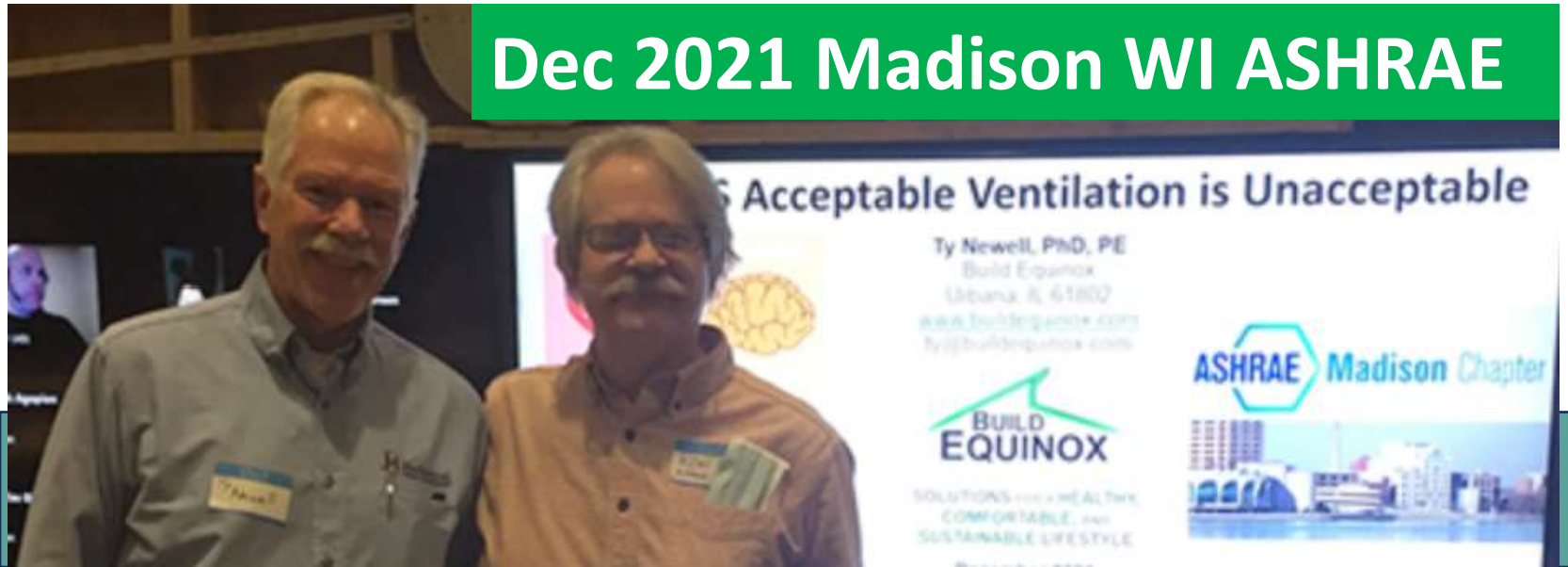
CONFERENCES PROGRAMS MEMBERSHIP COMMUNITY EVENTS DO

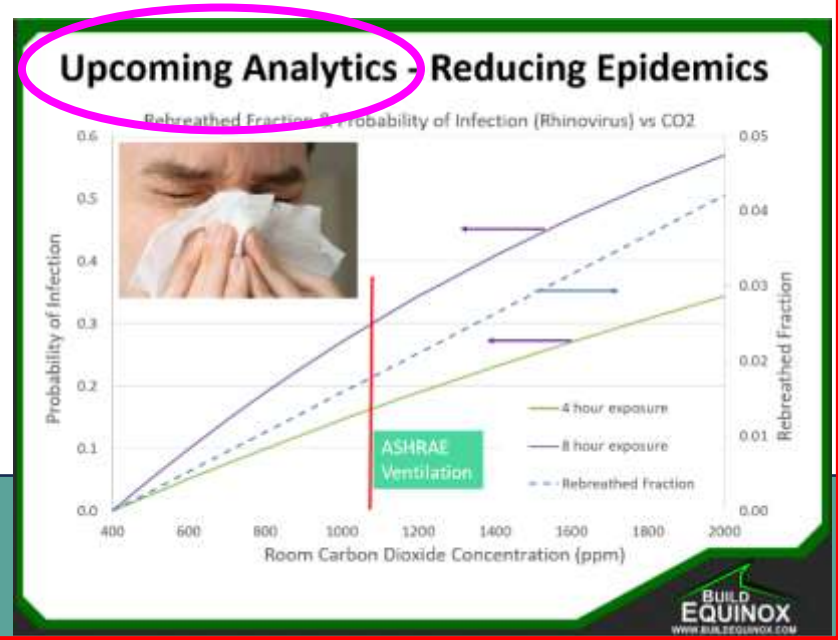
Home » Conferences » New IAQ Metrics to Avoid Being Stupid, Sick, and Tired

New IAQ Metrics to Avoid Being Stupid, Sick, and Tired

Our poorly ventilated homes and buildings are making us stupid, sick, and tired—at a cost that is staggering. Improvement of today's ventilation standards can increase human productivity with a value that is more than 100

Dec 2021 Madison WI ASHRAE





Don’t Carbonize Humans to Decarbonize Buildings!

“The purpose of a building is to keep people healthy, comfortable and secure; not to ***save*** energy”; University of Illinois seminar
Professor William Bahnfleth, Penn State Univ; ASHRAE President Emeritus

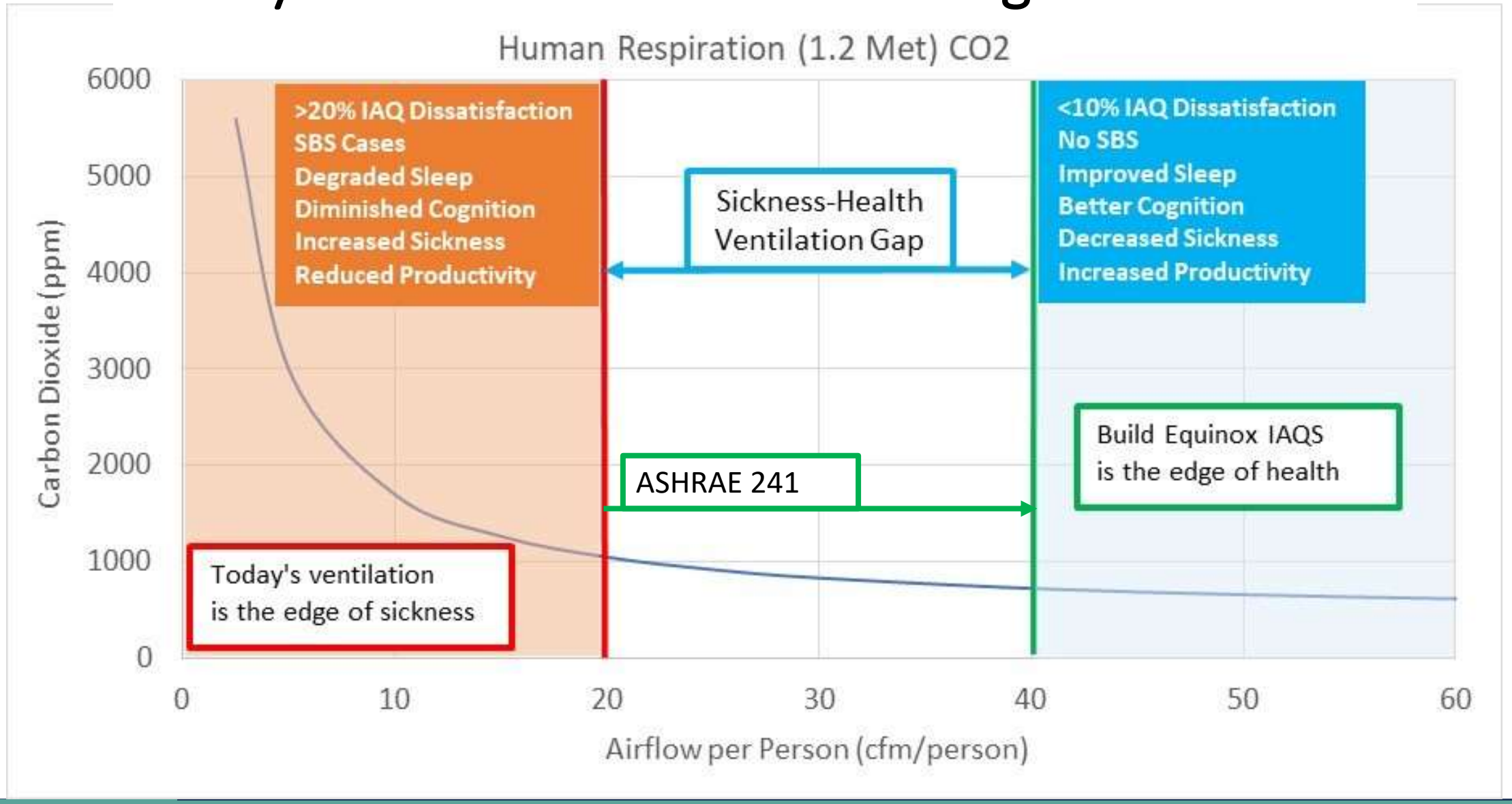
Featured Article

Filters are More Important (and Expensive) than Energy!

Don’t get us wrong. Energy is really important. That’s why we transformed our 4500sqft business facility to net zero operation.

IAQ is often left as a checkbox following today’s inadequate ventilation standards
The cost of healthy air is less than 1 ½ cents per hour per person more in harsh climates without energy recovery …. but energy recovery is justified on its own

Today's Ventilation Standards "Edge of Sickness"



2006 ASHRAE Journal Article on School Ventilation

Northeast Ohio schools leading state in new COVID-19 cases: See the Top 20

Updated: Mar. 07, 2023, 11:52 a.m. | Published: Jan. 06, 2022, 3:56 p.m.

Alexis Oatman; Cleveland.com

ASHRAE Technology award winning school designed ranks **number 4 on Ohio list for most Covid cases**

May 2006 ASHRAE Journal

Standard 62 IAQ Procedure

Reduced Outdoor Air For Auditorium

By Peter F. Johnson, Member ASHRAE

If you don't use the air purification option in the IAQ Procedure in ANSI/ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality,* you may miss out on a non-traditional but cost-effective design that reduces heating, cooling loads, duct

able Indoor Air Quality, IAQ procedure that combined the use of gas-phase cleaning and high-efficiency particulate filters for reduced OA. For greatest savings, an energy recovery unit (wheel) was added for energy recovery of the exhaust air.

This project was designed as an architectural showcase. It is a one-story insulated brick building with a built-up

Ventilation Rate Procedure vs. IAQ Procedure

Original Plan per Ventilation Procedure

Designed in 1999, three air-handling units required a total of 15,000 cfm (7079 L/s) outside air with 30% DS filters (MERV 5).

Optimized per IAQ Procedure

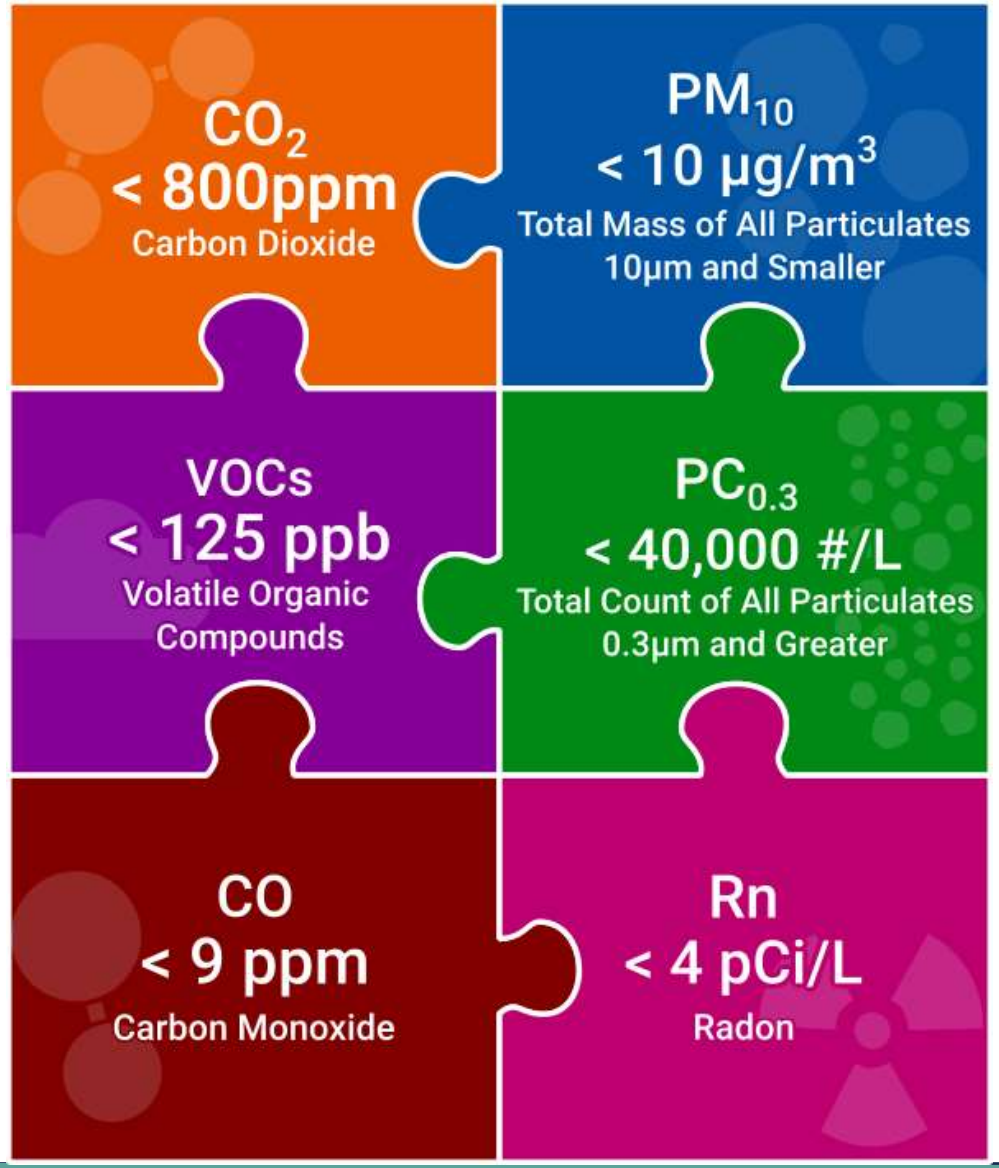
With the use of bipolar ionization and 80% DS filters (MERV 11), the outside air is reduced to 7,500 cfm (3540 L/s). Enthalpy wheel energy recovery systems were added to save additional energy.

Classroom Pollution & IAQ

We understand people pollution

- ~0.03kg/h CO2 per person, Met=1
  - Sleep = 0.7 Met
  - Strenuous Activity = 7 Met
  - Typical Activity ~1.3 Met
- ~6.3mg/h VOC per person
  - Breath ~2.5mg/h-person
  - Ozone, temperature, personal care products, hygiene, and more impact human VOCs
  - 3rd hand smokers impact IAQ dissatisfaction ~20-25 times of a clean clothed, recently washed, non-smoker
- Human particulate generation
  - ~100,000#/min (sitting still) to more than 1,000,000#/min with physical activity
  - Newell > 7,000,000#/min
    - Hygiene?/Genetics?/Age?
- You can average humans, but there is no average person!

Healthy IAQ Standard

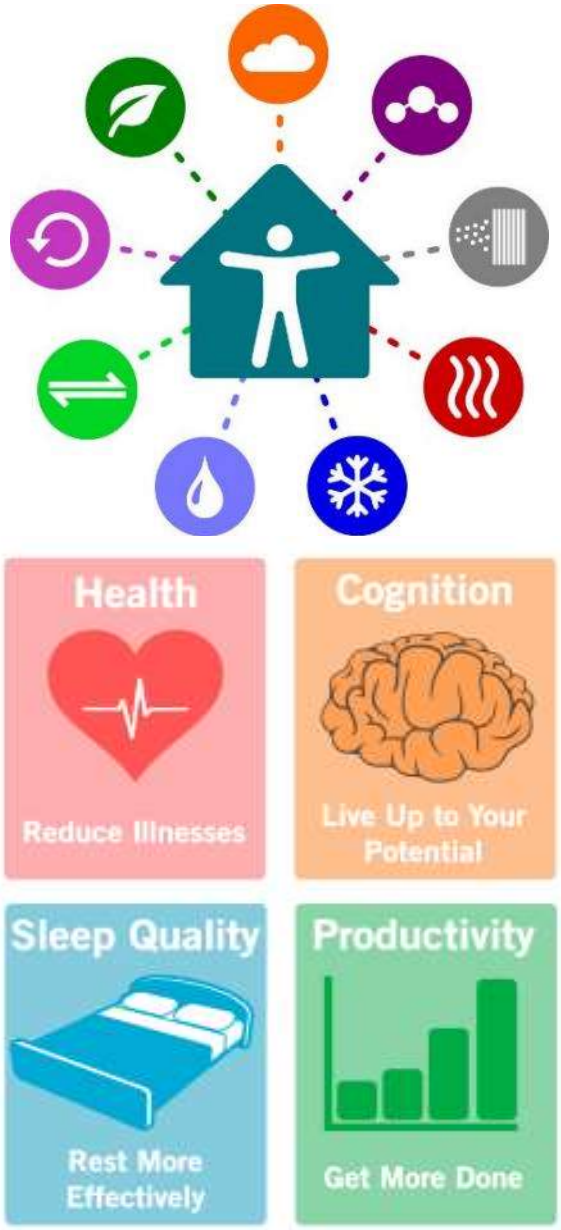


- **Human-centric IAQ Standard**
- **Not a "certification"**
- **Today's ACH and ASHRAE 62.1/62.2 are "building centric"**

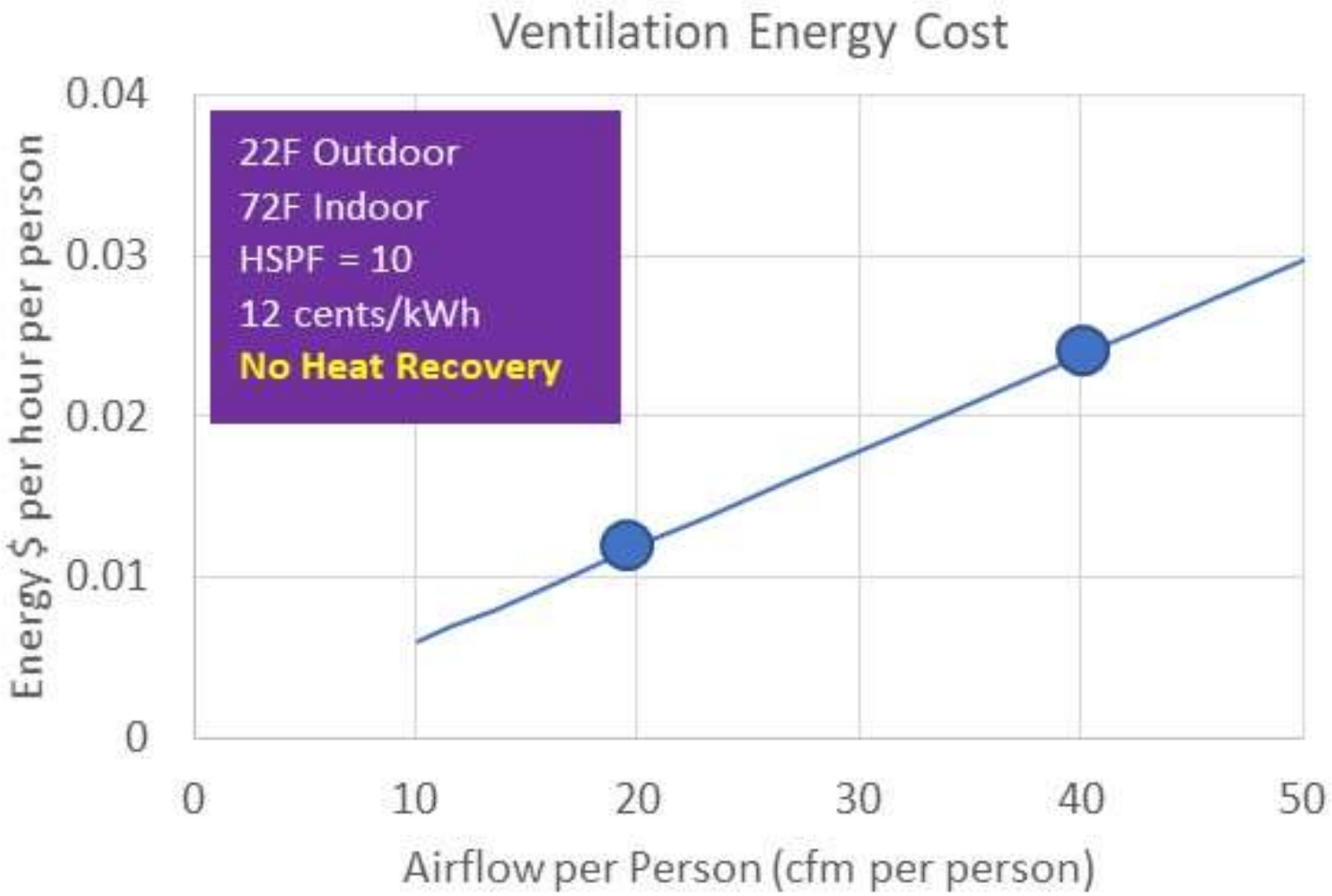
Each term is measurable and controllable in practical manners

- **Reduce sick days ~40%**
- **Improve cognition capability (eg, focus, creativity, decision making, information organization) ~10%**
- **Improve sleep with increased next day productivity**
- **Reduce indoor air quality dissatisfaction by 50% (25% to 12%)**

- **$50 vent energy/yr-person**
- **$500 sick day savings/yr-person**
- **$5000 productivity gain/yr-person**



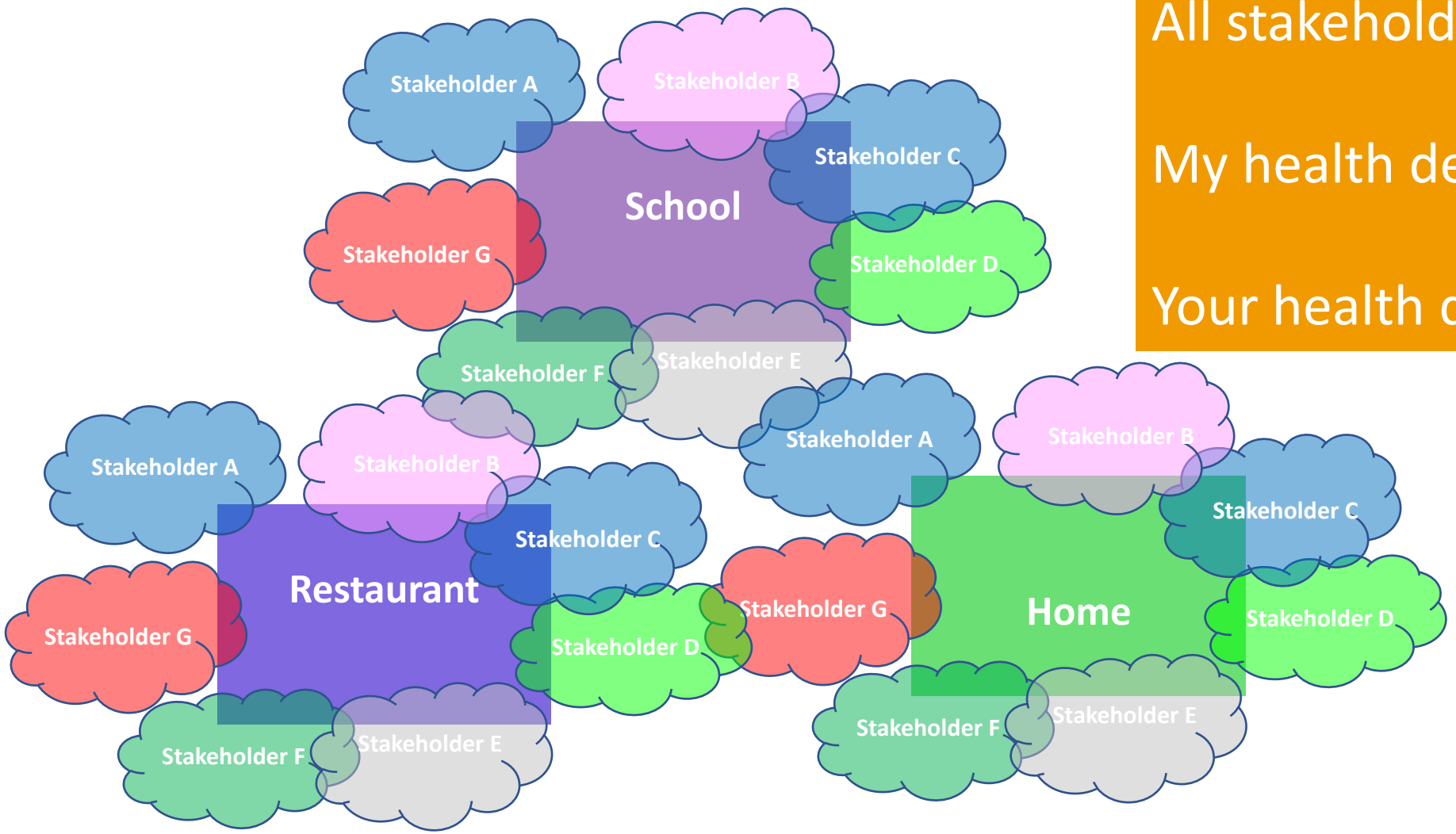
What If Fresh Air is Increased to 40cfm/person?



and, no heat is recovered??

- **"Acceptable" ventilation would cost 1 cent per hour per person**
- **Doubling ventilation to 40cfm/person would cost 2.5 cents per hour per person**
- **Are you worth an extra 1.5 cents per hour?**

7 degrees of Stakeholders – We're in this Together

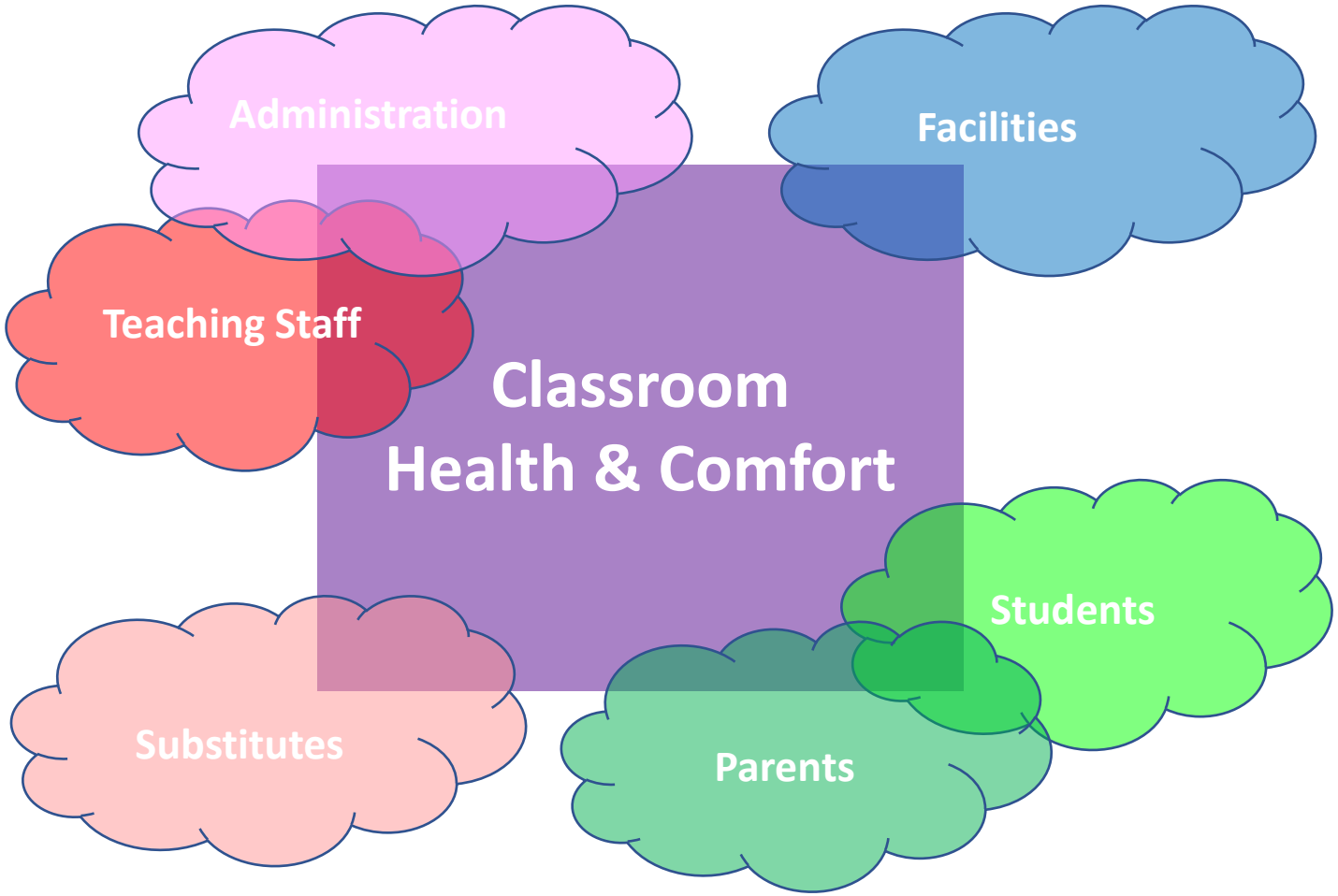


All stakeholders are connected

My health depends on you.

Your health depends on me!

Healthy Classrooms – Who Should be Involved?



Responsibility for creating safe, comfortable and energy efficient schools should involve all stakeholders.

Administration, teachers, students, parents, facility managers, substitute teachers …. want healthy, comfortable schools.

Classroom Covid - 20 Students, 1 Teacher

- from Build Equinox IAQ Calculator – FREE!
(download from BE February 2021 newsletter)

- Standard Conditions
  - 420 minute exposure
  - 1 Infectious
  - 1200ppm CO2
    - 20cfm/person
    - MERV 8 filters
  - 800ppm CO2
    - 40cfm/person
    - MERV 13 filters
  - Masking

		Immunity 0%	50%	75%
MERV 8 filter 20cfm/person	Infect Probability %	44	44	44
	Infection Multiplier	8.9	4.9	2.9
800ppm CO_2 40cfm/person	Infect Probability %	25	25	25
	Infection Multiplier	5.1	2.8	1.7
MERV 13 filter 40cfm/person	Infect Probability %	14	14	14
	Infection Multiplier	2.9	1.6	**0.9**
50% Mask Use 20% Mask Eff	Infect Probability %	12	12	12
	Infection Multiplier	2.4	1.3	**0.8**
80% Mask Use 80% Mask Eff	Infect Probability %	2	2	2
	Infection Multiplier	**0.4**	**0.2**	**0.1**

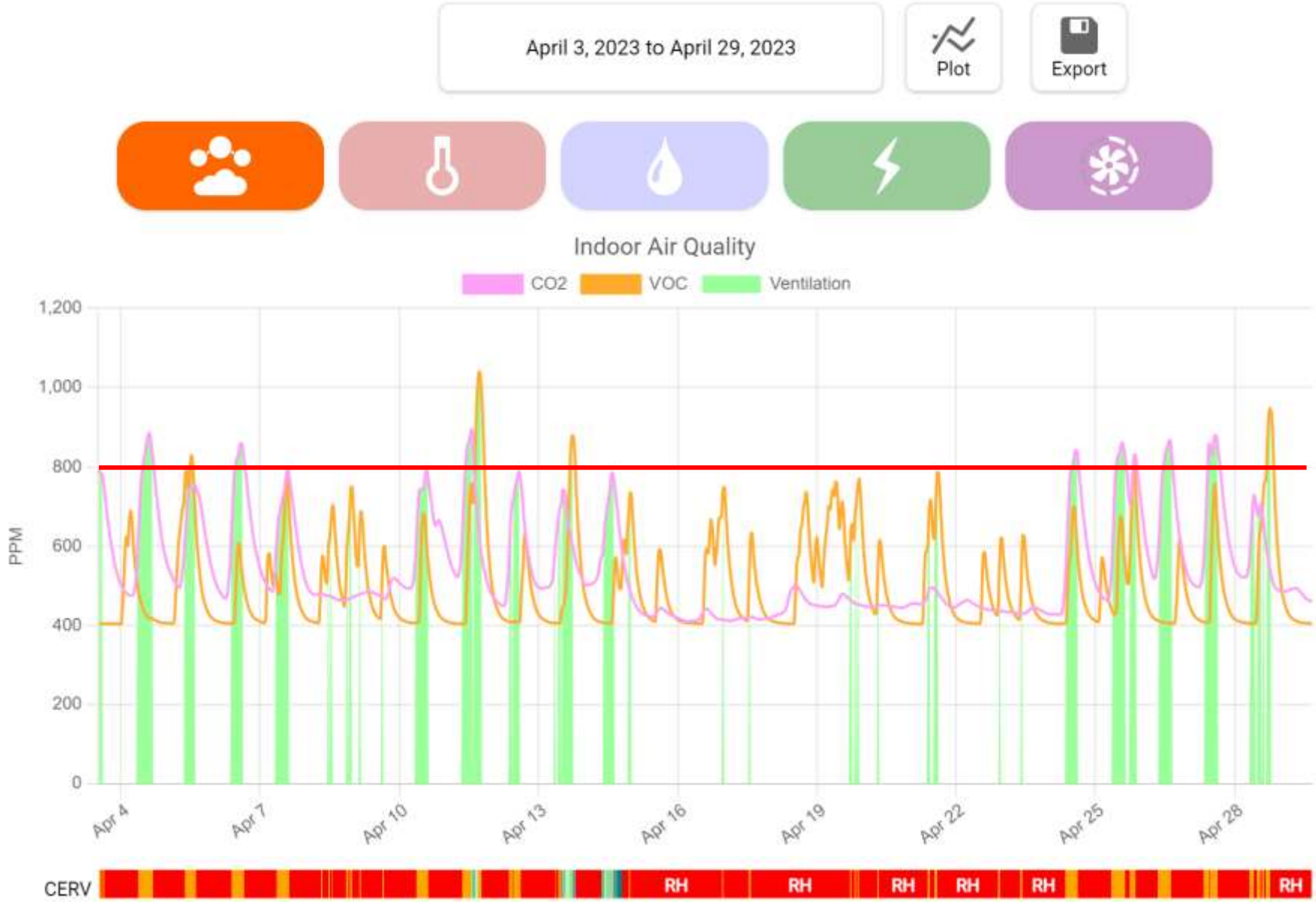
Brixham Hat Trick: Healthy, Energy Efficient and Sustainable

BRIXHAM MONTESSORI FRIENDS SCHOOL

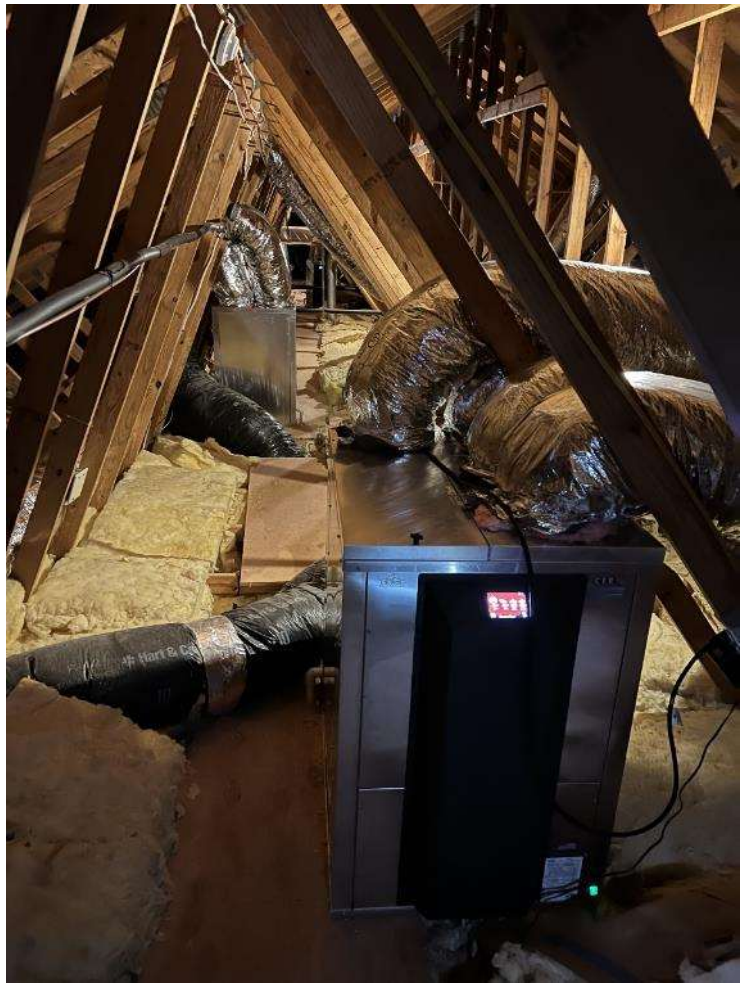
- BMFS: York Maine
- 8100sqft building; 90 students & staff
- 10.5 tons (126kBtuh) heat pumps replace propane heat
- Installed 5 smart ventilation units triggered on CO_2 and VOC
- Eliminates 14tonnes of CO_2 emissions
- 40% lower site EUI from 55 to 32kBtu/sqft
- 40% fewer sick days (1 per person/year) to ASHRAE 62.1

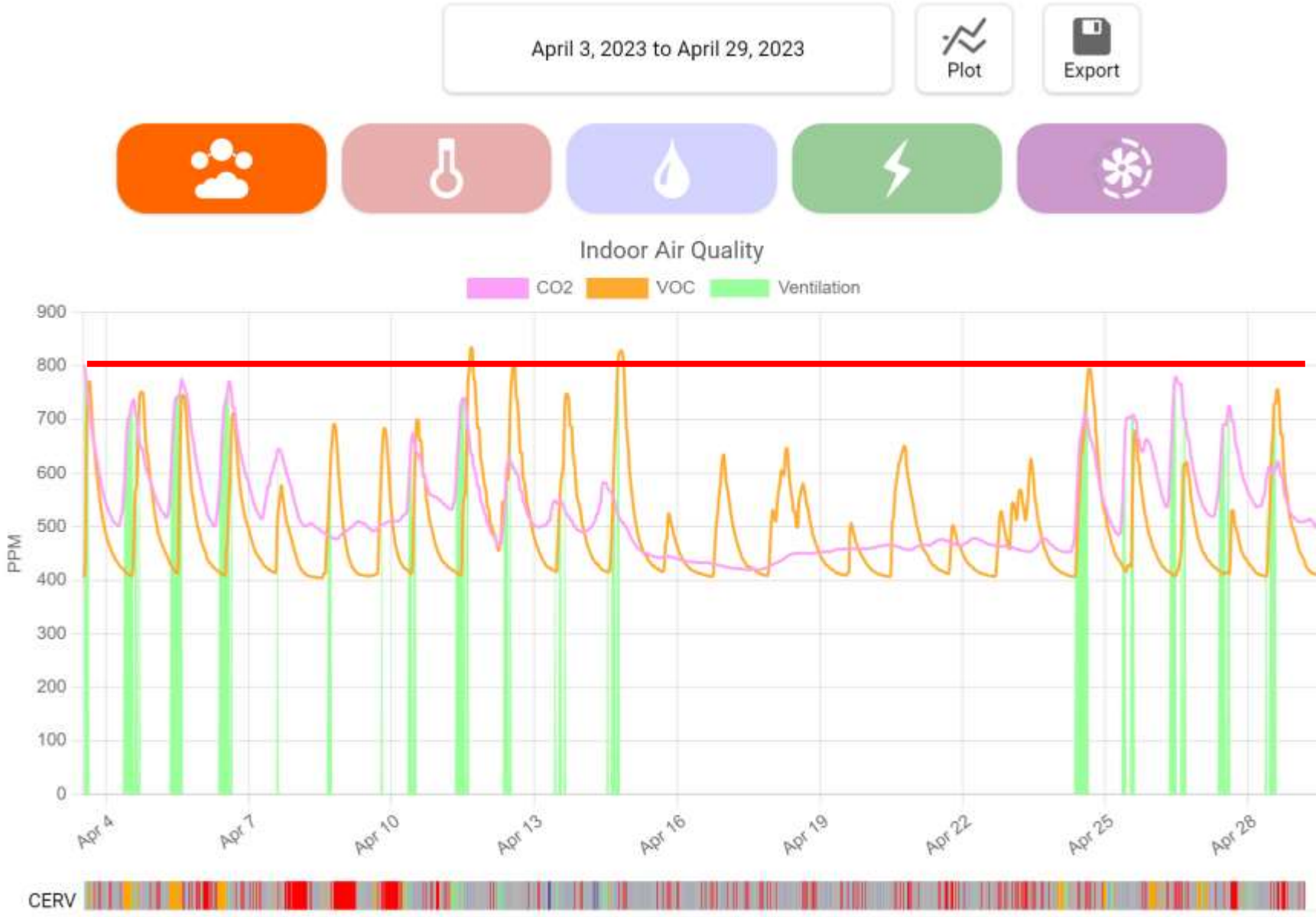
- $3000/year utility savings
- $45,000/year sick day savings (90 sick days at $500/day)

Downstairs (Unit#1)
April 3-29, 2023



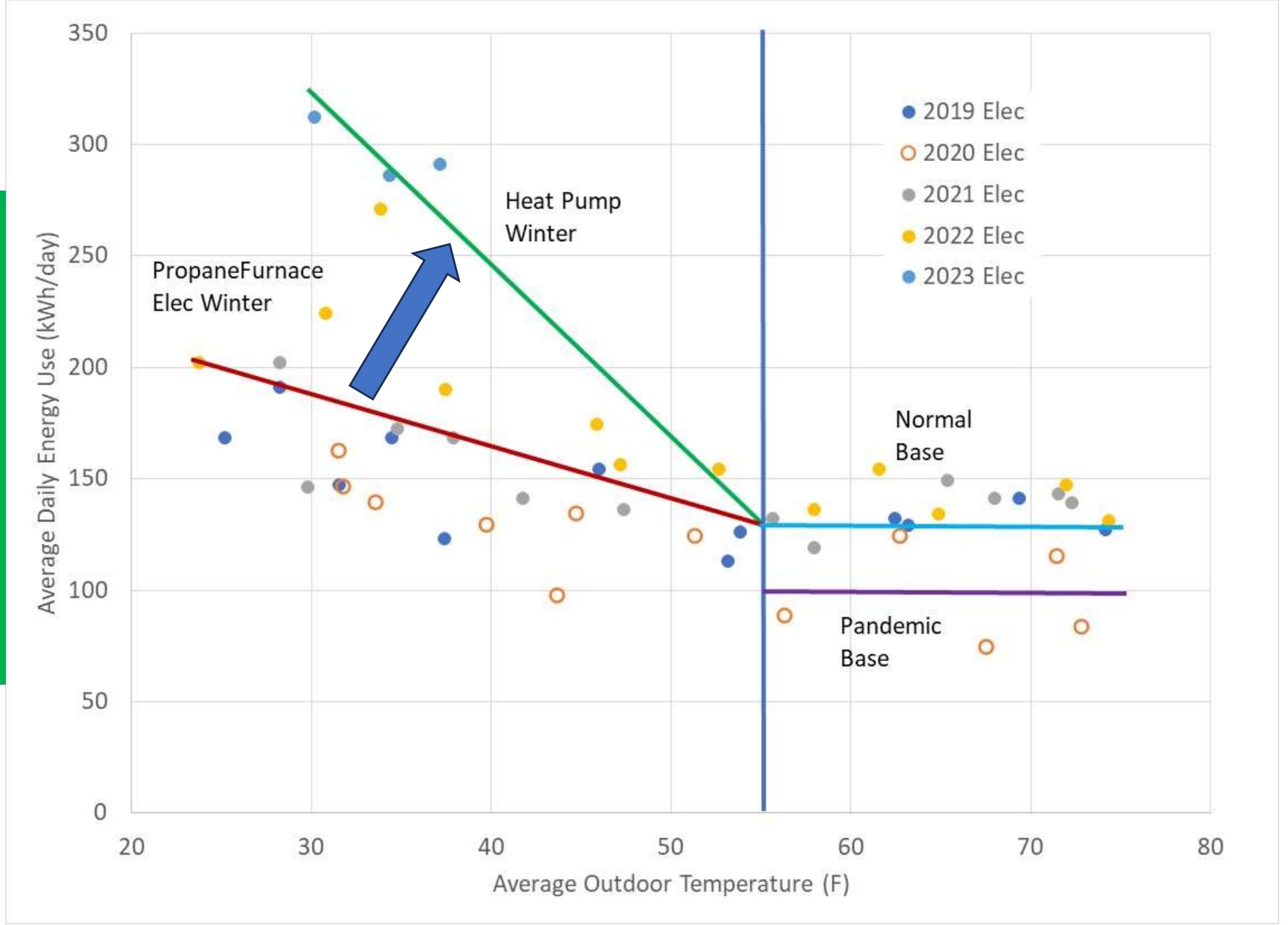
Upstairs (Unit#5)
April 3-29, 2023



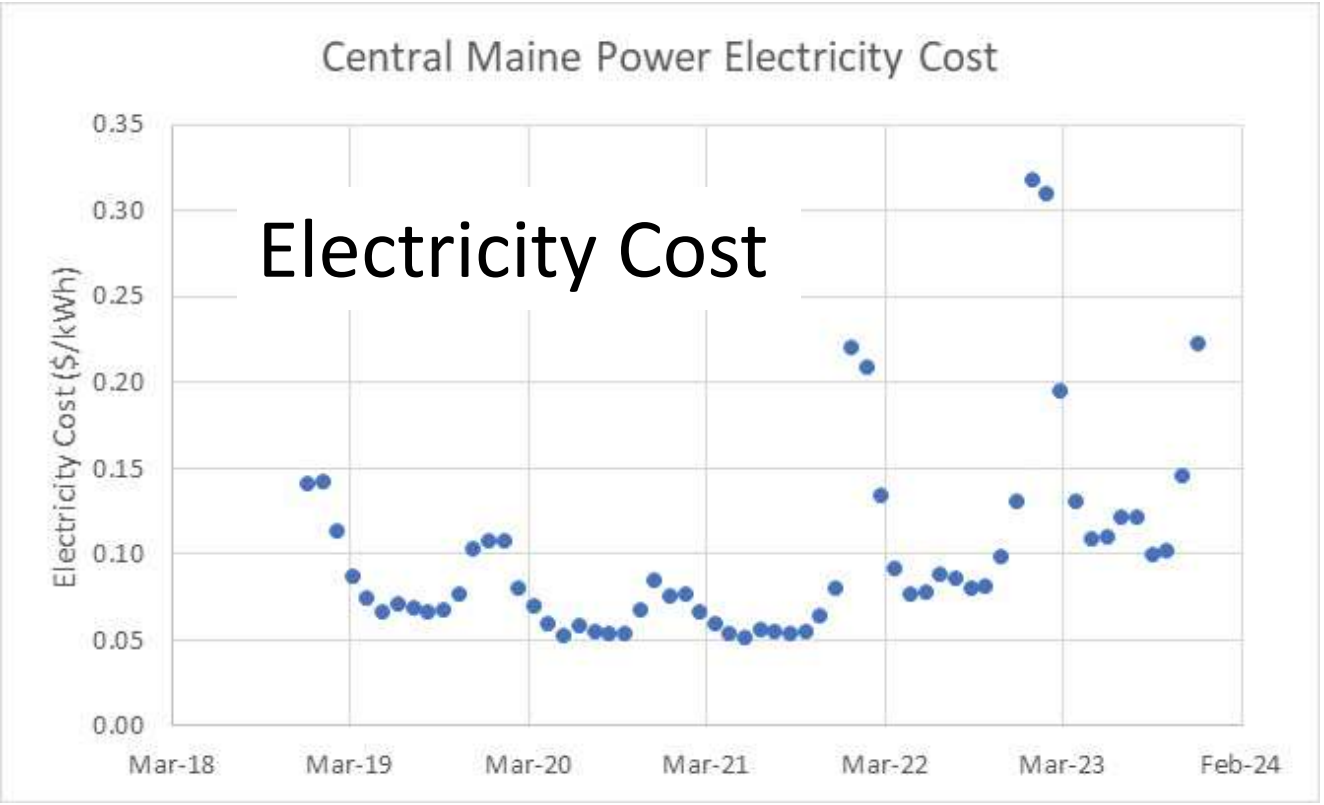


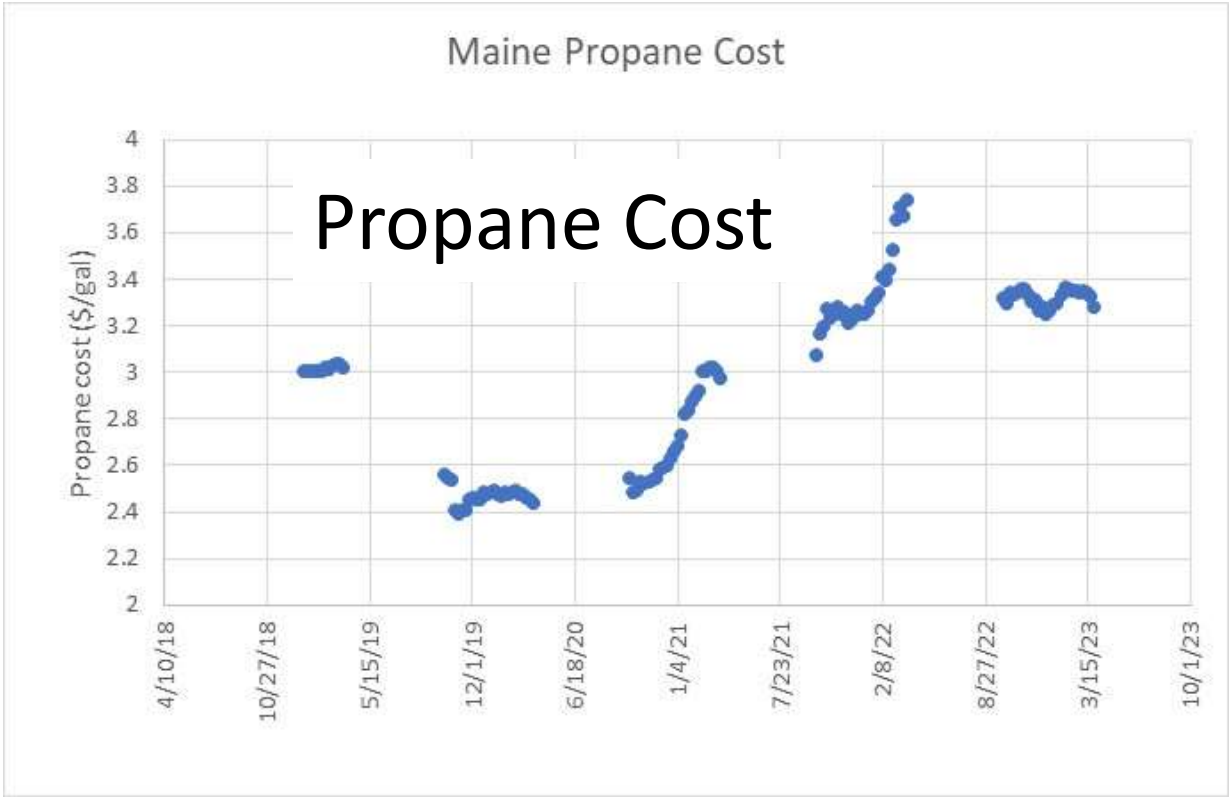
BMFS Energy

- Electric use increases, but energy overall energy use decreases
- Heat pump uses ~1/3 energy (electric) in comparison to high efficiency furnace
- As grid is decarbonized, site and source energy become the same



Southern Maine Energy $$$





- How do the economics from 3 years ago compare with today?
- Does conversion from propane to electric save $$$?

2019 Utility Costs

Month	Maine Fuel Oil (propane) $/gal	Central Maine Pow $/kWh	Propane Cost $	Electric Cost $	Total Elec & Propane $	HP Electric Cost $
January	2.4	0.201	1572	1204	2776	2170
February	2.4	0.202	1255	1068	2323	1883
March	2.4	0.173	1087	927	2014	1492
April	2.4	0.146	448	660	1109	879
May	2.4	0.134	0	541	541	541
June	2.4	0.126	0	492	492	492
July	2.4	0.130	0	526	526	526
August	2.4	0.129	0	519	519	519
September	2.4	0.126	0	491	491	491
October	2.4	0.127	46	548	594	635
November	2.4	0.136	970	653	1623	947
December	2.4	0.163	1213	919	2132	1562
Total					**15140**	**12138**

2023 Utility Costs (projected)

Month	Maine Fuel Oil (propane) $/gal	Central Maine Pow $/kWh	Propane Cost $	Electric Cost $	Total Elec & Propane $	HP Electric Cost $
January	3.4	0.378	2227	2266	4493	4085
February	3.4	0.370	1778	1956	3733	3448
March	3.4	0.255	1540	1369	2908	2202
April	3.4	0.190	635	857	1492	1141
May	3.4	0.169	0	681	681	681
June	3.4	0.170	0	663	663	663
July	3.4	0.182	0	732	732	732
August	3.4	0.181	0	729	729	729
September	3.4	0.159	0	620	620	620
October	3.4	0.162	66	696	762	807
November	3.4	0.206	1375	984	2359	1429
December	3.4	0.283	1719	1594	3313	2711
Total					**22486**	**19248**

Georgetown-Ridge Farm Junior High School

- 200 students in junior high school
- Rural with 75% free and reduced lunch
- 25,000sqft with multiple additions
  - Original school gutted and converted into gymnasium; two classroom wings
  - Cafeteria, library
  - Addition for locker rooms, music rooms, and special activity areas
  - Administration, nurse, counseling, special needs offices

Air Quality Improvement in Older Classrooms

Current state

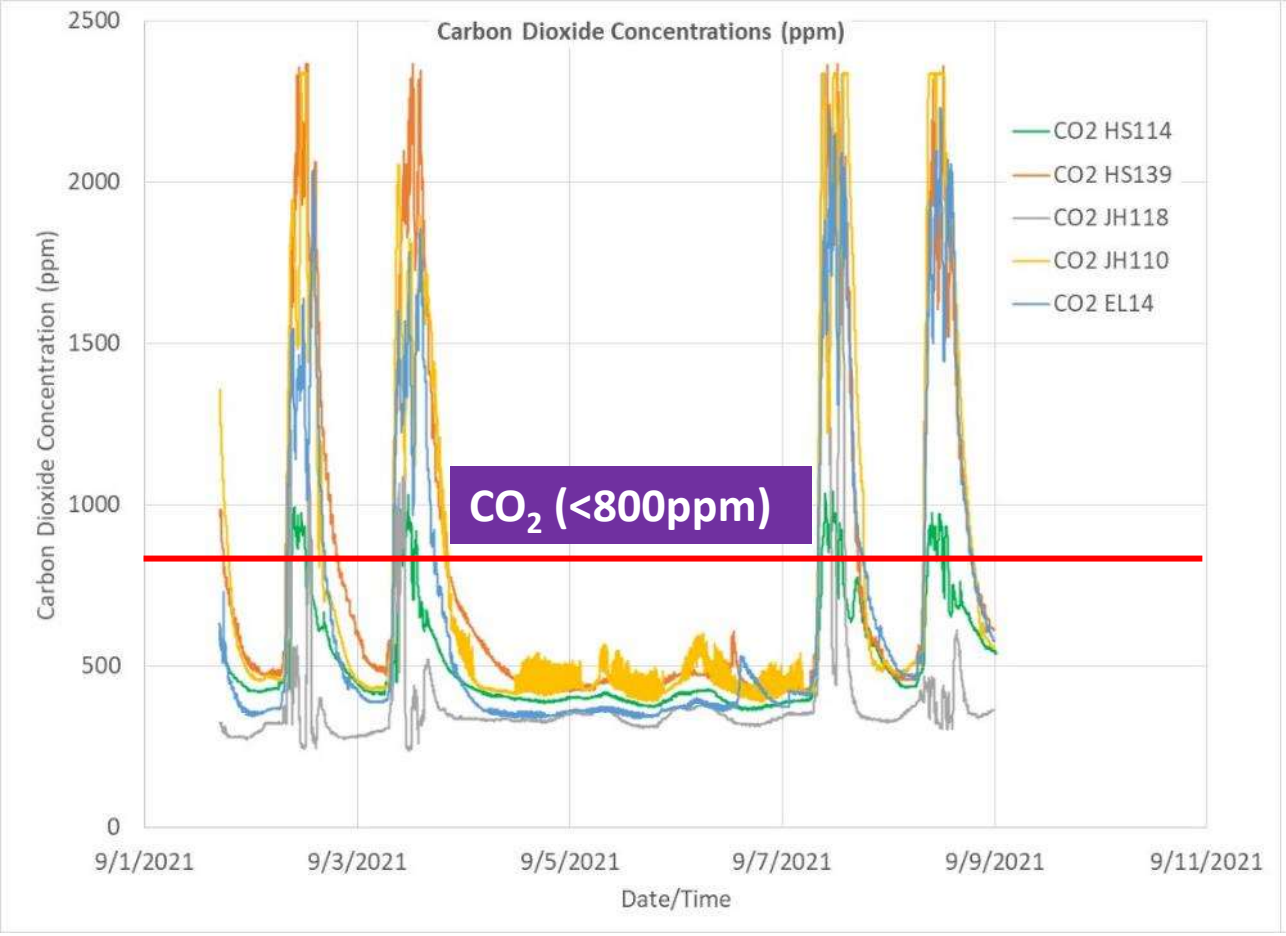
- No ventilation!
- Natural gas hot water radiators
- Inadequate window AC
- Window walls (upper half of exterior wall covered and insulated) with reduced windows
- **Electrical**
  - Original incandescent lights used three 20amp breakers
  - Each circuit with LEDs draws 2amps
  - Window AC 20amp breaker

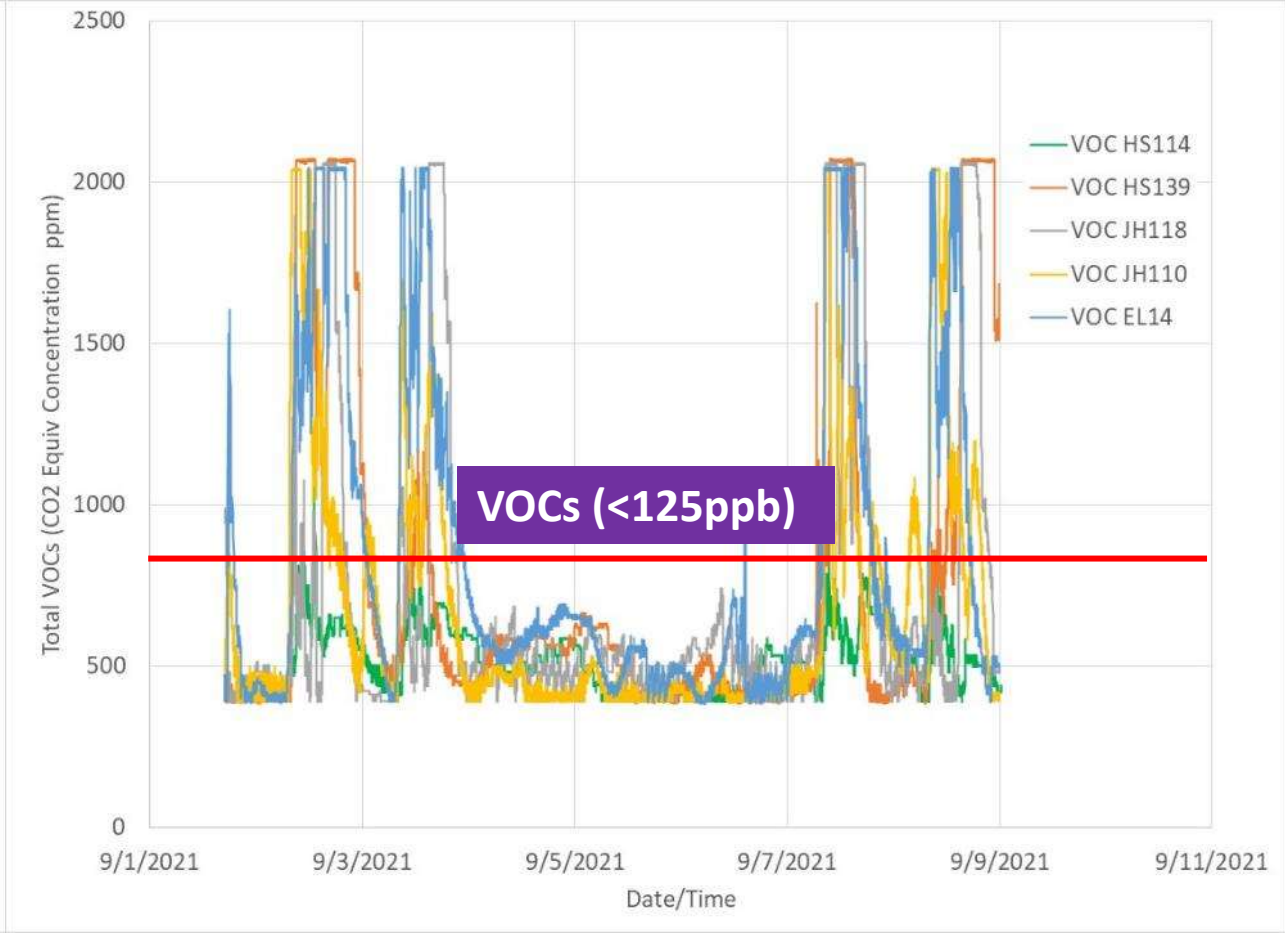
Concerns

- Covid
- Disinfectant spraying
  - Papers wet in the morning

How can a classroom in an older school be improved without a large capital project and without disruption?

Carbon Dioxide & VOC Trends (1 week data)



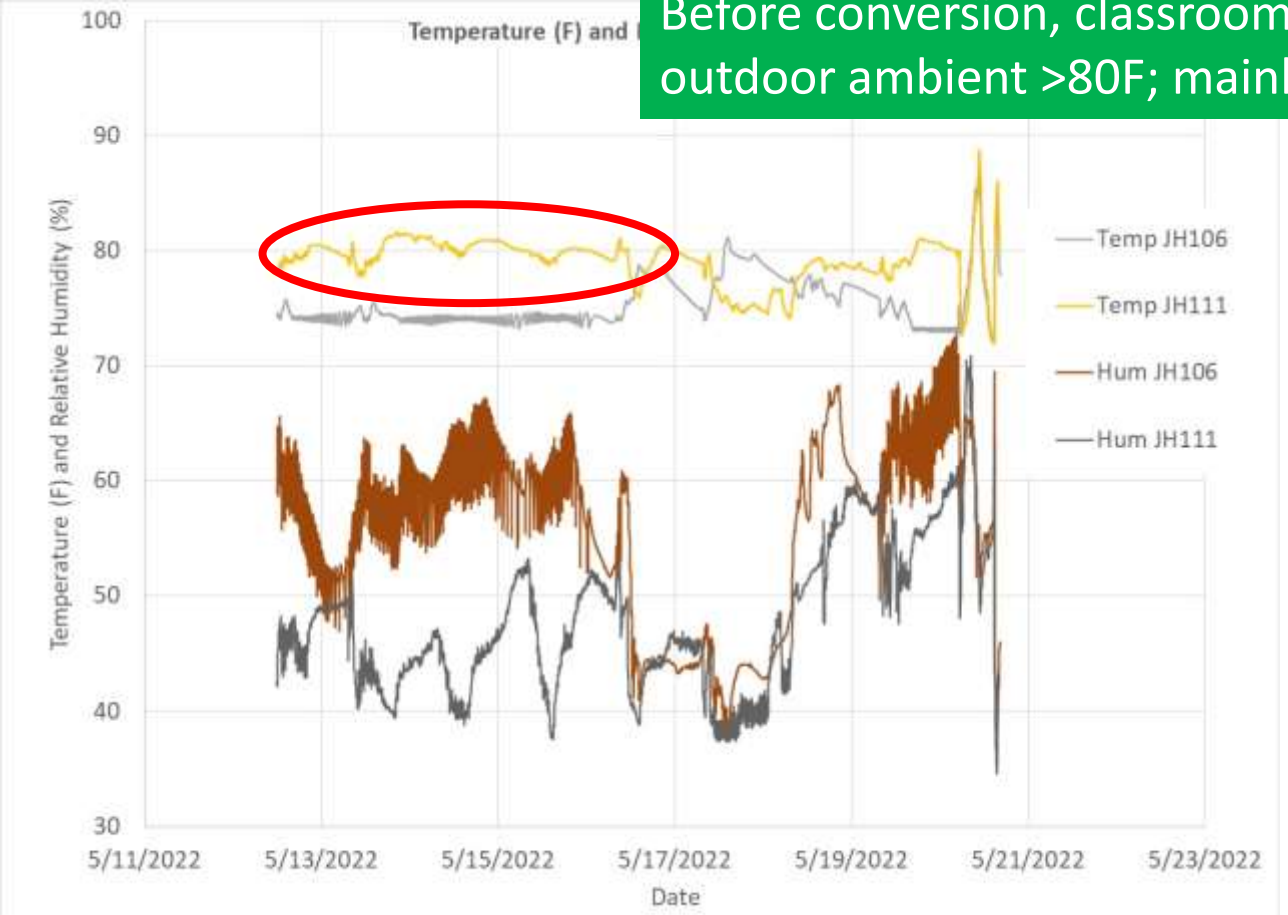


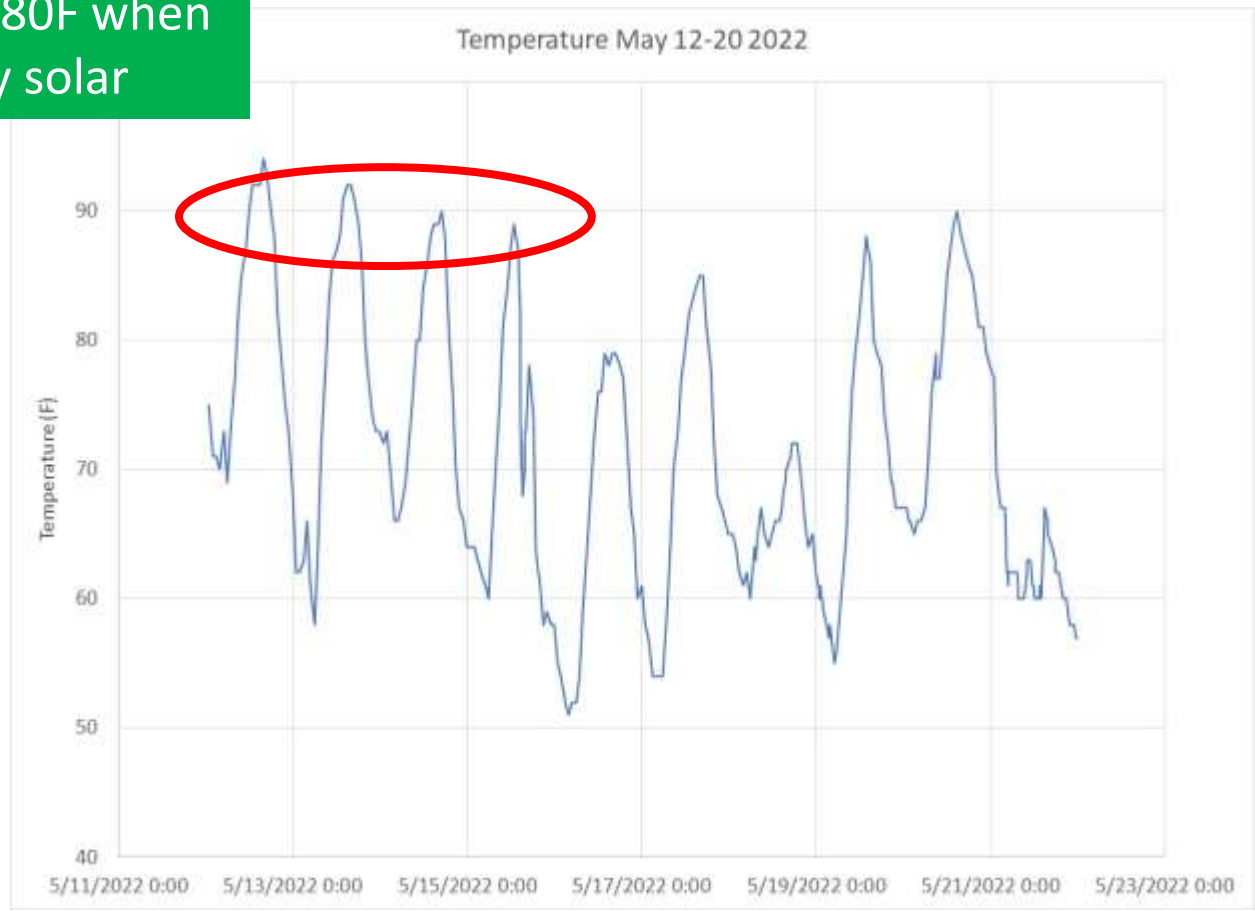
40cfm/person fresh air to reduce CO_2 and VOCs to IAQ Standard

Comfort – Junior High School (south and north side rooms)

- 1% productivity drop per 1F outside of one's comfort range
- Increasing rate of productivity drop the further from comfort range

Before conversion, classroom 80F when outdoor ambient >80F; mainly solar





Unitized Concept for IAQ and Electrifying Older Classroom

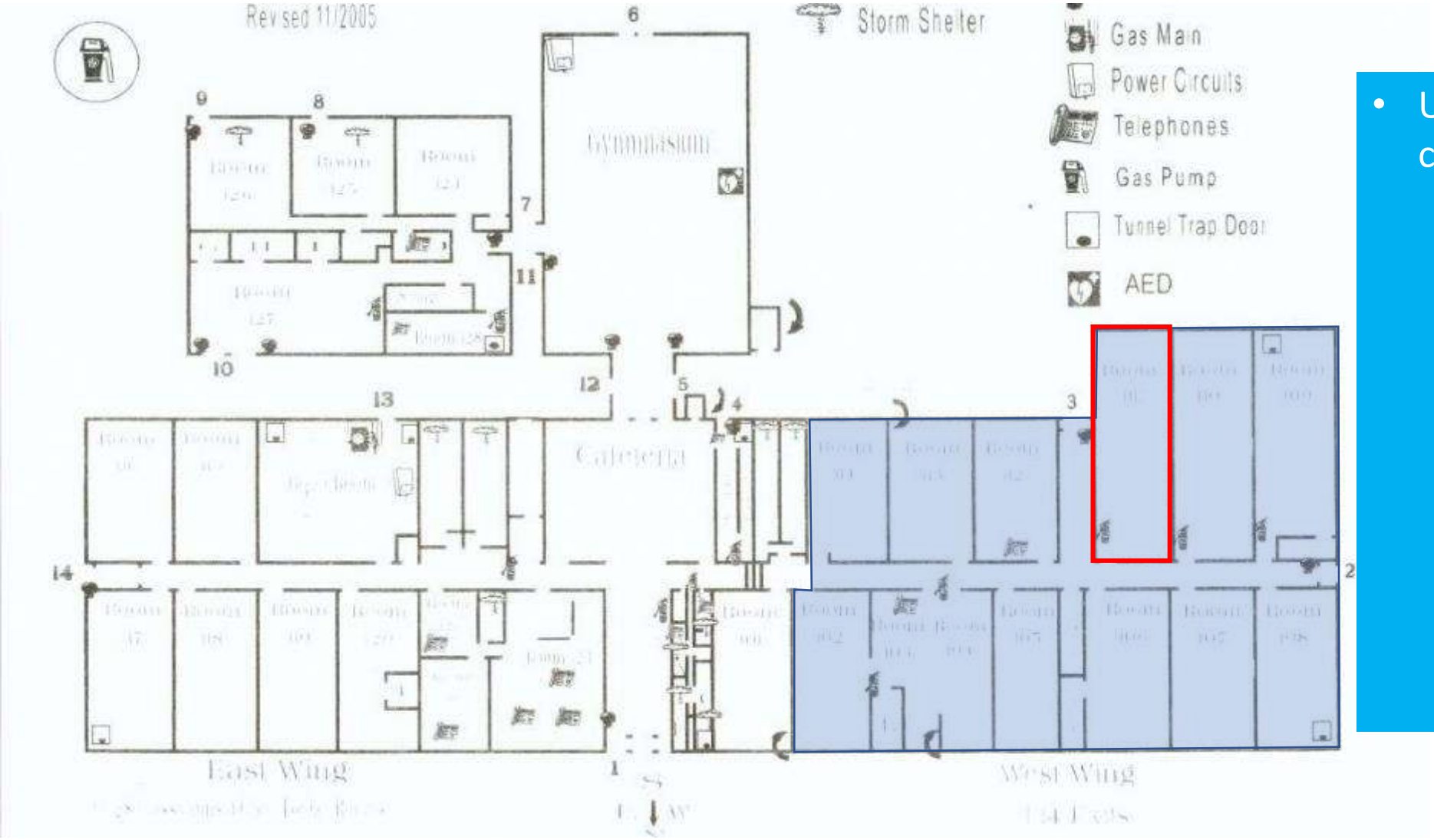
Unitized smart ventilation and comfort conditioning system

Multiple Goals

- Avoid classroom shutdown
- Unit < doorway size
- Room-by-room “rolling” installation
- Installation labor from local community
  - HVAC installer skill
  - Maximize funds spent within school community
  - Flexibility in installation scheduling
- Increase facility maintenance efficiency

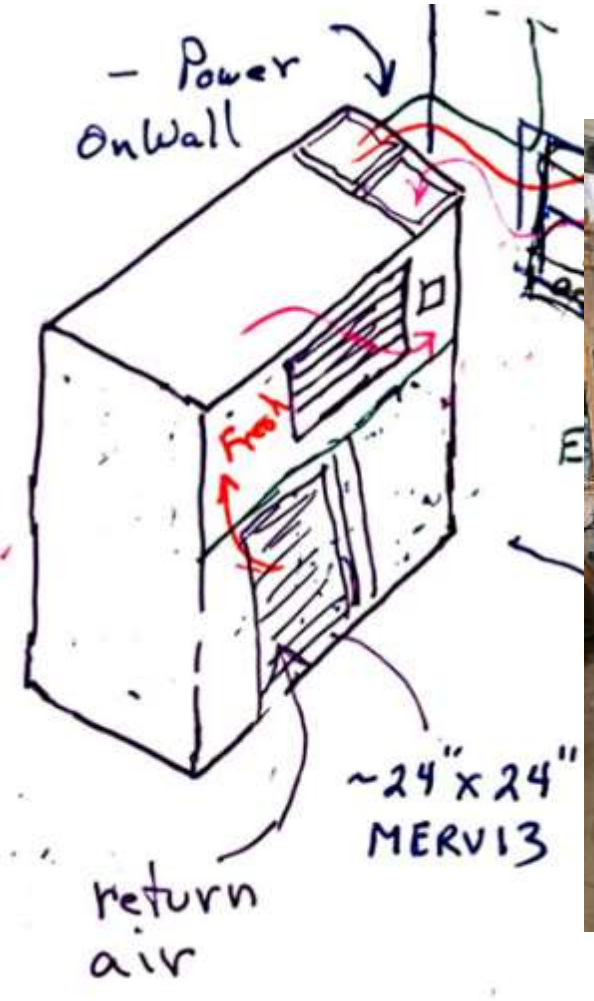
- Eliminate classroom disinfectant spraying
- Online classroom monitoring & control
- Reduce absenteeism and staff sick days
- Investigate IAQ effects on health (reduced, wheeze, headache, asthma triggers, etc)

GRF Junior High School – Convert 12 Classrooms



- Unitized fresh air, comfort conditioning system features
  - 1000cfm fresh air
  - 70% sensible & 60% latent energy exchange
  - 3ton, low temperature (70% capacity at -13F) heat pump capacity
  - UVGI (85% single pass kill efficiency)
  - MERV13 filtration
  - “Classroom quiet” operation

Concept to Production Reality



- Project design started Fall, 2022
- Initial unit installed July 2023
- 11 units currently in production

Installation – 4-6 Person-days Labor

- Set indoor unit & outdoor unit
- Pull wire from distribution panel to indoor unit
- Run wire from indoor unit to outdoor unit
- Run refrigerant linesets (two sets of 3/8” & ½” copper)

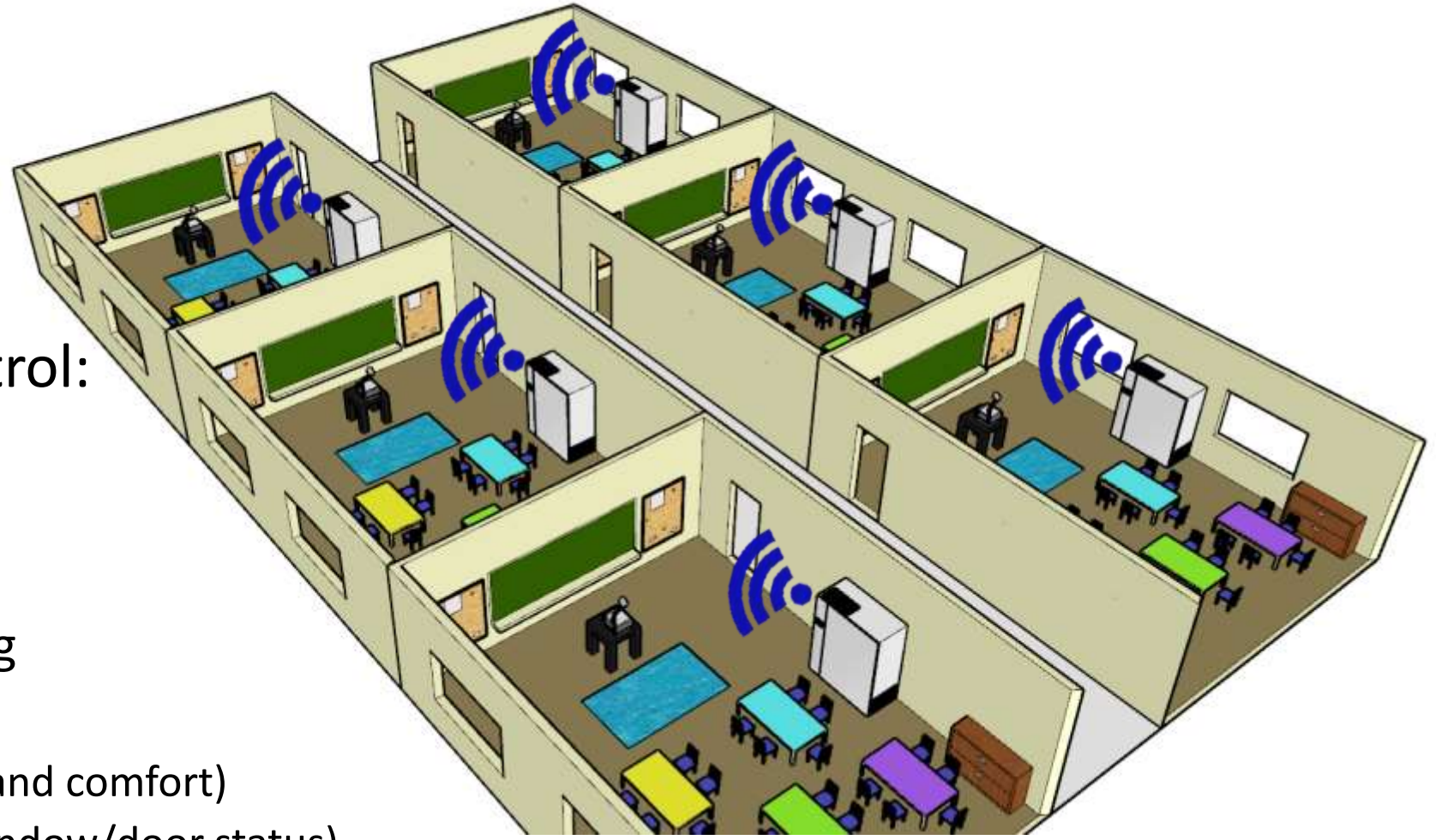
- Evacuate refrigerant linesets
- Run condensate line
- Install fresh air & exhaust air ducting
- Add duct shrouding; plug in, switch on, link to WiFi

Electrical

- No distribution panel upgrade required
- 40amp/240VAC Breaker; Max amps = 31 amps
- Three 20amp breakers for lighting combined with LEDs
- Window AC 20amp/240 breaker replaced with 40amp/240VAC

"Classroom Quiet"

Administration & Facilities Management – Simple Operation



- Dashboard Monitor & Control:
  - Online support
  - Replacement scheduling
    - Filters, UV lamps, etc.
  - Diagnostics/Troubleshooting
  - Classroom:
    - IAQ (CO2, VOC, Particulates and comfort)
    - Sensor status (occupancy, window/door status)

Administration & Facilities Management – Efficient Maintenance

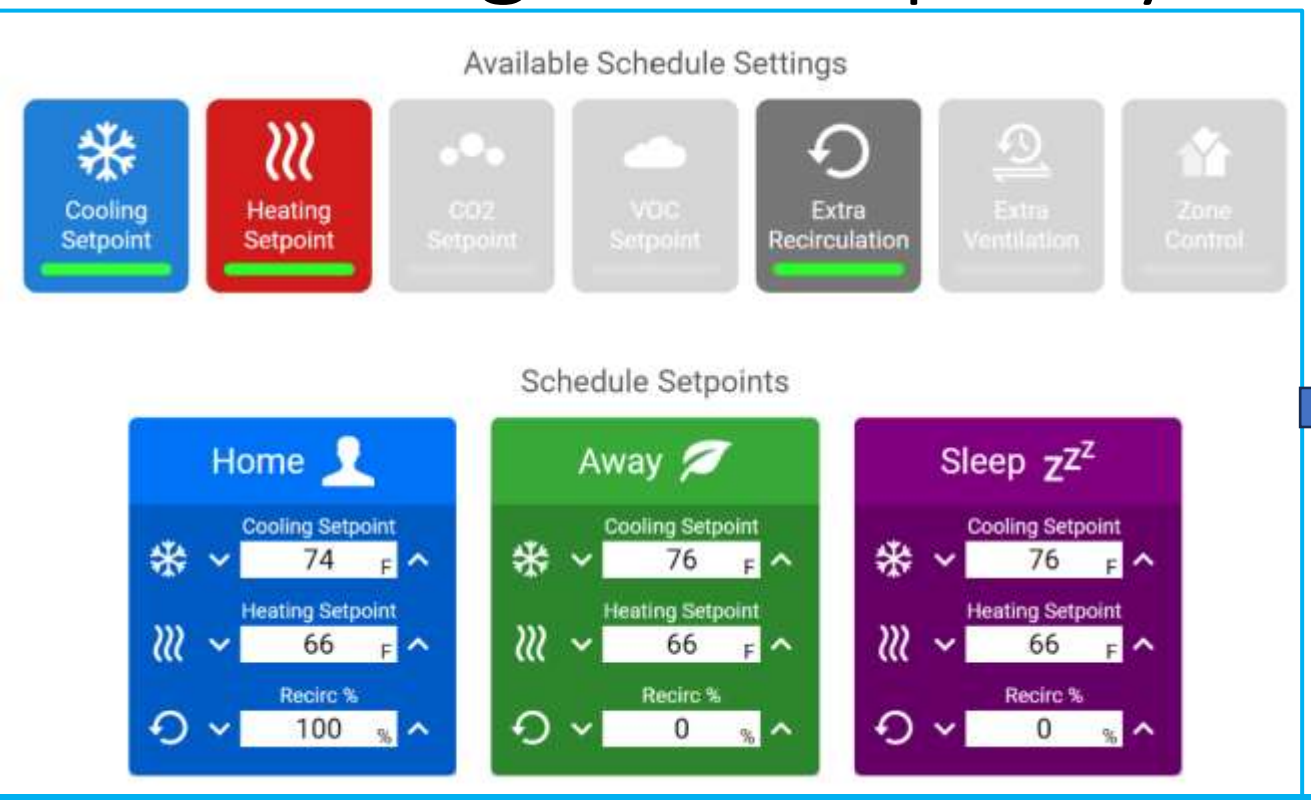
Classroom

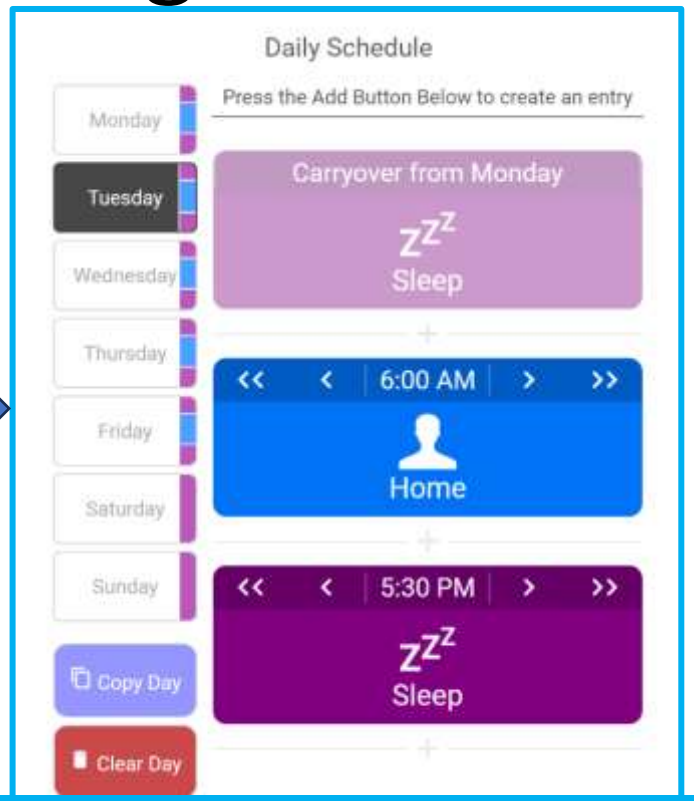
School building

- Dashboard Monitor & Control:
  - Classroom operation & status
    - Teacher
  - Building operation & status
    - Principal's Staff
  - District operation & status
    - Superintendent's Staff

School district

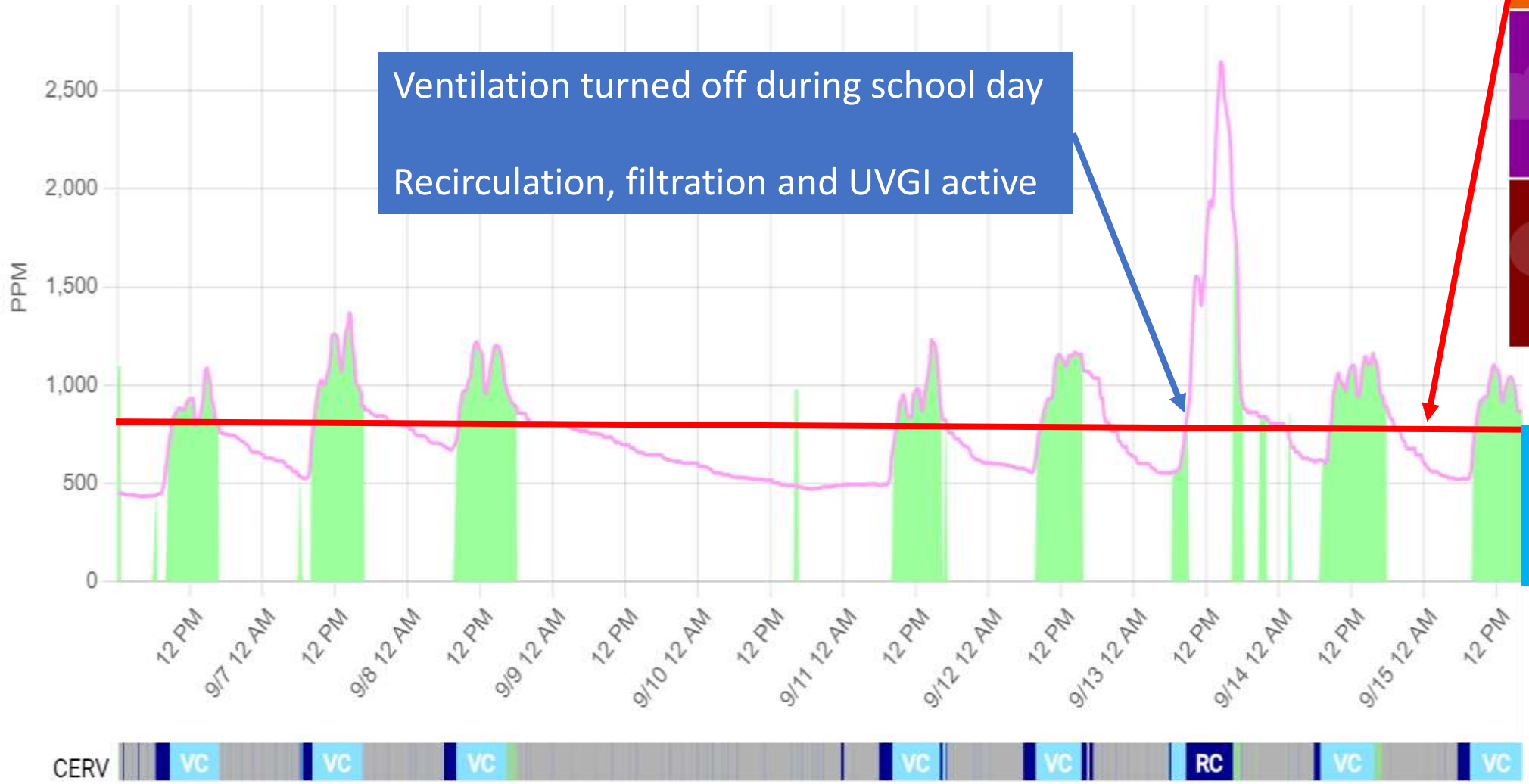
Scheduling & Occupancy Monitoring

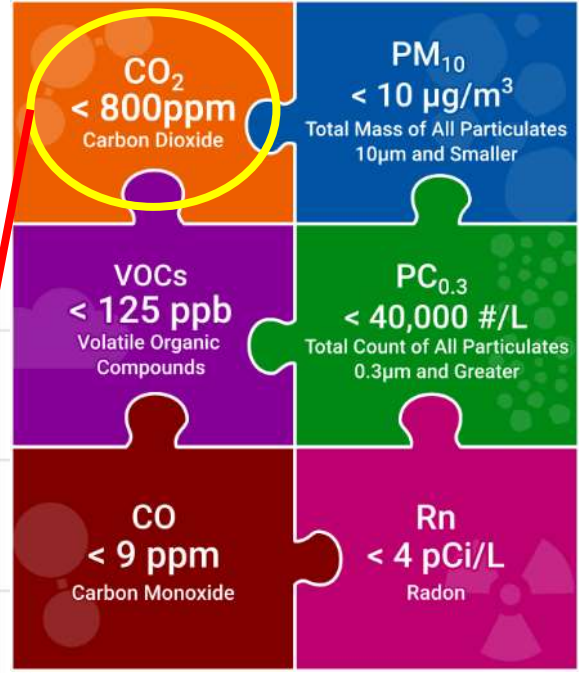




- Time “blocks” are defined and assigned to weekly schedule
- Simple menu selection for adding wireless sensors (occupancy, window/door opening, circuit sensing, auxiliary components (eg, dehumidifier, dampers, auxiliary fans)
- No “technology integrator” needed for setup & programming
- OTA (over-the-air) upgrading (like Tesla) allows new features and capabilities to be broadcast to existing units

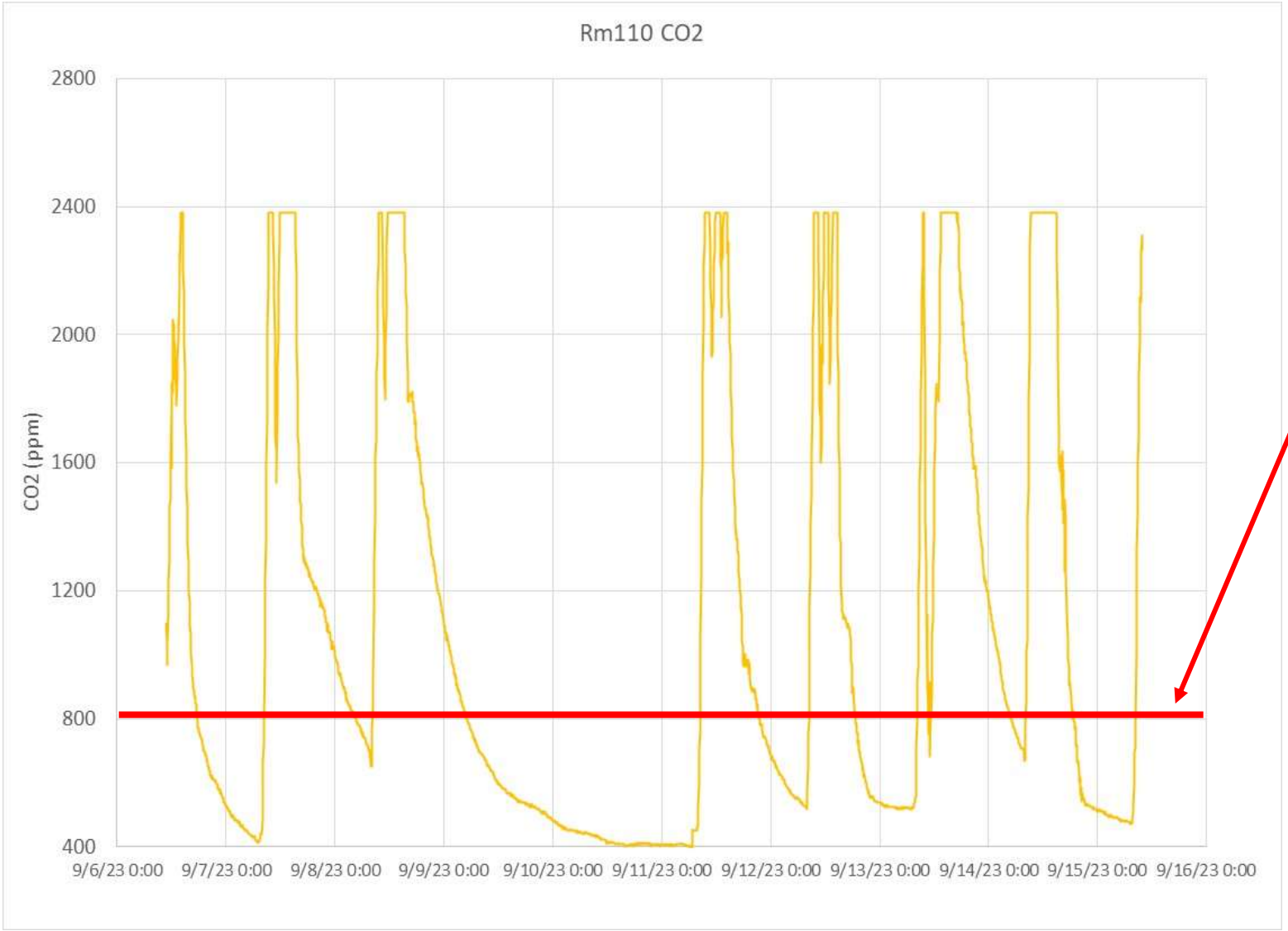
Classroom CO_2 Improvement

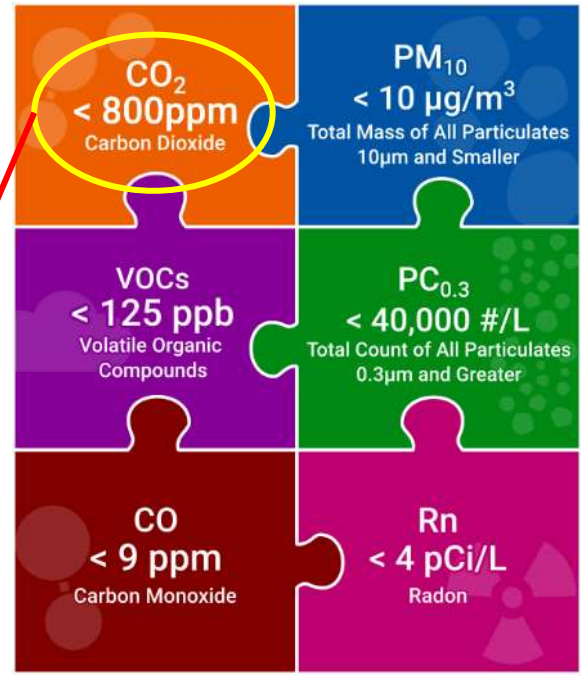




CO_2 standard will be attained when all classrooms converted

Adjacent Classroom CO_2 w/o Smart Ventilation



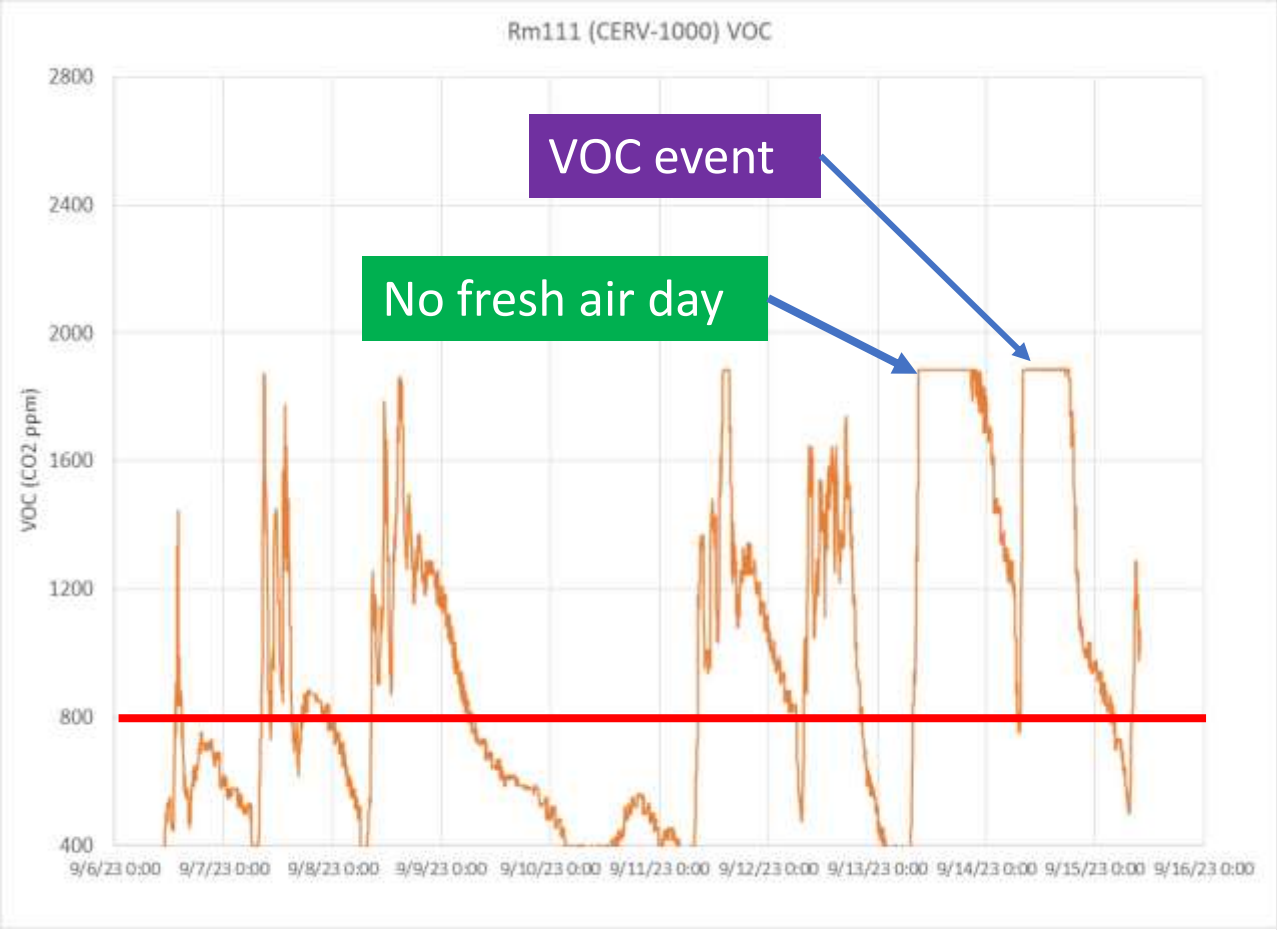


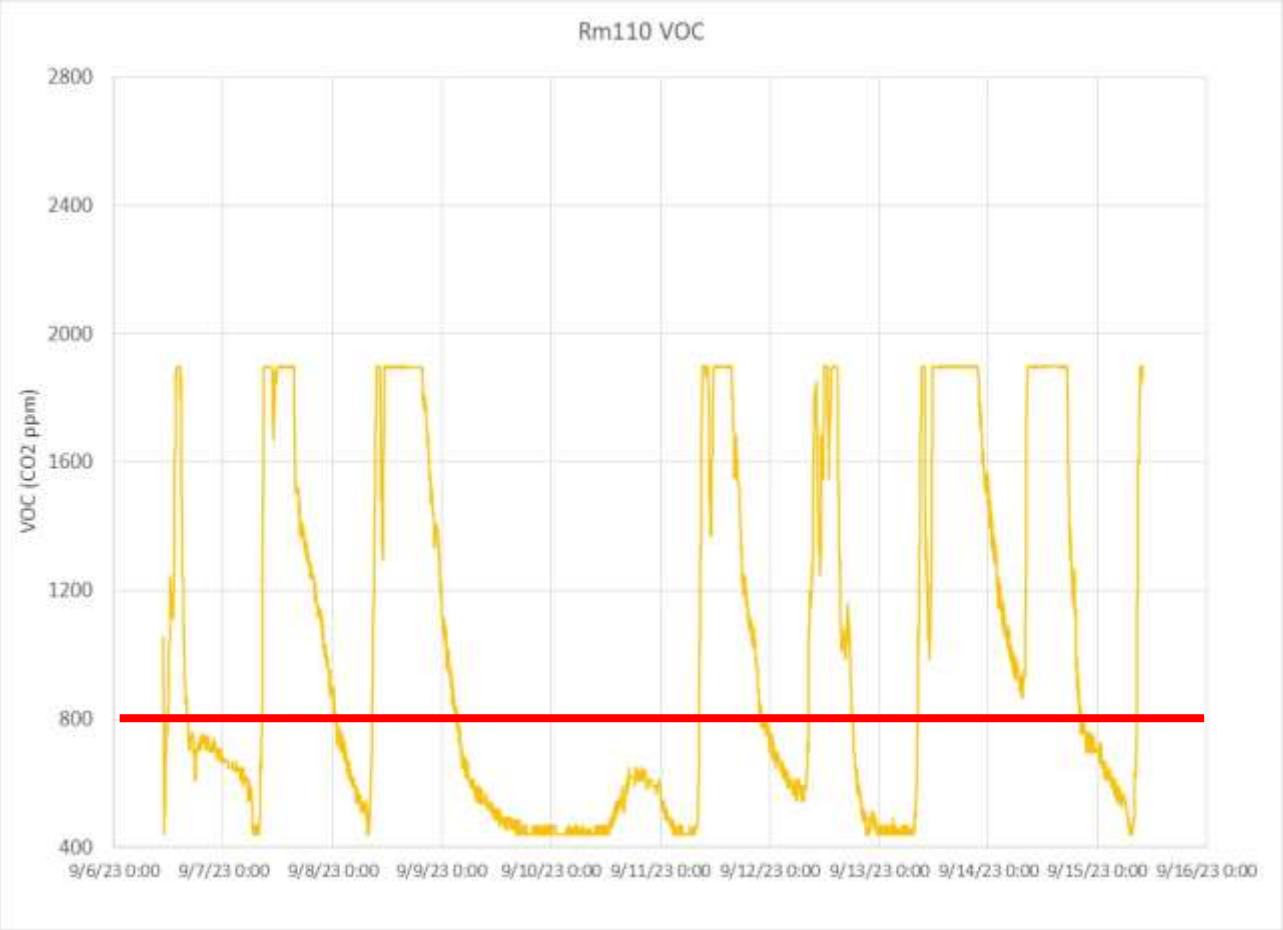
Hourly class changes opens door to poor hallway air quality from other unventilated classrooms

Classroom VOCs – CO_2 Scale (800ppm CO_2 ~ 125ppb VOCs

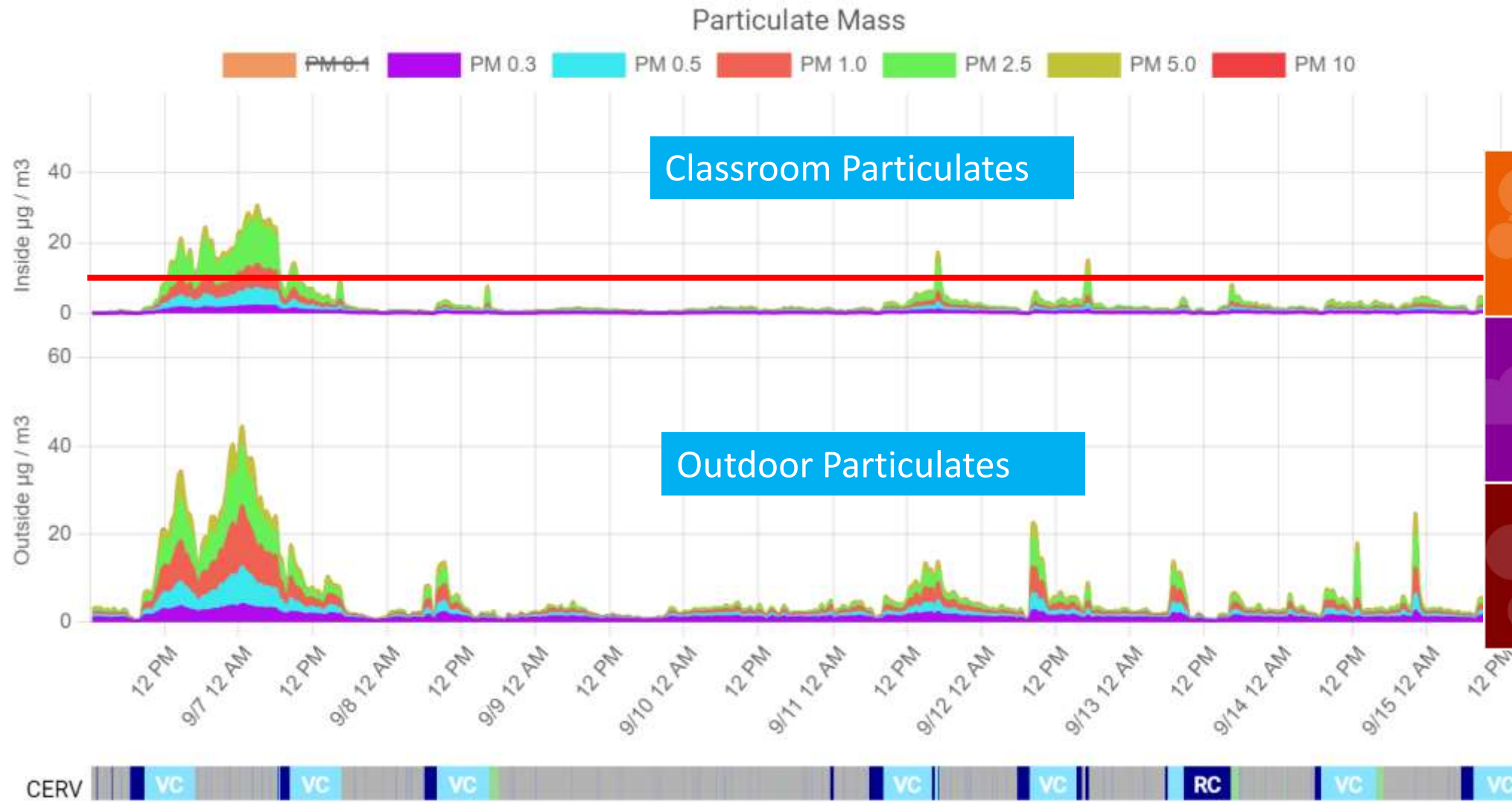
Converted Classroom

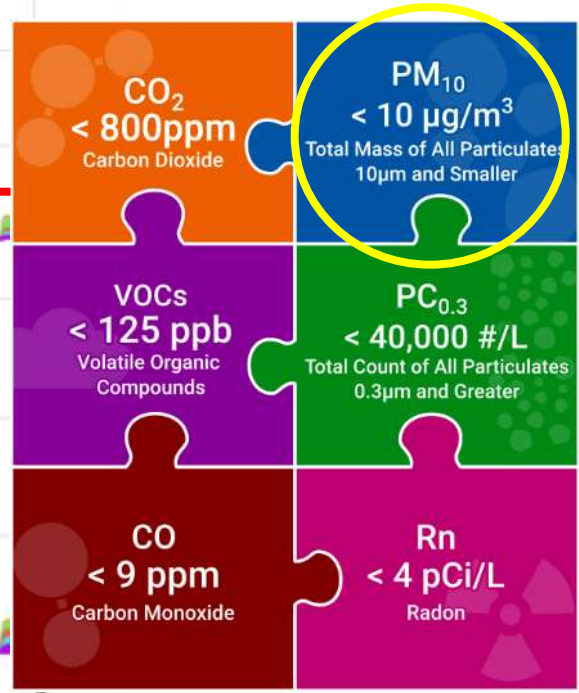
Adjacent (Unconverted) Classroom



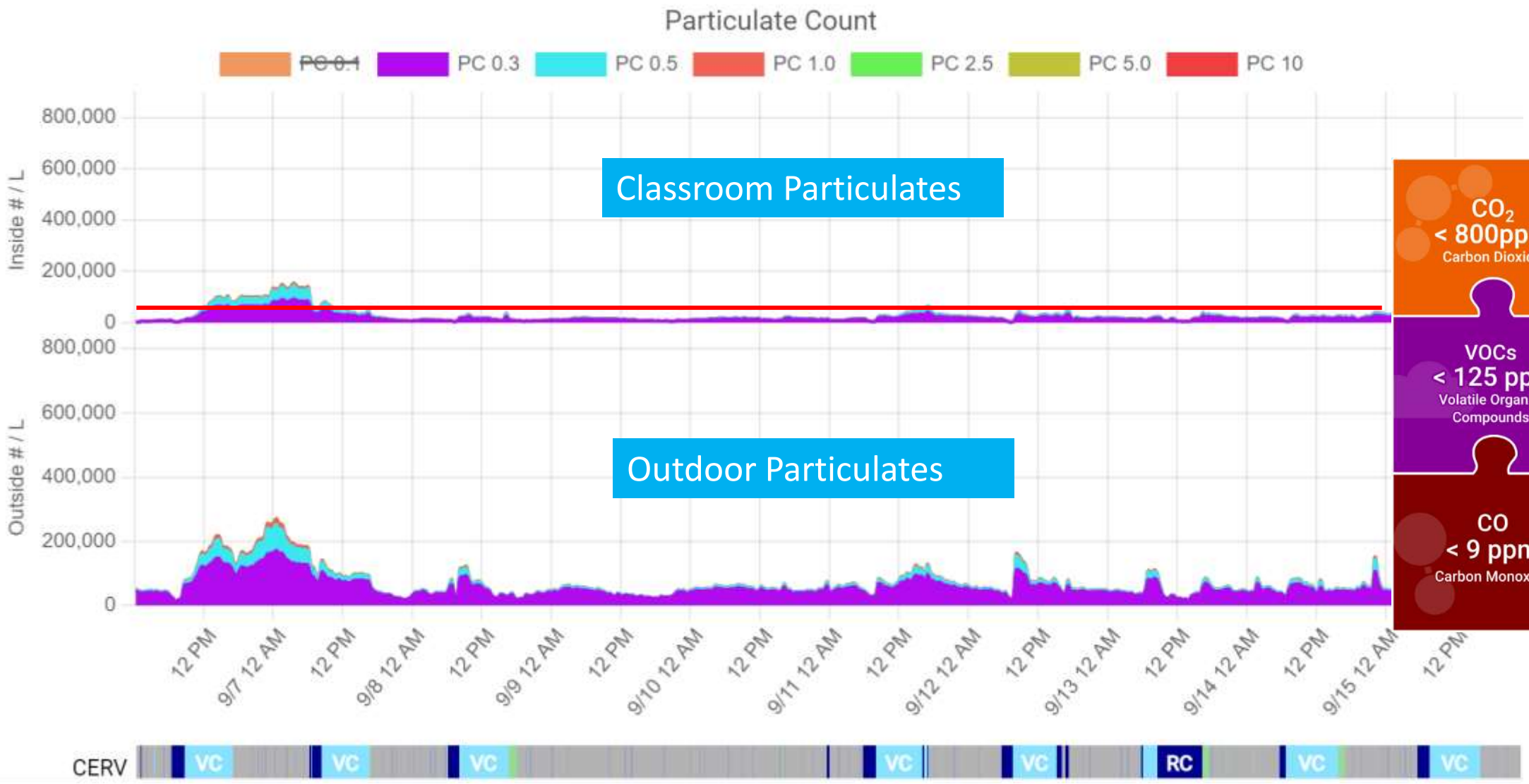


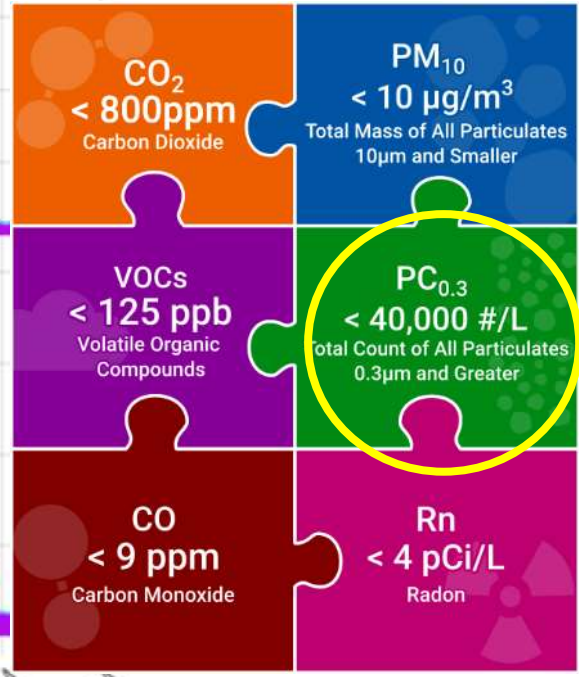
Classroom PM10 (<10µ; µg/m^3)



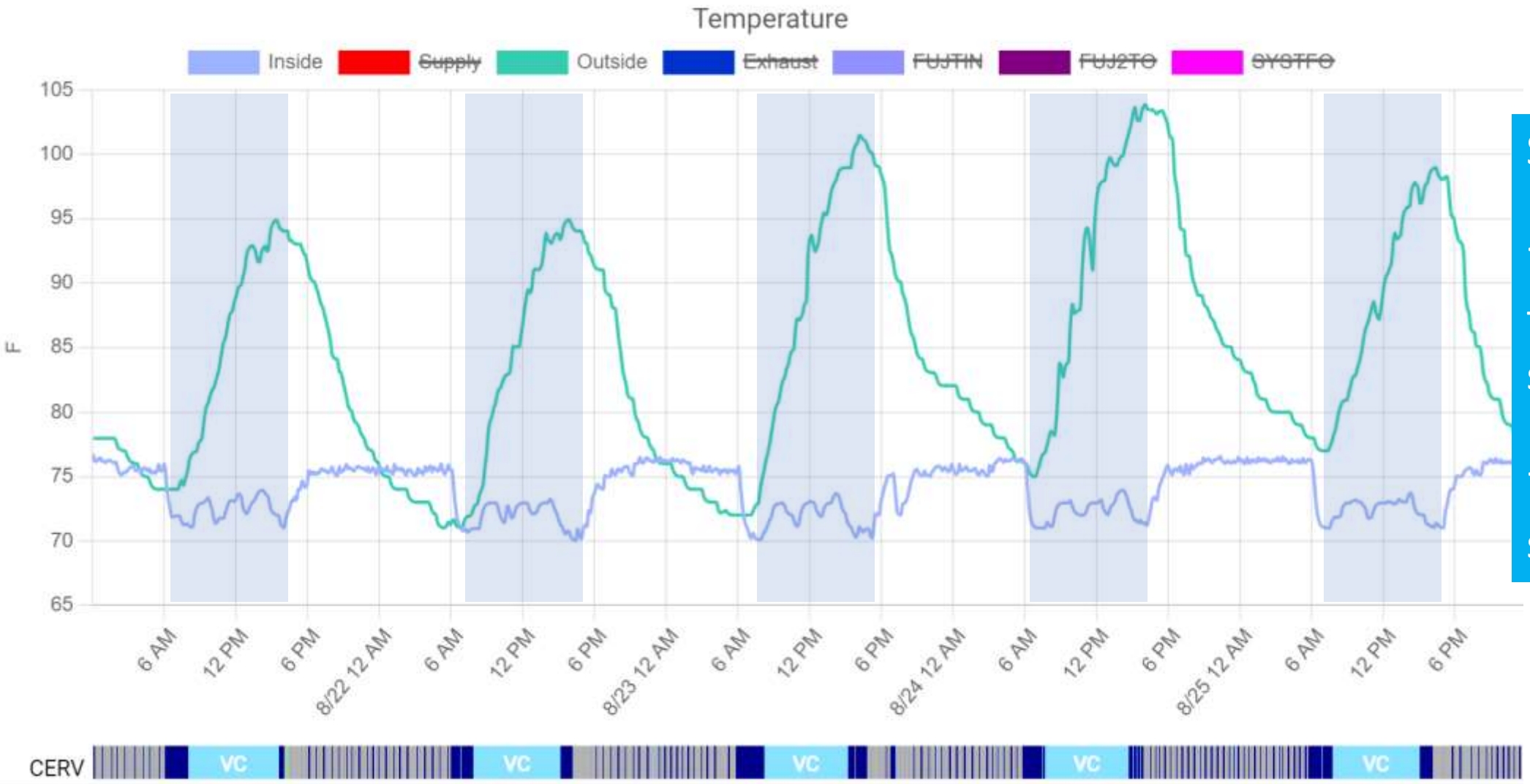


Classroom Particulate Count (>0.3µ; #/liters)





Classroom Comfort - 100+F Weather



Summer Mode

72F classroom temperature setpoint

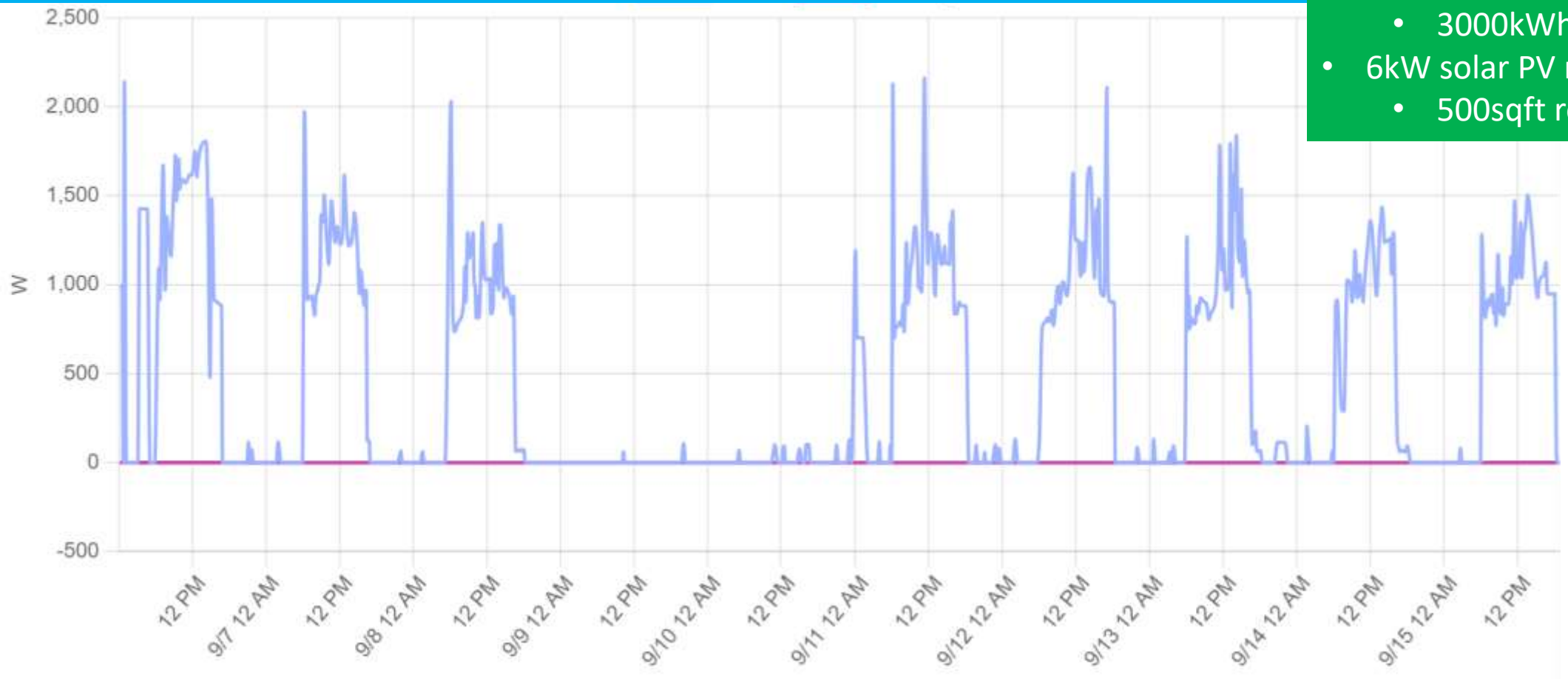
76F after hours setback

Power & Energy Usage

Power and energy usage are monitored and archived

- Total Power/Compressor Power/Fan Power (Diagnostic information)
- Uses 40% less power than window AC units during similar weather (80F-90F)

- Warm weather energy ~11kWh
- ~$1.70/day summer operation (8cents/day per student)
- Annual predicted energy ~7000kWh
  - 4000kWh class (20% year)
  - 3000kWh no-class (80% year)
- 6kW solar PV net zero class
  - 500sqft roof area



30kBtuh DD heat (class)
12kBtuh DD heat (unoccupied)

Classroom Capital & Energy Cost

Fresh Air and Comfort Conditioning System Cost

- Fresh air and comfort conditioning unit = $25K
- Installation cost = $5K (in house) up to $15K (contract)
- Total Cost $30K-40K; $30-40/sqft (~$50-60/sqft for central system installation)
- $30,000/10 years/180days per year/21people per class = **80cents per day per person**
- Option: net zero classroom:
  - Annual utility cost = $840/y ($0.12/kWh and increasing!; 7000kWh/classroom)
  - 6000W solar PV = $18,000 ($3/W installed $ in our area before credits)
    - ~$9000 net cost (30% solar tax credit for tax-exempt; 20% Solar Renewable Energy Credits in Illinois)
    - 10 year payback
    - Install classroom-size PV systems as workforce training systems

Health, Comfort & Sustainability in Classrooms

- Don’t carbonize people while decarbonizing buildings!
- Health and comfort should be the objective of building design and renovation…energy is a constraint
- Older classrooms can simultaneously and economically be converted into healthy, comfortable and sustainable environments
- Unitized concept reduces classroom disruption and can be installed by local community HVAC installers, increasing money spent by a community within the community
- Improved classroom IAQ will reduce sick days, improve productivity and improve classroom performance: $50 ventilation gets you $500 health and $5000 productivity!

Thank you!

G-RF Classroom Energy Analysis (ZEROs)

Zero Energy Residence Optimization software
Free-to-use, online software
Buildequinox.com/zeros

Inputs

- ~750sqft/classroom (20students*30sqft/student + 150sqft for Teacher)
- 750sqft roof = R12
- 250sqft exterior wall; R9
- 25sqft double glazed window
- 180 day school year; 10 hours/day (20% occupied, 80% unoccupied)
- 840cfm fresh air ventilation (40cfm/person)
    - 60-80%sensible; 40-60% latent recoveries

Classroom Energy Outputs

Zero Energy Residence Optimization software
Free-to-use, online software
Buildequinox.com/zeros

Outputs

- Occupied electrical energy = 4000kWh/y (20% of year)
- Unoccupied electrical energy = 3000kWh/y (80% of year)
- Annual electrical energy usage = 7000kWh/y
- Winter Design Day (-10F) = 30,000Btu/h (occupied); 12,000Btu/h (unoccupied)
- Summer Design Day (104F) = 20,000Btu/h (sensible, occ); 12,000Btu/h (latent, occ)
- = 12,000Btu/h (sensible, unocc); 800Btu/h (latent, unocc)
- Optional: net zero classroom: 6000W solar PV = 7200kWh annual energy
  - Use for training and developing local installers
  - ~500sqft PV array (less than class area)