A controlled intervention study in two Canadian schools: ventilation and air cleaning for the control of infectious aerosols and particles indoors

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Canadä

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Study design to validate the benefit and impact of using HEPA-based portable air cleaners

A collaboration with a Provincial Government

Two schools: similar baseline ventilation systems (1 section with mechanical ventilation and 1 section without), ~30 rooms, built in late 1950s, ~300 occupants.

Intervention: In the intervention school, portable air cleaners with a HEPA filter were deployed each classroom and common areas (i.e. library).

**Control**: A second school with baseline ventilation functioned as the control.

Outcomes: 1) Particle (PM1.0 and PM2.5) concentration, CO_2 level, power consumed by PACs, filter efficiency, and airborne and surface sampling of respiratory viruses and bacteria. 2) Aggregate absenteeism due to illness.

Time: April-June 2023, filter changed in August 2023, September 2023 to June 2024.
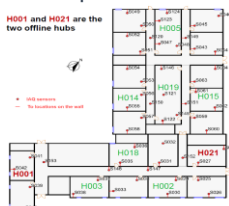
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Instrumentation and measurement parameters

Outdoor AQ sensor on rooftop

IAQ sensor #2

PAC

IAQ sensor #1
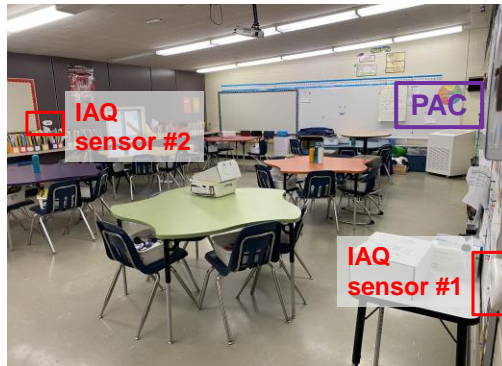
SASS 3100

IOM cassette sampler

- Sound level with PAC on <54 dBA for all classrooms.
- Airflow rates of PACs were measured in each room (adding equivalent clean air ~2.5 ACH).
- 11 PACs were installed with a timer (08:00-17:00), 11 PACs were not controlled by a timer, on 24/7.
- Airflow rates from centralized HVAC system supply/return grills were measured.
- Plug power consumption, indoor/outdoor CO_2, PM1, PM2.5, PM10, RH, and T are continuously monitored.
- **Airborne and surface respiratory viruses and bio-marker sampled in March 4-8, 2024.**
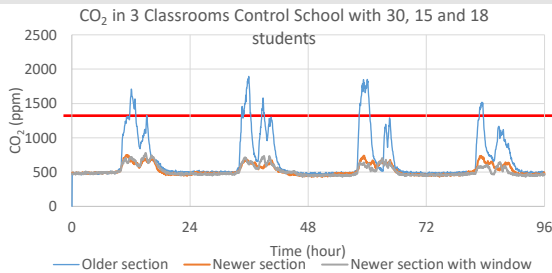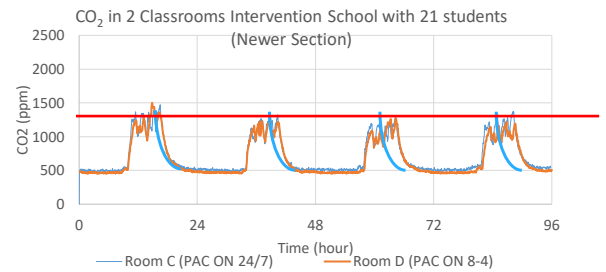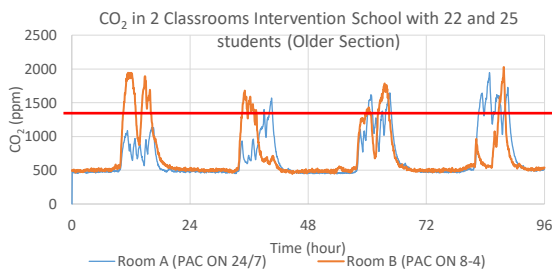
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Results and discussion

- **CO_2 concentration, decay after school, and air change per hour**
- **PM2.5 concentration**
- **Viruses and biomarker sampled**
- **Absenteeism due to illness**

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CO$_2$ concentration March 4-8, 2024

CO$_2$ in 3 Classrooms Control School with 30, 15 and 18 students

Space type	CO$_2$ concentration above outdoors (ppm)	Time after occupancy (hr)
Classroom (> 9 years)	900	1

Potential CO$_2$ concentration metrics based on ASHRAE 62.1 ventilation rate procedure (Persily, 2022)
Outdoor CO$_2$ ~500 ppm

CO$_2$ in 2 Classrooms Intervention School with 22 and 25 students (Older Section)

CO$_2$ in 2 Classrooms Intervention School with 21 students (Newer Section)

Air change per hour based on CO$_2$ decay: time period

Date	startTime	endTime	ACH	R2	startTime	endTime	ACH	R2
2024-03-04	16:01:49	16:59:28	-0.60	0.60	17:01:49	17:59:27	-1.04	0.96
2024-03-05	16:01:49	16:59:29	-0.72	0.70	17:01:50	17:59:28	-1.10	0.97
2024-03-06	16:01:50	16:59:28	-0.42	0.45	17:01:49	17:59:28	-1.08	0.99
2024-03-07	16:01:49	16:59:29	-0.27	0.40	17:01:50	17:59:29	-0.96	1.00
2024-03-08	16:01:50	16:59:28	-0.41	0.51	17:01:49	17:59:29	-0.92	1.00
2024-03-09								
2024-03-10								
2024-03-11	16:01:50	16:59:29	-0.79	0.80	17:01:50	17:59:29	-0.88	0.99
2024-03-12	16:01:50	16:59:29	-0.65	0.72	17:01:50	17:59:30	-0.96	0.98
2024-03-13	16:01:52	16:59:30	-0.92	0.79	17:01:52	17:59:30	-1.03	0.98
2024-03-14	16:01:51	16:59:30	-0.63	0.90	17:01:51	17:59:30	-0.26	0.49
2024-03-15	16:01:51	16:59:31	-0.61	0.90	17:01:52	17:59:30	-0.12	0.11
2024-03-16								
2024-03-17								
2024-03-18	16:01:52	16:59:31	-0.02	0.00	17:01:52	17:59:31	-1.19	0.98
2024-03-19	16:01:52	16:59:32	-1.25	1.00	17:01:53	17:59:32	-0.71	0.90
2024-03-20	16:01:53	16:59:32	-0.86	0.72	17:01:53	17:59:32	-1.17	0.96
2024-03-21	16:01:53	16:59:32	-0.65	0.54	17:01:53	17:59:31	-1.14	0.96
2024-03-22	16:01:53	16:59:32	-0.86	0.75	17:01:53	17:59:31	-1.10	0.98

- Thermostat setting: fan switch from ON to Auto after 6 PM.
- Outdoor air damper position unknown.
- An exploratory exercise to use existing data to quantify outdoor air ventilation rate – can be a challenge in large buildings.
- More data points (locations and time) can help address uncertainties.

Air Change per Hour based on CO_2 decay: decay curve R^2

15-day Ave. ACH in Classrooms in Intervention School (R^2>0.9 only)

ACH = 0.73
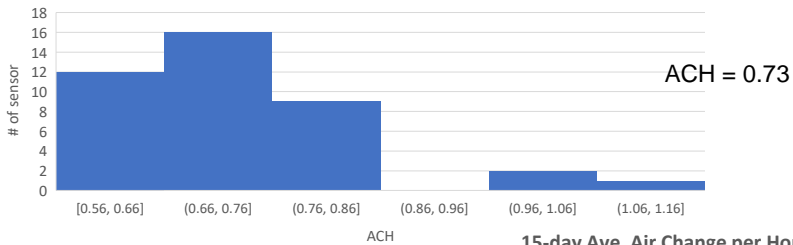
15-day Ave. Air Change per Hour in Classrooms in Intervention School
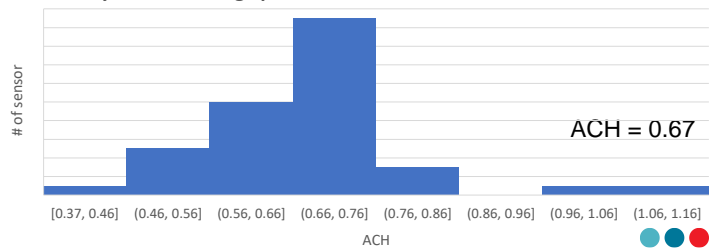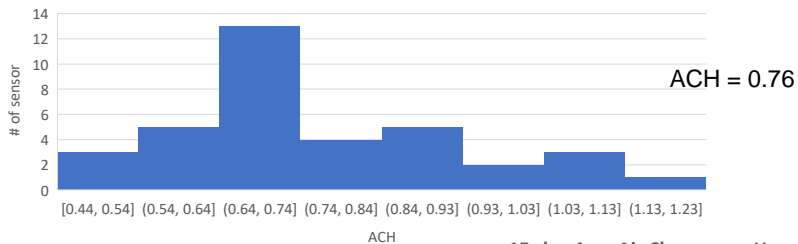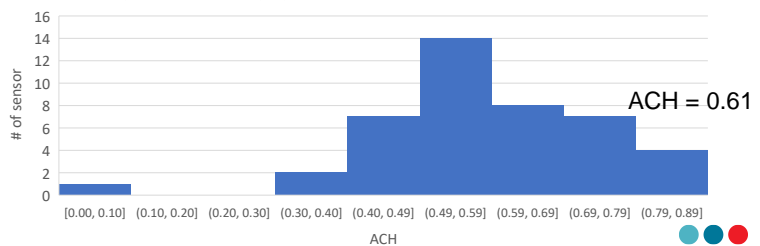
ACH = 0.67

Air Change per Hour based on CO_2 decay: decay curve R^2

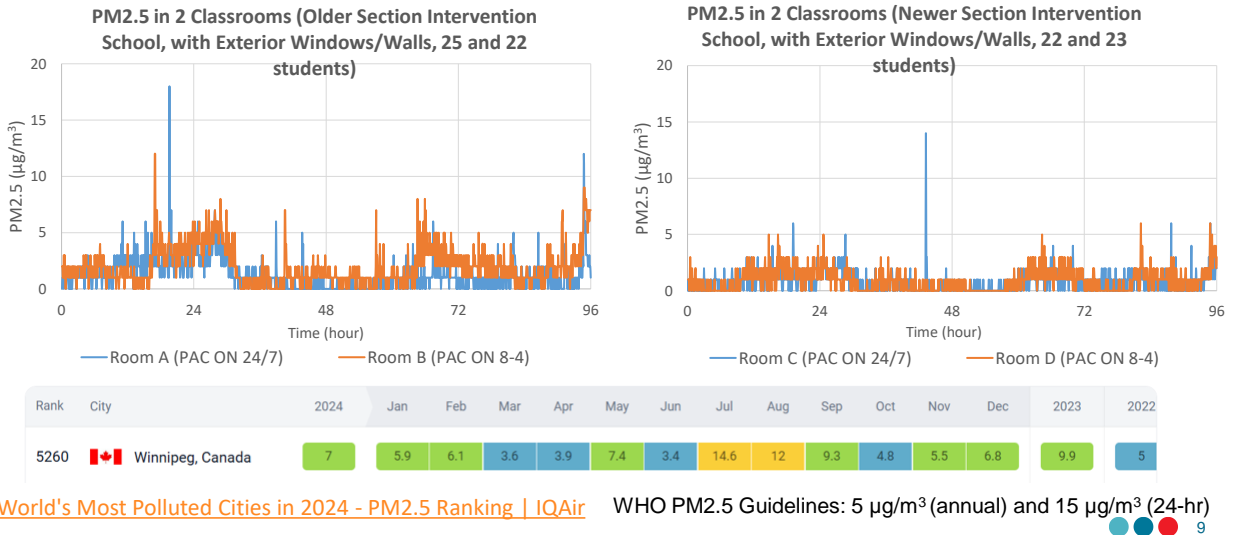**15-day Ave. ACH in Classrooms in Control School (R^2>0.9 only)**

ACH = 0.76

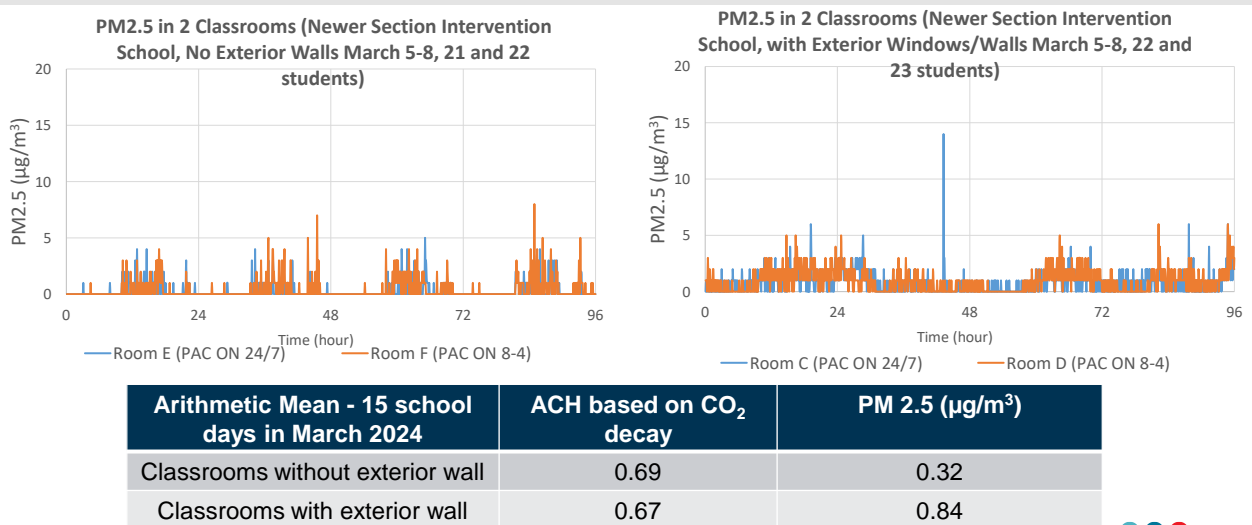**15-day Ave. Air Change per Hour in Classrooms in Control School**

ACH = 0.61

# PM2.5 concentration in intervention school: older vs. newer sections

PM2.5 in 2 Classrooms (Older Section Intervention School, with Exterior Windows/Walls, 25 and 22 students)

Room A (PAC ON 24/7) — Room B (PAC ON 8-4)

PM2.5 in 2 Classrooms (Newer Section Intervention School, with Exterior Windows/Walls, 22 and 23 students)

Room C (PAC ON 24/7) — Room D (PAC ON 8-4)

Rank	City		2024	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2023	2022
5260	🇨🇦 Winnipeg, Canada		7	5.9	6.1	3.6	3.9	7.4	3.4	14.6	12	9.3	4.8	5.5	6.8	9.9	5

World's Most Polluted Cities in 2024 - PM2.5 Ranking | IQAir

WHO PM2.5 Guidelines: 5 µg/m³ (annual) and 15 µg/m³ (24-hr)

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PM2.5 concentration in intervention school: with and without exterior walls/windows

PM2.5 in 2 Classrooms (Newer Section Intervention School, No Exterior Walls March 5-8, 21 and 22 students)

Room E (PAC ON 24/7) — Room F (PAC ON 8-4)

PM2.5 in 2 Classrooms (Newer Section Intervention School, with Exterior Windows/Walls March 5-8, 22 and 23 students)

Room C (PAC ON 24/7) — Room D (PAC ON 8-4)

| Arithmetic Mean - 15 school days in March 2024	ACH based on CO_2 decay	PM 2.5 (µg/m³)
Classrooms without exterior wall	0.69	0.32
Classrooms with exterior wall	0.67	0.84

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PM2.5 concentration: intervention vs. control school

PM2.5 in 2 Classrooms: Control vs. Intervention Schools Older Section March 5-8 2024

Control school older section

Intervention school older section PAC ON 24/7
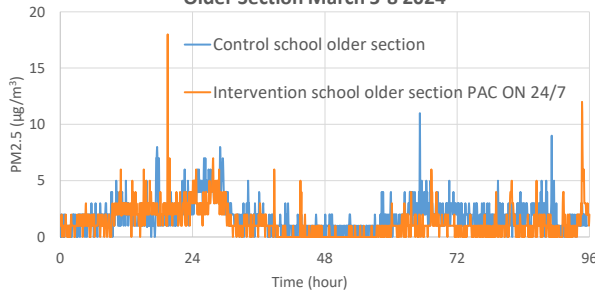
PM2.5 in 2 Classrooms: Control vs. Intervention Schools Newer Section March 5-8 2024

Control school newer section

Intervention school newer section (PAC ON 24/7)
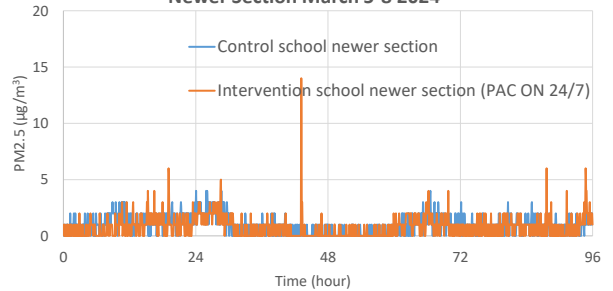
Approximate Equivalent Ratings for Filters Tested Under ASHRAE Standard 52.2 (MERV) and ISO 16890	
ASHRAE MERV* (Standard 52.2)	ISO 16890 Rating
1-6	ISO Coarse
7-8	ISO Coarse >95%
9-10	ePM_{10}
11-12	$ePM_{2.5}$
13-16	ePM_1

AM March 2024	PM 2.5 ($\mu g/m^3$)	ACH based on CO_2 decay	Equivalent clean air added by PACs in ACH
Control school (Old)	1.88	0.84	0
Control school (New)	0.67	0.74	0
Intervention school (Old)	1.38	0.67	2.5
Intervention school (New)	0.55	0.70	2.5

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PAC's ability to reduce indoor particle concentration during wildfire events in 2023

$$PM_{removal\ efficiency} = 1 - \frac{PM_{indoor}}{PM_{outdoor}}$$

School	Date	PAC (Y/N)	Outdoor PM1 conc ($\mu g/m^3$)	Indoor PM1 conc ($\mu g/m^3$)	Outdoor PM2.5 conc ($\mu g/m^3$)	Indoor PM2.5 conc ($\mu g/m^3$)	PM1 removal efficiency	PM2.5 removal efficiency
Control	May 16, 2023	N	22.07	14.97	32.11	15.55	0.29	0.48
Intervention		Y	24.65	9.26	34.07	9.69	0.61	0.70

Rank	City		2024	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2023	2022
5260	🇨🇦 Winnipeg, Canada		7	5.9	6.1	3.6	3.9	7.4	3.4	14.6	12	9.3	4.8	5.5	6.8	9.9	5

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Virus, bacteria, and biomarker samplers

	SASS 3100	IOMs
Filter	Polypropylene Electret Filter	Gelatin Filter
Sampling time	33 min	At least 5 hours
Sampling flow rate	300 lpm	2.5 lpm
Total m^3/sample	9.9 m^3	0.75 m^3

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Viruses

Target	Detected*
Rhinovirus	No
Rotavirus	No
Adénovirus	No
Sars-Cov-2 (orf-1b)	No

* Detection limit:
   SASS 3100 = 3.8 copies / m^3
   IOMs = 50 copies / m^3

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Bacteria and bio-markers

Target		Detected
Upper respiratory tract	*Streptococcus salivarius*	No
	Streptococcus sanguinis	No
	Neissaria subflava	Yes (1x)
Human skin	*Staphylococcus epidermidis*	Yes
	Staphylococcus hominis	Yes
	Staphylococcus aureus	No

IOMs vs. SASS (positive samples)

SASS vs IOM (Both schools)

SASS vs IOM % (Both schools)

- S.aureus
- S.epidermidis
- S.hominis
- N.subflava
- S.salivarius
- S.sanguinis
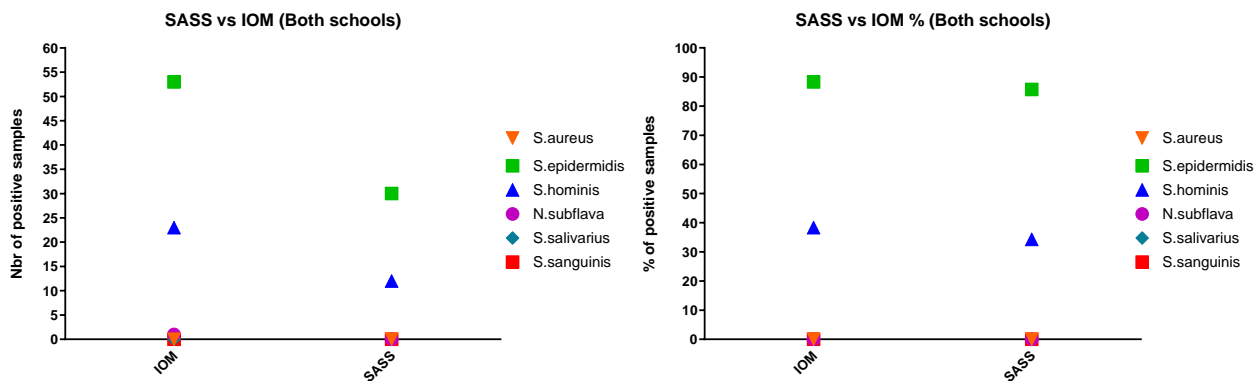
of positive samples per student

S1 (intervention) vs S2

Copies / student (Positive samples only)

S.epidermidis
S.hominis
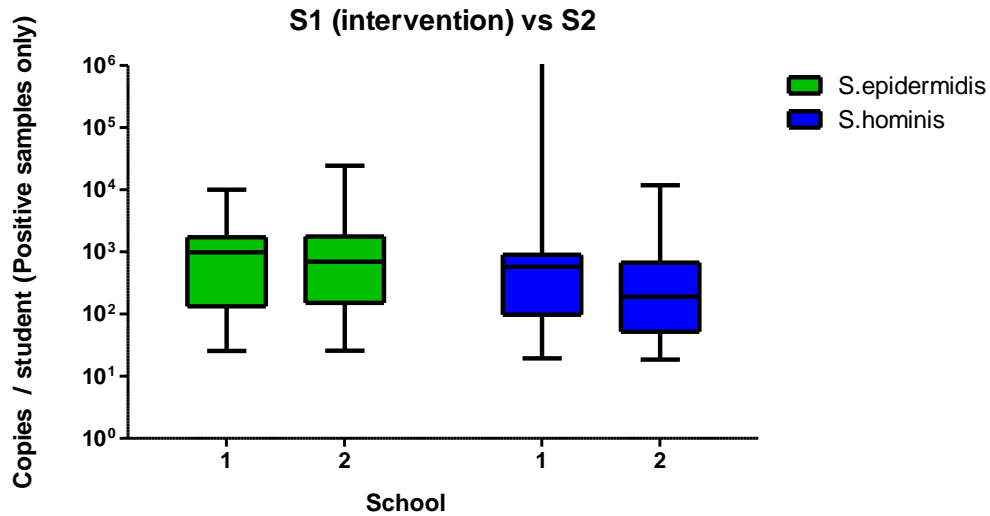
School

Classroom with positive *S.epidermidis* samples

S.epidermidis School #1 (intervention)

SASS   IOM

S.epidermidis School #2

SASS   IOM

Copies of *S.epidermidis* / student
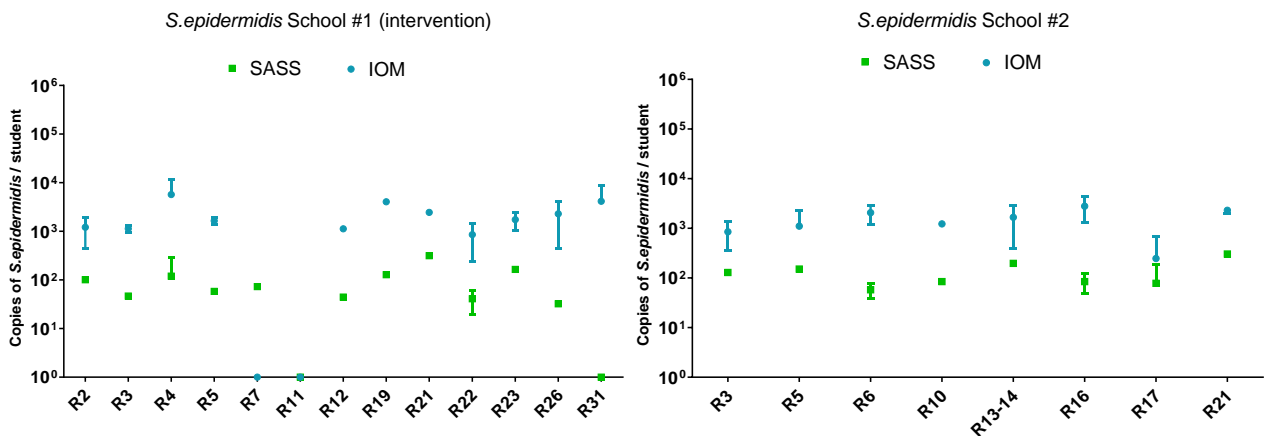
Classroom with positive *S.hominis* samples

S.hominis School #1 (intervention)

■ SASS ● IOM

(Scatter plot: y-axis "Copies of S.hominis / student" from 10^0 to 10^{12}; x-axis categories R2, R7, R22, R23, R26)

S.hominis School #2

■ SASS ● IOM

(Scatter plot: y-axis "Copies of S.hominis / student" from 10^0 to 10^{12}; x-axis categories R3, R5, R6, R21)
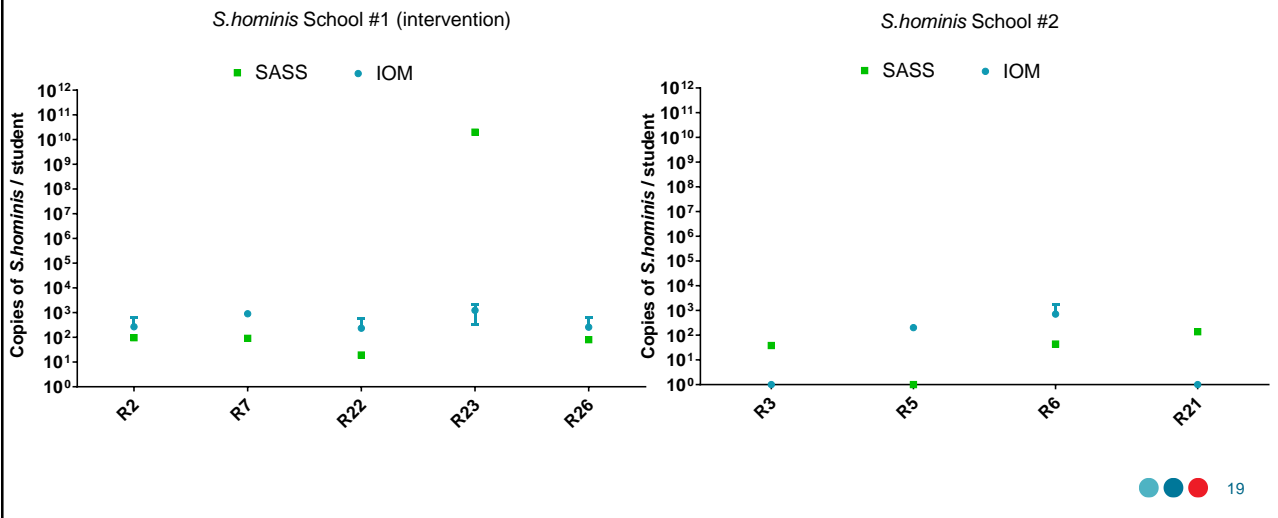
Ventilation, particle, and bio-marker

Arithmetic Mean - 15 school days in March 2024	ACH	PM 2.5 concentration ($\mu g/m^3$)
Classrooms in control school <u>with</u> positive biomarker samples	0.89	1.47
Classrooms in control school <u>without</u> positive biomarker samples	0.76	1.11
Classrooms in intervention school <u>with</u> positive biomarker samples	0.75	0.70
Classrooms in intervention school <u>without</u> positive biomarker samples	0.68	0.83

Absenteeism due to illness Sept 2023 – June 2024
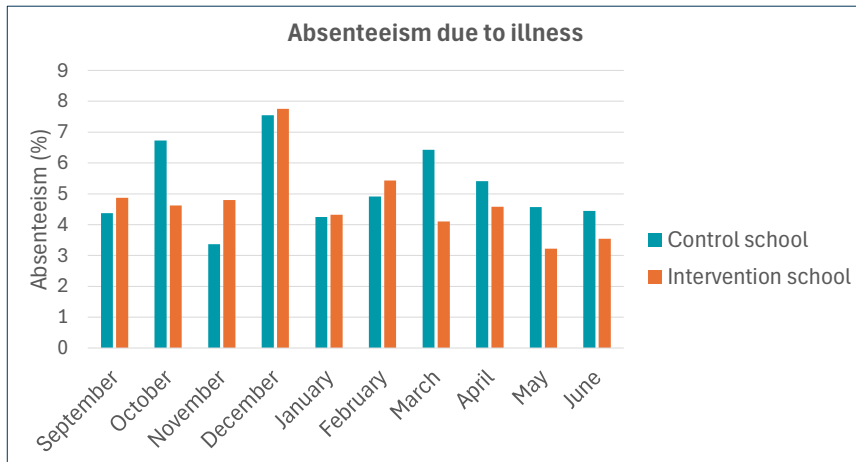
Summary

- The indoor CO_2 concentrations were dependent on the presence of occupants. The outdoor air ventilation rates can be estimated based on the decay of CO_2 concentration after school. The two schools had comparable outdoor ventilation rates (~0.7 ACH). More data points (locations and time) can help address uncertainties.

- The outdoor particle sources play a significant role in deciding the indoor particle concentrations in classrooms with exterior walls. Caution should be taken when replying on indoor PM2.5 concentration (only) to represent airborne transmission risk in real world buildings.

- The PAC units in the intervention school delivered equivalent clean air at a rate of ~2.5 ACH to the classrooms and reduced indoor PM2.5 concentration (compared to the PM2.5 concentration in the control school).

- The use of PAC units in the intervention school didn't appear to reduce the students' absenteeism due to illness or the presence of bacteria and biomarker indoors.

THANK YOU!

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