Practical issues when measuring the effectiveness of ventilation

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Presentation Structure

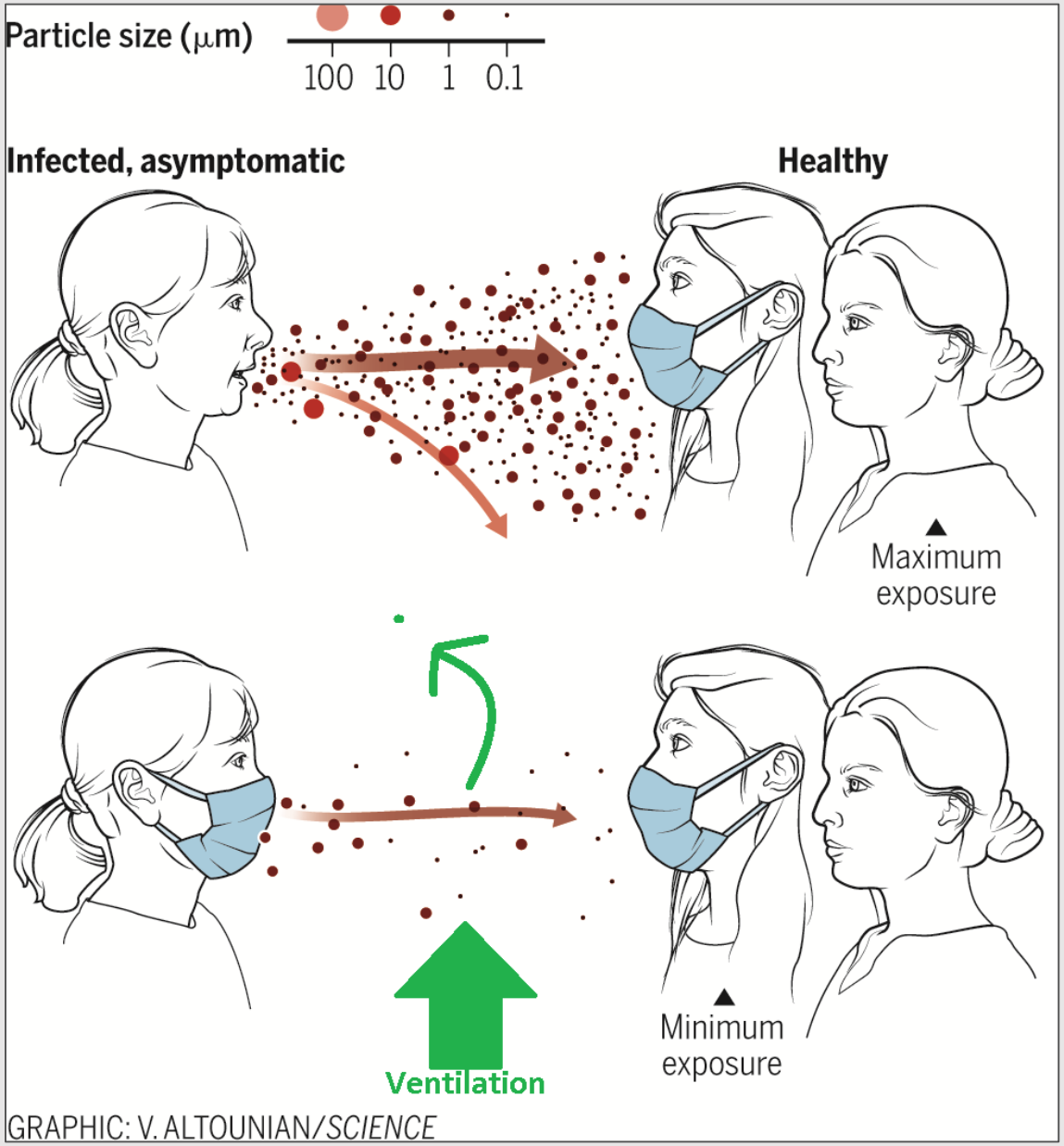
- Why ventilation
- Effectiveness of ventilation
- Theory
- How we measured
- Results and Discussion
- Conclusion and Recommendations

Why ventilation? Why effectiveness?

- Ventilation can reduce the risk of Covid19
- Research over two years in 100 schools showed an association between classroom ventilation rate and student performance - reading and maths (R = approx. 0.4) but not absenteeism*
- Ventilation rate was associated with mean number of visits to the school nurse due to respiratory symptoms*

* An assessment of indoor environmental quality in schools and its association with health and performance March 2015. Building and Environment 93 DOI: 10.1016/j.buildenv.2015.03.006

Ventilation
Dilution
Solution



Equilibrium Concentration

$$Q = \frac{r}{C}$$

Where

Q = Airflow rate in m^3/s

r = Quanta emission rate/s

C = Equilibrium conc. in quanta / m^3

Dilution Ventilation :Theoretical

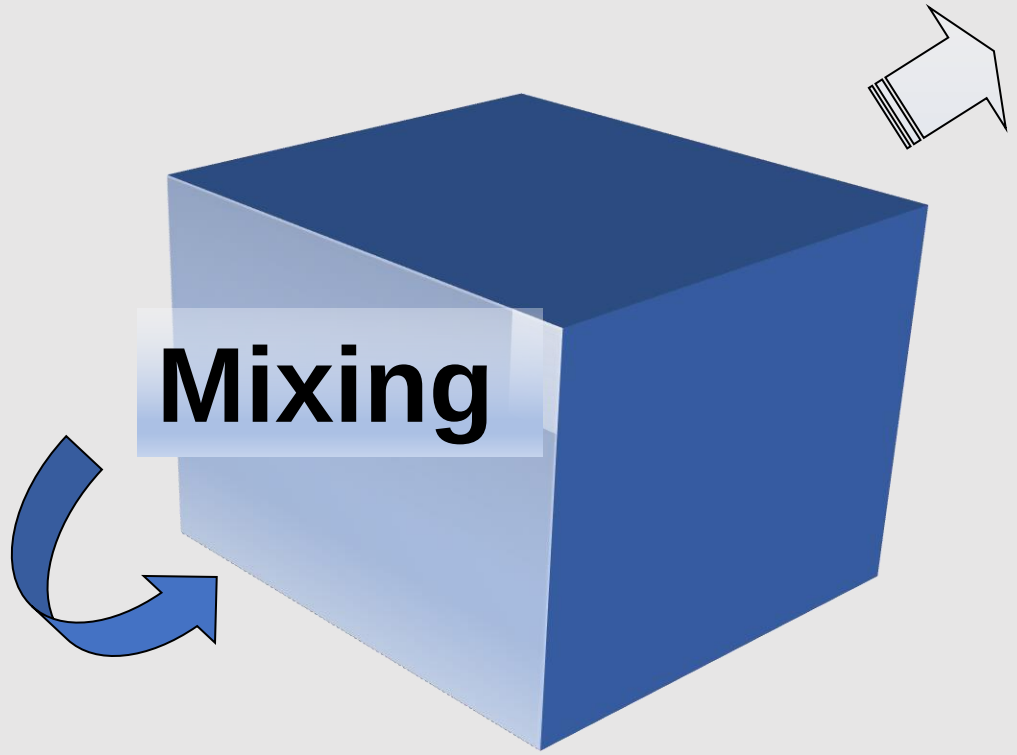
- C = E / Q
  or Q = E/C

where:

C = concentration

E = emission rate

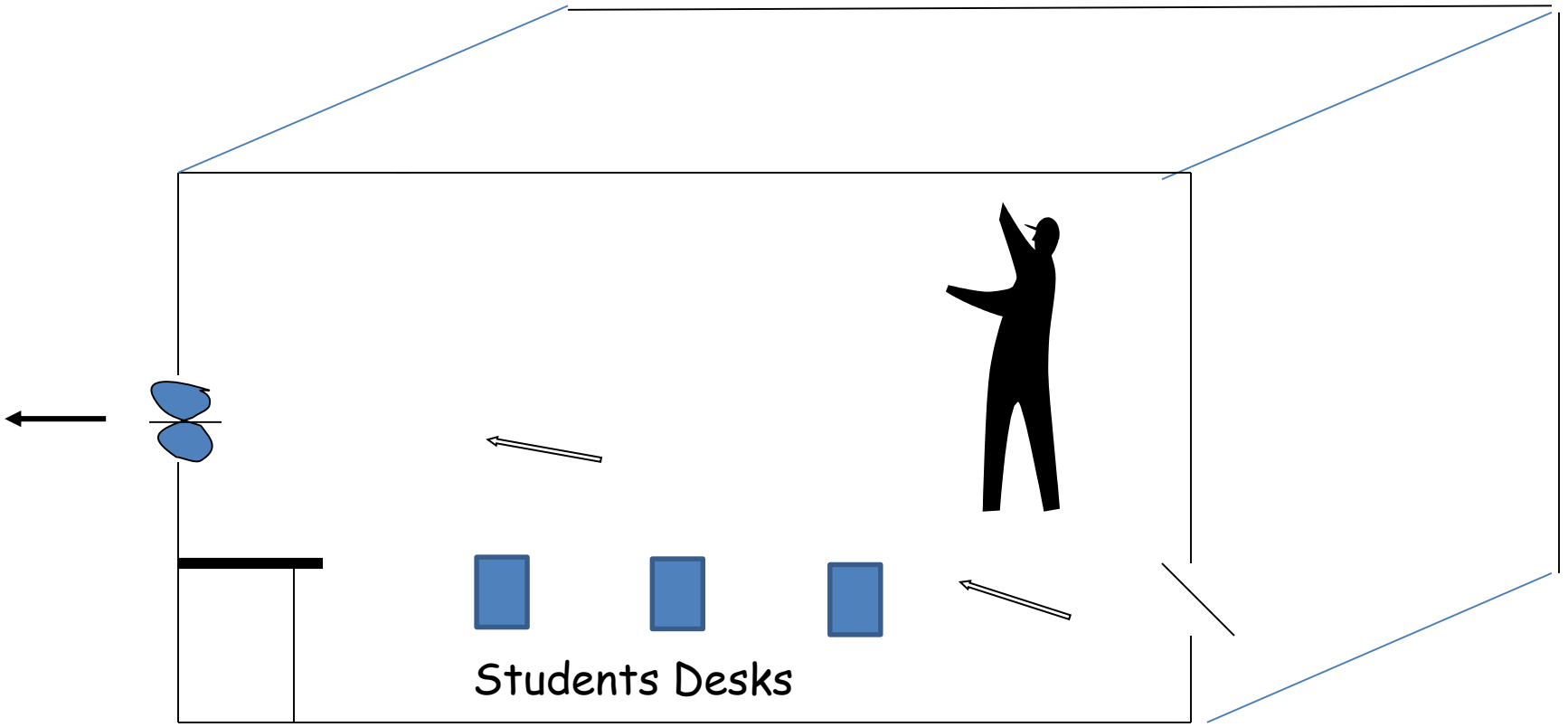
Q = ventilation rate



Types of General Dilution Ventilation

- Infiltration (natural ventilation, windows etc…)
- Mechanical ventilation - Air conditioners

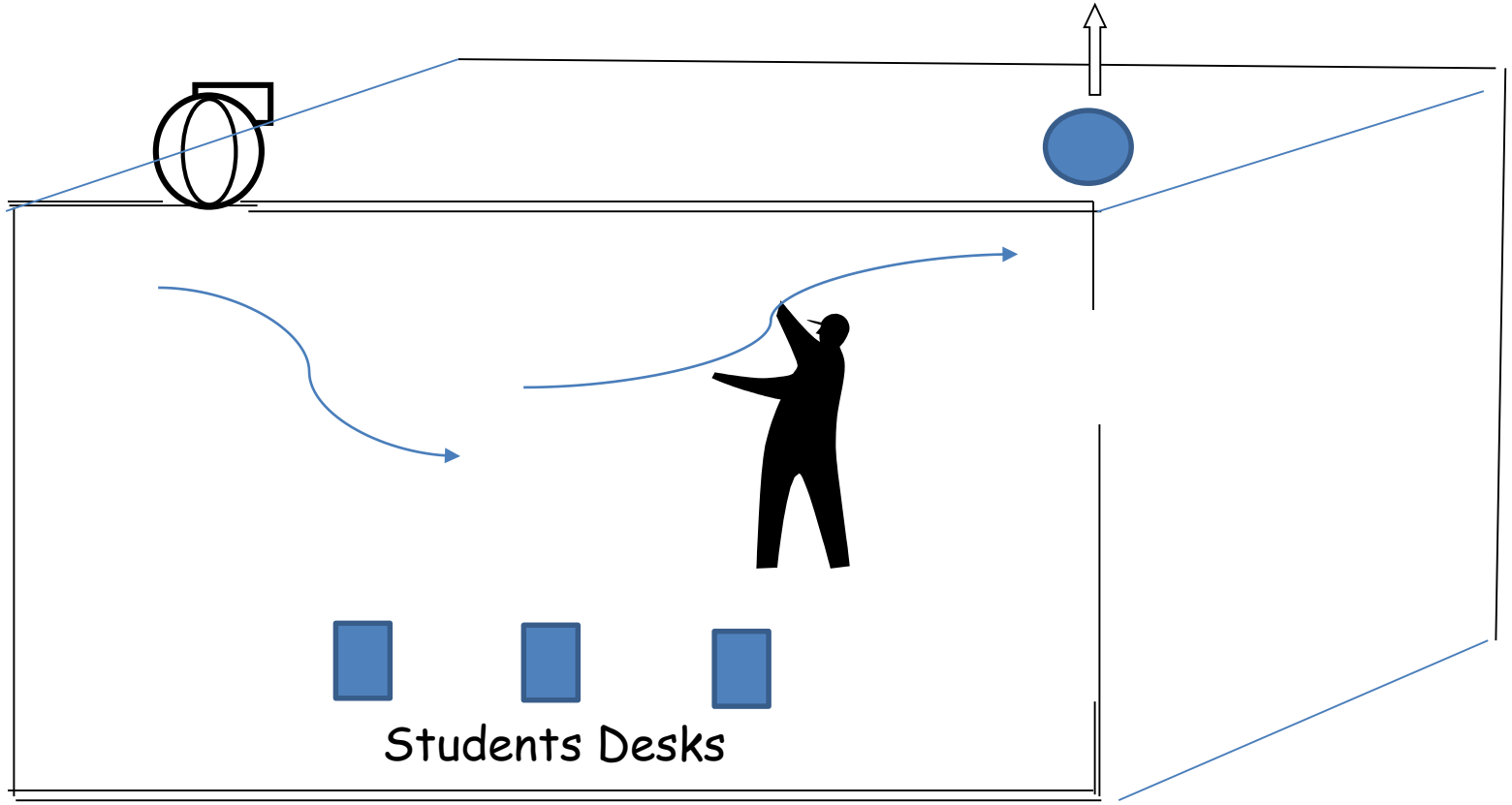
Examples of Dilution Ventilation



Good or poor air inlet and exhaust?

= fan

Examples of Dilution Ventilation



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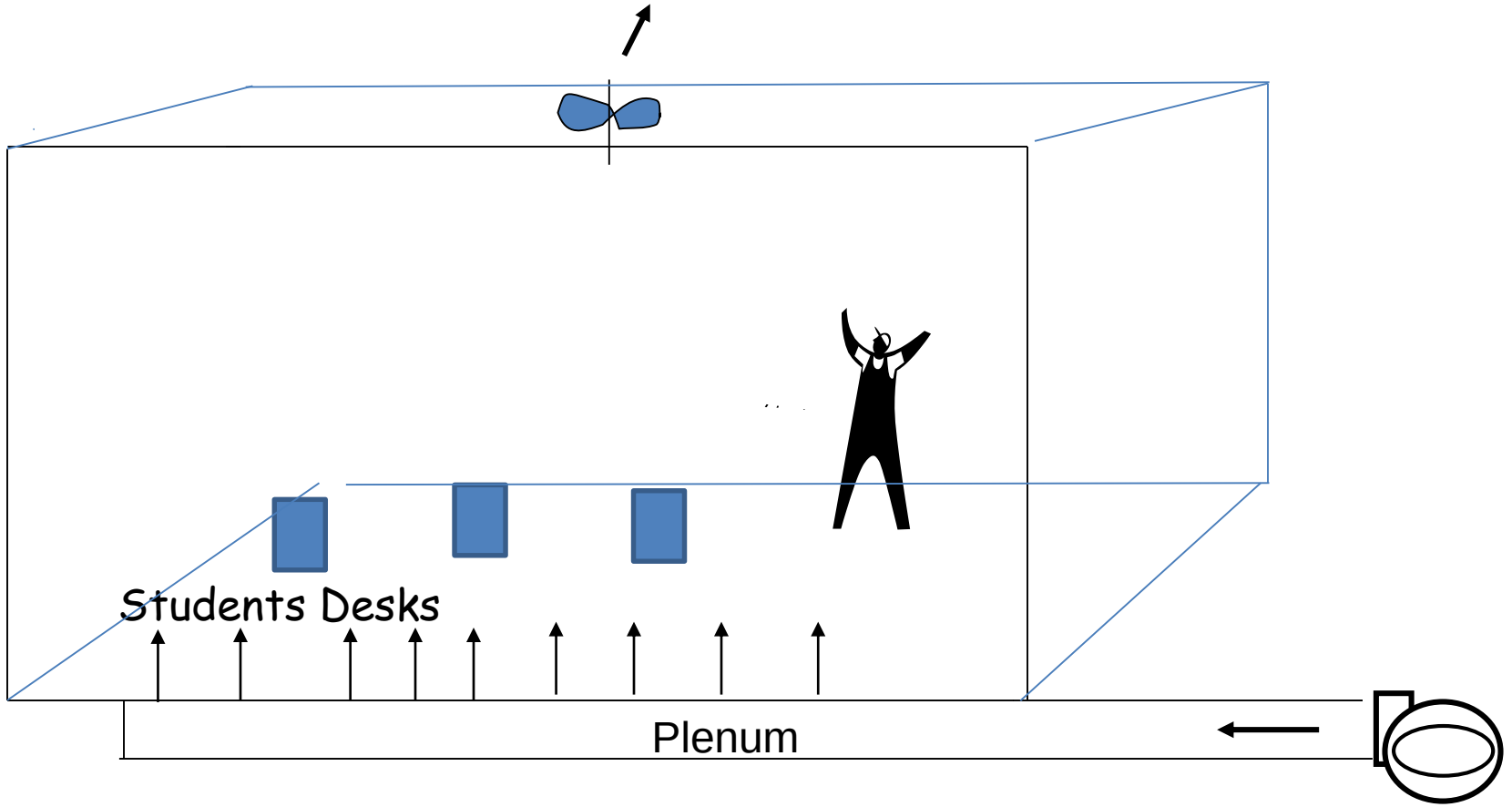

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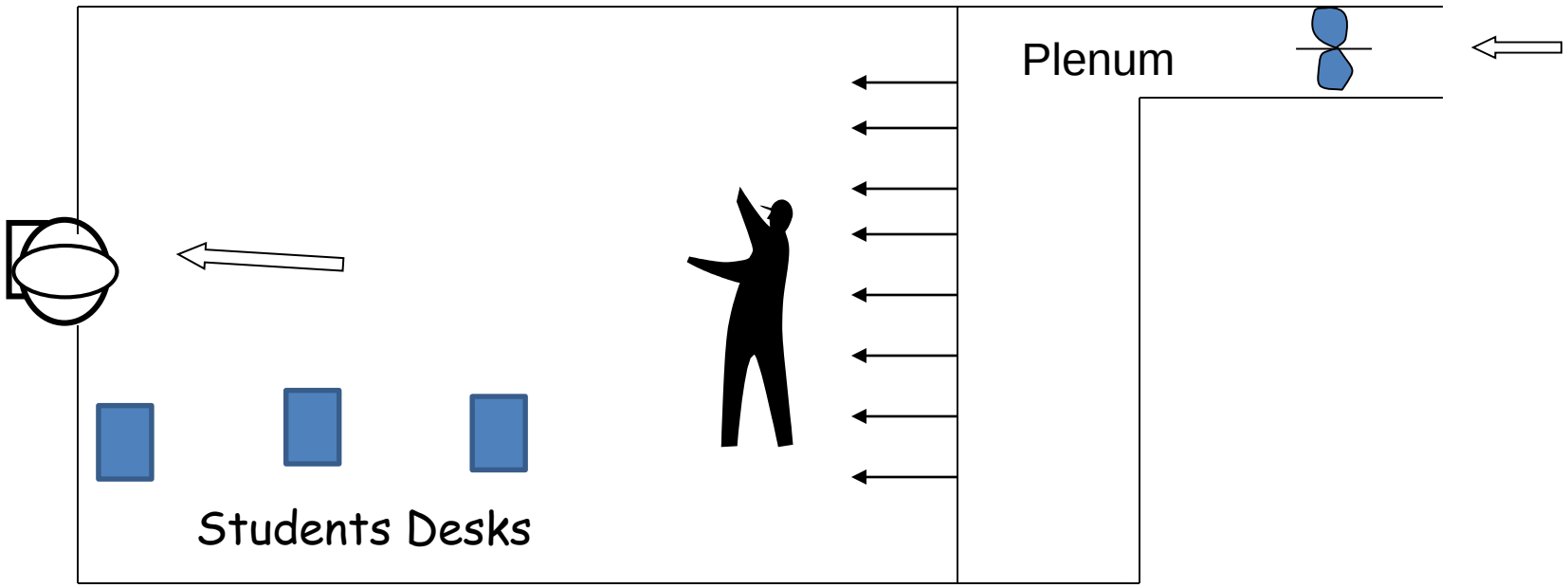
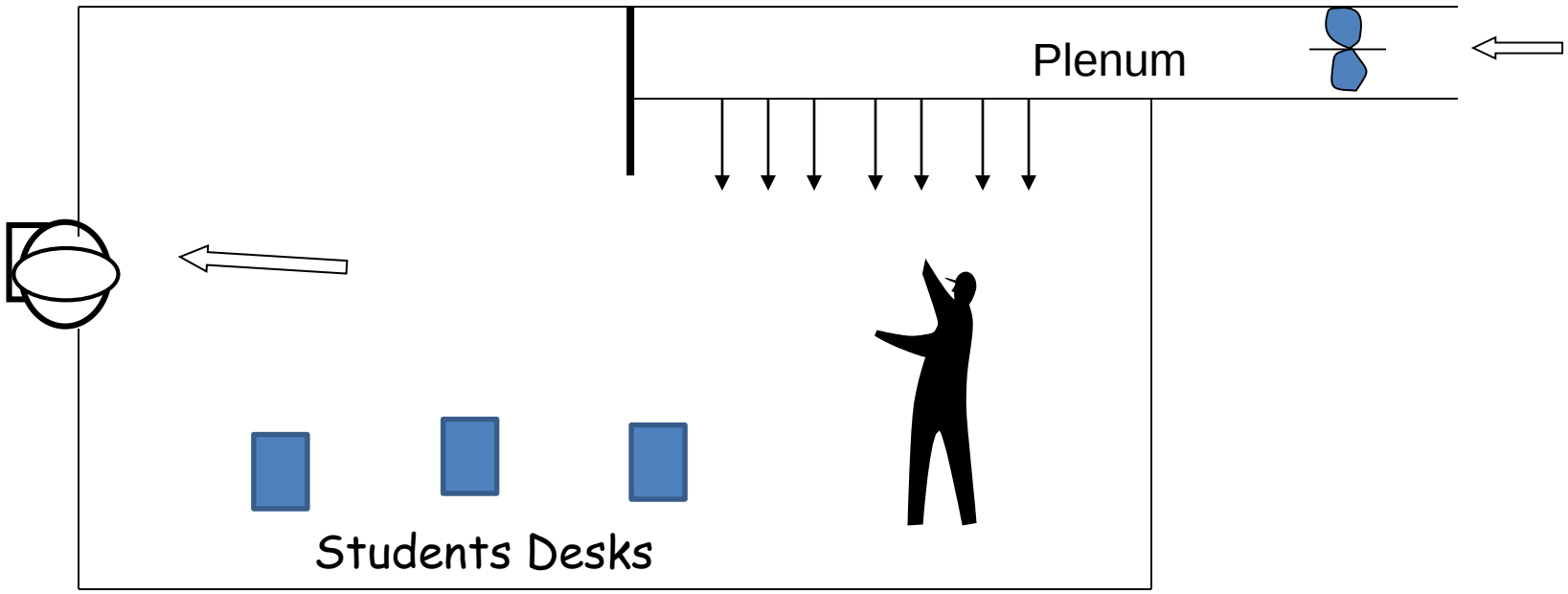


Good or poor design

Examples of Dilution Ventilation



Good or poor design?

Measuring ventilation at the Wits School of Public Health Building

Objectives:

- Measure air changes per hour (ACH) in a sample of common rooms and the ventilation effectiveness where possible
- Estimate Maximum Room Occupancy to limit airborne virus transmission from guidelines
- Provide recommendations to minimize this risk, for a safe return to campus

Ventilation Standard

- 10 l/s per person guidance suggested by WHO (2021) and Fisk (2012)
- Fisk derived his guide by considering health effects from a variety of indoor air contaminants **together** with the economic cost of fresh air supply
- The guidance was chosen arbitrarily. It does not represent a safe ventilation rate to protect from airborne virus cross infection.

Roadmap to improve and ensure good indoor ventilation in the context of COVID-19. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.

William, J. Fisk, Douglas, Black and Gregory, Brunner: Changing ventilation rates in U.S. offices: Implications for health, work performance, energy, and associated economics. *Building and Environment* 2012; **47**: 368-72.

Possible methods used* to measure ventilation rate using CO_2

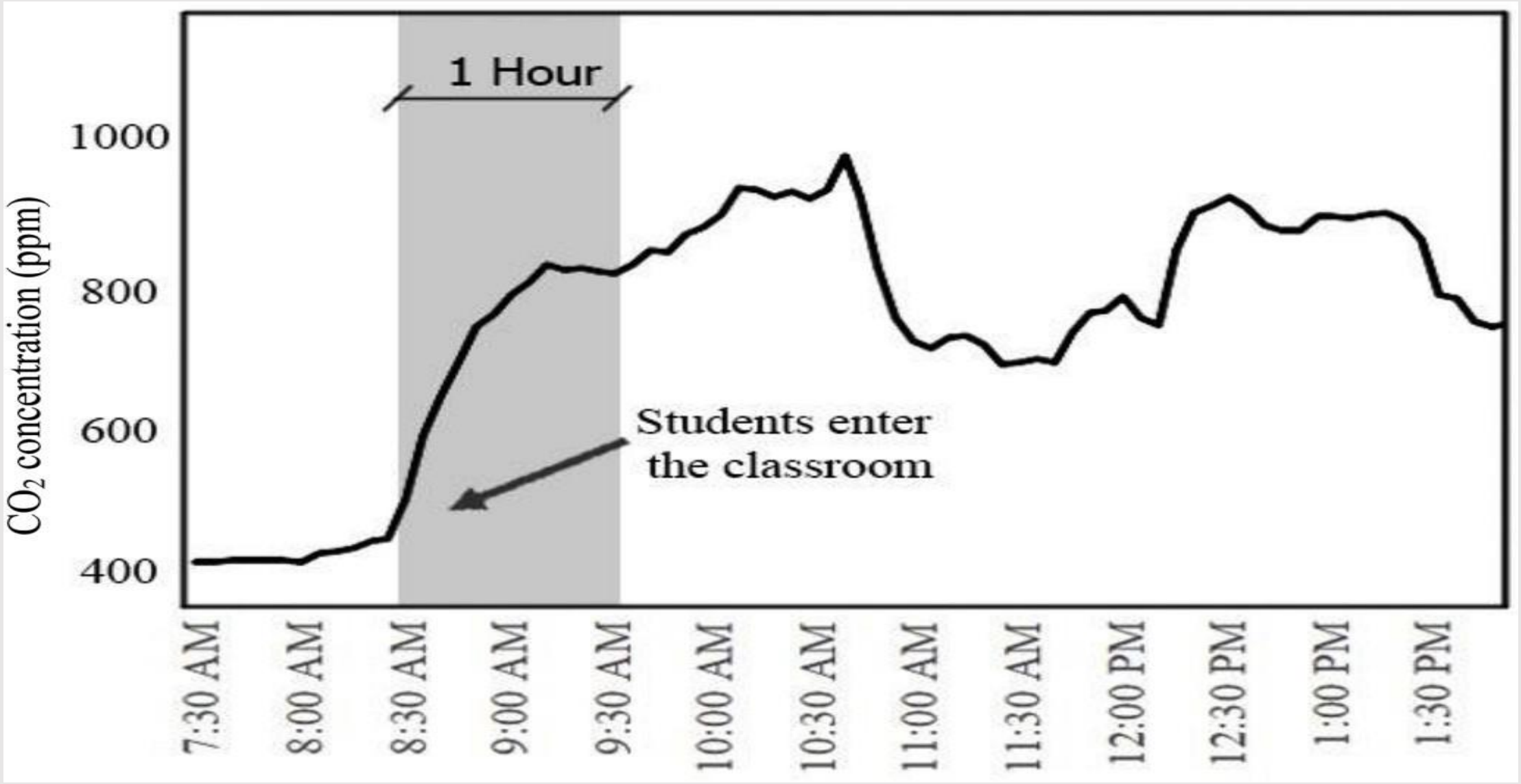
The rate of fresh air supplied to the room can be calculated in three ways:

1. rate of increase of CO_2 generated by the students
2. final steady concentration after a known amount of CO2 is released at a fixed rate into the room air
3. rate of decay of CO_2 generated by the students after they leave the class room

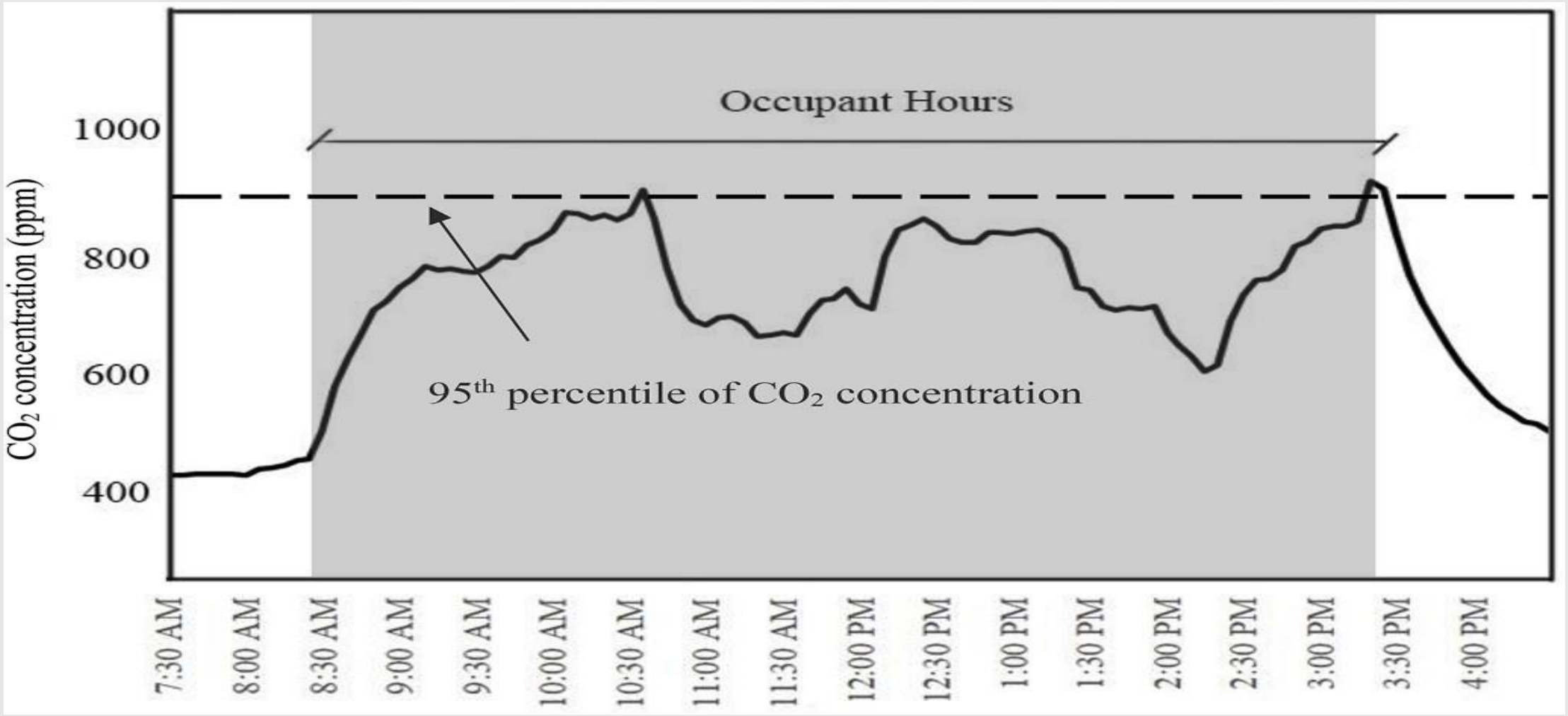
*From a paper on Uncertainty Analysis of CO_2 concentrations in 220 classrooms in t he United States Mid West

Adel Kabirikopaei, Josephine Lau 220 classrooms in t he United State Mid West Building and Environment 179 (2020) 107003

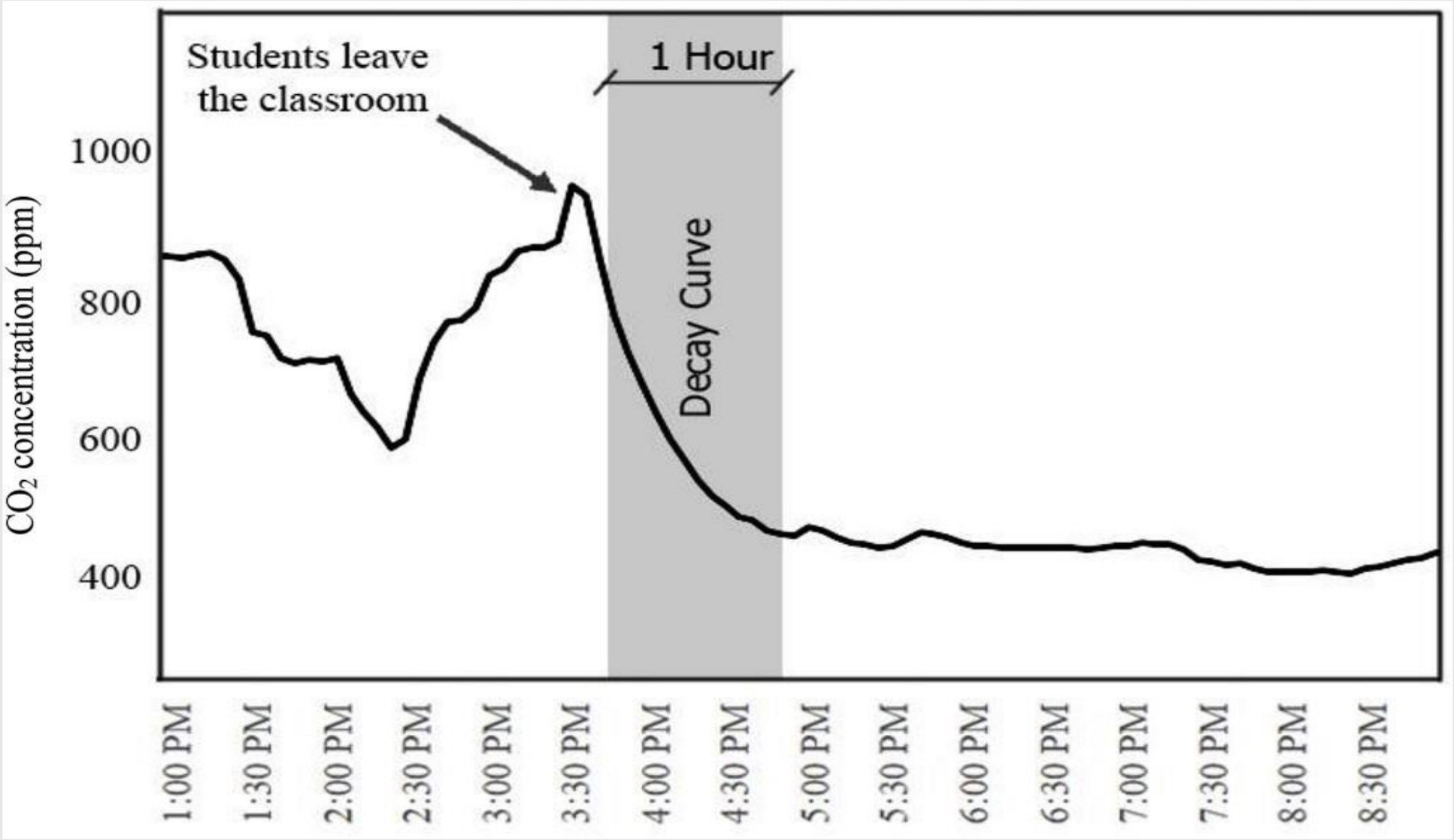
Build-up method



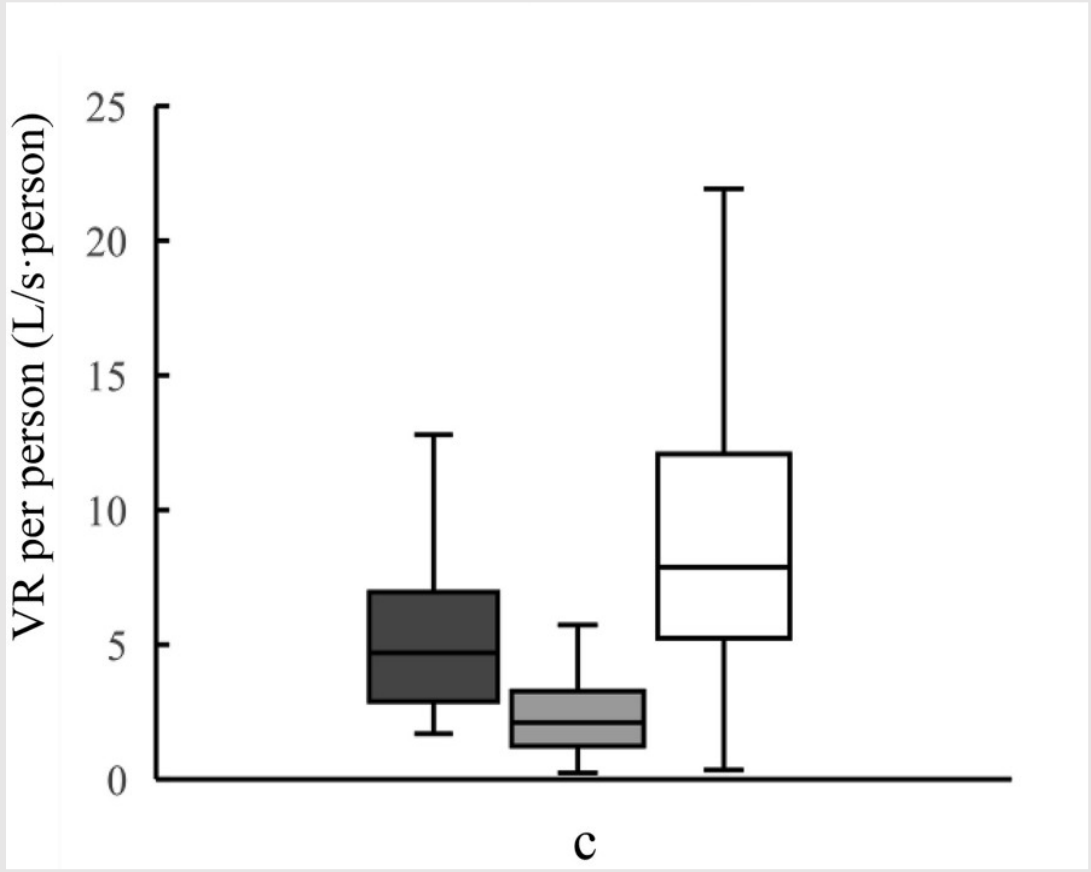
The Steady State Method

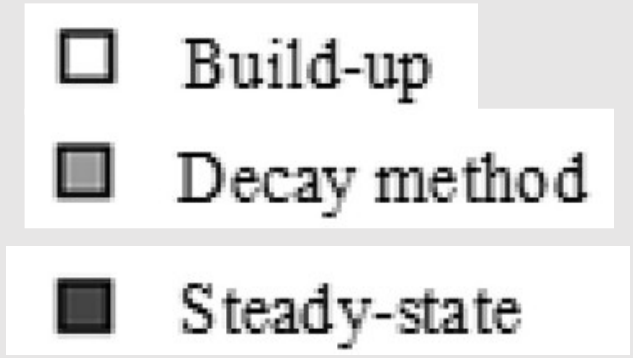


The Decay Method



Autumn results comparing 3 methods





*From a paper on Uncertainty Analysis of CO_2 concentrations in 220 classrooms in t he United States Mid West
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Ventilation measurements

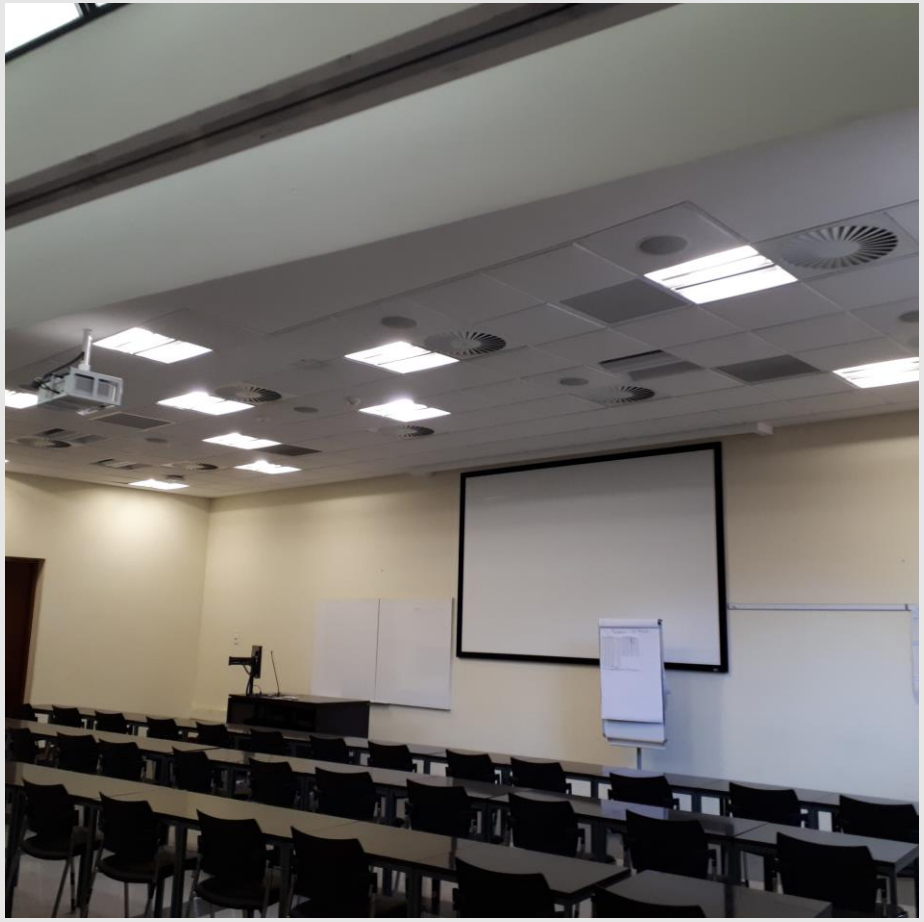
In ten common or shared rooms, meeting and lecture rooms, including a lift and a restroom

under worst- and best-case conditions, i.e. with windows and doors closed and open respectively

Decay Method Design used at the School of Public Health

- Windows and doors were closed (worst case conditions)
- A tracer gas (CO_2) was released from a fire extinguisher
- Three desk fans were used to promote CO_2 mixing until it was evenly distributed - as determined by CO_2 monitoring
- The fans were then switched off, the monitor was left in the middle of the room at 1.2 m from the floor
- After 30 mins the best-case conditions were activated, i.e. windows and doors opened, and the measurements continued for the remainder of the test period, until the CO_2 conc. reached ambient levels

Ready Steady Go



Lecture Room 1 and2 School of Public Health

Bathroom ventilation air supply with air inlet adjustment

Step One : Assessing ventilation -qualitative

Don’t forget your smoke tubes

Step Two: Air supplied or changed per hour (ACH)

Air changes per hour*

= Air vol in per hour

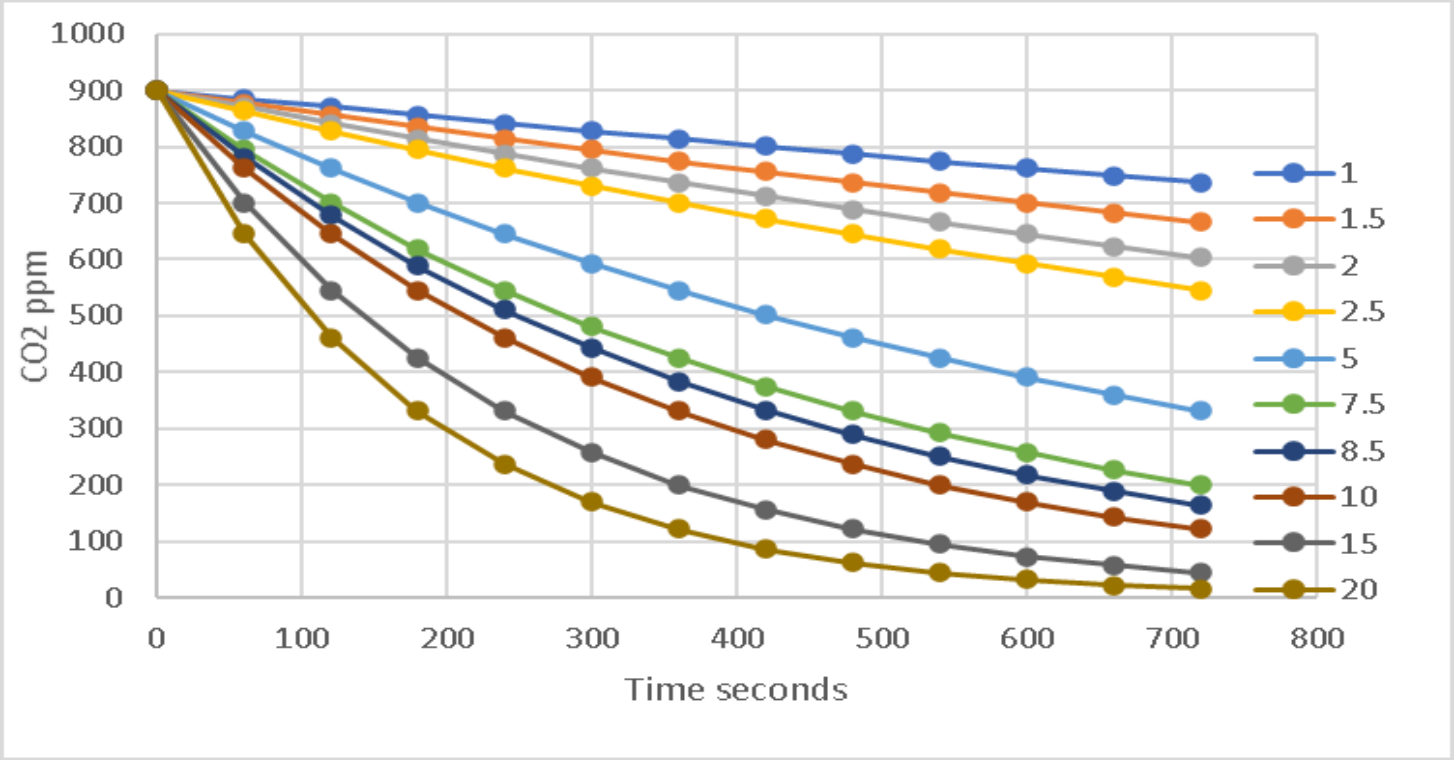
total room volume

*Assumes perfect mixing

Step Three: Release and mixing of CO_2

Step 4 – “continuous” CO_2 monitoring

Decay in CO_2/quanta Concentration (ppm) with Time and air supply rate – Air changes per hour



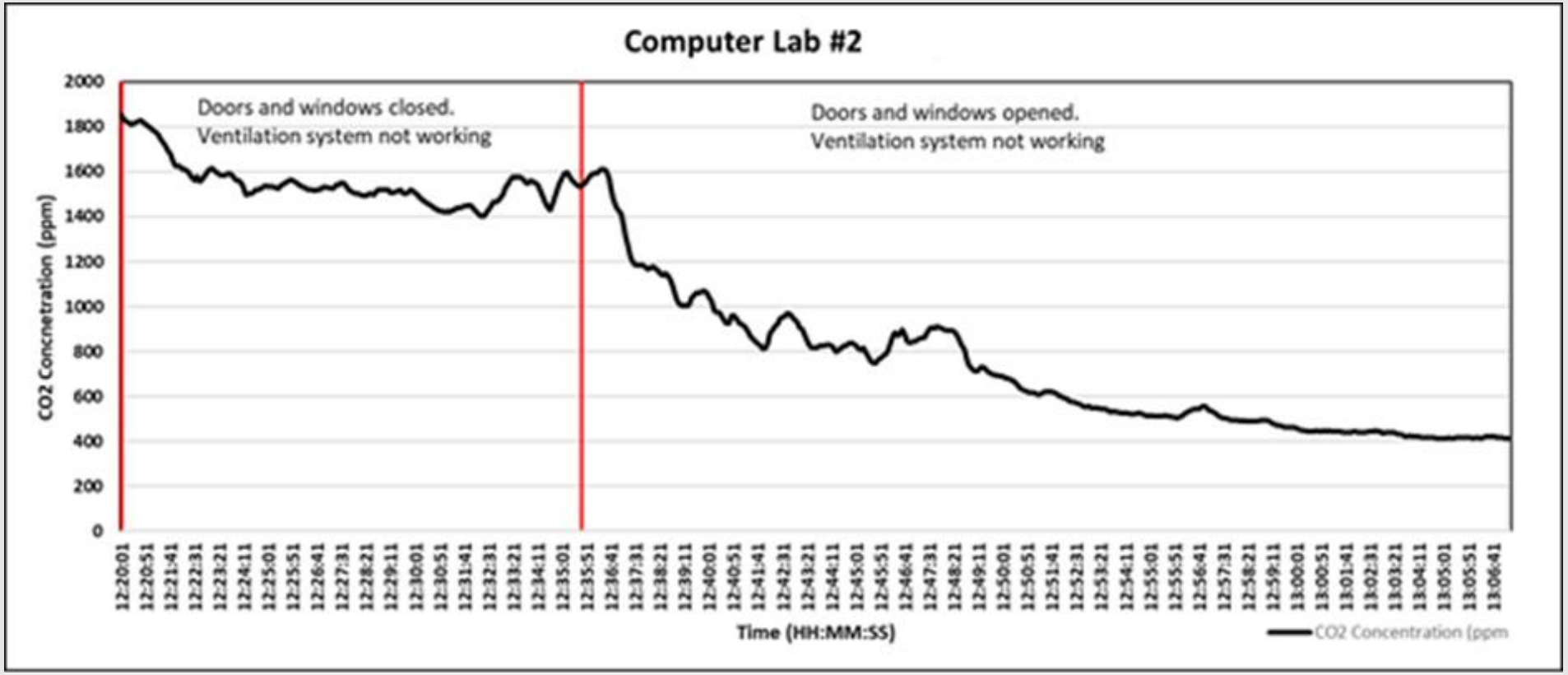
$$C = C_o\, e^{-ACH * t}$$

Where

C_o	=	**Initial contamination conc. (virons / m³) left "Y" axis**
Q	=	**Airflow ($m^3\ s^{-1}$)**
V	=	**Volume of ventilated space (m^3)**
t	=	**Time (s) "X" axis**
ACH	=	**Ventilation rate (Q/v) on right "Y" axis**

Measurements in progress – Computer lab

Results:


Computer Lab #2
Doors and windows closed.
Ventilation system not working
Doors and windows opened.
Ventilation system not working
CO2 Concnetration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
12:20:01
12:20:51
12:21:41
12:22:31
12:23:21
12:24:11
12:25:01
12:25:51
12:26:41
12:27:31
12:28:21
12:29:11
12:30:01
12:30:51
12:31:41
12:32:31
12:33:21
12:34:11
12:35:01
12:35:51
12:36:41
12:37:31
12:38:21
12:39:11
12:40:01
12:40:51
12:41:41
12:42:31
12:43:21
12:44:11
12:45:01
12:45:51
12:46:41
12:47:31
12:48:21
12:49:11
12:50:01
12:50:51
12:51:41
12:52:31
12:53:21
12:54:11
12:55:01
12:55:51
12:56:41
12:57:31
12:58:21
12:59:11
13:00:01
13:00:51
13:01:41
13:02:31
13:03:21
13:04:11
13:05:01
13:05:51
13:06:41
Time (HH:MM:SS)
CO2 Concentration (ppm

Ventilation effectiveness:

$$\frac{\textbf{Effective}\ \text{Outside Air volume Supplied}^{*}\ \text{or ACH (from rate of CO2 decay)} * 100}{\boldsymbol{Actual}\ \textit{Outside Air volume Supplied}}$$

*Measured in the center of each room at 1.2m from the floor

Rooms which have Mechanical Ventilation	ACH CO_2 decay method	ACH from air flow anemometer	**Ventilation effective-ness %**	Comment
Resource Centre	2.0	2.0	100	4 of the 6 air supply working. Double door and some high windows open
Lecture Rm 1/2	2.3	9.0	26	Two of 8 air supply registers were not working. No windows
Lecture 4: windows closed	5.5	14.0	39	Mechanical ventilation was working
windows open	7.6	14.0	54	Open windows improved mixing efficiency

Rooms which have Mechanical Ventilation	ACH CO2 decay method	ACH from air flow anemometer	Ventilation effectiveness %	Comment
Ladies Rest Room	3.3	3.4	97	‘Flapped’ doors to mix CO_2 - no plug point for fans
North LIft	3.1	48*	6	Poor mixing - dead ceiling space above lift roof fans

* Air flow path in the lift was not observed. Some of the air measured may be have been recycled and not been outside air.

Results: Recommended maximum occupancy for rooms in the School of Public Health

Room Occupancy (social distancing 2m)	Recommended maximum occupancy*	Criterion
Resource Centre (151)	44	Ventilation
Comp lab 2 (33)	9	Ventilation
Lecture Rm ½ (87)	29	Ventilation
Lecture Rm 3	30	Social distancing
Lecture Rm 4	20	Social distancing
129 (AV-room) (13)	9	Ventilation
156 (PG-AV-room) (15)	7	Ventilation
Meeting Room 112 (10)	8	Ventilation
Meeting Room 210	10	Social distancing
North Lift	1	Social distancing

Note

*The recommended occupancy is based on social distancing or 75% of the best-case ventilation occupancy whichever is the smaller

Conclusion

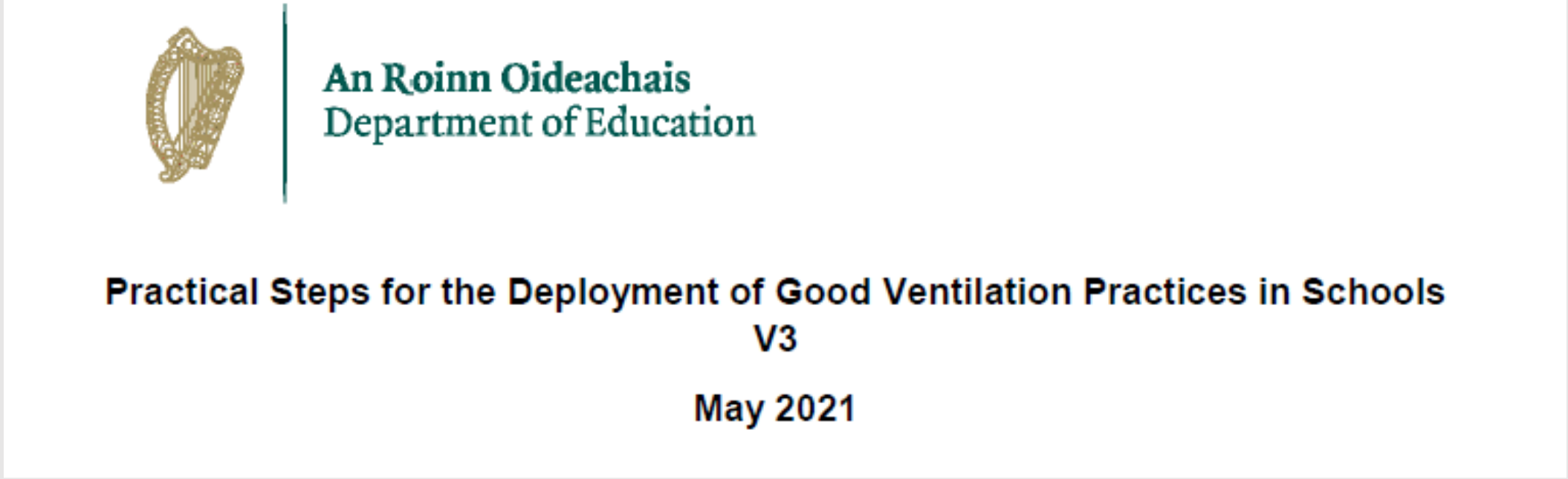
- Occupancy numbers determined using WHO ventilation guidance would allow fewer occupants than when using 2 meters social distancing
- Ventilation in a room (at a center point) can be reasonably easy to measure using CO_2 injection, mixing and CO_2 decay monitoring
- Improving ventilation may contribute significantly to the reduction of exposure to virus quanta via the aerosol pathway

Recommendations

- The results suggest that improved maintenance would allow greater numbers of students to safely use the School's facilities
- Improved window use will improve ventilation and together with other exposure control elements, e.g. hand washing, masks etc. could help reduce the risk of airborne SARS CoV19
- A maintenance priority list should be considered, to manage the repair of ventilation equipment in poorly ventilated rooms as funds become available

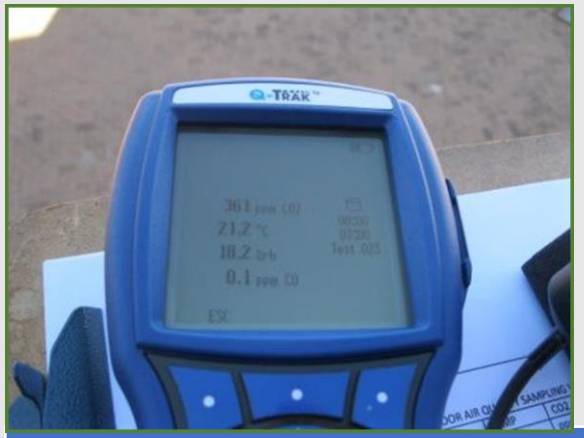
Indoor Air Quality Case study

Practical steps to improve the ACH in school rooms



https://www.gov.ie/en/campaigns/a128d-back-to-school/?referrer=http://www.gov.ie/backtoschool/


The End



Tools for Indoor Air Quality Assessments

Tools to Test IAQ	Function
Smoke tubes or Wizard	Test pressure difference, demonstrate air currents
Bolometer TSI Accubalance	Measure air register supply
IAQ - Q-TrakTSI 7545 indoor air quality monitor	Measure temperature, humidity, CO2 (indicator of outdoor air supply), CO measure of fugitive exhaust gasses
Detector tubes, charcoal tube sampling with GCMS if a specific chemical is suspected,	Test compliance or more likely determine source
Nose	Detect volatile chemicals
Hot wire Anemometers	Measures the velocity of air currents