Targeted extraction of exhaled breath

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TAPAS: Tackling Air Pollution at School
Networking Event

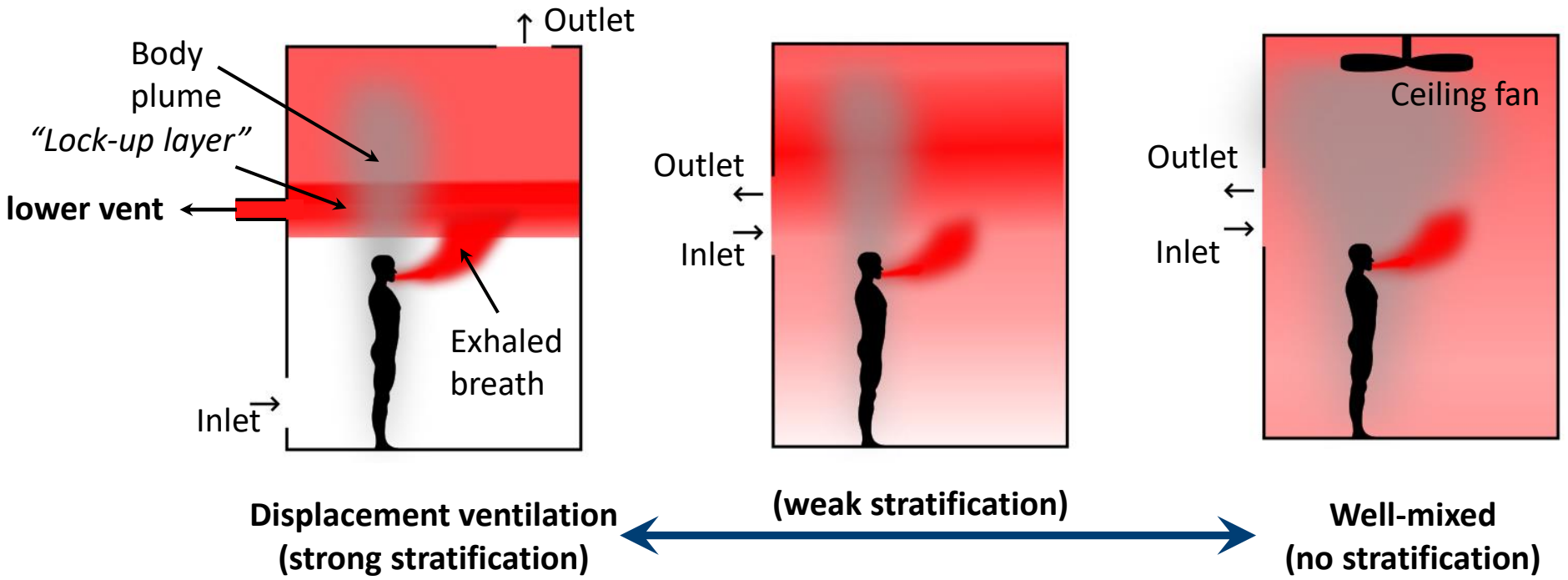
9th March 2023

Motivation

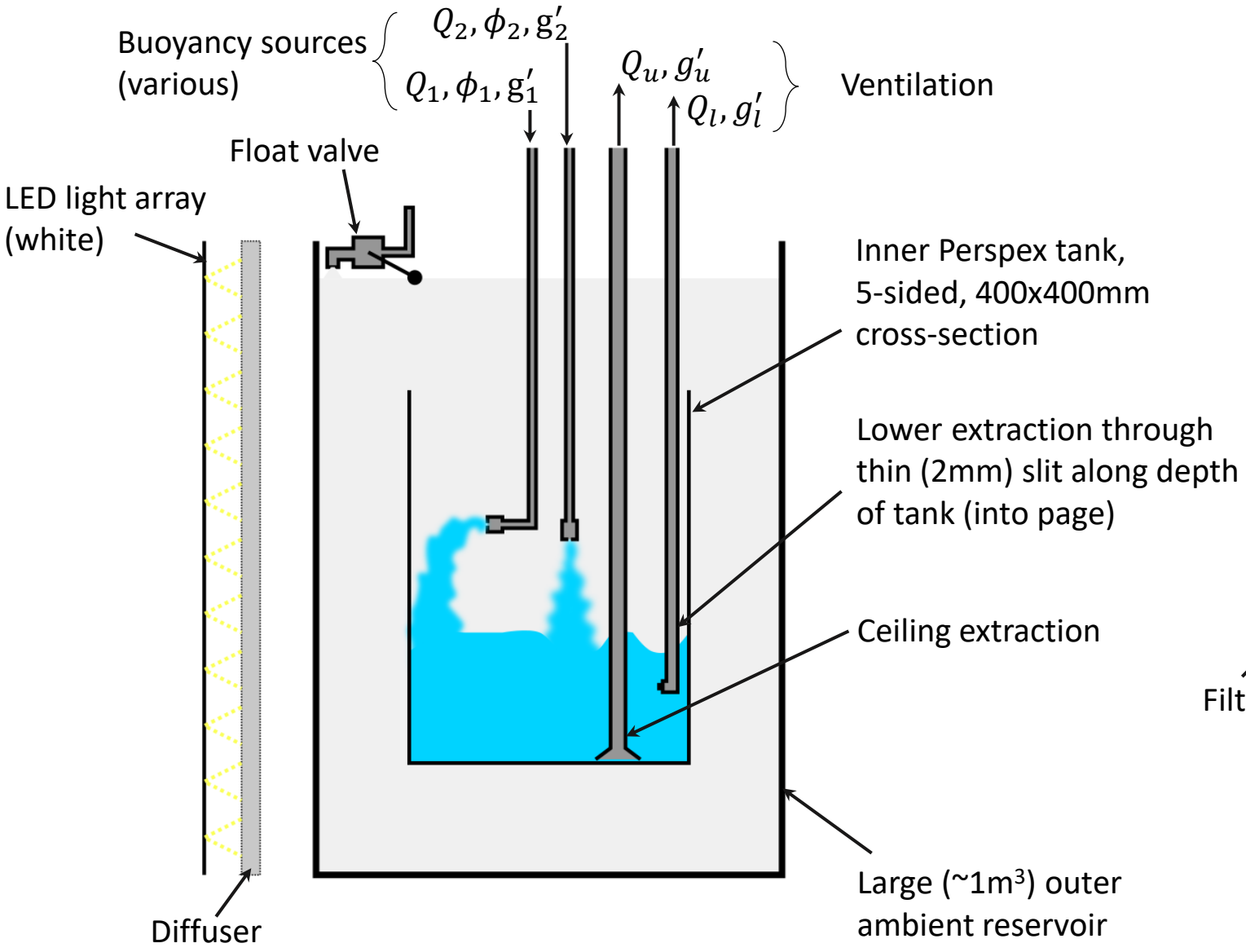
- Exhaled breath distributions play a critical role in airborne virus transmission, e.g. Infection probability is greater if the local concentration of infected breath is greater.

- Buoyancy leads to stratification in rooms (layers of varying concentration).

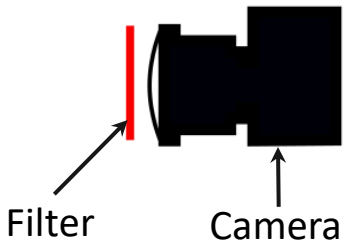
What is the effect adding a ventilation outlet in the layer of high concentration?



Experimental Setup

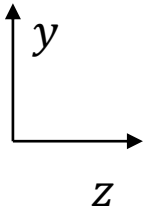


- Open side of Perspex box provides low level inlet (gravity flipped)
- Buoyancy sources supplied with salt solution
- All flowrates and densities measured
- Scalar (dye) distribution measured by dye attenuation



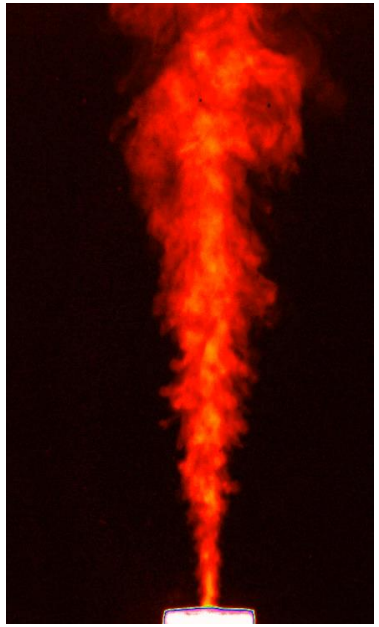
Calibration
(~Beer-Lambert Law)

$$I(x,y) \longrightarrow \phi(x,y)$$



Buoyancy Sources

Vertical plume,
Plume parameter
$\Gamma = \frac{5Q^2B}{8\alpha M^{5/2}} = 0.1$



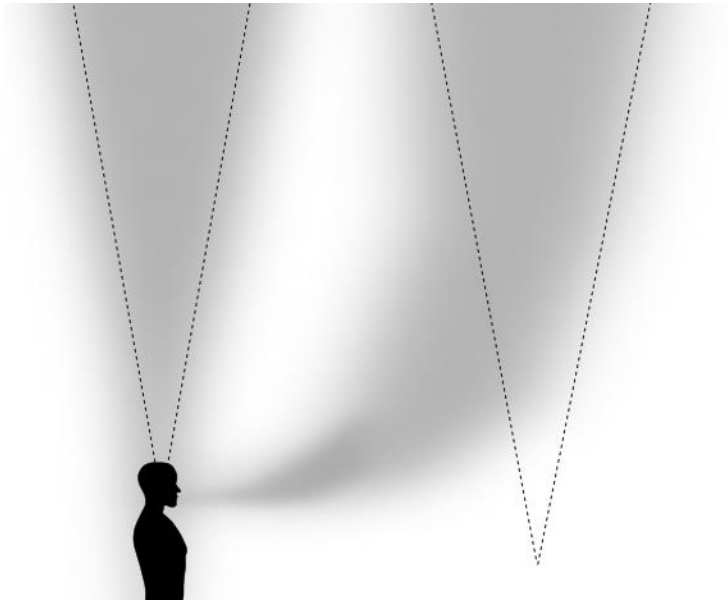
Continuous buoyant jet
$Fr = \frac{u}{\sqrt{g'd}} = 8.7$
$\Gamma = 0.03$

~Equivalent to breathing rate 10 l min^{-1}

Intermittent buoyant jet
(4s period, 50% duty cycle)

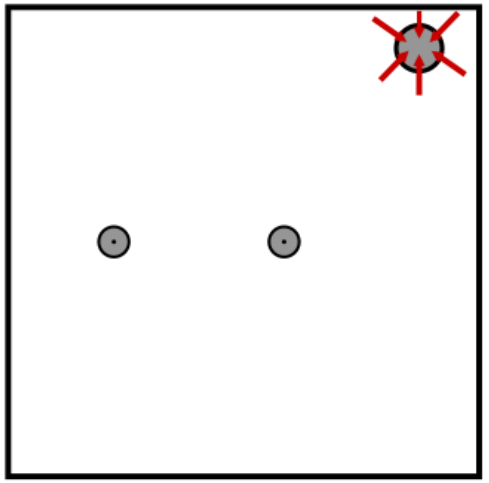
Common time averaged
volume Q and buoyancy flux B

Complexity of a person is distilled into a two buoyancy source system (body and breath)

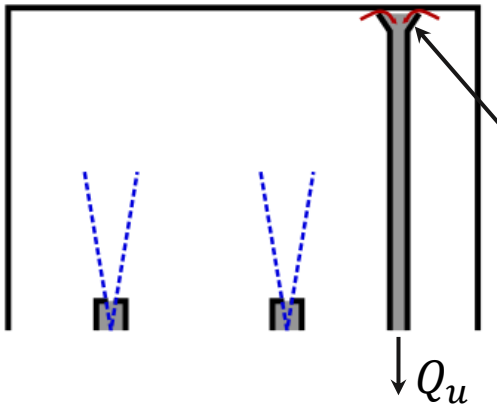


Results: Two Buoyancy Sources

View from above



View from front



From scaling $\frac{t_{full-scale}}{t_{model}} \sim 1.2$

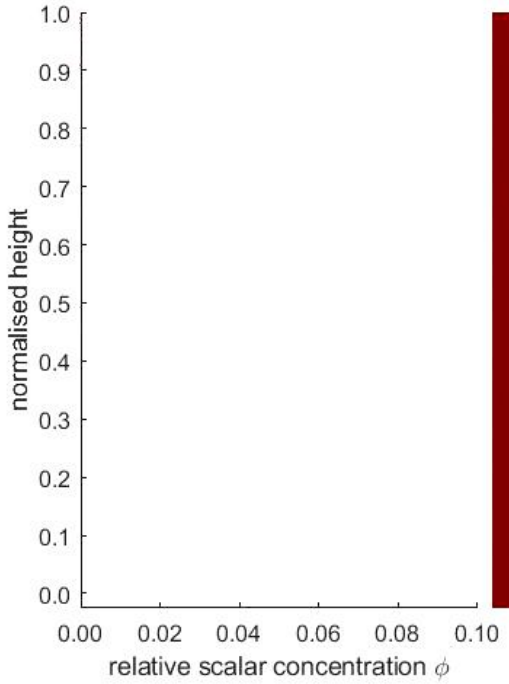
(almost *real time*)

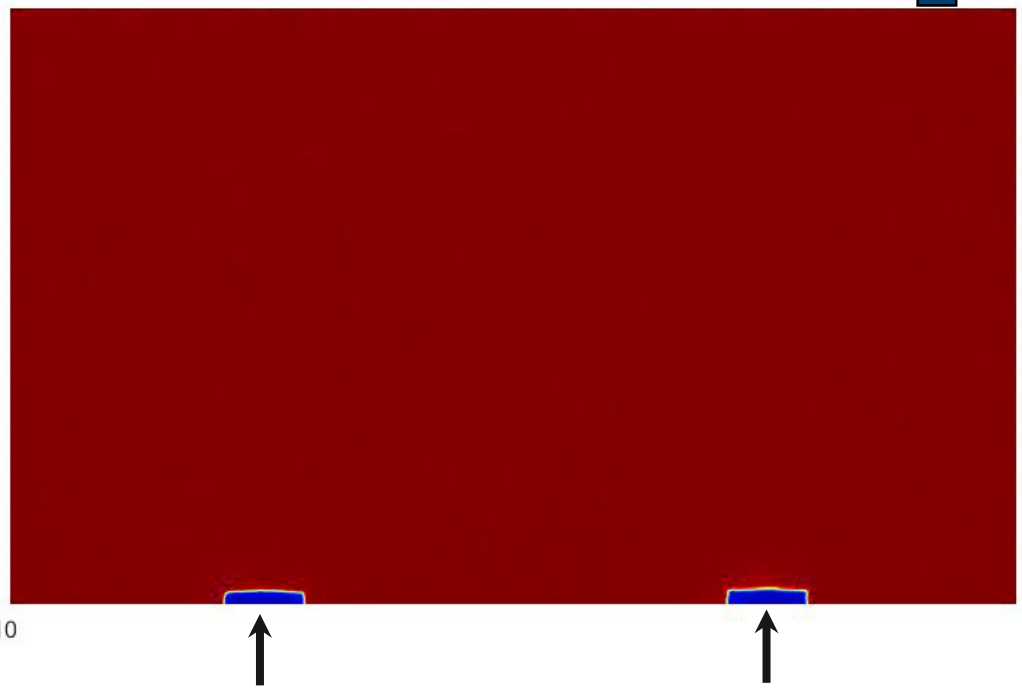
$\frac{B_2}{B_1} = 0.22$

$Q_u = 38$ cm^3 s^{-1}

Equivalent to ~16 l s^{-1} at full scale

(x60 speed)





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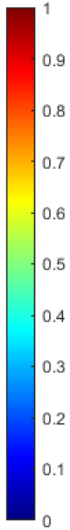


$Q_1 = 2.3$ cm^3 s^{-1}
$g_1' = 42.3$ cm s^{-2}
$B_1 = 97.0$ cm^4 s^{-3}
$\phi_1 = 0$

$Q_2 = 2.0$ cm^3 s^{-1}
$g_2' = 10.8$ cm s^{-2}
$B_2 = 21.5$ cm^4 s^{-3}
$\phi_2 = 1$

Results: Two Buoyancy Sources (continued)

Lower ventilation fraction: $Q_r = \frac{Q_l}{Q_u + Q_l}$

Instantaneous distribution

Steady distributions:

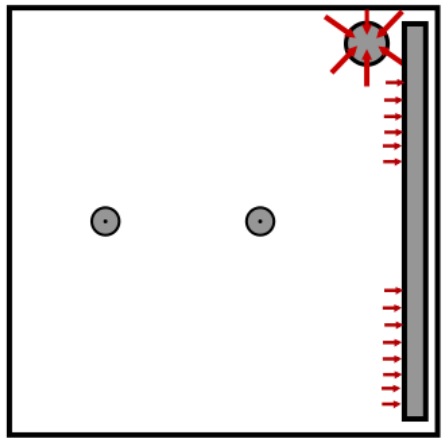
$Q_r = 1$ $Q_r = 0.25$

$Q_r = 0.75$ $Q_r = 0$

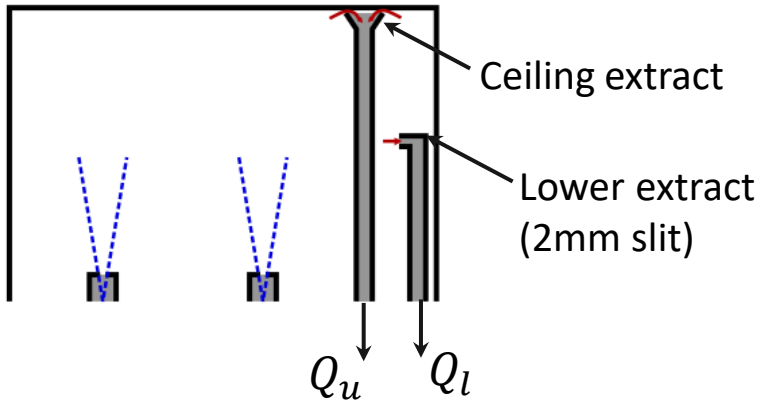
$Q_r = 0.5$

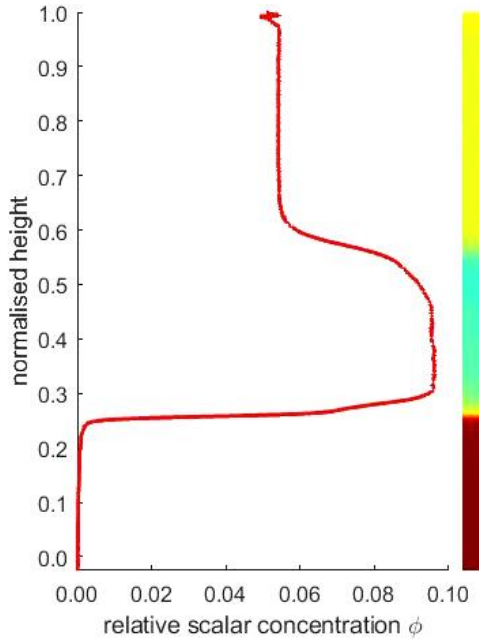
$Q_{vent} = Q_u + Q_l = 38\ \text{cm}^3\ \text{s}^{-1}$

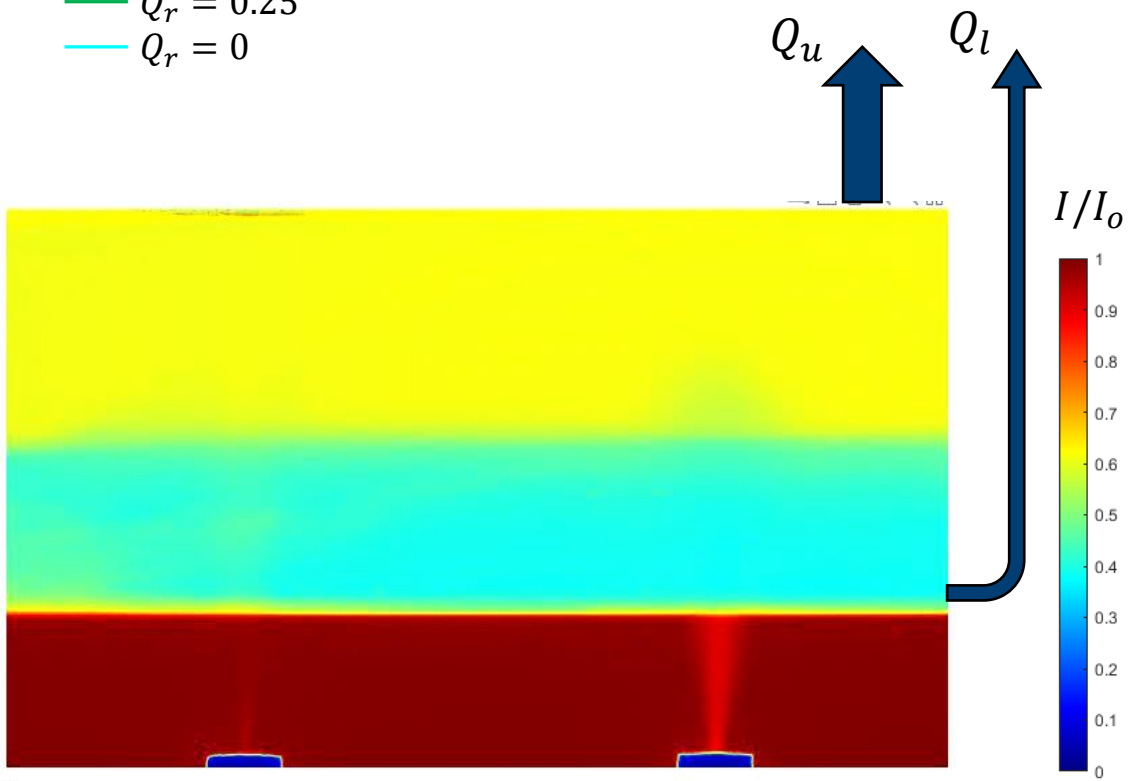
View from above



View from front





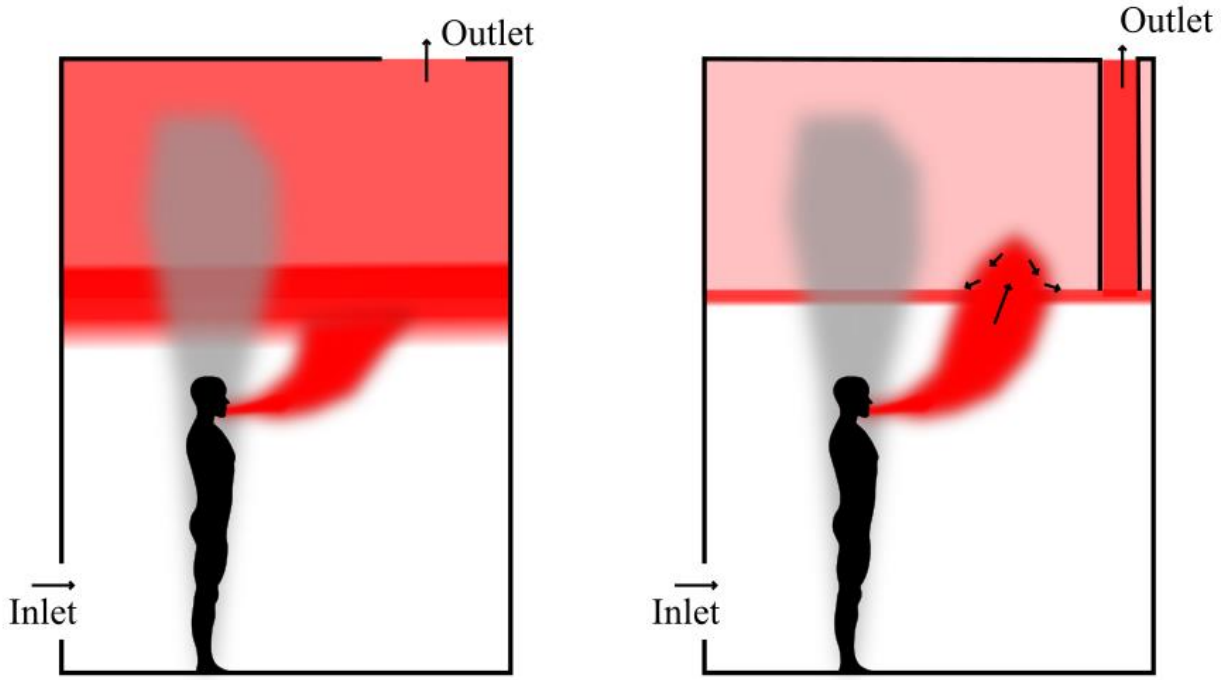


Conclusions

1. Varying strength buoyancy sources drive stratification in rooms, while many other effects drive mixing.

2. Exhaled breath is a weak source that will tend to settle at a lower height – “lock-up layer”

3. Lowering the outlet height to give targeted extraction of this layer reduces its thickness, and reduces overall scalar concentration in the space.



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