Installment 2

On the Effects of Face Masks, Distance and Building HVAC Systems in the Spread of Infectious Aerosols

7-10-2020

Thoughts & Opinions of

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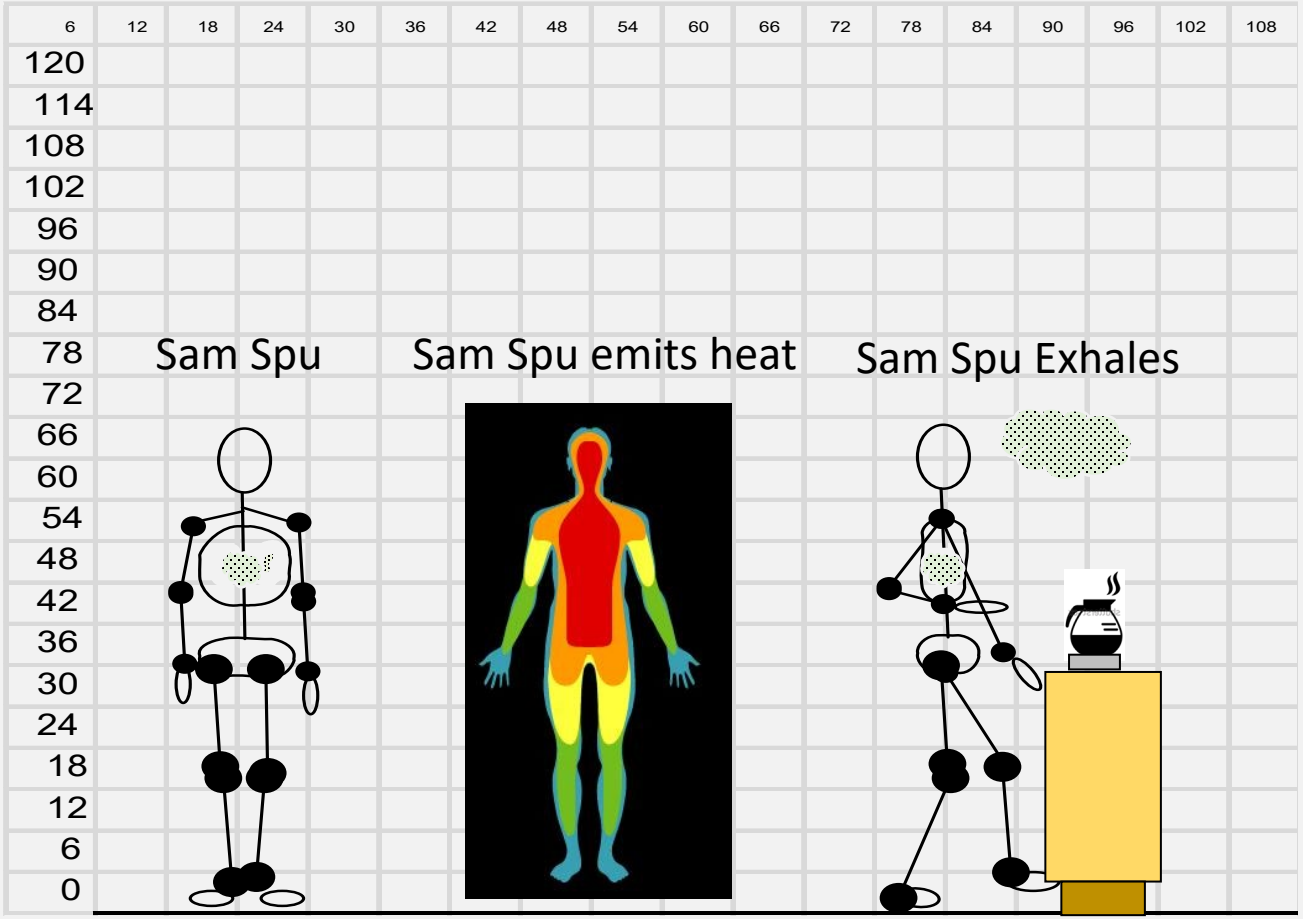
11.

In the next few slides, Henry contemplates what an HVAC designer thinks about people.
In the past, most people did not care much what he thought about them.

People generate heat. Sitting, in an office, about 250 BTU/hr- of sensible energy.
This is the same order of magnitude as heat given off by a 75-watt light bulb.

People exhale moisture at 1/10th to 1/4th of a cup per hour, depending on heart rate- 150 BTU/hr of latent energy
This is the same order of magnitude as the steam given off by a coffee pot warmer.



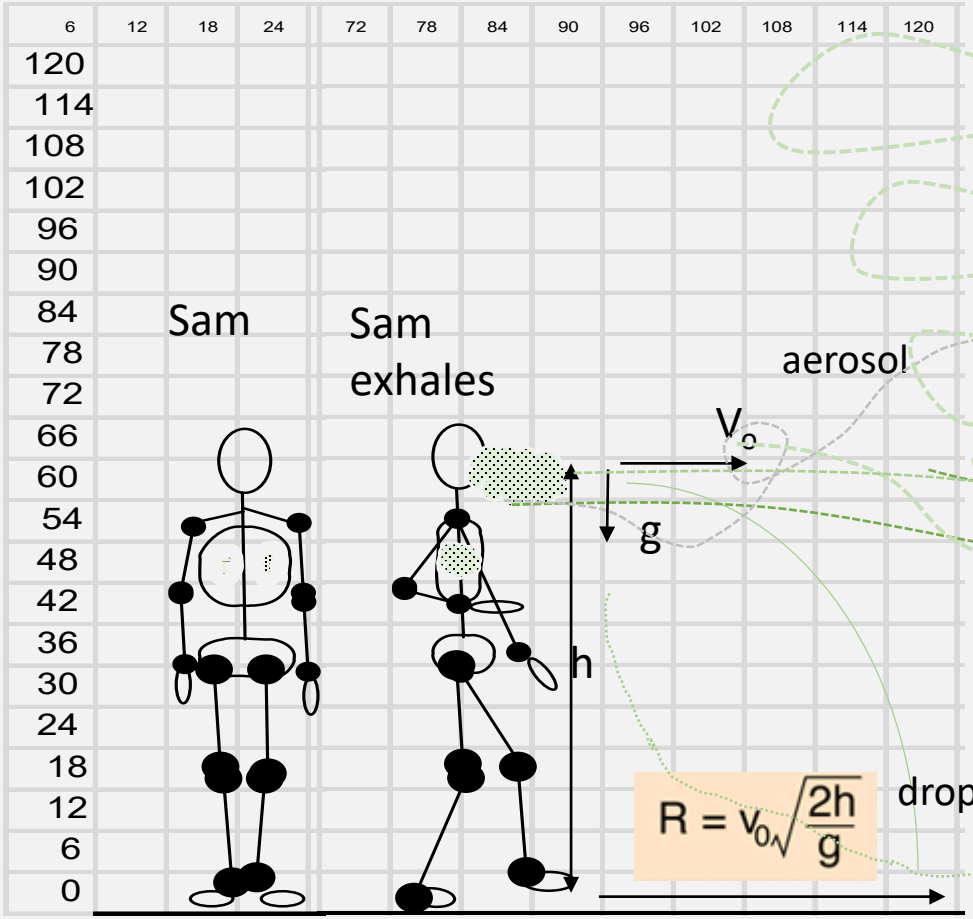
People in buildings also generate perspiration, noise, and stink. They demand lighting, refrigerators, electronic devices, vertical transportation, and comfort control.

These facts about people are essential elements of HVAC design, but only indirectly related to the spread of infectious aerosols.

12.

People inhale air and exhale nitrogen (78%), oxygen (16%), CO2 (4%) and (2%) of “other stuff” (slide 3)
The temperature and humidity of a breath is 98.7 F and 100% relative humidity crossing the lips but, the thermodynamic state changes quickly as it dissipates into the ambient room air.

People breath in 0.5 liter puffs about 15 times a minute.
This works out to 0.3 cubic feet per minute of saturated vapor containing droplets.



The liquids carried in the gas cloud are in a wide range of sizes from small droplets to invisibly small aerosols. There is an Important distinction between a “droplet” and an “aerosol”. Droplets follow a ballistic trajectory to the floor by gravity. Aerosols ride up thermal convective cells and surf down room air currents. They can remain airborne for a much longer time.
An HVAC designer knows something about room air temperature and currents

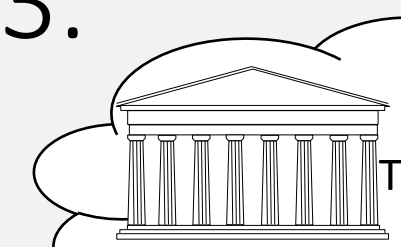
A droplet will become an aerosol if enough of its surface water evaporates before it hits the ground. Surface evaporation is driven by room relative humidity.

How do we know this?
The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) has done controlled experiments and analyses on the effect of relative humidity in the spread of infection in Surgeries. Understanding this phenomenon is important in design of Health Care Facilities.

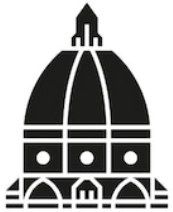
Virus can attach to both droplets and aerosols.

13.

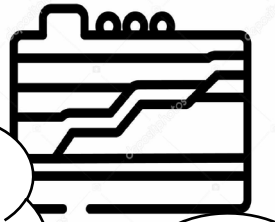
People bring a wide range of requirements and expectations of their indoor environment.
Until recently, most people did not consider building HVAC as a particularly high priority.



The Parthenon!

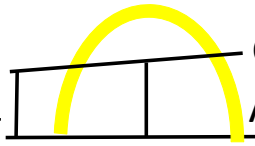


Brunelleschi's Dome!



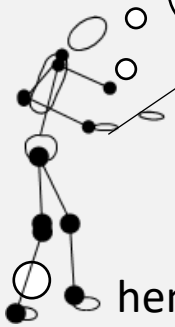
Centre Pompidou!

Machu Pichu!



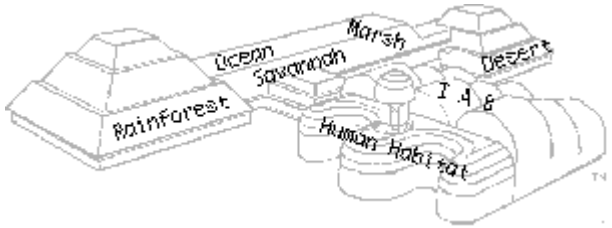
Golden Arches!

Falling Water!



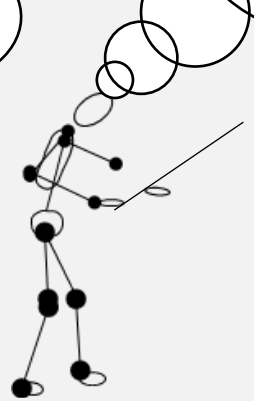
henry

While most people have a clear idea of the perfect building



Biosphere 2?

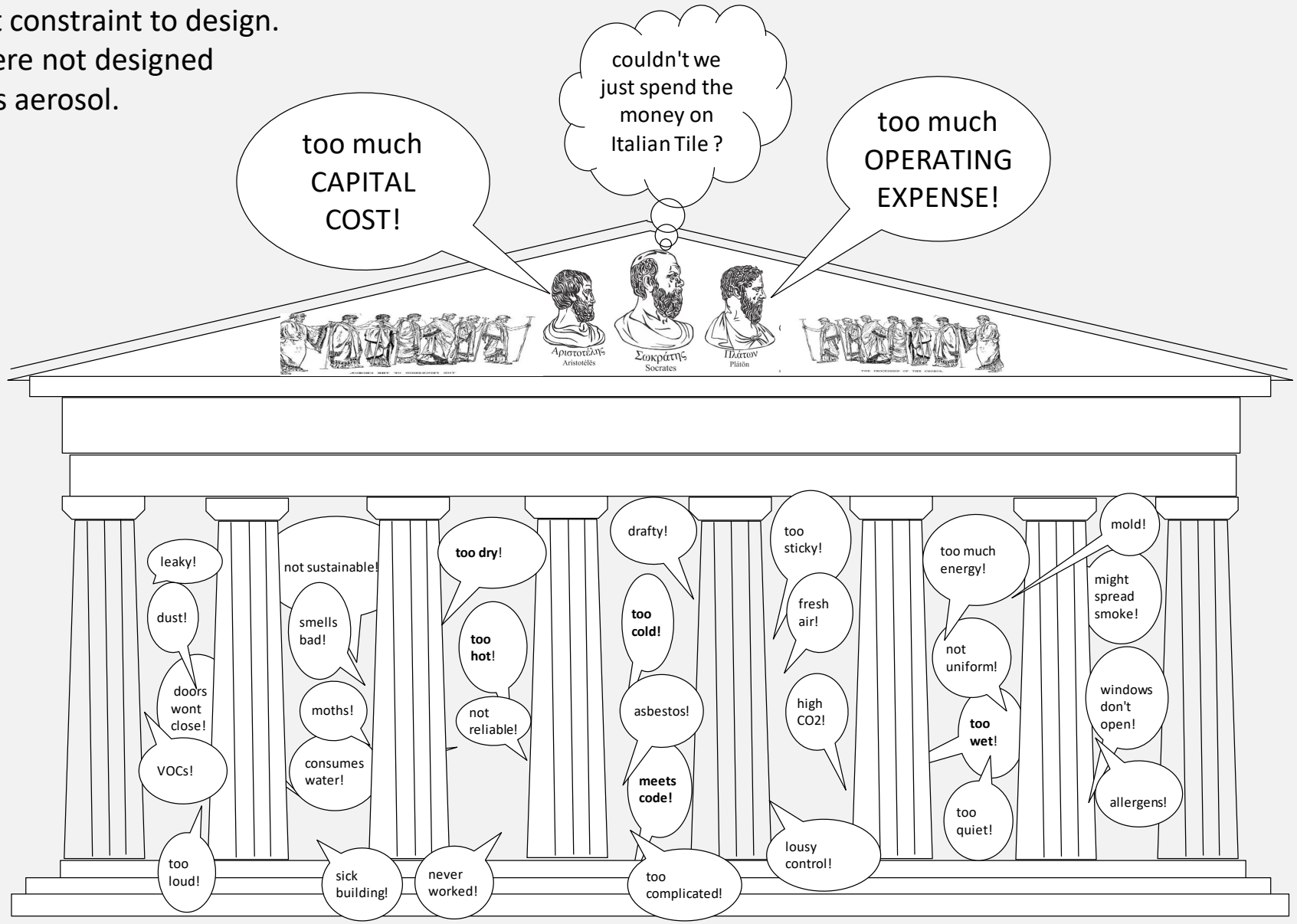
They would have been in there 25 years by now…(if the AC had worked)

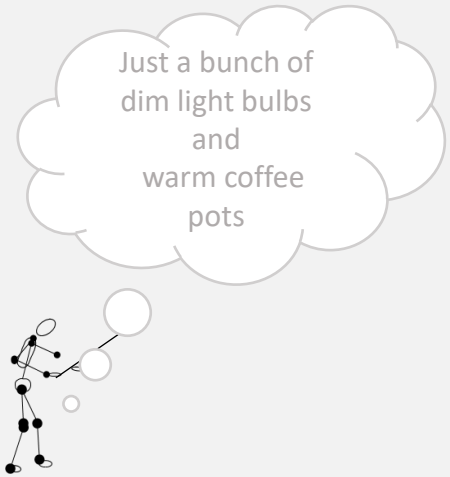


It is harder for people to come up with an idea of the perfectly air-conditioned building

14.

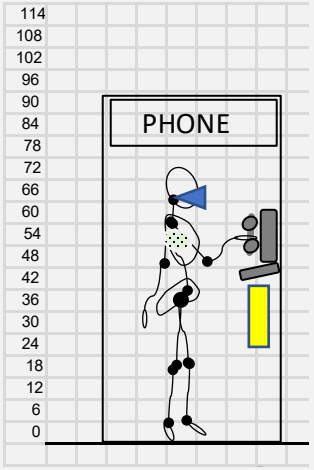
Nevertheless, People are remarkably sensitive and often quite vocal to their indoor environments.
But it is generally not possible to design a system that satisfies all the people, all the time.
Design and operation involves balancing a range of needs and wants.
Cost is often among the biggest constraint to design.
Most building HVAC systems were not designed
to eliminate all risk of infectious aerosol.





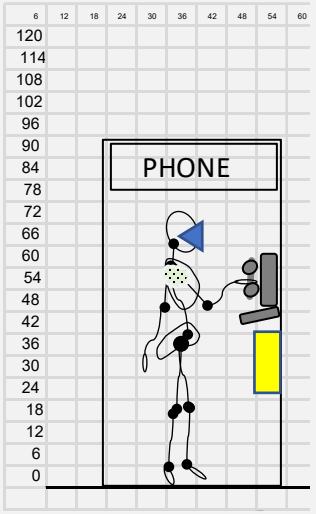
15. How could building HVAC contribute to spread of virus? A thought experiment (1)

*Su Spre Finds a **Phone Booth**!*
Not many are left out there.
Su has virus but doesn't know.
She wears a mask. It is moist due to exhalation of vapor.



Phone booths and yellow pages were replaced by cell phones and zoom. People's behavior can change quickly.

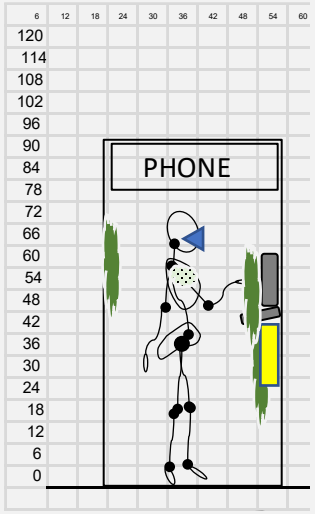
Su phones Sam Spu.
"Hey Sam, ever been in a phone booth?" She messes with her mask



Masks reduce droplet bomb launches but not the leaks of exhaled vapor and moisture.

Visualizing the effectiveness of face masks in obstructing respiratory jets
Siddhartha Verma,[a] Manhar Dhanak,[b] and John Frankenfield[c]
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7327717/

As she waits, she touches her mask, the phone, the phone buttons, the phone book, the walls.



The combination of mask leakage and touching things quickly infuses fluids into the fine films that exist across almost all surfaces. Virus thrives in many of these films and can live for days.

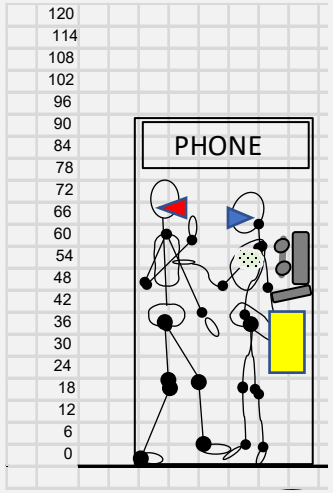
Most surfaces on earth are covered in invisible biofilm that hosts entire ecosystems of microscopic organisms. Even the skin on your body.

"Never Home Alone"
by Rob Dunn 2018 Basic Books

Add to your summer reading list?

16. How could building HVAC contribute to spread of virus? A thought experiment (2)

Sam arrives.
He also wears a mask but does not have this virus. The Phone booth is very tight
They are in close proximity.



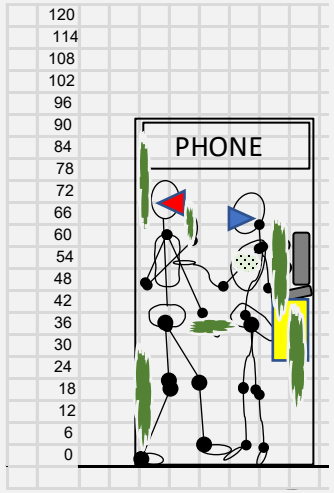
This phone booth is
3 feet wide
3 feet long
8 feet high

9 square feet (ft2)

72 cubic feet (ft3)

When the door is closed the booth is tightly sealed

Sam closes the door and now he touches the phone, the buttons, the phone book. He touches his face. Virus in the film gets in his nose, eyes and mouth. This may be the primary vector of virus spread "Fomite Transmission."



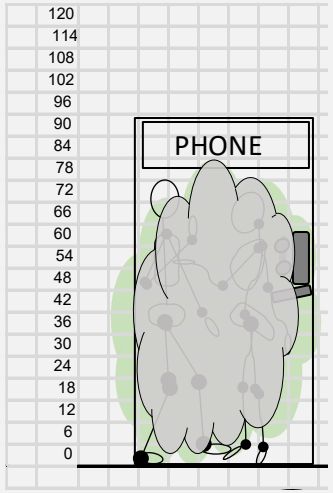
Although 2 people in this close proximity may seem improper, it's not unlike densities in crowded elevators, busses or subways.
Guiness record for phone booth stuffing? 25 people. Set in 1959.

Risk of virus spread is higher in spaces where people are in close proximity. Elevators, Restrooms, Lobbies. The Fomite Transmission vector is reduced or maybe eliminated through frequent sterilization of surfaces and handwashing

While we are all individually responsible for this hygiene, there are an increasing number of people focused on sterilizing surfaces. This near endless job should not be thankless. Remember to say "thank you" to those who are sanitizing our indoor environments.

The windows of the phone booth are fogging up. It Appears to be getting steamy.

What is going on in there?

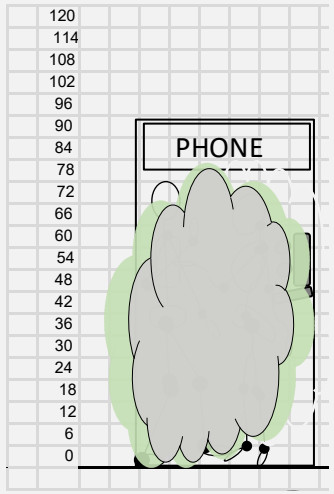


The volume is sealed. Concentration of the exhaled moisture increases and it begins condensing on the cool glass.

How could building HVAC contribute to spread of virus? A thought experiment (3)

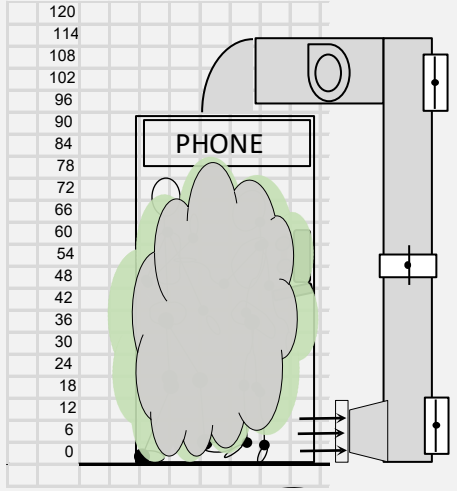
17.

Henry grows concerned.
As Su and Sam breathe, the oxygen level in the booth is dropping, concentrations of CO2, nitrogen, water vapor, and other stuff (including virus) increases.



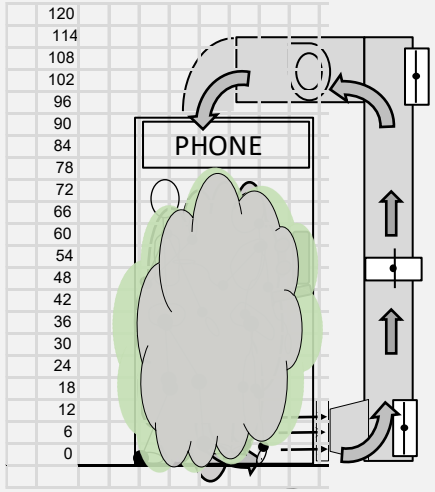
People in close proximity in a sealed space reduces oxygen and increases CO2. Remember Biosphere 2!

He rigs up a rudimentary HVAC system. It has a fan that blows down from the top and draws out from the bottom through sheet metal ductwork. Three dampers control air direction.



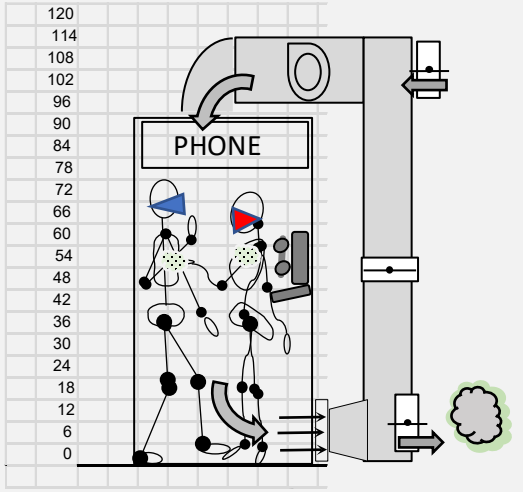
Dampers are metal plates with rubber edge seals. They pivot on a shaft rotated by either a ¼ turn motor or positioned by hand

The fan starts up. It is pushes 6 cubic feet per minute (ft3/min).
The windows stay foggy. He doubles the speed of the fan to 12ft3/min. Still nothing.



12ft3/min blown over 9ft2 (1.3cfm/ft2) is typical of flow in an office. The air in the booth is entirely recirculated. Concentration of contaminants continues to increase as the people exhale.

Henry repositions the dampers. The booth clears up almost instantly! Su and Sam are now breathing 100% fresh outside air. The contaminated gas has been flushed back outside!

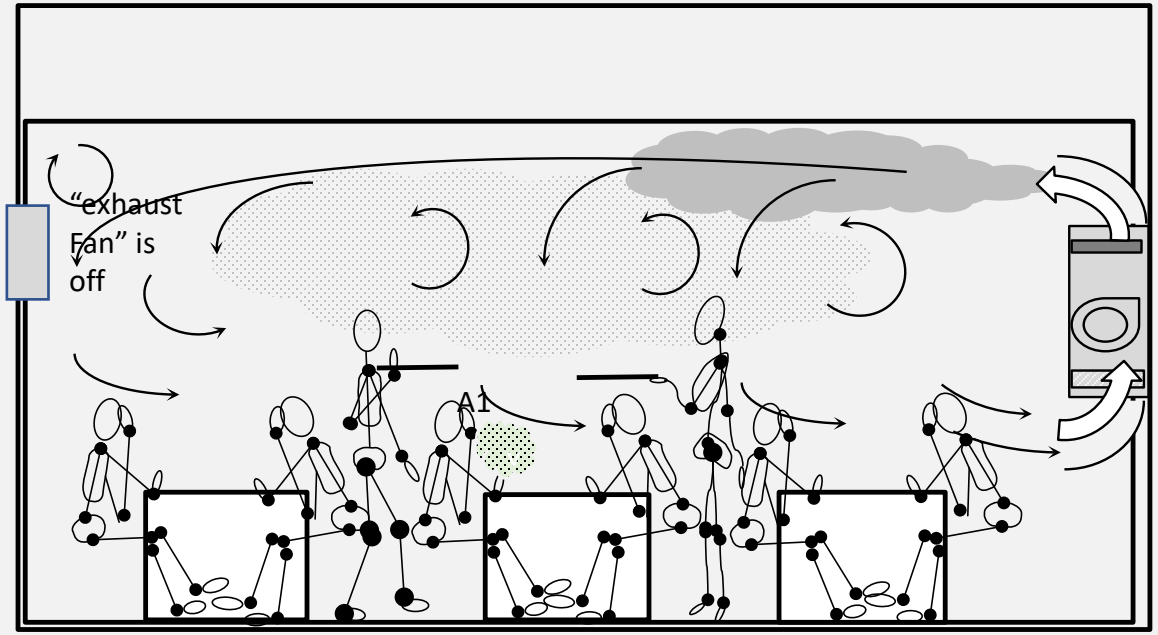


Actual HVAC systems that include coils and filters involve other processes not as simple to describe in the context of virus spread.

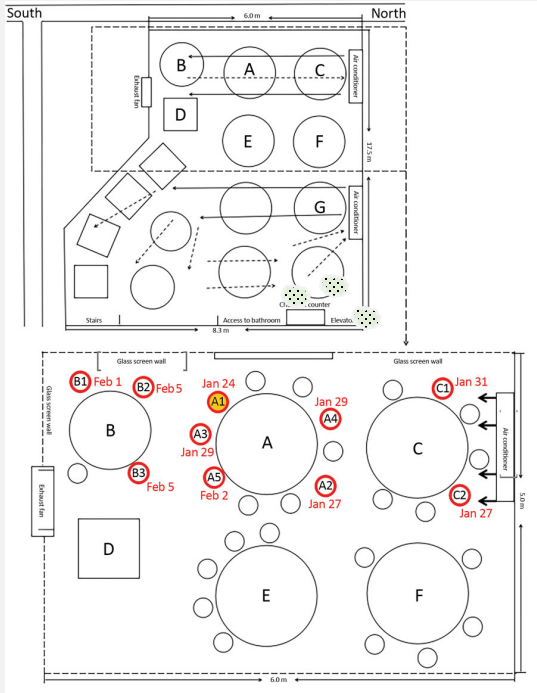
Lu J, Gu J, Li K, Xu C, Su W, Lai Z, et al. COVID-19 Outbreak Associated with Air Conditioning in Restaurant Guangzhou, China, 2020.

18. How could building HVAC contribute to spread of virus? An example of mostly recirculating system.

Henry imagines the restaurant in China that is subject of a recent epidemiological study.
This study is well worth reading. An index case “A1” is seated at a table in a crowded space conditioned with a ductless AC unit. Customers at adjacent tables who became infected were carefully traced. An “exhaust fan” is shown on the opposing wall but described no further. For purposes of his thought experiment, Henry assumes the “exhaust fan” was off.
While fomite transmission could certainly be a vector, so could droplets or aerosols that got entrained in the high velocity layer of mixed and turbulent room air currents and remained airborne.



With mostly recirculated air and no introduction of fresh air, the concentration of “A1s” contaminants would continue to increase in the breathing zone of other diners until he finished lunch and left the room.



This all seems plausible, but raises a question: What is the minimum concentration of virus in breathing air and/or exposure time needed to start an infection? Knowing that, one could begin to estimate minimum gross ratio of recirculation-to-ventilation in the HVAC system.

19.

How could building HVAC contribute to spread of virus?
An example of 100% ventilation.

This is a much-simplified diagram of an HVAC system in an operating room where the micro-environment of the surgical site must be extremely sterile to prevent infectious contamination.
The HVAC set up in an autopsy lab is similar, except it is designed to protect the medical examiner from airborne contaminants, fumes, fluid droplets and aerosols generated by “the specimen”. Sci-fi movies often start with this.

In our example, 100% fresh outside air is introduced at low velocity from the ceiling in a parallel and uniform pattern sweeping down over the people and is drawn out near the floor. This air does little mixing and does not recirculate. Often there are deep HEPA filters on either or both the supply and exhaust. Sometimes air scrubbers/carbon filters.

Many operating rooms use a humidifier to maintain high moisture in the air. High room humidity reduces evaporation of the surface of droplets-reducing the potential of aerosol generation.

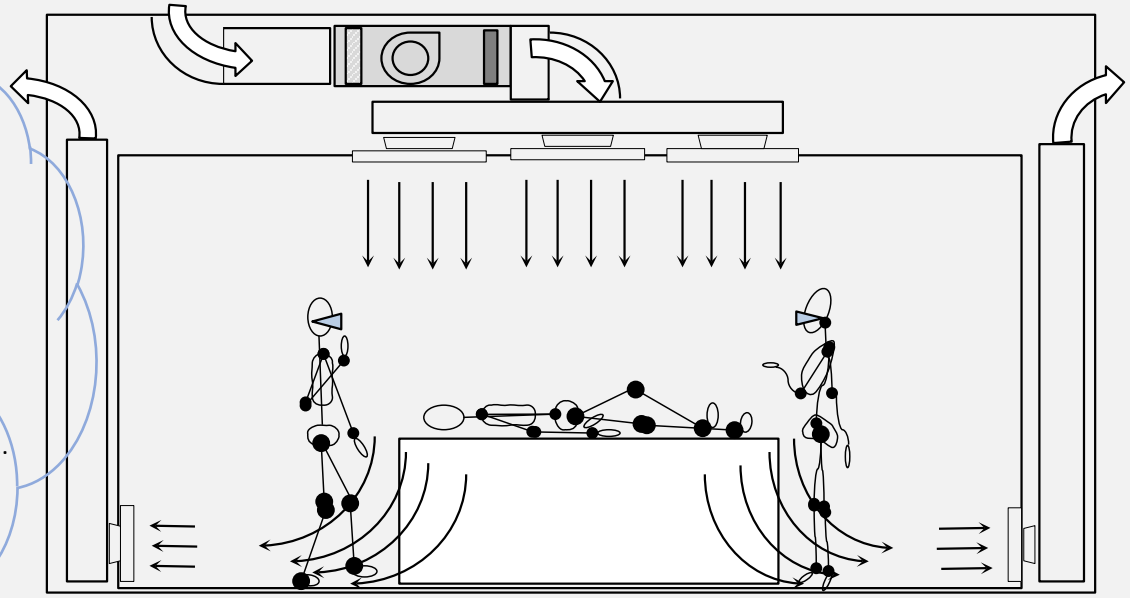
The HVAC industry organization, ASHRAE provides an amazing amount of general Information for designers. Specific guidance for our fast-moving situation is somewhat limited but evolving.

https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

Slow moving single pass parallel stream room airflow in the direction of gravity seems like a good idea for reducing spread of infectious aerosols and droplets.

It is the system of choice for cleanrooms, pharmaceutical manufacturing plants, assembling parts for extra terrestrial vehicles….

How practical would it be to consider retrofitting other building system types?



20.

How could building HVAC contribute to spread of virus?

The two previous examples represent two extremes in the quality of air in our breathing zone:
Full recirculation, highly turbulent mixing versus full parallel downdraft of fresh air.
Although there is no such thing as a “typical” office building HVAC, most share characteristics with each of our examples.

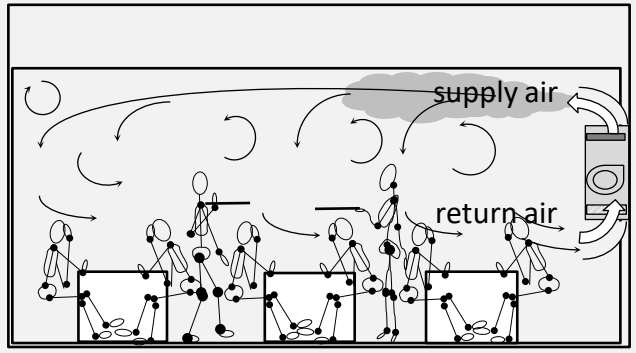
Other factors are important:

- Local climate
- Envelope construction
- Occupancy patterns, densities, demographics
- Internal heating loads and process requirements
- Ventilation air change rates
- Pressure relationships
- Thermal zoning

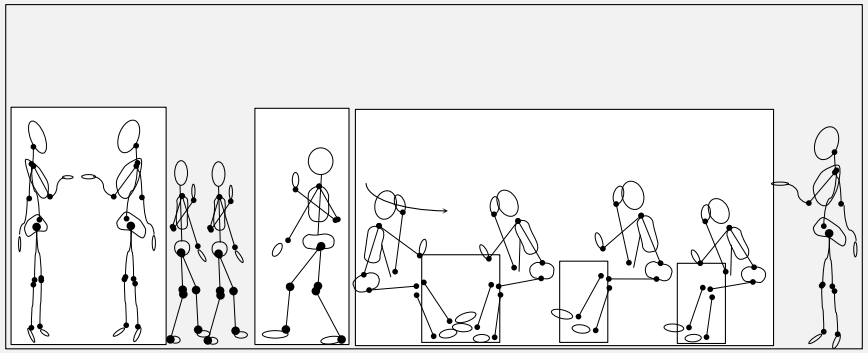
Can existing HVAC systems be improved to better control spread of infectious aerosols and droplets?

Yes, but not without considering a number of factors that are to be reviewed in our next installment.

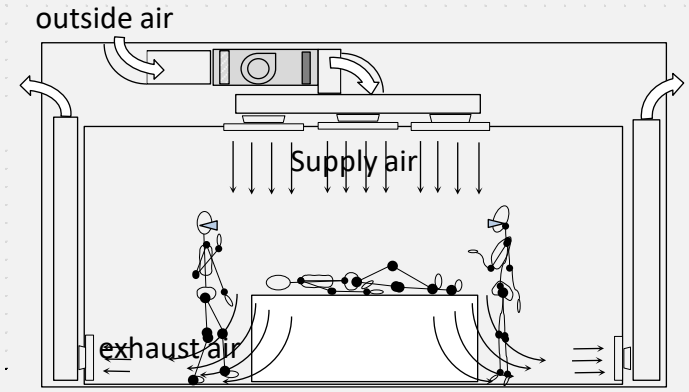
Worst case: recirculating, mixing, turbulent



“typical” office

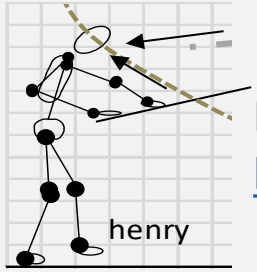


Best case: all fresh air, vertical, parallel



21. There could be more . . . Installment 3?

- More on the ratio of outside air and recirculated indoor air on concentration of virus.
- More on the importance of ventilation effectiveness-and room induced air flow
- More on significance of relative humidity (ASHRAE recommendations)- room humidifiers.
- On the effectiveness of UV light in space vs UV light in air handling system.
- On various types and location of filtration.
- On the relative merits of various air handler typologies.
- More on masks and mask effectiveness.
- Architectural challenges in maintaining distancing.



Respond to Henry?
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