Installment 3

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

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Thoughts & Opinions of

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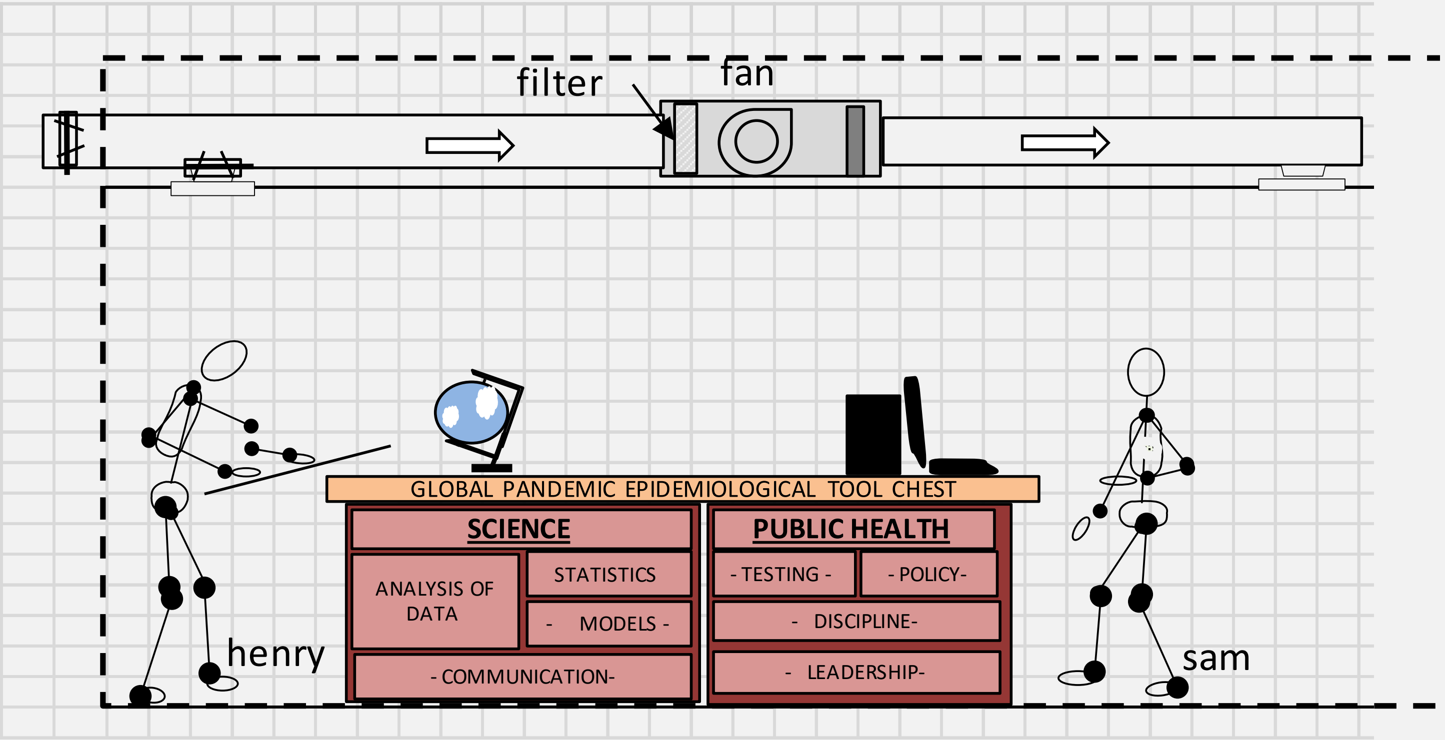
22. Henry and Sam were in their office back when the news that there might be viral pandemic first came across the internet. "People are dying on the other side of the world. How is this going to affect our lives", they asked each other. Henry and Sam weren't too concerned - there are well developed organizations, systems, infrastructures, tools, and most importantly, really smart people who know how to use them, they thought. "They will figure it out".



Despite some initial success in enforcing reduction of mobility, assembly, and commerce to flatten the infection growth curve, the drawers of our epidemiological tool chest proved to be poorly stocked with guidance, plans, tests, masks, and leadership to drives societal behavior.

Before long, it became clear it wasn't going to be a "they will figure it out" kind of thing. A virus of this sort exists for no other purpose than seeking out new human hosts. It is transmissible at low concentrations apparently through fomite transfer, contact with airborne droplets and inhalation of infected aerosols.

We began to realize that human-to-human interaction, community behavior and governmental policy are as important in control of viral spread as pharmaceuticals, medical technologies, or miracle cures. It has been difficult for us, however, to submit to the discipline required to sustain new practices in hygiene, distance, masks, limited assembly.

Our previously packed and buzzing office of 75 was abandoned and work resumed in 75 distanced homes. Transition to Zoom interaction concealed the fact that not everyone in the world was so lucky as to keep their job. The economic calculus that balances gross national product to human condition became exposed and raw.

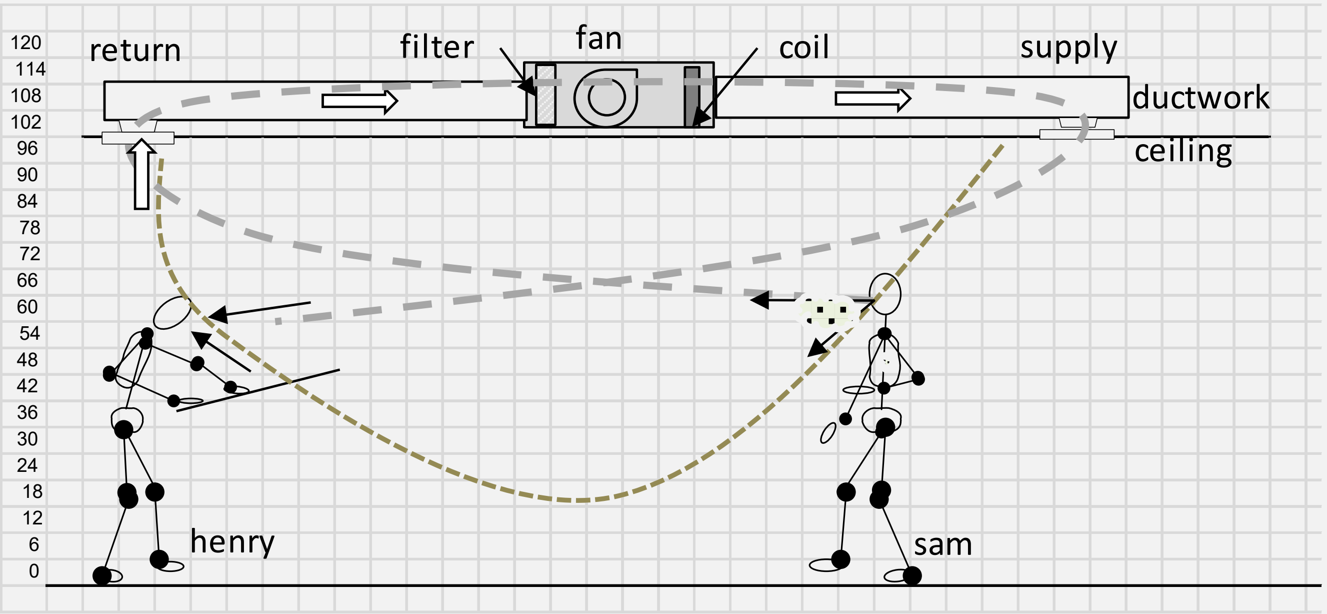
And now the question: How do we keep the economy from collapsing without providing people the opportunity to pack themselves inside buildings to work and teach and drink and joke and sing and eat and watch hockey?

"Well Sam," says Henry, " I guess we got to do our part! How can we help figure out how to keep these old building HVAC systems from spreading infection?"

23. Sam has the virus. Henry, occupying the same room, wants to know if he might be breathing in Sam's virus?
That could happen if either:
a. Particulates and aerosols containing Sam's virus gets sucked through the air conditioning and blown back out or,
b. Room air currents induced by the HVAC system sweep the virus into his breathing zone.

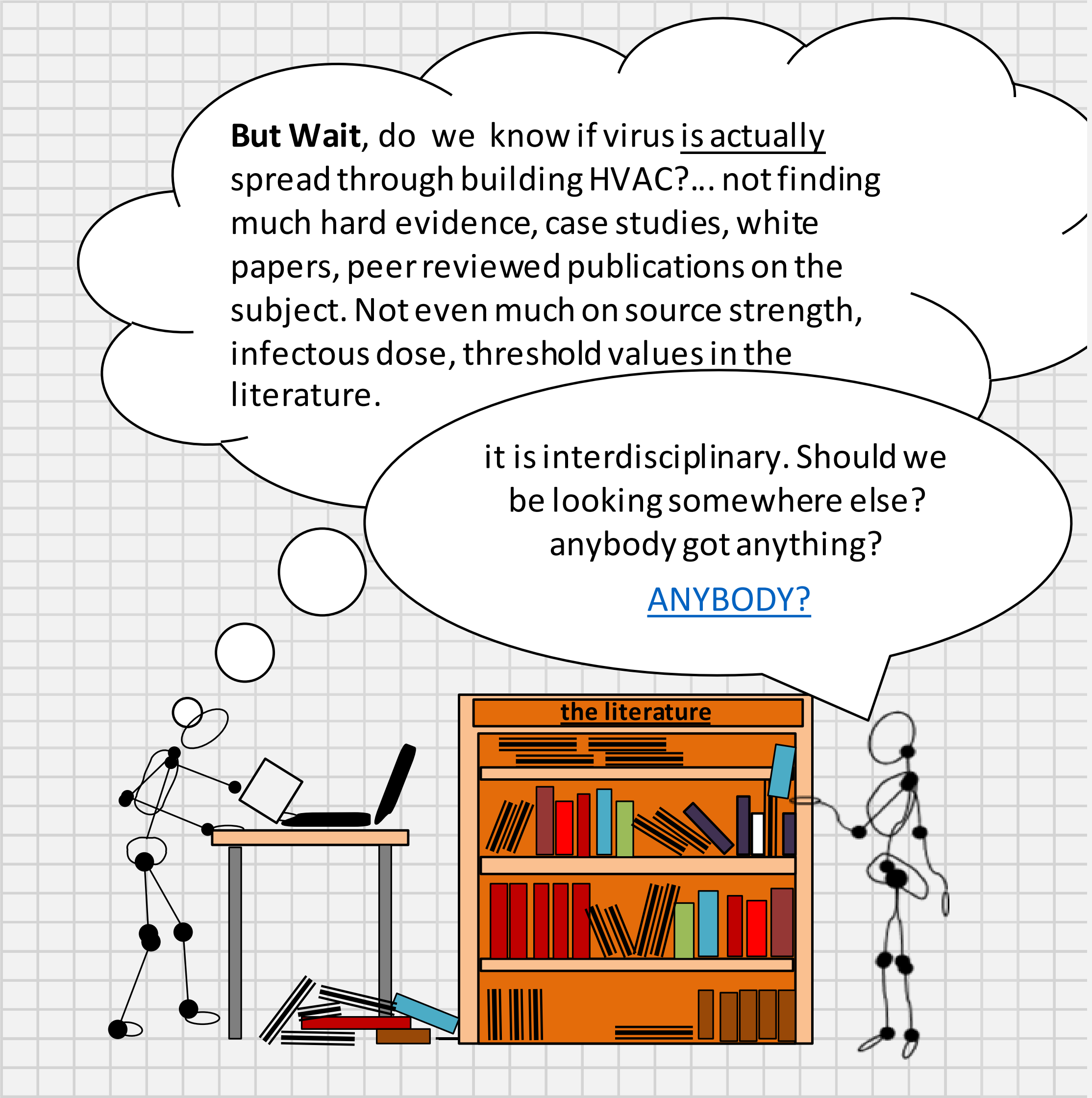
Control of contaminates generated within and circulated through indoor spaces is a common problem in HVAC design.
The physiology of people who occupy buildings is quite sensitive to a wide variety of stinks, spores, gases, fumes and particulates. Breathing some of these has serious medical implications, even at extremely low concentrations- or short exposure times.

HVAC designs intended for laboratories, hospitals and manufacturing have been highly successful controlling these risks. Indoor Air Quality standards, established through minimum ventilation rates and filtration efficiencies, have been a part of building codes for decades.



But priorities for buildings such as office, classrooms and assembly buildings also involve cost - lowest initial construction, renewal and replacement along with annual operation and maintenance, energy, carbon. Despite the HVAC designer's focus on initial cost, cumulative annual costs, over the building life cycle, can be many multiples higher.
Building energy use that represents 28% of total national energy consumption, a huge burden on global greenhouse gas emissions, is largely driven by HVAC systems. The power and thermal energy needed to create, and move, tempered ventilation air is often the single biggest energy demand in an office or classroom building. Figuring out ways to reduce building energy load while maintaining sufficient ventilation requirements is among the routine challenges faced by the HVAC designer.

24. A pause to reflect.



Is there any reason to suppose that airborne circulation of this virus is fundamentally different from other viruses or other contaminants that we routinely control under the category "Indoor Air Quality?" Probably not but there is little published proof.

Even William Blanfleth P.E., chair of ASHRAE's Epidemic Task Force recently acknowledged [the]"circumstantial case for aerosol transmission of COVID-19 seems strong, but Public Health Organizations have high standards of proof." The HVAC designer needs more than "circumstantial!" We need the proof! We need minimum infectivity concentration levels, time and limit values of exposure, life span of infectious aerosol. The HVAC designer sure hopes the science that determines these fundamental facts is underway, and data will be available soon.

In the absence of actual data, Henry is left to rely on 30 years of messing around with building airflows and speculates that yes, this infection can be transmitted through, or by, HVAC systems, and there is indeed a cause for concern as buildings are re-occupied.

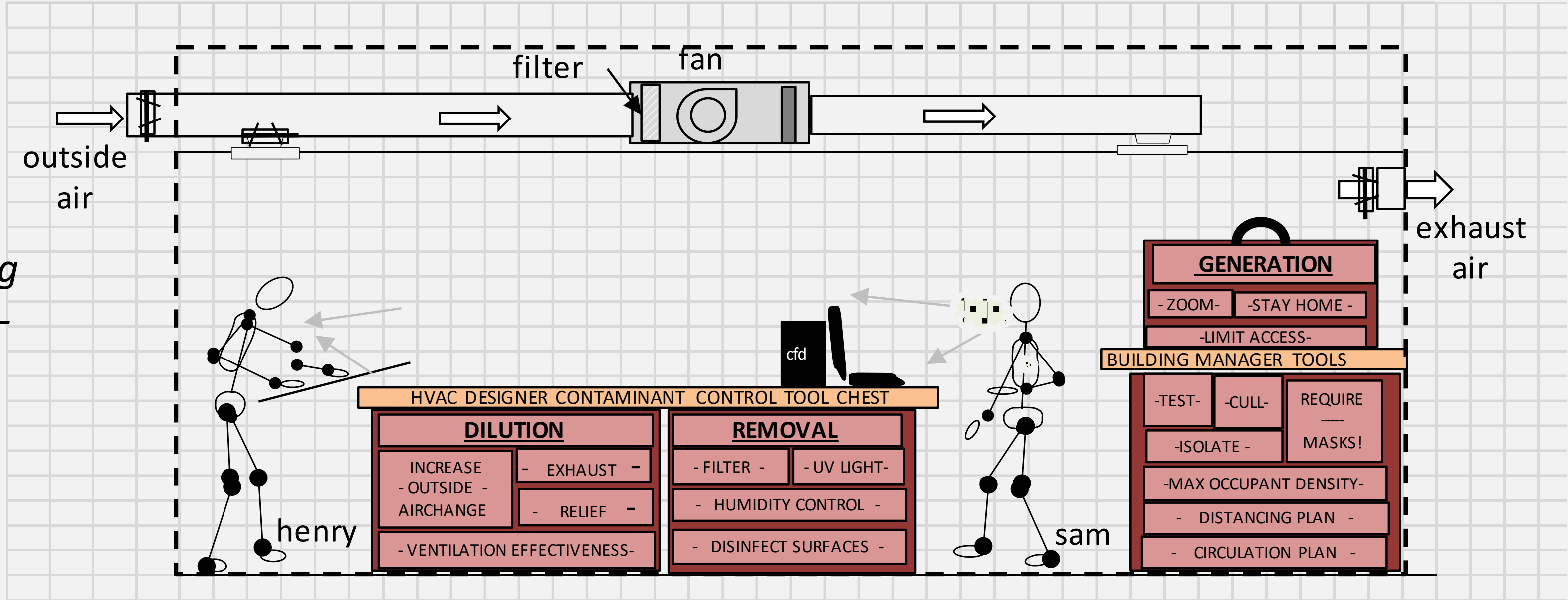
BREAKING NEWS 'A Smoking Gun': Infectious Coronavirus Retrieved From Hospital Air . . . . "unambiguous evidence that there is infectious virus in aerosols."

25. These are tool chests that can be used to control bulk concentration of contaminants in a building.

Primary Tools:
*1. Reduce **Generation** of contaminant*
***2. Remove** the contaminant from the airstream*
***3. Dilute** the concentration of contaminant*

*Controlling the **Generation** of a virus in a building is not typically the purview of the HVAC designer- It is accomplished through management, human behavior, building access, distancing, testing and masks.*

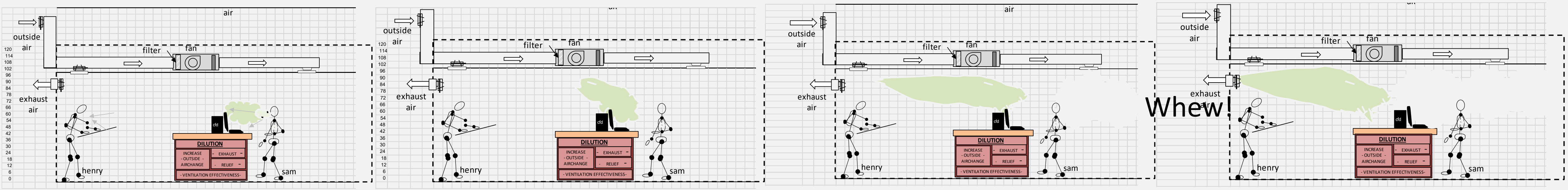
***Dilution** and **Removal** are HVAC design tools.*
Subsets within these tools include:
***Containing** contaminants within exhaust enclosures.*
*Arranging space functions and **pressurization** to promote one-way flow of contaminants from Clean Spaces to Dirty Spaces.*



Sam Spu sneezes Into the CFD computer!
Come on Sam-disinfect all those surfaces.

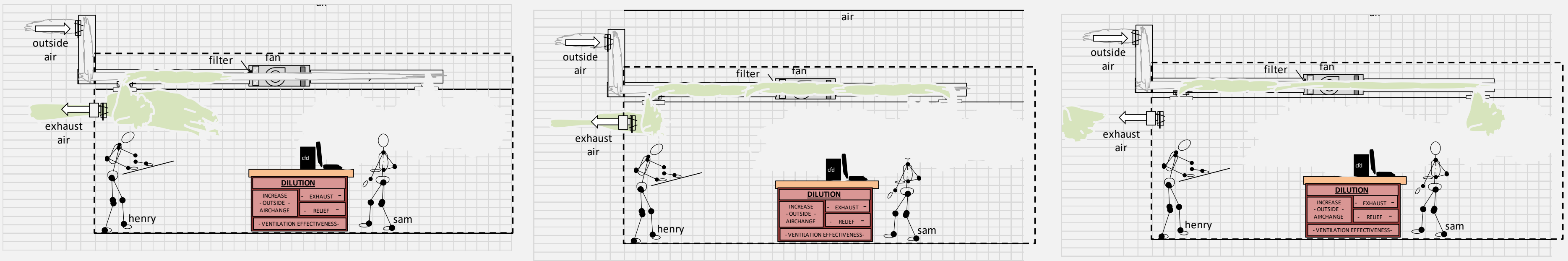
Less obvious - the reality that the air in a typical room does not behave as the uniform plug shown in our phone booth example. The speed, direction, location, and residence time of any individual air molecule is really quite complex.
CFD - Computational Fluid Dynamics is a tool increasingly used in HVAC design to understand and control room airflow dynamics.

26. Henry imagines a film strip in which we watch a plume of exhaled spew expand and move across a cross current induced by the HVAC. The magnitude, direction and speed of the result depend on many factors, including the difference between plume and room temperature, room humidity, HVAC airflow rate, velocity of the supply air jet, location of the exhaust grille, even configuration of the furniture in the room and rapid door operation. The dampers are set to only bring in and then supply 100% fresh clean air. Looks like Sam's sneeze is going to clear Henry's breathing zone. The infectious aerosol is being fully exhausted.



Below, the dampers are set to provide a mixture of outside and return air. In many cases where buildings were not designed for 100% ventilation, this will be a more realistic scenario. Some of the contents of the plume are purged but other contents recirculated.

Dilution controls concentration which depends on the ratio of the rate of exhaust to recirculation.



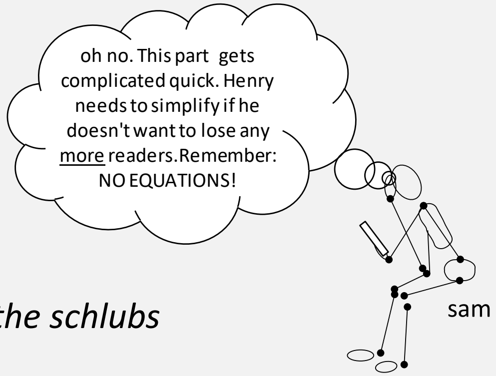
You get the idea, <u>adjusting the ratio of fresh to recirculation controls bulk viral load over time</u>. Presuming Sam doesn't sneeze again, the recirculating air will contain less and less of the original contaminant, eventually going to zero. Risk of infection is a function of the number of sources, amount of exposure time, and concentration.

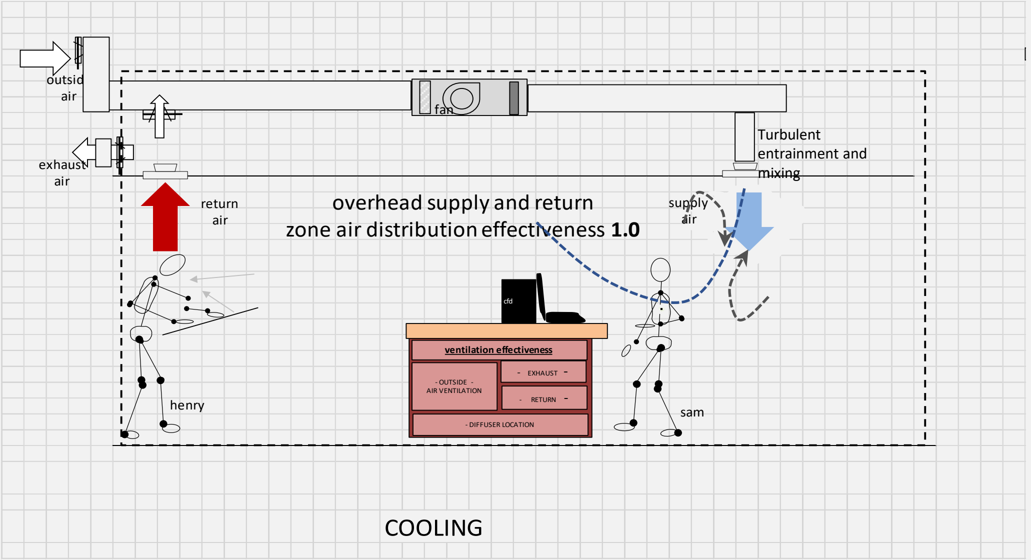
Kishor Khankari, Ph.D., Fellow ASHRAE is among an increasing number of experts in modeling the dynamics of 3-dimensional building airflow. [In a recent paper,] he demonstrates how sensitive contaminant concentration is to room layout, furniture and location of air devices. "Ventilation Effectiveness" is the general term for this.

27.

Ventilation effectiveness is the ratio of actual to ideal mixing in a ventilated room. It addresses the fact that air does not flow through the building as a uniform plug.

Q: What is the biggest difference between being inside and outside?
A: Recirculation
Q: If recirculation spreads virus, why not just blow all fresh air?
A1: System wasn't designed to do it. Louvers, coils, ducts too small.
A2. Cost way too much in energy in winter and summer. Boilers, chillers too small
Q: Why can't we just open the windows?
A: Might work in some places, at some parts of the day. Good for bosses in corner offices, not so good for the schlubs in the interior cube farms. Plus, nobody would be happy with the temperature control.

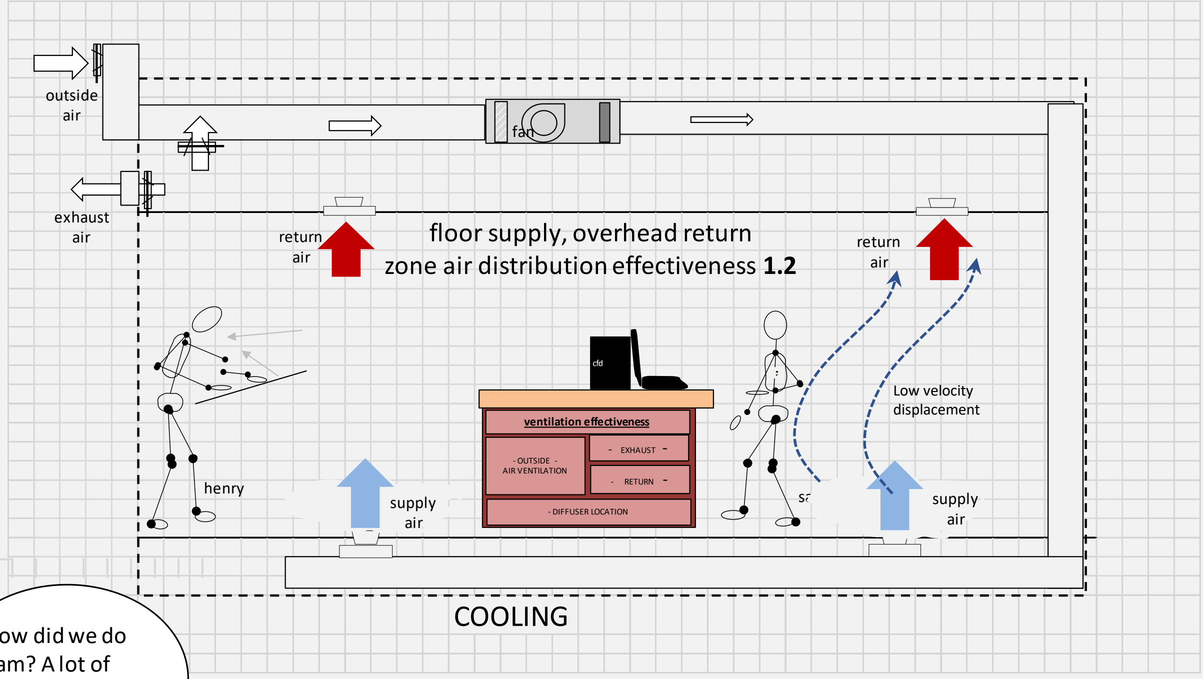


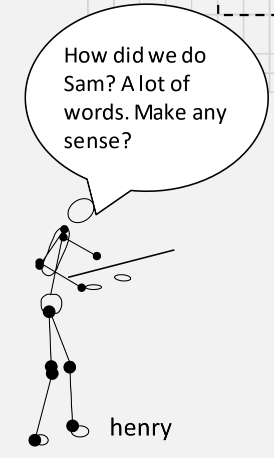


Building codes generally require HVAC designers use a formula, expressed by ASHRAE (under the daunting title of "Standard 62.1") to assure systems and components are sized to provide a sufficient quantity of fresh air to maintain a healthy building. The factors involved in this algebra are number of building occupants, the area that is conditioned, and a "ventilation effectiveness" term that relates to path the mixture of fresh and recirculated air takes through room to reach the breathing zones of the occupants. Some air distribution systems work better than others.

The graphic shows is a "conventional" overhead set up with turbulent supply diffusers and return grilles in the ceiling. The effectiveness factor has been given a rating of 1.0. Standard 62.1 includes a variety of other configurations for heating and cooling supply, return, outside air intake proximity to exhausts. The rating values become multiplying factors in an equation that determines the absolute minimum value of fresh outside air that must be designed into the system.

28. Another configuration, with the supply air more gently diffused at the floor level, flows vertically up, washing over the occupants to ceiling return. This has been found to be more effective in getting fresh air to people’s breathing zone, and, is given a value of 1.2 which, in the formula, credits the design with a 20% improvement in “effectiveness”. This then enables reduction in the magnitude of outside air, often offering substantial reduction in building energy consumption. A building designed this way can get some LEED points.



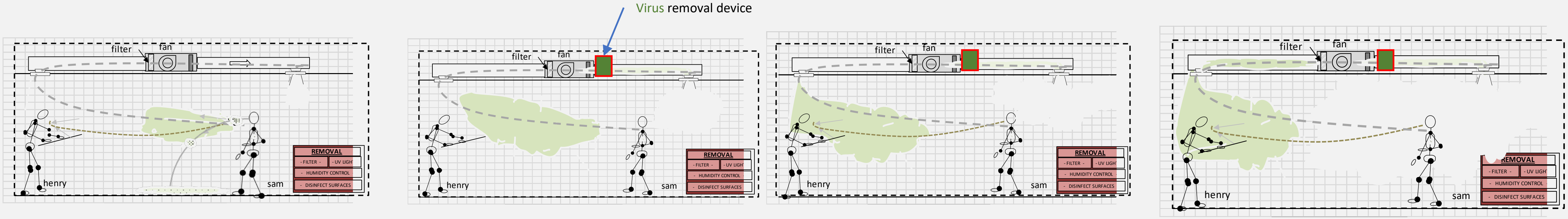


This method of assigning a factor that rates “Ventilation Effectiveness” based on simple rules is rudimentary.
CFD modeling provides much more insight into specific air distribution flows given the multitude of geometric and thermodynamic considerations that contribute to its performance. We <u>could</u> model and design every space, but generally <u>do not</u>. “HVAC Designer fees are way too high already !” They would say.

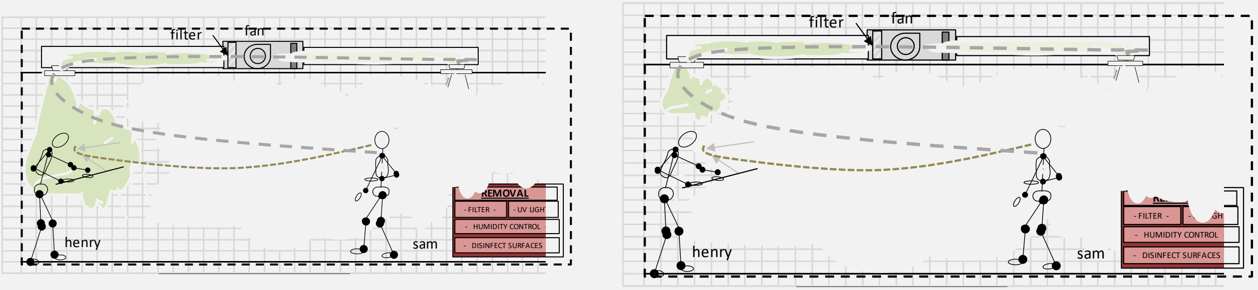
One last thing. Although we are compelled by code to design systems that meet minimum air requirements, we are increasing applying real time instrumentation with spaces to determine actual occupancy and/or instantaneous need for fresh air. Known as “Demand Based Ventilation,” room CO2 levels are continuously monitored, and the ratio of outside to recirculated air adjusted to maintain a constant space set point. Why is CO2 a good indicator of occupancy? Because 4% of what people routinely and reliably exhale is CO2. The more CO2 in the room, the more people, the more fresh air we need to provide. This is a clever way to prevent wasting the energy of over-ventilating under occupied spaces. A worthy goal prior to pandemic, but maybe no longer as high a priority.

29. Henry imagines another film strip scenario in which the magnitude, direction and speed of plume follows a different and possibly more dangerous path. The air distribution factors described above are different, and now the plume's remnants end right in Henry's breathing zone. Not good.

The first frame reinforces the continued need to wear a mask inside to prevent launching droplets that become aerosols.

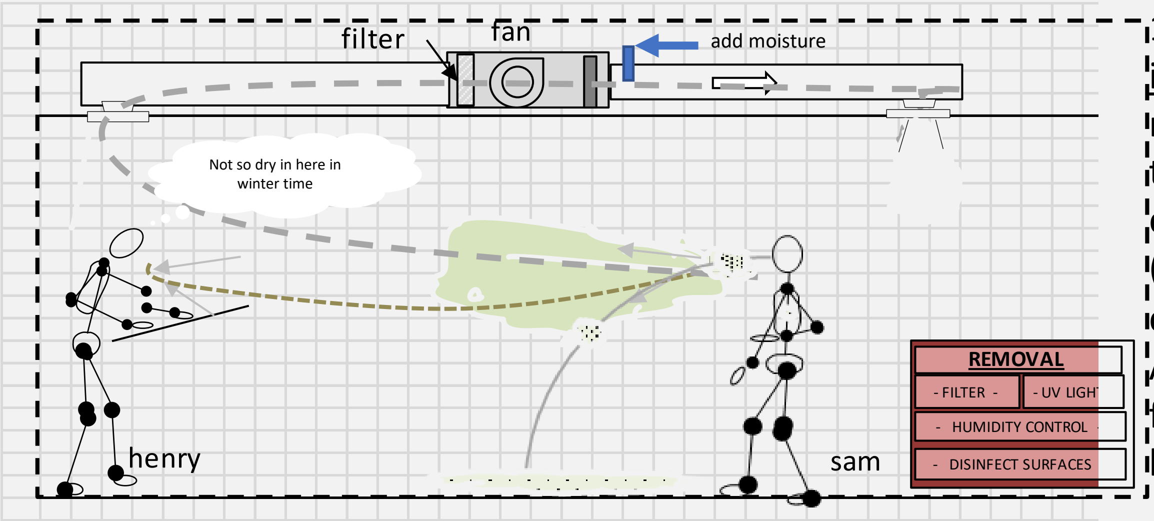


In this film strip we imagine a very effective virus **removal** device within the air handler. This device could be a large, high efficiency HEPA filter bank, bipolar ionizer, or perhaps some sort of UV light rack. Where will these approaches work and how well will they work? We plan to review the efficacy of several removal techniques, including those that are not within the HVAC system in subsequent postings.

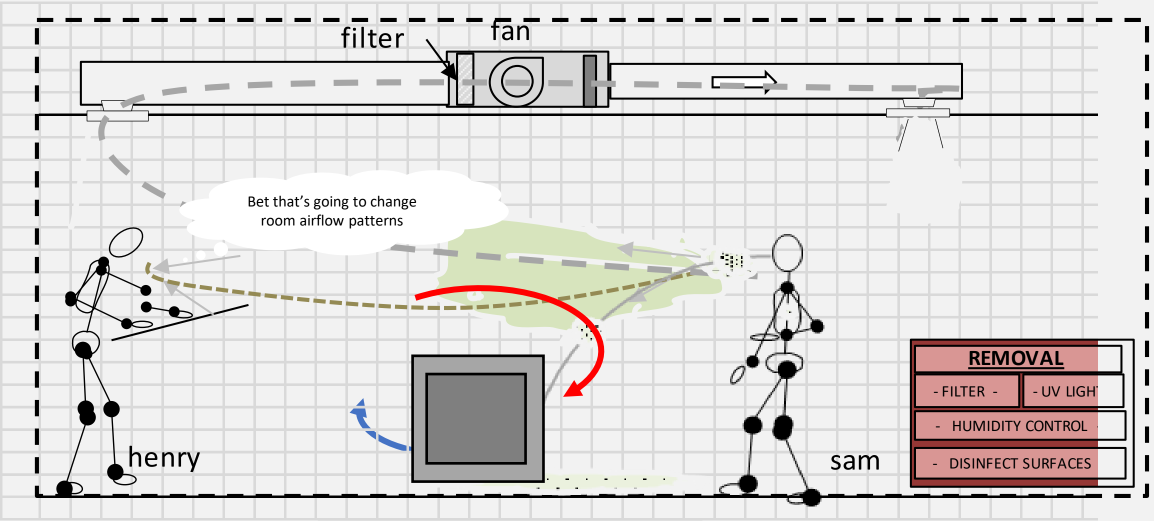


Our team uses a CFD platform in its HVAC design work and plans to include a few compelling videos in the next installment. As that team is currently finishing up actual project work for paying clients, you get to look at Henry's much less compelling 2-D Excel illustrations.

30. A few more comments on the first frame of the last film strip, which captures the moments just after Sam's unmasked sneeze.



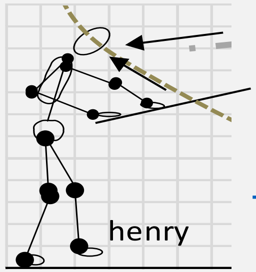
1. ASHRAE guidance suggests that rapid fallout of virus droplets can be increased and generation of aerosols reduced by maintaining the minimum space relative humidity greater than 40%. In healthcare settings this has demonstrated to be high enough to limit evaporation of the droplet wall thus maintaining the minimum droplet mass needed to fall (as predicted by Galileo). This reduces the problem of floating, hanging, drifting aerosols, and acts as a mechanism for **Removal** of a virus. At present this is one of the few actionable bits of technical guidance from ASHRAE. While it might be simple to implement and control humidification in some cases, it could be difficult and expensive in others.



2. There are a variety of techniques and technologies, some established, some emerging, that enable continuous disinfection, **Removal** of virus from room air, independent of the primary HVAC system. These could be stationary or mobile devices that are mounted in the ceiling or resting on the floor. Recirculating fan-filter units, humidifiers, electrostatic precipitators, bi-polar ionizers, UVC Germicidal Lamps - each has proven worth in disinfecting specific applications. Henry has yet to see sufficient evidence to validate that one or more of these approaches reduces the virus load outside its immediate area of influence to prove its worth. We need more data!

31. There could be more . . . Installment 4?

- 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.
- Introduction to CFD Modeling for Room Air Distribution
- 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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