We Need to Talk About Ventilation

How is it that six months into a respiratory pandemic, we are still doing so little to mitigate airborne transmission?

Zeynep Tufekci
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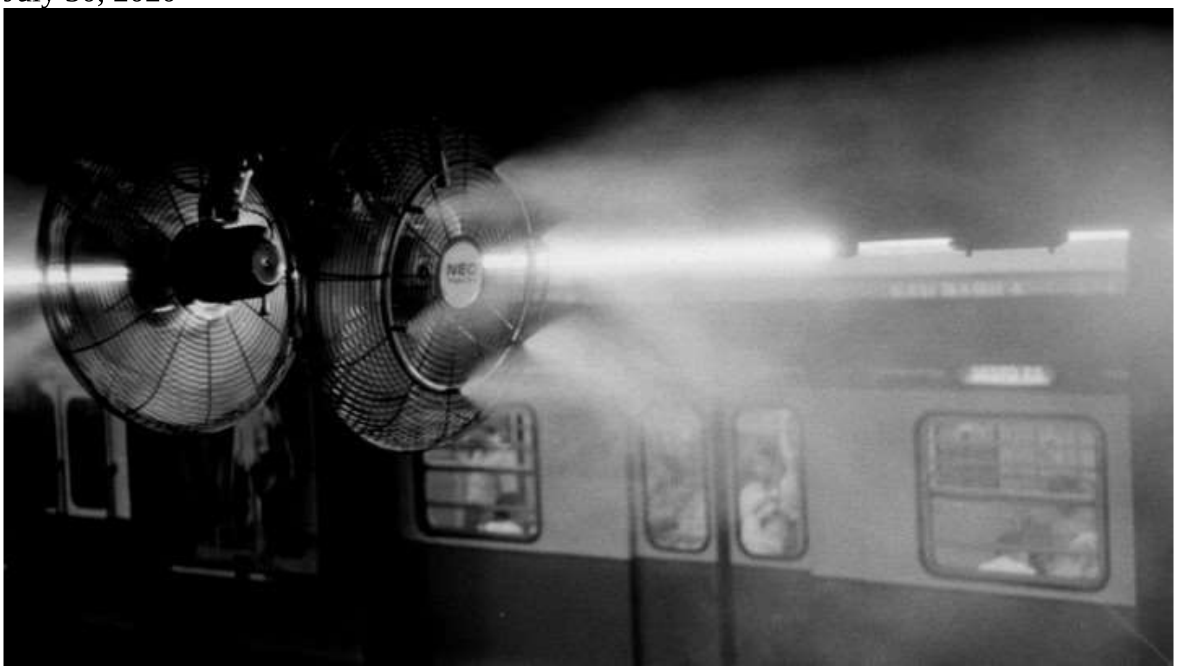

I recently took a drive-through COVID-19 test at the University of North Carolina. Everything was well organized and efficient: I was swabbed for 15 uncomfortable seconds and sent home with two pages of instructions on what to do if I were to test positive, and what precautions people living with or tending to COVID-19 patients should take. The instructions included many detailed sections devoted to preventing transmission via surfaces, and also went into great detail about laundry, disinfectants, and the exact proportions of bleach solutions I should use to wipe surfaces, and how.

My otherwise detailed instructions, however, included only a single sentence on “good ventilation”—a sentence with the potential to do some people more harm than good. I was advised to have “good air flow, such as from an air conditioner or an opened window, weather permitting.” But in certain cases, air-conditioning isn’t helpful. Jose-Luiz Jimenez, an air-quality professor at the University of Colorado, told me that some air conditioners can increase the chances of spreading infection in a household. Besides, “weather permitting” made it all seem insignificant, like an afterthought.

While waiting for my results, I checked the latest batch of announcements from companies trying to assure their customers that they were doing everything right. A major U.S. airline informed me how it was diligently sanitizing surfaces inside its planes and in terminals many times a day, without mentioning anything about the effectiveness of air circulation and filtering inside airplane cabins (pretty good, actually). A local business that operates in a somewhat cramped indoor space sent me an email about how it was "keeping clean and staying healthy," illustrated by 10 bottles of hand sanitizer without a word on ventilation—whether it was opening windows, employing upgraded filters in its HVAC systems, or using portable HEPA filters. It seems baffling that despite mounting evidence of its importance, we are stuck practicing hygiene theater—constantly deep cleaning everything—while not noticing the air we breathe.

How is it that six months into a respiratory pandemic, we still have so little guidance about this all-important variable, the very air we breathe?

The coronavirus reproduces in our upper and lower respiratory tracts, and is emitted when we breathe, talk, sing, cough, or sneeze. Figuring out how a pathogen can travel, and how far, under what conditions, and infect others—transmission—is no small deal, because that information enables us to figure out how to effectively combat the virus. For COVID-19, perhaps the most important dispute centers specifically on what proportion of what size droplets are emitted from infected people, and how infectious those droplets are, and how they travel. That the debate over the virus's modes of transmission is far from over is not a surprise. It's a novel pathogen. The Columbia University virologist Angela Rasmussen told me that, historically, it took centuries to understand how pathogens such as the plague, smallpox, and yellow fever were transmitted and how they worked. Even with modern science, there are still debates about how influenza, a common annual foe, is transmitted.

In particular, the size of infectious particles really matters, because that determines how they travel—are they big enough to be quickly pulled down by gravity or are they small enough to float around? Since the beginning of the pandemic, the World Health Organization has considered the primary mode of COVID-19 transmission to be respiratory droplets. These droplets are defined as particles bigger than 5 to 10 microns in diameter, and WHO guidelines say that once they are sprayed out of someone's mouth, they travel ballistically and fall to the ground within close range of the infected person. For the WHO, that range is about three feet; for the Centers for Disease Control and Prevention, which also considers droplets to be the primary mode of transmission, it's six feet. The dominance of a ballistic-droplet mode of transmission in this pandemic would mean that we should focus mostly on staying out of droplets' range, especially to prevent them from falling on our unprotected mouth, nose, and eyes—hence the social-distancing guidelines. It also would mean that keeping that distance would be *enough* to stay safe from an infected person, on the other side of a room for example. (Of course, our hands can still potentially pick them up from surfaces and bring them to our face, hence the importance of hand-washing.)

There is a big dispute in the scientific community, however, about both the size and the behavior of these particles, and the resolution of that question would change many recommendations about staying safe. Many scientists believe that the virus is emitted from our mouths also in much smaller particles, which are infectious but also tiny enough that they can remain suspended in the air, float around, be pushed by air currents, and accumulate in enclosed spaces—because of their small size, they are not as subject to gravity's downward pull. Don Milton, a medical doctor and an environmental-health professor at the University of Maryland, compares larger droplets "to the spray from a Windex dispenser" and the smaller, airborne particles (aerosols) "to the mist from an ultrasonic humidifier." Clearly, it's enough to merely step back—distance—to avoid the former, but distancing alone would not be enough to avoid breathing in the latter.

The disagreement got heated enough that earlier this month, hundreds of scientists around the world signed a letter, pleading with the WHO to acknowledge these smaller particles as an extra mode of transmission and to update its guidelines accordingly. Some experts I spoke with told me that they had been trying to convince the WHO to take the possibility of airborne transmission since March, and that the open letter was borne out of frustration about lack of progress. Signatories who study aerosols—the smaller, floating particles—including professor Linsey Marr of Virginia Tech and Jimenez, told me that they don't disagree with the idea that transmission at close range represents the most risk, as per the WHO and CDC guidelines. But they disagree that the dominance of close-contact transmission *implies* that ballistic trajectories or larger respiratory droplets are the overwhelming mode of transmission. In their view, even some portion of that close-contact transmission is likely due to aerosols, and many experts told me that they think even particles bigger than the WHO's definition of respiratory droplets (larger than 5-10 microns in diameter) can float for a bit. In response, the WHO published a scientific brief on July 9 acknowledging the possibility of airborne transmission, but still concluding that COVID-19 is "primarily transmitted" between people through respiratory droplets and touching, and that the question needs "further study."

Part of the difficulty with this discussion has been that the relevant experts, including infectious-disease specialists, epidemiologists, environmental and aerosol engineers, don't even agree on the terminology. The particles we emit from our mouths can be called droplets, microdroplets, droplet nuclei (particles that start out bigger but get smaller because of evaporation) or aerosols. There is no clear line between big and small particles and droplets and aerosols; it's a continuum with complex aerodynamics depending on the environment, and to make matters worse, the same word—like aerosol—sometimes means something different in each field. The terminological confusion led Milton to write a "Rosetta Stone" paper to try to clarify the terms across fields. For this article, I'll call the spray-borne particles that travel ballistically "droplets," and the ones that can float "aerosols" (regardless of what size the particles may be, as the key question is whether they can float and be pushed around by air—and that size cut-off remains disputed).

Plus, this debate has a long history: From the mid-19th century into the 20th century, infectious-disease specialists fought a long and hard-won battle against "miasma" theories of disease that posited that filth and noxious odors, instead of germs, were responsible for disease. In a seminal 1910 book, the public-health pioneer Charles Chapin distinguished "spray borne" diseases (WHO's droplets that maximally travel only a few feet) from "dust borne" ones—spread by aerosols, or airborne transmission. He concluded that most pathogens were either "spray-borne" or spread through contact, and worried that an over-reliance on "air-borne" theories would needlessly scare the public or cause them to neglect hand-washing. More than a century later, there are still echoes of those concerns.

There are also different kinds of "airborne" transmission—the term can sound scarier than reality and can become the basis for unnecessary scaremongering. For example, some airborne diseases, such as measles, will *definitely* spread to almost every corner of a house and can be expected to infect about 90 percent of susceptible people in the household. In the virus-panic movie *Outbreak*, when Dustin Hoffman's character exclaims, "It's airborne!" about Motaba, the film's fictional virus, he means that it will spread to every corner of the hospital through the vents. But not all airborne diseases are super-contagious (more on that in a bit), and, for the most part, the coronavirus does not behave like a super-infectious pathogen.

In multiple studies, researchers have found that COVID-19's secondary attack rate, the proportion of susceptible people that one sick person will infect in a circumscribed setting, such as a household or dormitory, can be as low as 10 to 20 percent. In fact, many experts I spoke with remarked that COVID-19 was less contagious than many other pathogens, except when it seemed to occasionally go wild in super-spreader events, infecting large numbers of people at once, across distances much greater than the droplet range of three to six feet. Those who argue that COVID-19 can spread through aerosol routes point to the prevalence and conditions of these super-spreader events as one of the most important pieces of evidence for airborne transmission.

Saskia Popescu, an infectious-disease epidemiologist, emphasized to me that we should not call these "super-spreaders," referring only to the people, but "super-spreader events," because they seem to occur in very particular settings—an important clue. People don't emit an equal amount of aerosols during every activity: Singing emits more than talking, which emits more than breathing. And some people could be super-emitters of aerosols. But that's not all. The super-spreader–event triad seems to rely on three V's: venue, ventilation, and vocalization. Most super-spreader events occur at an indoor venue, especially a poorly ventilated one (meaning air is not being exchanged, diluted, or filtered), where lots of people are talking, chanting, or singing. Some examples of where super-spreader events have taken place are restaurants, bars, clubs, choir practices, weddings, funerals, cruise ships, nursing homes, prisons, and meatpacking plants.

Strikingly, in one database of more than 1,200 super-spreader events, just one incident is classified as outdoor transmission, where a single person was infected outdoors by their jogging partner, and only 39 are classified as outdoor/indoor events, which doesn't mean that being outdoors played a role, but it couldn't be ruled out. The rest were all indoor events, and many involved dozens or hundreds of people at once. Other research points to the same result: Super-spreader events occur overwhelmingly in indoor environments where there are a lot of people.

Benjamin Cowling, the head of epidemiology and biostatistics at the University of Hong Kong School of Public Health, points to a case at a restaurant in Guangzhou where a yet asymptomatic COVID-19 patient infected nine other people, many of whom were sitting at other tables but were in the direct line of the air conditioner, which was blowing air from one end of the restaurant to the other. Tables right next to the patient's but not downwind did not have a single infected person, and closed-circuit camera videos from the day show that the people at the infected tables didn't interact with the patient at all. It was the air. Cowling's colleagues analyzed the fluid dynamics of that outbreak, showing that the air conditioner blew the air in one direction, where it hit a wall, recirculated back, and was pushed out again, basically trapping the unlucky tables downwind, with the infected air going "round and round and round," as Cowling described it to me.

In another super-spreader event, at a choir practice of 61 people in Skagit, Washington, a single patient caused 32 confirmed and 20 likely COVID-19 cases—almost everyone in the room. In another striking case, at a Korean call center, where people talk all day, 94 out of 216 people on one floor of the building were infected, with cases clustered on one side of the floor but some as far as 20 desks away from each other, with a few as far away as the opposite wall. Only three people on other floors were infected, despite the employees sharing a lobby and elevators, reinforcing that surfaces aren't efficient transmitters, but that shared air pockets can be, almost regardless of distance.

For these super-spreader events, Milton says you have to "really jump through hoops to argue that they were anything other than transmitted by air." But it's not only COVID-19's super-spreader events that are indoors. The rest of the pattern of spread of COVID-19 —when it is spreading slowly, in small numbers—is also overwhelmingly through indoor transmission. Milton told me that if those sprayed droplets were the primary means of transmission, we would expect to see more transmission outdoors, since the droplets are being ejected with some force and falling on people, but that doesn't seem to be the case. Even if sunlight, which can deactivate viruses, were dampening transmission outdoors, one would at least expect to see a lot more outdoor transmission than we are seeing now. Instead, epidemiologists are finding that this disease stalks us indoors.

There is also evidence from health-care settings. Hitoshi Oshitani, a virology professor at Tohoku University Graduate School of Medicine in Japan, told me that quarantine officers on the Diamond Princess cruise ship, who followed standard precautions against droplets and close contact, nonetheless got infected anyway. This was an important clue for Japanese scientists about the importance of aerosols. "Those were professionals," he said. For him, that meant that it was unlikely they slipped up, and more likely that the disease acted in ways they weren't prepared for. A recent (preprint) paper showed that health-care workers in the United Kingdom—where hospitals are older and ventilation measures are poorer—were getting sick at higher rates than those in the United States where many hospital buildings come with ventilation mitigation measures. And in a peer-reviewed paper just published in *Nature*, researchers reported finding viral RNA in more than half the air samples in a hospital, including outside patients' rooms and in the hallways. While it remains a question how infectious those particles may have been, Marr told me that it was significant that "100 percent of samples from the floor under the bed and all but one window ledge were positive for viral RNA, indicating that the virus was transported through the air and settled onto these surfaces."

However, to date, there is also no evidence of *truly* long-range transmission of COVID-19, or any pattern of spread like that of measles. Screaming "it's airborne!" can give the wrong impression to an already weary and panicked public, and that's one reason that some public-health specialists have been understandably wary of the term, sometimes even if they agreed aerosol transmission was possible. Cowling told me that it's better to call these "short-range aerosols," as that communicates the nature of the threat more accurately: Most of these particles are concentrated around the infected person, but, under the right circumstances, they can accumulate and get around.

All this has many practical consequences. As Marr, from Virginia Tech, says, if aerosols are crucial, we should focus as much on ventilation as we do on distancing, masks, and hand-washing, which every expert agrees are important. As the virologist Ryan McNamara of the University of North Carolina told me, all these protections stack on top of one another: The more tools we have to deploy against COVID-19, the better off we are. But, it's still important for the public to have the correct mental model of the reasoning behind all the mitigations, since even those agreed-upon protections don't all behave the same way under an aerosol regime.

For example, current WHO guidelines don't recommend masks indoors if a distance of one meter can be maintained. Similarly, the CDC makes scant reference to the distinction between indoor and outdoor transmission in its mask guidance, and recommends masks in public settings, "especially when other social distancing measures are difficult to maintain." However, an aerosol regime would suggest that distancing isn't as protective indoors as one would hope, especially since people eating and drinking tend to be talking while unmasked. (The CDC seems to recognize this when it recommends hosting gatherings outdoors, though it still officially stresses transmission through droplets).

Under an aerosol regime, we would have different rules for the indoors and the outdoors (especially since, in addition to the diluting power of air, sunlight quickly deactivates viruses.) We would mandate masks indoors regardless of distancing, but not necessarily outdoors. Marr told me that she wears her mask outdoors only if she's interacting with people, if she's in a crowd, or if she cannot maintain distance. Yet, in the United States, many locales are mandating masks indoors *and* outdoors under the same rules, forcing even the solitary person walking her dog to mask up. And there are places, such as Chicago, where beaches are closed because officials fear crowds, but indoor restaurants and gyms remain open with mild restrictions.

As another example, you may have seen the many televised indoor events where the audience members are sitting politely distanced and masked, listening to the speaker, who is the only unmasked person in the room. Jimenez, the aerosol expert, pointed out to me that this is completely backwards, because the person who needs to be masked the most is the *speaker*, not the listeners. If a single mask were available in the room, we'd put it on the speaker. This is especially important because cloth masks, while excellent at blocking droplets (especially before they evaporate and become smaller, thus more likely to be able to float), aren't as effective at keeping tinier aerosol particles out of the wearer's mouth and nose once they are floating around the room (though they do seem to help). We want to see the speaker's mouth, one might say, but that is a problem we can approach creatively—face shields that wrap around the head and seal around the neck, masks with transparent portions that can still filter, etc.—once we stop ignoring the problem. In fact, designing a high-filtration but transparent mask or face shield might be an important solution in classrooms as well, to help keep teachers safe.

Once we pay attention to airflow, many other risks look different. Dylan Morris, a doctoral candidate at Princeton and a co-author of the first paper to confirm that the virus could remain infectious in aerosolized form, under experimental conditions, showed me a clip of a group of people in a conga line, separated six feet apart by ropes. They were merrily dancing, everyone standing behind someone else, in their slipstream—exactly where you don't want to be, inhaling aerosol clouds from panting people. Similarly, Jimenez pointed out that, when a masked person is speaking, the least safe location might be beside them or behind them, where the aerosols can escape from the mask, though ordinarily, under a droplet regime, we would consider the risk to only be in front of them. The importance of aerosols may even help explain why the disease is now exploding in the southern United States, where people often go into air-conditioned spaces to avoid the sweltering heat.

Finally, all this would have implications for people around COVID-19 patients, especially in the community. In U.S. health-care settings, precautions against aerosols are usually already in place, partly because health-care workers undertake procedures—such as intubation—that generate aerosols even if a disease isn't very prone to creating them. (Most COVID-19 guidelines, including from the WHO and the CDC, from the beginning acknowledged aerosols to be a risk in health-care settings because of such procedures; the dispute has always been whether aerosol transmission occurs organically in everyday settings). However, in the community, accepting aerosol risks would mean that people around COVID-19 patients at home or anyone high-risk, such as the immunocompromised, should at least be provided with higher-grade masks such as N95s, which do a better job of keeping aerosols out.

There are two key mitigation strategies for countering poor ventilation and virus-laden aerosols indoors: We can dilute viral particles' presence by exchanging air in the room with air from outside (and thus lowering the dose, which matters for the possibility and the severity of infection) or we can remove viral particles from the air with filters.

Consider schools, perhaps the most fraught topic for millions. Classrooms are places of a lot of talking; children are not going to be perfect at social distancing; and the more people in a room, the more opportunities for aerosols to accumulate if the ventilation is poor. Most of these ventilation issues are addressable, sometimes by free or inexpensive methods, and sometimes by costly investments in infrastructure that should be a national priority.

Last week, I walked around the public elementary school in my neighborhood while thinking about what we could do if we took aerosol transmission more seriously. It's a single-story building, all the classrooms have windows, some have doors that open directly to the outside, and many have a cement patio right outside. Teaching could move outdoors, at least some of the time, the way it did during the 1918 pandemic. Moreover, even when indoors or during rainy days, opening the doors and windows would greatly improve air circulation inside, especially if classrooms had fans at the windows that pushed air out.

When windows cannot be opened, classrooms could run portable HEPA filters, which are capable of trapping viruses this small, and which sell for as little as a few hundred dollars. Marr advises schools to measure airflow rates in each classroom, upgrade filters in the HVAC system to MERV 13 or higher (these are air filter grades), and aspire to meet or exceed ASHRAE (the professional society that provides HVAC guidance and standards) standards. Jimenez told me that many building-wide air-conditioning systems have a setting for how much air they take in from outside, and that it is usually minimized to be energy-efficient. During a pandemic, saving lives is more important than saving energy, so schools could, when the setting exists, crank it up to dilute the air (Jimenez told me that Shelly Miller, a fellow professor at the University of Colorado specializing in indoor air quality, persuaded the university to do just that.)

Jimenez also wondered why the National Guard hadn't been deployed to set up tent schools (not sealed, but letting air in like an outdoor wedding canopy) around the country, and why the U.S. hadn't set up the mass production of HEPA filters for every classroom and essential indoor space. Instead, one air-quality expert reported, teachers who wanted to buy portable HEPA filters were being told that they weren't allowed to, because the CDC wasn't recommending them. It is still difficult to get Clorox wipes in my supermarket, but I went online to check, and there is no shortage of portable HEPA filters. There is no run on them.

Some countries have already bucked the trend of ignoring short-range aerosols. Oshitani told me that in Japan, researchers took short-range aerosol transmission seriously from the start, and focused on the few transmission events that spread the disease to large numbers of people at once. Cowling, of Hong Kong University, told me the same thing: He considers short-range aerosols and super-spreader events to be key to the spread of COVID-19. Japan was expected to fail by many, as it implemented an unconventional response, bucking WHO guidelines, eschewing widespread testing, and forcing few formal lockdowns. However, Japan masked up early, focused on super-spreader events (a strategy it calls "cluster busting"), and, crucially, trained its public to focus on avoiding the three C's—closed spaces, crowded places, and close conversations. In other words, exactly the places where airborne transmission and aerosols could pose a risk. The Japanese were advised not to talk on the subway, where windows were kept open. Oshitani said they also developed guidelines that included the importance of ventilation in many different settings, such as bars, restaurants, and gyms. Six months later, despite having some of the earliest outbreaks, ultradense cities, and one of the oldest populations in the world, Japan has had about 1,000 COVID-19 deaths total—which is how many the United States often has in a single day. Hong Kong, a similarly dense and subway-dependent city, has had only 24 deaths.

To be clear, the science concerning aerosols isn't settled, which is acknowledged by the signatories of the letter to the WHO urging recognition and mitigation of possible aerosol risks. Rasmussen, the Columbia virologist, could easily rattle off many things she'd like to know about airborne transmission: how much infectious virus is in a given droplet, if some people shed a lot more of the virus than others, or, at what point in their infection, if the virus is more concentrated in the droplet nuclei and what constitutes an infectious dose. But facing a pandemic, we have to act with imperfect information. The letter writers stress that "we must address every potentially important pathway to slow the spread of COVID-19," even if evidence is incomplete, especially since some of the measures are as simple as opening a window and moving outdoors. This is especially crucial because mitigations stack: The more we have available, the more effective they become.

In this period when we don't have all the answers, much is at stake. My COVID-19 test was negative, so I didn't need to worry about that, but I wonder about the alternate world, where we take aerosols seriously, had I tested positive, I would have been sent home with firm instructions on opening windows, a loaner HEPA filter, N95 masks for my housemates, and strong warnings not to assume that staying six feet away from me was enough.

Marr told me that she "sheepishly" switched her elementary- and middle-school-age children to a private school because she was able to make a case with the school to take "good ventilation" seriously, in addition to wearing masks and social distancing. Not every school will have such resources, but maybe providing those resources is exactly what we should aspire to for all schools. If the signatories of the letter to the WHO are correct, then adding ventilation to our mitigation stack is exactly what we should focus on, doing everything necessary ranging from the more expensive upgrades to our air-quality infrastructure to opening the windows that are right within our reach.

Zeynep Tufekci is a contributing writer at The Atlantic and an associate professor at the University of North Carolina. She studies the interaction between digital technology, artificial intelligence, and society.