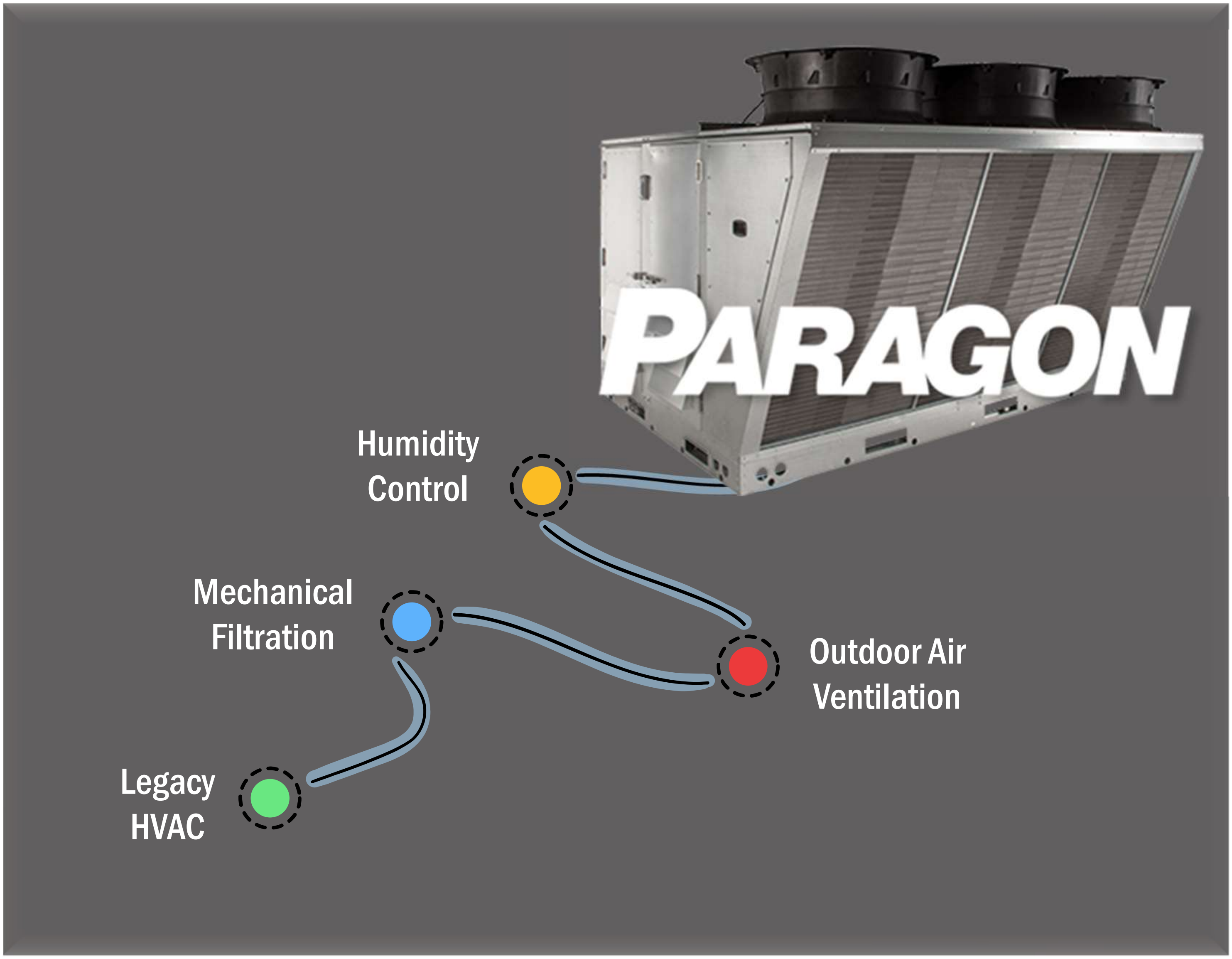

Transforming the HVAC Industry into Healthy, Safe & Comfortable Buildings

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Executive Summary

The average American spends 90% of his time indoors, a place where pollutant concentrations are often two to five times higher than outside (EPA, 1987). In fact, these concentrations have only risen in the past decades as we strive for air-tight, energy-efficient buildings. Realizing now the importance of clean indoor air, the industry has placed more focus on indoor air quality (IAQ). By definition, IAQ is the type and concentration of indoor air contaminants.

Indoor air quality affects us more than one might imagine. Poor IAQ can lead to:

1. Irritation of the eyes, nose, and throat

2. Headaches, dizziness, and fatigue

3. Respiratory diseases, heart disease, and cancer

These symptoms are the product of Sick Building Syndrome (SBS), though non-chronic symptoms often disappear after leaving the building (ASHRAE, n.d.). Researchers estimate conservatively that the economic benefit of improving IAQ in U.S. offices is more than $60 billion annually (Fisk, et al., 2011). These benefits, primarily better productivity and reduced health costs, *far* exceed what building owners would have spent on additional energy and construction costs. In return, employees have better comfort, health, well-being, learning outcomes, and work performance (ASHRAE, 2020). Therefore, it is in a company's best interest to provide their employees with clean indoor air.

Naturally, the next question is "How can we improve indoor air quality?". ASHRAE points to three avenues:

1. Source control

2. Ventilation

3. Air cleaning

Source control means designing HVAC systems around temperature and moisture targets that reduce the likelihood of mold and airborne contaminants. Ventilation refers to the percentage of outdoor air (OA) introduced into the building. As one can imagine, higher rates of OA dilute contaminant concentrations. Lastly, air cleaning uses technology and/or filters to remove pollutants.

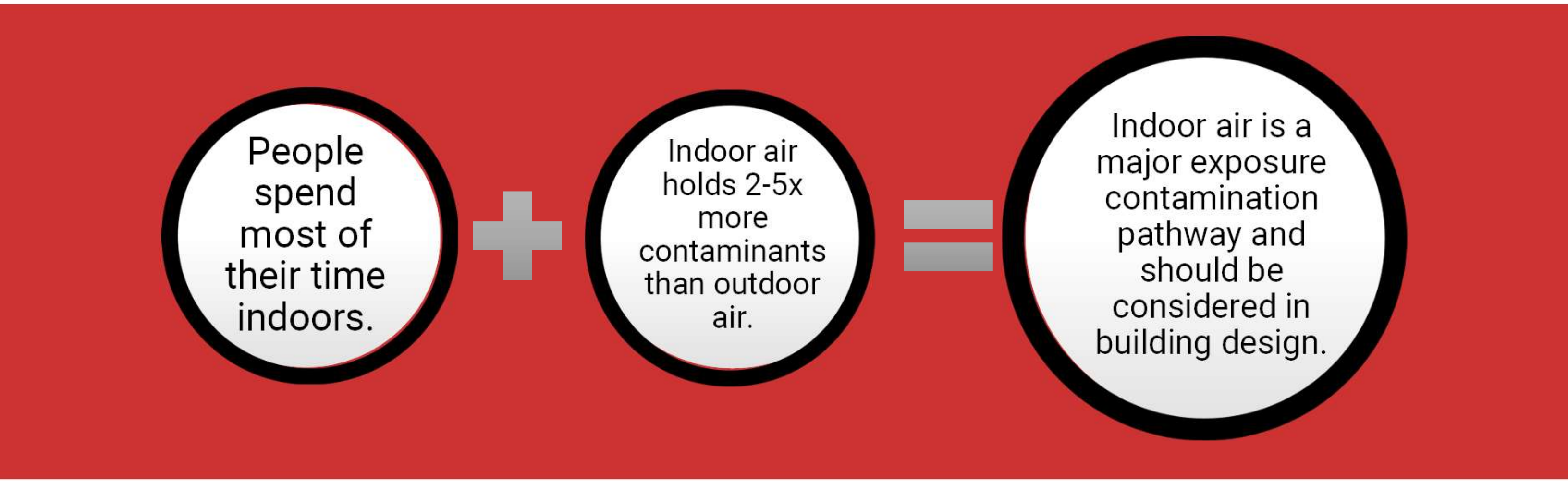
CaptiveAire, an industry leader in HVAC and kitchen ventilation, sees clean indoor air as a necessity. Its products are designed and tested with indoor air quality at the forefront, with the goal of exceeding standards set by ASHRAE 62.1, the consensus U.S. *minimum* ventilation standard. The following white paper shares CaptiveAire's approach to IAQ and the science behind their stance.

Indoor Air Quality

What is it? & Why is it important?

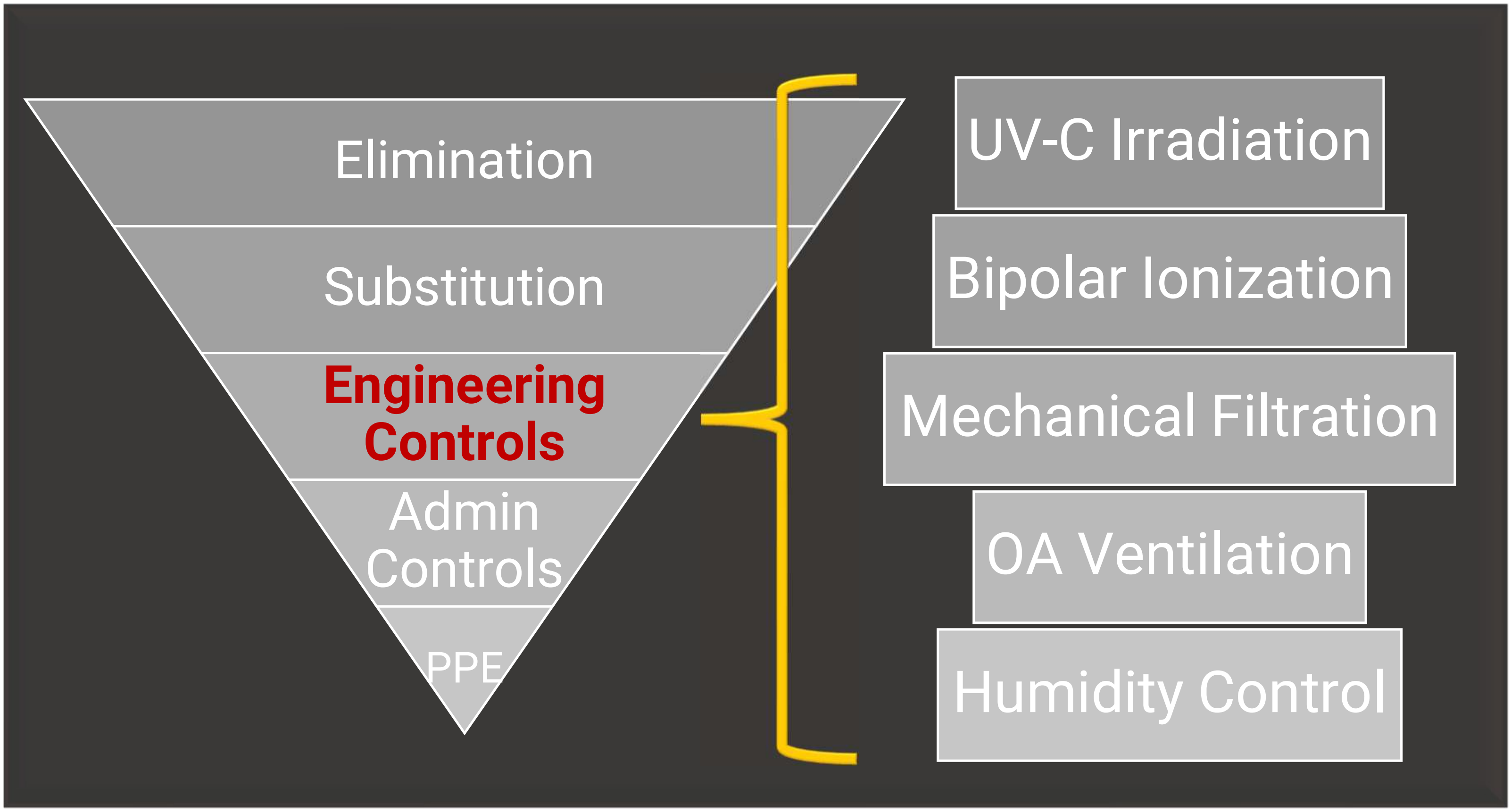
As mentioned earlier, indoor air quality is the type and concentration of pollutants in indoor air. Contaminants include particulate matter (PM), volatile organic compounds (VOCs), odors, allergens, and pathogens like viruses, bacteria, and mold spores. When present, they all contribute to poor indoor air quality. As they build up, occupants of buildings with poor IAQ suffer from Sick Building Syndrome. Symptoms include nausea, fatigue, headaches, and respiratory problems (ASHRAE, n.d.). Taken together, these symptoms decrease productivity, drive away customers, and increase medical costs for employers, making IAQ far more than a health concern. Improved IAQ is a clear benefit for occupants' well-being, but it is *also* in a company's best economic interest to supply clean indoor air for its workers.

Improving Indoor Air Quality



You don't have to look far to improve indoor air quality. The best place to start is with your HVAC system. While other avenues exist, changes to HVAC are both practical and efficient. See the pyramid below for other strategies.

There are five common practices to improve IAQ via HVAC. These include UVC germicidal irradiation, bipolar ionization, mechanical filtration, outdoor air ventilation, and relative humidity control.



UV-C Germicidal Irradiation

The ultraviolet spectrum can be divided into three categories: UV-A, UV-B, and UV-C (Albers, 2022). UV-A and UV-B are what reach the earth's surface, causing our skin to tan and burn. UV-C, however, does not reach earth's surface, which is fortunate because it's extremely damaging to our cell's DNA and RNA! That said, UV-C is powerful when it comes to killing certain germs and airborne contaminants. By replicating that wavelength, we can irradiate the germs on surfaces. On the downside, as it pertains to IAQ, UV-C has limited practical application within forced air systems, as the airflow (CFM) rates through HVAC systems are too high and the velocities too fast for the UV-C rays to be effective (Figure 1). Like how one quickly runs their hand over a flame without getting burned, the air and germs in an HVAC system move past the UV-C bulbs too fast to be effectively disabled because of low residence time. UV-C also requires energy for operation and has a high initial cost.

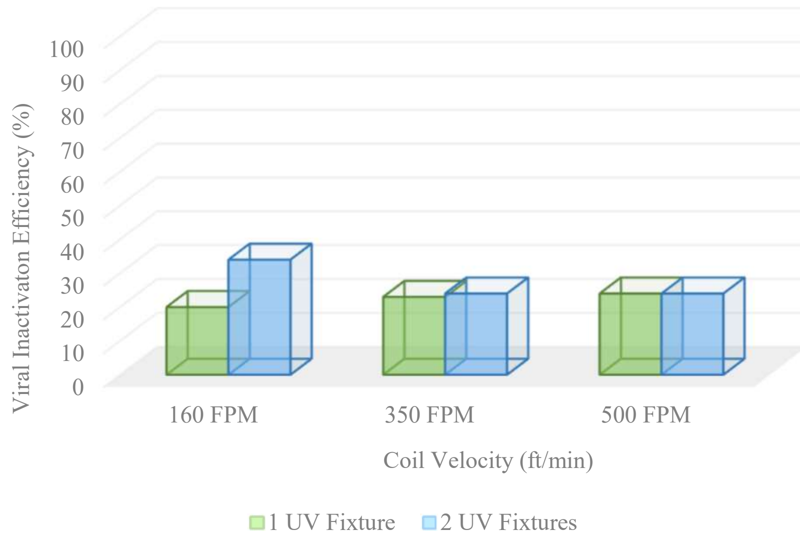


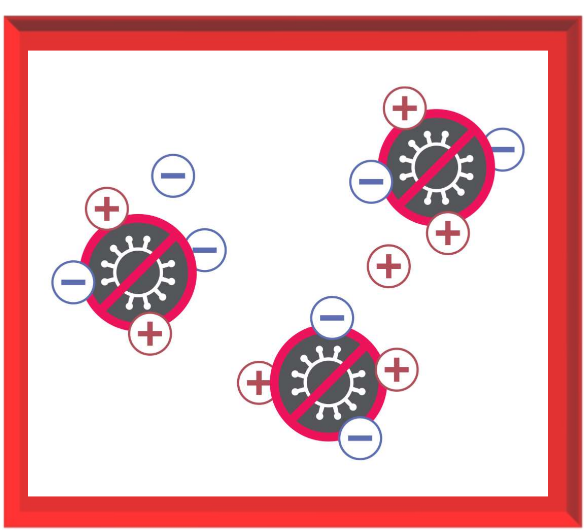
Figure 1. Viral Inactivation Efficiency vs. Airflow Rate through Duct

Lastly, one must be vigilant when working with UV-C bulbs, since their wavelengths will permanently damage our cells. UV-C can also produce unwanted by-products with other surfaces exposed for long durations, where long-term health impacts are not fully understood.

Bipolar Ionization

Residence time: the duration for which a substance of interest stays in a system

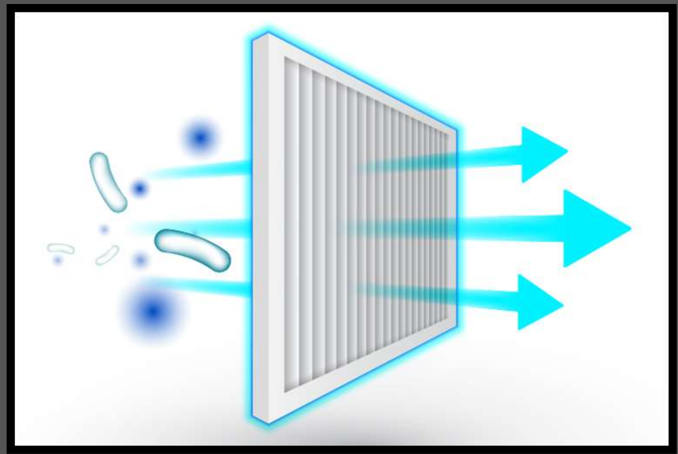
Bipolar ions are positively and negatively charged molecules. They're made when air passes through an electronic device that splits up water vapor molecules (Albers, 2022). The result is ions that act like magnets. These magnets can attract airborne contaminants. Once enough have been trapped, their particles are more likely to be caught by a downstream air filter. The positive and negative ions can also stick to germs. In that case, the ions rid germs of their hydrogen, thereby killing the germ.



Bipolar ionization is also under current evaluation for its odor and VOC removal properties. On the downside, certain air ionizers produce ozone as a byproduct, a well-known airway constrictor to our lungs. Ionization also poses hurdles with residence time. Since the ions react in 60 seconds or less, some HVAC systems don't meet the required residence time for proper treatment of contaminants in the space (Albers, 2022). Similar to UV-C, it's also common for broken systems to go unnoticed, a frequent occurrence with the added controls.

Mechanical Filtration

Mechanical filtration via air filters, typically MERV or HEPA rated, can trap nearly all airborne contaminants down to the viral level. They are usually built with several fiber mats, arranged to capture a variety of particle sizes. Once a contaminant contacts the fibers, it undergoes interception, impact, and diffusion (Albers, 2022). Downsides of mechanical filtration are an increase in static pressure and the need for regular filter replacement, both adding costs to the system.



Ventilation with Outside Air

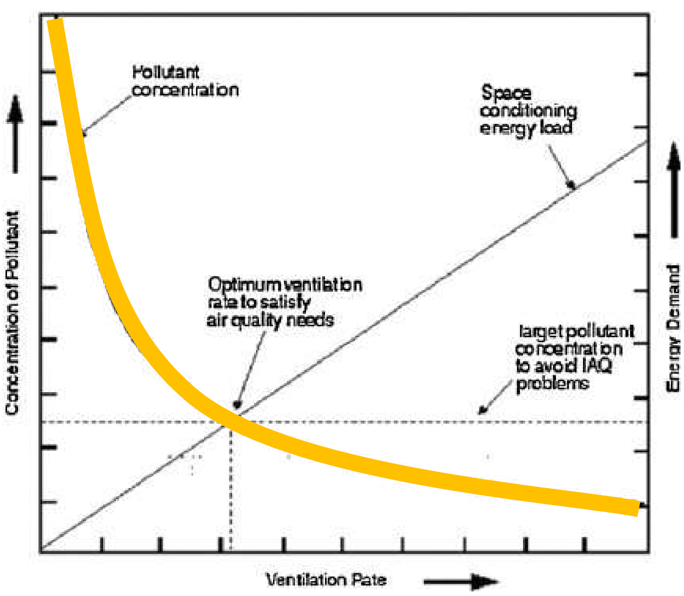


Figure 2. Pollutant concentration decreases as outdoor air ventilation increases (ResearchGate).

While ASHRAE dictates the *minimum* rate of outside air into a building, that rate can be increased during the design phase of a building by selecting equipment capable of handling higher ventilation loads. Due to advancements in technology, modern rooftop HVAC units with built-in OA capabilities called DOAS (dedicated outdoor air system) units now afford engineers the opportunity to provide higher levels of ventilation. They draw in outside air but temper it to ideal conditions before its release into the building. This yields filtered air at desirable temperatures and humidity. **Bringing in fresh, outside air also diffuses and dilutes contaminants that have built up inside a building (Figure 2).** While supplying clean air, DOAS units simultaneously exhaust stale air from low quality areas like bathrooms and kitchens, thereby removing the most pollutants.

Economizers, devices on traditional HVAC equipment, provide extra ventilation when outdoor conditions are favorable, however this is only a small portion of the year (less than 5%). Relying on economizers is not a consistent approach to adequate ventilation.

Ventilation often works off a desired OA percentage or indoor carbon dioxide (CO_2) levels. Utilizing a CO_2 detection process to control ventilation is known as Demand Controlled Ventilation (DCV). Introducing outside air is almost always beneficial unless you're in a heavy pollution zone. In that case, higher MERV or HEPA filtration may be justified.

Humidity Control

Spread of Airborne Contaminants < **40 - 60% RH** < **Mold Growth**

Relative humidity in a building is a strong determinant for contamination. Ideally, buildings hold 40% to 60% relative humidity. Below 40%, the transmission of airborne germs greatly increases. Anything above 60% supports the growth of mold. See the chart below for the connection between humidity and health. It derives from Sterling's 1986 paper, titled "Indirect Health Effects of Relative Humidity in Indoor Environments" (Arundel, et al., 1986, Figure 3).

HVAC systems can remove moisture from the air through cooling, as cold air cannot hold as much moisture. To add moisture, on the other hand, often requires a humidifier in the HVAC system or supply duct. Since this is not a common feature in most HVAC units, buildings tend to rely on latent (moisture) loads produced naturally by occupants for humidification.

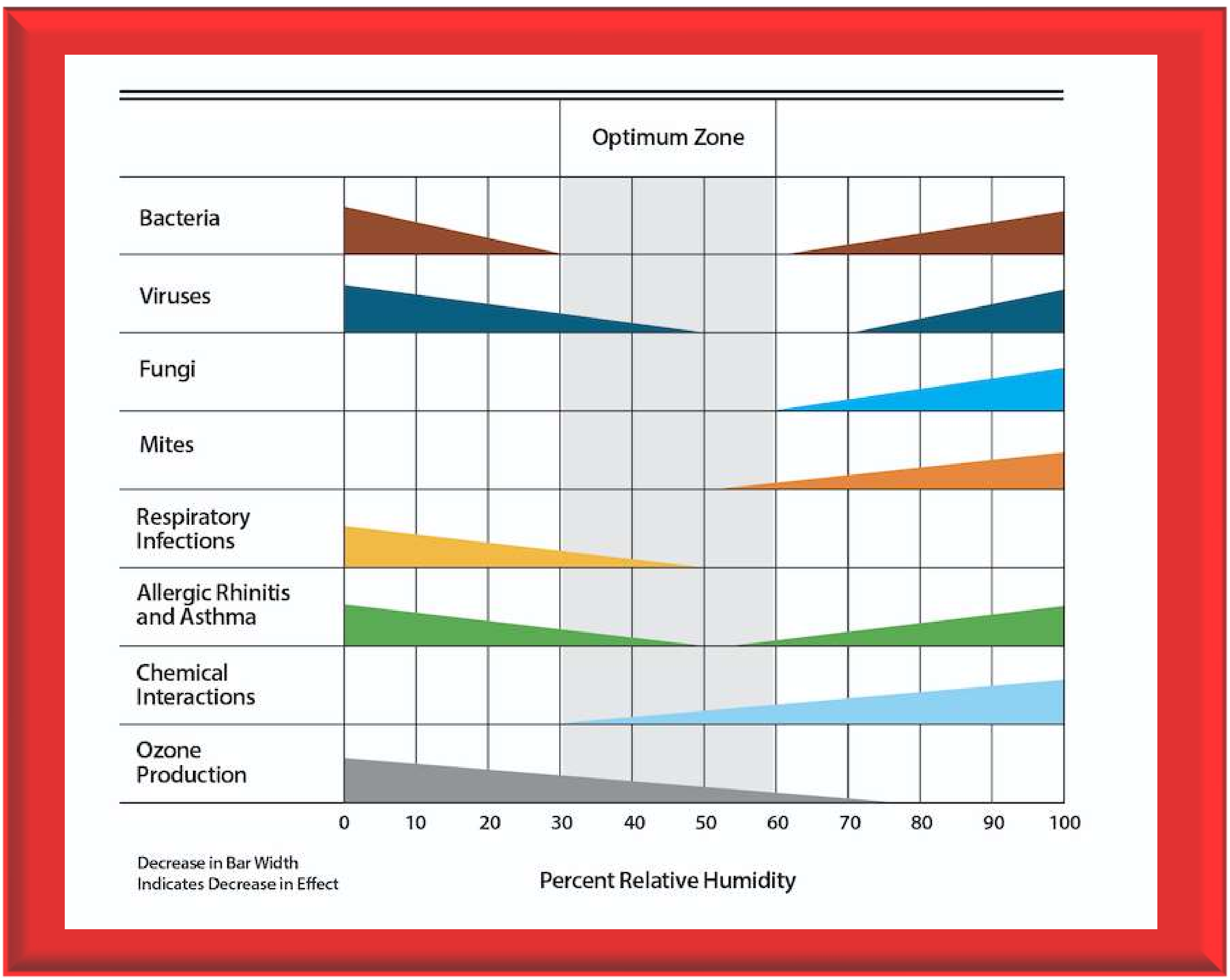
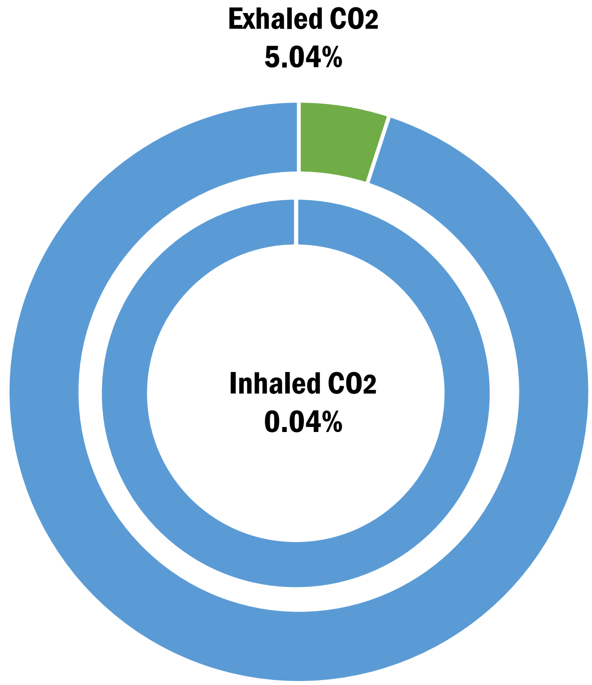
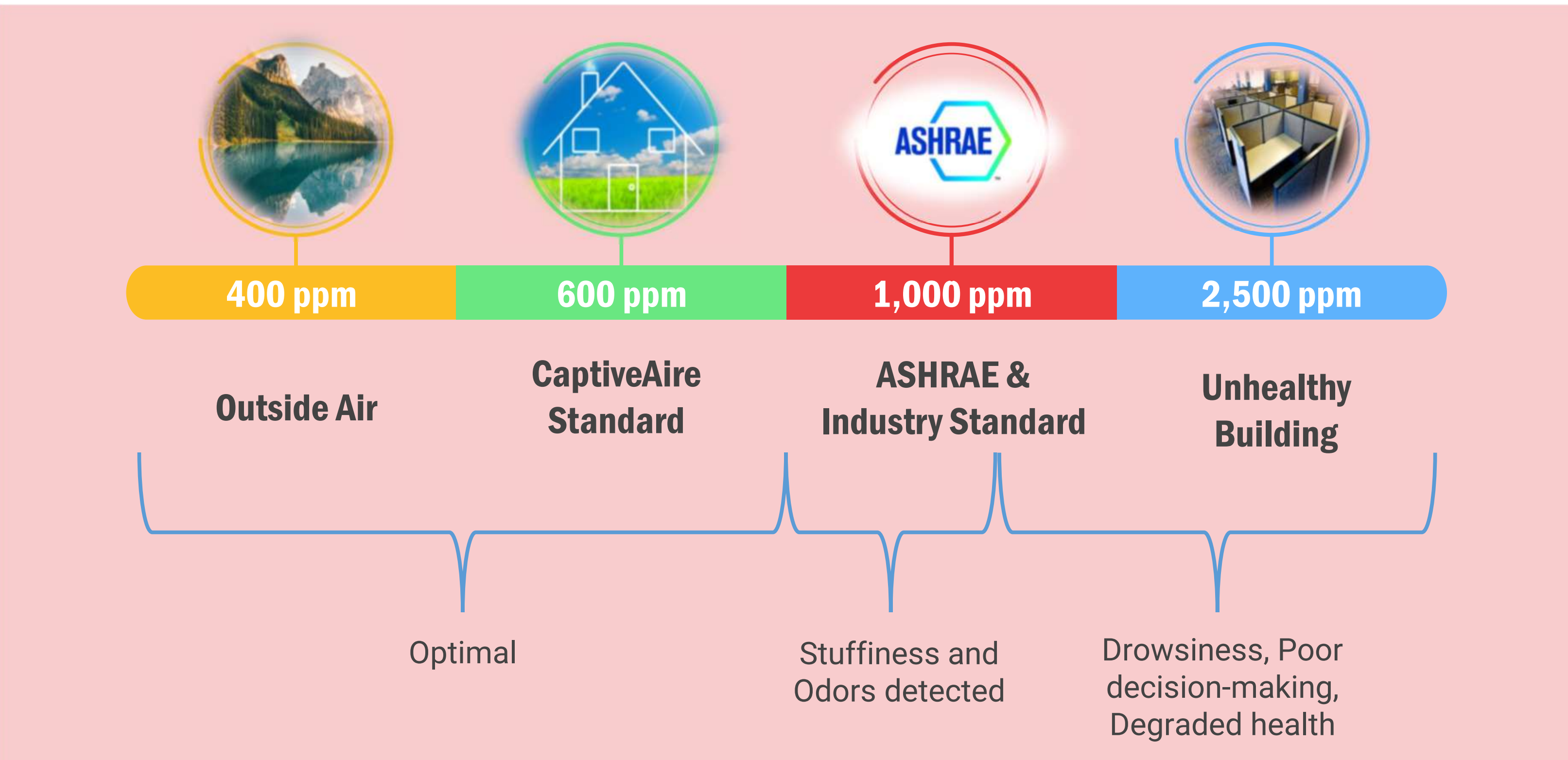


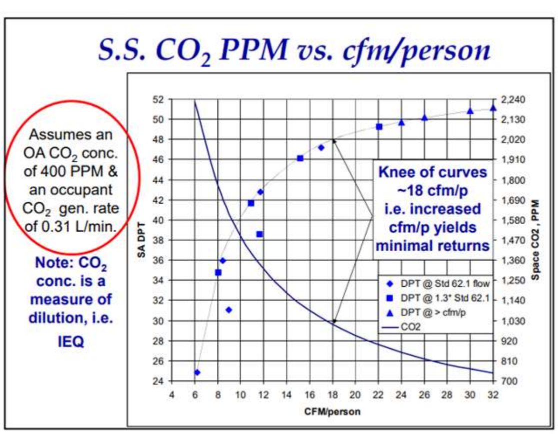
Figure 3. The Effects of Humidity on Contaminant Existence and Propagation

Carbon Dioxide

How we feel inside a building relies heavily on its carbon dioxide concentration. For reference, carbon dioxide makes up 0.04% of our outside air. This is about 400 ppm (parts per million). Indoors, though, we experience much higher levels of CO_2, sometimes up to 5,000 ppm, just from people exhaling. Therefore, if we don't bring in enough outside air, we welcome Sick Building Syndrome. After all, higher CO_2 levels typically mean more people are in a space, creating higher chances for viral and bacterial transmission. The figure below shows what happens at different CO_2 levels, and why CaptiveAire holds itself to a higher standard than ASHRAE and industry.



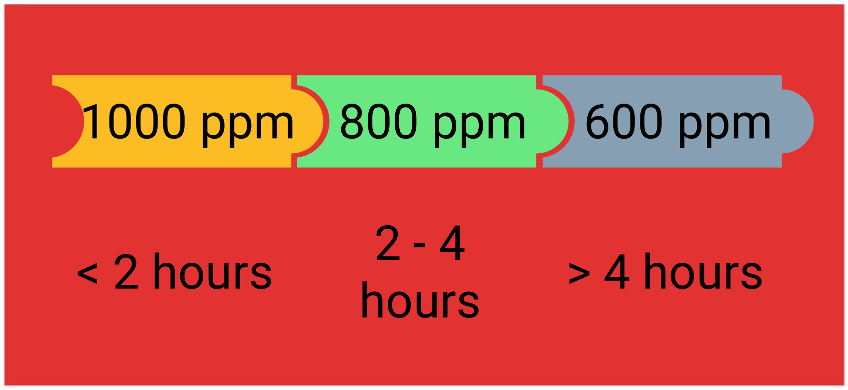




Dr. Mumma, a Professor Emeritus at Penn State University, demonstrated that CO_2 concentrations decrease exponentially as ventilation increases. Dr. Mumma recommends increasing ventilation 30% above ASHRAE 62.1 minimums. However, to obtain CO_2 levels below 1,000 ppm, even higher levels of OA may be required. (Mumma, 2017).

CO_2 Exposure

Adverse health effects, lower productivity, and decreased cognitive function depend not only on the amount of CO_2 in a room, but how long one is in the room itself. While 1,000 ppm is the typical standard, its adverse effects set in after just a short exposure. Because of this, CaptiveAire has chosen a CO_2 standard of 600 ppm, considered healthy for sustained exposure.



While CO_2 may not be a direct proxy for airborne pollutants, it *is* a proxy for outdoor air ventilation (ASHRAE, 2022). This common misconception for CO_2 as a pollutant proxy is often made because the Wells-Riley equation, used to track airborne transmission, assumes unlikely parameters. These include steady-state conditions, universal infection rates, and no differences between pathogens.

However, HVAC systems with outdoor air capabilities can still decrease your exposure to airborne pollutants. This is because DOAS (dedicated outdoor air systems) exchange and dilute indoor air, giving contaminants less time to ruminate or propagate.

Technology	What is it?	Support from Industry	Support from CaptiveAire	Why?
UVGI	UV-C light inactivates germs by mutating DNA	✓	✗	Inactivates contaminants but does not eliminate them. Requires prolonged exposure; exposure harmful to humans
Bipolar Ionization	Produces +/- ions that attach to germs	✓	✗	Can produce ozone and requires longer residence times.
Mechanical Filtration	Filters out particulates with MERV or HEPA	✓	✓	Highest capture rate with the least residence time.
Outdoor Air Ventilation	Increasing OA% beyond the min. set by ASHRAE	✓	✓	OAV provides heliosanitized air for optimal ppm levels.
Humidity Control	Keeping RH between 40-60%	✓	✓	Prevents mold growth and the spread of airborne contaminants.

Figure 4. IAQ Technology and its support from Industry vs. CaptiveAire

CaptiveAire vs. Industry

While industry promotes UV-C, bipolar ionization, and economizers, CaptiveAire takes a different approach. After third party testing, CaptiveAire confirmed that the best way to achieve optimal IAQ is through mechanical filtration, OA ventilation, and moisture control. We aim to provide the simplest solution that provides fresh air *and* ensures the best comfort possible. See the chart above for a summary of industry vs. CaptiveAire standards (Figure 4).

After extensive testing, done by LMS Technologies in Minnesota, we concluded the following (LMS Technologies, 2021):

1. UV-C and bipolar ionization technology should not be used in roof top units due to high cost, insufficient residence time, and unknown health effects.
2. MERV 13 filters should be the minimum filter requirement in DOAS and roof top units.
3. Increasing air changes per hour (ACH) is the easiest way to reduce viral concentrations quickly. Exceeding ASHRAE 62.1 minimums is recommended for maintaining employee health and productivity.

IAQ is about more than just occupant health. It's an economic battle as well. When buildings have bad indoor air quality, their occupants are less productive, disadvantaged learners, and experience adverse health symptoms. As a result, companies reactively spend more money on healthcare expenses, sick leave, and lost productivity. The better solution is a proactive one. That's why CaptiveAire is committed to designing HVAC and kitchen ventilation systems with exceptional air quality in mind. After ample research, CaptiveAire found that the best buildings achieve optimal IAQ through mechanical filtration, OA ventilation, and humidity control. CaptiveAire's Paragon HVAC combines all three. For more information on how Paragon fits into your next building, visit their website.

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