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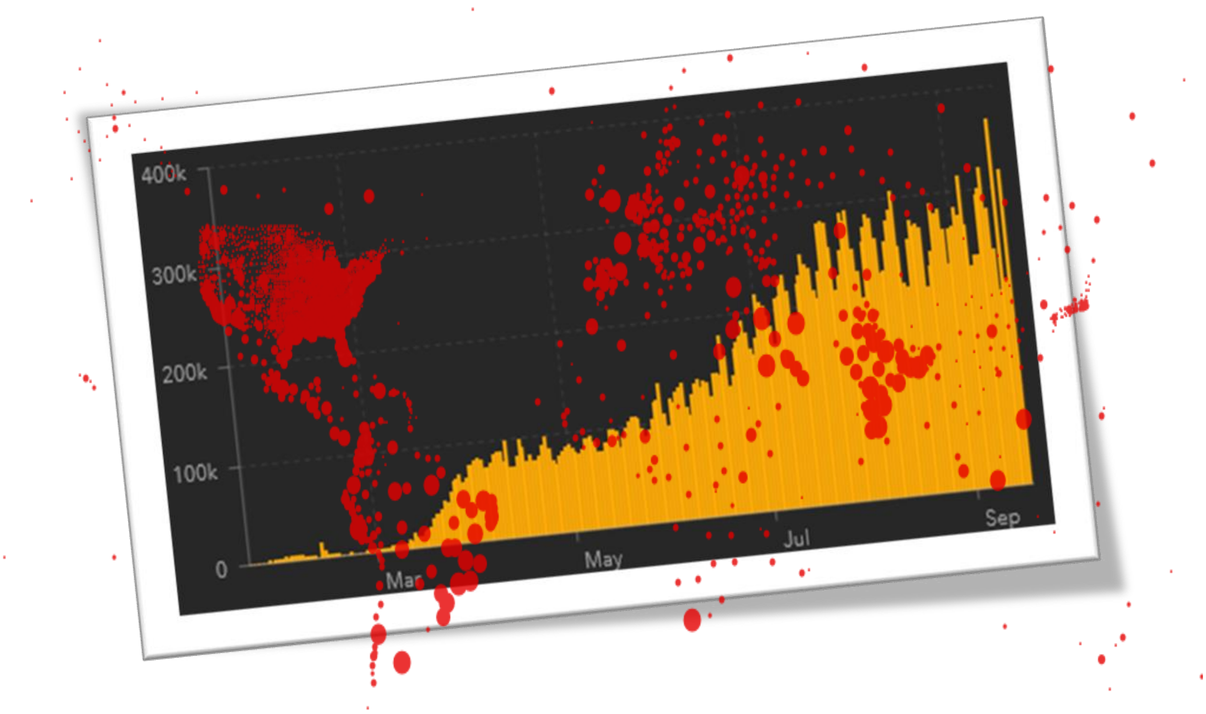
Killing COVID-19 in Indoor Air



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[Graphics adapted from Johns Hopkins University data: https://coronavirus.jhu.edu/map.html]

Air Hygiene and Managing COVID Risks

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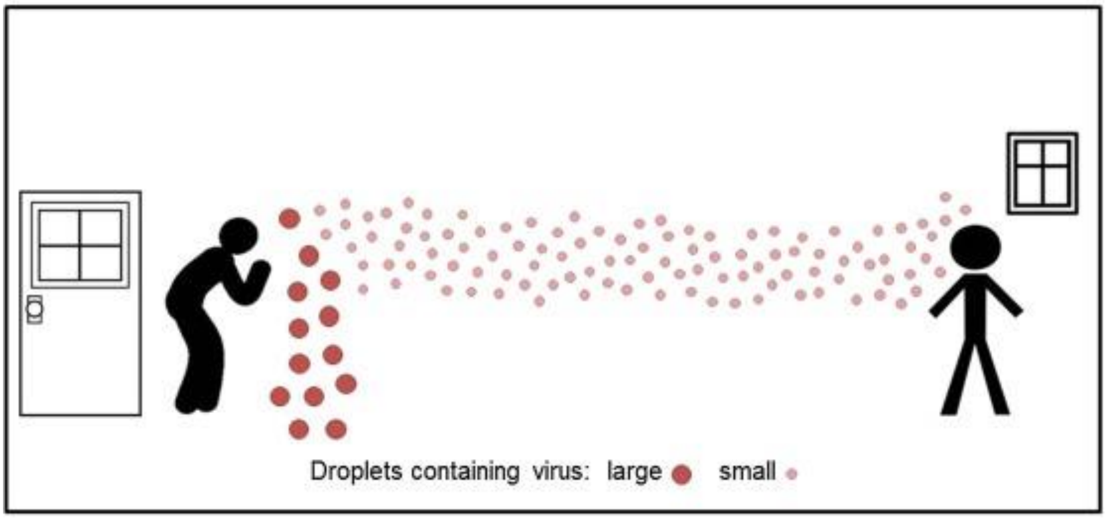
1. Why is air hygiene important?

On average each of us respires about six litres of air per minute. We do it without thinking, thanks to our autonomic nervous system. But the apparent simplicity of the action conceals the elaborate biology and physics involved. Our lungs are highly evolved gas exchange mechanisms, which spread incoming air over about 50 square metres of cell surface, to absorb oxygen and release carbon dioxide. That huge area of respiratory epithelium contains thin, damp, highly vascularized cell layers which are ideal for gas exchange. They are also a perfect front door for infectious agents such as viruses, bacteria, and fungi.

Airborne diseases have probably been around since the first air-breathing land animals evolved hundreds of millions of years ago. In healthy people, our complex and adaptable immune system deals with most infectious agents before they can cause symptoms. However, those who are older or who have underlying health issues are more susceptible to infectious diseases. There are some perennial problems, such as tuberculosis and influenza, which still cause widespread disease and death even though they have co-existed with humans for millennia. For new diseases, which often cross over from animals, the immune system is starting with a blank page. That is why we have no innate immunity to COVID-19, and why it has taken such a toll and remains such a threat to heath

There are typically two routes of airborne infection. The first is short-range and relies on relatively large droplets of infected fluid passing from one person to another. Hence why viruses have evolved to cause coughs and sneezes, to help them spread better between hosts. The droplets tend to settle out of the air quite quickly, so someone further away will not be as exposed as someone close to the infected person. Hence the "social distancing" recommendations for COVID-19. Initially, it was thought to be spread mostly by droplets.

The second mechanism requires the infectious agent to become "aerosolized" or "airborne". This means that it can float in much smaller droplets, present in normal exhaled breath. These can persist in the air for some time and drift much further away from the host. Initially, there was incomplete evidence that COVID-19 was airborne. However, it is now clear that the virus can spread long distances and can persist in the air for some time (https://doi.org/10.1136/bmj.m3206, https://doi.org/10.1093/cid/ciaa939). This is in common with influenza, for example, and may explain the high infection rates and prevalence of asymptomatic transmission.



Small droplets persist in air (Source: https://doi.org/10.1093/cid/ciaa939)

Therefore, keeping the air that we breathe as clean as possible is a good way to reduce COVID-19 transmission. Like all preventive measures, it cannot solve the problem on its own, but clean air means lower infection risk.

2. How to clean the air?

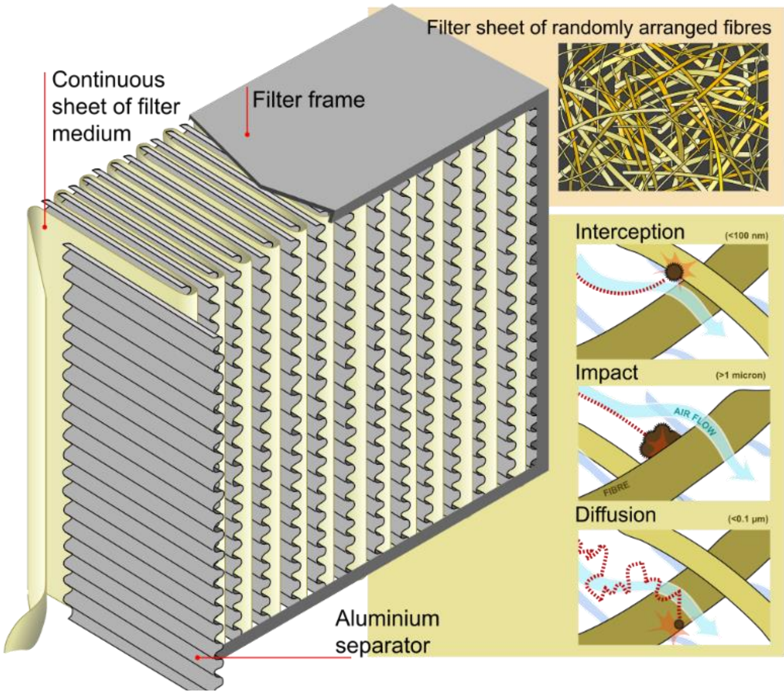
One approach is to let gravity do its work. If the infectious droplets are heavier than air, they will eventually settle out and can be cleaned from surfaces using chemical techniques. If only large particles are infectious then this might be practical, but fully airborne infection takes a long time to dissipate. Some COVID-19 hygiene protocols, especially those involving medical or dental aerosol-generating procedures (AGPs) require the area to be completely vacated and left for an hour or more before re-use. This gravity-based mitigation seems cheap and easy but has severe economic implications for businesses. Dentists using this approach can only work at less than 50% capacity for AGP patients, with obvious effects on income.

A key challenge in sterilization is to balance efficacy with practicality and running costs. Some techniques are ideal for small, high value, critical use items but not cost-effective for cleaning enough air for a large group of people to breathe. Remember, humans need six litres per minute each. Any device for widespread air cleaning needs to be fast, and inexpensive on a cost-per-litre basis.

Heat and radiation are two of the more common approaches for solid items. For example, many medical items are sterilized using superheated pressurized steam or gamma radiation. Both techniques involve large, expensive machinery, but for treating relatively small amounts of solid material, and where absolute sterility is vital, they are well suited. For surface disinfection of larger areas, chemicals are often used instead. These can be very effective if used properly, hence the focus on surface cleaning to contain COVID-19, especially in shared areas. However, chemical disinfection of air is less practical. Ozone treatment and ionization are also used for cleaning and sterilization, but they also have their problems and are typically used in closed systems.

The most tested methods for cleaning air in large volumes are filtration and ultraviolet light.

3. HEPA filtration



Source: Wikipedia

Air filtration techniques involve passing air through a fine-grained substrate which removes solids and particles but allows the constituent gases to pass through. This can be as simple as a gauze trap for lint and hair, as used in many domestic appliances. To remove smaller particles, high efficiency particulate air (HEPA) filters are used. HEPA systems can be very effective and the highest-rated systems can reduce particle density to one million times less than normal room air.

The grade of filter determines the size of particle retained by the substrate, and at what efficiency. But there is a trade-off between retention efficiency and air flow. Very fine-grained filters create a barrier to rapid air movement, known as back pressure, which can be problematic for high volume applications.

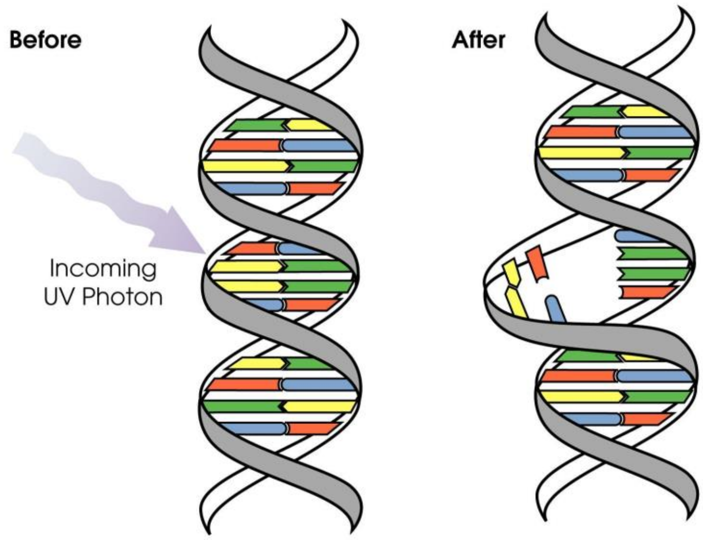
Typically, the highest grade of filtration is only used in critical areas such as medical operating theatres, semi-conductor fabrication plants, etc. For most applications, a slightly lower grade filter is sufficient, especially when used with other techniques. We chose HEPA13, a widely accepted grade for cleaning air in public applications.

4. How does ultraviolet light work against viruses and bacteria?

Sunlight contains a spectrum of light that humans can directly experience, ranging from infrared (heat) through the visible range to ultraviolet (sunburn). It has probably long been used to help heal wounds, but the sun's antibiotic effect was only proved in the late nineteenth century when the infectious mechanism of disease was discovered.

We now know that ultraviolet light is the main mechanism which destroys infectious agents. Ultraviolet light is divided into three ranges of increasing energy (and decreasing wavelength). UV-A causes our skin to tan, and over time accelerates skin damage and ageing. UV-B can cause sunburn but is also required for humans to generate vitamin D – vital for health. The most energetic UV band, UV-C, is filtered out by the ozone layer in our atmosphere. Without an ozone layer we would need to live indoors. Exposure to UV-C is harmful to all life.

The impact of UV-C on living organisms happens at a molecular level, in their DNA and RNA. These complex molecules, critical for the replication and survival of all life, including viruses, have chemical bonds which are disrupted by light in a certain energy or wavelength range. This effect peaks in the UV-C range, at around 250nm. Hence, irradiation with UV-C either kills or prevents replication. Both outcomes prevent disease transmission.



UVC alters DNA/RNA structures (Source: NASA)

Producing UV-C light is relatively easy. Mercury vapour emits light at 253.7nm when excited by an electrical current. Long used in fluorescent lighting, this emission causes a phosphor coating in the strip to fluoresce, thus converting the ultraviolet to visible light which can be used for illumination. A UV-absorbent coating prevents any stray emissions. Mercury-based UV-C lamps use exactly the same principle but without the phosphor, and using non-UV-absorbing glass, which allows the UV-C to escape. One downside of mercury lamps is that they also emit at 185nm, which generates ozone, the trimolecular form of oxygen. Although useful in the high atmosphere to protect us from UV, and in some applications as a germicide, ozone is also a respiratory irritant and pollutant. Most UV-C bulbs are therefore treated to absorb the 185nm emission. Ultraviolet light can also be produced by light-emitting diodes (LEDs) which are increasing in efficiency and lifespan.

5. Does UV-C kill coronaviruses, and specifically COVID-19?

The evidence that UV-C is lethal to life is widespread and well documented in the scientific literature. Experiments have been conducted to determine the lethal dose for various families of bacteria, fungi, and viruses. This includes coronaviruses, which cause the common cold as well as more severe disease such as SARS and COVID-19. In fact, coronaviruses seem to be one of the easier virus families to kill. Experiments done with SARS virus after the outbreak in 2003 showed a killing effect of UV-C (reviewed here https://doi.org/10.3205/dgkh000343).

Emerging data now shows the same is true of COVID-19.

(e.g.https://doi.org/10.1080/22221751.2020.1796529,
https://doi.org/10.1101/2020.06.05.20123463)

Therefore, the science is clear. A device with a sufficiently powerful UV-C source will kill COVID-19.

There are a few small caveats. Firstly, ultraviolet light is like visible light in that it travels in straight lines. Therefore, shadow effects can occur if areas are shielded from illumination. For this reason, “naked bulb” irradiation devices, which use unshielded UV-C sources to sterilize whole rooms, may not be fully effective where an opaque obstacle (e.g. furniture) blocks the light path. Shadow effects mean that surface cleaning is still needed. Open source devices also pose significant safety hazards to operators and passers-by. The UV-C radiation is highly damaging to eyes and skin with even very short exposure times. Wand-style handheld devices, where the operator is present during use, are especially dangerous. Therefore, unshielded devices must only be used if a room is uninhabited and entry of people (or escape of light) is prevented. The safe use of open source, naked bulb UV-C is possible but may prove impractical in small, busy environments.

Perhaps the best and safest use of UV-C against COVID-19 in most settings is as an enclosed, high-volume air purifier, in conjunction with a good surface cleaning protocol.

6. How does the Grant ap360 fight COVID-19?

Taking the logic discussed above into consideration, Grant Instruments set about designing a device which could clean high volumes of air quickly and safely, with minimal user intervention. Furthermore, we wanted to apply our principles of accuracy and durability, gained from nearly seventy years in designing laboratory instrumentation, to ensure that the device performs predictably and consistently over time. To do this, we made a few key decisions. Firstly, we decided on a “belt and braces” approach to make sure we killed viruses at first pass. We employed a high capacity HEPA13 filter to remove large particles up to 3 microns (including dust, pollen, and larger aerosol droplets) as well as many smaller particles. The air that comes through the filter is then irradiated by powerful UV-C lamps, to kill any remaining organisms, before being recirculated into the room.

The device is called the ap360 because we wanted to achieve an air flow of 360 cubic metres per hour, reasoning that a typical medium-sized office or treatment room is around 6m x 6m x 2.5m, giving an air volume of 90 cubic metres or about 3000 cubic feet. We wanted to clear that volume in fifteen minutes, to allow air to be completely changed four times per hour – hence ap360.

Note that we could have aimed for a larger target room size and beefed up the engineering to cope. However, we reasoned (on the basis of some smoke experiments) that unless the air within a large space is well mixed by other means, increasing the device capacity would just recycle air close to the machine leaving unmixed dead spots further away. Using a 6m x 6m “air cell” approach means that larger rooms can be adequately and predictably cleaned with multiple devices rather than with one large (and probably very noisy) machine.

We achieved our desired output (which is still quite large) by optimizing the filter type, size of light chamber, capacity of fan, and wattage of bulbs. A mis-matched fan and filter would have caused back pressure issues that limited flow. A powerful fan with weak bulbs would mean too little energy is absorbed during the short passage of air through the machine to guarantee virus killing. The same holds true for a too-wide light chamber: since attenuation of light dose away from the source follows an inverse square law, we need to ensure that the furthest point from the bulb still receives sufficient energy.

The effect of our optimized components is to ensure that, even if we had no HEPA filter in place, the dwell time and UV irradiance within the device would kill any viruses. Similarly, if the HEPA was used on its own it would probably remove most of the viral load. Having the HEPA (99.95% filter efficiency) element also allows us to remove particulates, pollen, and other allergens, extending the usefulness of the device beyond virus control. One last optimization here: our fan electronically auto-regulates its speed to ensure a constant volume flow for the required setting, as measured by a separate flow sensor. In HEPA filtration as filters become dirty the fan needs to work harder to force air through. On most devices that means that flow is reduced and they get less effective. But with the ap360 we deliberately over-engineered, choosing a high quality, German-made fan that compensates for higher back pressure without loss of air flow.

7. Further details

We are very proud of the ap360. It is as much a scientific device as it is an air cleaner, and we think it makes a big contribution to cost-effective air hygiene in public spaces. After only a short time, it is already in use in a wide variety of settings. We can provide the ap360 in plain white or customized with your own logo, messages or livery. If you have bigger need, we can also manage fleet leasing and servicing, for a fully hands-off, no hassle usage model.

If you would like to know more, please contact us:

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