Filtration Study
for the City of Vancouver

Final Report

Prepared for:

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GLOSSARY OF TERMS

AHJ	Authority Having Jurisdiction
AHU	Air Handling Units
ASHRAE	American Society of Heating Refrigerating and Air Conditioning Engineers
BCBC	British Columbia Building Code
BCCDC	British Columbia Centre for Disease Control
COV	City of Vancouver
ECM	Electronically Commutated Motor
HRV	Heat Recovery Ventilators
IAQ	Indoor Air Quality
LEED	Leadership in Energy and Environmental Design
MERV	Minimum Efficiency Reporting Values
NBC	National Building Code
NO_2	Nitrogen Dioxide
$PM_{2.5 \text{ or } 10}$	Particulate Matter in the air (2.5 microns <u>or</u> 10 microns or less in width/diameter)
SO_2	Sulphur Dioxide
WELL	WELL Certification Standard
WHO	World Health Organization
VBBL	Vancouver Building Bylaw
VOC	Volatile Organic Compounds

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EXECUTIVE SUMMARY

Integral Group has been retained by the City of Vancouver (COV) to carry out a study on Part 3 and Part 9 building filtration. The intent of this study is to understand the current code requirements, typical and best industry practices, and the ability or challenges for the industry to accommodate higher levels of filtration to address wildfire smoke and traffic-related air pollution (TRAP) in Vancouver.

Based on Integral Group's review, filtration specifications in Vancouver are primarily driven by good practice and/or sustainability frameworks, such as WELL, LEED, and Passive House, rather than stipulated by building code. **Across all three regulatory levels of building code**, from the National Building Code (NBC) to the British Columbia Building Code (BCBC) to the Vancouver Building Bylaw (VBBL), **there are no explicit filtration requirements stipulated for existing or new buildings**. Within Vancouver, however, projects going for rezoning may be required to certify under LEED or Passive House, thus triggering the same outdoor air filtration requirements within these sustainability frameworks.

Inline with these sustainability frameworks, **MERV 13 filtration is emerging as the typical industry practice for outdoor air filtration in new buildings**, particularly those in urban contexts. According to the recommendation within the WELL standards, MERV 13 filtration is generally sufficient in British Columbia, including urban areas with traffic, since the concentrations of small and particularly harmful particulate matter 2.5, or $PM_{2.5}$, are below the 15 μg/m^3 standard for indoor spaces. At main traffic arterials, $PM_{2.5}$ levels often exceed the World Health Organization (WHO) annual average target of 5 μg/m^3, reinforcing the benefits of MERV 13. However, there is ample support documents and evidence from a range of health-related guidelines, such as *ASHRAE Guide to Indoor Air Quality (IAQ) 2009 and the British Columbia Centre for Disease Control (BCCDC)*, that **areas with regular wildfire smoke should target MERV 16 filtration as a minimum due to the smaller particle sizes**.

During wildfire events, the concentration of $PM_{2.5}$, or particulate matter with width or diameter of 2.5 μm or less, can rise as high as 200 μg/m^3. MERV 13 filters will only be 50% efficient with removing particles of this size range when new and will deteriorate quickly as the filters saturate. In comparison, MERV 16 filters will remove 85 to 95% of the wildfire smoke particulate matter. **Despite the clear difference in particulate removal efficiencies**, and the negative health impacts of $PM_{2.5}$ exposure above the recommended limits, **there are practical considerations or challenges for accommodating higher levels of filtration in Part 3 and Part 9 buildings**, including:

- Market Availability
    - MERV 16 filters are not typically available in 25 mm, 50 mm, or 100 mm deep pleated / panel filters
    - **Residential heat recovery ventilators (HRV) are not designed to accommodate MERV 16 filters**
- Fan Power and Energy Consumption
    - MERV 16 filters have higher initial pressure drops, roughly double compared to MERV 13 filters
    - Increase in pressure drop will result in higher fan power and energy consumption
- Maintenance and Cost
    - MERV 16 filters cost roughly five times more than MERV 13 filters
    - MERV 16 filters require more frequent replacements to maintain airflow performance
- Overall Effectiveness
    - **Existing buildings with leaky envelope will have limited or reduced benefits from improved outdoor air filtration**, particularly with keeping out small particulate matter, such as $PM_{2.5}$
    - **Wildfire events, although expected to be more common in the future, occur infrequently**

In light of all the considerations above, it is recommended that the **City of Vancouver considers setting a minimum filtration efficiency for all new Part 3 and Part 9 buildings**. This will ensure that future buildings, including those not requiring certification under a sustainability framework, will achieve and maintain a minimum filtration performance. Given that there is an existing performance gap with the current products in the marketplace, such as residential heat recovery ventilators not being available with MERV 16 filters, **it is recommended that MERV 13 is the starting minimum filtration efficiency stipulated for all new Part 3 and Part 9 buildings**. Not only will this be accepted and implemented easily by an accustomed market, but this will also bring about the immediate benefits of removing larger particulate matters associated to traffic air pollution and dust, without incurring significant penalties on energy consumption and efficiency. Based on area cost of construction, projects can expect negligeable cost increase on the basis of targeting MERV 13, including for multi-unit residential buildings with smaller air handling units (AHU). For larger AHU that filter outdoor air, MERV 13 filtration will likely be provided using deeper filters in lieu of pleated panel filters. This will provide building operators with the option to temporarily put in MERV 16 filters during a wildfire event.

To account for the increasing occurrence of wildfire events, and deteriorating air quality, the **City of Vancouver could consider a future “step change” to the minimum filtration efficiency, to increase from MERV 13 to MERV 16 as a minimum filtration efficiency**. Similar to the Energy Step Code, this may provide the market with sufficient time to innovate and develop products with higher levels of filtration, including residential HRVs. Alongside continual improvements in fan and motor technologies, MERV 16 filtration could be provided with similar energy efficiency in the future. While this could be an option, it is recommended that this “step change” be made based on the “typical” air quality in the future without wildfire smoke.

For existing buildings that have poorer airtightness, improving the envelope should be the priority, to improve overall energy efficiency as well as to provide an opportunity to improve indoor air quality. As such, **retrofitting these buildings with higher efficiency filtration may not be an effective approach**.

While wildfire smoke is responsible for most severe air quality issues in BC, **a review of TRAP was also carried out for worst-case traffic arterials** in the Lower Mainland, including Clark Drive. Pollution levels were compared to the World Health Organization’s (WHO) thresholds for when these pollutants pose health risks. Some key TRAP pollutants including ozone (O_3), sulphur dioxide (SO_2) and carbon monoxide (CO) were shown to be consistently below the WHO thresholds. **$PM_{2.5}$ limits were frequently in excess of WHO annual thresholds, which reinforces the benefits of MERV 13 filtration as a minimum for traffic arterials.**

The review also showed that **nitrogen dioxide (NO_2) levels consistently exceed WHO thresholds** and could pose health risks. There are, however, **practical challenges for developing filtration policy to deal with NO_2:**

- Technical & Market Considerations
  - **NO_2 gaseous molecules are too small for mechanical filters with MERV ratings**
  - Unlike MERV, there is **no rating standard to measure carbon filter efficiency at removing NO_2**
  - As a result, carbon filters do not carry reliable data for removing NO_2
  - Some specific carbon filter models such as HEGA do provide efficiency data for removing NO_2. However, HEGA carbon filters have limited supply and availability
  - Carbon filters are primarily marketed for dealing with odor
  - It is challenging to map reduction in NO_2 concentration away from traffic arteries
  - Carbon filters are high cost and quickly become saturated, requiring replacement

Given these challenges, **introducing specific filtration requirements for dealing with nitrogen dioxide is not recommended**. A more practical solution is to encourage planting of trees and vegetation, which are shown to reduce concentrations of the gas, and which carry other benefits.

In Integral Group’s review, other filtration technologies were also studied, including particle ionization products. While particle ionization products could be effective, they are not recommended for general and non-critical applications since these technologies are more expensive to implement and produce ozone as a by-product.

1. INTRODUCTION

Integral Group has been retained by the City of Vancouver (COV) to carry out a study on Part 3 and Part 9 building filtration. The intent of the study is to understand the current code requirements, typical or best industry practices, and the ability or challenges to accommodate higher levels of filtration to address wildfire smoke and traffic-related air pollution in Vancouver. For code requirements, this study will review the current version of the Vancouver Building Bylaw (VBBL), as well as the British Columbia Building Code (BCBC), and the National Building Code (NBC).

2. DEFINING PARTICULATE MATTER AND HEALTH IMPACTS

This section defines air quality and health impacts. Typically in BC, air quality can be described as very good, with $PM_{2.5}$ levels typically below 15 µg/m^3, which is the WELL standard for indoor spaces, as well as the 24-hour exposure limit recommended by the WHO. Locally to main roads and junctions, traffic fumes have been shown to exceed the 5 µg/m^3 WHO limit for annual average $PM_{2.5}$ levels.

Figure 1: The Relative Particle Sizes[1]

[1] www. visualcapitalist.com/visualizing-relative-size-of-particles/

2.1 Wildfire Smoke

1. The particle size of wildfire smoke is usually 0.4 µm – 0.7 µm, which is at the smallest range of what mechanical filters can deal with. In addition to generating strong odors, the $PM_{2.5}$ density caused by wildfires may be as high as 200 µg/m^3.
2. Wildfire events in BC are a seasonal occurrence, generally occurring between April and September. Depending on the region, the intensity and duration of wildfire smoke will vary. The plot below shows a spike in Vancouver's $PM_{2.5}$ concentration during August 2021 which was caused by wildfire smoke:

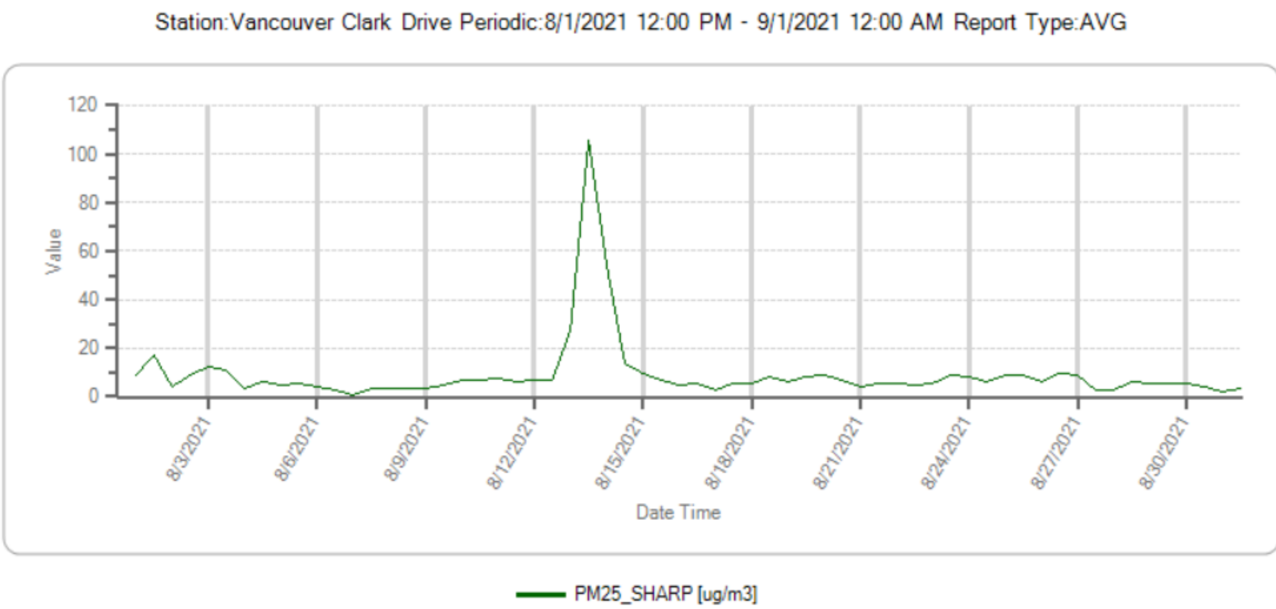

Figure 2: $PM_{2.5}$ data collected on Clark Dr., Vancouver BC, in August 2021[3]

3. The health impacts of wildfire smoke, specifically the concentration of $PM_{2.5}$, is significant. The BC Centre for Disease Control (BCCDC) states that "the very small particulate $PM_{2.5}$ travels deep into your lungs when you inhale", which "may result in a number of symptoms (sore throat, eye irritation, mild cough, headaches, etc.)" [4]. The Government of Canada also states that $PM_{2.5}$ has been shown to be "strongly associated with cardiovascular and respiratory mortality and morbidity endpoints". [5]

2.2 Traffic Related Air Pollution

1. Traffic-Related Air Pollution (TRAP), as defined by Health Canada, includes emissions from vehicle exhaust, fuel evaporation and chemical offsets from brakes and tires. The primary pollutants which impact health include:[6]
    1. Nitrogen Dioxide (NO_2) – a harmful gas in its own right and a key component in the chemical reaction that creates Ozone (O_3).
    2. Particulate Matter – Small, air-born particles. The data presented considers $PM_{2.5}$,
    3. Black Carbon – Also known as 'soot', refers to fine particles that's result from incomplete combustion processes. Black Carbon is part of $PM_{2.5}$.
    4. Ultrafine Particles (UFP) – Air-born particles with a diameter less than 1 micron (PM_1).

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[3] https://www2.gov.bc.ca/gov/content/environment/air-land-water/air/air-quality/current-air-quality-data/bc-air-data-archive

[4] http://www.bccdc.ca/health-info/prevention-public-health/wildfire-smoke

[5] https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-fine-particulate-matter-pm2-5-residential-indoor-air.html

[6] https://www.canada.ca/en/health-canada/services/publications/healthy-living/infographic-does-traffic-take-your-breath-away.html

5. Carbon Monoxide (CO) – A colorless, odourless gas that results from incomplete combustion of carbon-containing fuels.
6. Benzene and other Volatile Organic Compounds (VOC)s – Results from the production and storage of fuels.

2. Several health organizations stipulate maximum thresholds for the pollutants found in TRAP. These guides are described below and their limits captured in Table 1.

Table 1: Thresholds for Acceptable Air Quality, Converted to µg/m3

Pollutant	Averaging Time	CAAQS Limits ($\mu g/m^3$)	WHO Limits ($\mu g/m^3$)	NAAQS Limits ($\mu g/m^3$)	Most Stringent Limit ($\mu g/m^3$)
Fine Particulate Matter ($PM_{2.5}$)	24-Hour	27	15	35	15
	Annual	8.8	5	12	5
Ozone (O_3)	8-Hour	124	60	150	60
Sulphur Dioxide (SO_2)	1-Hour	183	-	197	183
	24-Hour	-	40	-	40
	Annual	13	-	-	13
Nitrogen Dioxide (NO_2)	1-Hour	113	25	188	25
	Annual	32	10	100	10
Carbon Monoxide (CO)	8-Hour	-	-	10 mg/m3	10 mg/m3

3. Canadian Ambient Air Quality Standards (CAAQS)
   1. The Canadian Ambient Air Quality Standards (CAAQS) provides thresholds for acceptable pollutant concentrations in the air. Pollutants of particular importance are NO2, O3, SO_2, $PM_{2.5}$.
   2. CAAQS limits provided in Table 1 represent their 'Red Level' for air quality management, meaning that at this threshold they recommend the most stringent actions possible to improve air quality.
4. World Health Organization (WHO)
   1. The WHO's fact sheet for Ambient outdoor air pollution from September 2021[7], provides air quality thresholds for $PM_{2.5}$, SO_2, NO_2, and O_3. For $PM_{2.5}$ and NO_2, they stipulate a 24-hour mean concentration of 15 $\mu g/m^3$ and 25 $\mu g/m^3$ respectively.
   2. The WHO's 2021 global air quality guidelines provide guidance on the threshold at which key air pollutants pose health risks. As such, the limits provided in Table 1 are valid for both outdoor and indoor concentrations of each gas.
5. National Ambient Air Quality Standards (NAAQS)
   1. ASHRAE 62.1 2016 references the Environment Protection Agency's standards[9] for six principal pollutants. These include the five pollutants listed in Table 1 plus lead.

[7] https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[9] https://www.epa.gov/criteria-air-pollutants/naaqs-table

2. ASHRAE 62.1 provides specific limits for each pollutant; for example the CO limit is not to be exceeded more than once per year.

2.3 Recorded Data at Traffic Arterials

1. To assess worst-case TRAP across Lower Mainland, data was gathered from heavily trafficked arteries including Clark Drive, Second Narrows, Burnaby South and YVR, and compiled for comparison against the limits defined in Table 1. The readings from Clark Drive are presented in Figure 3, Figure 4 and Figure 5 below. The annual readings from the other stations are presented in Appendix B. Note that some units are in parts per million (ppm) or parts per billion (ppb) as opposed to µg/m3, to keep the y-axes more consistent between units.
2. Figure 3 demonstrates that O_3 and CO 8-hr targets are not exceeded at Clark Drive.
3. Figure 4 demonstrates that 24-hr $PM_{2.5}$ targets are approached but not exceeded for WHO, while NO_2 targets are frequently exceeded for both WHO and CAAQS 'yellow limit', which denotes some action is required.
4. Figure 5 demonstrates that based on annual data at Clark Drive, $PM_{2.5}$ and NO_2 thresholds are regularly exceeded. The recorded NO_2 level remains above the WHO limit for NO_2 throughout the entire year.
5. Figure 6 demonstrates that daily SO_2 levels at Burnaby South are comfortably below WHO and CAAQS thresholds. Clark Drive sensor does not provide data for sulphur dioxide, however, per Appendix B, the traffic arterials are comparable on other TRAP metrics.

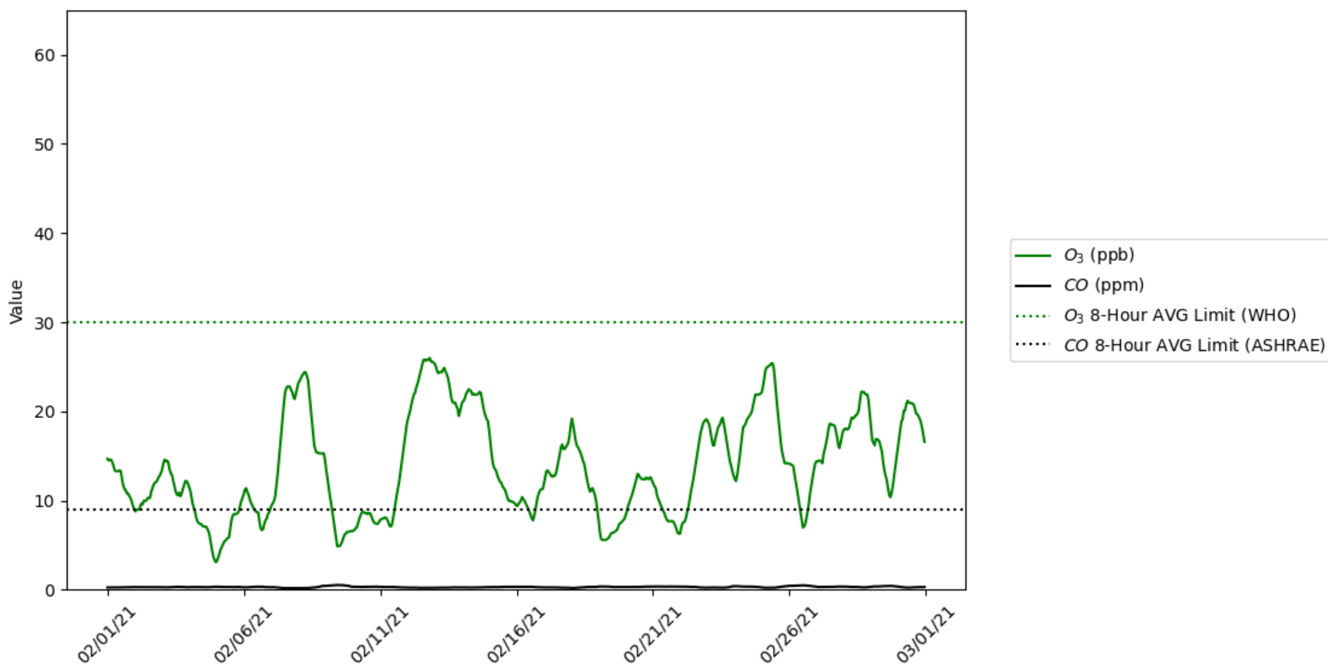

Figure 3: Daily Ozone (ppb) and Carbon Monoxide (ppm) measurements at 'Vancouver Clark Drive' – Feb 2021

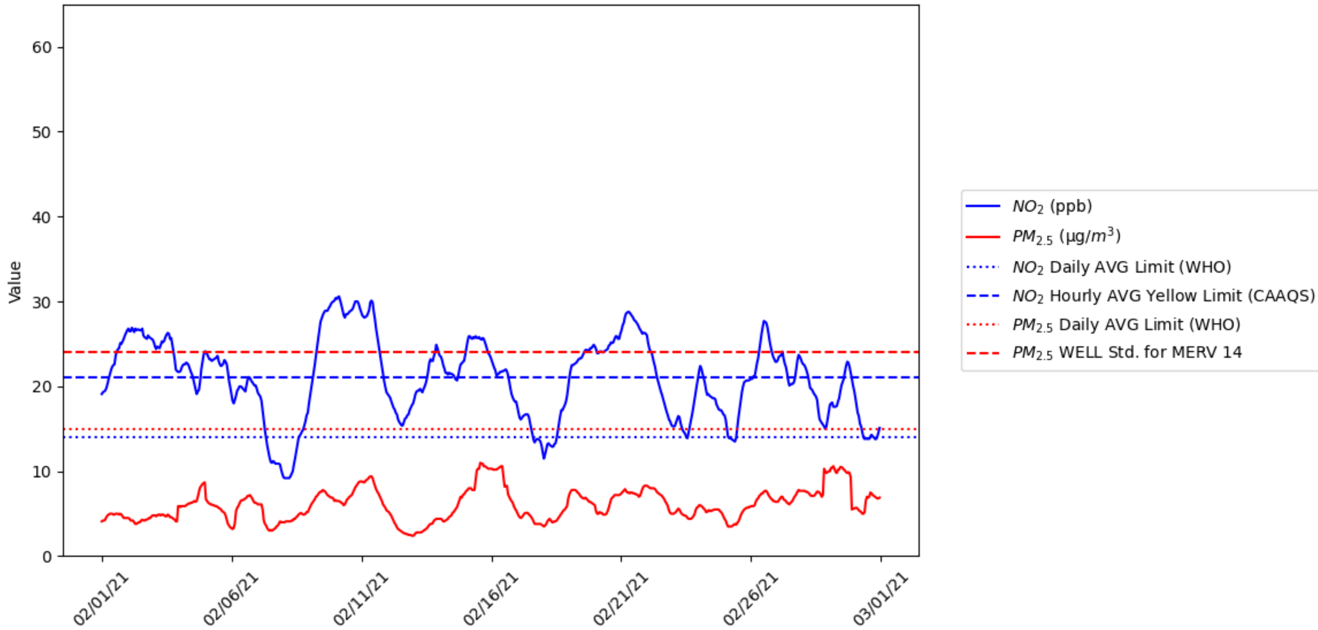

Figure 4: Daily $PM_{2.5}$ (µg/m3) and Nitrogen Dioxide (ppb) measurements at 'Vancouver Clark Drive' – Feb 2021

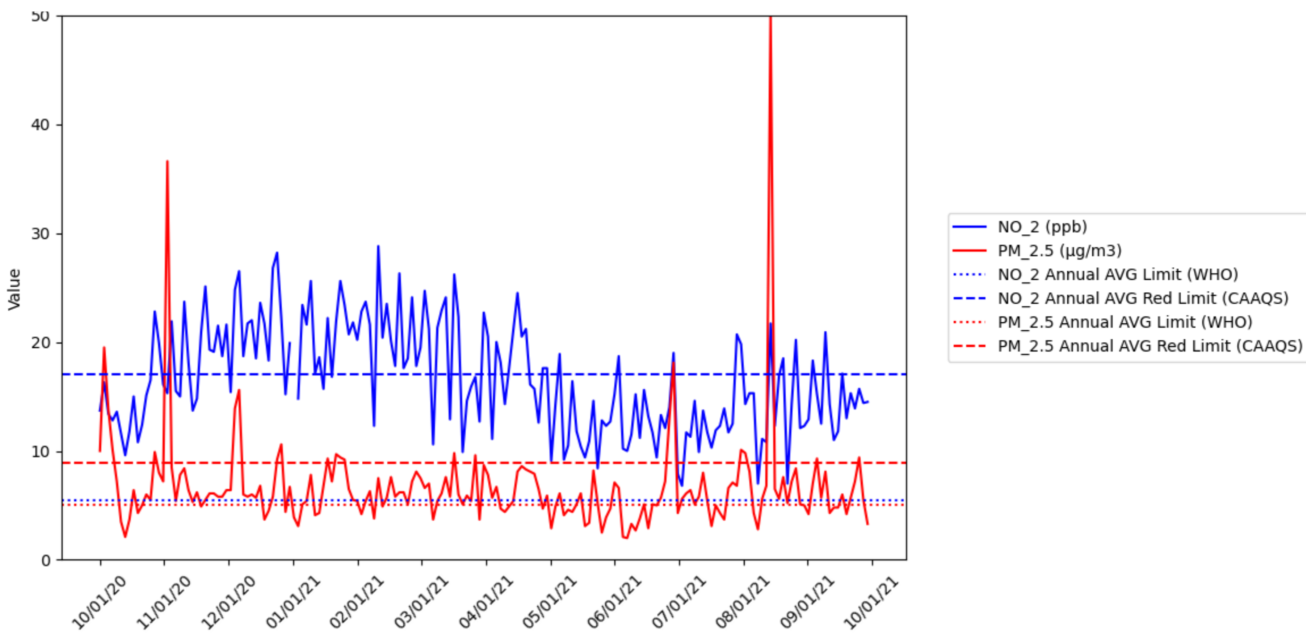

Figure 5: Annual $PM_{2.5}$ (µg/m3) and Nitrogen Dioxide (ppb) measurements at 'Vancouver Clark Drive'

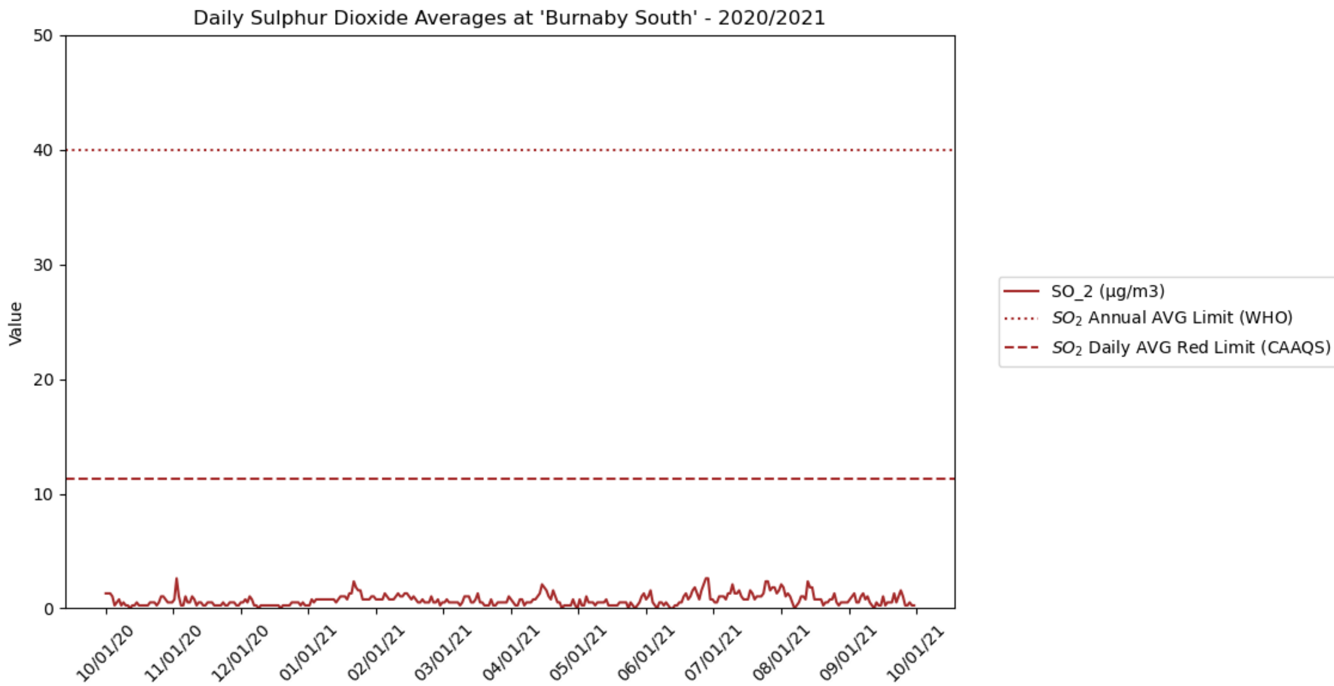

Figure 6: Daily Sulphur Dioxide measurements (µg/m3) at 'Burnaby South'

2.4 Airborne Pathogens

1. Flu and coronavirus are examples of pathogens which become airborne when exhaled droplets from infected building occupants aerosolize and can become suspended in the air for hours. Unlike particles from traffic and wildfire, airborne pathogens that are responsible for spreading infection are almost always generated and spread indoors.
2. The optimum approach recommended by the Harvard T.H School of Public Health[10] for minimizing risk of indoor pathogen spread is to first maximize outdoor air (OA) ventilation as much as possible. The World Health Organization[11] recommend 4 - 6 air change per hour (ACH) ventilation to minimize risk in offices and classrooms.
    1. For buildings with leaky envelope, poor filtration, or which are primarily naturally ventilated, boosting OA ventilation for reducing pathogen spread is incompatible with filtering PM from outside. For these buildings, an airborne pathogen pandemic combined with a wildfire event is very challenging to deal with.
3. Where OA ventilation rates cannot be boosted to meet 4 - 6 ACH, the recommended approach of the Harvard T.H School of Public Health is to improve filtration using re-circulation systems. This will 'clean' air of airborne pathogens, as air is filtered and returned to the building. This process will also remove wildfire smoke from the air, though it should be noted that wildfire smoke particles are smaller and require a higher level of filtration.
4. In-space 'air scrubbers' such as portable HEPA filtration units can also be used to meet the 4 – 6 ACH target for individual spaces. These units will likewise also remove wildfire particles from the air. No filtration systems will remove CO2 from the air, however, which is why the optimum solution for health is to maximise the provision of outdoor air.

3. <u>**CURRENT CODE AND BEST PRACTICES**</u>

The industry standard for minimum filter rating for a packaged AHU is MERV 8. The industry is beginning to exceed this as MERV 13 becomes more common, as is recommended by the BCCDC, ASHRAE, and Energy Efficient Building Guidelines. For wildfire smoke, several guidelines recommend filters rated MERV 16 and above.

[10] https://covid-19.forhealth.org/

[11] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/media-resources/science-in-5/episode-10---ventilation-covid-19

3.1 Code Requirements

1. In the VBBL (2019) and BCBC (2018), there are no minimum filter efficiency ratings, however there are ways to indirectly incur such requirements. Vancouver's 'Green Building Policy for Re-Zoning' [12] requires non-residential buildings, when rezoning, to meet Passive House requirements or LEED Gold certification. MERV 13 is respectively either required, or likely targeted for outdoor air filters.
2. In the National Building Code (NBC), there are no minimum filter efficiency ratings, although there are requirements for the use of adsorbent (carbon) filters. It requires that these filters are *"a) installed to provide access so that the [carbon] can be reactivated or renewed, and b) protected from dust accumulation by air filters installed on the inlet side"*.

3.2 Best Practices

1. ASHRAE
    1. ASHRAE Standard 62 2001 (except addendum n) does not prescribe any minimum filter ratings above MERV 6.
    2. ASHRAE's Guide to Indoor Air Quality (IAQ) (2009) recommends filter ranges for various conditions.
        1. For situations where *"outdoor air is non-compliant and contains external sources of particles, odors, and irritants"*, this Guide recommends a filter rated MERV 11 – 14, in combination with a medium efficiency gas phase air cleaner (for example, a carbon filter). The intent behind the recommendation is for the MERV 11-14 filter captures particulate while the Air Cleaner removes odor.
        2. Due to wildfire's small particle size (0.4 µm – 0.7µm), the Guide's strategy for "lowering occupant exposure to airborne pathogens" is more appropriate to BC. For this, the Guide recommends filters rated MERV 14-16.
2. BC Centre for Disease Control (BCCDC)
    1. The BCCDC's 2014 Evidence Evaluation report[13] considers 'Filtration in Institutional Settings during Wildfire Events'. The results section of this report concludes by saying that "it is unlikely that MERV 13 or lower will provide effective protection from wildfire events. A higher degree of protection will be offered by increasing MERV ratings up to MERV 17".
3. Local Industry Standard
    1. Mechanical specifications in BC typically include:
        1. MERV 8 filters on indoor recirculation units such as fan coil units (FCUs)
        2. MERV 8 filters as standard for OA units
        3. MERV 13 filters as best practice for OA units, with MERV 7 pre-filters
        4. Other types of filter such as carbon and electronic are not common practice and only for specific applications
4. WELL Building Standard
    1. WELL is a tool focused on improving building conditions such as thermal comfort and air quality. The focus is on health, rather than energy efficiency.
    2. The target for indoor air quality is for $PM_{2.5}$ to be less than 15 µg/m^3.
    3. WELL requires MERV 14 minimum where annual average air quality $PM_{2.5}$ threshold is between 24-39 µg/m^3.
    4. WELL requires MERV 16 minimum where annual average air quality $PM_{2.5}$ threshold is 40 µg/m^3 or greater. Given wildfire smoke often exceeds 150 µg/m^3, the annual average of areas affected will often exceed the 40 µg/m^3 threshold. Given how far in excess of this level wildfire events are, a reasonable interpretation is that a minimum rating of MERV 16 should be used for wildfire events.

[12] https://bylaws.vancouver.ca/Bulletin/G002_2017April28.pdf

[13] http://www.bccdc.ca/resource-gallery/Documents/Guidelines%20and%20Forms/Guidelines%20and%20Manuals/Health-Environment/WFSG_EvidenceReview_FiltrationinInstitutions_FINAL_v3_edstrs.pdf

5. LEED and Passive House
    1. Passive House requires MERV 13 on AHU's.
    2. For LEED, there is an optional credit requiring MERV 13 filtration that is commonly targeted, especially for Gold or Platinum certification.
6. In Summary:
    1. MERV 8 is the standard industry practice for outdoor air and recirculating air filtration, with some instances of upgrading to MERV 13 for OA filtration. This is not required by code.
    2. MERV 13 are recommended by the BCCDC, ASHRAE, Passive House, LEED, and WELL for typical Part 3 buildings. This is particularly true where typical outdoor air is impacted by traffic fumes and other contaminants.
    3. MERV 13 is not an effective filter for wildfire smoke.
    4. Carbon filters reduce VOC, gases and odors and should be used in combination with a particulate pre-filter, however they do not remove small wildfire smoke particles.
    5. The BCCDC, ASHRAE, and WELL recommend MERV 16 or higher for dealing with wildfire smoke.

4. FILTRATION: OPTIONS AND CONSIDERATIONS

This section will primarily focus on mechanical filters, specifically pleated and bag filters, as they are relatively low cost, can be manufactured to meet specific MERV ratings, and do not produce chemical by-products. This section will also discuss a common type of sorbent filter, Carbon Filters, which are often used with mechanical filters.

When comparing filters, the industry standard is Minimum Efficiency Reporting Value (MERV). Table 2 shows the efficiency that each rating implies for three ranges of particle size. For example, a MERV 13 filter captures a 50% or more of the total particles sized between 0.3μm - 1μm, 85% or more of those sized between 1μm - 3μm, and 90% or more of those sized between 3μm – 10μm.

When considering a filter's effectiveness against wildfire smoke, we consider the filter's minimum % efficiency for particles sized 0.3 μm - 1 μm. Because traffic fumes are composed of particles ranging from 0.1 μm – 10 μm we should consider the filter's effectiveness for all sizes of particles.

Table 2: ASHRAE Standard 52.2 MERV Ratings

Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, μm			Average Arrestance, %
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0	
1	N/A	N/A	$E_3 < 20$	$A_{avg} < 65$
2	N/A	N/A	$E_3 < 20$	$65 \leq A_{avg}$
3	N/A	N/A	$E_3 < 20$	$70 \leq A_{avg}$
4	N/A	N/A	$E_3 < 20$	$75 \leq A_{avg}$
5	N/A	N/A	$20 \leq E_3$	N/A
6	N/A	N/A	$35 \leq E_3$	N/A
7	N/A	N/A	$50 \leq E_3$	N/A
8	N/A	$20 \leq E_2$	$70 \leq E_3$	N/A
9	N/A	$35 \leq E_2$	$75 \leq E_3$	N/A
10	N/A	$50 \leq E_2$	$80 \leq E_3$	N/A
11	$20 \leq E_1$	$65 \leq E_2$	$85 \leq E_3$	N/A
12	$35 \leq E_1$	$80 \leq E_2$	$90 \leq E_3$	N/A
13	$50 \leq E_1$	$85 \leq E_2$	$90 \leq E_3$	N/A
14	$75 \leq E_1$	$90 \leq E_2$	$95 \leq E_3$	N/A
15	$85 \leq E_1$	$90 \leq E_2$	$95 \leq E_3$	N/A
16	$95 \leq E_1$	$95 \leq E_2$	$95 \leq E_3$	N/A

4.1 Mechanical Filters – Pleated Media

1. Pleated filters use a pliable material such as paper or polyester which is folded many times in strategic ways to increase surface area. It is typically housed in a cardboard frame.
2. These filters can be manufactured to suit nearly all particulate filtration requirements, although the pressure drop increases considerably as we increase the filter's MERV rating.
3. The nominal depths for pleated filters are 25mm, 50mm or 100mm. It may seem counterintuitive, but typically, if two filters have the same MERV rating, the deeper one has a lower pressure drop.

Table 3: Pleated Media Technical Data[16]

MERV Rating	Nominal Depth [mm]	Pressure Drop at 2.54 m/s [Pa]	Minimum% Efficiency at 0.3 µm - 1 µm	Minimum % Efficiency at 1 µm – 3 µm	Minimum % Efficiency at 3 µm – 10 µm	Approx. Cost [CAD / ft^2]
8	100	34.8	N/A	20	70	$4 - $5
11	100	49.8	20	65	85	$5 - $7
13	100	84.6	50	85	90	$10 - $12
14	100	92.1	75	90	95	$40 - $45
15	100	107.0	85	90	95	$40 - $45
16	300	184.1	95	95	95	>$70

4.2 Mechanical Filters – Bag Filters

1. Bag Filters use large, seamless pockets attached to a metal frame. These pockets are made of porous material which allows air to pass through, trapping particulate matter inside the bag. The number of pockets in one filter is variable, generally between 3 to 10. That material used also varies with the MERV rating, though both fibreglass and synthetic materials are common.
2. Functionally, bag filters allow passing air to expand each pocket, increasing the pocket's surface area. For this reason, bag filters should primarily be used at a constant air volume to keep the pockets expanded. If there is variable air volume, the pockets may deflate, leading to inefficiencies and potentially damaging the filter.
3. In terms of pressure drop, cost and size, bag filters are inferior to pleated filters. However, because the surface area of a bag filter will exceed the equivalent pleated filter, their lifespan is noticeably longer.
4. The cost of these units are a function of the unit's frame size, number of pockets, depth of pockets, and material used.

4.3 Other Types of Filtration

1. Carbon Filters
    1. Carbon filters are extremely porous filters which make use of *adsorption*. This process involves organic compounds in the air reacting with carbon, causing them to stick to the filter.
    2. The cost of carbon filters is roughly double typical pleated filters.
    3. These filters are designed for removing VOC, gases and odor from the air, which pleated and bag MERV filters do not do. A function of the mechanism of adsorption is that large amounts of particulate can quickly

[16] Costing taken from https://www.grainger.ca/en

saturate the carbon, making it ineffective. The recommended approach is to filter the air before sending it through the carbon filter, per ASHRAE's Guide to Indoor Air Quality, Section 3.2.1.2.

4. During the 2021 wildfire season in Kelowna BC, however, it was anecdotally reported that many residents used MERV 13 filters in combination with Carbon filters to mitigate odor. These carbon filters were lasting as little as one week before becoming saturated. Given the high cost of these filters, MERV 16 would be more effective for pre-filtration of carbon filters.
5. There is no benchmarking system for the effectiveness of carbon filters in removing gases and VOC. As a result, carbon filters do not carry reliable data for efficiency or lifespan. On this basis, California's EPA[18] have been wary of mandating any sorption-based filters such as carbon for dealing with TRAP gases and VOC.

Table 4: Carbon Filter Hybrid with Pleated Filter Technical Data

MERV Rating	Nominal Depth [mm]	Pressure Drop at 2.54 m/s [Pa]	Minimum% Efficiency at 0.3 µm - 1 µm	Minimum % Efficiency at 1 µm – 3 µm	Minimum % Efficiency at 3 µm – 10 µm	Approx. Cost [$ / ft^2]
8	100	105	N/A	20	70	$18
13	100	112	50	85	90	$30

2. Other filtration options such as Ultraviolet Germicidal Energy (UV-G), Photo-Electrochemical Oxidization, Dehydrogeneration Polymer (DHP) and Bi-Polar Ionization are effective, although they are typically more expensive and produce chemical by-products which are undesirable. These technologies may develop and become more comparable with mechanical options in future, but are currently more limited to specialist applications, see Appendix A.

4.4 Practical Considerations

1. Fan power:
    1. For existing buildings and AHU's with limited power, the increased pressure drop of MERV 16 filters may adversely impact performance and flowrate as well as energy consumption.
    2. High efficiency fans such as those with electronically commutated motor (ECM) drive can accommodate the increase in pressure without significant penalty (roughly 5-10%) however there are limitations with availability of ECM in BC. ECM fans are generally 30% - 40% more expensive than typical fans.
2. Maintenance
    1. Maintenance is of critical importance in ensuring filters and ventilation systems operate effectively. Without regular maintenance, any filter will saturate (i.e., 'clog up') with PM. This will negatively impact energy consumption, flowrate, and air quality.
    2. Maintenance should be carried out on an as-required basis, rather than at specific intervals. Although a MERV 8 pre-filter and MERV 16 primary filter begins with an initial static pressure (SP) below 125 Pa, most are designed with a final SP of 250 – 325 Pa. Ideally, the filter is connected to pressure sensors on either side which provide an alarm signal when a new filter is required.
    3. Figure 4 below shows the impact of wildfire smoke in Vancouver on filters. At the start of the event, a new MERV 14 filter was inserted. The image shows how much PM the filter had picked up after only 6 days.

[18] https://ww2.arb.ca.gov/sites/default/files/2017-10/rd_technical_advisory_final.pdf

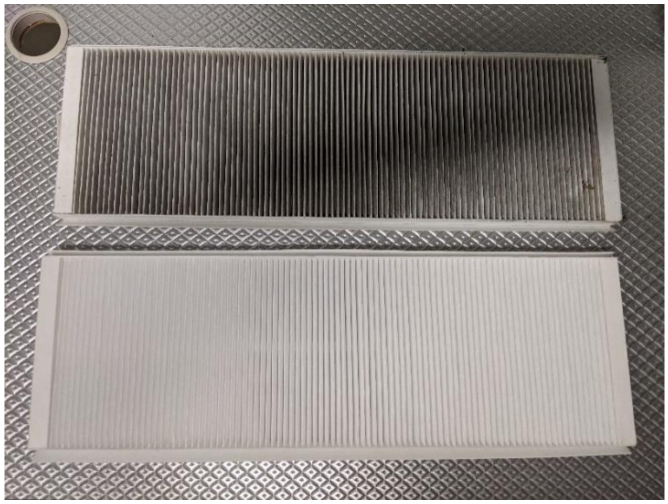

Figure 7: Example of the impact of six days' wildfire smoke on a MERV 14 filter

3. Pre-filters and Temporary Filters
    1. Incorporating a lower-quality pre-filter is an effective strategy to increase the longevity of a higher efficiency, higher cost primary filter. By using a pre-filter to capture larger particulate matter, the primary filter can be expended capturing the smaller particles it was designed for.
    2. Including a pre-filter or temporary filter may require some additional infrastructure:
        1. For example, an additional casing for additional filters are available on some manufacturer's AHUs:

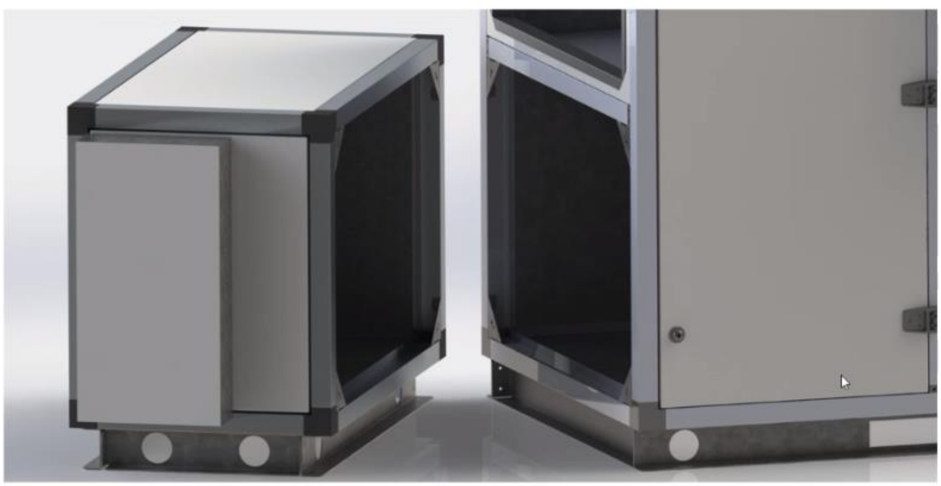

Figure 8: Example infrastructure available to accommodate an additional filter

        2. Another option is to include a filter bank in-duct in the supply stream, although a casing (similar to that shown above) is still required.
    3. MERV 13 and above will all benefit in terms of longevity from a pre-filter. Anecdotally, using a MERV 8 pre-filter will roughly double the useful life of such filters.
    4. Carbon filters will also benefit from a pre-filter, particularly during wildfire season where PM intensity is high and saturation occurs quickly.

4. Airtightness / Infiltration
    1. New buildings generally have high standards as required for energy compliance, however, many existing buildings with leaky envelope will have limited benefit from upgraded AHU filtration given that outdoor air will bypass the units.

2. For these spaces, the optimum approach is in-space air cleaners such as recirculating HEPA filtration units. Unlike increased filtration on Direct Outdoor Air Systems (DOAS), these interior units have an added benefit of filtering airborne pathogens which are omitted, and subsequently inhaled, indoors.

5. DISCUSSION AND RECOMMENDATIONS

Table 5 below provides an overview and comparison between MERV 8 through MERV 16 filters' sizes, pressure drops, efficiencies and costs.

Table 5: Technical Data for Recommended Filters

Filter Type	MERV Rating	Nominal Depth [inches]	Pressure Drop at 2.54 m/s [Pa]	Minimum% Efficiency at 0.3 µm - 1 µm	Minimum % Efficiency at 1 µm – 3 µm	Minimum % Efficiency at 3 µm – 10 µm	Approx. Cost [$ / ft^2]
Pleated	8	100	34.8	N/A	20	70	$4 - $5
Pleated	13	100	84.6	50	85	90	$10 - $12
Pleated	15	100	107.0	85	90	95	$40 - $45
Pleated	16	300	184.1	95	95	95	>$70
Pleated w/ Carbon	8	100	105	N/A	20	70	$18

Given the benefits of higher filtration in areas vulnerable to wildfire smoke, annual levels of traffic related $PM_{2.5}$ at main roads and the practical considerations around implementing MERV 16, Integral's recommendations are as follows:

1. For all new Part 3 and Part 9 buildings:
    1. MERV 13 should be stipulated as the new starting efficiency for all outdoor air filtration:
        1. This will be more easily accepted and implemented by an accustomed market and will bring about immediate benefits in removing ~50% of wildfire particles and significantly more PM associated with traffic air pollution and dust, without incurring significant penalties on energy consumption and efficiency.
        2. For larger air handling units (AHU) that filter outdoor air, MERV 13 filtration will likely be provided using deeper filters in lieu of pleated panel filters. This will provide building operators with the option to temporarily put in MERV 16 filters during a wildfire event.
    2. The City of Vancouver could consider a future 'step change' to increase from MERV 13 to MERV 16 as the minimum filtration efficiency:
        1. This will help account for the increasing occurrence of wildfire events and deteriorating air quality, and the wider costs to health.
        2. Similar to the Energy Step Code, this may provide the market with sufficient time to innovate and develop products with higher levels of filtration, including residential HRVs.
        3. Alongside continual improvements in fan and motor technologies, MERV 16 filtration could be provided with similar energy efficiency in the future. While this could be an option, it is recommended that this "step change" be made based on the "typical" air quality in the future without wildfire smoke.
    3. Consideration should be given to incentivizing pre-filters and alarm-based detection systems which help operators to carry out maintenance correctly.
    4. As a general recommendation during wildfire events, windows should be closed, and DDC systems engaged to ensure buildings remain positively pressurized. For developments facing busy traffic arteries and which can expect poorer air quality due to TRAP, natural ventilation is not recommended as the primary means of cooling, particularly at lower levels of the building.

2. For existing buildings:
    1. Where existing buildings have poor airtightness, improving the envelope should be given priority.
        1. This will improve overall efficiency as well as providing an opportunity to improve IAQ. Given the potential costs of upgrading building envelope, priority should be given to vulnerable populations that are more at risk from wildfire smoke.
        2. While the building envelope is leaky, retrofitting these buildings with higher efficiency filtration may not be an effective approach.
        3. Recirculating AHU’s can be fitted with higher filtration to improve IAQ. In-space air cleaners such as HEPA filtration units can also provide benefit for vulnerable populations.

6. CONCLUSIONS

Filtration standards for outdoor air ventilation have been improving in recent years, in part organically and in part prompted by health and wellness standards and good practice, rather than Building Code. MERV 13 has been emerging as typical industry practice for outdoor air filtration in new buildings in BC, which is generally in line with the recommendations of WELL and WHO since the concentrations of small and particularly harmful particulate matter 2.5, or $PM_{2.5}$, are below the annual average of 24 $\mu g/m^3$ at which MERV 14 is recommended, and typically below the most stringent outdoor target of 5 $\mu g/m^3$ based on WHO. At traffic arterials, $PM_{2.5}$ levels often exceed the WHO target, reinforcing the benefits of MERV 13.

Given the increasing frequency and severity of wildfire events, however, and their impact on health, a higher level of filtration such as MERV 16 filtration is desirable in buildings in BC. Given there are significant practical considerations around mandating MERV 16 filtration in new buildings, it is recommended to set a more realistic threshold for new Part 3 and Part 9 buildings and consider a long-term implementation strategy to raise the standard to MERV 16 at a later date. This would allow the market sufficient time to prepare, innovate and develop products with higher levels of filtration. In the interim, larger AHU’s which adopt MERV 13 as the target can likely ensure this is provided using deeper filters in lieu of pleated panel filters. This will provide building operators with the option to temporarily put in MERV 16 filters during a wildfire event.

Consideration should also be given to existing buildings, particularly those with vulnerable populations that will be more at risk of serious health implications from wildfire smoke. Where existing buildings have leaky envelope, improving the envelope should be the priority, to improve overall energy efficiency as well as provide an opportunity to improve indoor air quality through improved filtration.

Although TRAP generates NO_2 levels that exceed WHO limits at traffic arteries, introducing specific requirements for dealing with NO_2 are not recommended, given the lack of maturity in the current market for carbon filters to reliably mitigate the issue. An alternative approach is to encourage vegetation which is shown to reduce levels of NO_2 and PM as well as providing psychological health benefits.

INTEGRAL GROUP

Sincerely yours

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APPENDIX A – ALTERNATE AIR CLEANERS

Bipolar Ionization	
- Bipolar ionization generates both positive and negative ions that interact with the virus surface protein and alters it to a highly reactive group called hydroxyl radicals. Hydrogen is removed to form H2O. The outer surface of the virus is removed and is no longer infectious. - **Matterhorn, Atmos Air**	
Pros	Cons
- Causes airborne particulate matter to cluster and form larger particles that can settle more rapidly or be filtered more effectively - Neutralizes odors and Volatile Organic Compounds (VOC)s - Inactivates/kills viruses - Reduces amount of outdoor air required - Low upfront costs and maintenance costs - No additional pressure drops in system - Previous systems had ozone as a by-product, but newer tech can avoid the ozone by-product creation - Other studies found that nearly all microorganisms were removed (98-99%) within nearly 15 min - Large fungi reduction occurred within the first 10 min (90-100%) - Fomite reduction was found to be 99.4% within 30 minutes	- One study found little change with ionizer on and off between the inside and outside of the chamber (results were not statistically significant) - In a study the ionization led to a decrease in some hydrocarbons but also an increase in partial hydrocarbons resulting in an increase in oxygenated VOCs (increase in total organic carbons by 114%) - Some negligible differences in PM when using bipolar ionization - By-product formation can occur which can be more harmful - Under 50% of PM 2.5, PM 10, and VOCs were removed (44%, 40%, 36% respectively)

DHP	
Dehydrogeneration Polymer (DHP) is an antimicrobial substance that can reach everywhere that air reaches in a space. Diffusers can be plugged into standard outlets or be installed inside the HVAC system. Unlike the use of hydrogen peroxide vapour, dry hydrogen peroxide can be used at very low concentration levels. **Synexis, TRANE**	
Pros	Cons
- Dispersed in a continuous stream, there is continuous microbial reduction - Is less concentrated than hydrogen peroxide vapour because it is not aqueous and has less competition with water molecules - Inactivates/kills viruses - Reduces amount of outdoor air required - Studies have shown an 86% reduction in microbial counts within 6 hours - The half time is between 30-60 minutes, therefore, there is sufficient time for the DHP to pass through the system and still be effective - Some devices have shown a 95% microbial reduction within an hour - Rooms can be occupied during usage - The effects of DHP utilization can continue beyond 7 days - A study has shown that fomite reduction is 75% effective within 6 hours - A study has shown that fungi reduction is 86% effective within 6 hours - Total bacterial reduction capacity has reached 99% within 1 hour - Studies have shown significant reductions in hospitalization stays for airborne related infections	- Despite low levels (0.5-20 ppb) well below the safety regulations (1 ppm) the presence of DHP in the air still seems unsafe - A DHP system requires suitable levels of reactivity, which may be difficult to assess - Air changes per hour can still have a significant impact on results - Little data has been collected on the effect of DHP on reducing VOC and PM2.5 or PM10

<table>
<tr><td colspan="2">Photo-Electrochemical Oxidation</td></tr>
<tr><td colspan="2">- Use of filter with UV-A lights to activate photocatalyst that destroys microorganisms entrained on the filter through a photochemical reaction to remove bacteria, viruses, fungal spores, and overall improve air quality
- Molekule Air Mini</td></tr>
<tr><td>Pros</td><td>Cons</td></tr>
<tr><td>- Inactivates/kills virus
- Filters VOCs
- Oxidize and mineralizes chemical and microbiological organic matter included in the air
- Virus reduction (99.95% in an hour)
- Filters can self-decontaminate with UV-A LED lights
- Extremely effective at bioaerosol reduction
- Studies have shown significant reductions in hospitalization stays for airborne related infections
- 95% or greater reduction in particulate matter within a single pass
- Nearly 100% removal of VOCs within 120 min
- Nearly 100% removal of fungal spores
- Free standing installation
- Basic Firmware and App used to turn the unit on, off, and change the fan speed
- No ozone production and suggests that it may break ozone down</td><td>- Not as effective at the reduction of formaldehyde
- Can be harmful if human skin exposure</td></tr>
</table>

APPENDIX B – RECORDED ANNUAL AIR QUALITY

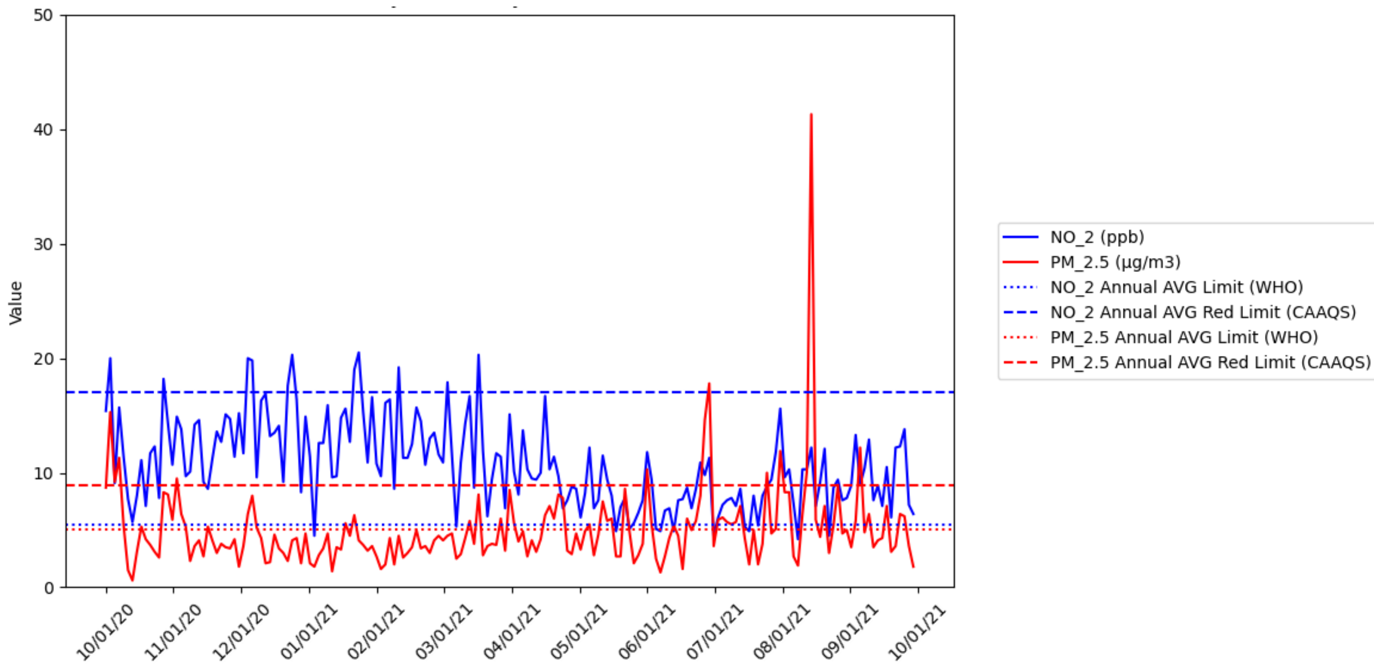

Figure 9: Annual $PM_{2.5}$ (μg/m3) and Nitrogen Dioxide (ppb) measurements (μg/m3) at 'Burnaby South'

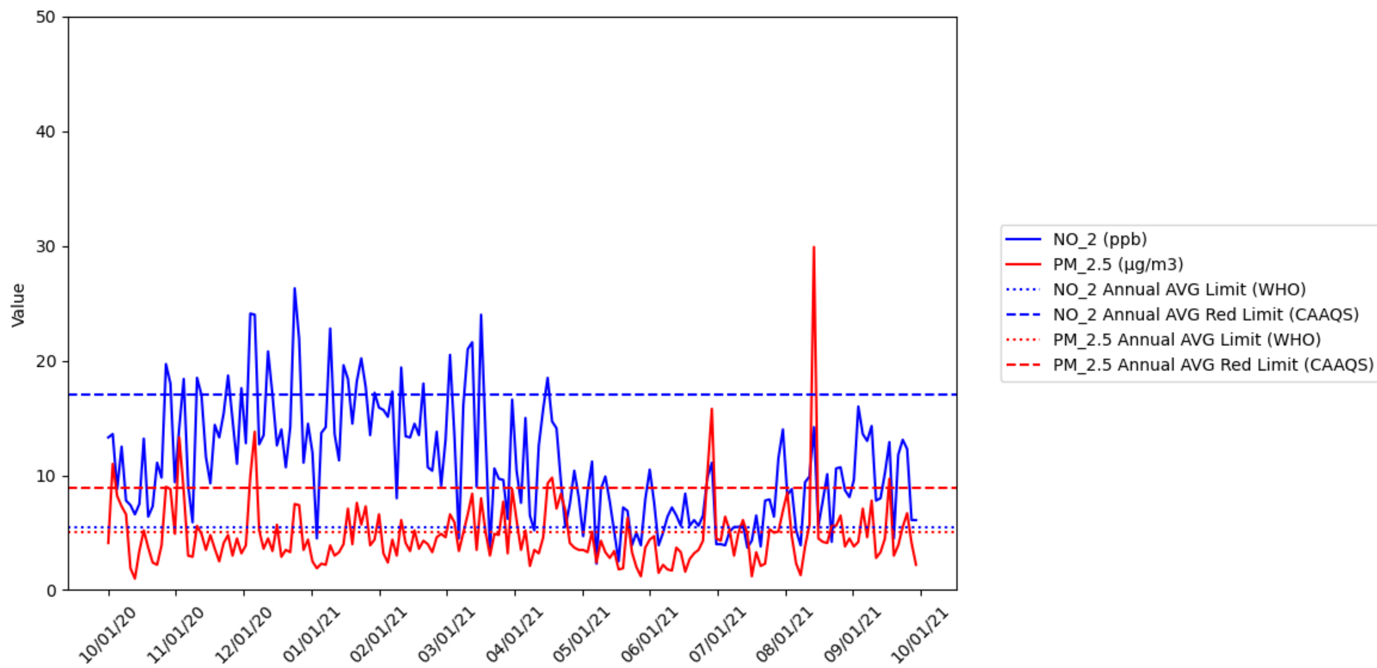

Figure 10: Annual $PM_{2.5}$ (μg/m3) and Nitrogen Dioxide (ppb) measurements at 'YVR International Airport'

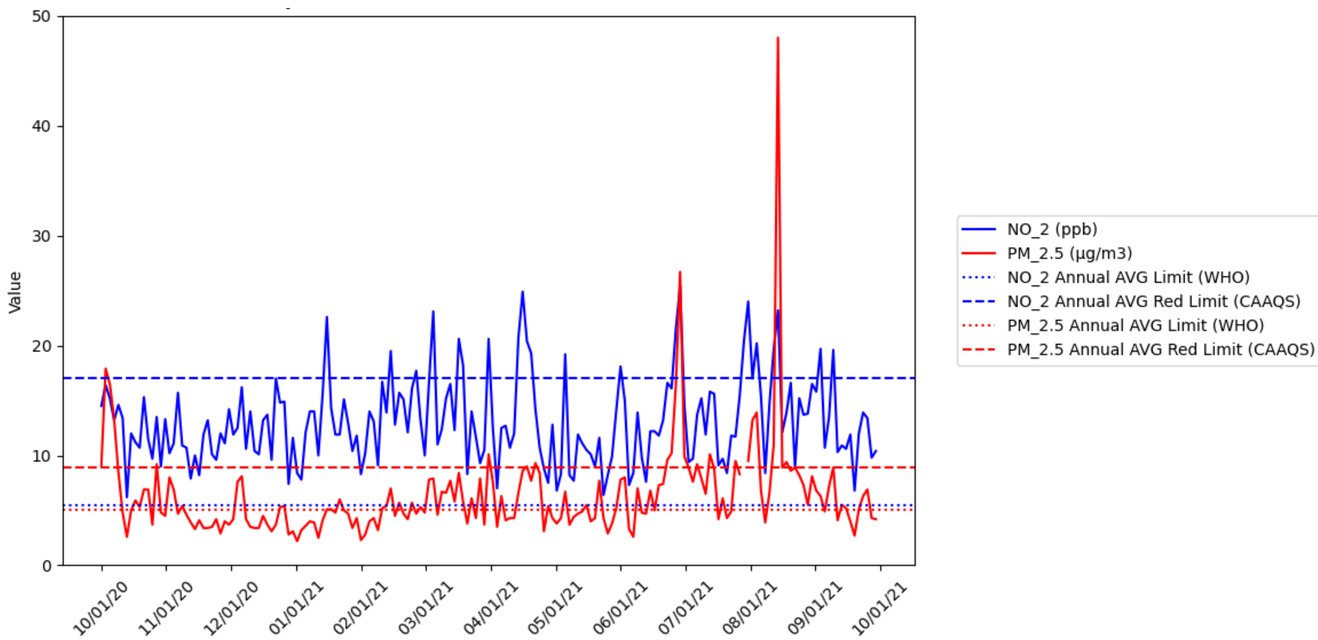

Figure 11: Annual $PM_{2.5}$ (µg/m3) and Nitrogen Dioxide (ppb) measurements at 'Vancouver Second Narrows'