Hummingbird™ Product efficacy testing for SARS-CoV2 (COVID-19) and variants Decontamination / Filtration with HVAC Airflows Report

November 2022

Tested at:

University of Southern California
Keck School of Medicine

The Hastings Foundation & The Wright Foundation Laboratories – Biosafety Level 3

USC
Testing & Research staff:
Dr. Lucio Comai
Jill Henley
Phillip Sell

All the work with live SARS-CoV-2 virus was performed in the Biosafety Level 3 laboratory at the University of Southern California (USC) and supervised by Dr. Lucio Comai, PhD, Scientific Director of the BSL3 lab. All tests were performed by BSL3 COVID Core staff. SARS-CoV-2 resources are supported by a grant from the Keck COVID-19 Research Fund.

Table of Contents

Covid-19 Independent Peer Review Team

The peer review team is made up of independent experts in the areas of epidemiology, bioaerosols and engineering who assisted in recommendations of the test design, testing process and review of this final report in addition to the COVID Core USC BSL staff which performed all testing. The goal of the team was to try to make the testing as applicable to real-world scenarios as possible from an HVAC (Heating, Ventilation and Air Conditioning) system and mechanical engineering perspective as well as human aspiration of Covid-19 bioaerosols. No member of the independent team currently has any financial or other interest in Energy Cloud Inc. and the hummingbird™ air purification products tested.

The initial independent team started in 2021 and included testing at USC during that year with additional members added in 2022 to review the new and expanded testing.

Members listed in chronological order when they joined the team.

Epidemiology and Bioaerosols:

- Joshua Santarpia Ph.D., Research Director, Chemical and Biological Programs, National Strategic Research Institute (NSRI) & Program director for Biodefense and Health Security Degree Program at the University of Nebraska Medical Center
- David J. Mustra Ph.D., Clarity Scientific Solutions
- Larry Bowen, Bioaerosol Scientist, In-tox Products

Engineering

- Lance Lippencott P.E., Program Director Black & Veatch
- Ryan J. Pletka P.E. Vice President, Innovation & Strategy Black & Veatch
- Christopher Howard, Mechanical Engineer(HVAC) Black & Veatch
- Constantinos Sioutas ScD, is the Co-Director of the Southern California Particle Center (SCPC) Fred Champion Professor and Professor of Civil and Environmental Engineering and Aerospace and Mechanical Engineering at USC
- Mike Wolf P.E., Director of Regulatory Business Development Greenheck, ASHRAE member
- Mark Shoukry Ph.D., P.E., LEED AP, ASHRAE member

Independent Funding of the initial 2021 testing and setup was provided by Black & Veatch

---

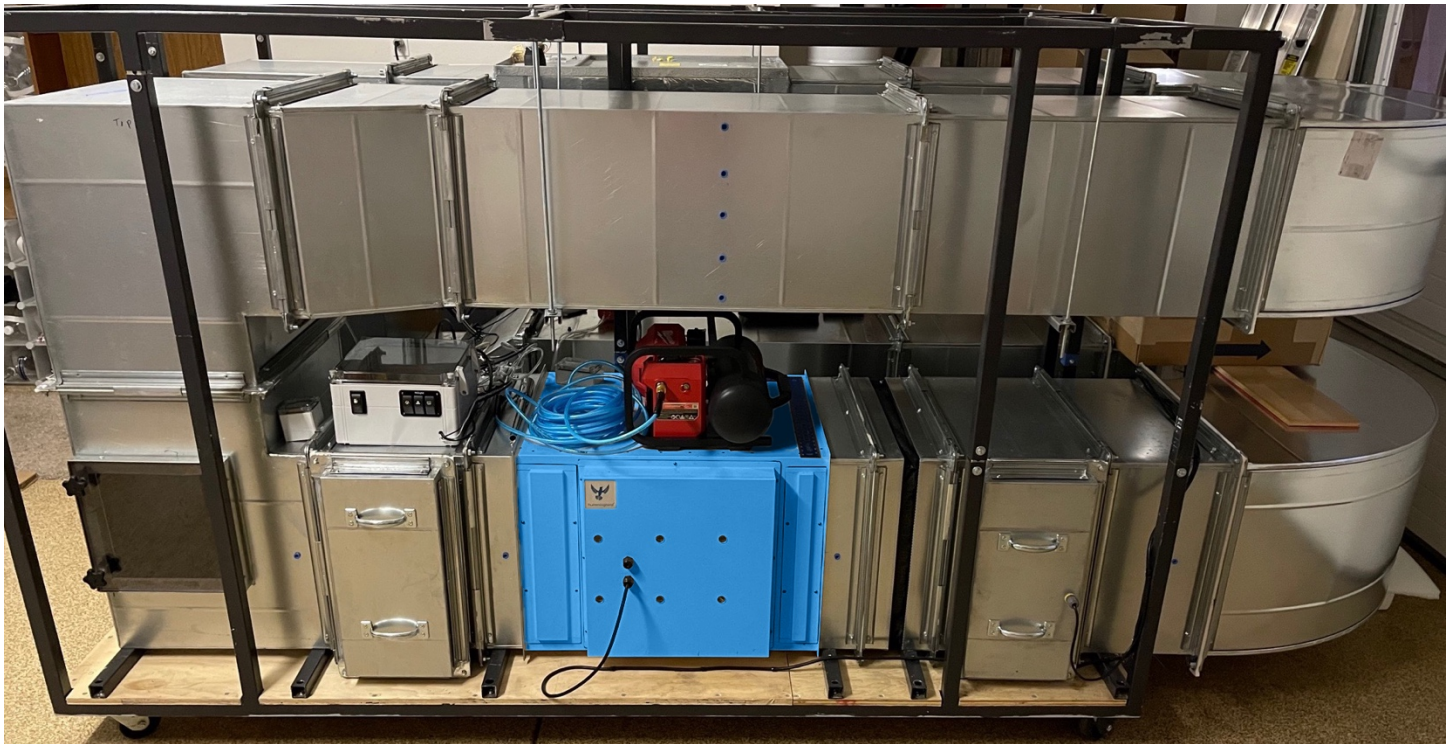
Introduction and background

In 2019 a novel coronavirus SARS-CoV2 was found to infect a cluster of patients in Wuhan China, and determined to be different than MERS-CoV2 and SARS-CoV[(1).] The new virus SARS-CoV2 (severe acute respiratory syndrome coronavirus 2) and the associated disease went on to create a worldwide pandemic named COVID-19.[(2)] Several studies demonstrated that the virus can be transmitted from respiratory emissions such as droplets and aerosolized breathing.[(3,4)] Additional studies looked to determine how the virus is transmitted which indicated that there is the possibility of the virus spreading beyond 6 feet around an infected individual through air currents or through the HVAC system. One such study and subsequent follow up report from Santarpia et al. (March 2020)[(5,6)] sampled air and surfaces at a hospital in Covid-19 patient rooms in addition to hallways outside of the rooms and demonstrated evidence of the virus on window ledges, under patient beds, in the hallways outside of patient rooms and up on the HVAC vents in the room. Our testing looked to further investigate can Covid-19 and variants survive in HVAC systems and can the hummingbird™ in-duct system deactivate Covid-19 in the HVAC system. Additionally, other versions of the hummingbird™ system are to be tested including an in-room portable unit and an automotive / aviation version.

Bio-aerosolized testing System

The goal of the disinfection efficacy testing was to test with realistic airflows found in HVAC systems. Traditionally, virus testing in BSL Level 3 and Level 4 labs is contained within a small 'primary' container which is worked on inside of a 6 foot or smaller bio-containment cabinet. The problem with this traditional setup, with respect to testing a bio-aerosol such as Covid-19, is that it's not real-world testing of how Covid-19 interacts and potentially lives as it circulates through the HVAC system and a building.

The **ABATE™ (Airborne Biological Assessment Threat Elimination)** system was built to solve this problem. The ABATE™ system achieves real-world /HVAC testing of bioaerosols with an air-handler / furnace, condenser coils and 50 feet of ducting and can be used to test different products and their effect on bioaerosols in airflows.

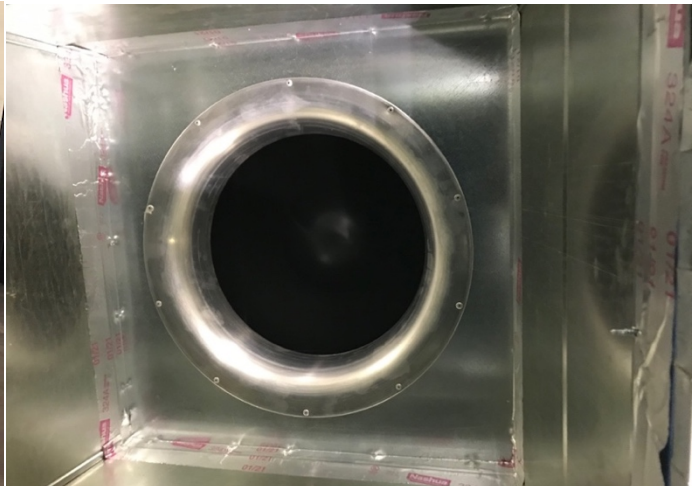


The ABATE system has two main configurations:

1. Multi-pass configuration is a closed loop system where the air and aerosolized Covid-19 is circulated in the closed loop for a set amount of time. This test can simulate multiple AC's (air changes through the system) and or timed trials.

2. Single-Pass configuration is set up so that aerosolized Covid-19 is only sent through the system one time allowing the filtration system being tested only a single pass attempt to deactivate the virus being tested. The Single-Pass test represents the best possible filtration efficacy. If the virus can be deactivated on a Single-Pass, it will not be infectious after leaving the system. It represents a single 'choke' point to be able to neutralize the virus as the air is circulated through the system. In the single-pass configuration a final 24" / 609.6 mm x 24" / 609.6 mm x 10" / 254mm HEPA (High efficiency particulate air) filter was used at the end of the line for bio-safety purposes and then the exhausted air fed into an additional air purification portable. These safety measures were further downstream from the virus collection point and had no bearing on the virus filtration efficacy.

Original Goodman Air Handler & Coil	New Commercial Fan



Airflow Speeds and Testing

In order to simulate a common sized HVAC system, the initial ABATE system was configured with a 5-ton Goodman furnace / air handler along with condenser coil. The intent was to test up to 2,000 CFM which is a realistic airflow level for this system. After finalizing and perfecting the ABATE system in the initial year of testing which was 2021, it was determined that the internal transition duct that was installed to help focus the virus, caused enough static pressure to slow the air flow to ranges from 700 - 1000 CFM. To overcome this internal static pressure and increase airflow testing capacity, a larger commercial fan was added to the ABATE system to achieve the original target CFM rate of 2,000 CFM for in-duct tests.

Airflow Measurements

Airflow measurements were taken immediately after the point of filtration as well as at the exit of the transition ducts which is immediately before the virus collection filter pads. Measurements were taken with a Fieldpiece STA2 Anemometer with duct size set and a traversal across the duct with 30 measurements which were averaged by the anemometer. For each different type of configuration of the overall system (single pass vs. multi-pass) and for each different type of filtration that shared the same airflow mechanical characteristics, the 30 measurement average was used. Because airflow naturally varies through different points in the duct it is fair to assume that even with the 30 averaged value used, there would normally be a + or – 25 CFM variance per 1000 CFM level.

Duct Sizes

Duct sizes of the ABATE system in multi-pass mode are 20" / 508mm high x 24" / 609.6 mm wide on the bottom row and 18" / 457.2 mm high x 20" / 508mm wide on the top row. For the Single pass configuration, the commercial fan 21.5" / 546.1mm high x 21.5" / 546.1mm wide sits on the top row, which quickly turns into a 180° turn into the bottom row of 20" / 508mm high x 24" / 609.6 mm wide.

Ozone Testing

Each test included an ozone air test to ensure that no ozone was produced by the filtration systems. The tests were conducted with a Forensics USA NIST calibrated ozone detector. No ozone was detected in any of the tests performed.

Virus Testing Logic & Methodology

The testing included aerosolizing SARS-CoV2 (Covid-19) and various variants of it through the ABATE system and through different filtration versions of the Hummingbird™ system. Dual filters were used for each test for additional confirmation of each test and directly placed within the air stream. An additional filter was used for qPCR testing with a specially engineering shrouded sample tube. The two internal filters were used for a Direct CPE assay.

Control Tests

Control tests were completed at the same airflow levels as the different filtration options tested, but without any filtration engaged. Covid-19 WT (original wild type), Delta and Omicron variants each had a separate Control Test.

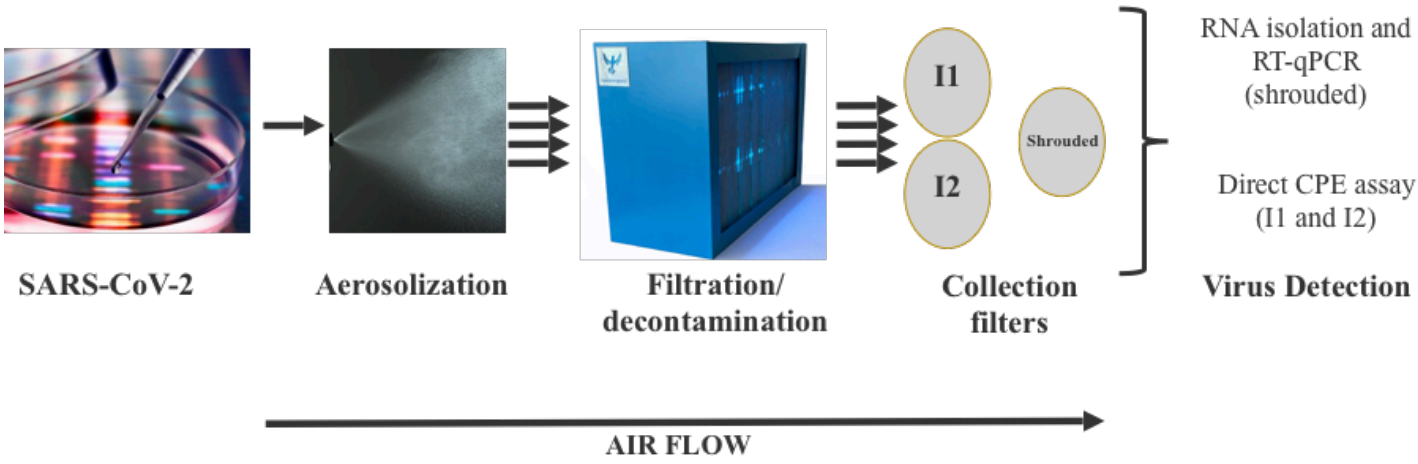
Aerosolized Composition & Strength

The goal of the efficacy testing was to prove that the hummingbird™ systems and different tested configurations could handle the largest of commercial buildings. Therefore, the team of 10 independent epidemiologists and engineers recommended that all testing was done with a large amount of virus to simulate a large number of infected individuals in a large building. The amount tested with each and every test was a 3,000x infectious dose, or enough to infect 3,000 individuals. The virus and various variants were also mixed with simulated saliva with mucin to simulate typical aerosolized breathing and aerosols of a human. This total mixture included 4 ml of Covid-19 / variant and 3 ml of simulated saliva.

Nebulizer & Particulate Measurement

The mixture was aerosolized inside of the ABATE system using three nozzle heads with pressurized air and liquid lines at 45 psi. Each nebulizing head was controlled with electronic shut-off valves. To aerosolize the large dose, is typically took between 15 and 45 seconds to fully aerosolize. Each test included 10 different levels of particulate measurements to quantify the mass, number and average particulate sizes. The aerosols were measured at the point of nebulizing and as the virus final collection points parallel to the point of qPCR collection. Sample data was collected in one second increments during the totality of each test. This data is supplemental and supportive that the tests were all conducted in a similar manner with similar nebulization. The epidemiology CPE and qPCR assays are the authoritative efficacy conclusion in regards to virus deactivation.

Bioaerosol Testing Logic Flow



Filter Capture and Processing

Two 47mm PTFE filters were mounted side by side in line of the air flow post flow concentration through a 6" / 152.4mm transition duct (Internal). A singular filter was placed in a shrouded capture column (shrouded) next to particle measurement equipment. Post nebulization and HVAC shutdown, the filters were removed for CPE and qPCR processing.

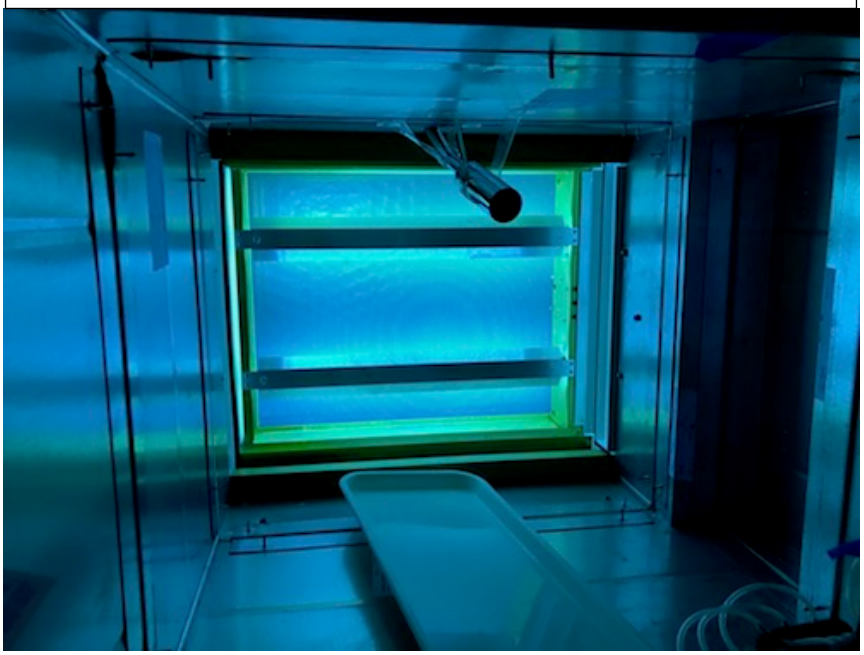
qPCR Processing

Using tweezers, the shrouded filter was placed directly into lysis buffer for RNA extraction. Total RNA was extracted following the manufacture instructions. cDNA was made using an iscript system. qPCR was performed using CDC validated SARS-CoV2 primer sets in a Taq polymerase system. All qPCR values are based on a known DNA standard curve. All analysis was performed using the Bio-Rad Maestro software algorithms for threshold.

CPE Processing

Using tweezers, the internal filters were removed and placed directly into separate tubes containing 200 microliter DMEM media, 10% FBS and penicillin/ streptomycin. 100 microliter was removed from each sample and placed into another tube for back-up. All samples were placed in -80 degree ºC for storage. Vero-E6 hACE2 cells were seeded and 24 hours later frozen samples were thawed and cells infected. Imaging was performed daily using a 4X magnification on a Revolve microscope.

Nebulizer Particulate Sample Probe & active Hummingbird™ system behind it.



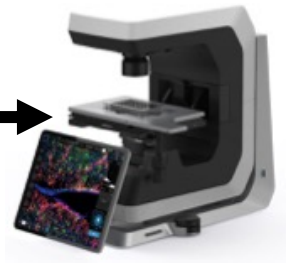
Cytopathic Effect (CPE) Assay

1. Plate Vero E6-hACE2 cells

2. Add elutes from collection filters

3. Incubation at 37^0C

4. Detection of CPE (4x magnification)



Output CPE

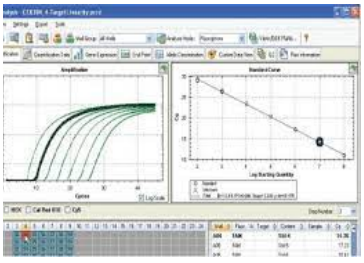
Quantitative Polymerase Chain Reaction (qPCR)

1. RNA Extraction

2. cDNA Synthesis

3. qPCR Run

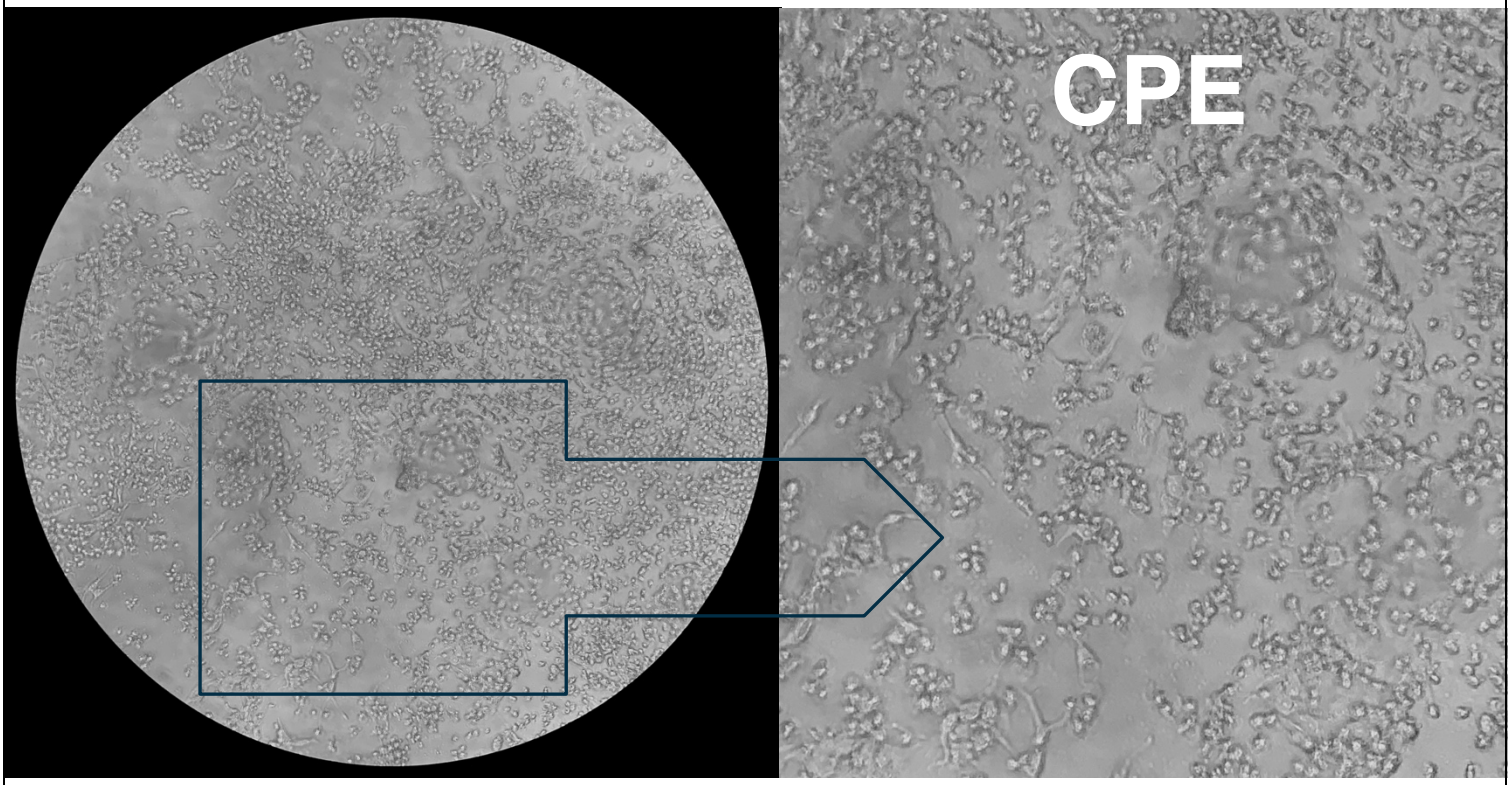
4. qPCR Analysis



Example of High-resolution Microscope Images of Single Wells

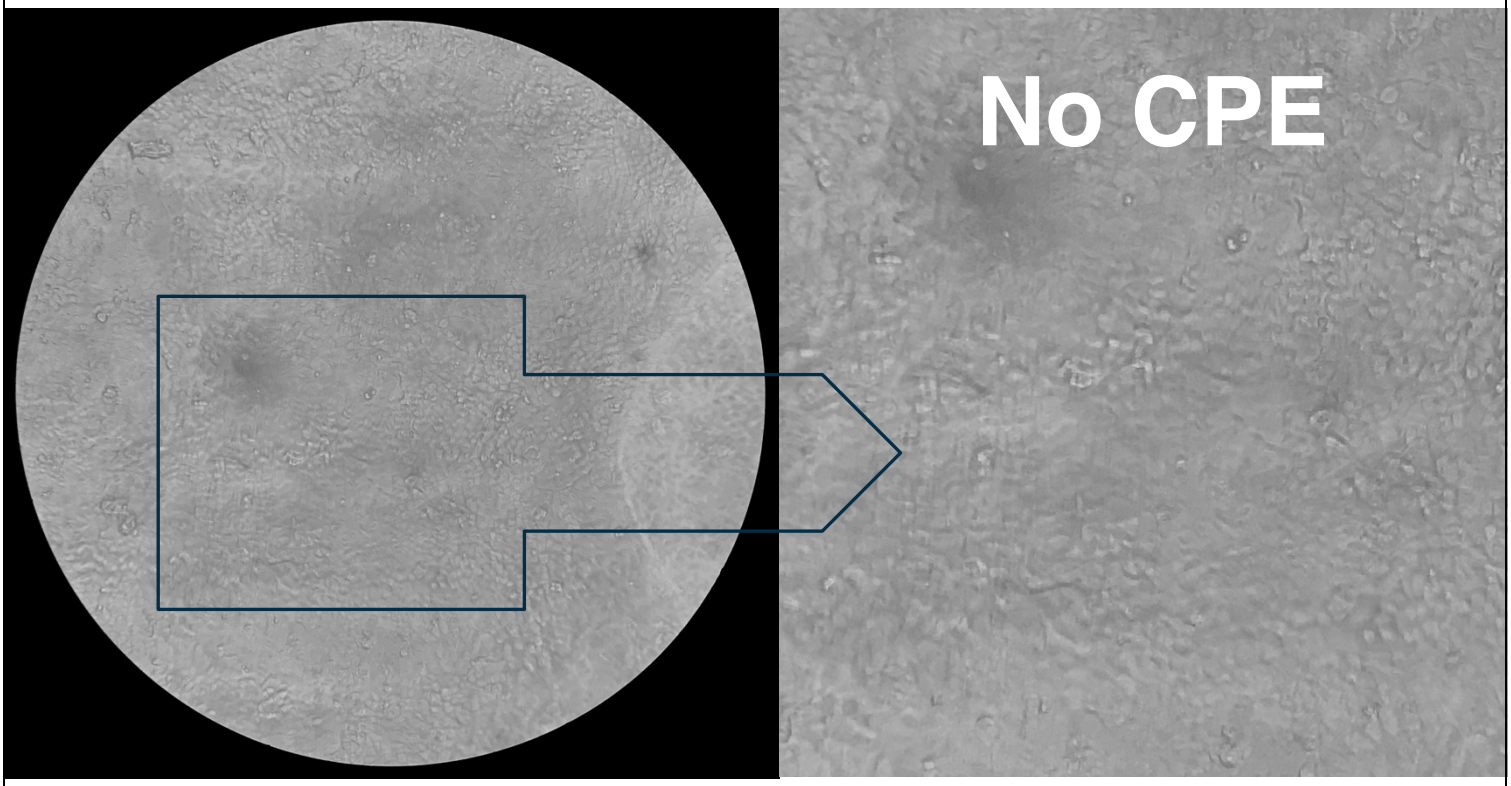
Test: Baseline (No Filtration) / Virus: Covid-19 WT (Wild Type) Day4 Filter I1_2 CPE Present

Full Scan Day 4 Zoom of Full Scan



Test: Hummingbird AP1000 / Virus: Covid-19 WT (Wild Type) Day 4 Filter I1_2 No CPE

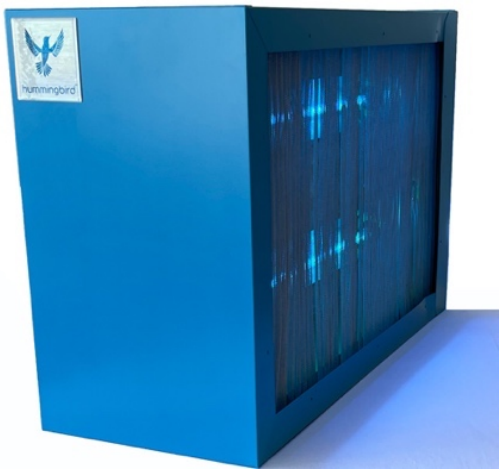
Full Scan Day 4 Zoom of Full Scan



Filtration Systems being tested

Three different hummingbird™ air purification models / systems were tested in this round of testing.

Hummingbird AP10000 (In-duct Model)



The hummingbird™ AP10000 is a system that uses multiple layers of protection to filtrate and disinfect. It includes both a MERV13 - 4" thick filter and photocatalytic oxidation chamber which consist of both UV light and Titanium Dioxide. The system is built to be installed in HVAC return ducts and intended to protect buildings by disinfecting the air when the building air is fully exchanged by the HVAC system, commonly measured in ACH (Air changes per hour). The systems can handle up to 2,500 CFM per unit and can be combined together to handle larger airflows and larger HVAC systems. The target for the virus testing is 2,000 CFM +/- 75 CFM. Multiple systems being used with the 2,000 CFM target could be combined to protect a 10,000 CFM airstream with 5 units combined for example. The system is also capable of breaking down VOC's (volatile organic compounds), but that is not being tested in these battery of tests.

Hummingbird Automotive / Aviation

The hummingbird™ Automotive / Aviation unit is aimed at disinfecting HVAC airstreams in transportation such as cars, trucks, buses, planes and other vehicles. It is intended to be installed in-line with the vehicle HVAC return ducting system and relies on the vehicles internal cabin fan to provide the air circulation. It is expected to directly work with automotive and aviation manufacturers to embed the system in future vehicles and planes. Like the AP10000, the system also breaks down VOC's (volatile organic compounds) and carbon monoxide. The expected need for transportation systems is to handle up to 600 CFM of airflows. The system was tested with the ABATE internal fan running at ~700 CFM to meet or exceed the requirements of internal automotive and aviation HVAC systems. The active airflow area was 10" / 254mm x 10" / 254mm which is similar to the average automotive filter sizes which are approximately 10" / 254mm x 9" / 228.6mm. The system can be designed to handle any size filter dimension.

Hummingbird™ Portable Model 888

The hummingbird™ portable Model 888 includes its own internal fan which is used to circulate the air through the system for disinfection. The system includes multiple filtration levels including a multi-layered HEPA filter, charcoal filters and photocatalytic oxidation. The system was tested inside the ABATE system for biosafety purposes. The hummingbird™ internal fan was used for moving airflow, not the ABATE commercial fan.

Legend / Definitions

Testing Parameters

Multi-pass	A closed loop system where infectious air flow recirculated through system
Single pass	An open system where infectious air flow was drawn through the system once
ml	Volume of virus in milliliters / to the total volume used (brought to total volume with synthetic saliva)
Portable 888	Hummingbird™ Portable Model 888
Filter Used	M13: MERV13 filter custom designed for hummingbird with 'Deep Fiber', HEPA is custom designed Multi-layered HEPA with carbon back & pre-filter
PCO	Photocatalytic Oxidation
PCO Light Source	UVC Lamp or UCC LED
Transition Duct	Internally used to decrease diameter of duct from 20" / 508_{mm} x 24" / 609.6_{mm} to 6" / 152.4_{mm} round to focus infectious material capture.

Testing Outputs

WT	Wild-type, clone of SARS-CoV-2 reference strain (2019-nCOV)
SA	SARS-CoV-2 variant of concern beta (B.1.351; South Africa, May 2020)
Delta	SARS-CoV-2 variant of concern delta (B.1.617.2; April 2021)
Omicron	SARS-CoV-2 variant of concern omicron (B.1.1.529; November 2021)
BA.2	SARS-CoV-2 variant of concern omicron (B.1.1.529, BA.2; December 2021)
Cq	Quantitation cycle – cycle in which fluorescence can be detected through amplification of viral cDNA
Total GE	Genomic equivalent of SARS-CoV-2 RNA present based on a known standard curve
CPE	Cytopathic effect occurs when virus is present and kills permissive cells. Noted by the absence of cells and clumping of dead cells. CPE is evaluated at day 4 post infection
Y = Detected	Indicates CPE detected at d4 post infection from either or both filter 1 or 2
N = Not Detected	Indicates CPE was not detected at d4 post infection from either filter 1 or 2
ID50	Infectious dose is expressed as ID_{50} and refers to the number of pathogens sufficient to infect 50% of a given susceptible population
BLD-GE	Test was Beyond limit of detection for Genomic equivalent
CPE detection limit	CPE not present at d4 post infection indicates <10 PFU WT virus, < 100 PFU SA virus
Volume (CFM)	Post filtration CFM immediately after the filtration device. (Cubic feet per min.)
Volume (m^3/hr)	Post filtration m^3/hr immediately after the filtration device.(Cubic meters / hour)
Velocity (fpm)	Air velocity in feet per minute.
Velocity (m/s)	Air Velocity in meters / second
Velocity (mph)	Air Velocity in miles per hr
Particulate Sensor:	Green Color: Viral Collection Point (sensor 3F9D2F02D9EA0D72) Red Color: Nebulizer Collection Point (sensor: C5D11573560D083D)
Pressure Across Filter	Pressure drop across filtration in WC (inches water column)
Mass Concentration	PM 1.0: 0.3 to 1.0 µm (microns) PM 2.5: 0.3 to 2.5 µm (microns) PM 4.0: 0.3 to 4.0 µm (microns) PM 10: 0.3 to 10.0 µm (microns)
Number Concentration	Part Number .5: 0.3 to 0.5 µm (microns) Part Number 1.0: 0.3 to 1.0 µm (microns) Part Number 2.5: 0.3 to 2.5 µm (microns) Part Number 4.0: 0.3 to 4.0 µm (microns) Part Number 10: 0.3 to 10.0 µm (microns)

Test: Covid-19 WT Baseline: No Filtration

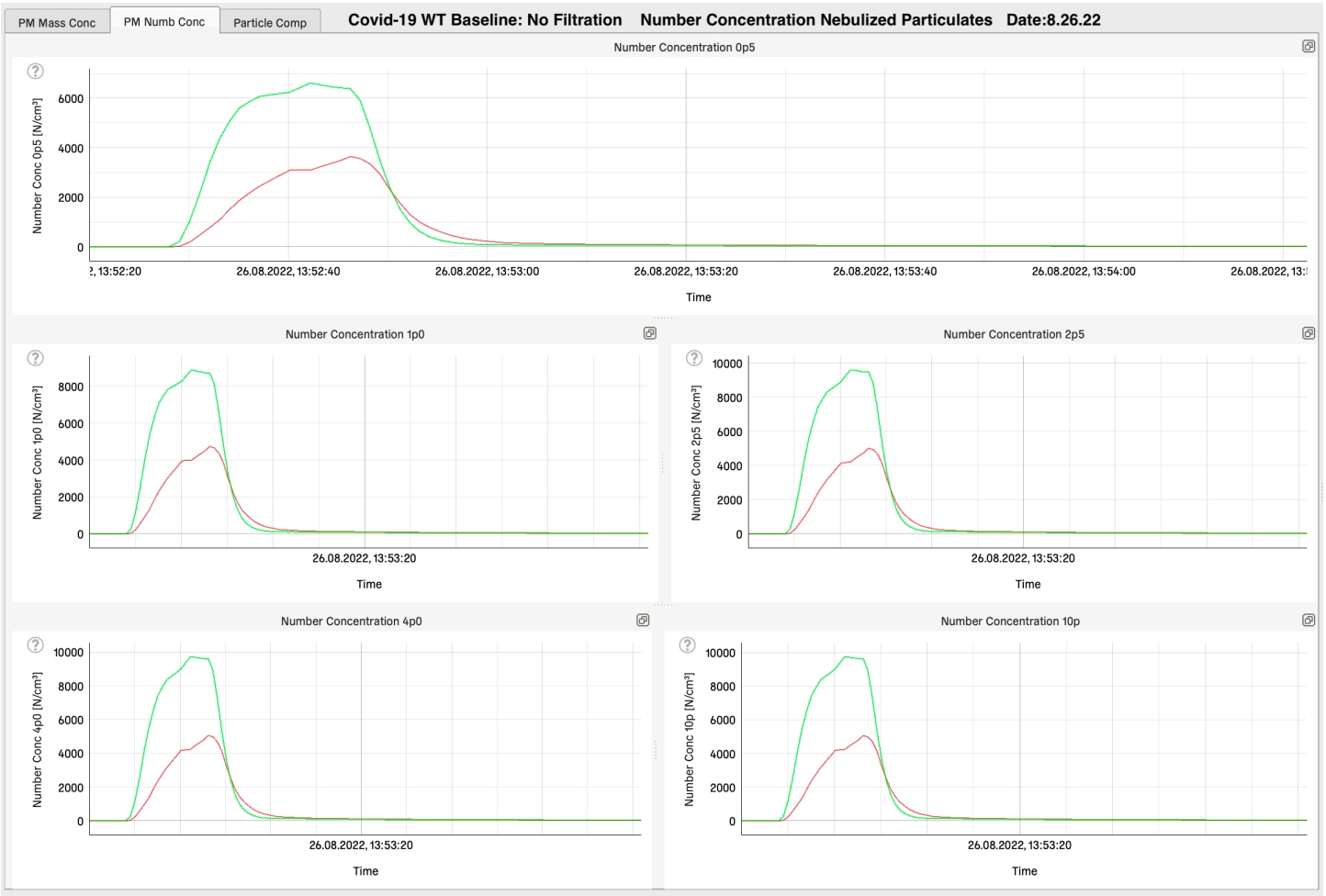
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Baseline - No Filtration	WT PI	Single Pass	4/7	3000^{+}	<45 sec.	-	-	-	1.7316E+04	Y	Y

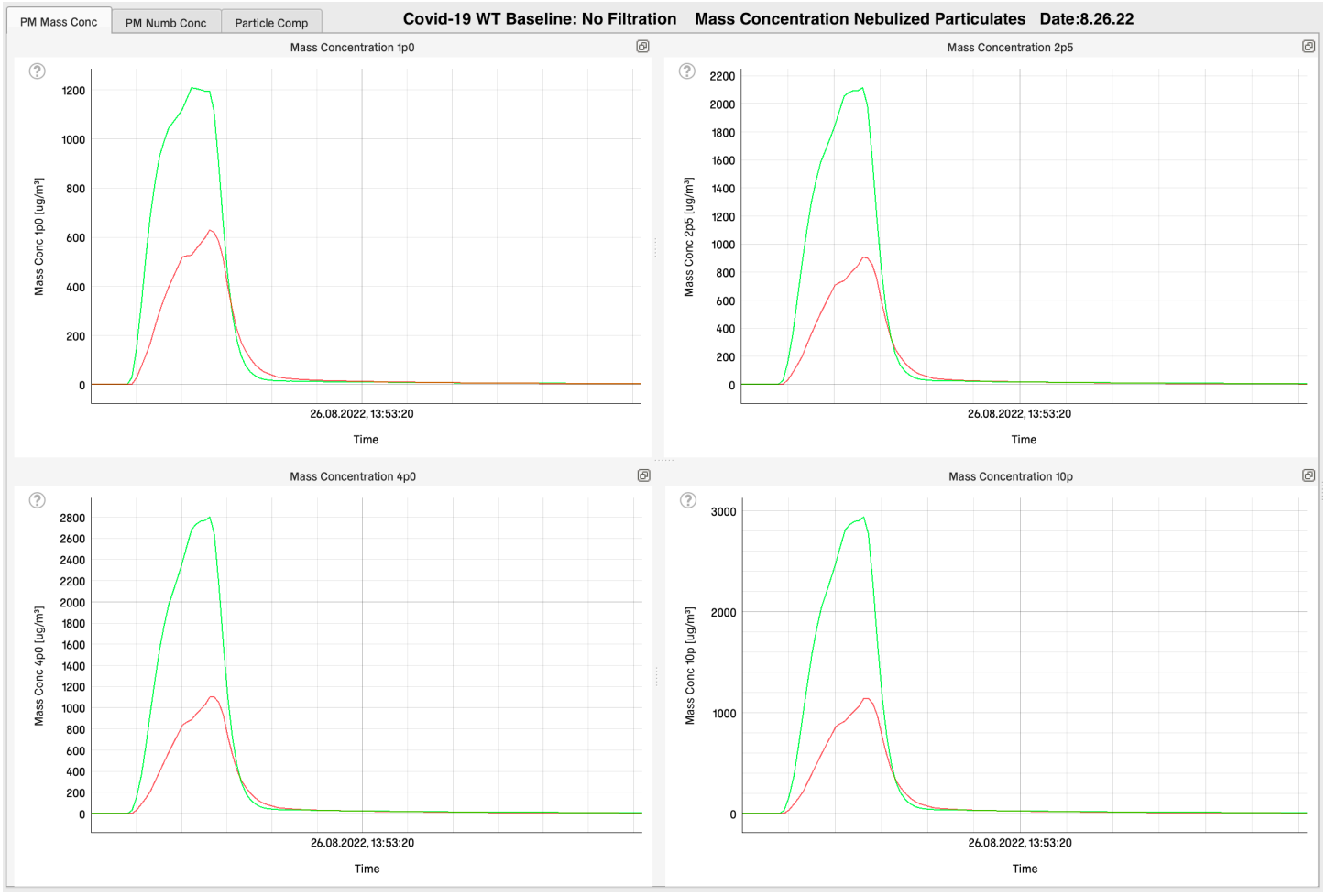
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.80	629.3	906.5	1101.7	1141.7	3644.5	4734.3	5006.9	5050.2	5058.3
Post Filter	0.86	1208.6	2114.6	2802.9	2940.5	6613.0	8883.8	9595.1	9713.3	9735.6

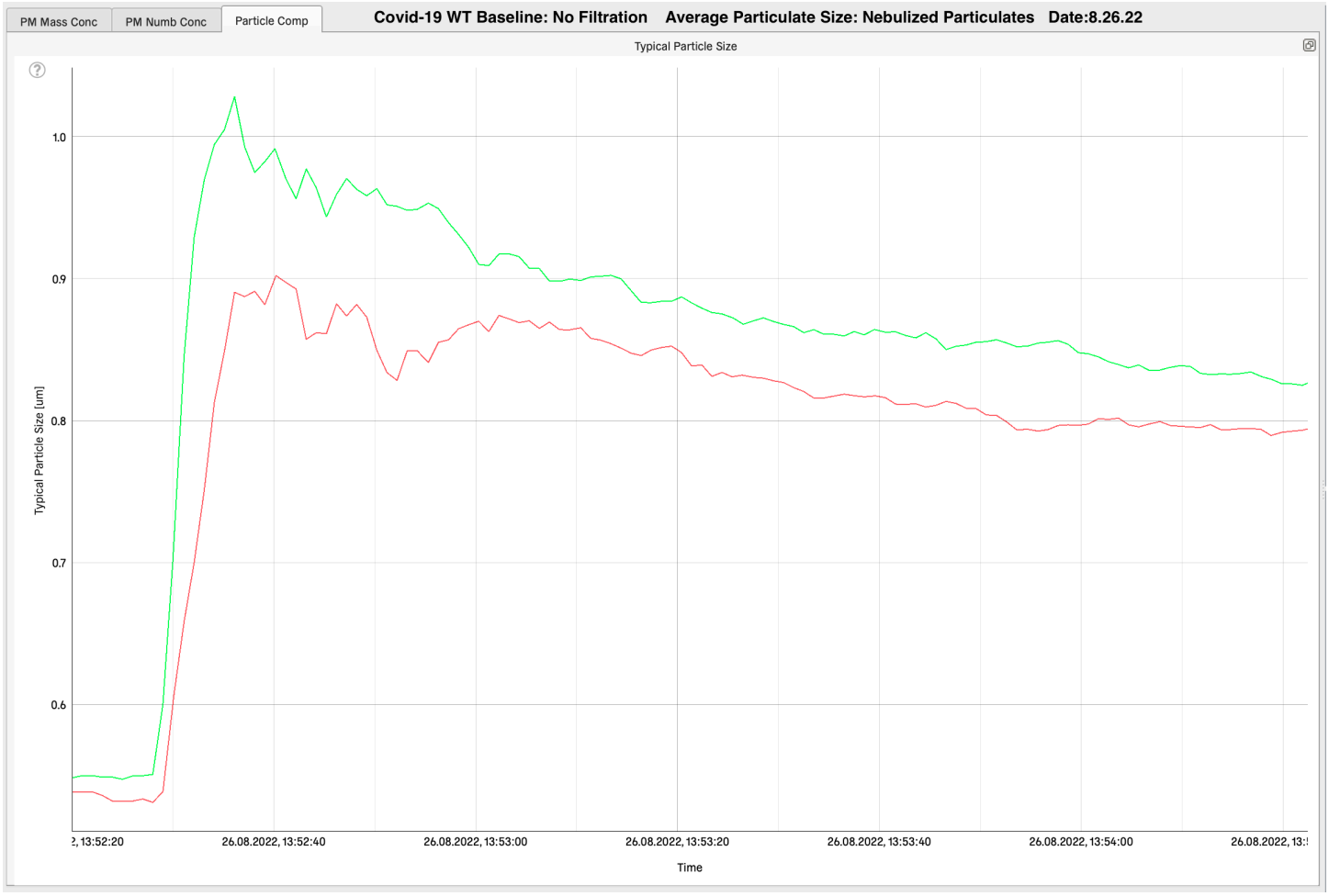
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1940	3296.08	582	2.96	55.61	4893.98	89.50

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
N /A	20” x 24”	6”	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Baseline: No Filtration Mass Concentration Nebulized Particulates Date:8.26.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
26.08.2022, 13:53:20
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Baseline: No Filtration Average Particulate Size: Nebulized Particulates Date:8.26.22
Typical Particle Size
Typical Particle Size [um]
26.08.2022, 13:52:40
26.08.2022, 13:53:00
26.08.2022, 13:53:20
26.08.2022, 13:53:40
26.08.2022, 13:54:00
Time

Test: Delta Baseline: No Filtration

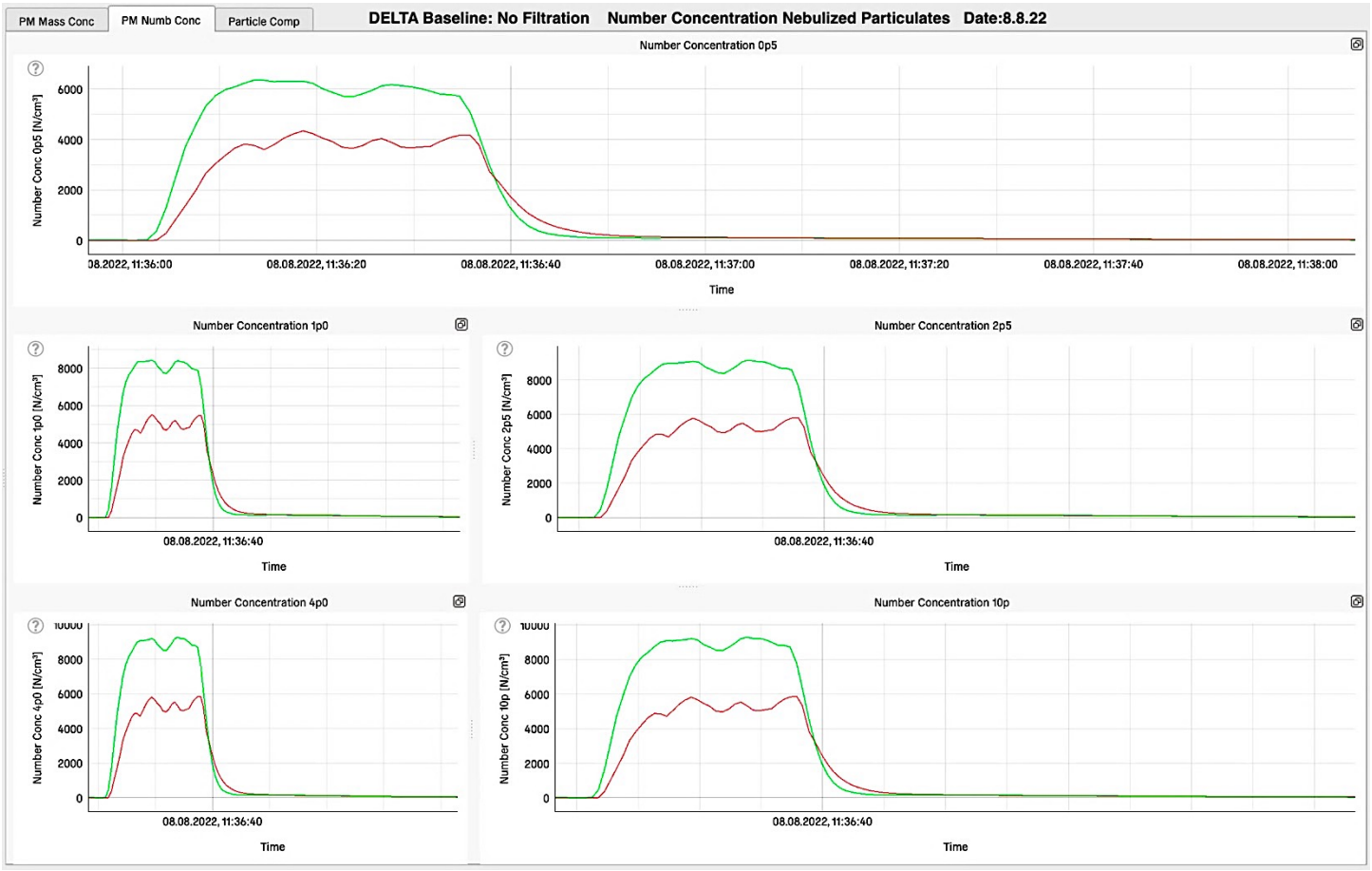
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Baseline - No Filtration	Delta	Single Pass	4/7	3000+	<30 sec.	-	-	-	1.23816E+03	Y	Y

Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.80	728.2	1,068.1	1,309.3	1,357.6	4,341.8	5,517.9	5,792.6	5,846.1	5,855.9
Post Filter	0.87	1,151.7	2,032.0	2,698.3	2,831.6	6,357.2	8,428.1	9,139.2	9,261.8	9,284.7

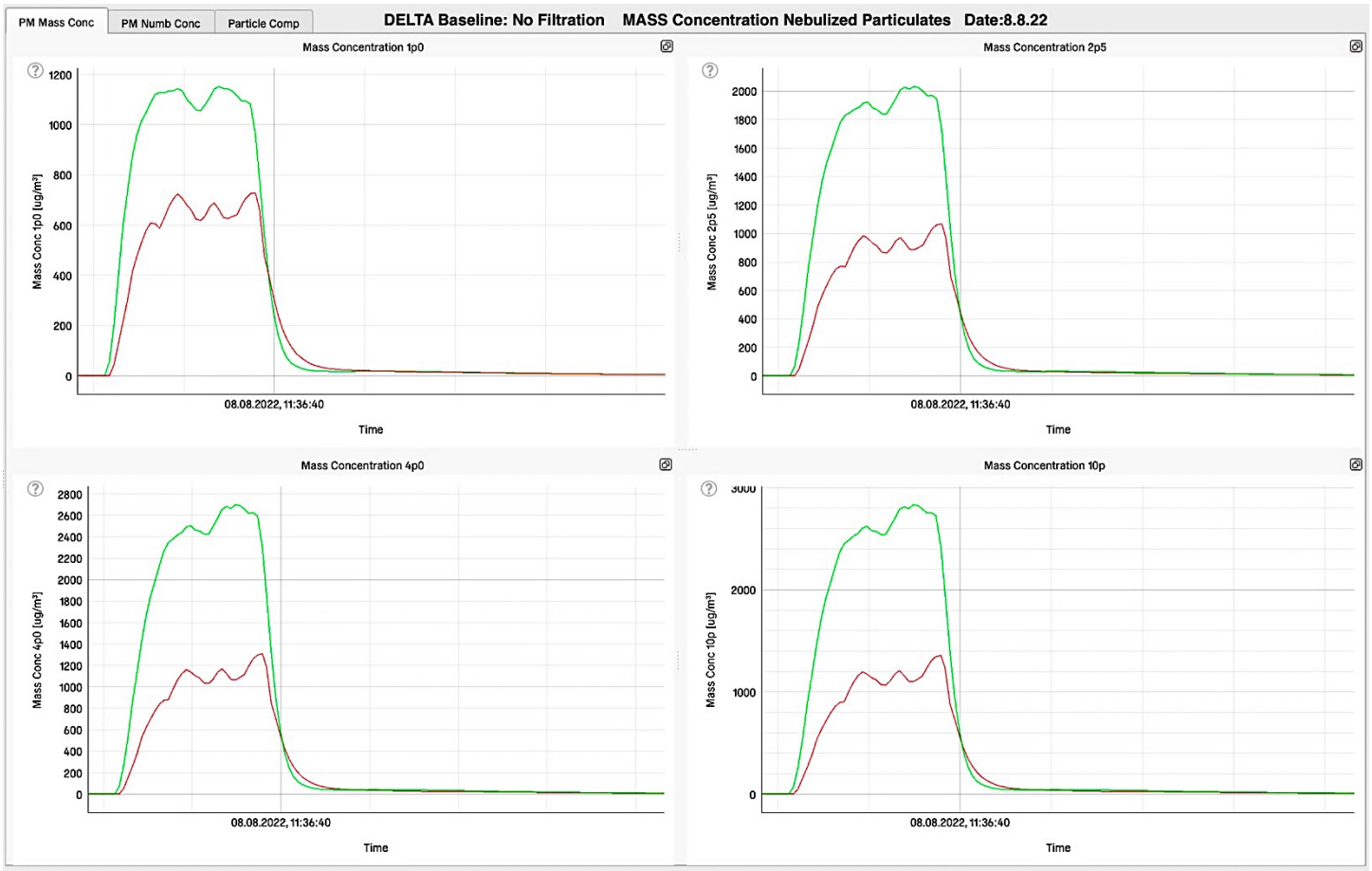
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1940	3296.08	582	2.96	55.61	4893.98	89.50

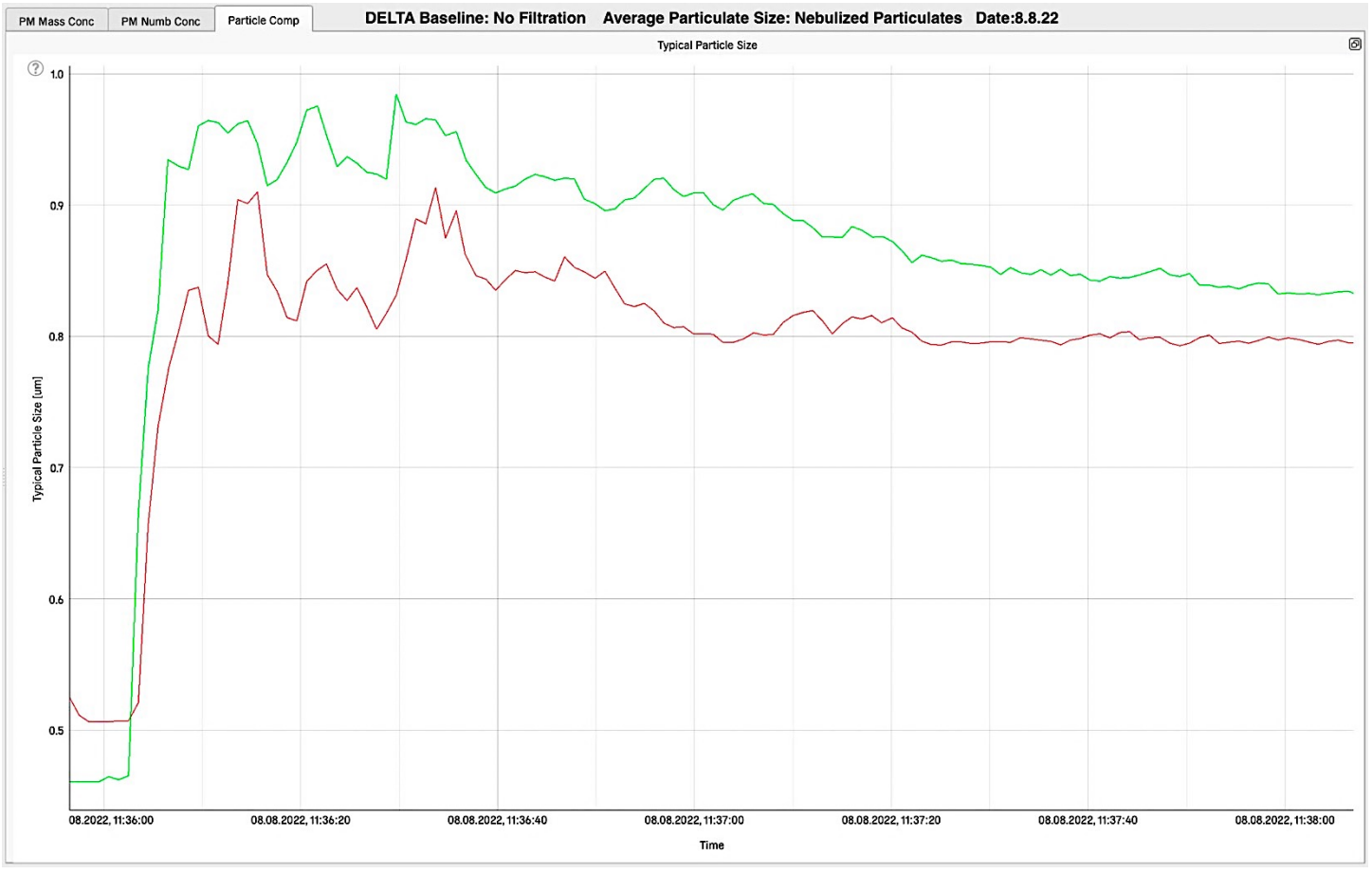
Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
N /A	20" x 24"	6"	0.0



Test: Delta Baseline: No Filtration CFM: Date: 8.11.22 (Continued)





Test: Omicron Baseline: No Filtration

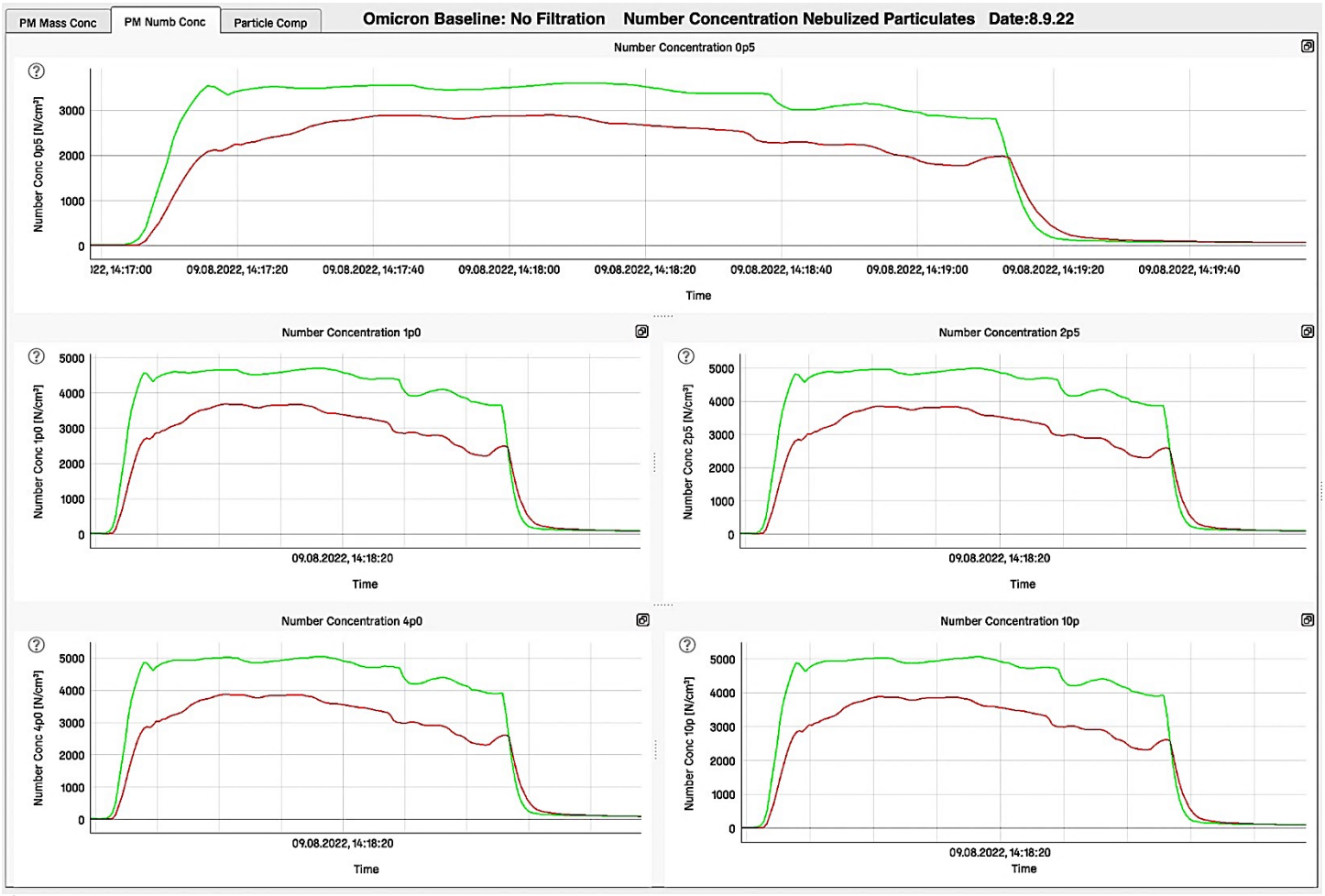
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Baseline - No Filtration	Omicron	Single Pass	4/7	3000+	<30 sec.	-	-	-	1.56646E+03	Y	Y

Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.78	483.7	659.3	779.0	802.9	2,898.2	3,679.9	3,851.0	3,877.8	3,882.9
Post Filter	0.86	628.9	996.4	1,267.8	1,322.1	3,608.3	4,699.7	4,998.8	5,047.8	5,057.1

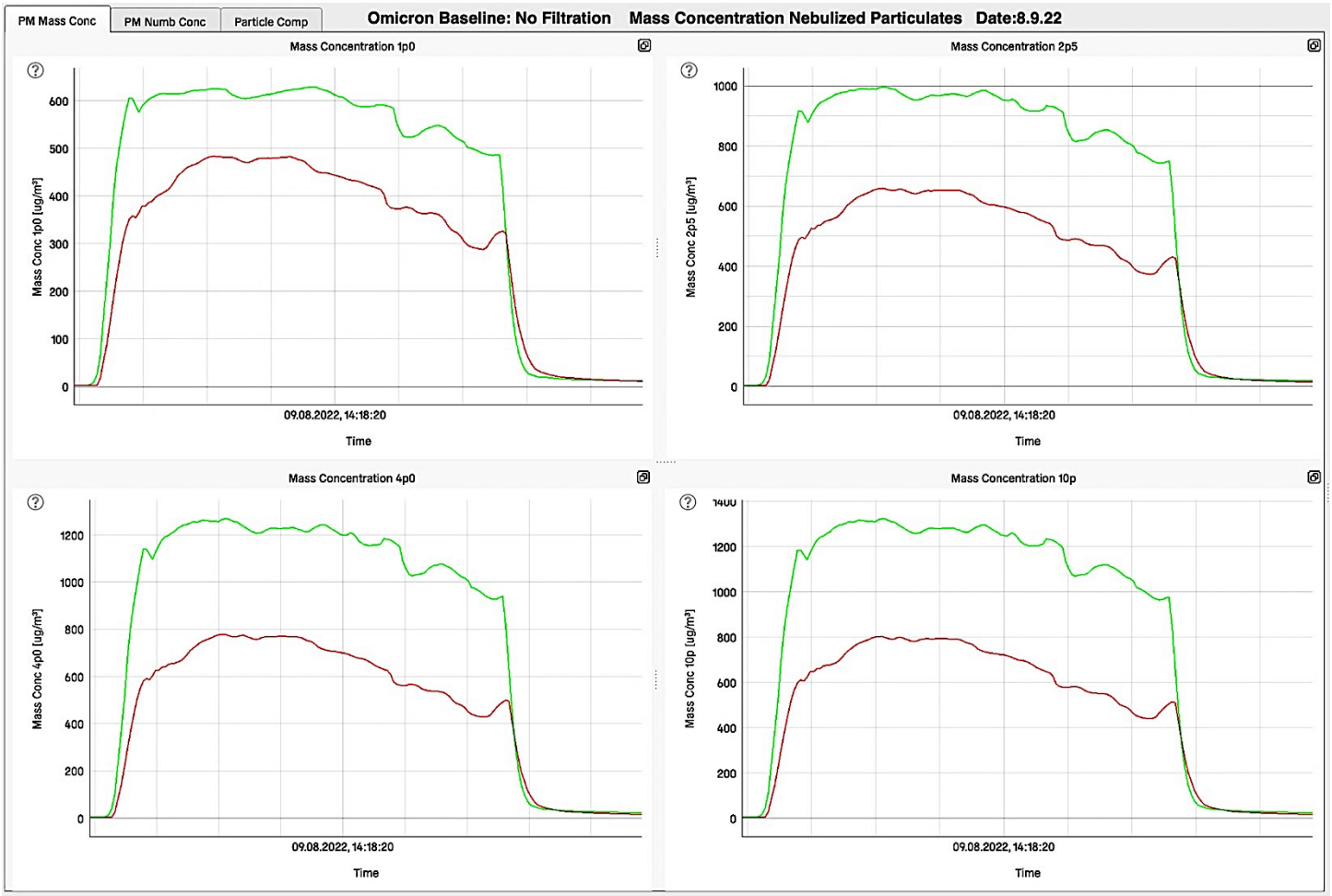
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1940	3296.08	582	2.96	55.61	4893.98	89.50

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
N /A	20” x 24”	6”	0.0



v 2.5


PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Baseline: No Filtration Mass Concentration Nebulized Particulates Date:8.9.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
600
500
400
300
200
100
0
09.08.2022, 14:18:20
Time
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
1000
800
600
400
200
0
09.08.2022, 14:18:20
Time
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
1200
1000
800
600
400
200
0
09.08.2022, 14:18:20
Time
Mass Concentration 10p
Mass Conc 10p [ug/m³]
1400
1200
1000
800
600
400
200
0
09.08.2022, 14:18:20
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Baseline: No Filtration Average Particle Size Nebulized Particulates Date:8.9.22
Typical Particle Size
Typical Particle Size [um]
1.0
0.9
0.8
0.7
0.6
0.5
2022, 14:17:00
09.08.2022, 14:17:20
09.08.2022, 14:17:40
09.08.2022, 14:18:00
09.08.2022, 14:18:20
09.08.2022, 14:18:40
09.08.2022, 14:19:00
Time

Baseline Conclusion

The baseline tests were all conducted with no filtration and were used to compare against different filtration solutions.

SARS-CoV2 / Covid-19 and all variants survived flowing through the HVAC test system at velocities of up to 2,000 CFM in the 20" / 508$_{mm}$ x 24" / 609.6$_{mm}$ ducts. Some airflow measurements were above 2,000 CFM but the average value of 30 measurements was used for all baseline tests which had a similar mechanical setup and profile.

It is interesting to note that the air velocity which was sped up while traversing the final 6" /152.4$_{mm}$ focus internal transition duct was over 55 mph / 4898 fpm which is four times greater than what is found in traditional commercial HVAC airflows and over eight times greater than typical residential HVAC airflows. This strongly indicates that Covid-19 and its variants can easily survive while being passed through HVAC systems and are likely spread throughout a building via the HVAC system. This is in addition to the previous year's testing which included Covid-19 WT and the Beta variant also surviving 50mph+ velocities in both single and multi-pass tests.

Test: Hummingbird™ AP10000: Covid-19 WT

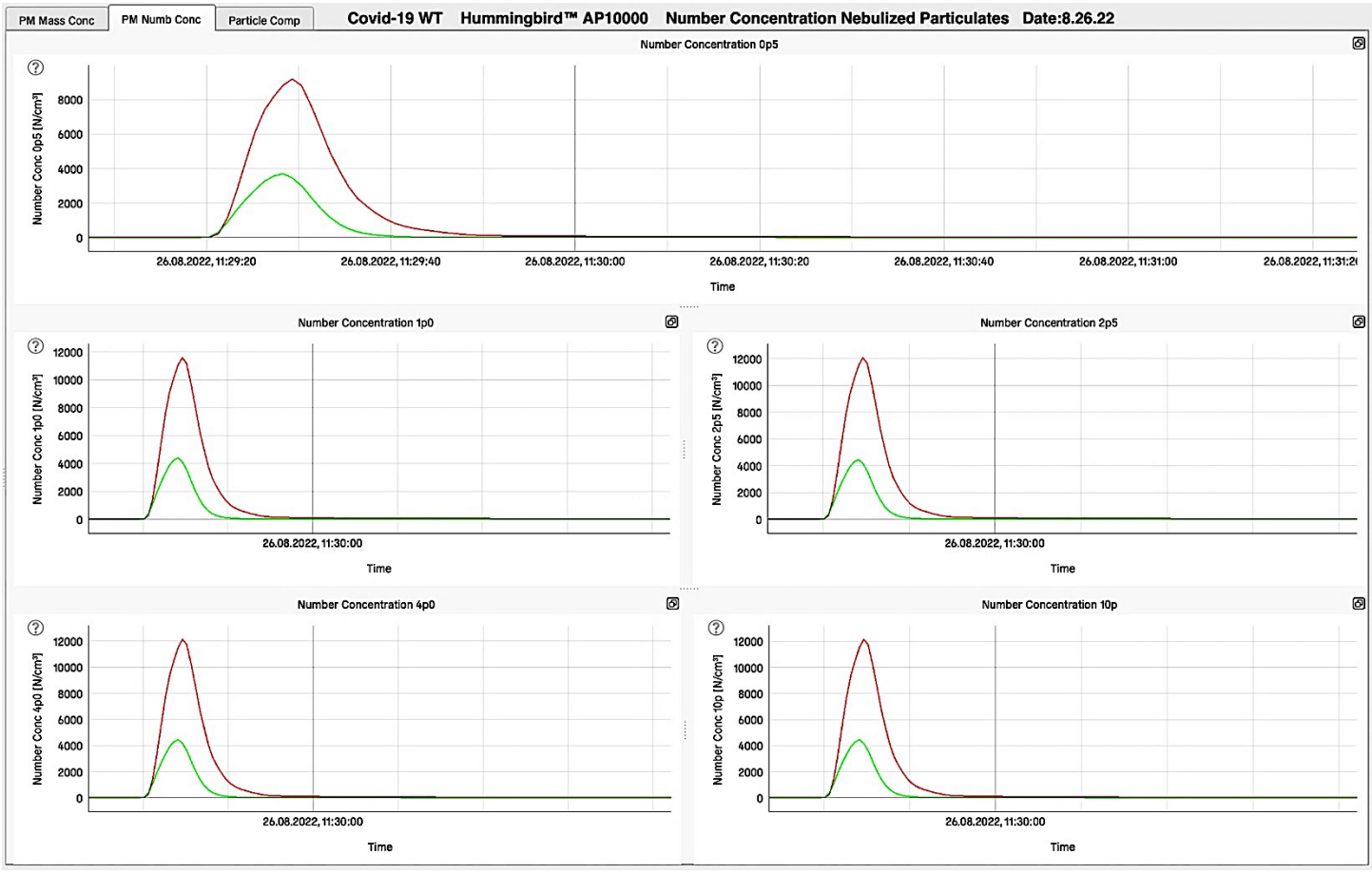
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird AP10000	WT PI	Single Pass	4/7	3000+	<45 sec.	Lamp	M13	√	3.05E+02	N	N

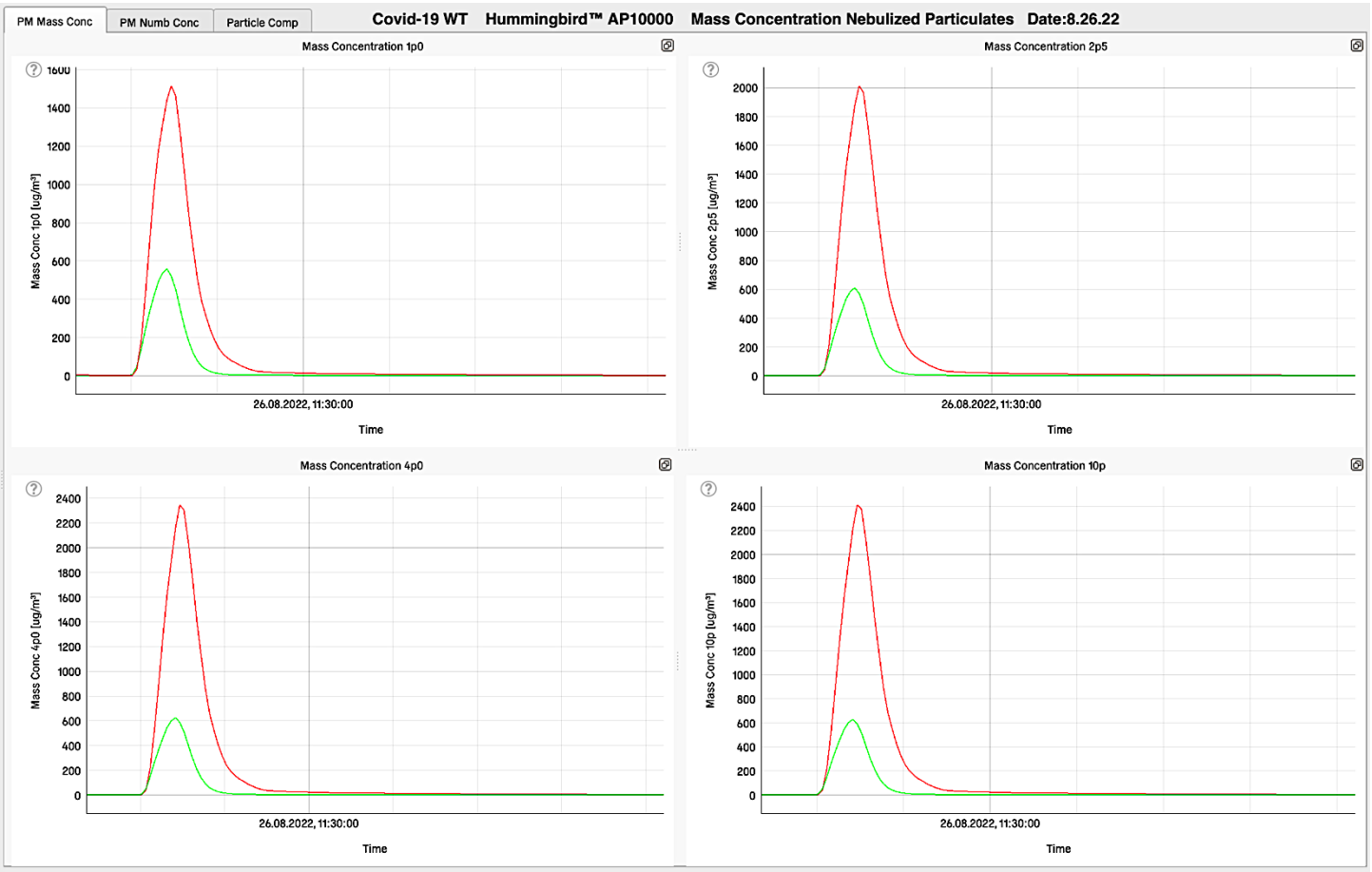
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.71	1,515.4	2,012.7	2,344.8	2,411.2	9,189.0	11,585.7	12,067.8	12,142.6	12,157.0
Post Filter	0.69	558.8	610.2	625.9	629.0	3,707.8	4,409.2	4,458.0	4,462.7	4,464.2

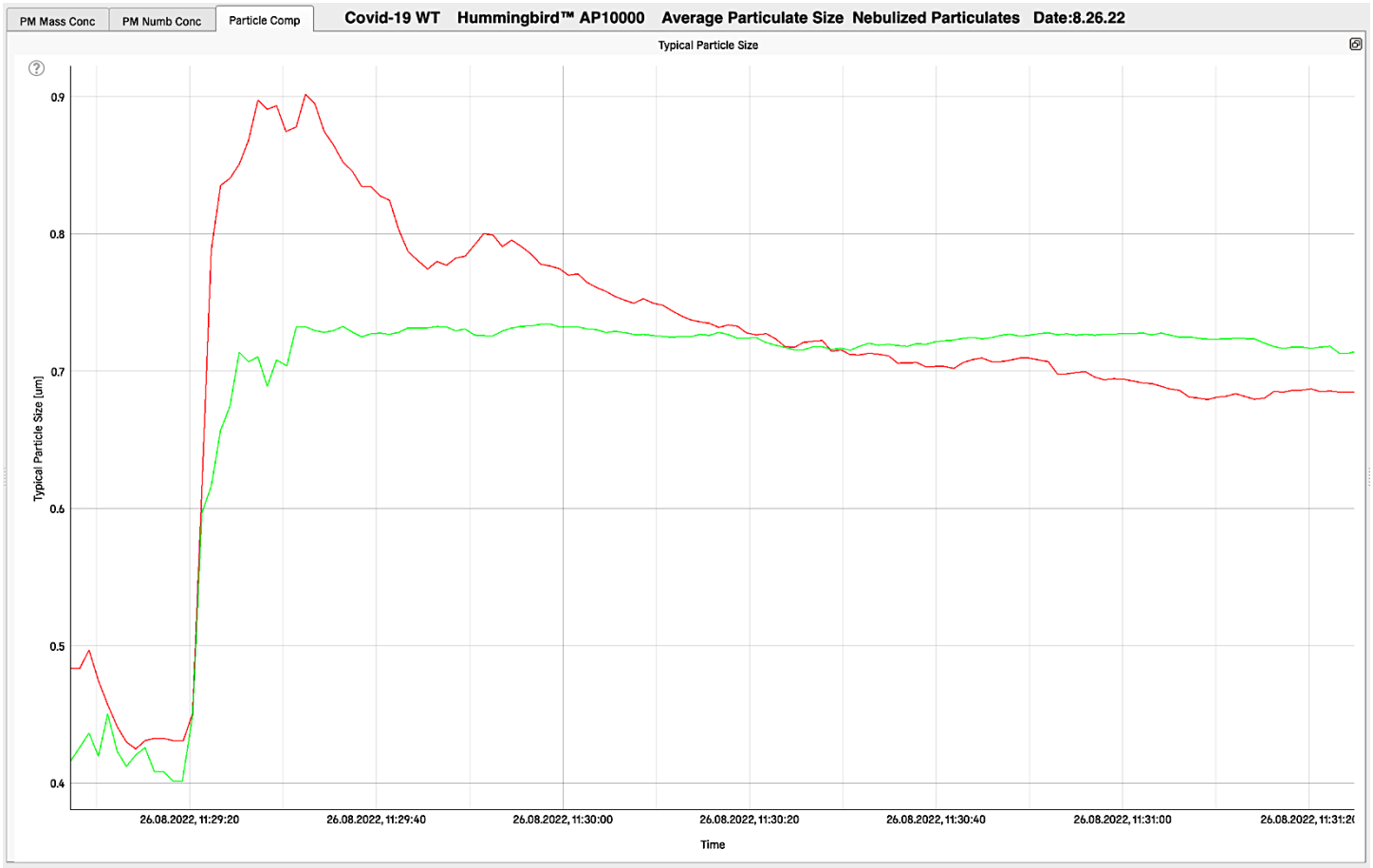
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1976	3357.25	592.8	3.01	51.19	4504.98	82.38

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.205"WC	20" x 24"	6"	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Hummingbird™ AP10000 Mass Concentration Nebulized Particulates Date:8.26.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
26.08.2022, 11:30:00
Time
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
26.08.2022, 11:30:00
Time
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
26.08.2022, 11:30:00
Time
Mass Concentration 10p
Mass Conc 10p [ug/m³]
26.08.2022, 11:30:00
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Hummingbird™ AP10000 Average Particulate Size Nebulized Particulates Date:8.26.22
Typical Particle Size
Typical Particle Size [um]
26.08.2022, 11:29:20
26.08.2022, 11:29:40
26.08.2022, 11:30:00
26.08.2022, 11:30:20
26.08.2022, 11:30:40
26.08.2022, 11:31:00
Time

Test: Hummingbird™ AP10000: Delta Variant

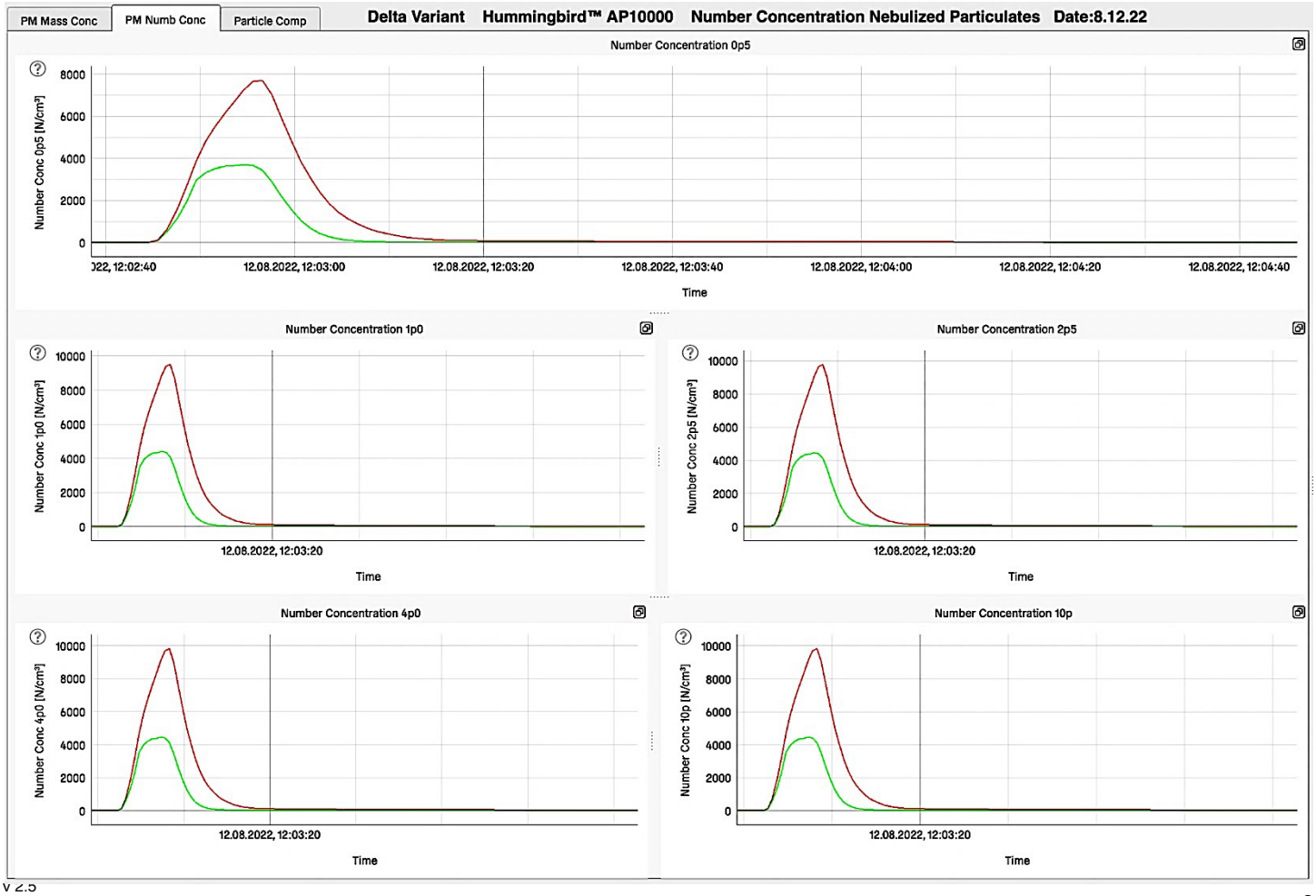
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird AP10000	Delta	Single Pass	4/7	3000+	<30 sec.	Lamp	M13	√	BLD-GE	N	N

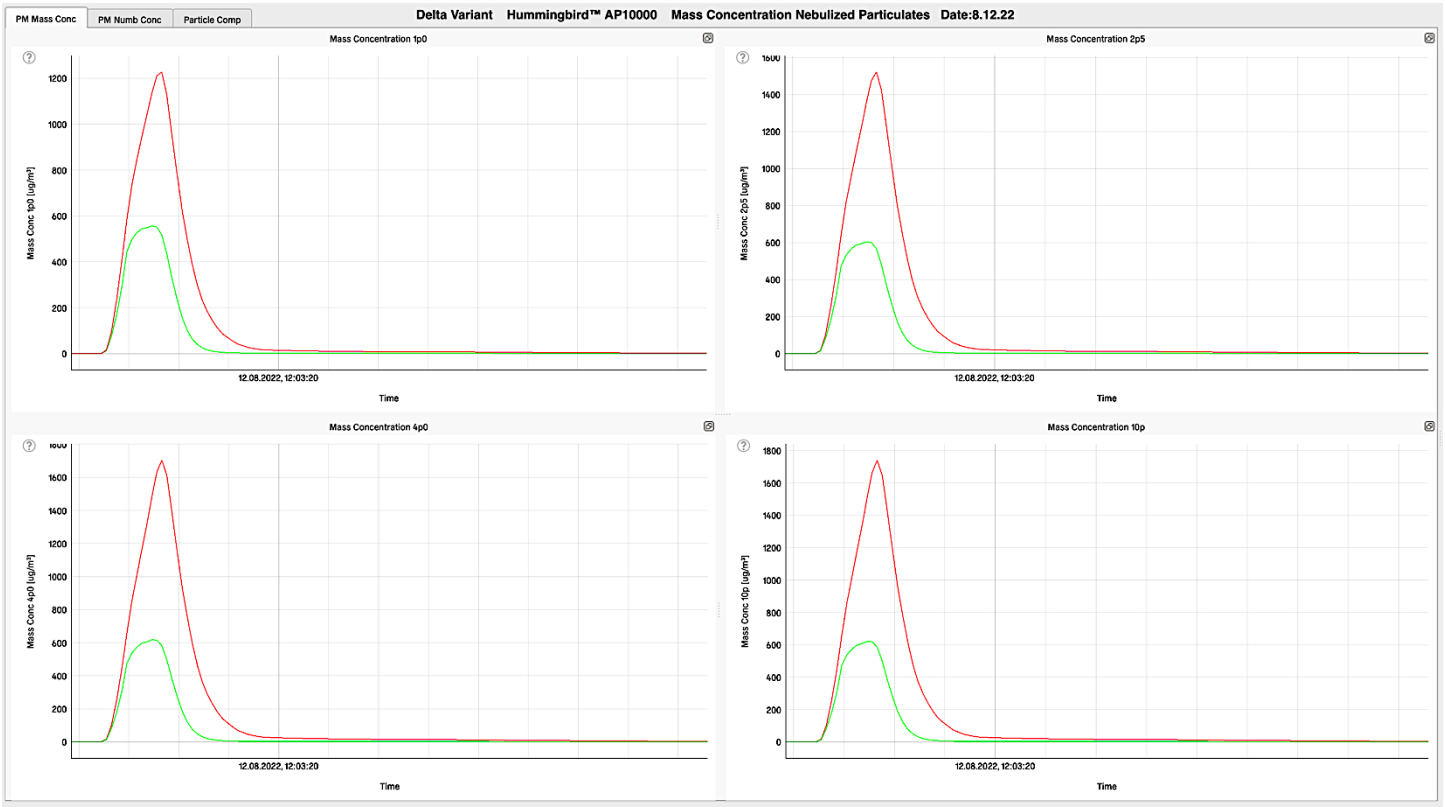
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.79	1,227.4	1,522.2	1,703.8	1,740.1	7,704.3	9,500.8	9,780.8	9,822.6	9,830.9
Post Filter	0.69	556.9	604.6	617.3	619.8	3,702.3	4,397.7	4,443.4	4,447.6	4,449.0

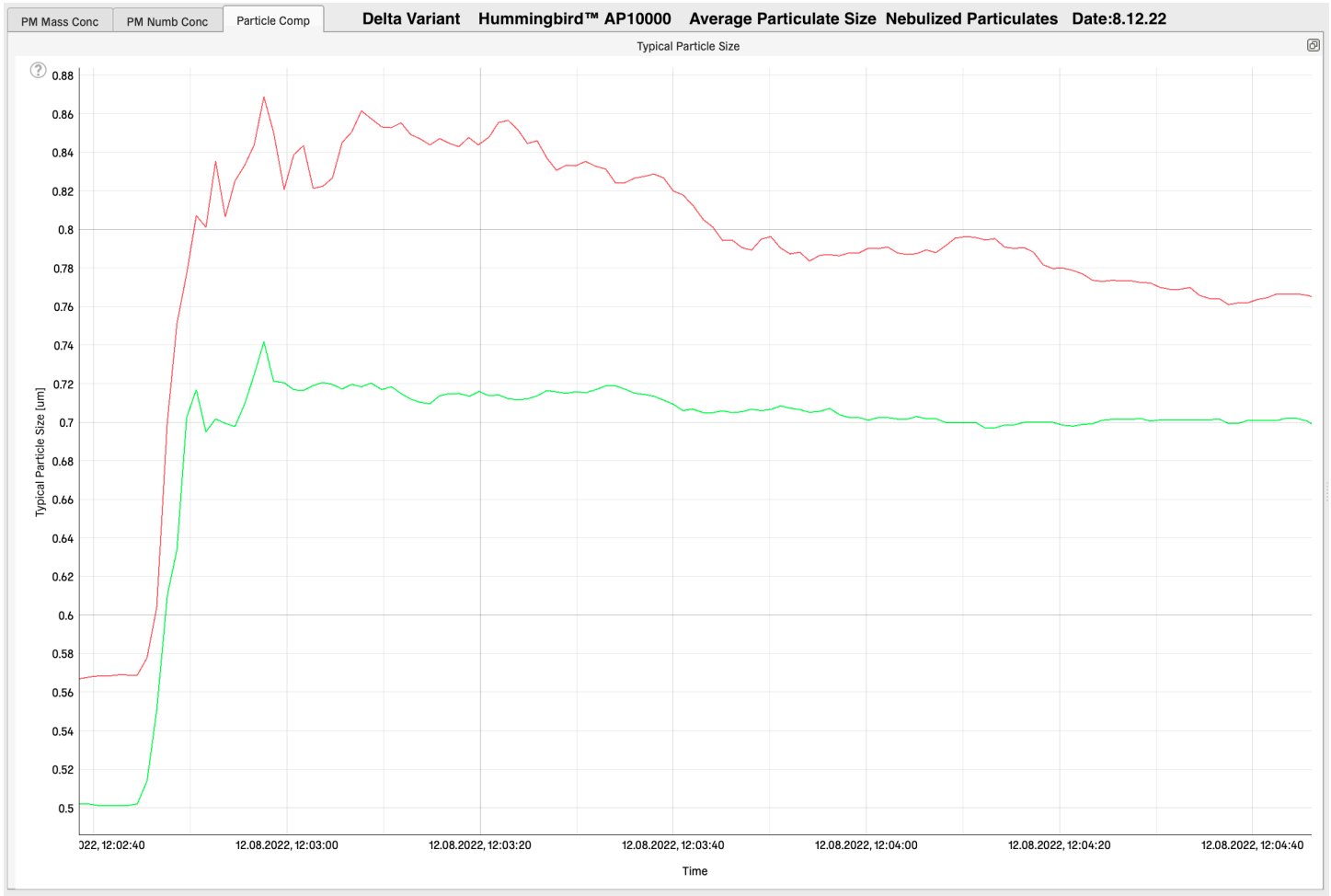
Post Filtration CFM	Post Filtration m³/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1976	3357.25	592.8	3.01	51.19	4504.98	82.38

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.205"WC	20" x 24"	6"	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Delta Variant Hummingbird™ AP10000 Mass Concentration Nebulized Particulates Date:8.12.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
12.08.2022, 12:03:20
Time
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
12.08.2022, 12:03:20
Time
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
12.08.2022, 12:03:20
Time
Mass Concentration 10p
Mass Conc 10p [ug/m³]
12.08.2022, 12:03:20
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Delta Variant Hummingbird™ AP10000 Average Particulate Size Nebulized Particulates Date:8.12.22
Typical Particle Size
Typical Particle Size [um]
022, 12:02:40
12.08.2022, 12:03:00
12.08.2022, 12:03:20
12.08.2022, 12:03:40
12.08.2022, 12:04:00
12.08.2022, 12:04:20
12.08.2022, 12:04:40
Time

Test: Hummingbird™ AP10000: Omicron Variant

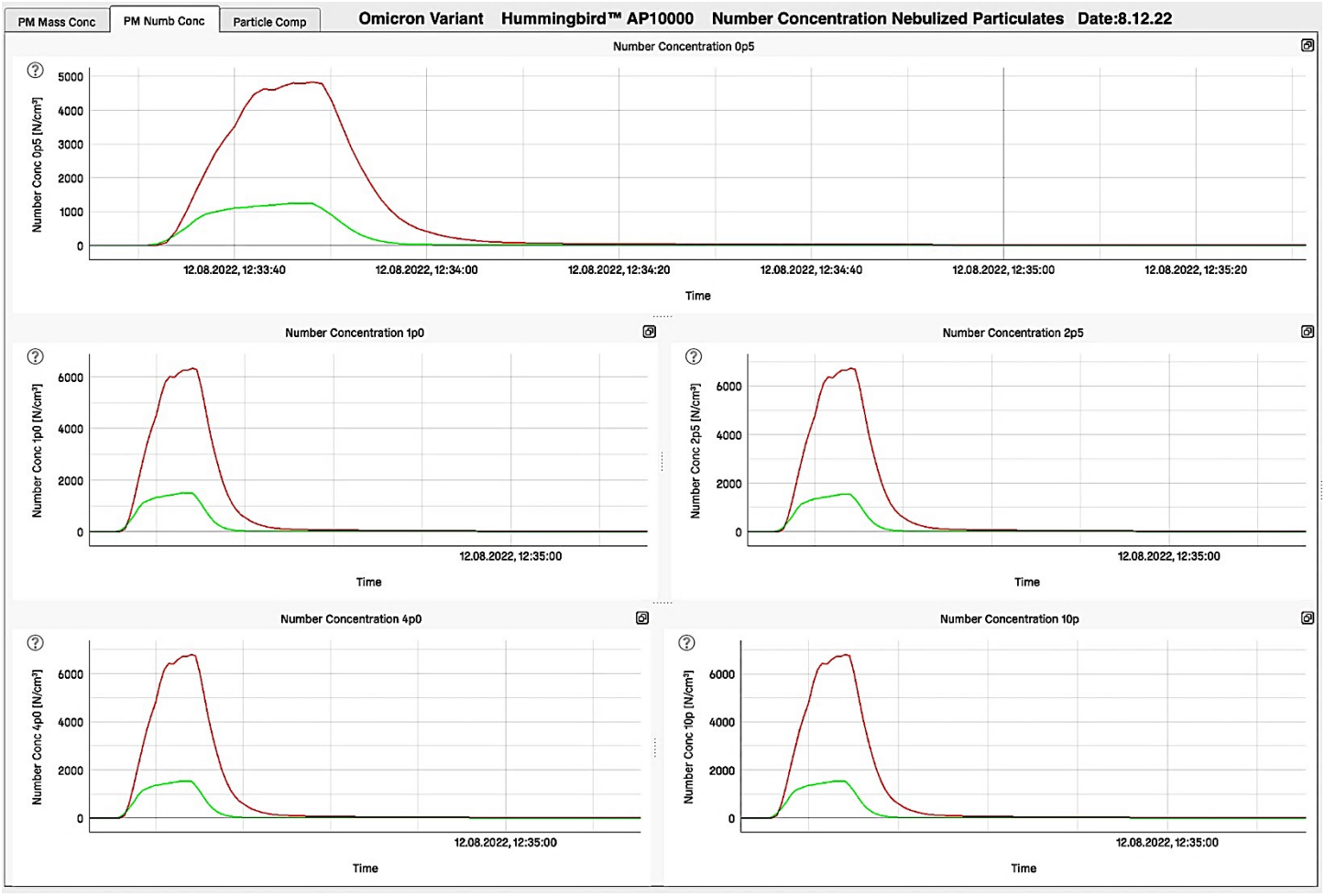
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird AP10000	Omicron	Single Pass	4/7	3000+	<30 sec.	Lamp	M13	√	5.10272E+02	N	N

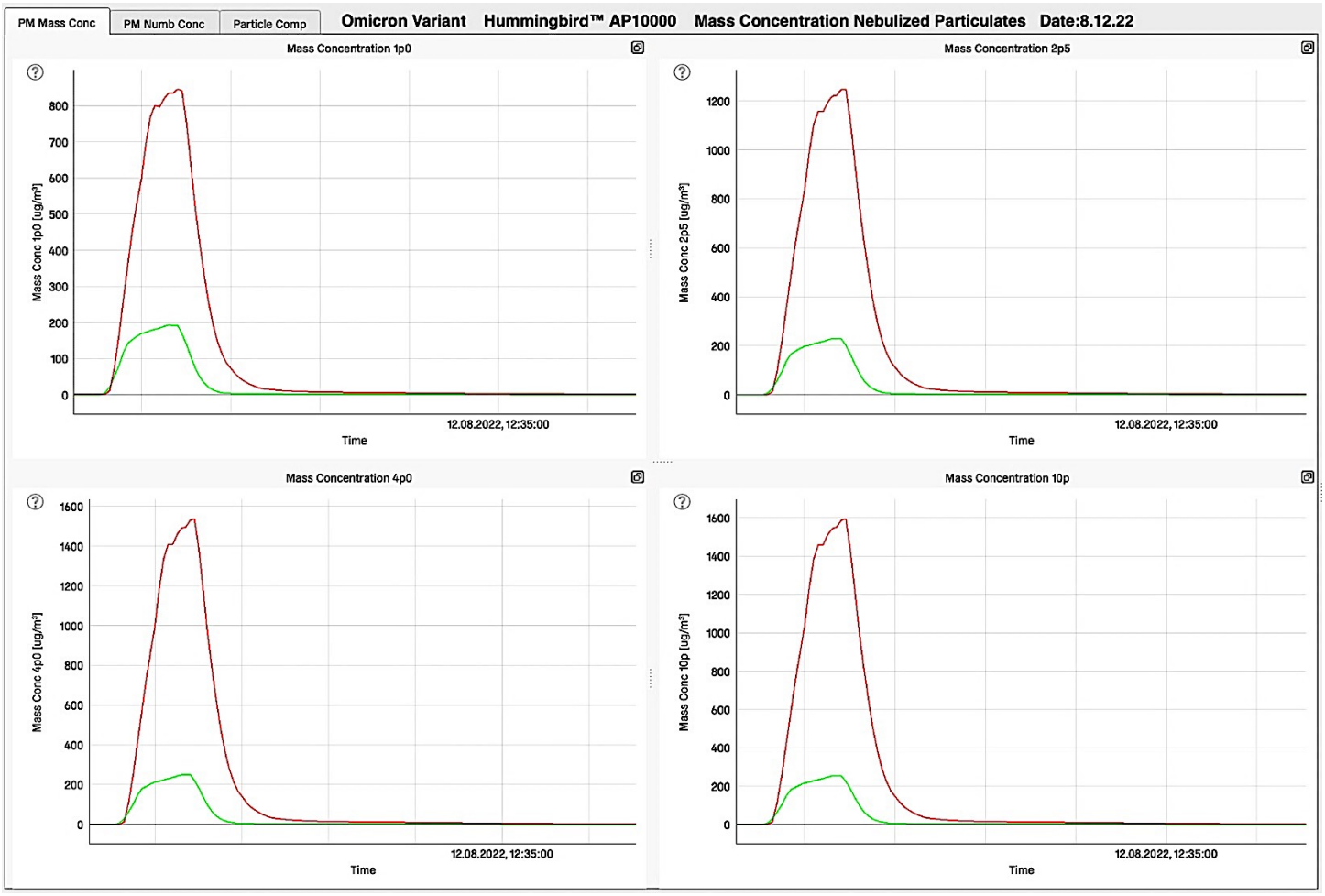
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.79	845.7	1,247.4	1,537.5	1,595.5	4,830.8	6,332.1	6,726.4	6,789.5	6,801.1
Post Filter	0.72	192.9	228.6	249.2	253.3	1,246.0	1,506.3	1,537.8	1,542.0	1,543.0

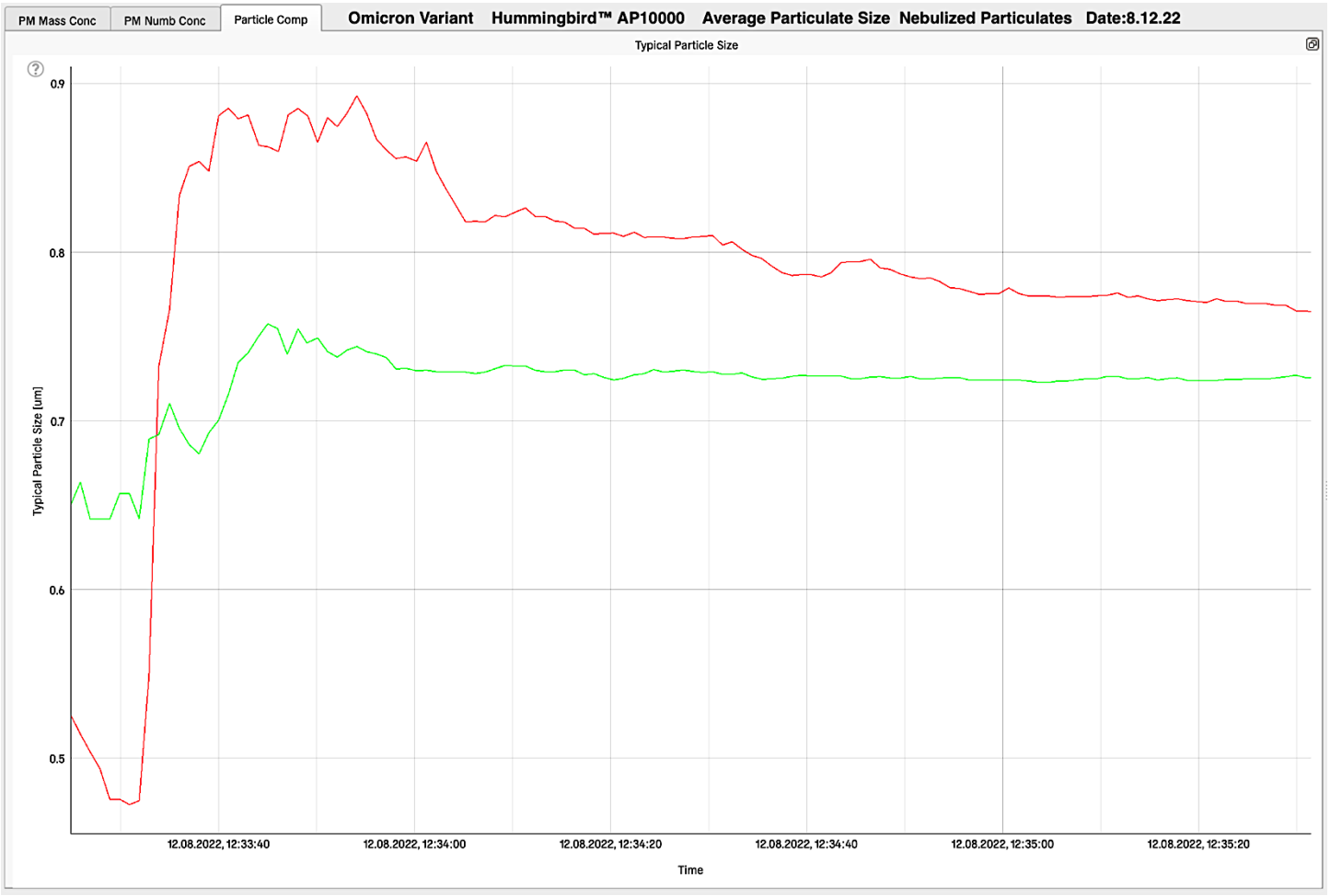
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1976	3357.25	592.8	3.01	51.19	4504.98	82.38

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.205“WC	20” x 24”	6”	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Variant Hummingbird™ AP10000 Mass Concentration Nebulized Particulates Date:8.12.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
12.08.2022, 12:35:00
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Variant Hummingbird™ AP10000 Average Particulate Size Nebulized Particulates Date:8.12.22
Typical Particle Size
Typical Particle Size [um]
12.08.2022, 12:33:40
12.08.2022, 12:34:00
12.08.2022, 12:34:20
12.08.2022, 12:34:40
12.08.2022, 12:35:00
12.08.2022, 12:35:20
Time

Test: Hummingbird™ AP10000: BA.2 Variant

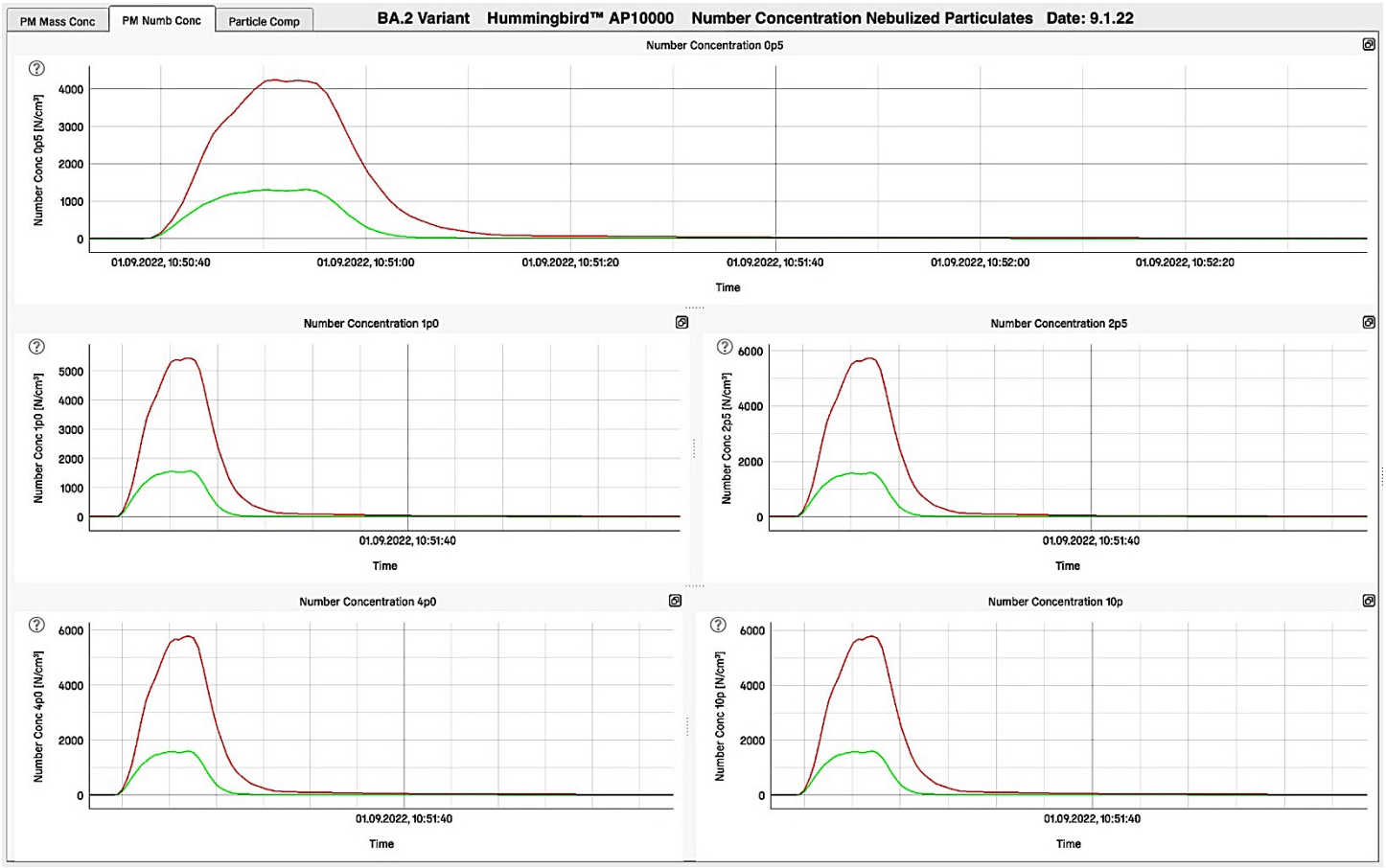
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird AP10000	BA.2	Single Pass	4/7	3000+	<45 sec.	Lamp	√	√	1.13256E+03	N	N

Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.83	720.2	1,020.8	1,230.6	1,272.6	4,242.2	5,435.9	5,730.9	5,777.6	5,786.3
Post Filter	0.68	199.7	223.9	234.3	236.3	1,314.0	1,570.6	1,592.9	1,595.4	1,596.1

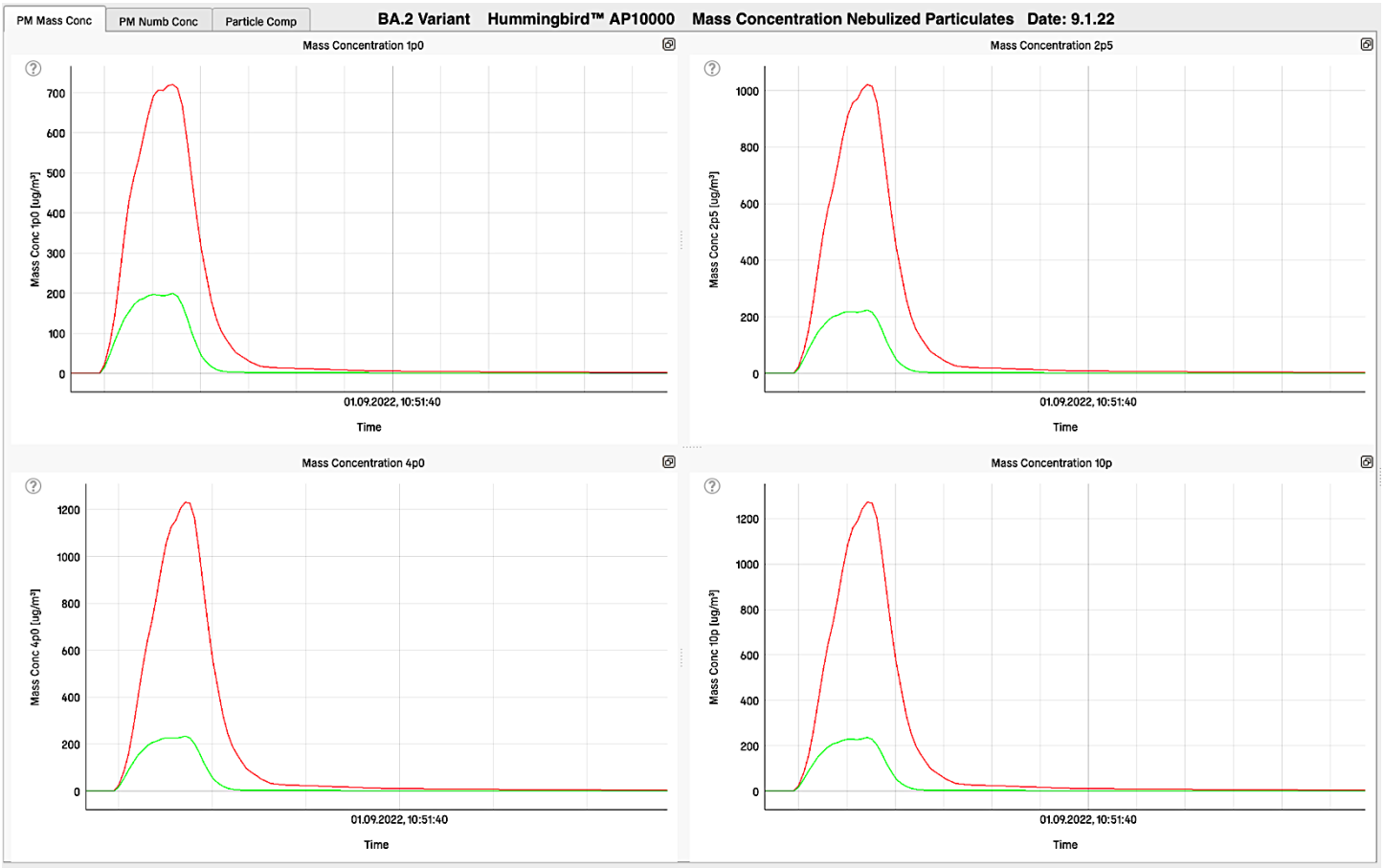
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
1976	3357.25	592.8	3.01	51.19	4504.98	82.38

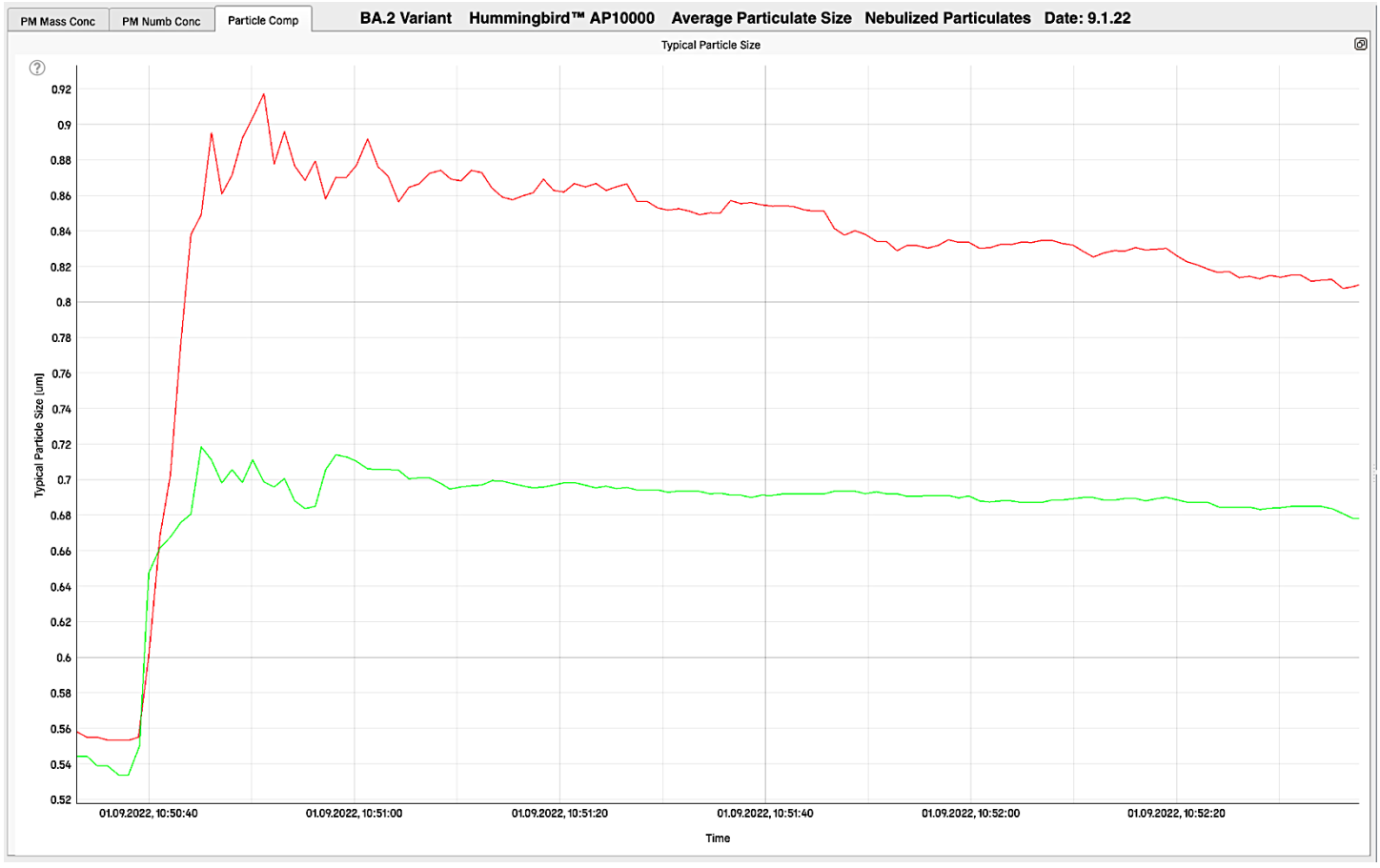
Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.205“WC	20” x 24”	6”	0.0



v 2.5


PM Mass Conc
PM Numb Conc
Particle Comp
BA.2 Variant Hummingbird™ AP10000 Mass Concentration Nebulized Particulates Date: 9.1.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
01.09.2022, 10:51:40
Time


PM Mass Conc
PM Numb Conc
Particle Comp
BA.2 Variant Hummingbird™ AP10000 Average Particulate Size Nebulized Particulates Date: 9.1.22
Typical Particle Size
Typical Particle Size [um]
01.09.2022, 10:50:40
01.09.2022, 10:51:00
01.09.2022, 10:51:20
01.09.2022, 10:51:40
01.09.2022, 10:52:00
01.09.2022, 10:52:20
Time

Hummingbird™ AP10000 Test Conclusion

- The hummingbird™ AP10000 inactivated / filtered SARS-CoV2 (COVID-19) to below detection limits in a single-pass test of 5 minutes as compared to the same control test under the same conditions.
- With *WT SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X+) of virus necessary for an infectious dose. (7)
- With *Delta SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X+) of virus necessary for an infectious dose. (7)
- With *Omicron SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X+) of virus necessary for an infectious dose. (7)
- With *Omicron BA.2 SARS-CoV2* we performed a pilot test and observed no CPE, suggesting that the filtration system inactivates this variant as the others.

Test: Hummingbird™ Automotive / Aviation: Covid-19 WT

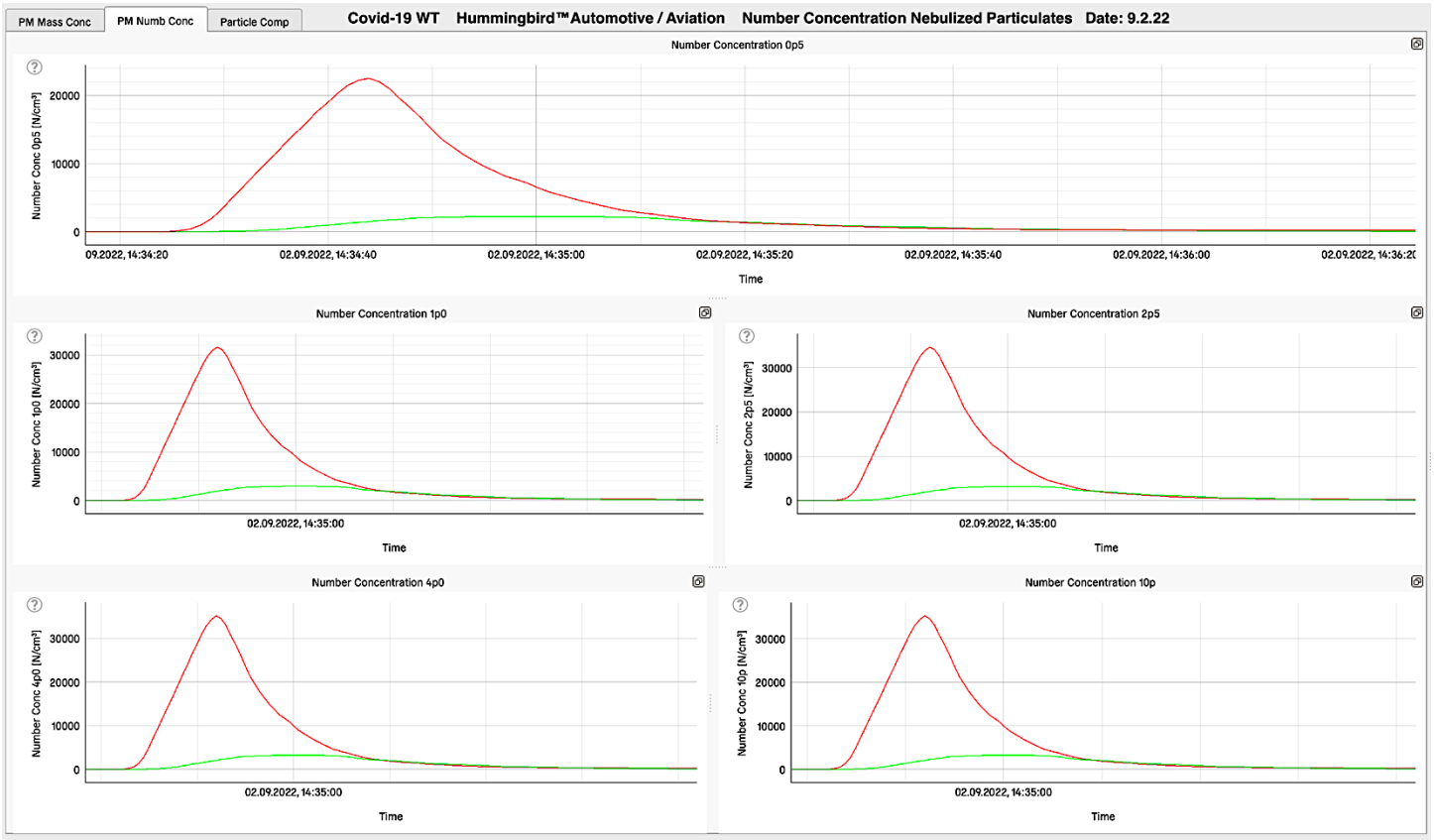
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Auto/Aviation	WT PL	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	BLD-GE	N	N

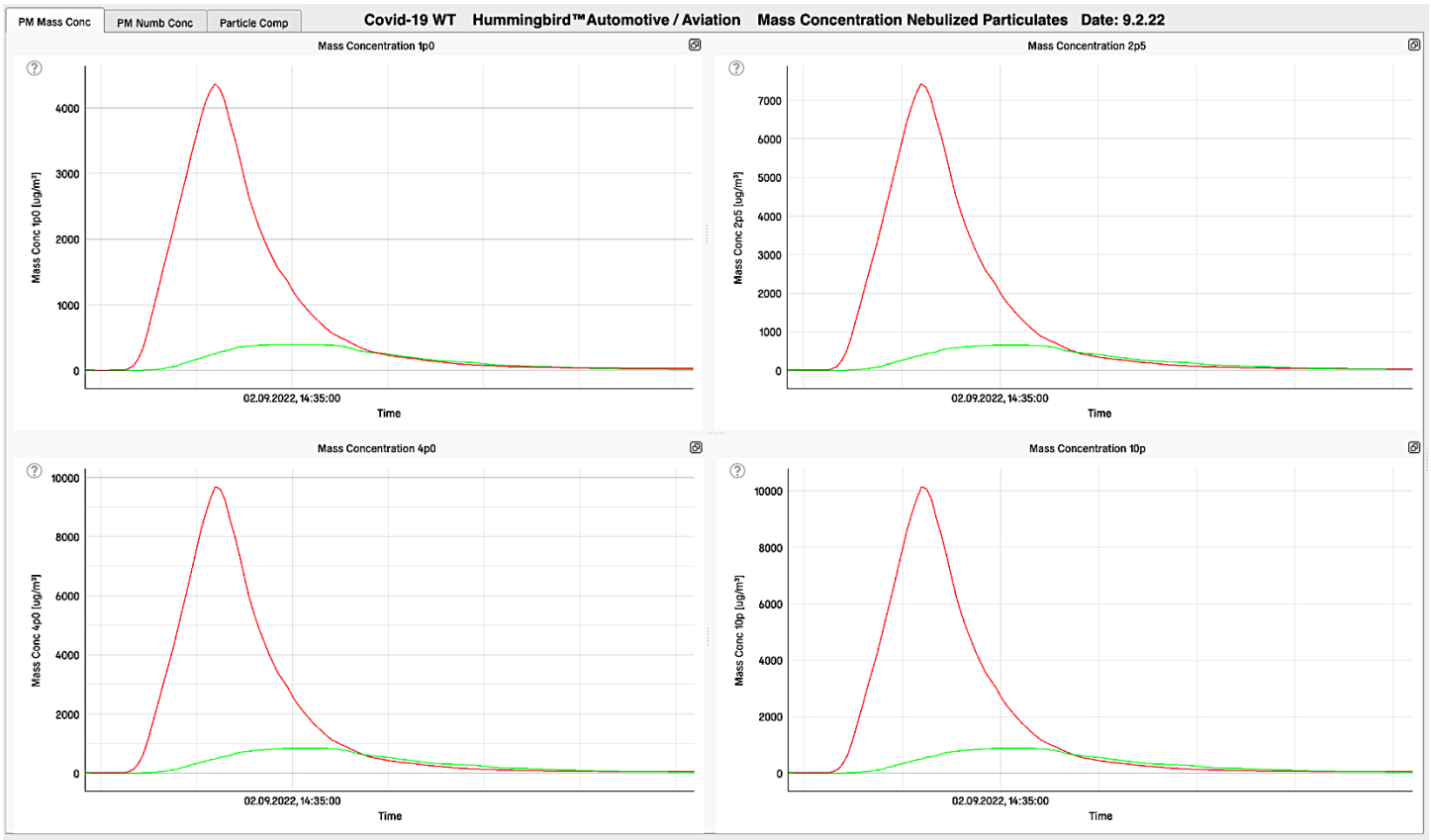
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.82	4364.4	7422.0	9693.6	10147.9	22516.0	31595.7	34649.0	35147.1	35236.6
Post Filter	0.88	397.4	654.4	844.9	883.0	2219.8	2940.6	3156.6	3192.3	3199.0

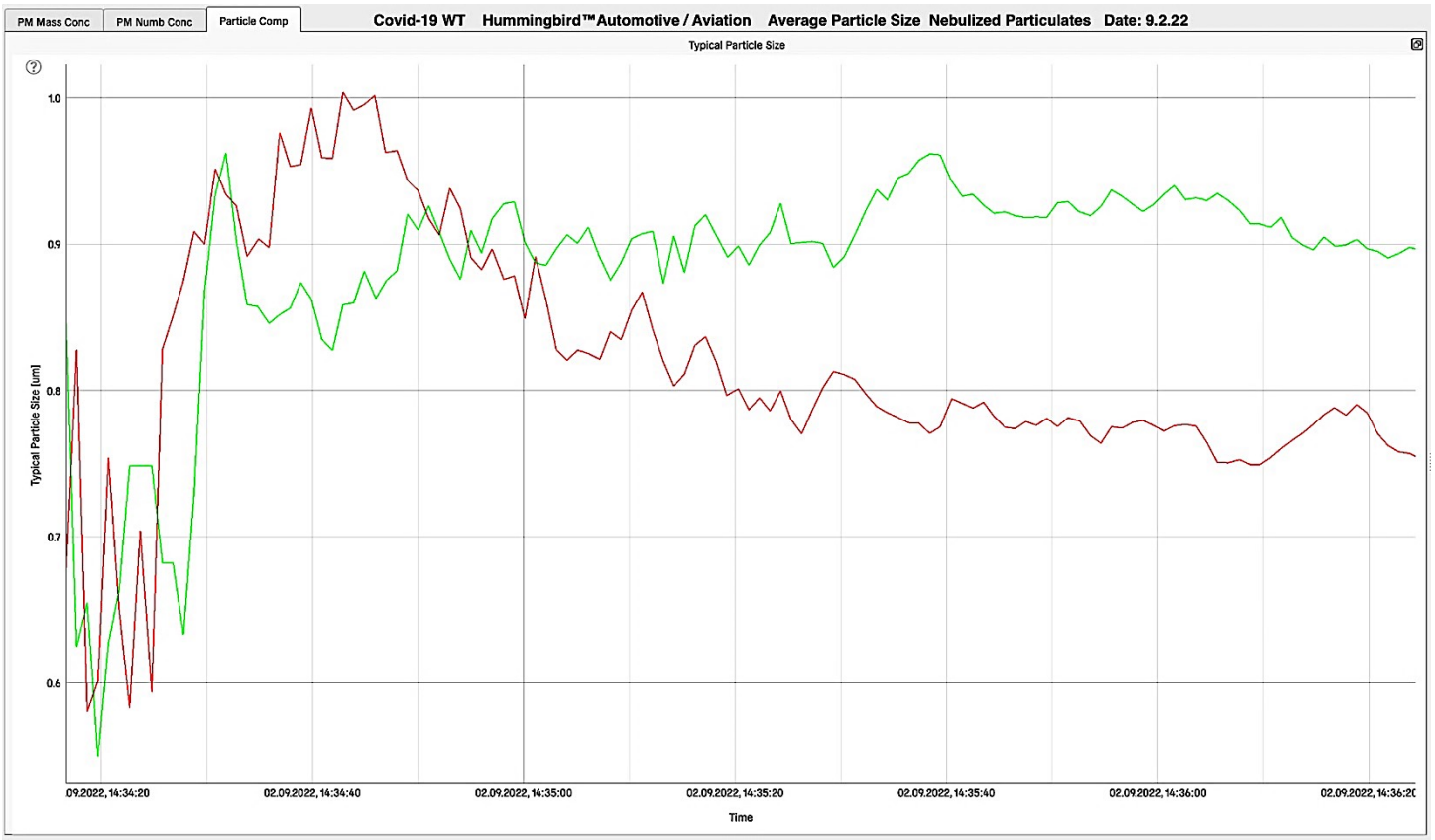
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
710	1206.3	213	1.08	5.23	460.96	8.41

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.62 WC	20” x 24”	6”	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Hummingbird™Automotive / Aviation Mass Concentration Nebulized Particulates Date: 9.2.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
02.09.2022, 14:35:00
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Hummingbird™Automotive / Aviation Average Particle Size Nebulized Particulates Date: 9.2.22
Typical Particle Size
Typical Particle Size [um]
02.09.2022, 14:34:20
02.09.2022, 14:34:40
02.09.2022, 14:35:00
02.09.2022, 14:35:20
02.09.2022, 14:35:40
02.09.2022, 14:36:00
Time

Test: Hummingbird™ Automotive / Aviation: Delta

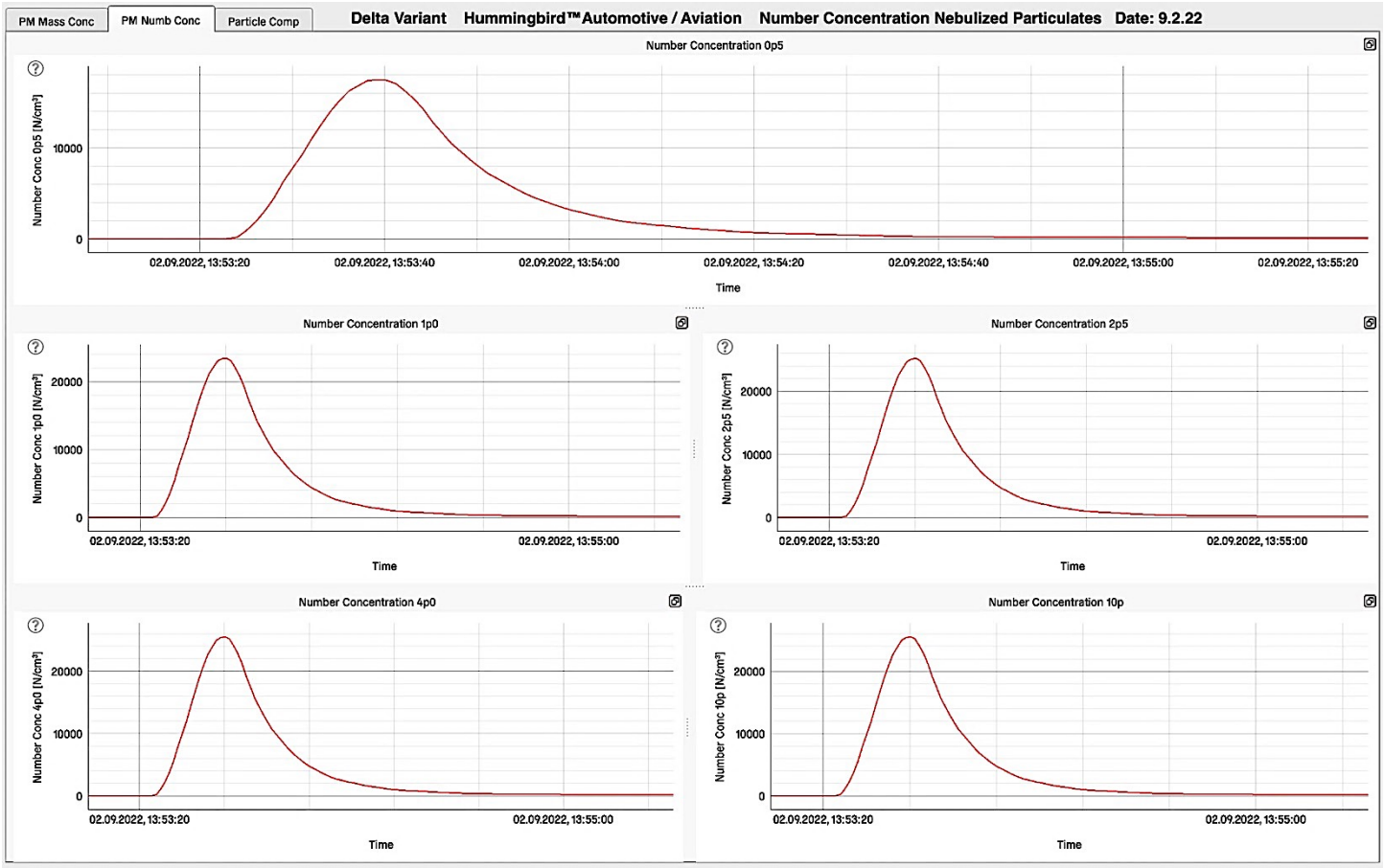
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Auto/Aviation	Delta	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	3.276E+02	N	N

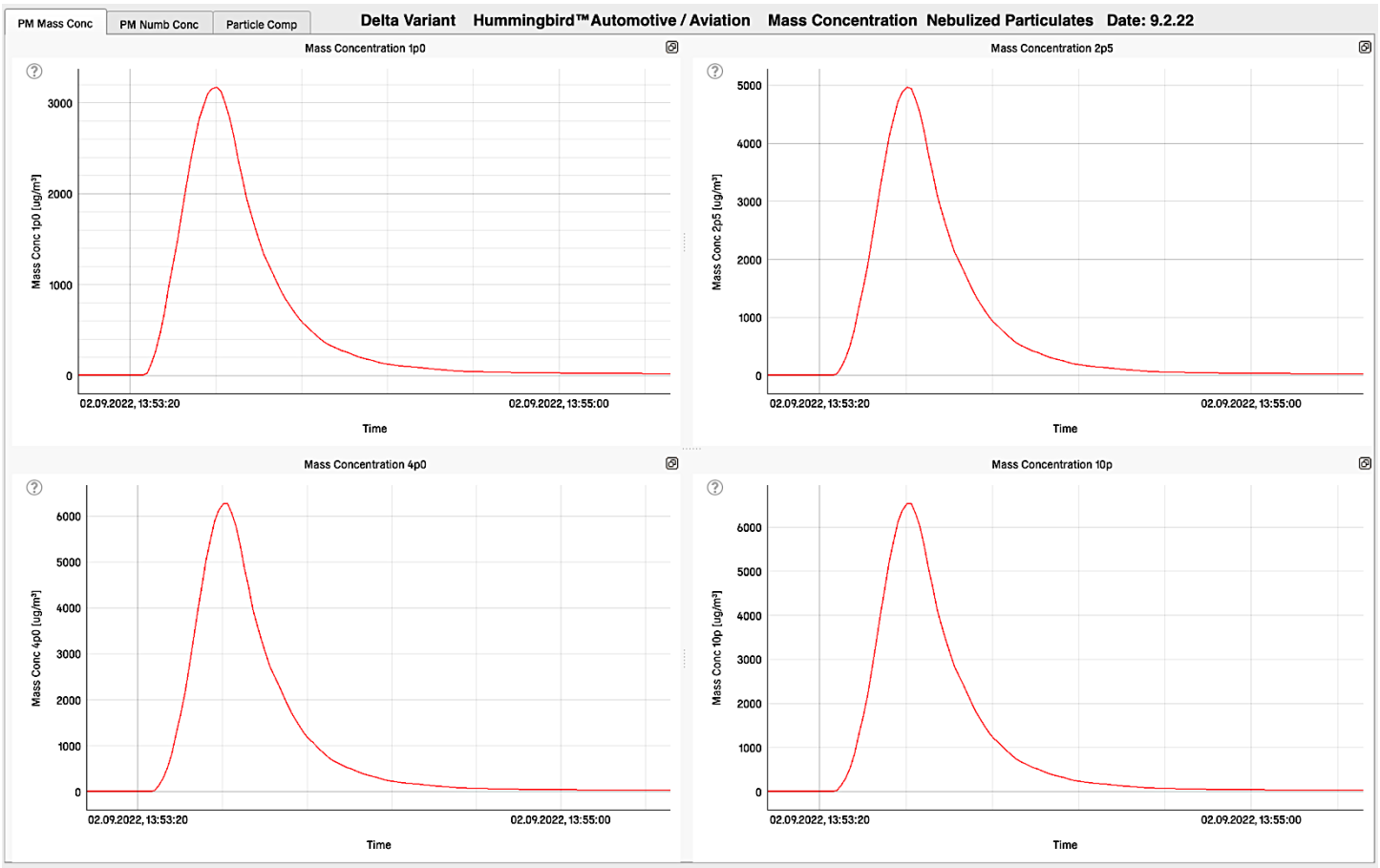
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.77	3,171.9	4,964.5	6,268.4	6,533.2	17,459.0	23,431.1	25,210.1	25,497.4	25,549.7

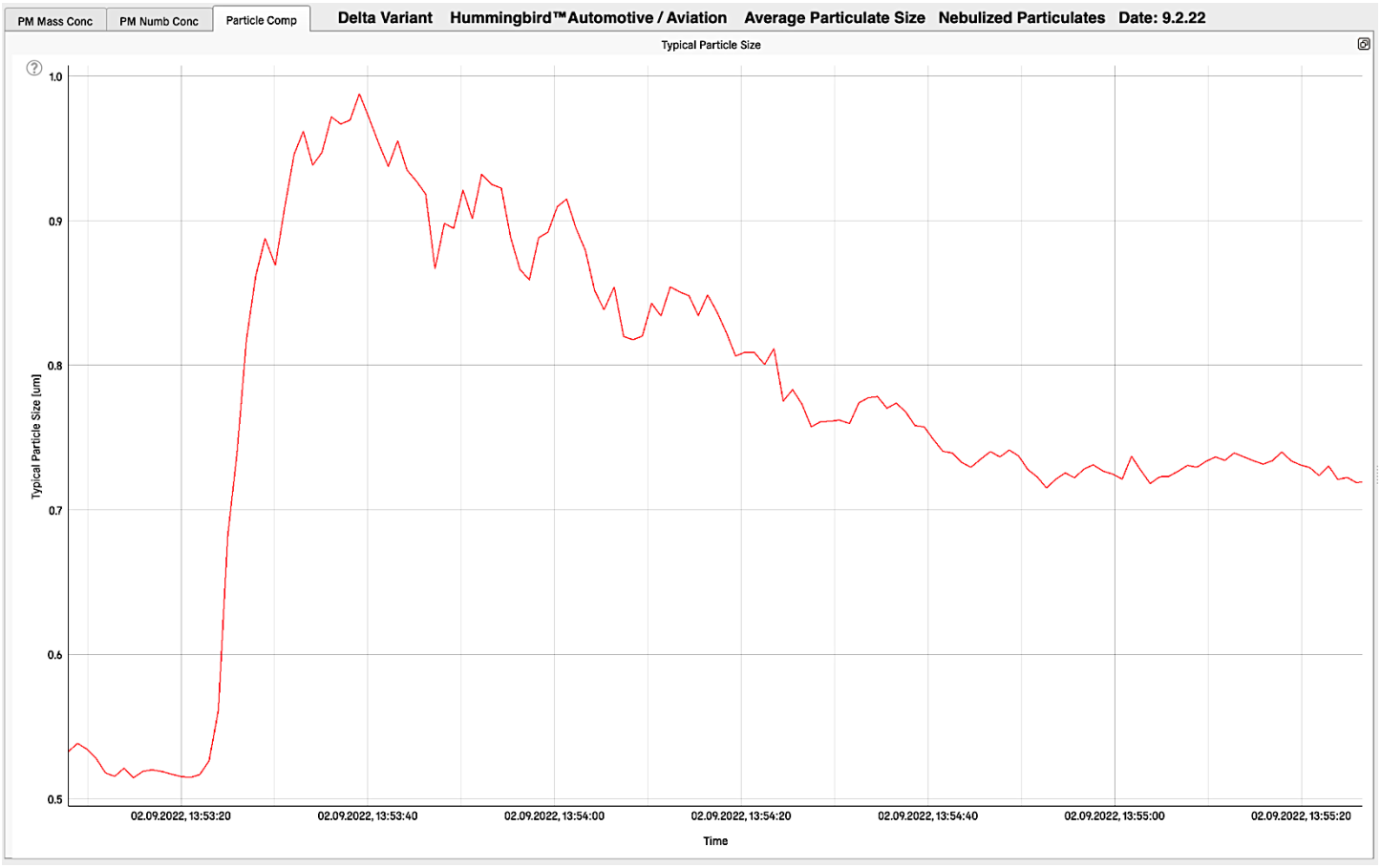
Post Filtration CFM	Post Filtration m³/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
710	1206.3	213	1.08	5.23	460.96	8.41

Graph Legend: Particulate Sensors
Red Nebulizing Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.62 WC	20” x 24”	6”	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Delta Variant Hummingbird™ Automotive / Aviation Mass Concentration Nebulized Particulates Date: 9.2.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
02.09.2022, 13:53:20
02.09.2022, 13:55:00
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Delta Variant Hummingbird™ Automotive / Aviation Average Particulate Size Nebulized Particulates Date: 9.2.22
Typical Particle Size
Typical Particle Size [um]
02.09.2022, 13:53:20
02.09.2022, 13:53:40
02.09.2022, 13:54:00
02.09.2022, 13:54:20
02.09.2022, 13:54:40
02.09.2022, 13:55:00
02.09.2022, 13:55:20
Time

Test: Hummingbird™ Automotive / Aviation: Omicron

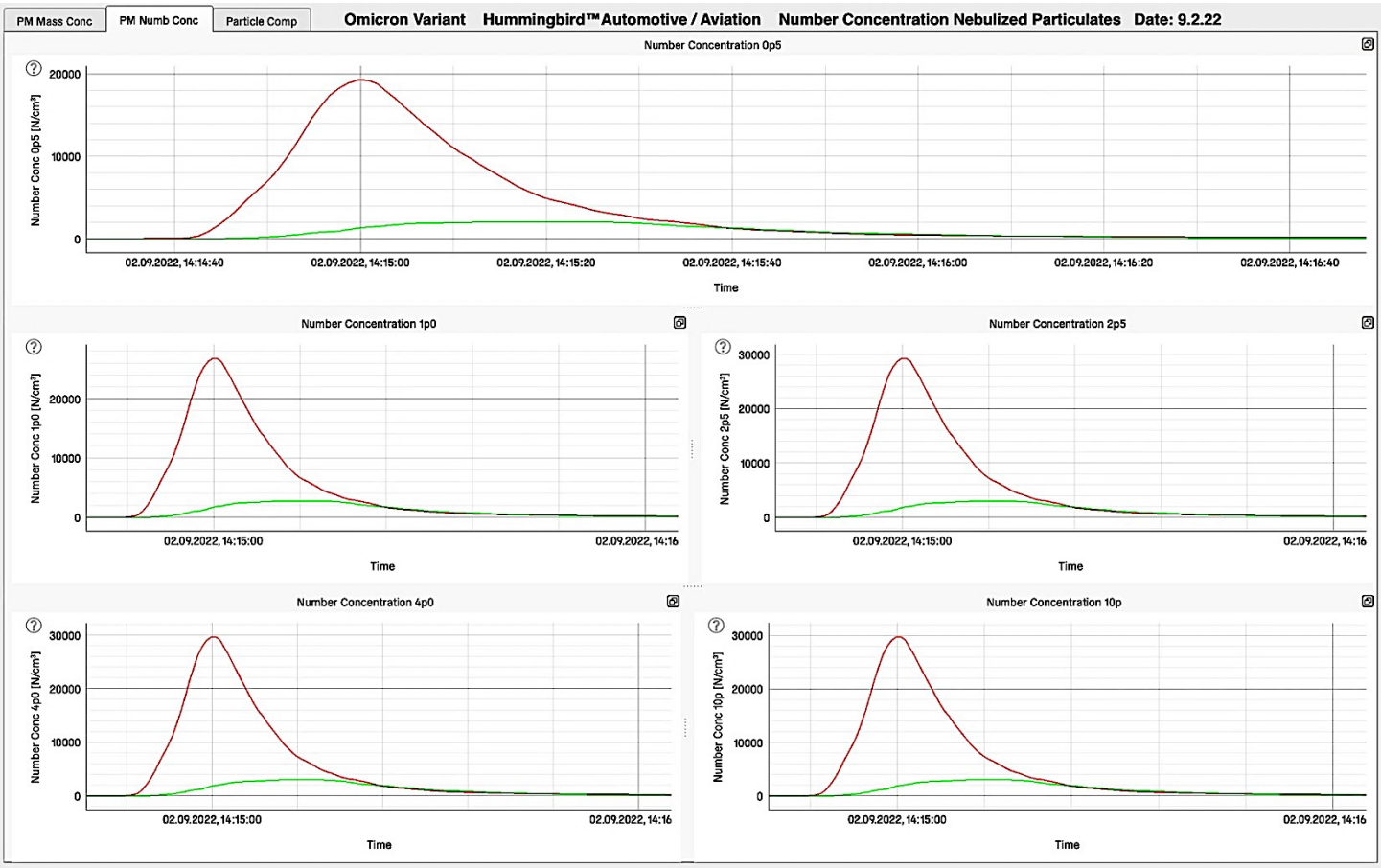
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Auto/Aviation	Omicron	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	3.4258E+02	N	N

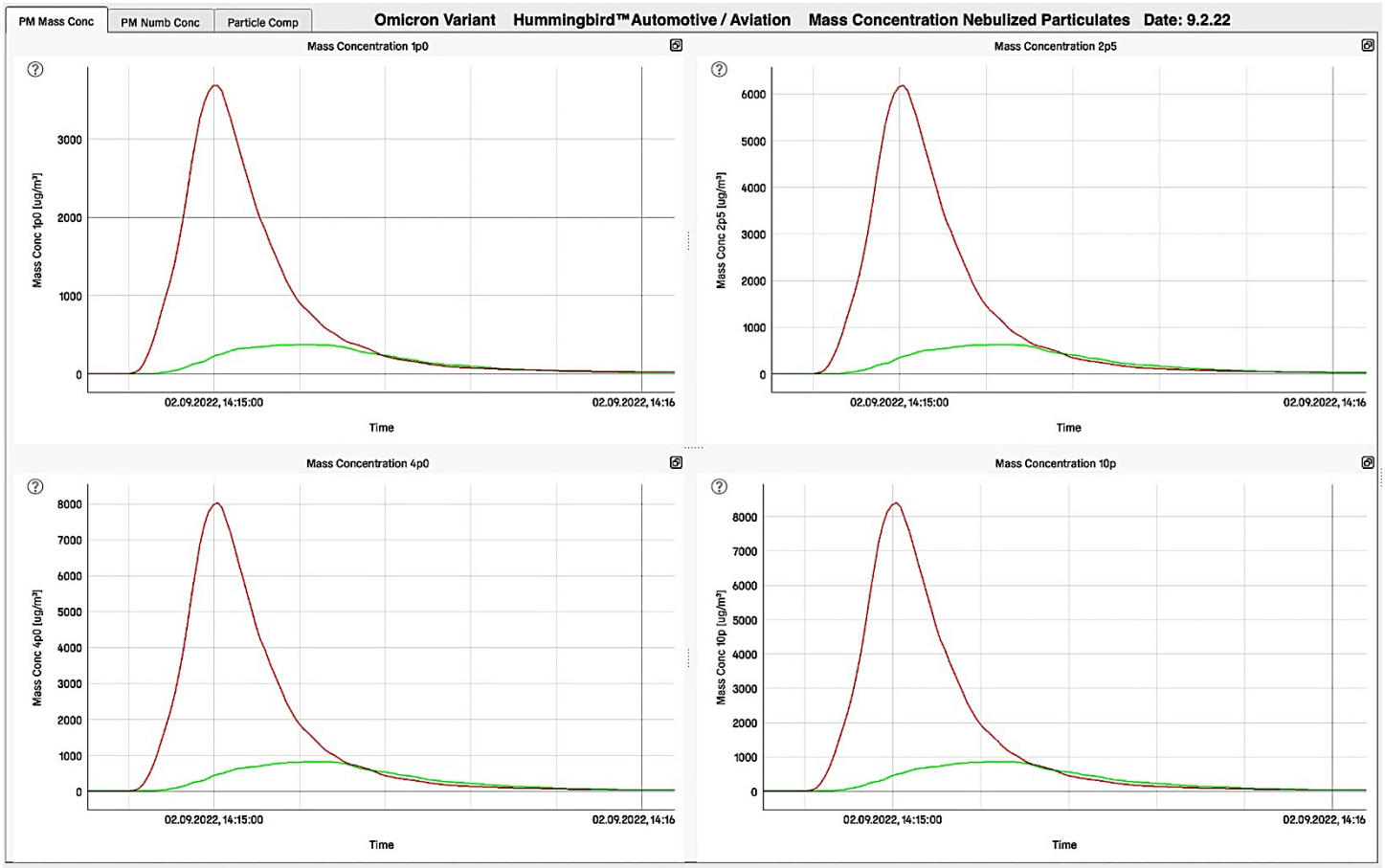
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.82	3684.4	6183.1	8034.0	8404.2	19286.0	26793.6	29256.2	29662.4	29735.4
Post Filter	0.92	373.1	631.4	823.6	862.0	2058.7	2748.2	2962.1	2997.7	3004.5

Post Filtration CFM	Post Filtration m³/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
710	1206.3	213	1.08	5.23	460.96	8.41

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.62 WC	20” x 24”	6”	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Variant Hummingbird™ Automotive / Aviation Mass Concentration Nebulized Particulates Date: 9.2.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
02.09.2022, 14:15:00
02.09.2022, 14:16
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Variant Hummingbird™ Automotive / Aviation Average Particulate Size Nebulized Particulates Date: 9.2.22
Typical Particle Size
Typical Particle Size [um]
02.09.2022, 14:14:40
02.09.2022, 14:15:00
02.09.2022, 14:15:20
02.09.2022, 14:15:40
02.09.2022, 14:16:00
02.09.2022, 14:16:20
02.09.2022, 14:16:40
Time

Hummingbird™ Automotive / Aviation Conclusion

- The hummingbird™ Automotive / Aviation inactivated/ filtered SARS-CoV2 (COVID-19) to below detection limits in a single-pass test of 5 minutes as compared to the same control test under the same conditions.
- With *WT SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X^{+}) of virus necessary for an infectious dose. (7)
- With *Delta SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X^{+}) of virus necessary for an infectious dose. (7)
- With *Omicron SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X^{+}) of virus necessary for an infectious dose. (7)

Test: Hummingbird™ Portable Model 888: Covid-19 WT

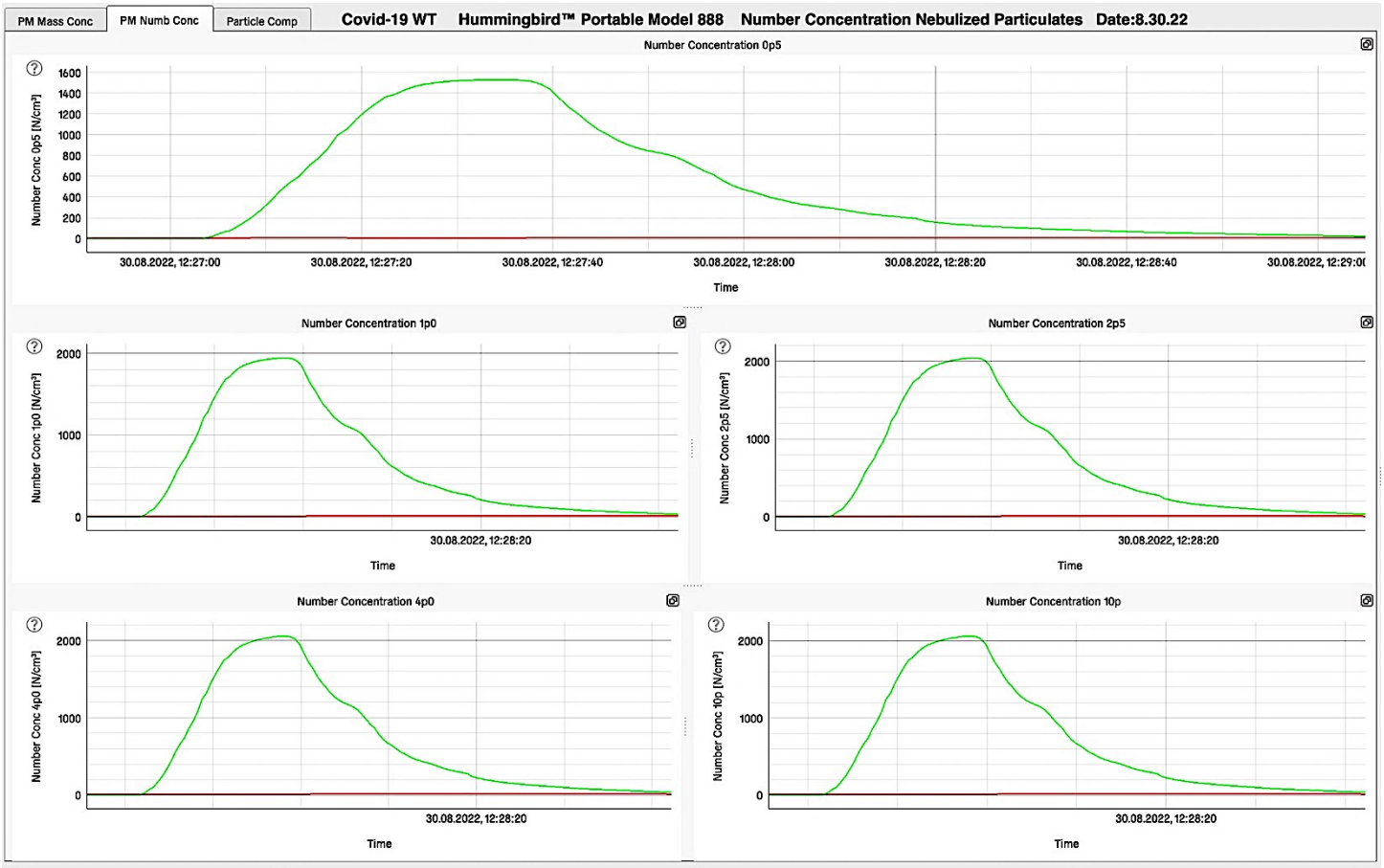
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Portable 888	WT PI	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	2.134E+02	N	N

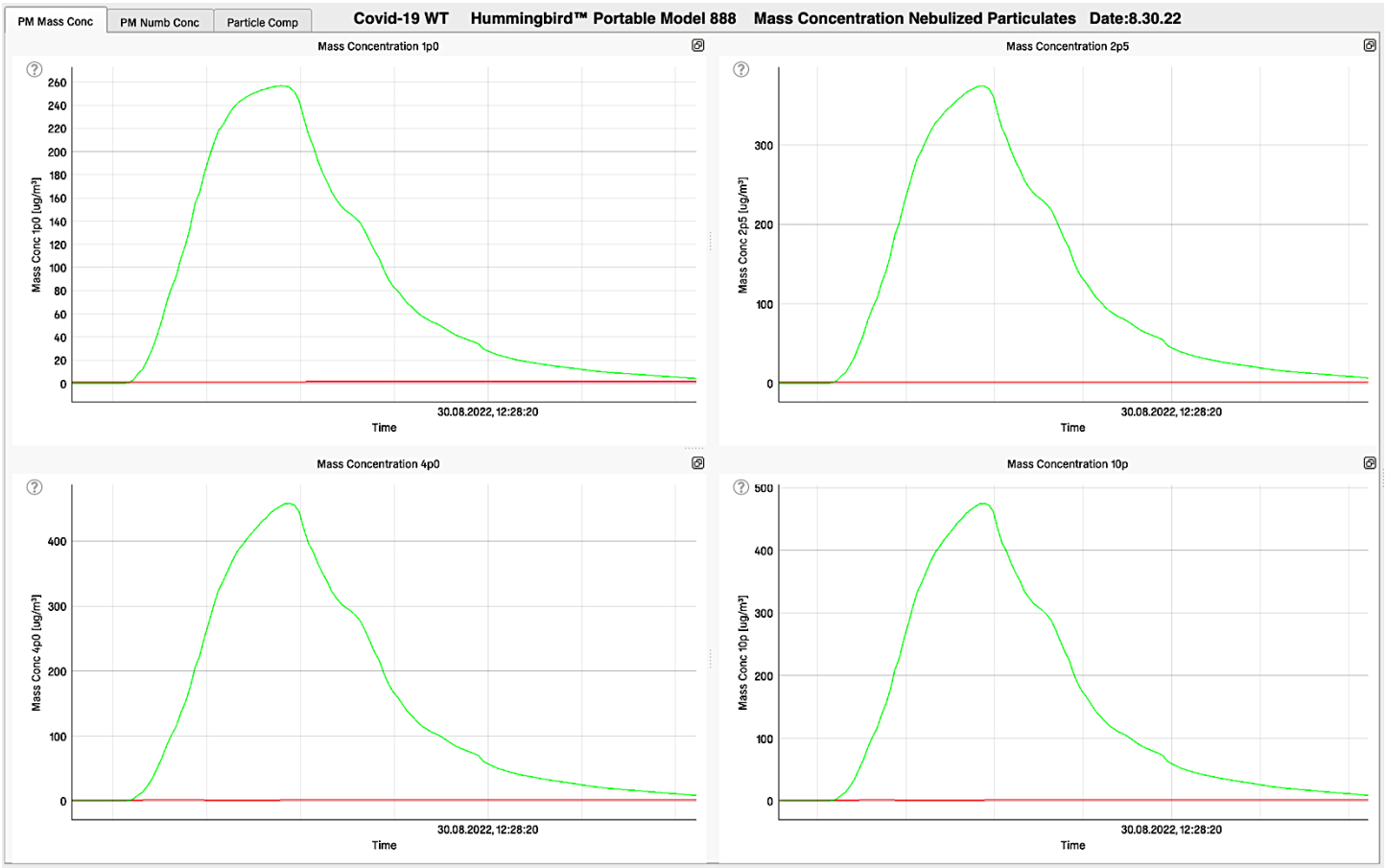
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Post Filter	0.83	256.7	374.3	457.8	474.6	1,528.7	1,944.6	2,042.5	2,058.1	2,061.2

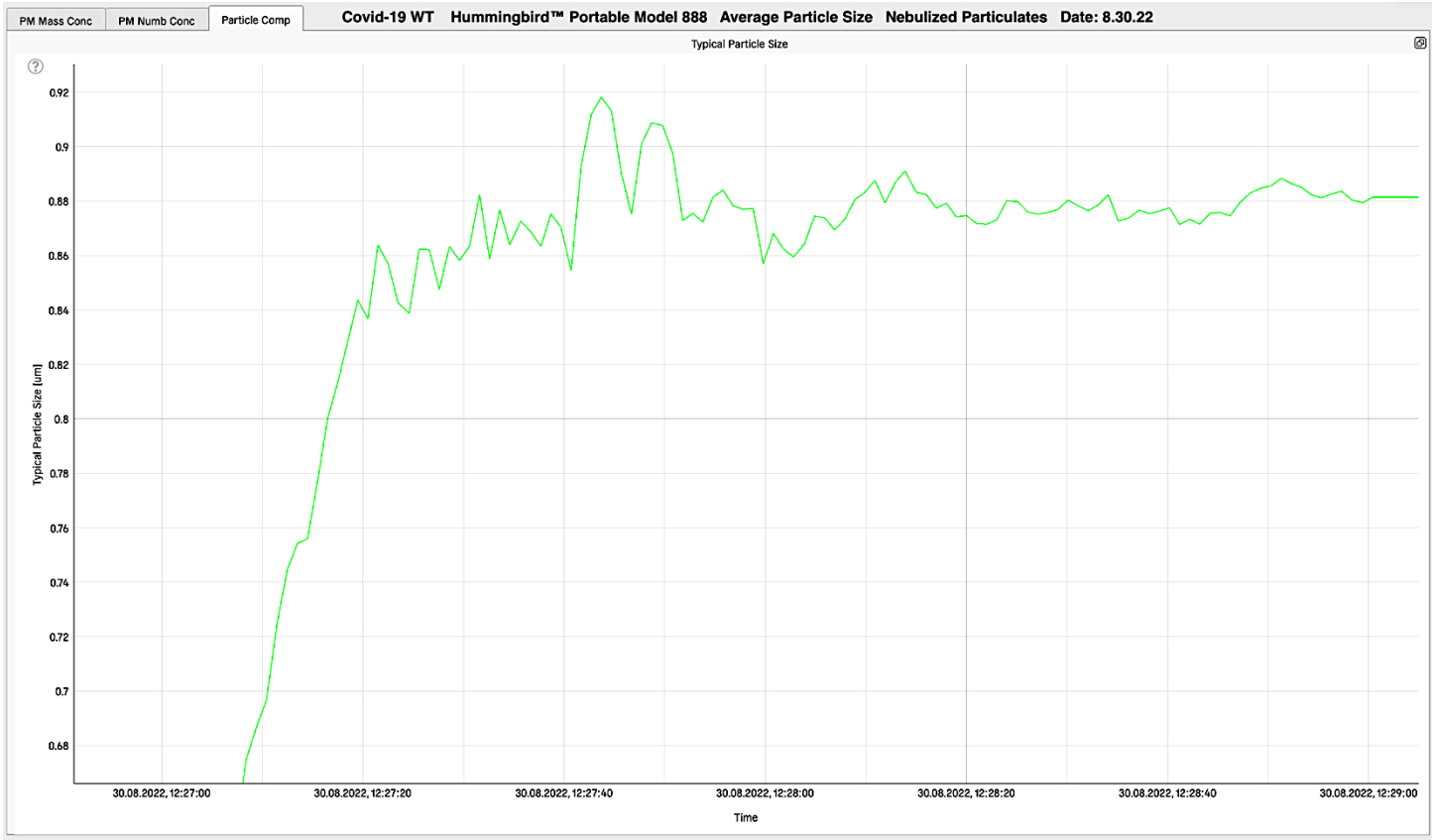
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
373.33	634.29	112	0.57	4.42	389	7.11

Graph Legend: Particulate Sensors
Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.05" WC	20" x 24"	6"	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Hummingbird™ Portable Model 888 Mass Concentration Nebulized Particulates Date:8.30.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
30.08.2022, 12:28:20
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Covid-19 WT Hummingbird™ Portable Model 888 Average Particle Size Nebulized Particulates Date: 8.30.22
Typical Particle Size
Typical Particle Size [um]
30.08.2022, 12:27:00
30.08.2022, 12:27:20
30.08.2022, 12:27:40
30.08.2022, 12:28:00
30.08.2022, 12:28:20
30.08.2022, 12:28:40
30.08.2022, 12:29:00
Time

Test: Hummingbird™ Portable Model 888: Delta Variant

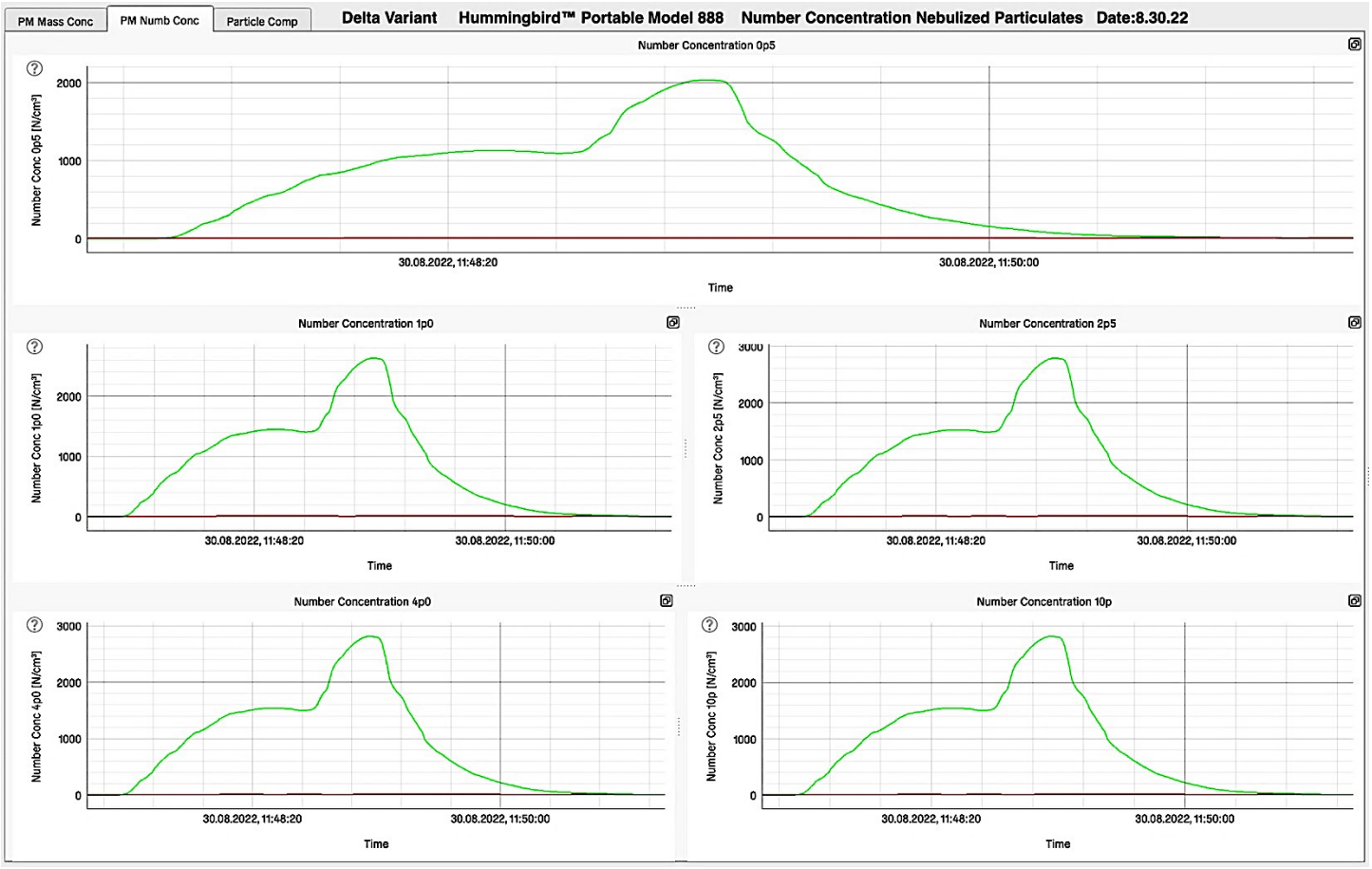
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Portable 888	Delta	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	3.15E+02	N	N

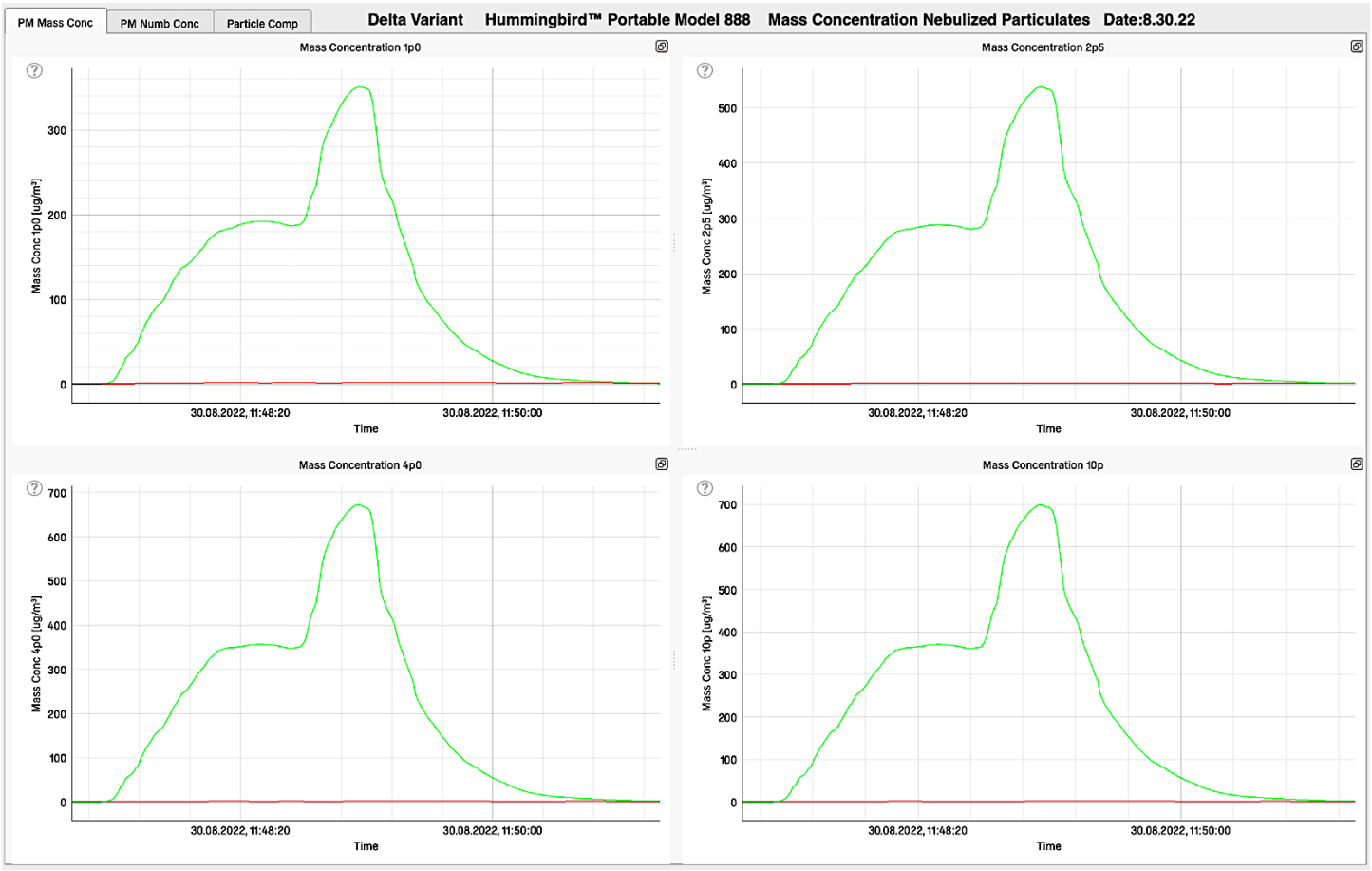
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Post Filter	0.86	350.9	537.6	672.6	699.7	2,033.7	2,632.0	2,789.6	2,815.2	2,820.1

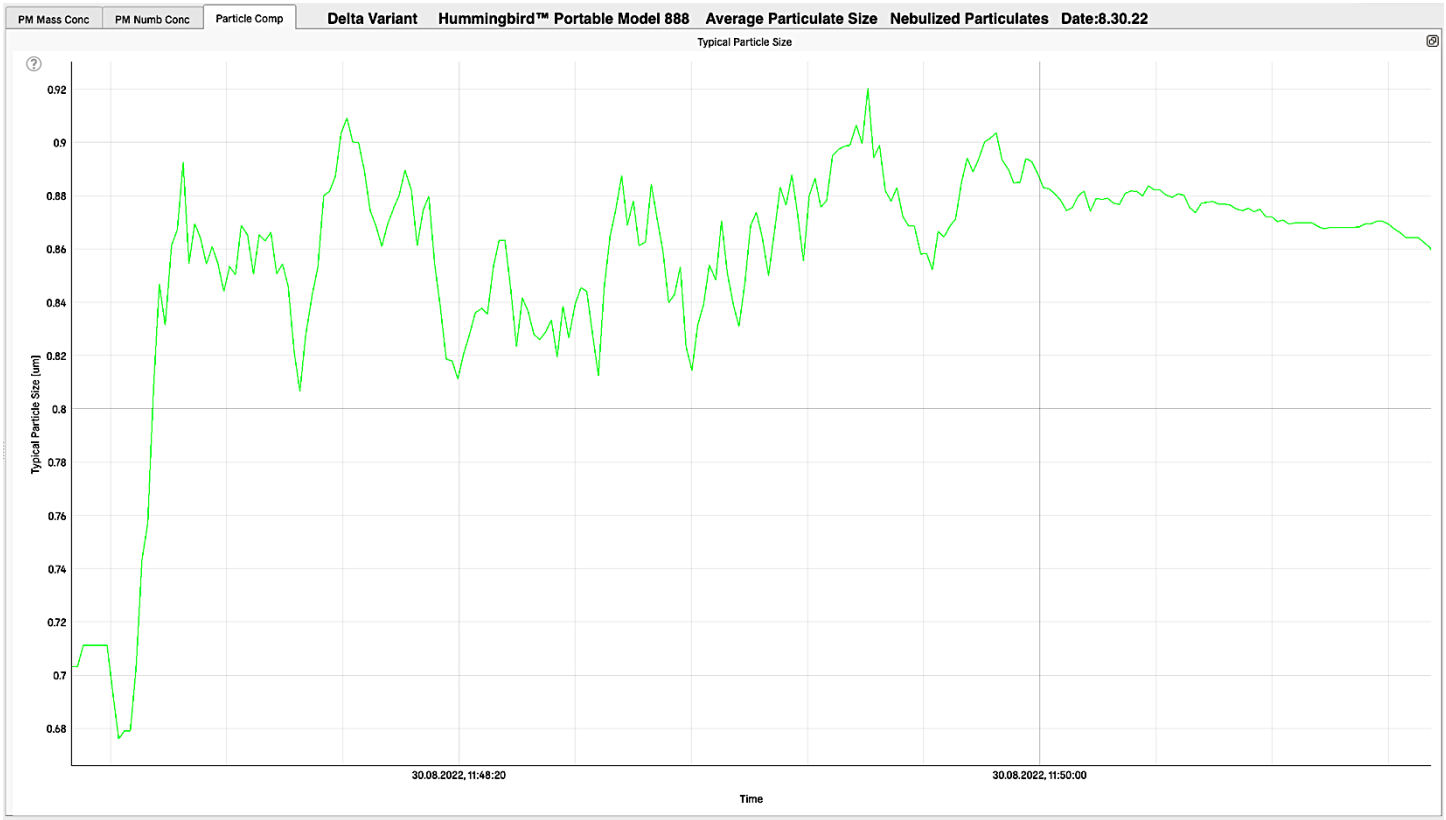
Post Filtration CFM	Post Filtration m³/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
373.33	634.29	112	0.57	4.42	389	7.11

Graph Legend: Particulate Sensors
Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.05" WC	20" x 24"	6"	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Delta Variant Hummingbird™ Portable Model 888 Mass Concentration Nebulized Particulates Date:8.30.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
30.08.2022, 11:48:20
30.08.2022, 11:50:00
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Delta Variant Hummingbird™ Portable Model 888 Average Particulate Size Nebulized Particulates Date:8.30.22
Typical Particle Size
Typical Particle Size [um]
30.08.2022, 11:48:20
30.08.2022, 11:50:00
Time

Test: Hummingbird™ Portable Model 888: Omicron Variant

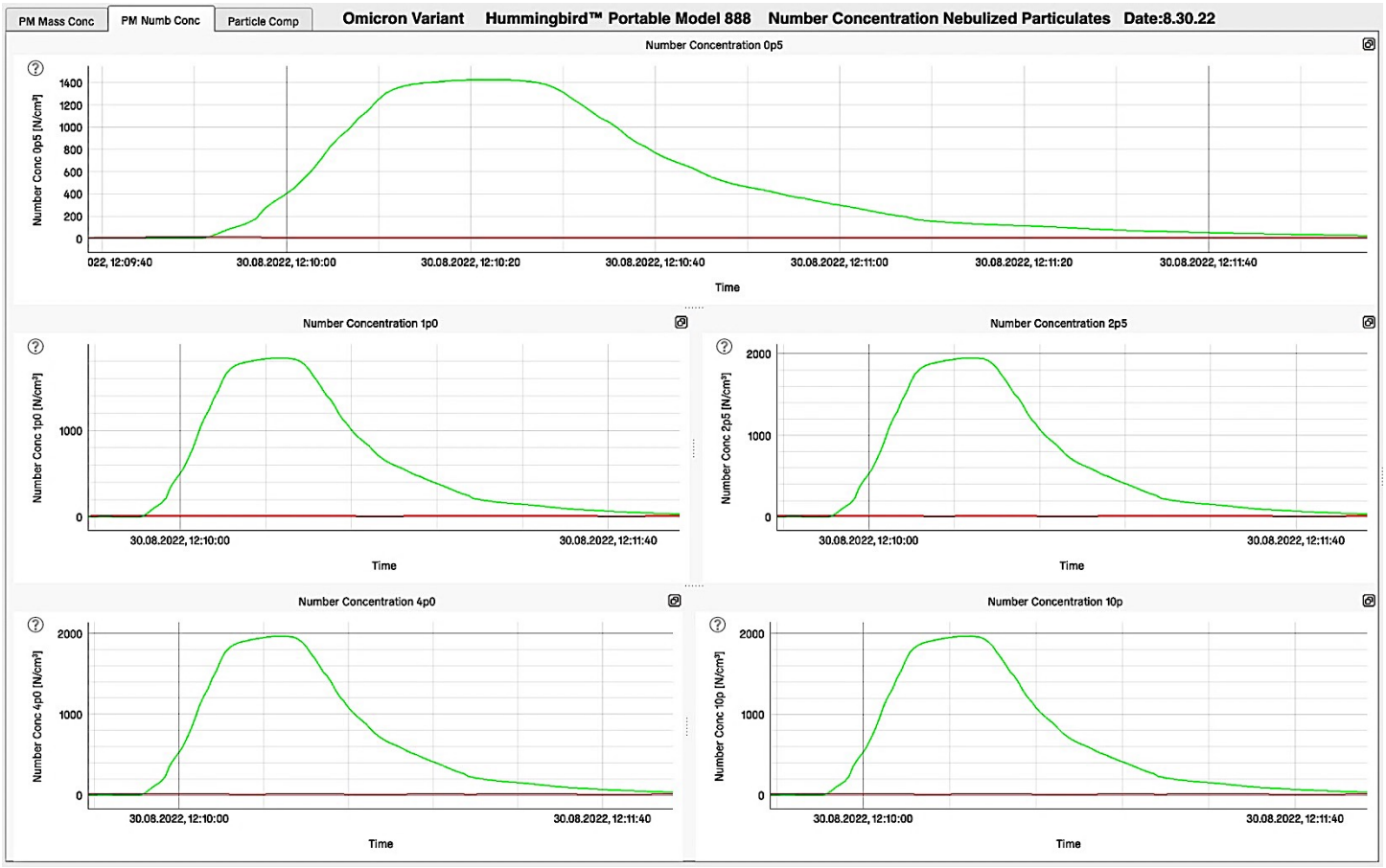
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Portable 888	Omicron	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	4.24E+02	N	N

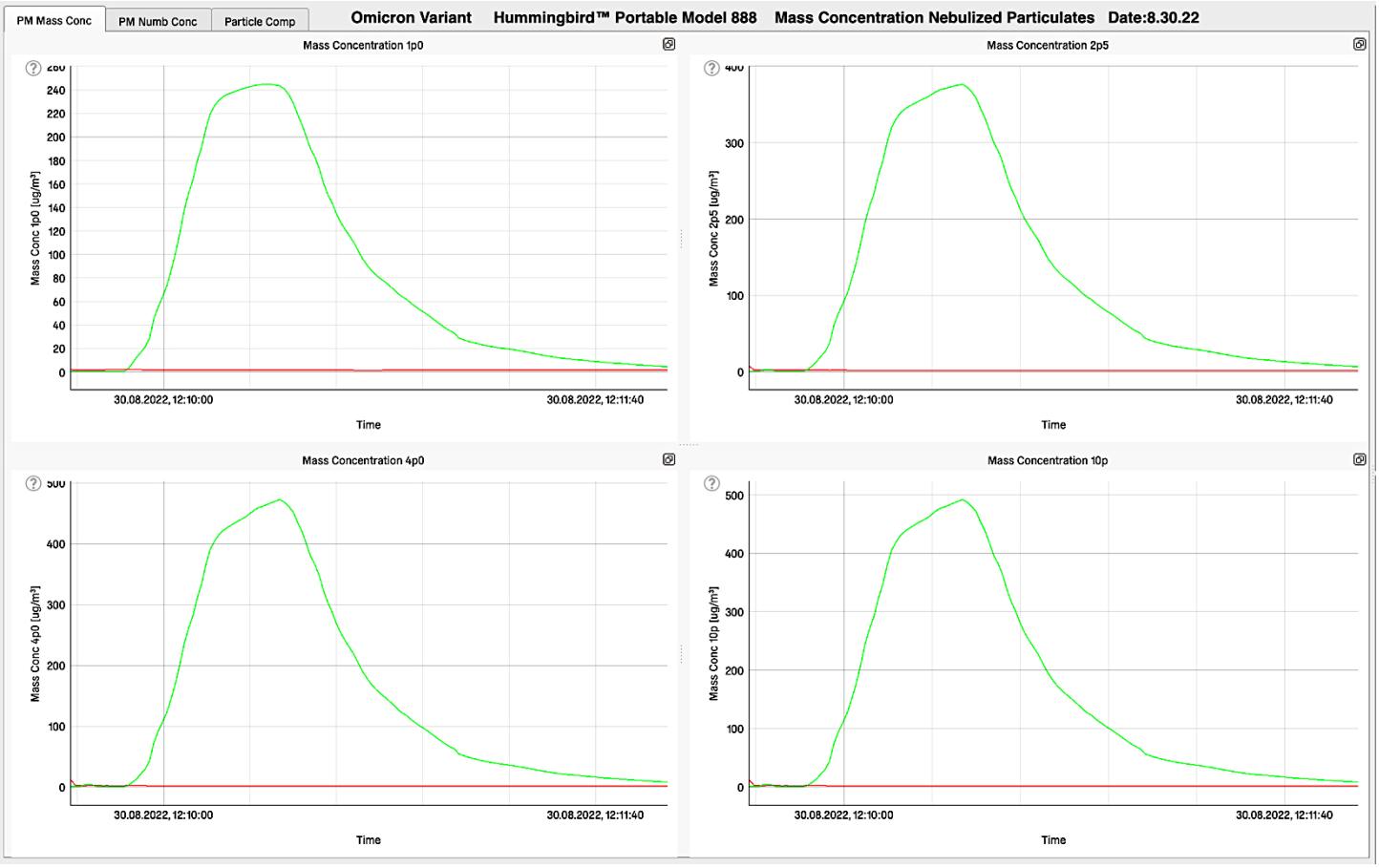
Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Post Filter	0.80	244.8	376.4	472.7	492.0	1,425.7	1,838.9	1,946.3	1,963.8	1,967.1

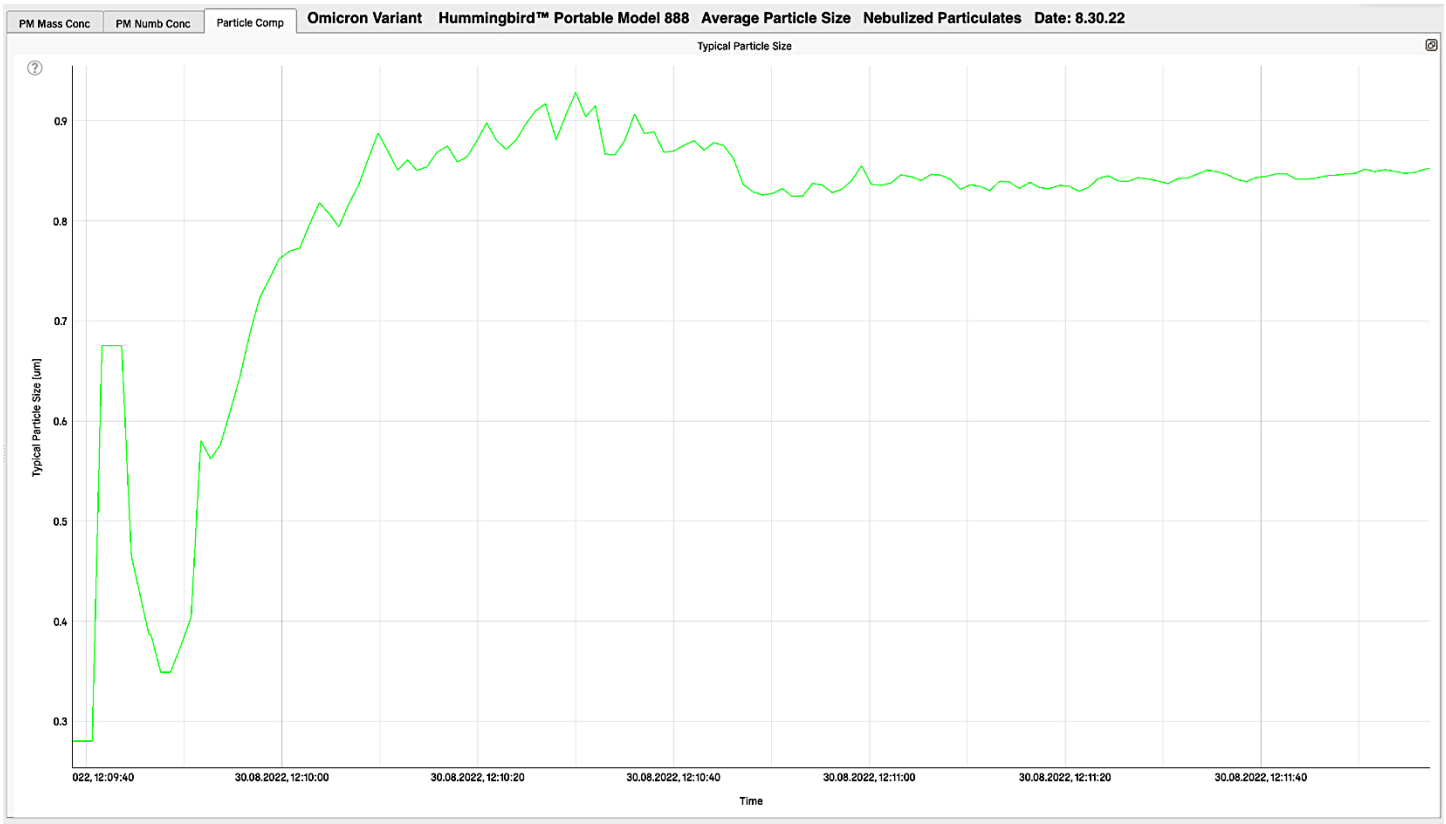
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
373.33	634.29	112	0.57	4.42	389	7.11

Graph Legend: Particulate Sensors
Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.05" WC	20" x 24"	6"	0.0




PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Variant Hummingbird™ Portable Model 888 Mass Concentration Nebulized Particulates Date:8.30.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
30.08.2022, 12:10:00
30.08.2022, 12:11:40
Time


PM Mass Conc
PM Numb Conc
Particle Comp
Omicron Variant Hummingbird™ Portable Model 888 Average Particle Size Nebulized Particulates Date: 8.30.22
Typical Particle Size
Typical Particle Size [um]
30.08.2022, 12:10:00
30.08.2022, 12:10:20
30.08.2022, 12:10:40
30.08.2022, 12:11:00
30.08.2022, 12:11:20
30.08.2022, 12:11:40
Time

Test: Hummingbird™ Portable Model 888: BA.2 Variant

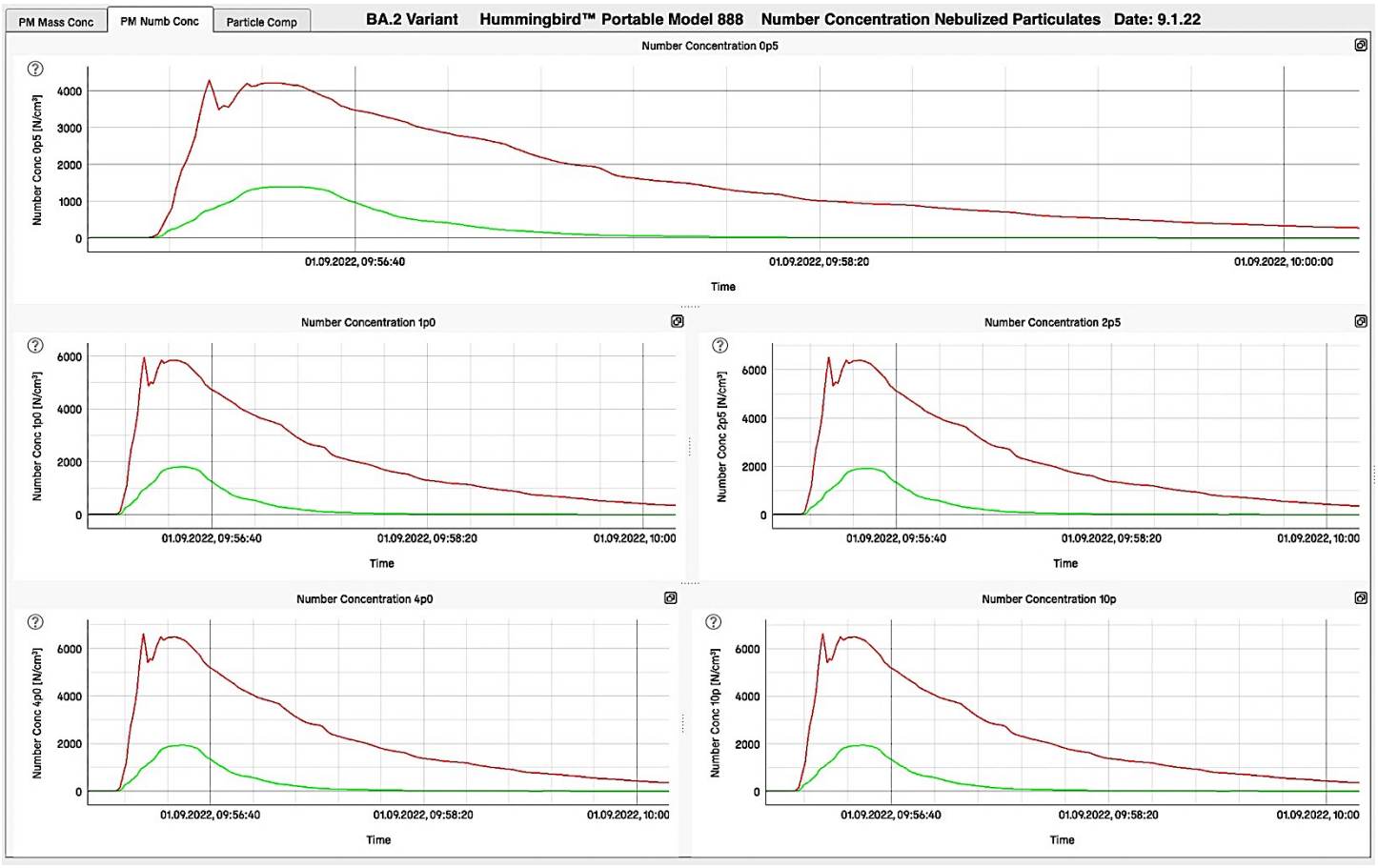
Model	Virus	Test Type	ML	Infectious Dose	Neb. Time	PCO Light Source	Merv Filter	PCO	Total GE	CPE Internal Filter 1	CPE Internal Filter 2
Hummingbird Portable 888	BA.2	Single Pass	4/7	3000+	<45 sec.	LED	HEPA	√	2.6676E+02	N	N

Particulate Sensor	Part. Avg. Size	Part. Mass 1.0 µm	Part. Mass 2.5 µm	Part. Mass 4.0 µm	Part. Mass 10 µm	Part. Number .5 µm	Part. Number 1 µm	Part. Number 2.5 µm	Part. Number 4.0 µm	Part. Number 10 µm
Nebulizer	0.82	823.0	1,384.2	1,800.2	1,883.4	4,282.8	5,974.5	6,534.6	6,625.8	6,642.3
Post Filter	0.88	240.5	369.7	463.4	482.2	1,394.2	1,803.4	1,911.7	1,929.3	1,932.7

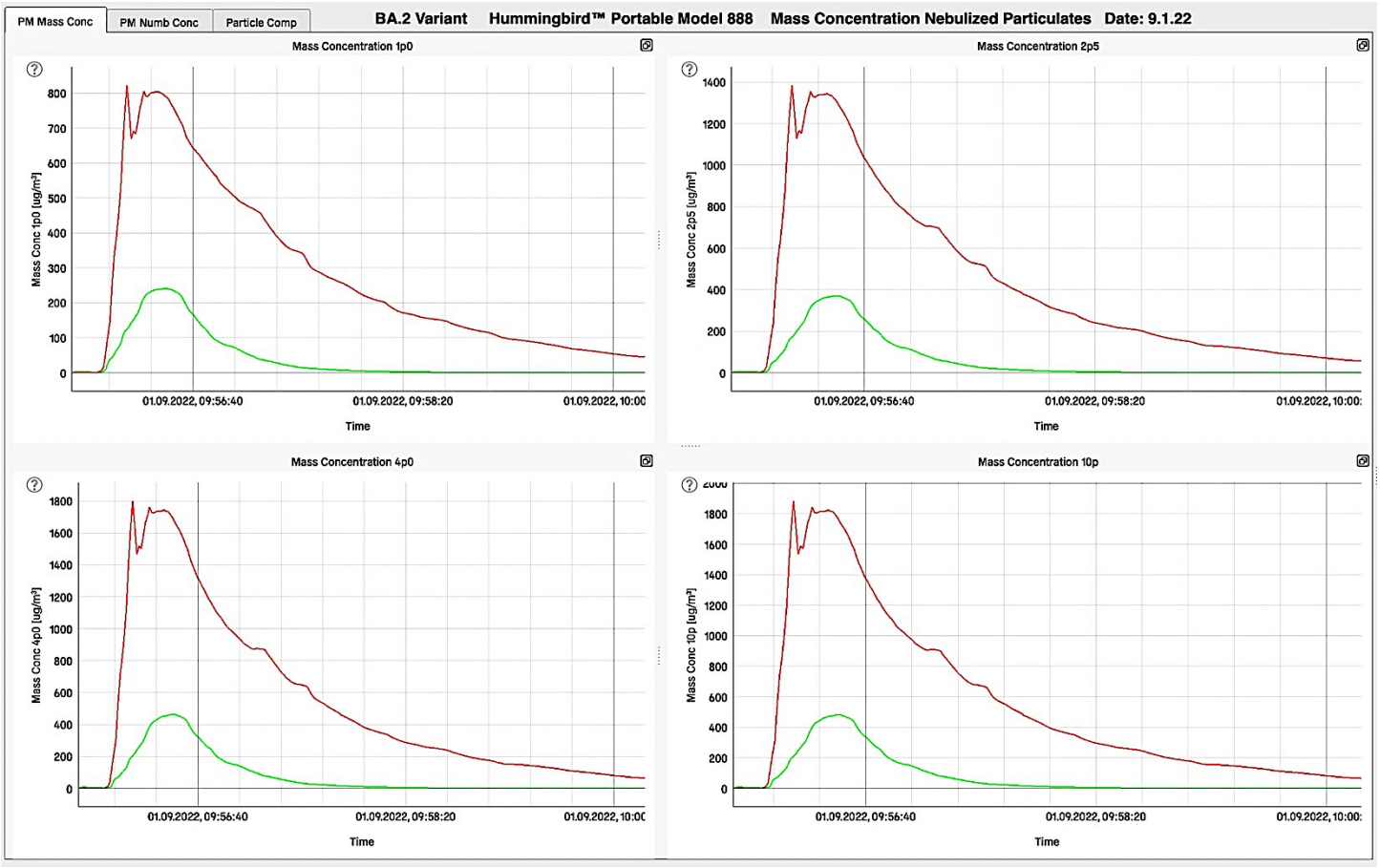
Post Filtration CFM	Post Filtration m^3/hr	Post Filtration Velocity (fpm)	Post Filtration Velocity (m/s)	Transition Duct Velocity (mph)	Transition Duct Velocity (fpm)	Transition Duct Velocity (km/h)
373.33	634.29	112	0.57	4.42	389	7.11

Graph Legend: Particulate Sensors
Red Nebulizing Sensor / Green Virus Collection Sensor

Pressure Across Filter	Post Filtration Duct Size	Transition Duct Size	Ozone Test ppm
.05" WC	20" x 24"	6"	0.0



v 2.5


PM Mass Conc
PM Numb Conc
Particle Comp
BA.2 Variant Hummingbird™ Portable Model 888 Mass Concentration Nebulized Particulates Date: 9.1.22
Mass Concentration 1p0
Mass Conc 1p0 [ug/m³]
Mass Concentration 2p5
Mass Conc 2p5 [ug/m³]
Mass Concentration 4p0
Mass Conc 4p0 [ug/m³]
Mass Concentration 10p
Mass Conc 10p [ug/m³]
01.09.2022, 09:56:40
01.09.2022, 09:58:20
Time


PM Mass Conc
PM Numb Conc
Particle Comp
BA.2 Variant Hummingbird™ Portable Model 888 Average Particle Size Nebulized Particulates Date: 9.1.22
Typical Particle Size
Typical Particle Size [um]
01.09.2022, 09:56:40
01.09.2022, 09:58:20
01.09.2022, 10:00:00
Time

Hummingbird™ Portable Model 888 Conclusion

- The hummingbird™ Portable Model 888 inactivated/ filtered SARS-CoV2 (COVID-19) to below detection limits in a single-pass test of 5 minutes as compared to the same control test under the same conditions.
- With *WT SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X+) of virus necessary for an infectious dose. (7)
- With *Delta SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X+) of virus necessary for an infectious dose. (7)
- With *Omicron SARS-CoV2* this leads to a 99.99% or greater effective decontamination/ filtration of infectious viral particles. This effective drop is when using a vast excess (3000X+) of virus necessary for an infectious dose. (7)
- With *Omicron BA.2 SARS-CoV2* we performed a pilot test and observed no CPE, suggesting that the filtration system inactivates this variant as the others.

References:

1. Zhu, N.; Zhang, D.; Wang, W.; Li, X.; Yang, B.; Song, J.; Zhao, X.; Huang, B.; Shi, W.; Lu, R.; et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. *N. Engl. J. Med.* 2020, *382*, 727–733.

2. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it

3. Centers for Disease Control and Prevention CDC Science Brief: SARS-CoV-2 and Potential Airborne Transmission. Available online: https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html

4. Sommerstein, R.; Fux, C.A.; Vuichard-Gysin, D.; Abbas, M.; Marschall, J.; Balmelli, C.; Troillet, N.; Harbarth, S.; Schlegel, M.; Widmer, A.; et al. Risk of SARS-CoV-2 Transmission by Aerosols, the Rational Use of Masks, and Protection of Healthcare Workers from COVID-19. *Antimicrob. Resist. Infect. Control* 2020, *9*, 100

5. Joshua L. Santarpia, Danielle N. Rivera, Vicki L. Herrera, M. Jane Morwitzer, Hannah M. Creager, George W. Santarpia, Kevin K. Crown, David M. Brett-Major, Elizabeth R. Schnaubelt, M. Jana Broadhurst, James V. Lawler, St. Patrick Reid, John J. Lowe Aerosol and Surface Transmission Potential of SARS-CoV-2 https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v3

6. Joshua L. Santarpia1,2*, Danielle N. Rivera2, Vicki L. Herrera1, M. Jane Morwitzer1, Hannah M. Creager1, George W. Santarpia1, Kevin K. Crown2, David M. Brett-Major1,Elizabeth R. Schnaubelt1,3, M. Jana Broadhurst1, James V. Lawler1,2, St. Patrick Reid1 & John J. Lowe Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care https://www.nature.com/articles/s41598-020-69286-3

7. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7216769