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MEASUREMENT OF AIRBORNE PARTICLES IN A DENTAL PRACTICE USING MULTIPLE OPTICAL PARTICLE COUNTER INSTRUMENTS

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Measurement of Airborne Particles in a Dental Practice using Multiple Optical Particle Counter Instruments

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Approved on behalf of NPLML by
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Executive Summary

From 8 June 2020, general dental practices and community dental services in England were permitted to resume face-to-face routine and urgent care for appropriate patient groups. This followed a period of pause (from 26 March 2020) on routine treatments during the height of the COVID-19 Pandemic.

The resumption of services included the delivery of both Aerosol Generating Procedures (AGPs) and other (non-AGP) activities. There was a requirement that this care be delivered in accordance with appropriate infection control and PPE requirements as set out in a revised Standard Operating Procedure (SOP) published by the Office of the Chief Dental Officer and NHS England on 8 June 2020 (version 2)[1] for dental practices to support the resumption of the full range of dental provision safely.

In July 2020, NPL in partnership with MyDentist conducted a feasibility study looking at AGPs[2], and the associated monitoring and measurement (in real time) of aerosol particle concentration in a dental surgery (clinical space) during actual patient treatment. This initial study suggested that in the particular clinical environment used, the particulate concentrations were driven by ambient background effects and non-AGP activities. It also found that the mean event duration time detected by the Optical Particle Counter (OPC) used in the study was approximately 10 minutes.

One recommendation of this feasibility study was *'That an in-depth larger scale follow-on study is conducted to build on these findings to include the testing and validation of multiple OPC instruments from across the sensitivity and cost spectrum to better capture the concentrations of airborne particles in surgeries during AGP procedures.'* The results from this follow-on study are described in this report.

Measurements of airborne particulates and gases were made at the Tonbridge MyDentist dental practice between 29th January 2021 and 12th February 2021. Measurements were made at a point approximately 0.5 m from the end of the dental chair in two surgeries of different sizes, but with similar air treatment regimes. Dental procedures were carried out on patients and a dental training manikin.

Four Aerosol Generating Procedures (AGPs) were performed on a training manikin under different room ventilation conditions. When the room was unventilated (air filtration unit off and window closed) a rise in particulate mass concentration could be detected which correlated with the AGP being performed. No discernible increase in particle number concentration was seen during this AGP indicating that the rise in particle mass concentration was due to a small number of large particles. As the Covid-19 virus is more likely to be associated with larger particles, particulate mass concentration is also thought to be a more useful metric for assessing the risk of Covid-19 prevalence than particle number concentration.

When the room was either naturally ventilated (window open) and / or mechanically ventilated (air filtration unit on) there was no rise in either particle mass concentration or particle number concentration during the AGPs performed on the training manikin, indicating that the ventilation was adequate enough to disperse any aerosols / particulates generated by the AGPs.

Measurements of particle number concentration and particle mass concentration were also performed during treatments on real patients in both surgeries with the window open and air filtration turned on. A total of 15 AGPs were performed. In one instance there was an increase in particle number concentrations coinciding with an AGP, where one type of particle sizing instrument saw an increase in particle number concentrations but the other particle sizing instrument and the particle mass concentration measuring instruments did not see an increase. Further examination shows that the increase seen by one of the particle sizing instruments was in particles with a diameter less than 0.3µm, which is the lower cut off for the other particle sizing instrument and these small particles will also have negligible mass, hence no increase seen by the particle mass concentration instruments. According to the Dentist's notes the AGP performed during this time was ultrasonic cleaning, which has the potential to produce a very fine water spray from the patient's mouth.

Key Findings:

- Performing an AGP on a manikin resulted in a significant increase in particulate mass concentration when the surgery was unventilated (air filtration off, window closed). No analogous increase in particle number concentration was observed, indicating that the rise in particle mass concentration was due to a small number of large particles.

- When the windows in the surgery was open, it was not possible to positively determine that the detected particle matter originated from AGPs – the open window was the dominant source of particulates / aerosols.

- During the manikin tests no AGPs were detected when the air filtration unit was on, indicating it was effective at removing particulates.

- Operating the air filtration unit with the window open reduced the background concentration of airborne particulates in the surgeries to lower levels than the unventilated surgery.

- When AGPs were performed on patients only one rise in particle number concentration was detected during ultrasonic cleaning, which has the potential to produce a very fine water spray from the patient's mouth.

- The results of the study supported the findings of NPL's earlier feasibility study in suggesting that even in a small dental surgery, the impact on in-surgery particle concentrations from AGPs was limited when appropriate mitigation procedures were used.

Contents

1. Aim

This was a follow-on investigation from the NPL feasibility study '*Feasibility Study on the Detection of Airborne Particulates in a Dental Surgery using an Optical Particle Counter*[2]*.* Measurements of airborne particulates and gases were made at the Tonbridge MyDentist dental practice between 29th January 2021 and 12th February 2021. Measurements were made in two surgeries of different sizes, but with similar air treatment regimes, whilst in a live (operational) clinical environment with patients and a training manikin. Five different instruments were used to assess the airborne particle number (or mass) concentrations present and how they were affected by Aerosol Generating Procedures (AGPs) with real-world mitigation processes in place.

The aim of this study was to build on the findings of the preliminary NPL study and expand the base of evidence for gauging particle removal times. These are highly relevant to add to the evidence base for determining suitable fallow times between patients. This study also examined the suitability of commercially available instruments to measure airborne particle concentrations, to determine background concentrations and to explore differences in detection of aerosols from different Aerosol Generation Procedures (AGPs) with real-world mitigation processes in place. Although this study is much more extensive than the preliminary NPL study, its limitations must still be recognised, and final conclusions must not be drawn from this study in isolation.

2. Instrumentation, Experimental Set Up and Dental Procedures

2.1 Instrumentation

Measurements were made with five types of particulate analysers and two gas sensors collecting data at 1 minute intervals.

2.1.1 Particle Counting and Sizing

Two types of optical particle sizing / counting instruments were used, both able to measure size distributions as well as total particle number. One instrument had a particle size measuring range of 0.15µm - 10µm with 32 intervals per decade, whilst the other had a range of 0.3µm - 10µm with 16 channels covering the whole size range.

2.1.2 Particle Mass Concentration

Three types of optical particle mass concentration instruments were used. Two were able to provide particle number concentrations over the following size distributions: 0.25µm - 35µm, 31 channels and 0.18µm - 100µm, 95 channels, respectively and provided particle mass concentrations for TSP, PM_{10}, PM_4, $PM_{2.5}$ and PM_1. The other instrument just gave particle mass concentrations for TSP, PM_{10}, PM_4, $PM_{2.5}$ and PM_1.

A single particle mass concentration instrument was set up in each surgery for the whole fortnight, whilst duplicate particle number / mass concentrations instruments were used in each surgery for 1 week at a time.

All three types of particle mass concentration instrument relied on the factory calibration.

2.1.3 Gas Concentration

One of the particle mass concentration instruments also had 2 gas sensors installed in each unit. One measuring carbon dioxide by non-dispersive infrared absorption and the other monitoring nitric oxide using an electrochemical cell.

2.2 Mitigation Measures

The key mitigation measures in place in the surgeries to limit the release of aerosols from AGPs for both manikin and patient procedures were:

- Wide bore 11mm aspiration tip,
- High volume suction at 300 ml min^{-1} This was assessed prior to this study by a dental engineer using a Suction Capability Test to ensure that units were running at or above the required 300 ml min^{-1};
- Four-handed dentistry for patients (where a dental assistant/nurse assists the dentist) and two-handed dentistry (dentist only) for the manikin tests:
- Use of rubber dam on patients as a physical barrier for many of the procedures with AGPs, not used during manikin tests;
- Air filtration Unit: HEPA filtration; 2 operating modes TURBO (666m^3 $hour^{-1}$) and HIGH (328 m^3 $hour^{-1}$).
- Open window

2.3 Experimental Set Up

Measurements were made in two surgeries in the Dental Practice. Surgery S4 had a volume of 27.63 m^3 (4.24m x 2.75m x 2.37m) and surgery S7 had a volume of 63.16 m^3 (6.50m x 4.10m x 2.37m). The dental practice is situated on the High Street in central Tonbridge and surgery S4 faces the road, whilst surgery S7 faces the back of the building towards urban dwellings and a churchyard. Tonbridge High Street had reduced traffic volumes during the measurement period due to the implementation of the 3rd Coronavirus lockdown in January / February 2021.

For all patient procedures the surgery had windows which were open and the air filtration was turned on. For non-AGP work the air filtration unit was set to HIGH and for AGPs the air filtration unit was set to TURBO.

Tests were also performed on a training manikin under different ventilation conditions as described in Section 2.4.

Table 1 gives the theoretical air exchange rate for the two surgeries based on the air filtration unit's mode. In practice the air exchange rate is likely to be lower than this, however the open windows and surgeries air conditioning units (unknown capacity) will help to increase the air exchange rate.

	Air Filtration Unit Operating Mode	
Surgery	**HIGH**	**TURBO**
S4	12 per hour	24 per hour
S7	5 per hour	11 per hour

Table 1 Surgery theoretical air exchange rates

All of the instruments were set up on a trolley to measure at the same height. The distance to the front of the trolley from the end of the patient's chair was 0.5m in both surgeries.

Measurements were made in surgery S4 from 29th January 2021 to 5th February 2021 and in surgery S7 from 5th February 2021 to 12th February 2021.

2.4 Dental Procedures

On 2nd February AGPs (High Volume Extraction, 3 in 1 syringe, high speed ultra sonic) were performed on a training manikin in surgery S4 under different ventilation conditions to determine their effectiveness to remove potential aerosols. The ventilation conditions are specified in Table 2.

Ventilation Condition	Start and End Time	AGP Period
Air filtration Off, Window Closed	Overnight – 11:30	10:45 – 11:00
Air filtration On, Window Closed	11:30 – 12:45	12:00 – 12:15
Air filtration Off, Window Open	12:45 – 14:00	13:15 – 14:00
Air filtration On, Window Open	14:00 – 15:56	14:30 – 14:45
Air filtration Off, Window Closed	15:56 - Overnight	None

Table 2 Time of Manikin tests and AGPs on 2nd February 2021

For all the other days, necessary dental procedures were performed on real patients under normal surgical conditions as described in Section 2.2. Dentists recorded the times of potential AGPs and these are given in Table 3. The CO_2 measurements were used to indicate surgery usage and surgery occupation.

Surgery	Date	AGP Period	Surgery	Date	AGP Period
S4	01/02/2021	11:25 – 11:52 16:28 – 16:48 18:15 – 18:25	S7	09/02/2021	08:10 – 08:30 11:30 – 12:15 14:00 – 15:10
S4	03/02/2021	09:30 – 09:44 11:15 – 11:48 16:15 – 16:31	S7	10/02/2021	09:11 – 10:28 11:18 – 11:52 13:11 – 13:51 15:09 – 15:25
S4	04/02/2021	10:35 – 10:14	S7	11/02/2021	11:53 – 12:18

Table 3 Potential AGP dates / times for procedure on real patients for both surgeries

3. Results and Discussion

The results given in this report are highlights, and give measurements where significant concentrations were measured. Days where no raised concentrations were detected have not been included for brevity. The complete set of results made between 29th January 2021 to 12th February 2021 can be requested from the authors.

The results from one of the particle number / mass concentration instruments have not been presented in this report as the instrument reported its results as a 2 hour rolling average and not as 1 minute averages. Hence it was unsuitable for detecting short term events. This was due to an error in the setup of the instrument – this instrument would otherwise have been expected to give results similar to the other instruments. The other instruments gave valid results.

For the Figures, individual instrument results have been identified by instrument serial number to aid anonymity.

3.1 Manikin Tests

Figure 1 shows a time series of the particle number and particle mass concentrations measured in surgery S4 during the day on 2nd February 2020. The changes in ventilation state is highlighted by the black line increasing with each change in ventilation state. The AGPs have been superimposed on this black line by increasing its magnitude by 500 during the period of the AGP. The black line is a visual of the representation of the ventilation and AGP timings.

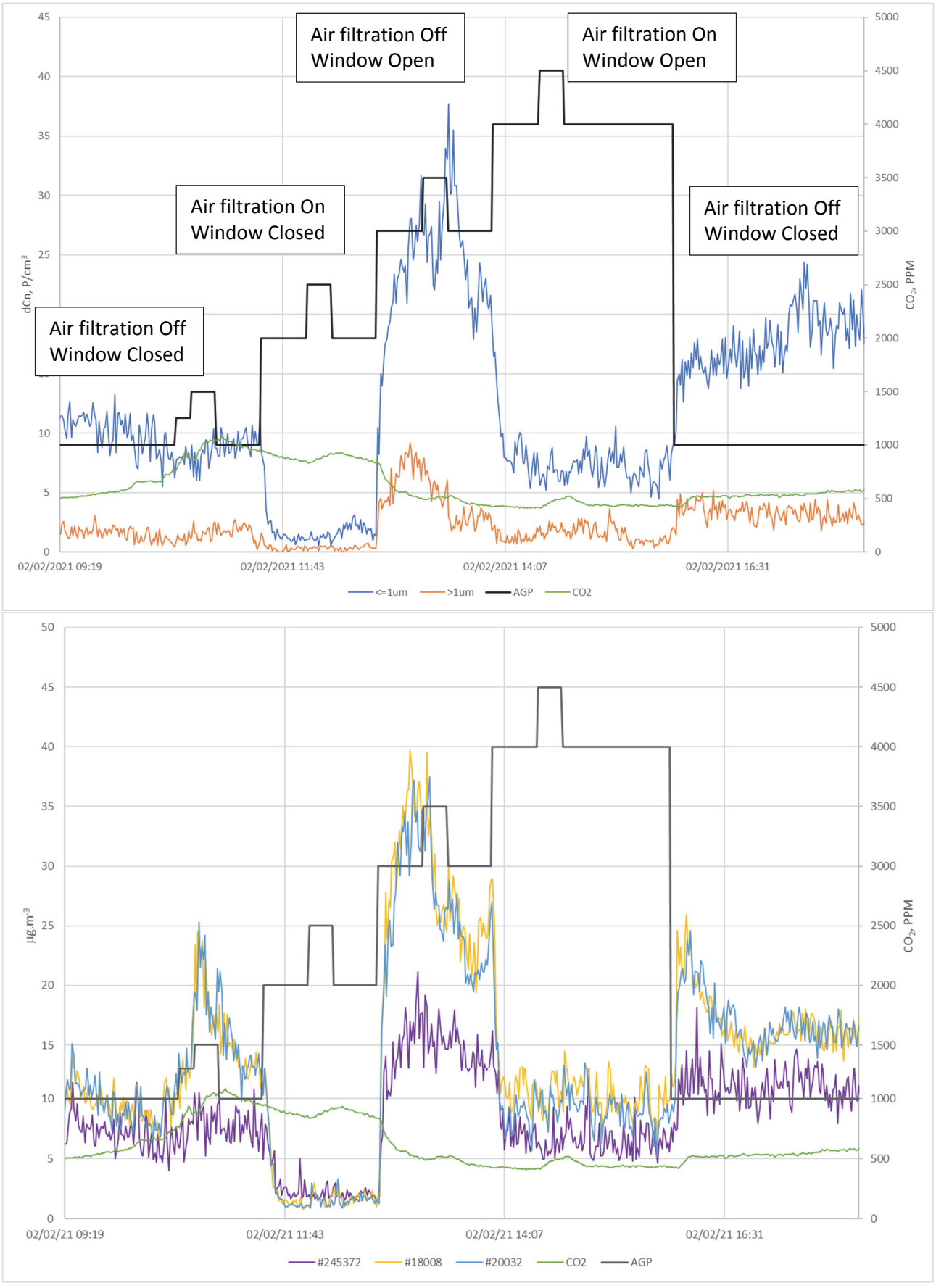


Figure 1 **Particle number concentrations (top); PM_{10} particle mass concentrations from three instruments (bottom) and carbon dioxide concentrations (both) measured during the manikin tests. The black line represents the ventilation state and is for indication only (see text in Section 3.1 for full details).**

It can be clearly seen that the air filtration unit is effective at removing airborne aerosols and particulates and unsurprisingly the open window lets in particles from outside.

Figure 2 gives PM_1, $PM_{2.5}$, PM_4 and PM_{10} particle mass concentrations measured from one instrument during the Air Filtration Off, Window Closed AGP.

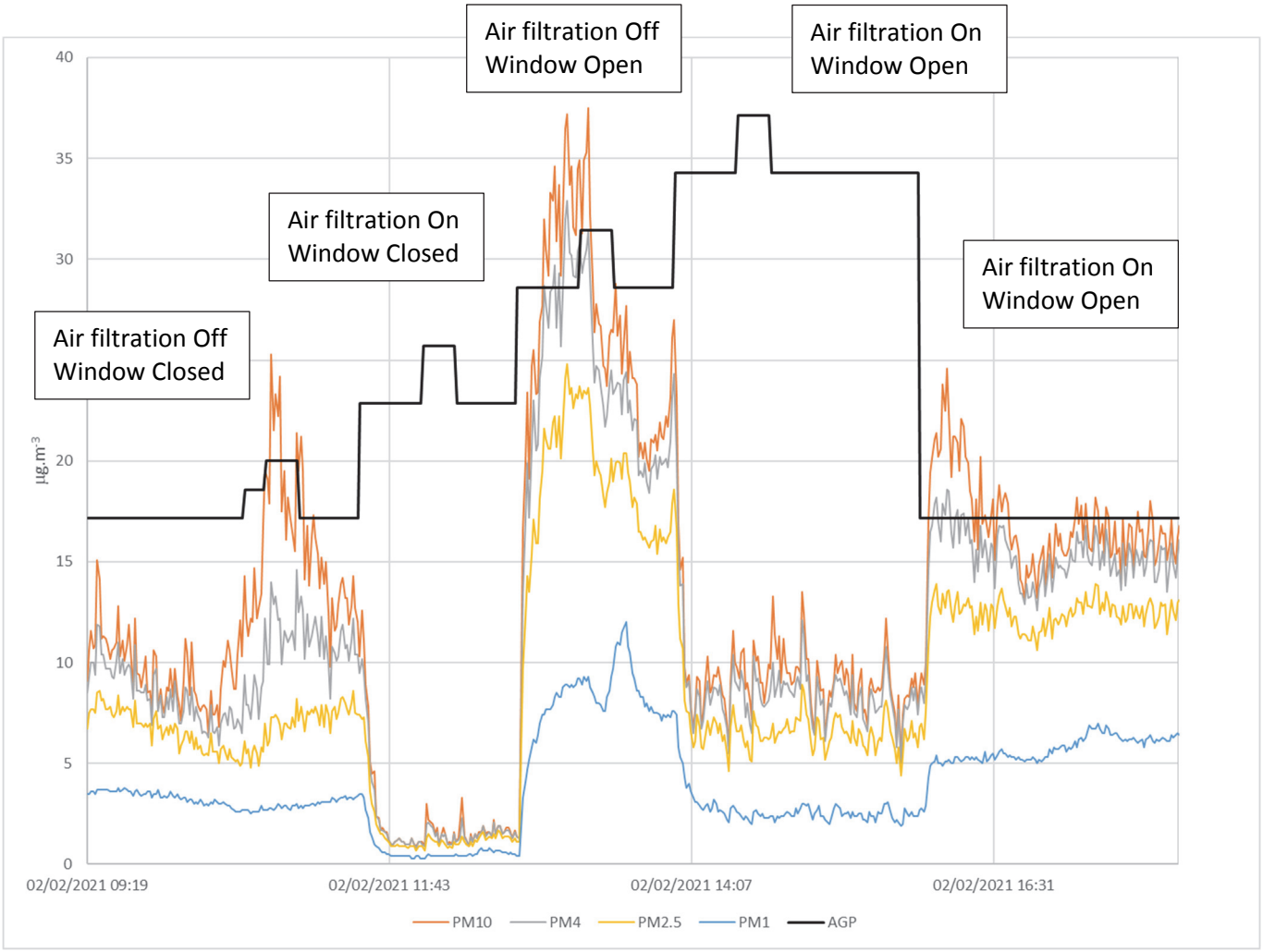


Figure2 **Particulate mass concentrations measured during the manikin tests on 02/02/2021. The coloured lines indicate the particle size fractions shown in the legend**

It can be clearly seen that the increase in mass concentrations during the Air filtration off, Windows closed AGP is in the larger size fractions.

The increase in particle number concentration and particle mass concentrations during the Air filtration off, Window open period is probably due to particulates entering the room from outside. Similar levels of particle mass concentration were measured in surgery S7 at the same time with its window open.

From Figures 1 and 2, no significant increase in either particle number concentration or particle mass concentration can be seen during the 3 AGPs performed under Open window and/or Air filtration ventilation.

The size distribution of particulates measured by the best resolution particle counter throughout the day is given in Figure 3.

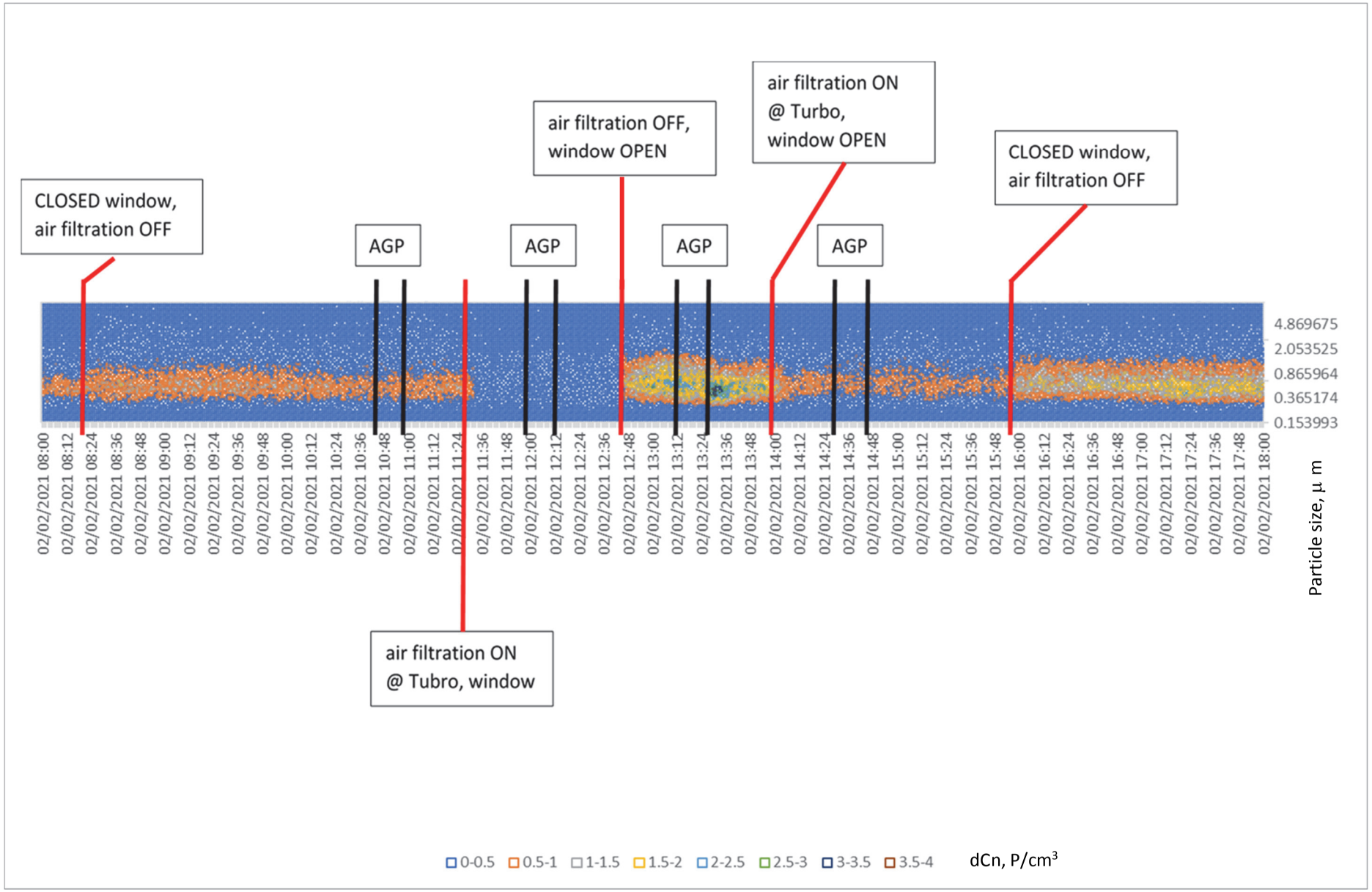


Figure 3 **Particle size distribution measured during 02/02/2021**

The changes in size distribution during the ingress of ambient air into the surgery during the Open window, no Air filtration ventilation regime can be clearly seen.

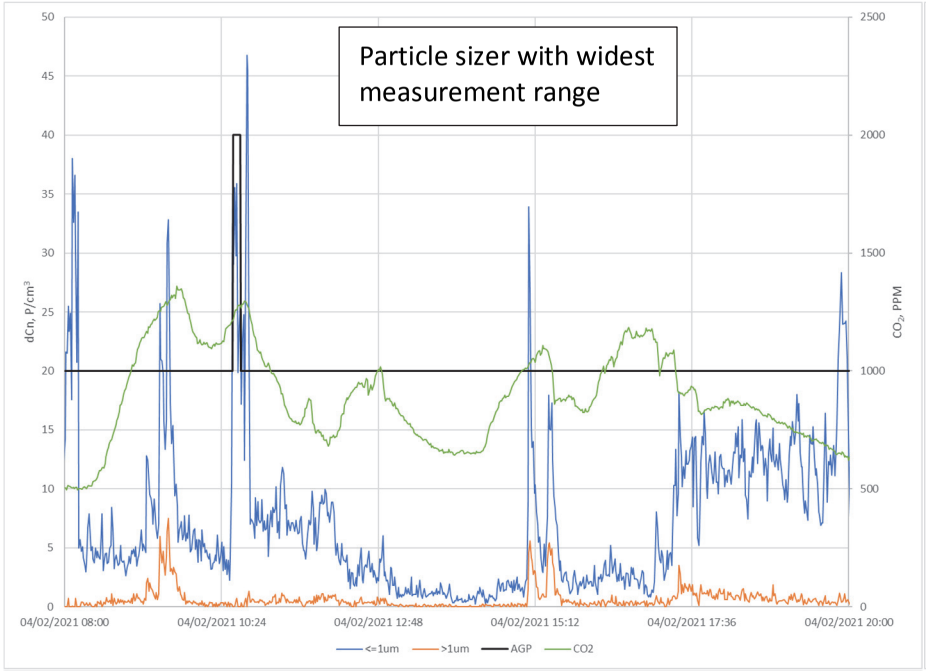
3.2 Patients

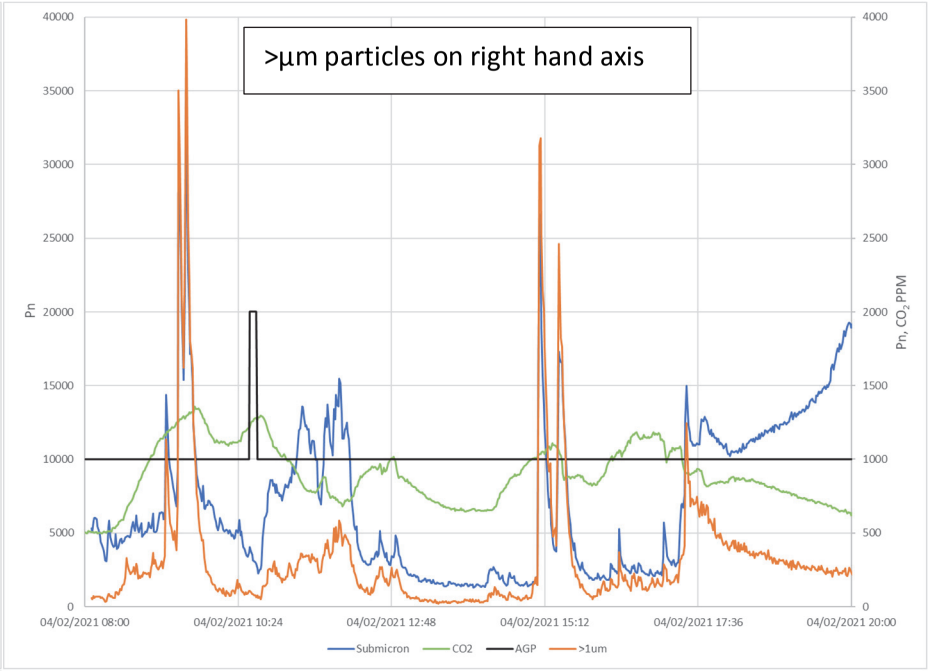
In the study of dental procedures on patients, only one significant increase coinciding with an AGP was found on 4th February in surgery S4 and is shown in Figure 4, where the particle sizer with the widest measurement range saw an increase in particle number concentrations but the other particle sizer and particle mass concentration measuring instruments do not see an increase. Further examination shows that the particle size of this peak was less than 0.3µm, which is the cut off size of the particle sizer with the narrower measurement range. These small particles will also have negligible mass, hence no increase seen by the particle mass concentration instruments.

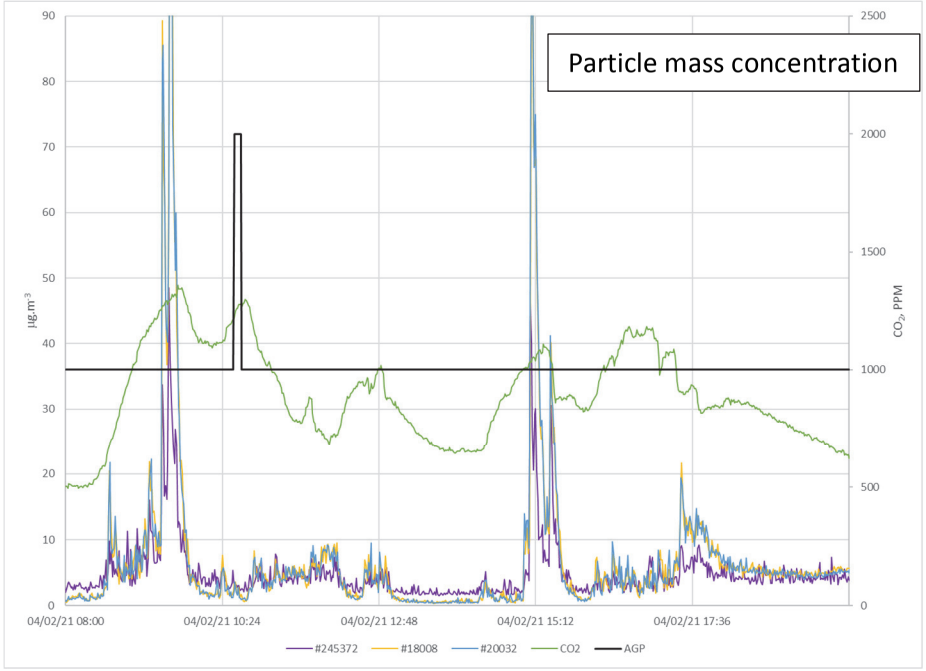
Figure 5 gives the size distribution measured throughout the day and clearly shows the peak in very small particles coinciding with the AGP. From the dentist's notes this AGP was an ultrasonic cleaning procedure which is known to produce a very fine aerosol spray.

Another increase in particulate concentrations on the 4th February was seen between 15:00 and 15:45 and this associated with a non AGP teeth cleaning procedure. These peaks contain particles with a wider size distribution than the earlier AGP peak.

Figures 6 to 7 give results from selected days to show the lack of increase in particles or aerosols generated from AGPs. Figures 8 to 9 show measurements made at weekends when the surgeries were unoccupied to give a room background measurement. In Figures 6 to 9 the mass concentration measuring instruments are identified by serial number to ensure anonymity.







Top 2 particle number charts

- Size <1mm
- Size >1mm
- Carbon Dioxide
- Indication of AGP timing

Bottom PM Mass chart

- #245372
- #18008
- #20032
- Carbon Dioxide
- Indication of AGP timing

Figure 4 **Particle number concentrations & particle mass concentrations measured on 04/02/2021 in surgery S4**

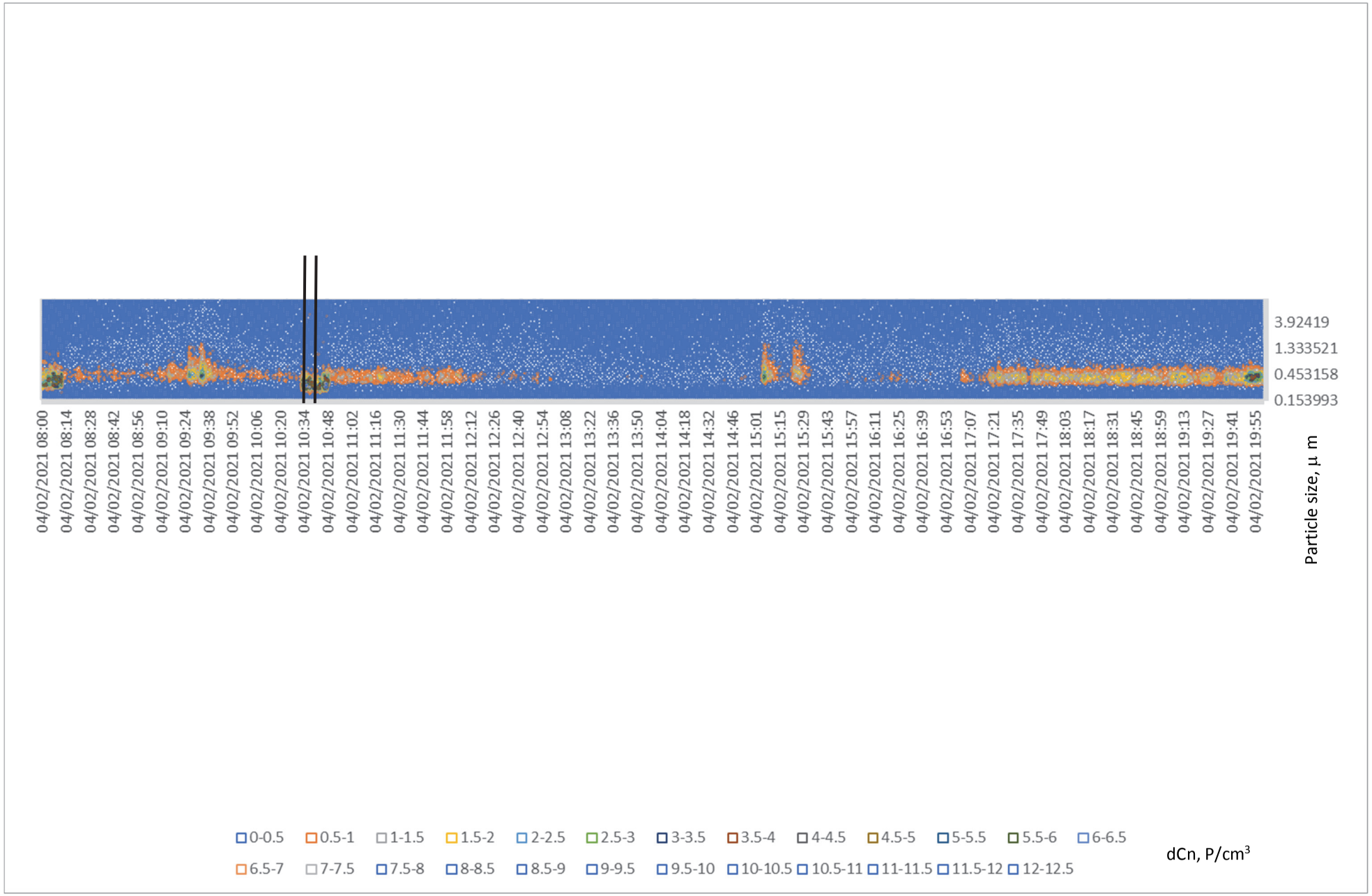
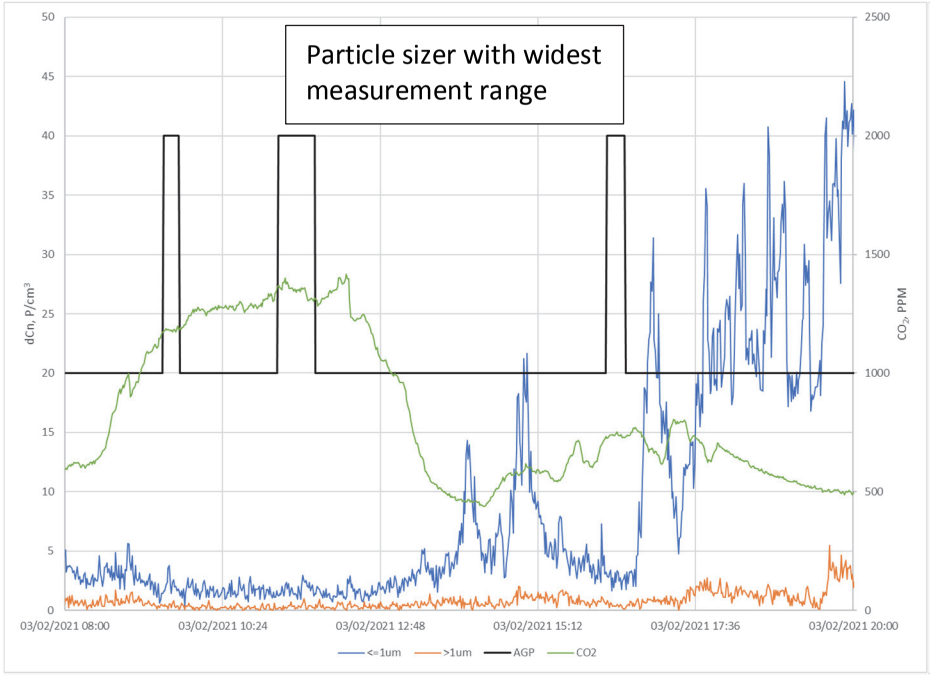
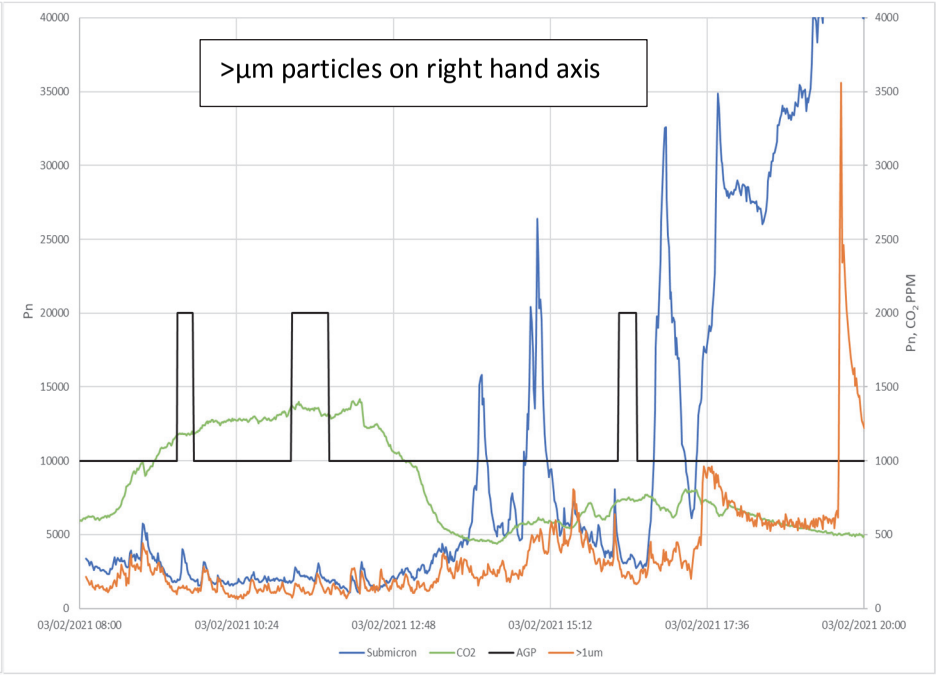
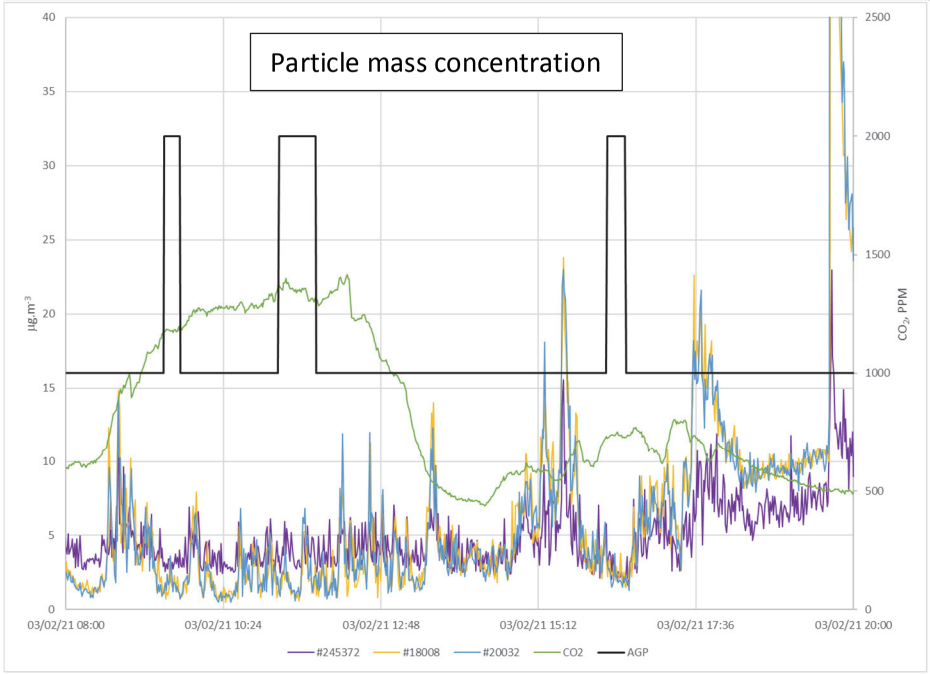


Figure 5 **Size distribution measured during 04/02/2021 in surgery S4**







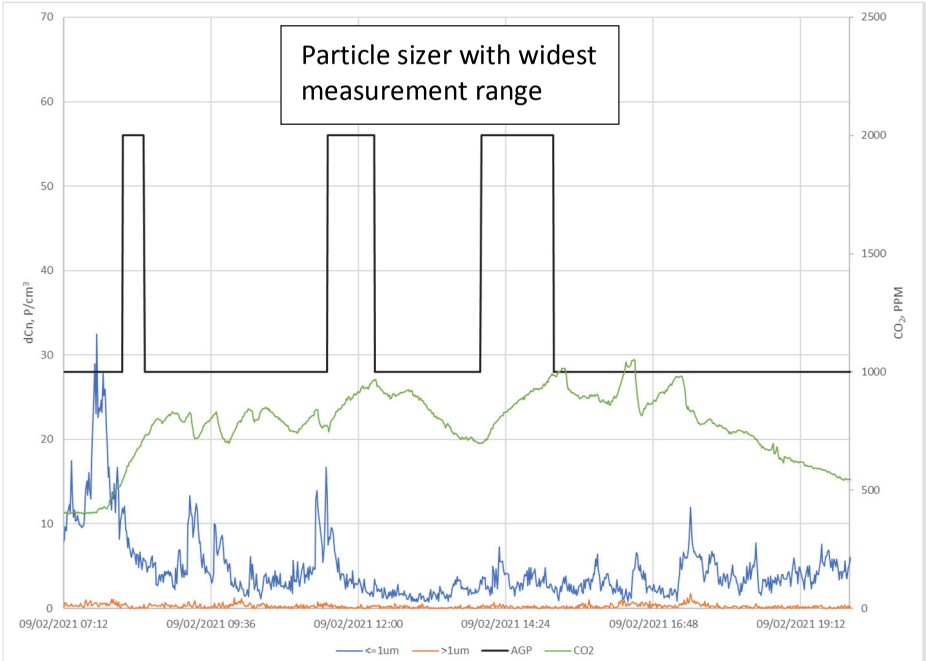
Top 2 particle number charts

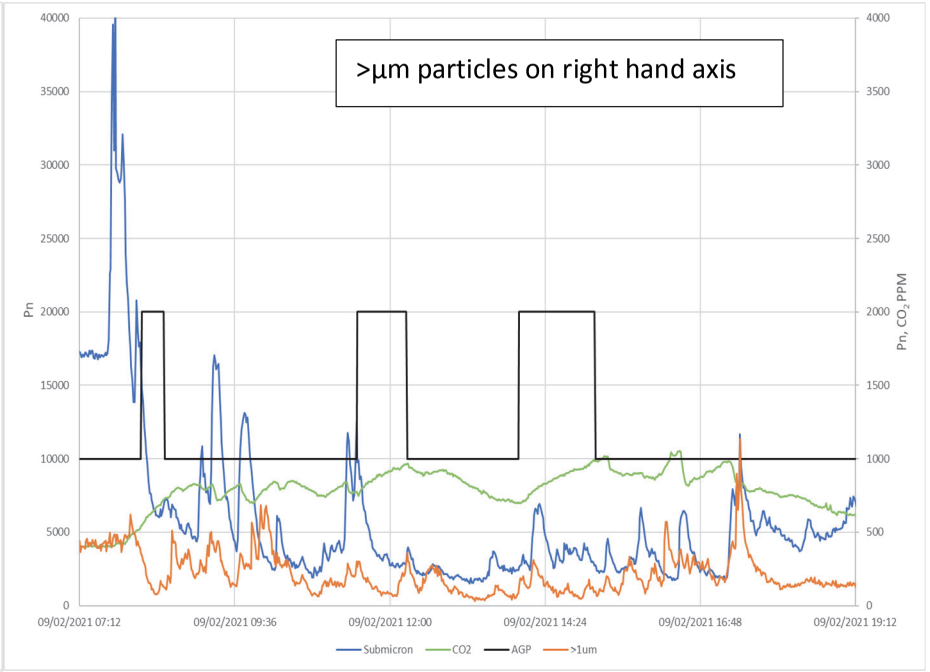
- Size <1µm
- Size >1µm
- Carbon Dioxide
- Indication of AGP timing

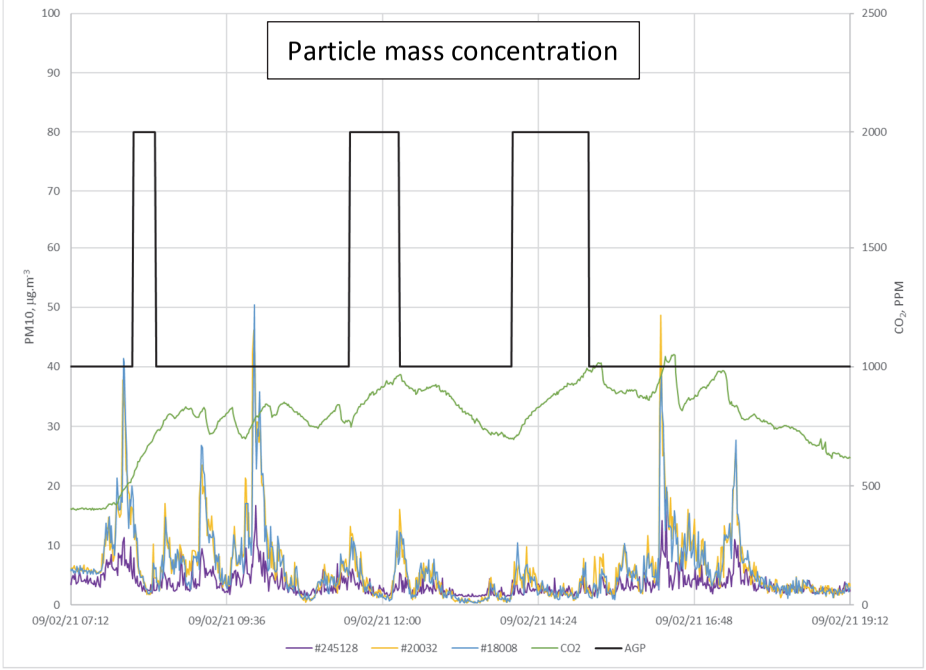
Bottom PM Mass chart

- #245372
- #18008
- #20032
- Carbon Dioxide
- Indication of AGP timing

Figure 6 Particle number concentrations & particle mass concentrations measured on 03/02/2021 in surgery S4







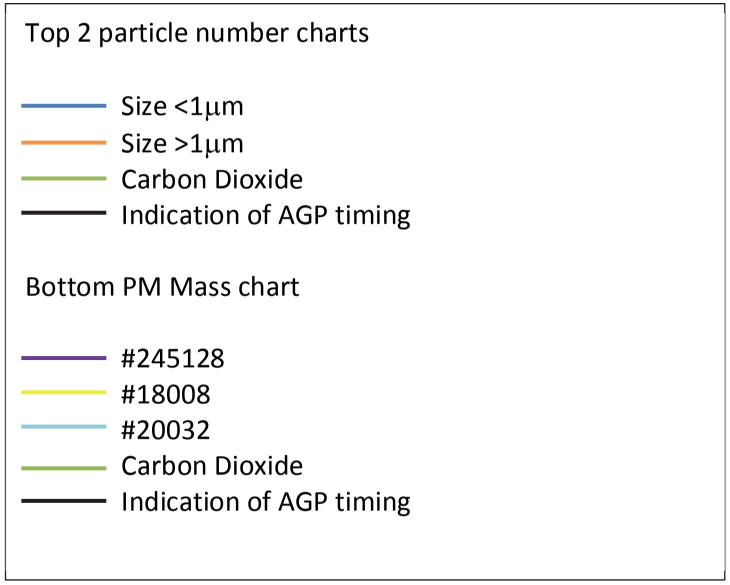
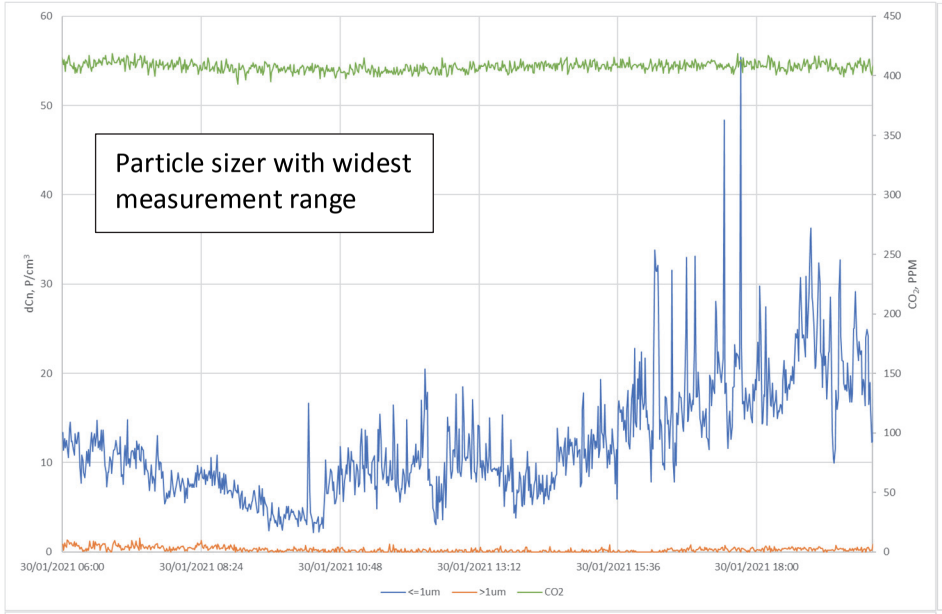
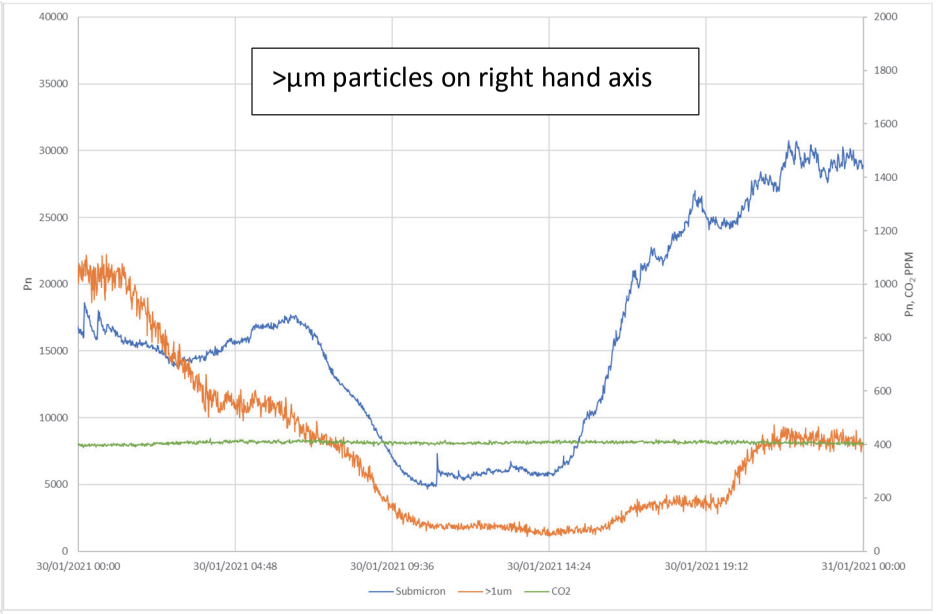
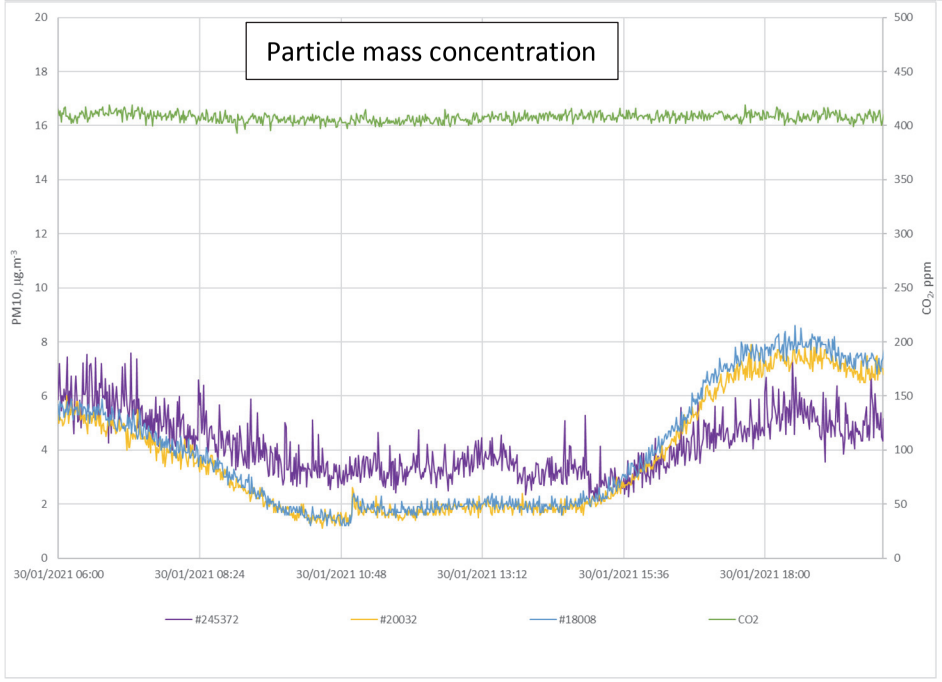


Figure 7 **Particle number concentrations & particle mass concentrations measured on 09/02/2021 in surgery S7**







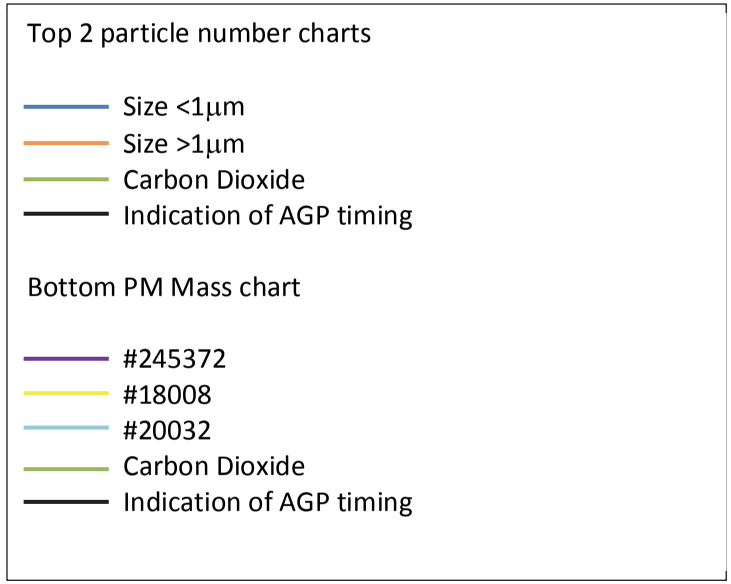
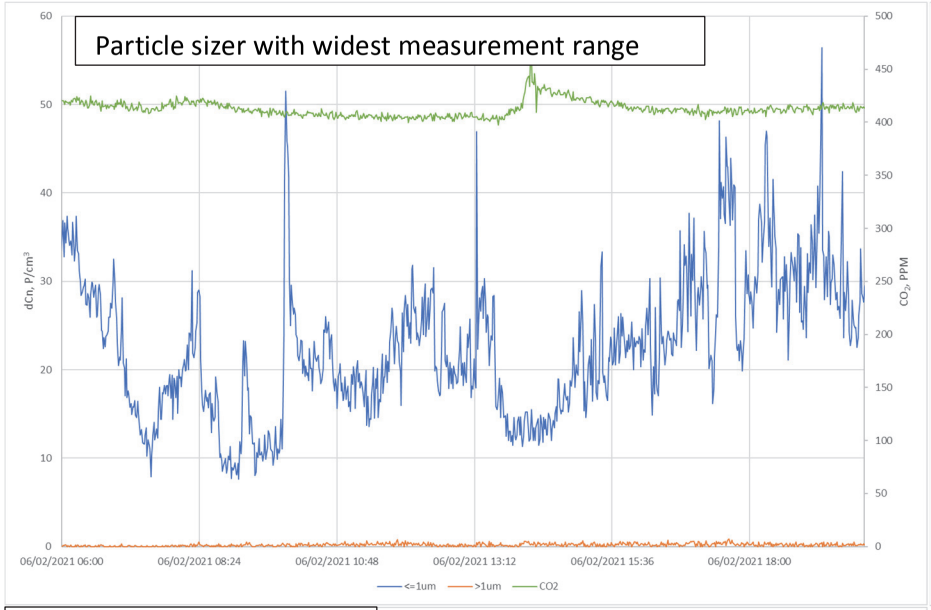
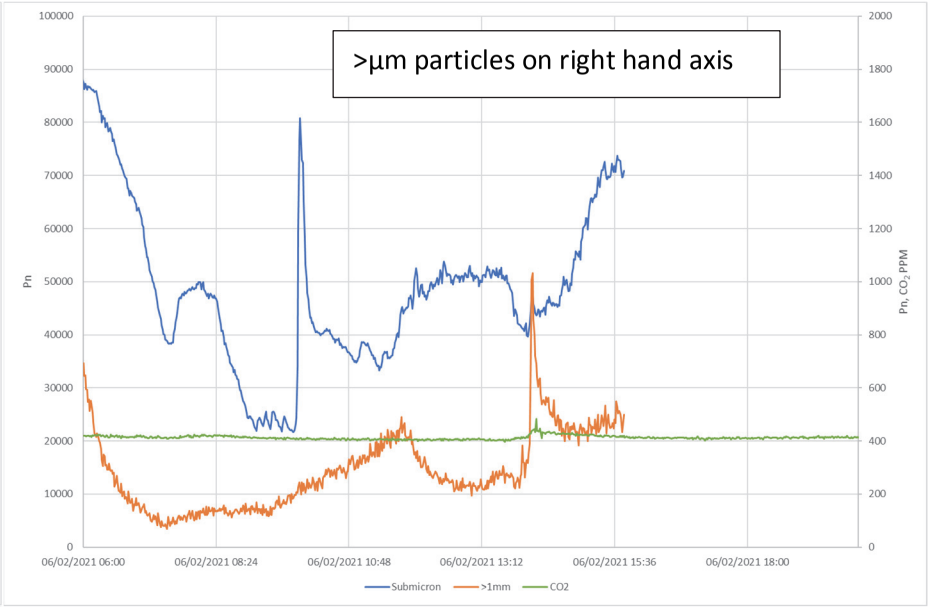
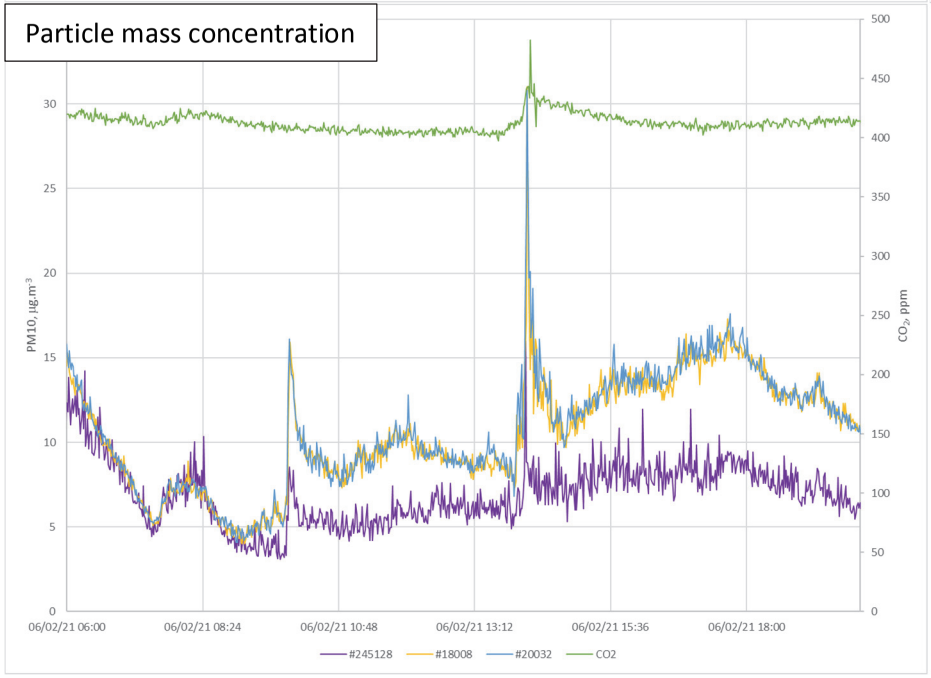


Figure 8 **Particle number concentrations & particle mass concentrations measured on 30/01/2021 in surgery S4**







Top 2 particle number charts

- Size <1µm
- Size >1µm
- Carbon Dioxide
- Indication of AGP timing

Bottom PM Mass chart

- #245128
- #18008
- #20032
- Carbon Dioxide
- Indication of AGP timing

Note TSI 3330 stopped at 15:46 on 06/02/2021

Figure 9 Particle number concentrations & particle mass concentrations measured on 06/02/2021 in surgery S7

4. Conclusions and Recommendations for Further Work

4.1 Conclusions

Four Aerosol Generating Procedures (AGPs) were performed on a training manikin under different room ventilation conditions. When the room was unventilated (air filtration off, window closed) a rise in particulate mass concentration could be detected which correlated with an AGP being performed. No increase in particle number concentration was seen during this AGP indicating that the rise in particle mass concentration was due to a small number of large particles and not a large number of small particles. Figure 2 shows this increase to be due to particles between PM_4 and PM_{10}. As the Covid-19 virus is more likely to be associated with larger particles, particulate mass concentration is also thought to be a more useful metric for assessing the risk of Covid-19 prevalence than particle number concentration.

When the room was either naturally ventilated (open window) and / or mechanically ventilated (air filtration unit) there was no detected rise in either particle mass concentration or particle number concentration during the potential AGP procedures performed on the training manikin, indicating that the ventilation was adequate enough to disperse any aerosols / particulates generated by the AGPs performed.

In all but one case, when the windows in the surgeries were open, it was not possible to positively determine that the detected particle matter originated from AGPs indicating that the open window was the dominant source of particulates / aerosols.

Measurements of particle number concentration and particle mass concentration were also performed during treatments on real patients in both surgeries with the window open and air filtration turned on. A total of 15 AGPs were performed. In only one instance an increase in particles number concentration was observed that coincided with an AGP, where the particle sizer with the widest measurement range saw an increase in particle number concentrations but the other particle sizer and particle mass concentration measuring instruments did not see an increase. Further examination shows that the particle size of this peak was less than 0.3µm, which is the cut off size of the particle sizer with the narrower measurement range. These small particles will also have negligible mass, hence no increase seen by the particle mass concentration instruments. According to the Dentist's notes the AGP performed during this time was ultrasonic cleaning, which as the potential to produce a very fine water spray from the patient's mouth.

The key findings of the work are summarised below:

- Performing an AGP on a manikin resulted in a significant increase in particulate mass concentration when the surgery was unventilated (air filtration off, window closed). No analogous increase in particle number concentration was observed, indicating that the rise in particle mass concentration was due to a small number of large particles.

- When the window in the surgery was open, it was not possible to positively determine that the detected particle matter originated from AGPs – the open window was the dominant source of particulates / aerosols.

- During the manikin tests no AGPs were detected when the air filtration unit was on, indicating that it was effective at removing particulates.

- Operating the air filtration unit with the window open reduced the background concentration of airborne particulates in the surgeries to lower levels than the unventilated surgery.

- When AGPs were performed on patients only one rise in particle number concentration was detected during ultrasonic cleaning, which has the potential to produce a very fine water spray from the patient's mouth.

- The results of the study supported the findings of NPL's earlier feasibility study in suggesting that even in a small dental surgery, the impact on in-surgery particle concentrations from AGPs was limited when appropriate mitigation procedures were used.,

4.1 Recommendations for Further Work

This study has provided some strong evidence to show that with the appropriate mitigations and correct ventilation in place, the effect of AGP procedures on the particle concentrations measured in a dental surgery in a surgery is very limited. Before this can be stated with certainty, however, some additional testing would be required. Two follow-on studies are recommended:

- The spatial variations in the surgery must be considered by repeating AGP measurements with both particle number and mass concentration measuring instruments at various locations around the surgery including in the near-field area where dentists and clinicians operate. This could be coupled with detailed air flow measurements. This will allow greater confidence in stating that there is no transfer from AGP activities between patients. It will also identify if there are pockets of air that are not efficiently 'cleared' of particulates through the use of ventilation. . The findings of previous studies could be further supported if it can be shown that a single point measurement in a surgery is representative of the particle number and mass concentrations in the surgery as a whole.

- Condensation Particle Counters (CPCs) and Mobility Particle Size Spectrometers (MPSSs) could be used to measure the particle number concentration and size distribution, respectively, in the submicron region. The initial NPL study included a CPC but the results were not reported due to noise to signal ratio issues. As smaller particulates have a much longer settling time than particles above a micron, they could require a longer fallow time. However, as they can be thought to mimic a gas in terms of flow dynamics, they may be more easily removed by effective ventilation procedures. These two opposing factors should be assessed by making CPC and MPSS measurements in multiple locations around a surgery.

The scope of these studies could also be extended to include patient to dentist transmission (near field measurements) and viral loading in different sized droplets.

5. References

1 Dental standard operating procedure: Transition to recovery, https://www.england.nhs.uk/coronavirus/publication/dental-standard-operating-procedure-transition-to-recovery/

2 Tompkins et al., Feasibility Study on the Detection of Airborne Particulates in a Dental Surgery using an Optical Particle Counter, NPL Report ENV 33, Sept 2020.