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**BLACK CARBON MEASUREMENTS IN THE UNITED KINGDOM –
TRIAL CAMPAIGN 2023**

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Black carbon measurements in the United Kingdom -
Trial campaign 2023

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1 BLACK CARBON TRIAL CAMPAIGN

A trial campaign was conducted at two sites with black carbon (BC) network aethalometers (Aerosol Magee Scientific, model AE33) to assess the suitability of a small cupboard ("PR5") type housing, which differs from the usual walk-in cabins used to accommodate these instruments.

This report is a summary of data for August – November 2023 collected at two new sites: Blackburn Audley Park and Derby Stockbrook Park.

2 INSTALLATION

At both sites, ambient air was drawn into the sampling system through a standard rain cap mounted on the end of a vertical tube. Size selection of the sampled aerosol was made by a PM_{2.5} cyclone placed close to the inlet of the aethalometer. All the tubing before the cyclone was constructed from stainless steel.

Figures 1 and 2 show the two sites, Blackburn Audley Park (site ID B7B) installed 22/08/2023, and Derby Stockbrook Park (site ID D7B) installed 08/09/2023; both are urban background measurement sites.



Figure 1 – PR5 housing at Blackburn Audley Park site.



Figure 2 – PR5 housing at Derby Stockbrook Park site.

3 DATA CAPTURE

Table 1 shows the data capture percentages for the period Q3-Q4:

22/08/2023 – 20/11/2023 for Blackburn Audley Park (site ID B7B) – Urban Background
 08/09/2023 – 20/11/2023 for Derby Stockbrook Park (site ID D7B) – Urban Background

These results are based on validated AE33 aethalometer data.
 For aethalometer: Red = <80 %; amber = 80-90 %; green = >90 %.

Table 1 – Data capture for BC measurements

Site	Q3-Q4*
Blackburn Audley Park (B7B)	100 %
Derby Stockbrook Park (D7B)	99 %

*Q3-Q4: time coverage from installation date (22/08/2023 for Blackburn Audley Park and 08/09/2023 for Derby Stockbrook Park) until 20/11/2023.

4 BC MASS CONCENTRATIONS

4.1 INTRODUCTION

The data presented in this report has been analysed following the same quality assurance and quality control (QA/QC) procedures used for all other datasets related to the BC network.

Table 2 shows mean values from all channels. Annual averages from the BC network in 2022 are also provided for Birmingham and London traffic sites as a comparison¹.

The results from the 880 nm channel give the quantitative concentration of “black” carbon (freshly emitted soot), and those from 370 nm channel indicate the presence of aromatic organic compounds that are found in wood smoke, biomass-burning smoke, and tobacco smoke. The ultraviolet particulate matter (UVPM) is calculated as the difference between UV and BC channels.

Table 2 – Mean mass concentration of particulate matter measured at specific wavelengths (in nm, indicated on brackets) by AE33 Aethalometers in Q3-Q4. As a comparison, annual mean values from Birmingham and London traffic sites are provided together with BC network 2022 average values measured at specific wavelengths at all sites across the UK.

Site	PM mass concentration / ($\mu\text{g m}^{-3}$)							UVPM
	UV (370)	Blue (470)	Green (520)	Yellow (590)	Red (660)	BC (880)	IR-2 (950)	
Blackburn Audley Park	1.12	1.08	1.03	1.00	0.97	0.94	0.95	0.18
Derby Stockbrook Park	1.14	1.06	1.00	0.96	0.93	0.90	0.90	0.24
2022 BC Network (BCN)								
Birmingham A4540 Roadside	2.03	2.06	1.95	1.91	1.84	1.81	1.82	0.22
London Marylebone Road	1.31	1.27	1.23	1.17	1.13	1.10	1.10	0.21
BCN Annual Average (2022)	1.10	1.01	0.95	0.92	0.87	0.84	0.84	0.25

4.2 TIME SERIES

Figure 3 shows the BC concentrations measured from the installation dates to 20 November 2023. The time resolution of the measurement is hourly. Elevated BC concentrations were observed during the initial days of September, whereas the prominent peak observed on 5 November can be attributed to Guy Fawkes fireworks.

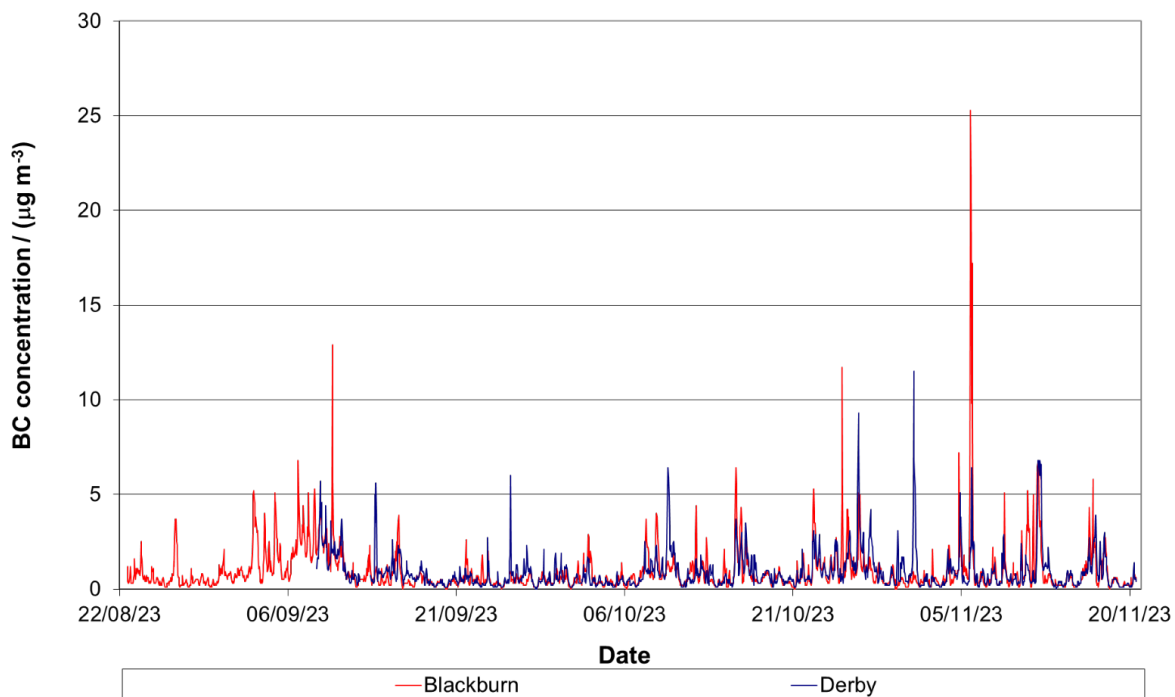


Figure 3 – Hourly BC concentrations between 22/08/2023 and 20/11/2023.

4.3 DIURNAL AND WEEKLY PROFILES – BC AND UVPM

This section presents analysis of the temporal variation of BC and UVPM concentrations. For all the charts, the continuous line is the mean value and the shaded area around the line represents the uncertainty in the mean y-value. This uncertainty is due to the spread of results over that averaging period calculated through bootstrap sampling, expressed with a level of confidence of 95 %.

The temporal variation plots (Figure 4 and Figure 5), which account for daily, hourly, and weekday patterns, show that the BC concentrations consistently surpass those of UVPM. Additionally, there are distinct spikes in BC concentrations, with the first notable surge occurring during early morning and a secondary spike appearing in the late evening. This temporal pattern indicates potential sources or activities that contribute to these elevated BC levels during these specific hours. Moreover, at the weekends, there is an increase in BC and UVPM concentrations, potentially due to secondary heating and/or recreational wood burning, which is particularly pronounced at the Derby Stockbrook Park monitoring site.

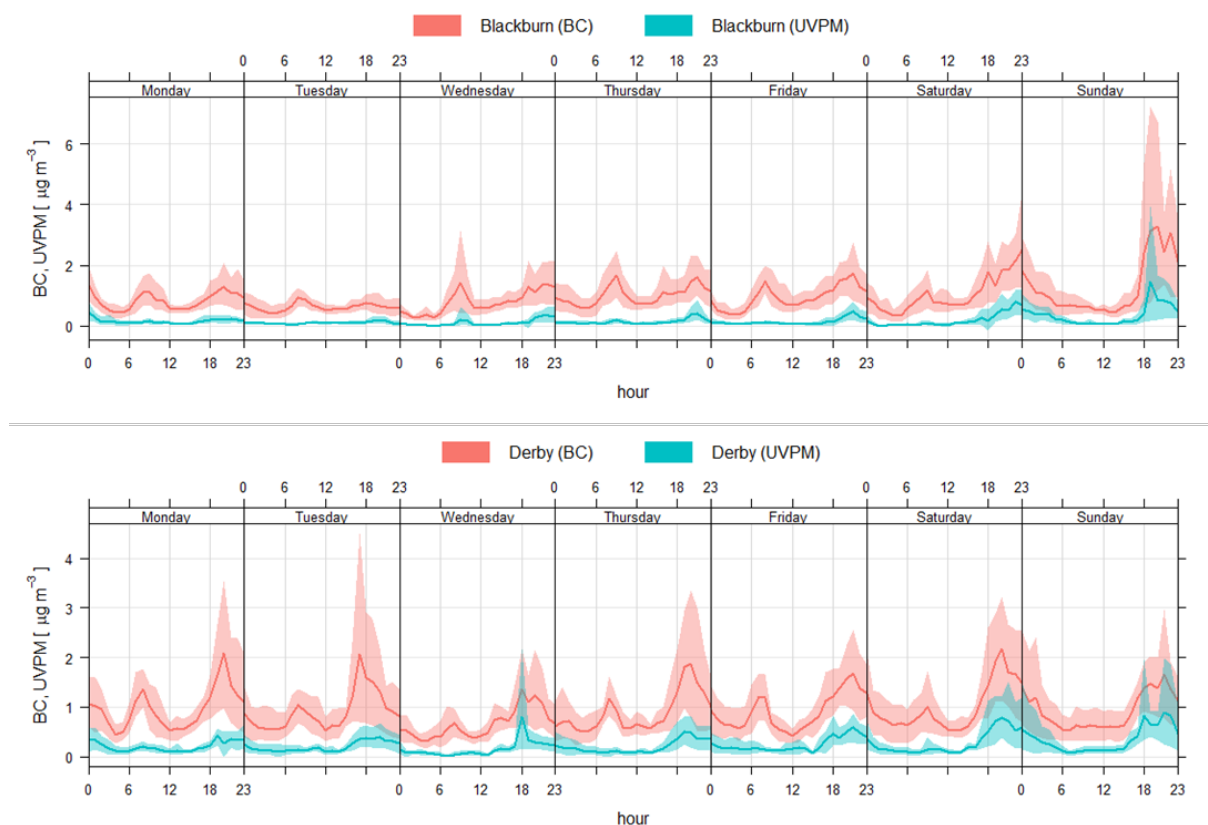


Figure 4 – Weekly variations of BC and UVPM concentrations at Blackburn Audley Park (top) and Derby Stockbrook Park (bottom).

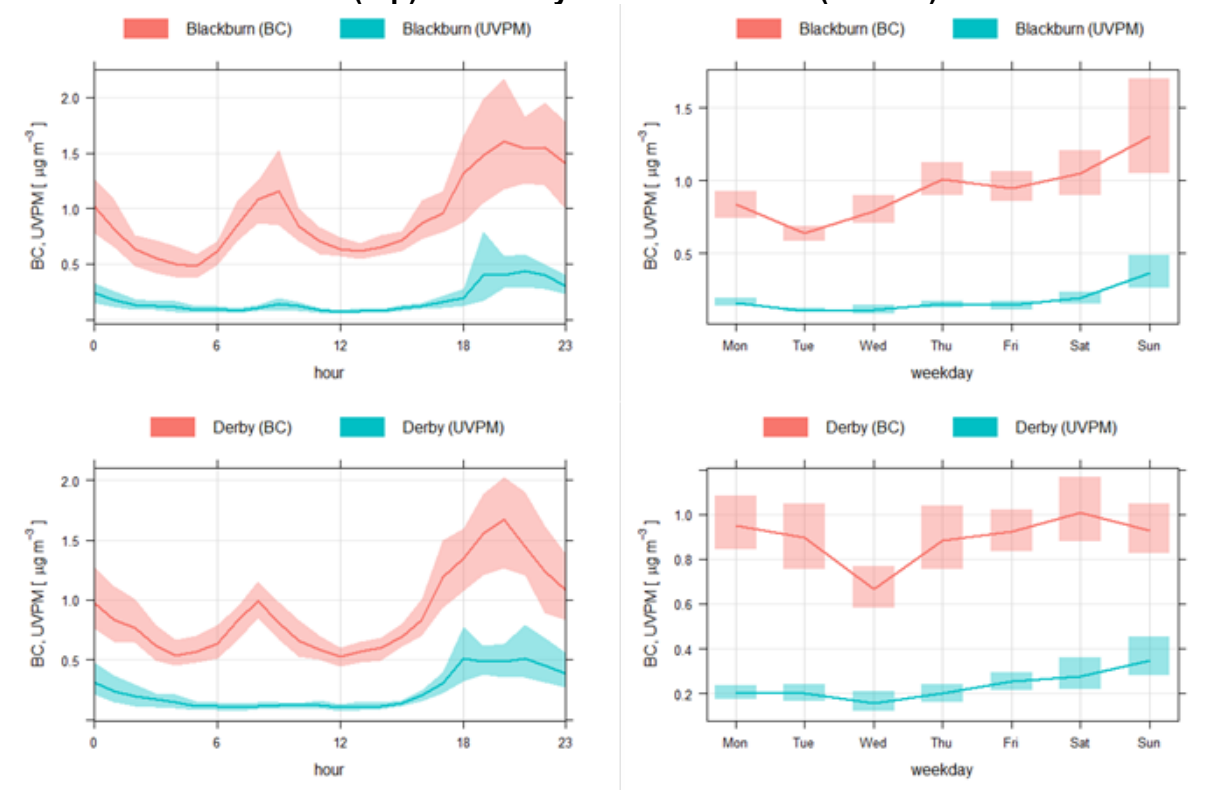


Figure 5 - Hourly (left) and weekday (right) variations of BC and UVPM concentrations at Blackburn Audley Park (top) and Derby Stockbrook Park (bottom).

5 TEMPERATURE AND HUMIDITY MEASUREMENTS

5.1 INTRODUCTION

The quality of data obtained from aethalometers can be influenced by several environmental parameters, including temperature and humidity. High temperatures can affect the stability of the aethalometer's internal components and sensors, potentially leading to inaccuracies in data. Conversely, low temperatures can reduce the instrument's efficiency, affecting its sensitivity and response time. Elevated humidity levels can lead to the condensation of water vapour on the aethalometer's optics or filters, potentially biasing measurements. On the other hand, very dry conditions can affect the dispersion of aerosol particles and the instrument's performance.

Sudden variations in temperature and humidity have a discernible influence on the noise and stability of aethalometer data. Such fluctuations are frequently a consequence of environmental factors, with the air conditioning (AC) unit installed within the cabin often being the main contributor. These rapid changes in temperature and humidity driven by the AC system, can introduce instability and noise into the aethalometer's measurements, potentially affecting data quality.

Throughout the duration of this campaign, the deployment of certified temperature (T) and relative humidity (RH) sensors at both monitoring sites have been implemented as follows:

- At the Blackburn Audley Park site, three probes were installed. The first probe (T/RH-ambient) was positioned outside the PR5 housing to measure the ambient air conditions. The second sensor (T/RH-enclosure) was placed within the cabin to monitor the enclosed environment's specific conditions. The third sensor (T/RH-sample) was situated at the sampling line in close proximity to the inlet of the aethalometer, facilitating the real-time monitoring of air conditions directly before the data acquisition. The system offers the advantage of 1 min resolution time, matching that of the aethalometer. Meteorological data (temperature and relative humidity) was also provided from a weather station located at Blackpool Airport, with an hourly average time resolution. In the middle of October, a stand-alone sensor (B7B-T/RH) was installed within the cabin as a backup for the previously described three-probe system.
- At the Derby Stockbrook Park site, a single sensor (D7B-temp/RH) was installed within the cabin to measure local environmental conditions. Meteorological data was also provided from a weather station located at Birmingham Airport, at an hourly average time resolution.

5.2 TEMPERATURE AND HUMIDITY PROBE DATA

Figure 6 presents two plots displaying the measurements of RH and T recorded at the nearest airports to Blackburn Audley Park and Derby Stockbrook Park, which are Blackpool Airport and Birmingham Airport, respectively.

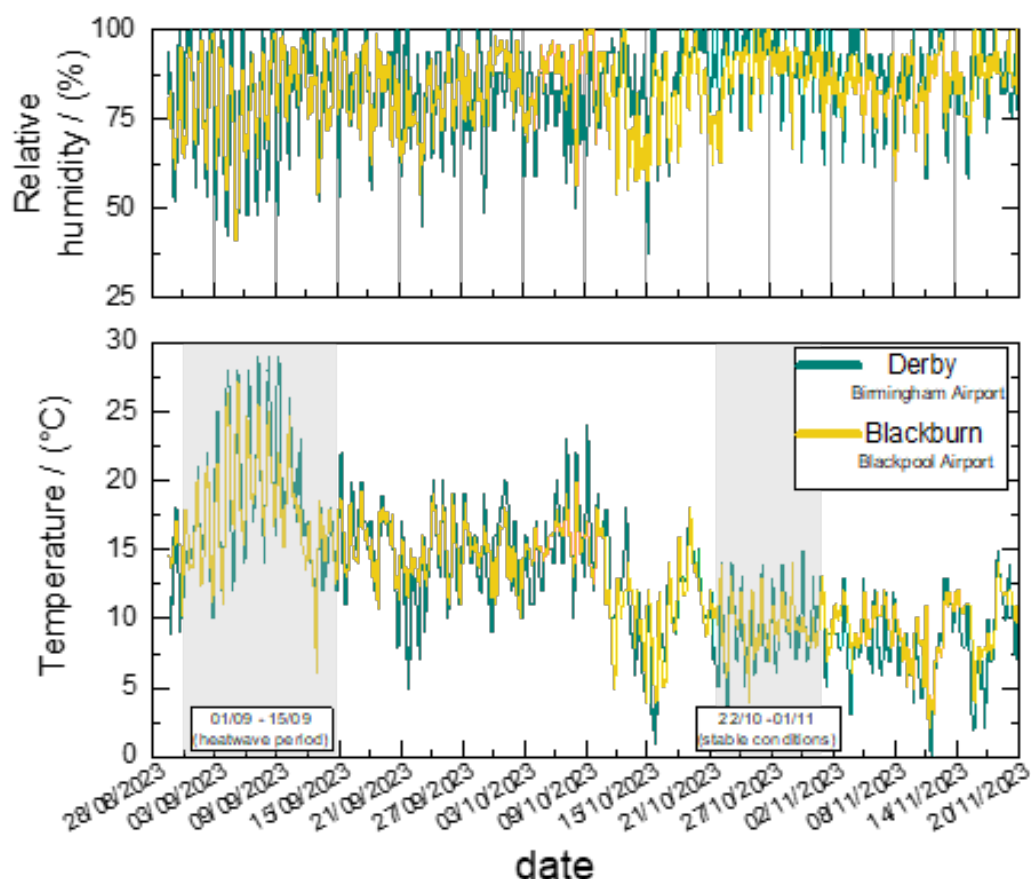


Figure 6 – Relative humidity and temperature measurements from Birmingham and Blackpool airports as ambient references for Derby Stockbrook Park and Blackburn Audley Park sites, respectively. In grey are two analysis periods, selected to study their impact on instrumental noise and black carbon data quality. They are described as the heatwave (01/09/23 – 15/09/23) and stable conditions (22/10/23 – 01/11/23).

Figure 6 provides a general overview of the meteorological conditions in the proximity of the respective monitoring sites. Two distinct periods have been deliberately selected for the focused analysis, the heatwave period from 1 to 15 September and the stable atmospheric condition period from 22 October to 1 November. These specific time frames have been chosen to conduct an in-depth investigation into the influence of temperature and humidity on instrumental noise and the quality of measured black carbon concentrations.

5.3 HEATWAVE PERIOD 01/09/23 – 15/09/23

Figure 7 illustrates the fluctuations in temperature observed during the heatwave period at the beginning of September. Throughout this timeframe, the ambient temperature shows significant variation, ranging predominantly between approximately 15°C to 30°C. Notably, during the days characterised by heightened external temperatures, both the temperature within the PR5 housing enclosure and the temperature measured at the sampling line (T-sample sensor placed in close proximity to the inlet of the Aethalometer), display changes within a narrower range, fluctuating from 15°C to 21°C.

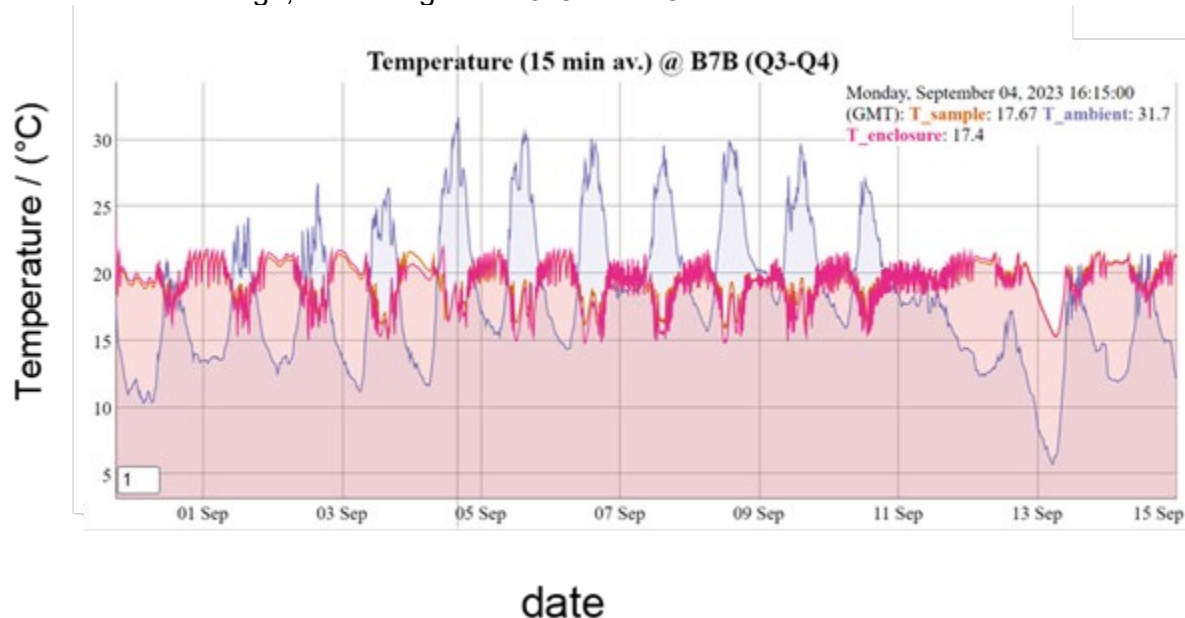


Figure 7 – 15 min averaged temperature measurements at Blackburn Audley Park site during the heatwave period (01/09/23 – 15/09/23). The highest ambient temperature, 31.7°C was recorded on 4 September in the afternoon.

RH measurements conducted by the three-sensor system at the Blackburn Audley Park site are presented in Figure 8. As a comparison, the 1 h averaged results from Blackpool airport are also included, showing a good agreement with the ambient air monitoring sensor (T/RH-ambient).

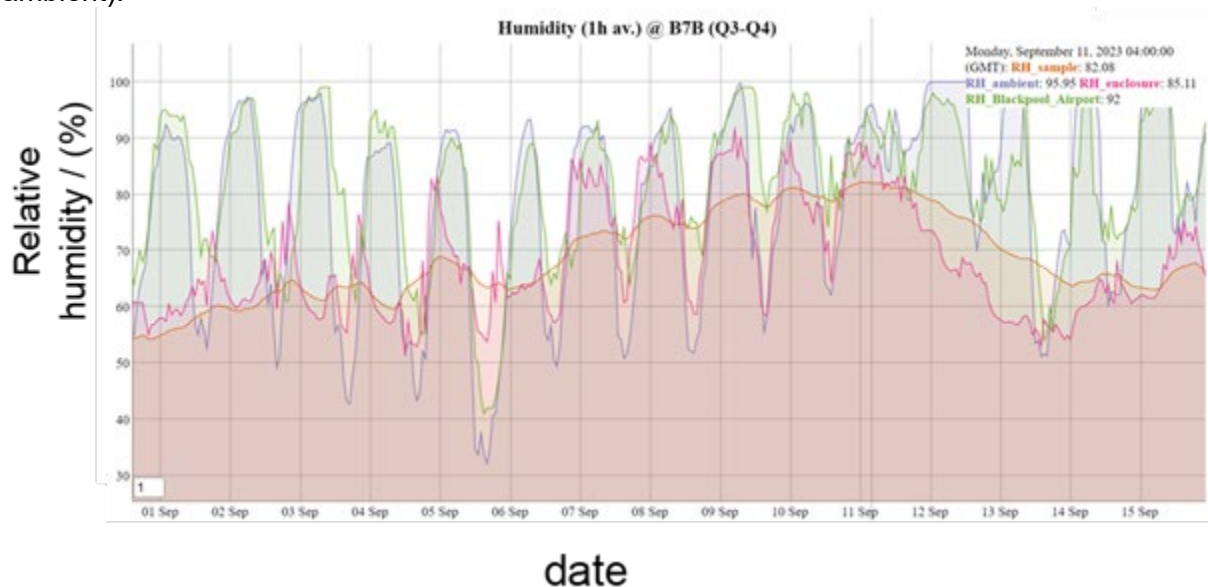


Figure 8 – Hourly averaged relative humidity measurements at Blackburn Audley Park site and at Blackpool Airport during the heatwave period (01/09/23 – 15/09/23).

Notably, Figure 8 demonstrates fluctuations in ambient relative humidity, ranging from approximately 40 % to 95 %. In contrast, the variations in humidity measurements within the enclosure are usually smaller than those observed outside the PR5 housing, with the exception of period between 5 September and 11 September. During that period, the RH within the cabin are similar to ambient conditions. Moreover, it can be observed that the RH-sample sensor readings (sensor installed at the sampling line near the Aethalometer inlet) shows a gradual rise in RH from approximately 60 % on 4 September to 82 % by 11 September. This steady increase in RH indicates possible condensation of water vapour during the heatwave period when the sampled ambient air enters the environment controlled by the AC unit, which is at a much lower temperature.

The impact of these conditions on BC measurements is presented in Figure 9. The blue data line represents validated measurements used to calculate 1 h averages. The green lines represent raw data from Aethalometer AE33 which in most cases are equal to validate results (thus the green line is not entirely visible on the plot). However, for the period between 8 to 11 September exceptionally low values of BC were excluded from the calculations, introducing a positive bias when computing the 1 h concentrations. Such negative BC values were not observed with the AE22 Aethalometer model previously used within the UK Black Carbon Network, thus a threshold value of -0.5 mg m^{-3} was employed to exclude unrealistic results from the overall measurement dataset. This approach may not be ideal for the new model AE33 where the time resolution is 1 min (instead of 5 min for the AE22 model).

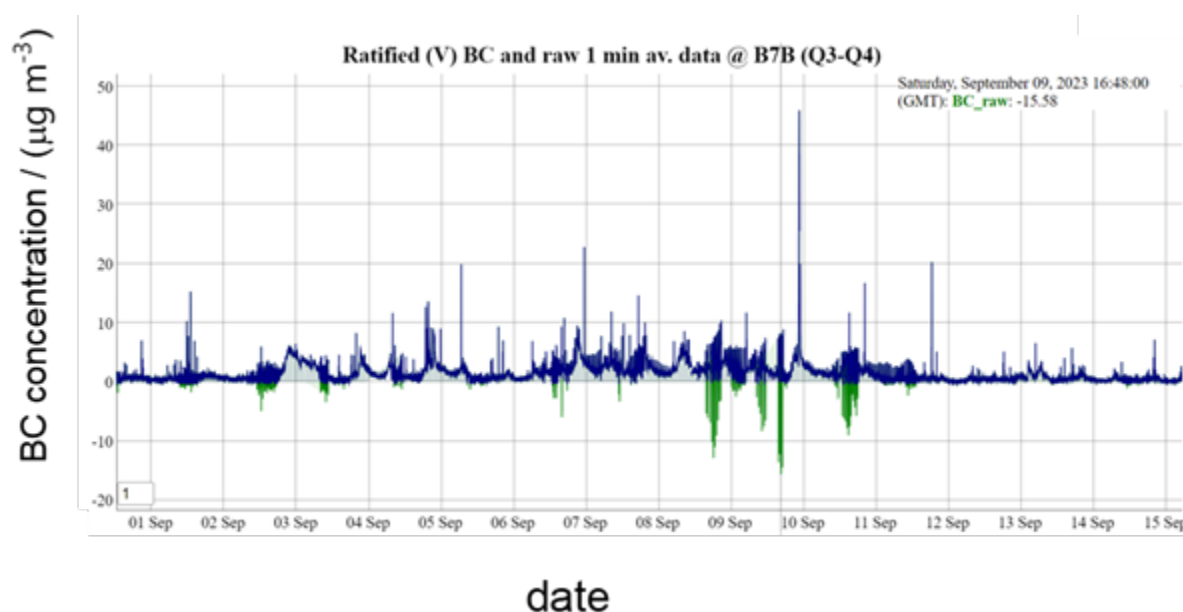


Figure 9 – One minute BC concentrations at Blackburn Audley Park site during the heatwave period (01/09/23 – 15/09/23). The blue line of data represents validated measurements. The green line of data represents raw data from the Aethalometer AE33.

An evident correlation emerges when considering the increasing RH observed in the sampling line, as presented in Figure 7, which could potentially account for the increased instrumental noise in Figure 9. This rise in RH is most likely due to ambient air temperature fluctuations and the operating AC system within the PR5 housing, leading to humidity condensation within the sampling line.

A similar analysis was conducted for the Derby Stockbrook Park sites during the same period. Figure 10 displays the temperature data recorded by a small sensor (D7B-temp) installed within the PR5 housing at the Derby Stockbrook Park site, compared to ambient temperature data obtained from Birmingham Airport weather station. It can be observed that the enclosure temperatures are notably higher than those reported at the airport. The observed pattern of temperature changes and the consistently higher range of temperatures recorded within the cabinet potentially indicates two scenarios: either a positive bias of the sensor resulting in invalid data or an issue with the proper operation of the AC system within the enclosure. Unfortunately, due to the limited memory capacity of the sensor system, verification to determine if this issue persists after the heatwave period could not be conducted. Moreover, access to the site was limited because of health and safety limitations arising from the cabinet doors opening directly onto the road. The whole housing was rotated at the end of November.

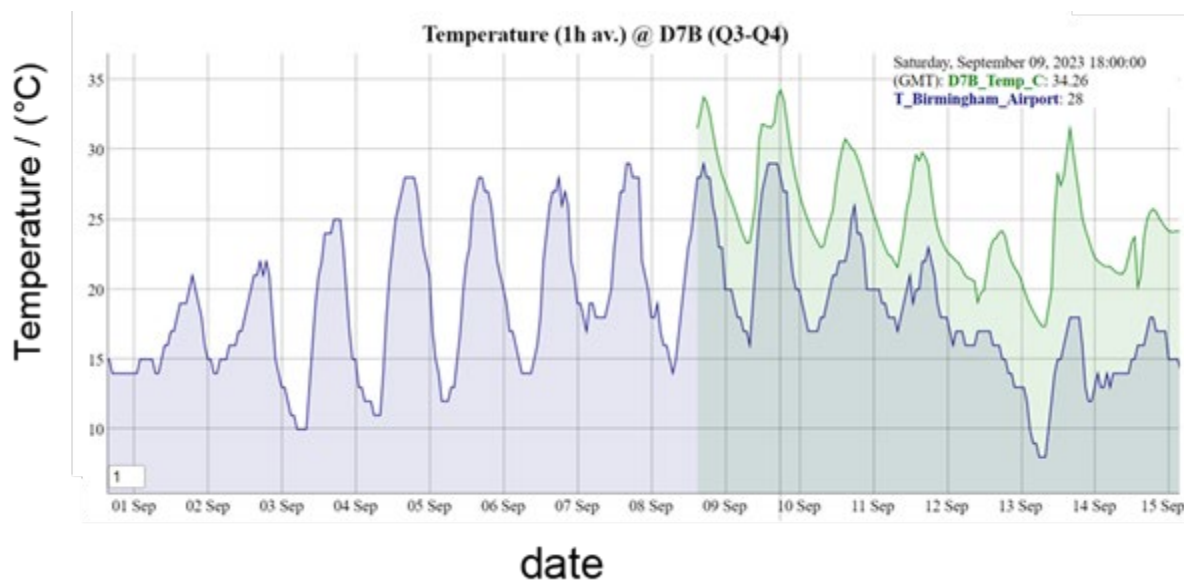


Figure 10 – Comparison of temperature data between a sensor inside the PR5 housing at the Derby Stockbrook Park site (D7B-temp) and ambient temperature recorded at Birmingham Airport weather station. Enclosure temperatures notably exceed those reported at the airport, suggesting a potential sensor bias or malfunction in the air conditioning system at Derby Stockbrook Park site. Note: installation date at Derby Stockbrook Park site is 8 September.

The RH results at the Derby Stockbrook Park site and the 1 h averaged results from Birmingham Airport are presented in Figure 11. The readings appear within a reasonable range, indicating that the issue observed with temperature readings, may be attributed to either a malfunctioning or inefficient AC unit within the PR5 housing.

As a comparison to Blackburn Audley Park site (see Figure 9), Figure 12 shows 1 min BC concentrations at the Derby Stockbrook Park site. It can be observed that at the Derby Stockbrook Park site, the potential influence of humidity and temperature fluctuations is less evident (raw data in green are equal to validated data represented as blue lines). However, it is important to note that the Aethalometer installation at this site occurred on 8 September, which was during the middle of the heatwave period. Thus, any potential enhanced instrumental noise levels may not be evident on the same scale as at the Blackburn Audley Park site, which operated for the whole heatwave period.

Unfortunately, the cause of a noticeable data gap on 12 – 13 September is uncertain; possibilities include a power cut or maintenance activities at the site.

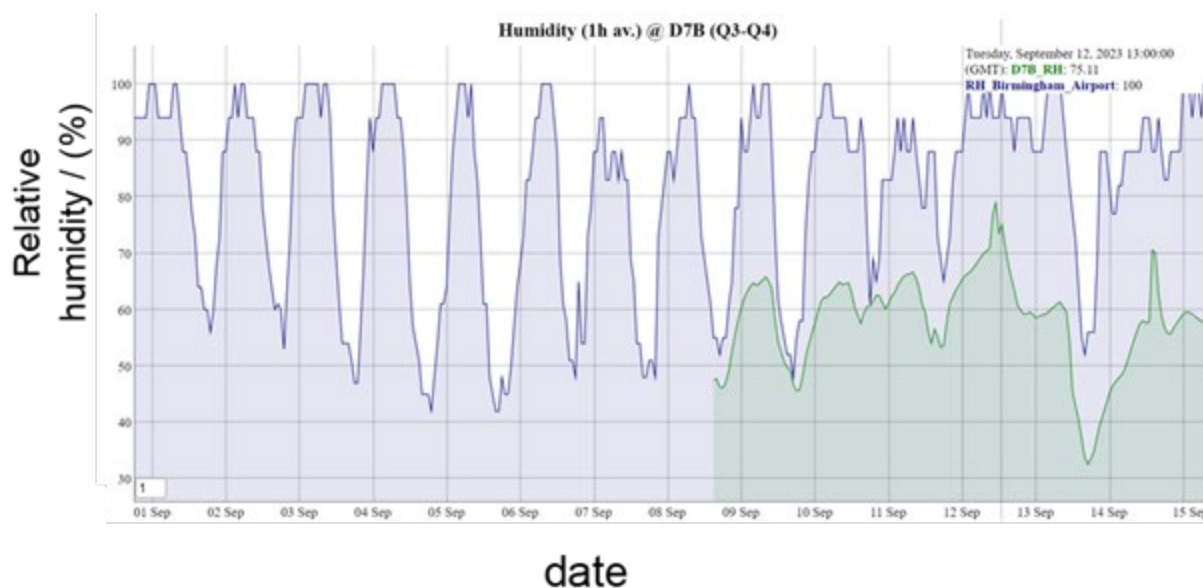


Figure 11 – Comparison of relative humidity data between a sensor inside the PR5 housing at the Derby Stockbrook Park site (D7B-temp) and the ambient relative humidity recorded at Birmingham Airport weather station. Note: installation at the Derby Stockbrook Park site is 8 September.

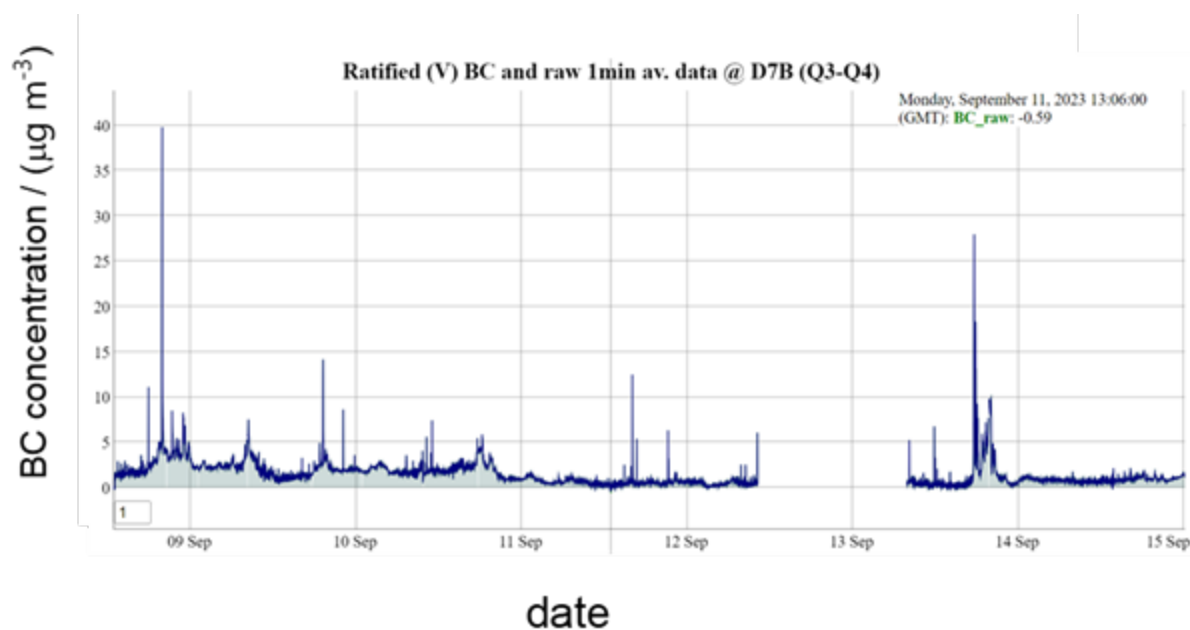


Figure 12 – One minute BC concentrations at Derby Stockbrook Park site during the heatwave period (01/09/23 – 15/09/23). The blue line of data represents validated measurements. The green line represents raw data from Aethalometer AE33 with the lowest measurement of BC on 11 September ($-0.6 \mu\text{g m}^{-3}$).

5.4 STABLE ATMOSPHERIC CONDITIONS 22/10/23 – 01/11/23

An analogous analysis to that in Section 5.2 was conducted for the timeframe spanning from 22 October to 1 November at both monitoring sites, characterised by stable atmospheric conditions. During this period, the prevailing temperatures were close to 9°C, indicating relatively cooler environmental conditions. Additionally, there was a consistent trend of notably high RH levels across both sites, contributing to a generally stable and moisture-rich atmosphere. This timeframe offered an opportunity to examine and compare the environmental parameters, particularly temperature and humidity, and their potential impact on the data quality connected with the instrumental noise at the respective monitoring sites.

Figure 13 illustrates 15 min averaged temperature measurements obtained from a three-sensor system and an additional small sensor (B7B-temp) placed within the PR5 housing, serving as a backup for the main three-sensor setup. A striking observation emerges from this comparison as both sets of temperature data showcase a high level of agreement. The readings from the backup sensor inside the housing closely align with those recorded by the three-sensor system, indicating a consistency and reliability between the measurements. Throughout this period, the temperature variations within the cabin fluctuated between 14°C to 22°C.

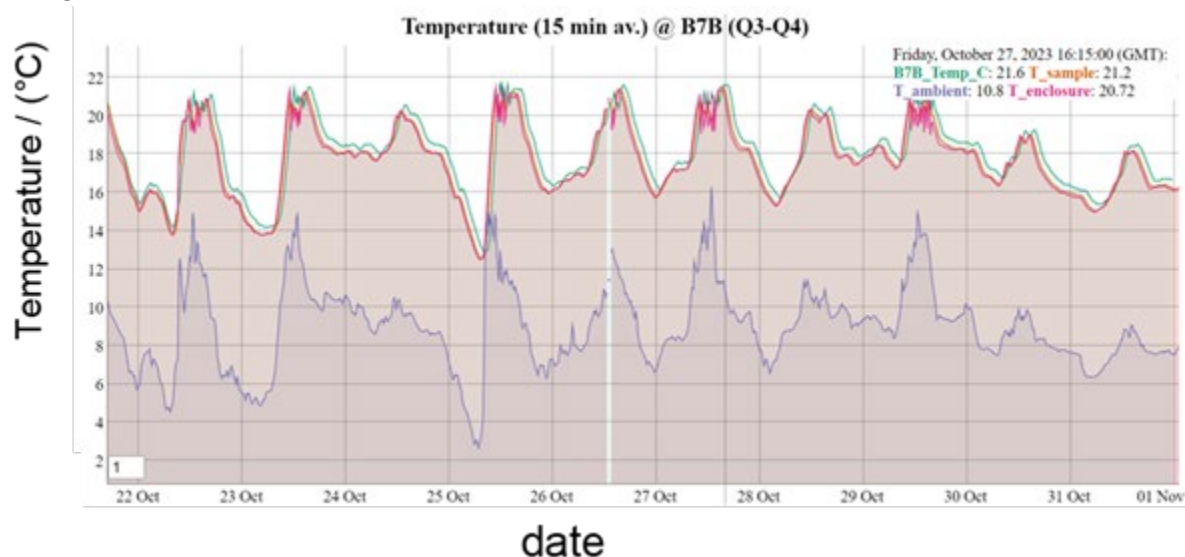


Figure 13 – Temperature 15 minutes averaged measurements at Blackburn Audley Park site during the stable condition period (22/10/23 – 01/11/23).

RH measurements during stable atmospheric condition period at the Blackburn Audley park site are presented in Figure 14. As a comparison, the 1 h averaged results from Blackpool Airport are also included showing a good agreement with the sensor monitoring ambient air (RH-ambient) at the site. Additionally, coherence between small sensor measurements (B7B-RH) and a RH enclosure readings once again confirms agreement between the different monitoring setups, both within and outside the housing.

During this period, the sampled RH measurements remain stable at around 55 %. This stability suggests a consistent and predictable humidity level within the sampling line. Additionally, contrasting with the previously described heatwave conditions in September, no significant fluctuations or substantial changes in RH were observed inside the PR5 housing.

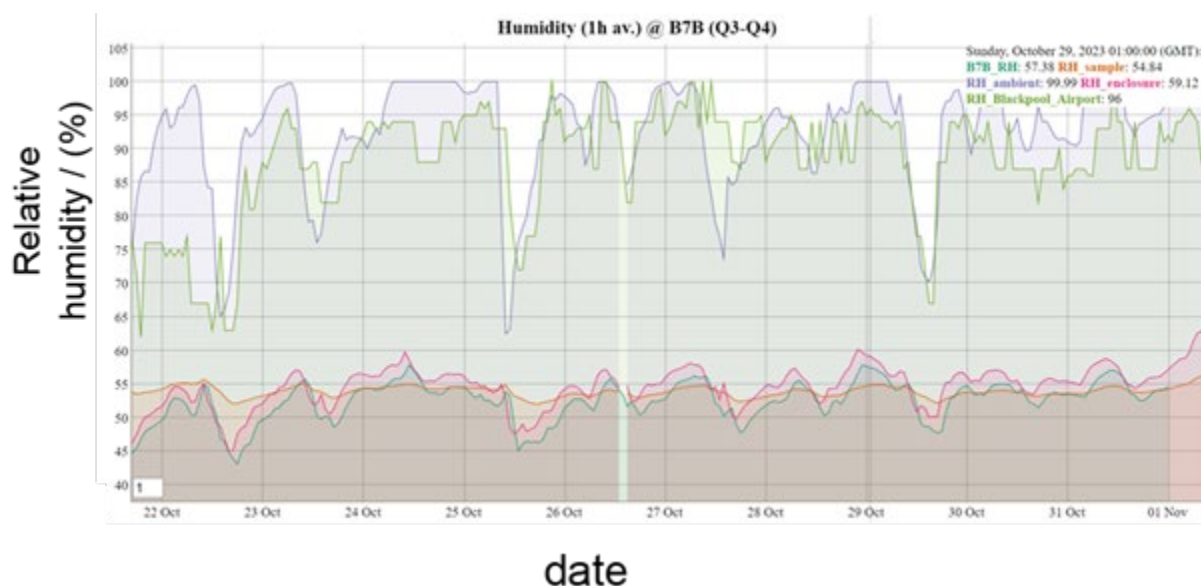


Figure 14 – Hourly averaged relative humidity measurements at Blackburn Audley Park site and at Blackpool Airport during the stable condition period (22/10/23 – 01/11/23).

Figure 15 and Figure 16 present BC concentration measurements at the Blackburn Audley Park and Derby Stockbrook Park sites, respectively, spanning a phase characterised by stable atmospheric conditions. Unlike the heatwave period (Figure 9), no elevated instrumental noise levels were observed during this period of stable conditions. The data displayed in these figures exhibit a notably good quality, evident from the absence of significant negative BC concentration measured by Aethalometer AE33. Thus, minimal differences were observed between the raw (green lines) and validated (blue lines) 1 min BC data, highlighting the consistency and reliability of the measurements during this stable atmospheric phase.

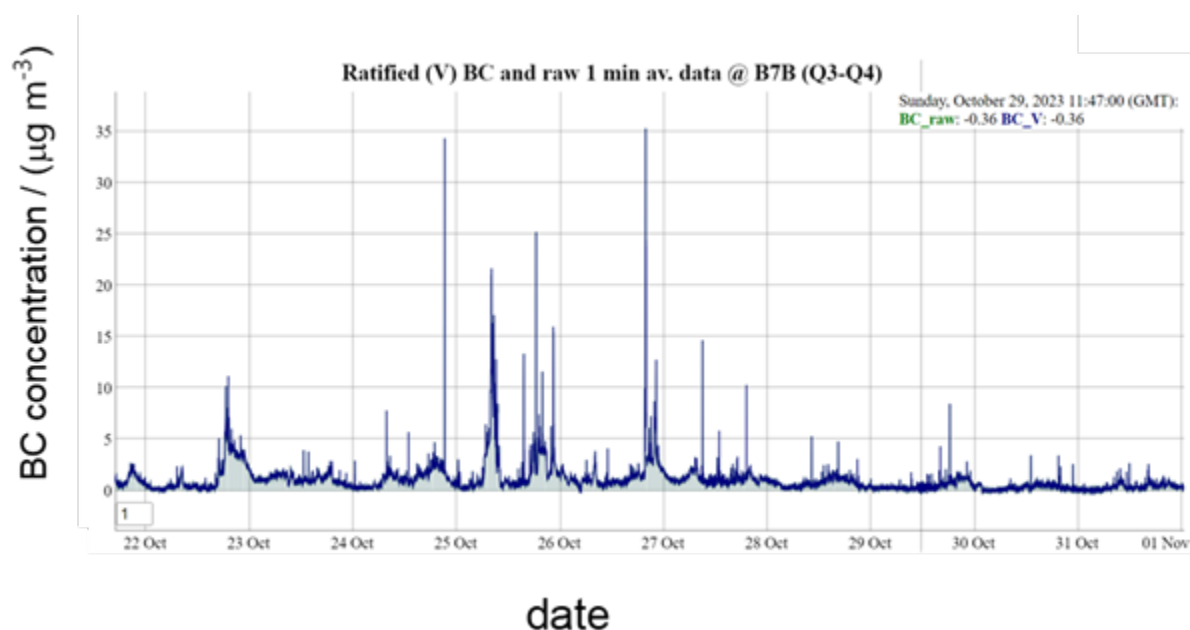


Figure 15 – One minute BC concentrations at Blackburn site during the stable conditions period (22/10/23 – 01/11/23). The blue line data represents validated measurements. The green line represents raw data from the Aethalometer AE33.

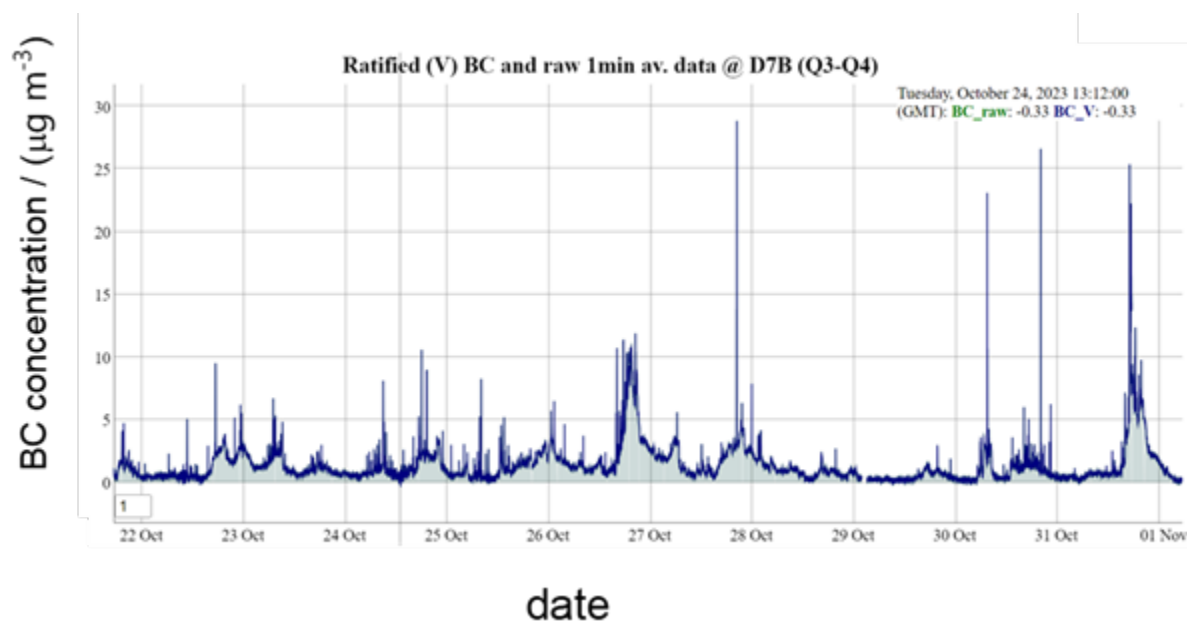


Figure 16 – One minute BC concentrations at Derby Stockbrook Park site during the stable conditions period (22/10/23 - 01/11/23). The blue line data represents validated measurements. The green line represents raw data from Aethalometer AE33.

6 CONCLUSIONS

The primary objective of this analysis was to study BC concentration data measured at Blackburn Audley Park and Derby Stockbrook Park, using aethalometers installed in compact PR5 housing rather than conventional walk-in cabins; with a focus on the potential impact of temperature and humidity variation on instrumental noise and data quality. Two distinct periods were selected based on differing temperature and humidity conditions: a heatwave in September and stable atmospheric conditions in late October.

The findings revealed noticeably increased instrumental noise affecting the data quality during the heatwave period of 01/09/23 – 15/09/23. This was especially observed at the Blackburn Audley Park site, where increased temperature and RH likely led to moisture accumulation inside the sampling line or the aethalometer's chamber case where the optical system and filter tap was installed. At the Derby Stockbrook Park site, where the instrument was installed on 8 September, and thus was not exposed to the same duration of the heatwave as AE33 at Blackburn Audley Park, no elevated instrumental noise levels were observed. It was also evident that the AC unit at Derby Stockbrook Park site is potentially inefficient or non-operational. This is based on available September data from the temperature and humidity sensor installed inside the PR5 housing at this site. Further investigation of the temperature range within the cabin could be potentially verified by the AC service unit, or by analysing temperature data from the ozone and FIDAS instruments (not operated by NPL).

Overall averaged BC concentrations at Blackburn Audley Park and Derby Stockbrook Park sites from date of installation to 20 November were within a typical range for urban background sites in the UK (see Table 2) with ~100 % data capture. However, the effect of enhanced instrumental noise levels during summer period might result in higher uncertainties when analysing seasonal (or short-term) changes of BC concentrations. Thus, a revision of the threshold values for data validity is recommended due to the heightened sensitivity of the AE33 model's 1 min measurements compared to the previous AE22 model's 5 min readings. Additionally, to minimise condensation of vapour within the sampling line at all Network sites, it is advised to isolate these lines with the use of insulation tubing, for example. It is also suggested to revise options to insulate the instrument itself, particularly the filter compartment, by using a plastic cover or bag.

Based on the results presented in this study, both sites are feasible to be incorporated into the Network. Extra caution should be taken when validating measurements conducted during heatwaves due to potential impact of temperature and humidity on the AE33 instruments noise. Given the increased occurrences of extreme weather, continuous monitoring of temperature and humidity may become necessary not only for the ambient air, but also for the enclosure of the cabin/PR5 housing and sampling lines near the instrument's inlet.

7 REFERENCE

- ¹ CIUPEK, K. *et al.*, Airborne Particle Concentrations, Particle Numbers and Black Carbon in the United Kingdom – Annual Report 2022. *National Physical Laboratory*, 2023. NPL Report ENV 50. <http://doi.org/10.47120/npl.ENV50>