

Supplementary Materials: Air Quality outside Schools in Newcastle upon Tyne, UK: An Investigation into NO₂ and PM Concentrations and PM Respiratory Deposition

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Study location description

Newcastle Upon Tyne (widely known as Newcastle) is the most highly populated city in the Northeast region of England. It has an estimated population of 300,820 people of which 5.5% (16,629) are children aged 0–4-years-old and 11.1% (33,717) are children aged 5–14-years old (school age) [23]. Once a leading region for industry and innovation, the Northeast of England has become increasingly deprived and is a region of marked, and widening, inequalities [24]. In 2019, Newcastle was the 32nd most deprived local authority of 326 in England [25]. Significant variations in deprivation exist within the city. Some areas are affluent and 12% of Newcastle residents live in the 10% least deprived areas in England, however almost 25% live in the 10% most deprived areas in England [25]. Areas of deprivation are primarily concentrated along the riverside and through the city centre [25] (see Figure S1).

Urban design

Newcastle upon Tyne is located along the north bank of the River Tyne and within 13 km of the North Sea coast. Newcastle's urban core contains most of the city's high-rise buildings and from here the city expands concentrically outwards. Wards closer to the urban core such as Jesmond and Gosforth contain narrow streets and tall, terraced housing, while the northwest wards are more rural. Newcastle has two large city centre universities and a major city centre football stadium. There is an international airport 10 km northwest of the city centre, a large central train station, and a suburban and underground metro system. There are 11 principal and 22 smaller parks in the city and 'The Town Moor' in the centre which is approximately 1000 acres. The A1M is a major motorway running through the west of the city, the A167 runs across the Tyne Bridge and through the city centre where it becomes a motorway for a short distance, and the A1058 travels from Jesmond to the coast. Industry in this area is primarily concentrated along the banks of the River Tyne in Walker and there are industrial estates in Fawdon, Kingston Park, Gosforth, Brunswick Village, Scotswood, Byker, Newburn, and Westerhope.

Meteorology

The mean UK temperature in spring 2019 was 8.4°C. Summer sees the hottest temperatures, sunniest days, and varying levels of rainfall. The mean UK temperature in summer 2019 was 15.1°C. Autumn is cooler than summer and can bring storms. The mean UK temperature in autumn 2019 was 9.1°C. Winter is the coldest season, has the shortest days, strongest winds, and is generally wet. The mean UK temperature in winter 2018/19 was 5.2°C. Data from the UK's national weather service (The Met Office) shows that between 1991 and 2020 Newcastle had an annual average maximum temperature of 12.29°C and an annual average minimum temperature of 5.24°C. For comparison, in the same period, England had an annual average maximum temperature of 13.82°C and an annual average minimum temperature of 6.12°C. Furthermore, Newcastle had an annual average rainfall of 744.01 mm and 134.12 days per year with rainfall >1 mm while England had an annual average rainfall of 869.59 mm and 135.21 days per year with rainfall >1 mm. This indicates that, on average, Newcastle is cooler and drier when compared to England overall. These

data can all be found at the Met Office Climate summaries (UK weather, <https://www.met-office.gov.uk/research/climate/maps-and-data/summaries/index>) and the Met Office UK climate averages (Newcastle weather from the Albemarle weather station, <https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages>).

Technical information AQMesh pod Quality Assurance

AQMesh pods are not Defra approved. Defra approved AQMs use a standard method suitable for statutory reporting but are costly to install and maintain meaning they can provide highly accurate data, but often at a limited number of locations within a city. AQMesh pods are not intended to be used in the same way as these monitors and they aim to provide air quality data over a larger area at a lower cost. They are classified as indicative as they use a different method to Defra approved AQMs and can be affected by weather conditions. Absolute values generated by AQMesh pods should be interpreted with caution, but they are good for showing trends and understanding how our behaviour affects air quality.

Study Limitations

This study analysed data from indicative AQMs that are not Defra approved, can be affected by weather conditions, and, like other low to mid cost AQM, can fail more frequently than precision monitors.

The AQMs from which data were obtained in this study are mostly affixed to lamp posts outside schools. Whilst every care is taken to ensure optimum placement of the AQMs, in some instances there may be features of the environment around them that impact on ambient pollutant concentrations, such as vegetation, bus stops or traffic lights.

One school (Sacred Heart Catholic High) already had an AQM in place when the NCC and UO Health Schools Project was established. The other 11 schools in this study were chosen by NCC due to concern that they were in pollution hotspots. This may mean that air quality outside these 11 schools is not representative of Newcastle schools overall and may lead to overestimations of ambient pollutant concentrations at schools.

RDDs are a method of estimating respiratory deposition only, and no guidance yet exists against which to compare the RDDs calculated in this study against. They do however provide an estimation of health risk from PM exposure.

Table S1. Comparison of WHO air quality guideline values (2005 and 2021) and EU/UK pollutant limit values for NO₂, PM_{2.5}, and PM₁₀ [11,12,16].

Pollutant	WHO (2021) guideline value <i>d</i>	WHO (2005) guideline value <i>e</i>	EU/UK limit value <i>f</i>	Comparison
NO ₂ annual mean	10 µg/m ³	40 µg/m ³	40 µg/m ³	WHO 2005 equal to EU WHO 2021 4x reduction
NO ₂ 1 hour mean	25 µg/m ³ <i>a</i>	200 µg/m ³	200 µg/m ³ <i>b</i>	WHO 2005 equal to EU WHO 2021 4x reduction in level for 80% less days
PM _{2.5} annual mean	5 µg/m ³	10 µg/m ³	25 µg/m ³	WHO 2005 60% less than EU WHO 2021 80% less than EU

PM _{2.5} 24-hour mean	15 µg/m ³ <i>a</i>	25 µg/m ³	-	WHO 2021 40% reduction of WHO 2005
PM ₁₀ annual mean	15 µg/m ³	20 µg/m ³	40 µg/m ³	WHO 2005 50% less than EU WHO 2021 75% less than EU
PM ₁₀ 24-hour mean	45 µg/m ³ <i>a</i>	50 µg/m ³	50 µg/m ³ <i>c</i>	WHO 2005 equal to EU WHO 2021 4x reduction
<i>a</i> not to be exceeded more than 3-4 days per year				
<i>b</i> not to be exceeded more than 18 times a year				
<i>c</i> not to be exceeded more than 35 times a year				
<i>d</i> WHO 2021 https://apps.who.int/iris/handle/10665/345329				
<i>e</i> WHO 2005 https://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf				
<i>f</i> EU/UK limit values https://uk-air.defra.gov.uk/assets/documents/Air_Quality_Objectives_Update.pdf				

Table S2. Previous school air quality studies conducted in the UK. Please note: Much of this data (study numbers 1-14 in italics) has been taken from a table in Osborne et. al (2021) with kind permission from the authors [17]. Please refer to Osborne et. al for the original table and further detail.

Study number	Study authors	Study environment	Data source	Location in the UK	Pollutants measured/modelled	Summary of concentration/exposure
1	<i>Broekstra et al. (2019)</i>	<i>Outside schools</i>	<i>Monitors</i>	<i>EU-wide including London</i>	<i>NO₂, PM_{2.5}, PM₁₀</i>	<i>Outside seven London schools, over four weeks, NO₂ ranged from 25 to 30 µg/m³, PM_{2.5} ranged from 1 to 17 µg/m³, and PM₁₀ ranged from 1 to 25 µg/m³.</i>
2	<i>Brook and King (2017)</i>	<i>Outside schools</i>	<i>Monitors</i>	<i>London</i>	<i>NO₂</i>	<i>802 primary and secondary schools (around 25% of all London schools) were in locations with average annual mean NO₂ levels exceeding 40 µg/m³.</i>
3	<i>Godri et al. (2011)</i>	<i>Outside schools</i>	<i>Monitors</i>	<i>London</i>	<i>NO_x, PM</i>	<i>Outside seven London schools, the mean NO_x over the 14-day monitoring period ranged from 33.4 to 343.3 µg/m³, and particle number count ranged from 6428 to 46,004.</i>
4	<i>Clark et al. (2012)</i>	<i>Outside schools</i>	<i>Modelling</i>	<i>London</i>	<i>NO₂</i>	<i>Annual mean NO₂ concentrations outside schools near Heathrow airport were estimated as ranging between 29.41–79.88 µg/m³.</i>
5	<i>Csobod et al. (2014)</i>	<i>Outside schools</i>	<i>Modelling</i>	<i>EU wide including the UK</i>	<i>NO₂, PM_{2.5}, O₃, CO, VOCs</i>	<i>24-h mean concentrations over five days for monitored schools in Western Europe (UK, Belgium, France, Austria, Germany) were 23.16 µg/m³ for PM_{2.5} and 29.51 µg/m³ for NO₂. The UK had the highest average NO₂ concentrations.</i>
6	<i>Howard (2015)</i>	<i>Outside schools</i>	<i>Modelling</i>	<i>London</i>	<i>NO₂</i>	<i>328,000 children (25%) were attending schools in London where the annual mean NO₂ exceeded 40 µg/m³.</i>
7	<i>King and Healy (2013)</i>	<i>Outside schools</i>	<i>Modelling</i>	<i>London</i>	<i>NO₂</i>	<i>433 London primary schools were in locations where annual mean concentrations exceeded the EU limit, and 82% were ‘deprived’ (>40% pupils on free school meals).</i>

8	Watts (2019)	Outside schools	Modelling	UK-wide	PM _{2.5}	6500 schools educating 2.6 million children are in areas exceeding annual mean PM _{2.5} of 10 µg/m ³ .
9	Dirks et al. (2016)	School commute	Personal exposure monitors	Bradford	Ultrafine (UFP) particles	The average UFP count for journeys to and from school ranged from 7000–28,000 particles per cm ³ for walkers and 3700–17,600 for those travelling by car.
10	Mölter and Lindley (2015)	School commute	Personal exposure monitors	Greater Manchester	NO ₂ , PM ₁₀	Children's fastest walking routes to school had an average NO ₂ exposure during the journey of 32.9 µg/m ³ and PM ₁₀ exposure of 20.9 µg/m ³ . Alternative routes led to a reduction in average exposure of 0.4 µg/m ³ for NO ₂ and 0.1 µg/m ³ for PM _{2.5} .
11	Pooley et al. (2010)	School commute	Personal exposure monitors	Lancaster	PM ₁₀	In an analysis of 65 routes, cumulative exposure to PM ₁₀ during the journey was below 5 µg/m ³ on 44% of routes, and above 20 µg/m ³ on 4% of routes.
12	Varaden et al. (2019)	School commute	Personal exposure monitors	London	NO ₂ , PM _{2.5}	Across 2000 journeys recorded by 250 children across five London primary schools, average PM _{2.5} ranged from 8–12 µg/m ³ and average NO ₂ ranged from 80–140 µg/m ³ .
13	Dowler and Howard (2017)	Roads near schools	Modelling	England and Wales	NO ₂	Across England and Wales, 2092 education or childcare providers were found to be within 150 m of a road breaching the annual mean legal limit for NO ₂ (40 µg/m ³).
14	Edwards et al. (2018)	School commute, inside schools, outside schools	Personal exposure monitors	London	Black carbon (BC)	Children experienced 15% of their daily black carbon exposure while travelling to school, and 44% while inside and outside the school.

15	Breathe London Wearables Study	School commute, day at school	Personal exposure monitors	London	NO ₂ , PM _{2.5}	Children exposed to 5x higher and 4x higher NO ₂ levels when travelling to and from school, respectively, than during their day at school. PM _{2.5} similar but the difference was less great.
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Table S3. Participating schools, pupil ages, air quality data collection start date and air quality monitor location information.

Name of school (abbreviation)	Age of pupils (years)	Data collection start date	Air quality monitor location information
Atkinson Road Primary Academy (AR)	4-11	27/11/2017	Affixed to a lamppost on Armstrong Road Located adjacent to a bus route Near to another school over the road
Broadway East First School (BE)	4-9	02/12/2017	Affixed to a lamppost on Broadway East Located close to the school drop off/pick up the hotspot School is co-located with another school, with two other schools nearby (all three schools outside the scope of this study)
Chillingham Road Primary School (CR)	4-11	01/04/2018	Affixed to a lamppost on Chillingham Road (high traffic volume) School is surrounded by tall, terraced housing and is close to a metro station
Cragside Primary School (CP)	4-11	20/12/2017	Affixed to a lamppost on a busy roundabout adjacent to the school playground School is close to a major hospital (the Freeman Hospital)
Knop Law Primary School (KL)	4-11	03/12/2017	Affixed to a lamppost on the corner of Hillhead Parkway/Arnside walk School is located within a residential area (consisting of nearby green spaces and two storey housing) Another primary school nearby (outside the scope of this study)
Sacred Heart Catholic High School (SH)*	11-18	03/12/2017	Affixed to a lamppost on Convent Road AQM is located close to the school drop off/pick up hotspot Co-located with a primary school School is in a small cul-de-sac off the main road
St Alban's RC Primary School	4-11	25/03/2018	Affixed to a lamppost on Westbourne Avenue Located adjacent to a bus route with a bus stop at the school entrance Co-located with a special needs school (outside the scope of this study) School is located within a residential area (consisting of two storey buildings), near to an industrial site
St Gabriel's Children's Day Nursery	0-5	20/12/2017	Affixed to a lamppost on Chillingham Road (high traffic volume) School is located within a residential area (consisting of tall, terraced housing)

St Mary's RC Secondary School (SM)	11-18	05/12/2017	Affixed to a lamppost on Benton Park Road (high traffic volume) Located adjacent to multiple bus routes Located near a busy metro station
St Teresa's Catholic Primary School (ST)	4-11	23/01/2018	Affixed to a lamppost on Heaton Road Located adjacent to a busy bus route, shops, cafes and traffic lights The school is located at the bottom of a steep embankment and is surrounded by vegetation (trees)
West Jesmond Primary School (WJ)	4-11	05/12/2017	Affixed to a lamppost on Tankerville Terrace School is located within a residential area (consisting of tall, terraced housing)
Westerhope Primary School (WP)	4-11	25/11/2017	Affixed to a lamppost on Hillhead Road Located adjacent to a busy bus route No localised 20mph speed limit outside school

* Sacred Heart Catholic High School is co-located with Sacred Heart RC Primary School which also engages with the data from the AQM.

Data capture and data flagging of school data

In 2018 NO₂ data capture at the 12 schools ranged from 37.2% to 77.8% meaning that no school met the Defra target of 90%. In 2019 all 12 schools had NO₂ data capture greater than 90% (range 91.5–99.7%). In 2018 PM₁₀ data capture ranged from 35.2% to 90.6% and only one school (data capture 90.6%) met the Defra target. In 2019 11/12 schools had data capture greater than 90% but one school only had data capture of 1.1%. The 2018 and 2019 data capture values for PM_{2.5} and PM₁ at the 12 schools are the same as the PM₁₀ values.

Data flagging are not available for PM₁. 0% of NO₂, PM₁₀, or PM_{2.5} data from the schools in this study were flagged as Lo-Lo. In 2018 two schools had NO₂ data flagged as Hi-Hi and three schools had PM₁₀ data flagged as Hi-Hi. However, data that flagged as Hi-Hi in 2018 represented a maximum of 0.30% of an individual schools' data (range 0.01–0.30%). In 2019, one school had PM_{2.5} data flagged as Hi-Hi and five schools had PM₁₀ data flagged as Hi-Hi. Again, data flagged as Hi-Hi in 2018 represented a maximum of 0.34% of an individual schools' data (range 0.01–0.34%). Data flagging information can be found in Tables S3–S15.

Table S4. Data flagging values, adapted from the Breathe London project [36].

AQMesh Pod Parameter	Lo-Lo	Lo	Hi	Hi-Hi
NO ₂ ppb	-10	-5	300	500
NO ₂ µg/m ³	-19.125	-9.5625	573.75	956.25
PM _{2.5} µg/m ³	-10	0	300	500
PM ₁₀ µg/m ³	-10	0	500	1000

Breathe London's NO₂ data flags use the units parts per billion (ppb) which were converted to µg/m³ using the European Commission NO₂ conversion factor of 1 ppb = 1.1925 µg/m³ for comparison with data collected in this study [37].

Table S5. Annual average and standard deviations of PM₁₀, PM_{2.5}, PM₁, and NO₂ concentrations at each of the participating schools during 2018 and 2019.

Location

Pollution concentration (µg/m³) (mean±SD) (median)

	PM ₁₀		PM _{2.5}		PM ₁		NO ₂	
	2018	2019	2018	2019	2018	2019	2018	2019
Urban background precision monitoring site	12.4±12.7 (9.9)	15.3±30.1 (11.5)	9.1±7.8 (6.9)	8.9±7.8 (6.8)	-	-	28.6±16.4 (25.9)	32.1±15.6 (30.4)
Roadside precision monitoring site	15.5±11.8 (13.2)	16.4±12.2 (13.5)	-	-	-	-	39.0±26.2 (36.4)	38.3±27.7 (35.7)
Atkinson Road Primary Academy	16.4±17.4 (12.1)	18.0±9.7 (14.5)	11.0±10.2 (6.9)	11.0±8.4 (7.2)	5.0±3.7 (3.5)	4.9±3.4 (3.5)	23.4±15.9 (19.7)	23.9±12.8 (20.6)
Broadway East First School	12.1±14.5 (9.6)	10.8±8.0 (8.6)	8.2±9.3 (5.6)	7.0±6.1 (4.9)	6.7±7.5 (3.8)	5.3±6.3 (2.8)	26.3±19.2 (19.3)	26.9±14.1 (23.7)
Chillingham Road Primary School	9.6±13.3 (7.1)	8.2±8.0 (6.0)	6.6±9.2 (4.3)	5.6±5.9 (3.7)	4.4±5.7 (2.6)	3.6±4.1 (2.5)	30.4±17.9 (24.9)	28.1±14.2 (24.8)
Cragside Primary School	8.2±12.0 (6.8)	9.6±6.3 (7.8)	3.8±5.3 (3.1)	3.7±1.5 (3.3)	2.1±2.2 (1.9)	2.1±0.4 (1.9)	33.4±23.5 (25.2)	31.3±16.0 (26.8)
Knop Law Primary School	11.9±22.7 (8.3)	14.5±30.4 (8.0)	5.3±7.1 (2.9)	6.7±19.1 (2.8)	2.4±2.8 (1.3)	5.2±3.5 (20.4)	25.1±33.1 (14.8)	30.3±13.4 (28.2)
Sacred Heart Catholic High School	11.1±15.9 (7.9)	12.0±17.9 (8.2)	7.1±8.8 (4.3)	7.0±7.6 (4.6)	4.4±4.7 (2.6)	4.5±4.8 (2.9)	25.1±19.7 (18.4)	40.0±33.4 (24.6)
St Alban's R C Primary School	19.0±29.5 (8.9)	25.4±30.0 (15.8)	10.7±18.6 (3.7)	12.2±15.8 (6.7)	7.2±13.4 (1.9)	10.3±18.0 (6.1)	25.4±40.7 (9.0)	32.3±17.8 (28.2)
St Gabriel's Children's Day Nursery	11.4±13.5 (9.3)	10.1±6.1 (8.2)	6.6±7.3 (4.9)	6.9±5.4 (5.0)	5.1±6.7 (2.6)	5.6±5.9 (3.3)	38.3±26.7 (30.3)	35.8±19.3 (31.0)
St Mary's Catholic School	11.9±15.2 (10.2)	13.1±16.8 (9.9)	7.4±8.4 (5.6)	8.0±9.0 (5.5)	5.8±3.4 (3.4)	6.1±7.4 (3.3)	32.6±24.6 (24.2)	29.2±16.7 (24.9)
St Teresa's Primary School	12.5±15.9 (9.1)	9.3±8.3 (6.6)	9.1±12.0 (5.1)	7.3±9.2 (4.1)	6.9±9.6 (3.2)	5.9±7.8 (2.9)	32.5±26.2 (25.0)	25.7±13.4 (22.3)
West Jesmond Primary School	9.1±9.9 (7.7)	8.3±5.8 (6.6)	8.7±10.4 (5.7)	7.3±8.0 (4.6)	7.6±8.8 (4.5)	6.4±7.2 (3.6)	36.3±19.5 (30.9)	22.7±14.1 (19.7)
Westerhope Primary School	7.0±15.2 (7.0)	7.8±18.6 (4.5)	3.9±10.3 (1.8)	3.1±4.7 (1.7)	2.2±9.4 (0.8)	1.3±1.8 (0.7)	26.5±28.5 (18.6)	21.7±11.2 (19.3)

Table S6. NO₂ data capture (%), and data flagging by school in 2018 and 2019.

School (ward)	2018			2019		
	Data capture (%)	Hi flags (%)	Hi-Hi flags (%)	Data capture (%)	Hi flags (%)	Hi-Hi flags (%)
Atkinson Road Primary Academy (Benwell & Scotswood)	37.2†	0	0	99.7	0	0
Broadway East First School (Parklands)	43.4†	0	0	99.7	0	0
Chillingham Road Primary School (South Heaton)	-	-	-	96.7	-	-
Cragside Primary School (North Heaton)	62.2†	0	0	99.2	0	0
Knop Law Primary School (Denton)	39.3†	0.05	0	96.0	0	0
Sacred Heart Primary School (Fenham)	43.7†	0	0	98.8	0	0
St Alban's R C Primary School (Walkergate)	-	-	-	99.6	-	-
St Gabriel's Children's Day Nursery (South Heaton)	77.8†	0.01	0.30	99.7	0	0
St Mary's Catholic School (Dene)	44.8†	0	0	99.7	0	0
St Teresa's Primary School (South Heaton)	-	-	-	99.7	-	-
Westerhope Primary School (Westerhope)	39.5†	0.52	0.11	99.7	0	0
West Jesmond Primary School (North Jesmond)	43.4†	0	0	91.5	0	0

† = insufficient data capture (below EU acceptable level of 90%)

- = unable to calculate

Table S7. PM₁₀ data capture (%), and data flagging by the school in 2018 and 2019.

School (ward)	2018			2019		
	Data cap- ture (%)	Hi flags (%)	Hi-Hi flags (%)	Data cap- ture (%)	Hi flags (%)	Hi-Hi flags (%)
Atkinson Road Primary Academy (Benwell & Scotswood)	35.2†	0.03	0.02	1.1†‡	0	0
Broadway East First School (Parklands)	43.4†	0.02	0	99.7	0	0
Chillingham Road Primary School (South Heaton)	-	-	-	96.7	-	-
Cragside Primary School (North Heaton)	66.4†	0	0	99.2	0	0
Knop Law Primary School (Denton)	36.5†	0.05	0	99.6	0.44	0.34
Sacred Heart Primary School (Fenham)	36.3†	0.19	0.01	98.8	0.08	0.01
St Alban's RC Primary School (Walkergate)	-	-	-	99.5	0	0.01
St Gabriel's Children's Day Nursery (South Heaton)	90.6	0.04	0	99.7	0	0
St Mary's Catholic School (Dene)	37.7†	0	0	99.7	0.09	0.01
St Teresa's Primary School (South Heaton)	-	-	-	99.7	0	0
Westerhope Primary School (Westerhope)	36.1†	0	0	99.7	0.14	0.01
West Jesmond Primary School (North Jesmond)	35.6†	0.21	0.06	99.7	0	0

† = insufficient data capture (below EU acceptable level of 90%)

‡ = apparent outlier - = unable to calculate

Table S8. PM_{2.5} data capture (%), and data flagging by school in 2018 and 2019.

School (ward)	2018			2019		
	Data cap- ture (%)	Hi flags (%)	Hi-Hi flags (%)	Data cap- ture (%)	Hi flags (%)	Hi-Hi flags (%)
Atkinson Road Primary Academy (Benwell & Scotswood)	35.2†	0	0	1.1†‡	0	0
Broadway East First School (Parklands)	43.4†	0	0	99.7	0	0

Chillingham Road Primary School (South Heaton)	-	-	-	96.7	-	-
Cragside Primary School (North Heaton)	66.4†	0	0	99.2	0	0
Knop Law Primary School (Denton)	36.5†	0	0	99.6	0.32	0
Sacred Heart Primary School (Fenham)	36.3†	0	0	98.8	0	0
St Alban's R C Primary School (Walkergate)	-	-	-	99.5	0	0.01
St Gabriel's Children's Day Nursery (South Heaton)	90.6	0	0	99.7	0	0
St Mary's Catholic School (Dene)	37.7†	0	0	99.7	0	0
St Teresa's Primary School (South Heaton)	-	-	-	99.7	0	0
Westerhope Primary School (Westerhope)	35.6†	0.04	0	99.7	0	0
West Jesmond Primary School (North Jesmond)	36.1†	0	0	99.7	0	0

† = insufficient data capture (below EU acceptable level of 90%)

‡ = apparent outlier

- = unable to calculate

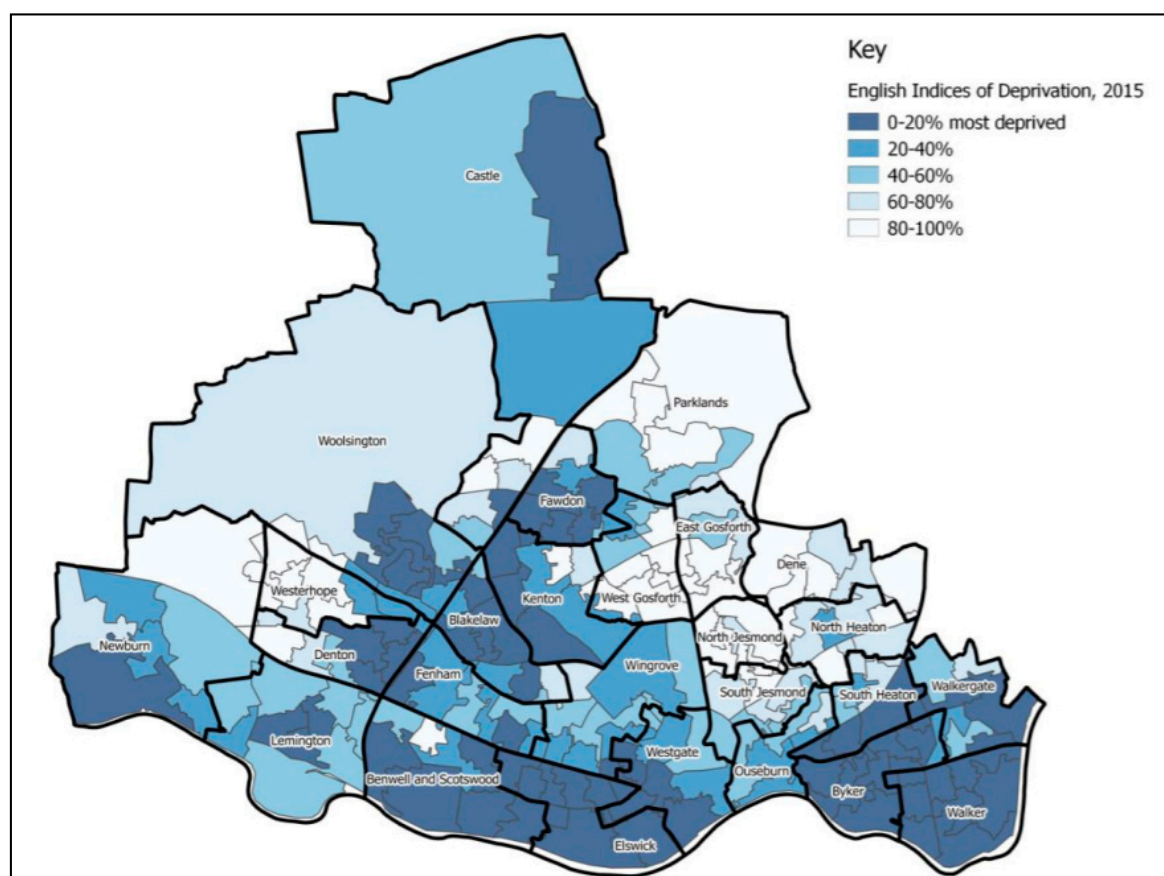


Figure S1. 2015 Index of Multiple Deprivation by ward in the city of Newcastle Upon Tyne [25].

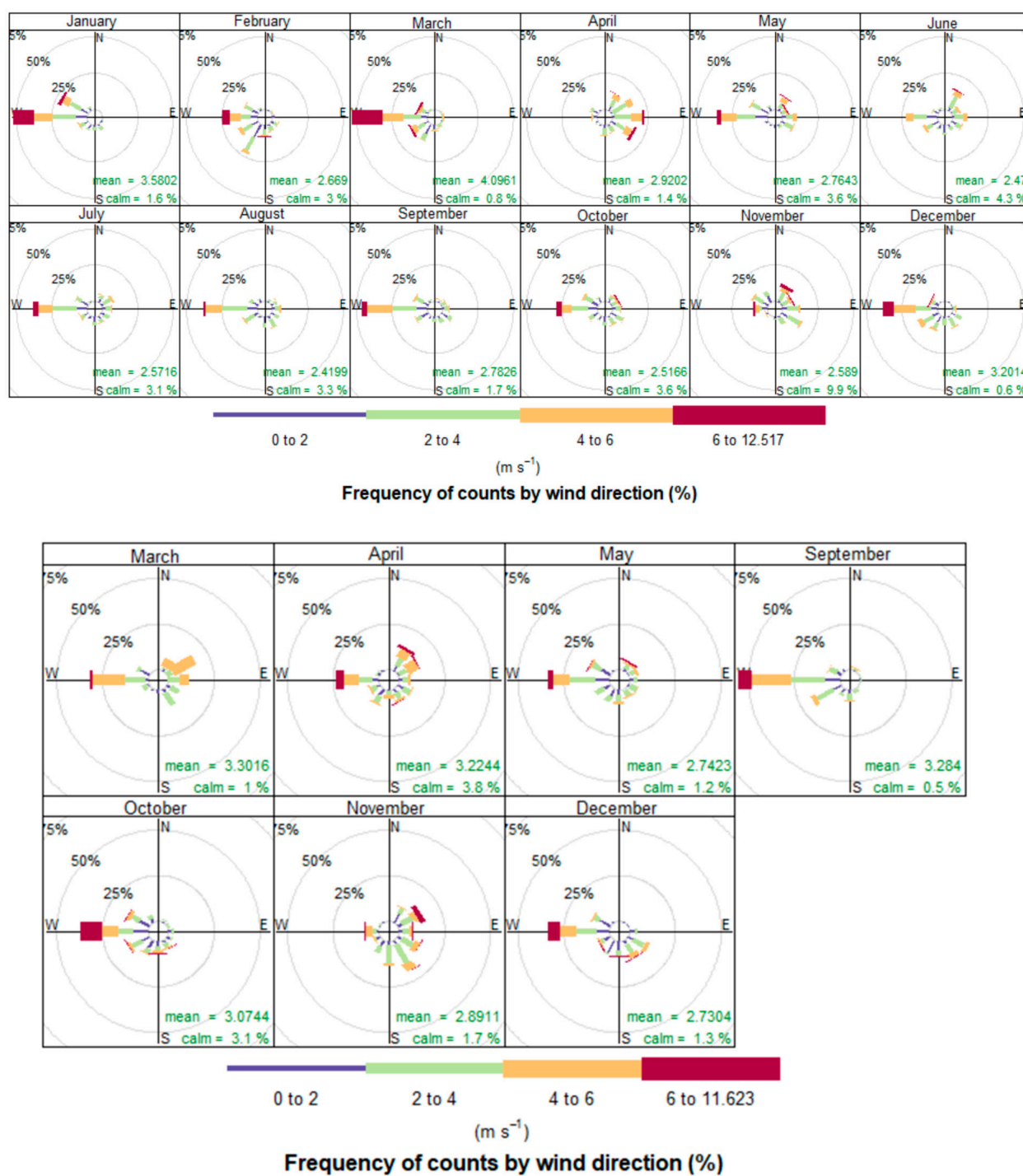


Figure S2. Monthly wind rose profile for 2018 (bottom) and 2019 (top) in Newcastle Upon Tyne.

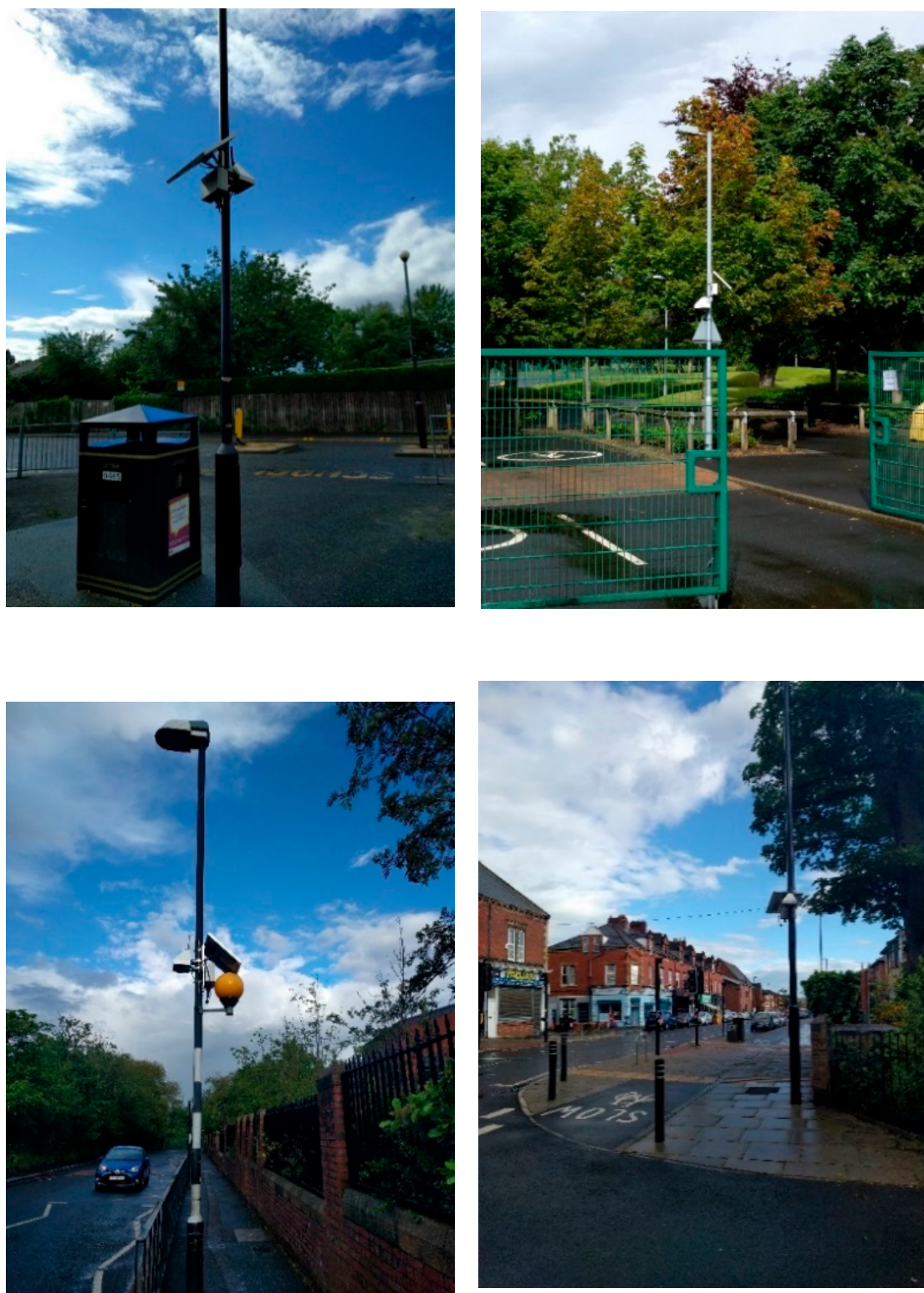


Figure S3. Examples of Healthy Schools project air quality monitor locations in Newcastle Upon Tyne

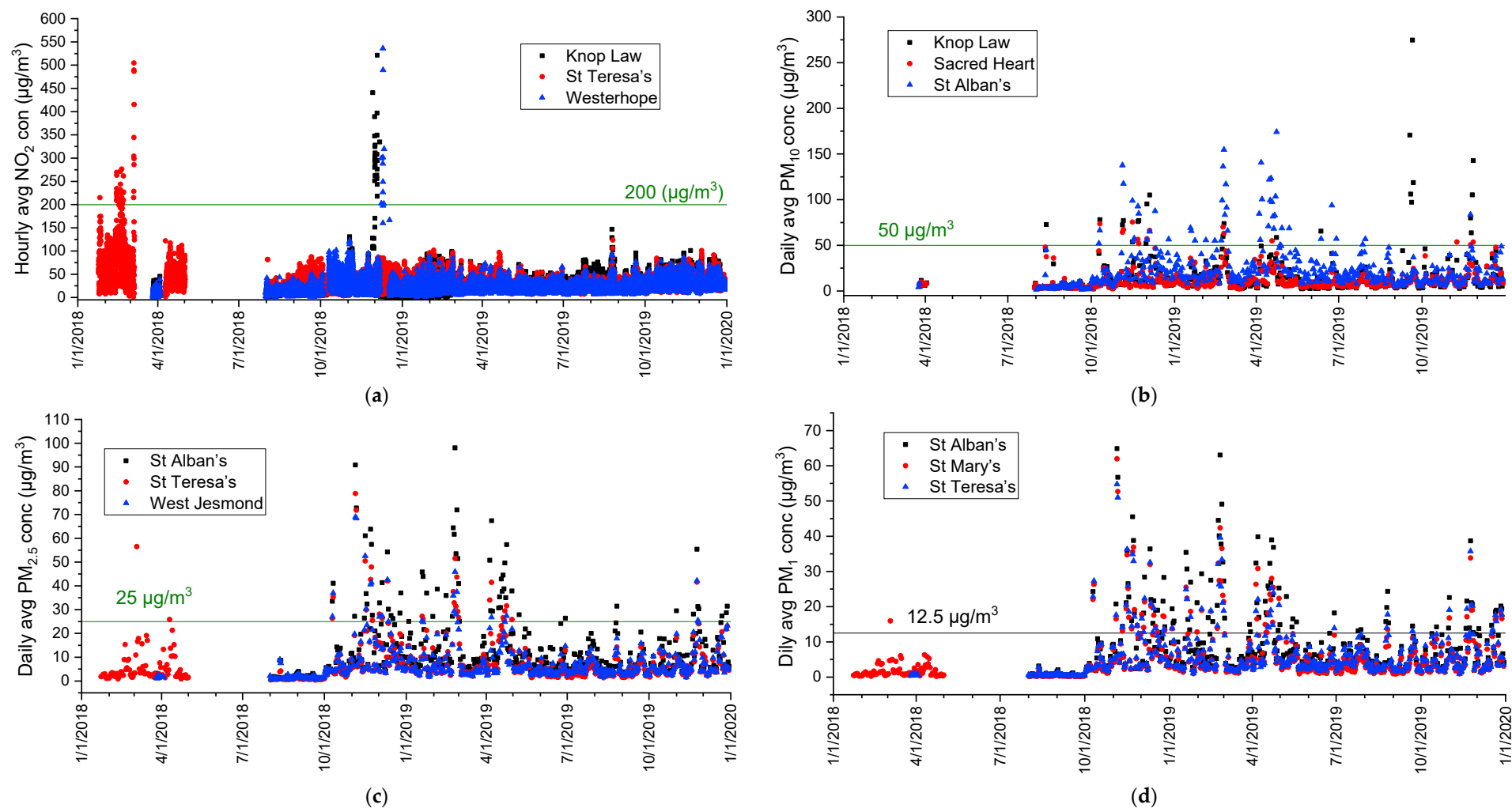


Figure S4. Scatterplots of (a) 1-h average NO₂ concern, (b) 24-h average PM₁₀, (c) 24-h average PM_{2.5} and (d) 24-h average PM₁ for schools with the highest number of exceedances of short-term WHO guidelines during 2018-2019.