

Personal Exposure and Air Quality in Northbank



A detailed study on commuter exposure
for Northbank Business Improvement District

by King's College London

July 2017



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1. Summary

The Northbank Business Improvement District (BID) is one of central London's most vibrant and diverse areas incorporating major transport hubs, historic shopping and tourist areas as well as Theatreland, law and academic neighbourhoods, a significant hotel presence and several corporate headquarters.

As a central London location however, the area also suffers from poor air quality. Indeed, The Strand, Aldwych and Fleet Street have been declared "Air Quality Focus Areas" by the Mayor due to the risk of significant public exposure (Transport for London, 2016).

The BID has a large transient population with the majority of workers in the BID commuting in from the greater London area taking combinations of tube/bus/rail and bike each day. For most people, the commute can represent their most significant exposure to air pollution each day. Thus, reducing exposure to pollution during the commute should lead to the greatest reductions in their daily exposure.

A report by the Air Quality Expert Group on particulate pollution in the UK (AQEG, 2005) concluded that there is 'no known safe level for exposure to particulate matter' and that therefore policies should 'focus on exposure reduction'.

The World Health Organisation, in a report into the health effects of Black Carbon concluded that a reduction in exposure to particulate containing Black Carbon and other material for which Black Carbon serves as an indicator should lead to a reduction in the health effects associated with particulate matter (World Health Organisation, 2012).

This study sought to gather data on the personal exposure characteristics of several workers in the BID area to better determine when, where and how individuals were exposed to particulate air pollution on their journeys into and out of the area and through the day.

Volunteers wore personal pollution monitors every day for two weeks and this information, along with GPS location data was used to assess differences in exposure between contrasting routes and/or modes of transport for each participant.

In all cases, the volunteers were able to change some aspect of their commute to avoid particulate pollution and so reduce their exposure. Exposure reductions of around 25% to 40% were achieved but for two people this was much greater.

This study includes pollution exposures above ground and during Underground (Tube) travel. The composition of particulate in each environment is different. Above ground, the monitor measures black carbon, highly correlated with exposure to traffic-related-air-pollution for which a substantial body of health effects evidence exists.

In the Underground, the monitor is sampling a range of particulates including black carbon and metal particles from rail, brake and wheel wear.

A recent review of subway particles published in 2015 concluded “It is still unclear whether subway air is more or less toxic than outdoor air” and that “at this stage the priority in subway air quality should be to reduce the high mass concentrations of aerosol present” (Moreno, 2015)

In June 2017, the Mayor of London announced a plan to improve air quality on the Tube. This includes a new commission to review the latest evidence on the health impacts of Tube dust.

Comparisons between above and Underground travel in this study should be considered with the above in mind.

2. Introduction

In October 2016 King's College London (King's) was commissioned by Northbank BID to undertake a study to assess the personal air pollution exposure characteristics of workers who commute into and work in the BID area.

The morning and evening rush hours coincide with peaks in daily pollution as these are also the busiest traffic periods. Transport for London (TfL) estimate 1.29 million people travel into central London on weekday mornings and this is growing. (TfL, 2015)

The same report notes that there continues to be a strong shift in London away from private car use towards public transport. Thus, understanding the exposure characteristics of commuter exposure is of increasing importance.

A report for Northbank BID published by Publica notes that Aldwych is "*The busiest point for bus transport in the city*" and that generally across the area "*The traffic flows ... dominate the character of the major streets in the area*" (Publica, 2015).

Personal exposure monitoring is a relatively new area of air pollution research and one made possible only in recent years by the miniaturisation of monitoring equipment which is small and light enough to carry and with sufficient battery to last a day. Whereas previously air pollution exposure calculations had to be estimated by postcode or nearest monitoring station, personal monitoring offers the chance to capture an individual's daily exposure patterns in minute-by-minute detail.

Every person's commute from home to work is unique. This study therefore aimed to investigate this diversity and provide practical recommendations for reducing air pollution exposure.

3. Aim

This study sought to characterise the particulate air pollution exposure of several workers commuting into and working in the Northbank BID area over the course of two weeks with the aim of identifying some facet of their journey that could be altered to reduce exposure.

4. Methodology

4.1. Study design

The overarching design of the study was a week 1 / week 2 structure.

In week 1, volunteers were asked to travel their normal route into and out of work.

King's and Northbank reviewed the data collected in week 1 and suggested a journey change to make in week 2 in consultation with the volunteers.

Asking volunteers to carry their monitor every day for a week gave a chance to capture routes more than once and so improve reliability of the study.

Working with The Northbank BID, recruitment forms were circulated to the business community in the BID through October and November 2016 seeking volunteers to take part in the study. The form outlined the project and the projected start date of 27th January 2017.

In December 2016, Northbank and KCL selected eight volunteers from the submissions. Volunteers were selected to provide to range of journey types and where it was felt that there was an opportunity to change some aspect of the journey to provide a suitable contrast.

Volunteers were contacted at the end of 2016 and attended a project initiation meeting at Northbank offices on 27th January 2017. Volunteers were shown how to operate the personal monitor and the GPS watch. All volunteers signed a participation form which outlined King's and Northbank's role in the project and that any sensitive data such as home location would be anonymised and held securely during and after the project.

Prior to the project start, through January 2017, one to one meetings were held with each volunteer to go through the study design in detail and also to learn more about their regular commute and what changes may be possible.

The first week of data collection occurred from 27th January to 3rd February 2017. The second week of data collection was between 24th February and 3rd March 2017.

4.2. Equipment

The instruments selected for this study were AethLabs microAeth AE51 (<https://aethlabs.com/microaeth>).

These instruments are small, reliable, portable and importantly can measure at high time resolution. These characteristics made this instrument a good choice for this study where monitors had to be worn all day in a range of conditions.

The microAeth samples ambient air at a set flow rate onto a small filter strip. As particulate accumulates on the filter, the instrument measures the rate of change in the absorption of light passing through the filter at 880 nm. This rate of change in light absorption, combined with the flow rate is then expressed as a mass of black carbon (BC) per cubic metre of air (m^3).

In Underground railway environments, the instrument will continue to measure black carbon but will also detect metal fragments, most especially iron from the wear of tracks, wheels and brakes. These would be registered by the instrument as indistinguishable from black carbon. (J.-C. Raut, 2008)

The instruments were set to a standard flow rate of 100 ml of air per minute and 1 minute averaging. At these settings, the instrument has a precision of $\pm 0.1 \text{ BC } \mu\text{g m}^{-3}$ (AethLabs, 2016).

The instruments were carried by researchers all day through each of the study weeks.

4.3. Non-linear loading correction

MicroAeths calculate black carbon (BC) concentrations from the rate of change of light transmission through the filter. The faster the filters turns black, the higher the instrument infers the black carbon concentration to be. The microAeth assumes a linear relationship between the rate of loading the concentration. However, research by (Virkkula, 2007) showed that this is not the case and in fact as the loading on the filter increases, the sensitivity of the instrument decreases.

Aethalometer measurements were corrected to account for this non-linear performance using the Virkkula formula.

5. Results



5.1. Theatre Manager

5.1.1. Introduction

The Northbank is home to much of London's Theatreland. Consequently, the area has a vibrant night-time economy with workers travelling into and out of the area outside normal rush hour peaks.

This volunteer is a theatre manager and commutes into Northbank from Hither Green in South London. Her normal commute involves walking to Hither Green station, an overground train to Charing Cross and then a walk either along the Strand or through Covent Garden to Aldwych. Like many night-time economy workers, her commute is outside normal rush hours.

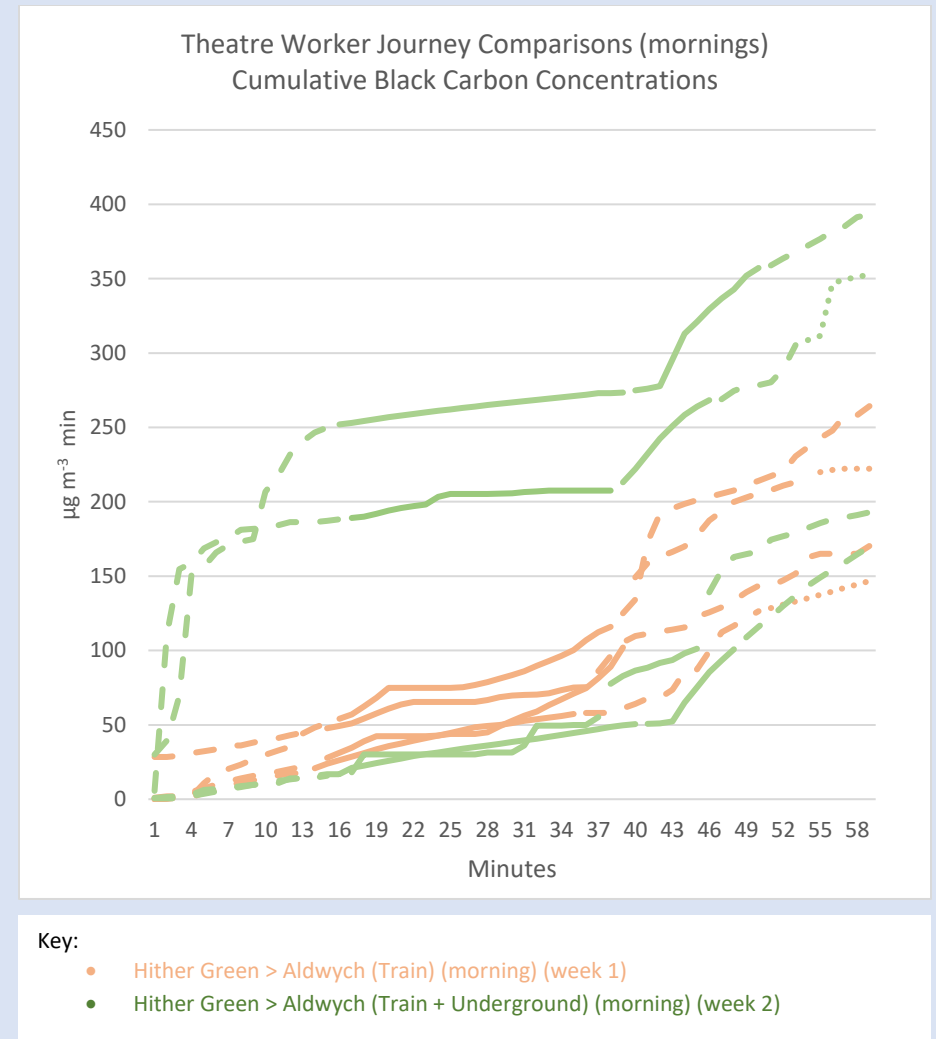
During week 1, the volunteer varied her walking routes to and from Hither Green station and to and from Charing Cross station. During week 2 she undertook more radical changes getting the overground train into Blackfriars and then the Underground train to Temple and walking up Arundel Street to Aldwych.

5.1.2. Results

Figure 1 shows the cumulative black carbon concentrations of journeys into and out of Aldwych in week 1 and week 2. The dashed part of the traces show walking, the solid parts are the train and the dotted parts in the home or office.

All journey times were equalised to the longest one to ensure a fair comparison. Only morning journeys are compared here as the volunteer only took the Underground in week 2 in the mornings.

Figure 1 Theatre Worker Week 1 Vs Week 2 journey comparisons



The graph shows that there is a range of concentrations across the journey types. Two of the highest cumulative concentrations are in week 2 on the Cannon St/Underground route. However, from the graph it can be seen that most of the exposure occurred during the walk at the beginning of these journeys. It seems clear from the graph that the low and high walking routes at the beginning and the end of the journey have a bigger effect on the overall concentration for the journey than the train and Underground parts.

With this in mind, the graphs in Figure 2 and Figure 3 show the difference between journeys where busy and quiet walking routes were taken both to and from stations in week 1 and week 2. Again, dashed line indicates walking and solid indicates train and tube.

Figure 2 Theatre Worker quiet Vs busy walking routes (week 1)

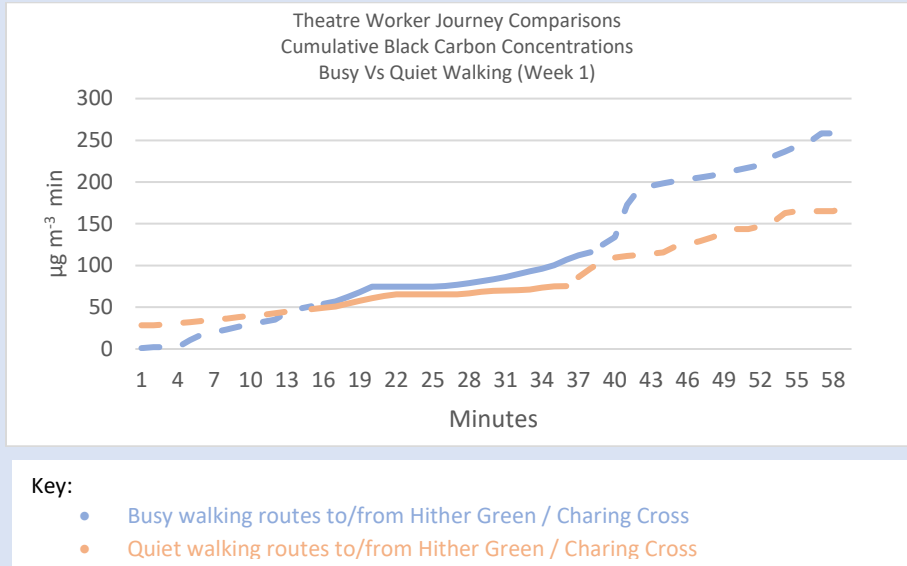


Figure 3 Theatre Worker quiet Vs busy walking routes (week 2)

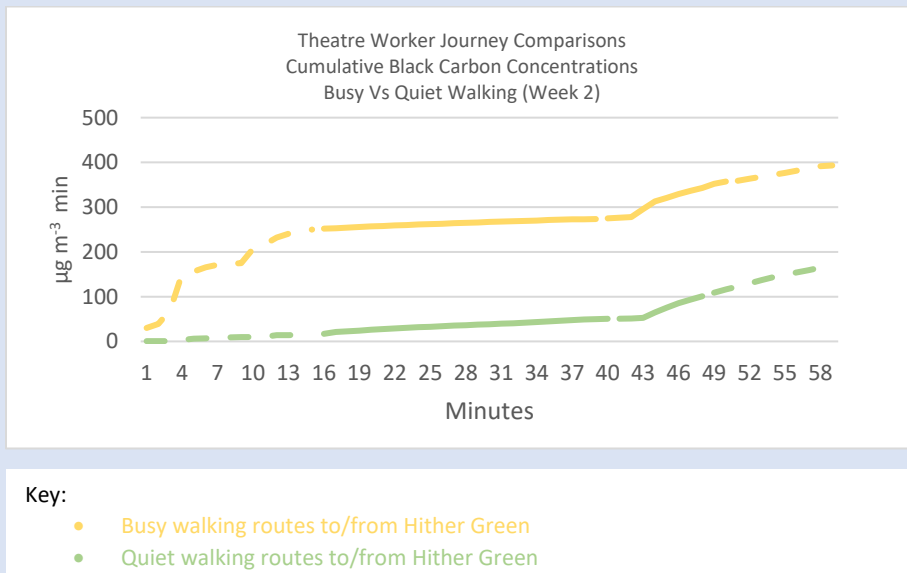


Table 1 below shows the cumulative totals for these journeys and the difference between them.

Table 1 Theatre Manager exposure comparison

Week 1	Cumulative total (µg m ⁻³ min)	Difference % (rel to highest)
Quiet Route	170.3	-35 %
Busy Route	264.3	
Week 2		
Quiet Route	169.8	-57 %
Busy Route	393.1	

5.1.3. Discussion

This experiment demonstrates that even in circumstances where two different train routes have similar exposure characteristics, a difference can still be made to the overall journey exposure by taking quieter routes to and from stations.

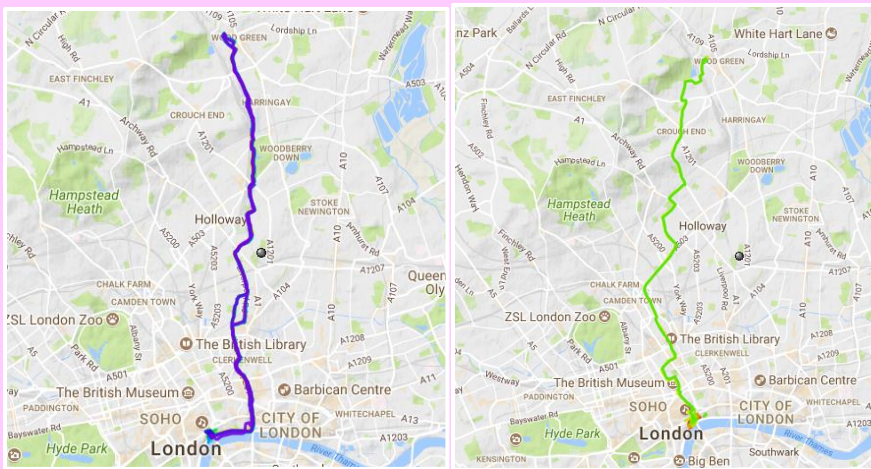


5.2. Cyclist

5.2.1. Introduction

The cyclist in this study lived in Wood Green and commutes to and from Savoy Place hotel each day. The journey takes just over an hour. In the first week of the study she took her normal route to work which involves some main roads around Finsbury Park and most of Farringdon Road.

Figure 4 Map showing week 1 (left) and week 2 (right) cyclist routes

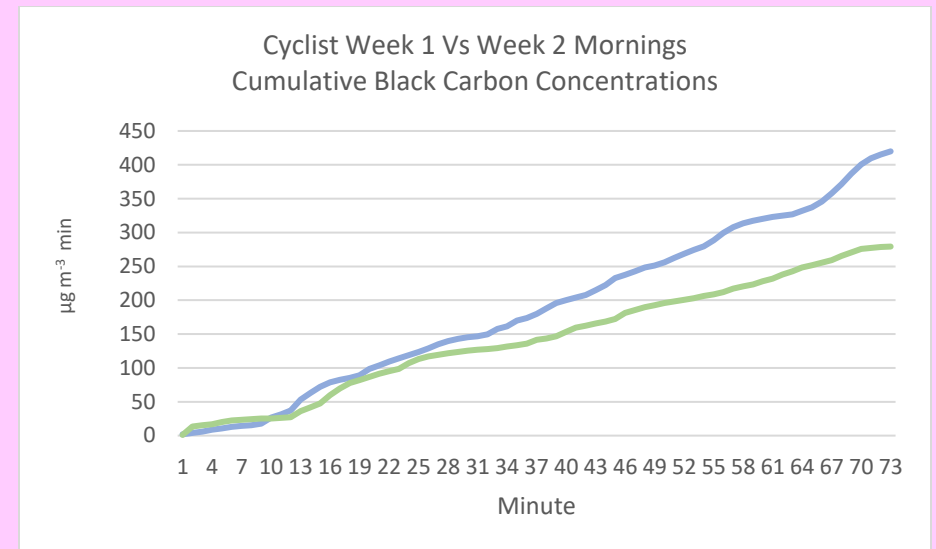


In the second week, she altered her route considerably choosing backstreets as much as possible through Fitzrovia, around King's Cross and cutting across Holloway Road through Crouch End to Wood Green. The route in week 2 was marginally longer than in week 1. In order to fairly compare the routes, the journey times were equalised using extra time in the office or at home where necessary.

5.2.2. Results

Figure 5 and Figure 6 show averages of black carbon concentrations measured during morning and evening commutes on 30th of January and 1st and 2nd of February.

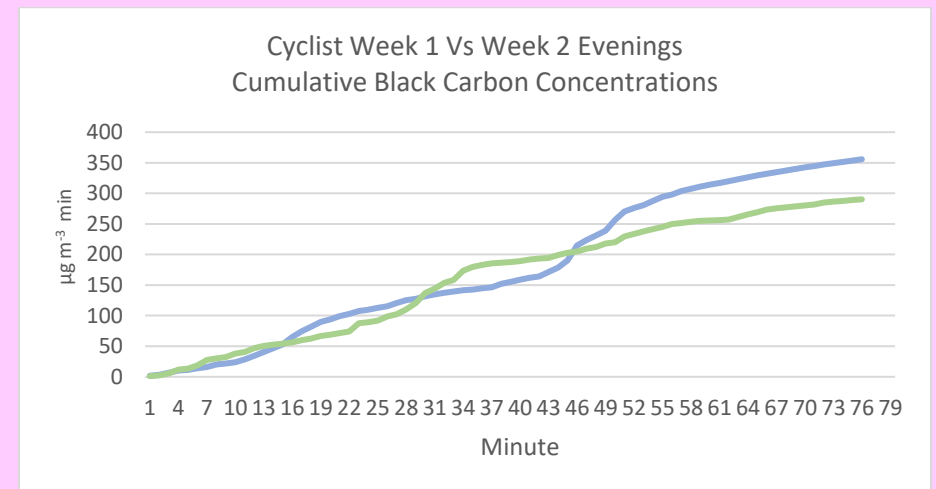
Figure 5 Cyclist week 1 Vs week 2 mornings



Key:

- Week 1 mornings (averages) (cumulative)
- Week 2 mornings (averages) (cumulative)

Figure 6 Cyclist week 1 Vs week 2 evenings



Key:

- Week 1 evenings (averages) (cumulative)
- Week 2 evenings (averages) (cumulative)

Table 2 below shows the cumulative black carbon totals for each of the morning and evening journeys and the percentage differences between the averages of week 1 Vs week 2.

Table 2 Cyclist exposure comparison

Journey				Cumulative total (Avg) ($\mu\text{g m}^{-3} \text{ min}$)	Difference % (rel to highest)
Week 1 mornings	278	458	524	420	
Week 2 mornings	270	252	316	279	-33 %
Week 1 evenings	297	340	430	356	
Week 2 evenings	261	294	316	290	-18 %

5.2.3. Discussion

The results show that, as an average over the three days, the cyclist was exposed to 33% less black carbon pollution during her morning cycles with low pollution routes in week 2, and 18% less on her evening cycles, even though the route in week 2 was slightly longer.



5.3. IT Worker

5.3.1. Introduction

This volunteer lives in Fulham and their normal commute involves a short walk to Fulham Broadway station then the District Line to Temple and a walk up Arundel Street to the London School of Economics (LSE) This is only one of many travel options available to them and in fact several combinations of journeys were undertaken as part of the study:

- Walk to Fulham Broadway > District Line from Fulham Broadway to Temple > Walk up Arundel St to LSE
- Walk to Fulham Broadway > District Line to St James Park > Walk to LSE
- Bus from Fulham Broadway to Shaftesbury Avenue > Walk through Covent Garden to LSE
- Bus to South Kensington > District Line to Embankment > Walk to along John Adam St to LSE

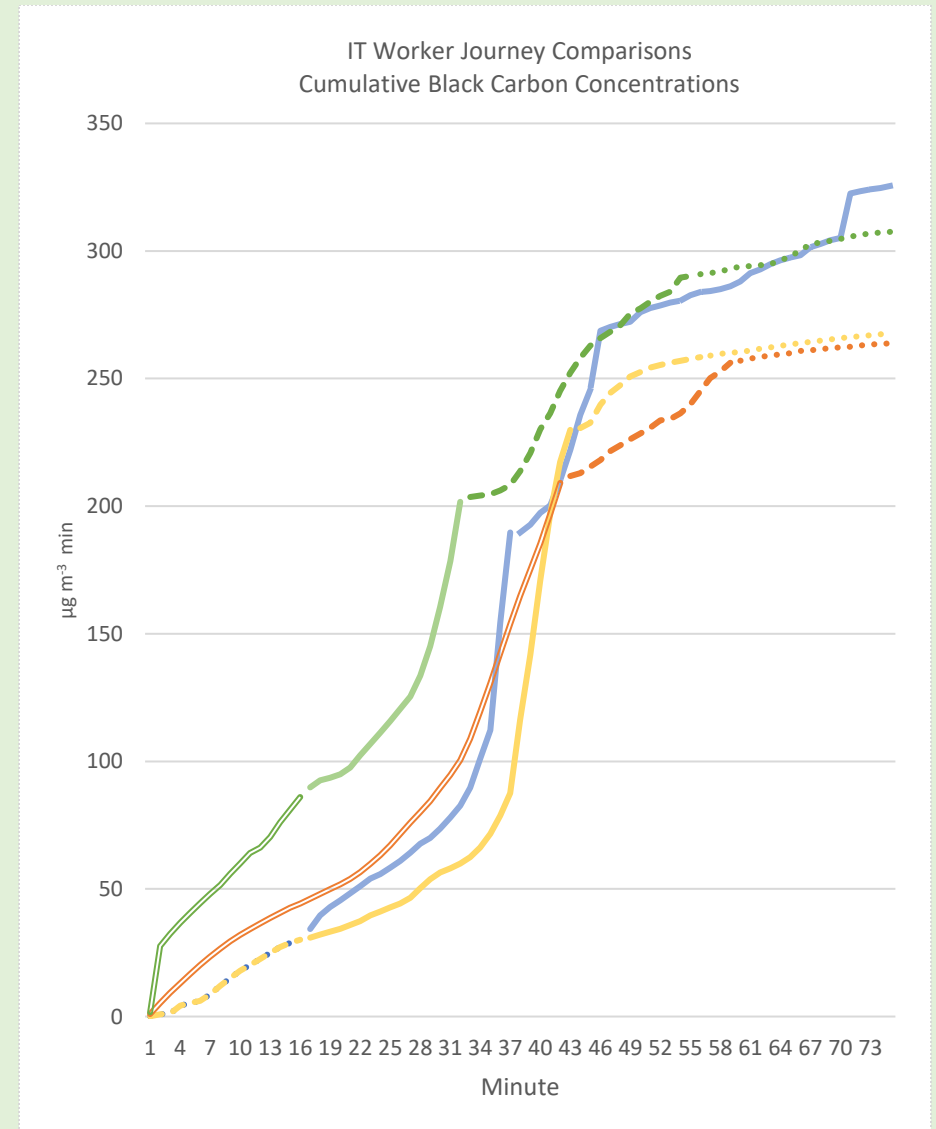
As with other contrasting journeys in this study, the journey lengths were equalised to the longest journey to make them comparable, adding time in the office or at home where necessary.

5.3.2. Results

Figure 7 shows the cumulative black carbon concentrations measured over each journey. The dashes lines indicate walking, solid lines the tube, double lines are bus journeys and dotted lines are time in the office.

(Note that the walking section of the [St James Park](#) route is hidden under the walking section of the [Temple](#) route)

Figure 7 IT Worker journey comparisons



Key:

- Walk > Fulham Broadway > Tube > St James Park > Walk
- Walk > Fulham Broadway > Tube > Temple > Walk
- Bus > Fulham Broadway > Shaftesbury Ave > Walk
- Bus > South Ken > Embankment > Walk

Table 3 below shows the cumulative totals for each of these journeys.

Table 3 IT Worker exposure comparison

Journey	Cumulative total ($\mu\text{g m}^{-3}$ min)	Difference (rel to highest)
Walk > Fulham Broadway > Tube > St James Park > Walk	326	
Walk > Fulham Broadway > Tube > Temple > Walk	268	-18% (Vs St James Park > Walk)
Bus > Fulham Broadway > Shaftesbury Ave > Walk	264	
Bus > South Ken > Embankment > Walk	308	

5.3.3. Discussion

The results show that, out of the four journey options, getting the District Line from Fulham Broadway to Temple and walking up Arundel St was comparable with getting the bus all the way from Fulham Broadway to Shaftesbury Avenue and walking to LSE through Covent Garden.

The graph also shows that Tube journeys added the quickest rise in cumulative exposure.

Getting the District Line to St James Park and then walking across town to LSE gave the highest concentration. This is likely because the volunteer was out being exposed to pollution for longer.

It's worth noting that the volunteer got the bus between home and South Kensington on four different occasions and that the range of concentrations seen across those journeys was large whereas all the Tube journeys tended to be about the same.

Bus journeys are very dependent on traffic conditions and therefore more likely to produce large ranges in time and resultant exposure.

Finally, although the journey which involved walking from St James Park to LSE resulted in the highest cumulative exposure, walking is

good for cardiovascular health and studies have shown that the benefit of walking (and cycling) in London always outweighs the dis-benefit of increased pollution exposure (Nazelle, 2016).



5.4. Motorcyclist

5.4.1. Introduction

Motorcyclists exposure has been less well studied than driver exposure. Motorcyclists though are clearly at risk of high exposures travelling as they do in the line of traffic.

The motorcyclist in this study lives the furthest from London of all our volunteers. His commute involved a journey of around an hour and a half from Yalding in Kent to Aldwych. His typical route was along the M20 and A20 and then onto the A2 for the final stretch into Aldwych. This volunteer varied his routes throughout the two week study period. His choice of routes was however more constrained than the cyclist volunteer in that a balance needed to be struck between possible quieter routes and increasing what was already a long commute.

The motorcyclist tried three route variations:

- B2016 from Yalding to Wrotham / M20 to M25 junction / A20 into Aldwych
- B2016 from Yalding to Wrotham / A20 all the way to Aldwych
- B2016 from Yalding to Wrotham / M20 to M25 junction / M25 to A2 junction / A2 to Aldwych

These are shown on the map below though the first route in blue is masked by the sections it shares with the other two (green and yellow).

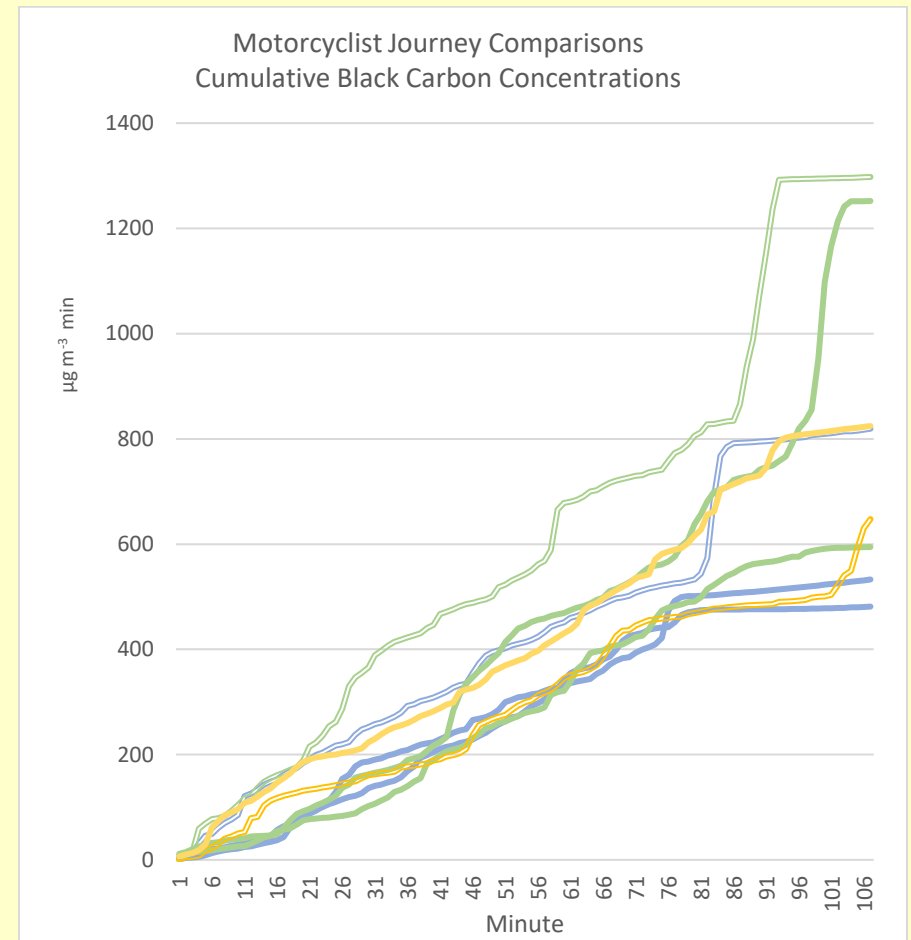


Again, in this analysis the journeys were equalized to the longest journey using extra time in the office or at home as necessary.

5.4.2. Results

Figure 8 below shows the cumulative black carbon concentrations measured over each journey. The solid lines show morning commutes while the split lines show evening commutes.

Figure 8 Motorcyclist journey comparisons



Key:

- B2016 from Yalding to Wrotham / M20 to M25 junction / A20 into Aldwych
- B2016 from Yalding to Wrotham / A20 all the way to Aldwych
- B2016 from Yalding to Wrotham / M20 to M25 junction / M25 to A2 junction / A2 to Aldwych

Table 4 below shows the average of the cumulative totals for each of the journeys in the graph.

Table 4 Motorcyclist exposure comparison

Journey	BC total ($\mu\text{g m}^{-3} \text{ min}$)	Difference (rel to highest)
B2016 from Yalding to Wrotham / M20 to M25 junction / A20 into Aldwych	611	-42% (Vs M25/A2)
B2016 from Yalding to Wrotham / A20 all the way to Aldwych	736	
B2016 from Yalding to Wrotham / M20 to M25 junction / M25 to A2 junction / A2 to Aldwych	1048	

5.4.3. Discussion

The graph in Figure 8 and the averages in Table 4 show that the route via the M20/M25 and A2 into London recorded two of the highest exposures of any of the journeys with both a morning and evening commute recording over $1200 \mu\text{g m}^{-3}$ black carbon over the course of the journey.

The other two routes show comparable exposures.

The average of the cumulative exposures of the M20/A20 route is 42% lower than the averages of the cumulative exposures on the M20/M25/A2 route.

There was no clear difference between morning and evening commutes.

Indeed, the averages mask some important points about the journeys; namely that this volunteer experienced a wide range of concentrations across his journeys.

Unlike cyclists, motorcyclists are more subject to traffic jams and delays. Indeed, the volunteer often noted traffic jams and delays on his journey notes. This variation in traffic conditions was likely responsible for the variation in recorded exposures.

This phenomenon was also noted in the IT Worker's results who also saw large variations in concentrations during bus journeys. Some were fast as traffic was light while some were very slow when traffic was heavy.

The advice for the motorcyclist in this study is to choose whichever route is the fastest or least congested to minimize exposure.



5.5. Hotel Facilities Manager

5.5.1. Introduction

The Northbank is home to several historic hotels and a thriving hotel sector supporting Theatreland and the local economy.

This volunteer is a hotel facilities manager, he lives in Harlesden and his normal commute involves a 10 minute walk to Harlesden station, catching the Bakerloo line to Charing Cross and a walk along the Strand to Aldwych.

For an alternative journey, the volunteer caught an overground train from Harlesden to Euston and walked to Aldwych.

Importantly, the volunteer varied this route further choosing a busy route down Southampton Row and Kingsway one day and a quieter route through Russell and Bloomsbury Squares and the backstreets of Covent Garden to Aldwych.

In the analysis, the journey times were equalised to enable a fair comparison though the two journeys were actually very similar in length.

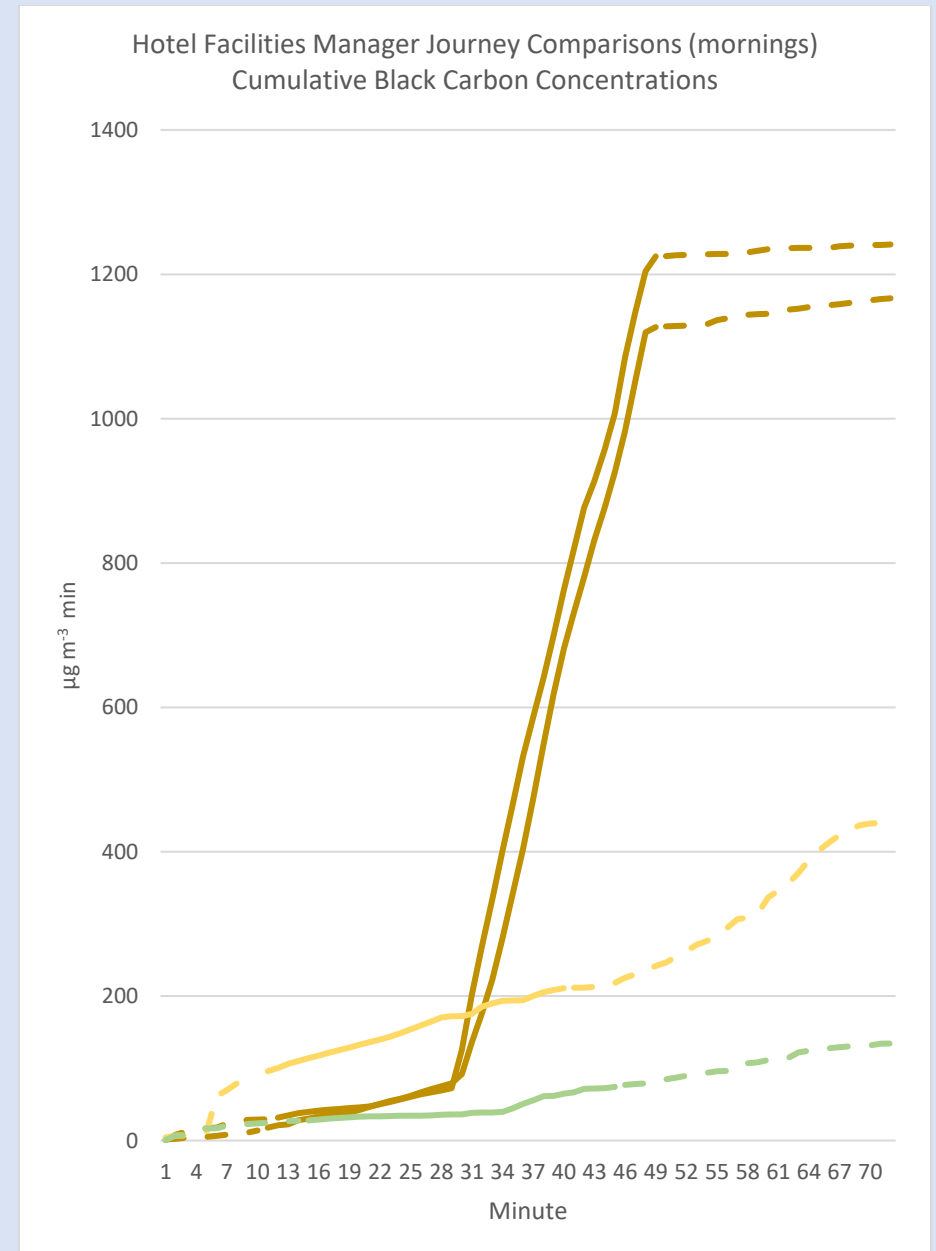
5.5.2. Results

Figure 9 shows the cumulative totals of two morning commutes on the Bakerloo line and two on the overground train to Euston.

The Bakerloo journeys are shown in brown and the overground + walking journeys are shown in yellow and green.

Walking sections to and from stations are shown as dotted lines.

Figure 9 Hotel FM journey comparisons



Key:

- Bakerloo line Harlesden to Charing Cross
- Overground line Harlesden to Euston / Walk (busy route)
- Overground line Harlesden to Euston / Walk (quiet route)

Table 5 below shows the cumulative totals for each of these journeys.

Table 5 Hotel Facilities Manager exposure comparison

Journey	Cumulative total ($\mu\text{g m}^{-3} \text{ min}$)	Difference (rel to highest)
Bakerloo (25-02)	1241	
Bakerloo (27-02)	1167	
Train+Walk (high)	440	
Train+Walk (low)	134	-89% (Vs Bakerloo 25-02)

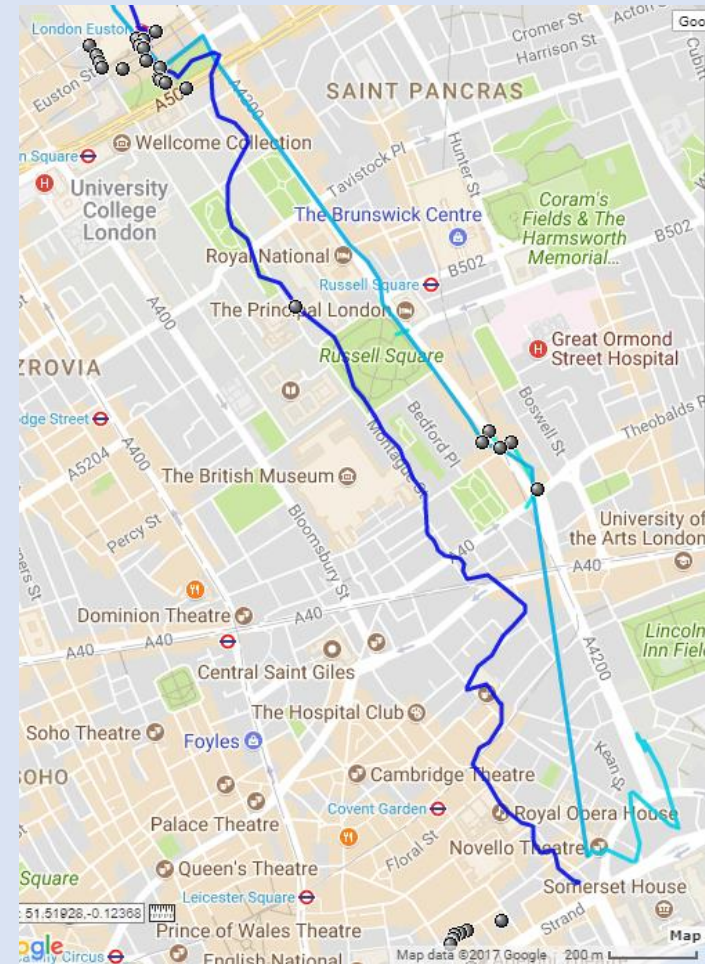
5.5.3. Discussion

The results show that the Bakerloo line journeys are around three times more polluted than the overground train journeys.

The results also show that by choosing a quieter backstreet route through Russell and Bloomsbury Square and Covent Garden, the volunteer was able to reduce his exposure still further to almost a tenth of the exposure experienced on the Underground.

Figure 10 opposite shows the GPS track of the busy and quiet walking routes taken from Euston station to Aldwych.

Figure 10 Hotel FM alternate walking routes in week 2





5.6. Office Worker

5.6.1. Introduction

The Northbank is home to several corporate headquarters with thousands of staff commuting in daily from across London.

The office worker volunteer in this study lived in West London and, like the IT Worker and Theatre Manager, has several options open to her for her commute.

Her typical journey involves walking to Northfields Tube station, getting the Piccadilly Line to Hammersmith, changing onto the District Line to Embankment then walking up Villiers Street to her office on John Adam Street.

The full range of journey combinations undertaken over the two-week period were:

- Walk to Northfields / Piccadilly Line to Hammersmith / District Line to Embankment / Walk to John Adam St
- Walk to Ealing Broadway / Central Line to Oxford Circus / Bakerloo to Embankment / Walk to John Adam St
- Walk to Ealing Broadway / Overground train to Paddington / Bakerloo to Embankment / Walk to John Adam St
- Walk to Ealing Broadway / District Line to Embankment / Walk to John Adam St

As with all other journey comparisons in this study, the journey times were equalized to the longest one to ensure a fair comparison.

5.6.2. Results

Figure 11 and Figure 12 opposite show these journeys split into morning and evening commutes with walking, Underground and home/office indicated with dashed, solid and dotted lines respectively.

Figure 11 Office worker journey comparisons (mornings)

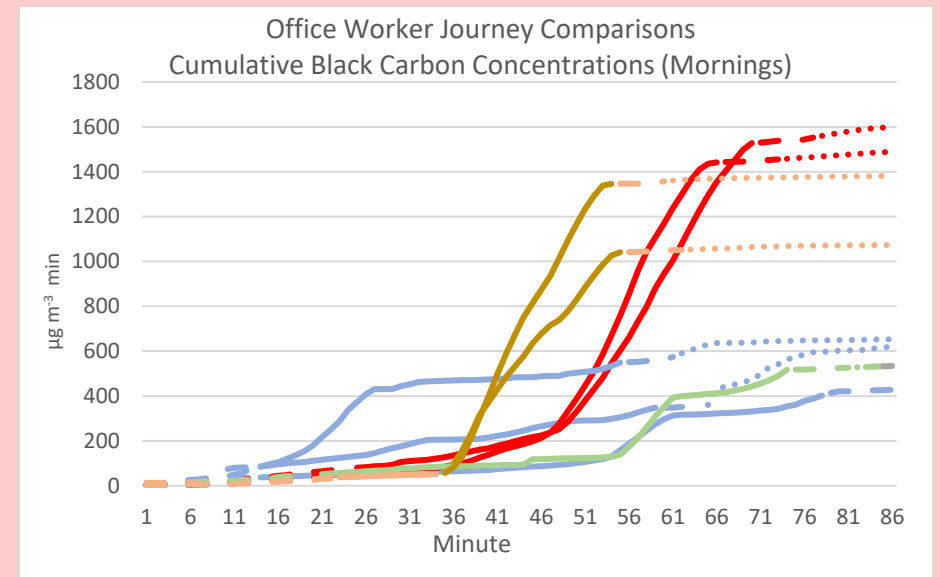
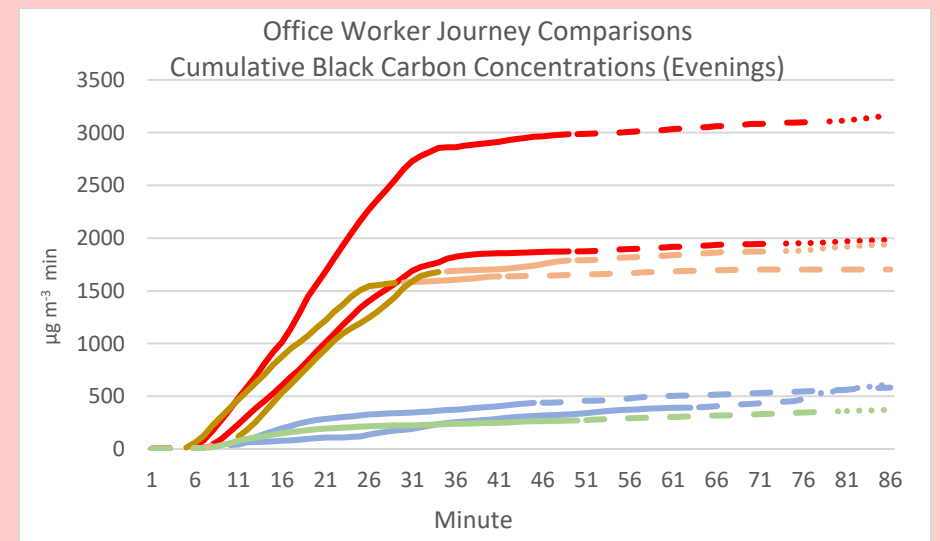


Figure 12 Office worker journey comparisons (evenings)



Key:

- Picadilly / District
- Central / Bakerloo
- Overground / Bakerloo
- District

Table 6 below shows the cumulative totals of all journey combinations shown in the graphs.

Table 6 Office Worker exposure comparison

Journey						Cumulative total (Avg) ($\mu\text{g m}^{-3}\text{ min}$)	Difference (rel to highest)
Piccadilly / District	428	582	620	629	653	582	-72% (Vs Central Bakerloo)
Central / Bakerloo	1490	1984	1600	3155		2057	
Overground / Bakerloo	1073	1703	1483	1941	1381	1516	
District	534	374	444			451	-78% (Vs Central/Bakerloo)

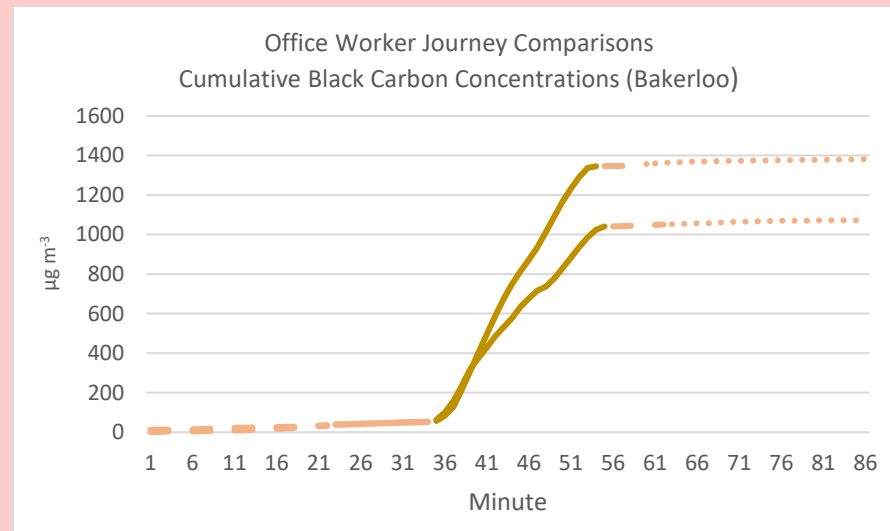
5.6.3. Discussion

The graphs and table above clearly illustrate that the journeys which involve the Bakerloo line are more polluted than the journeys on the Piccadilly and District lines by a factor of around four.

This is demonstrated very clearly on the journeys where the volunteer took the overground train from Ealing Broadway to Paddington and changed onto the Bakerloo line.

The Bakerloo line section is clearly visible in Figure 13 starting at around minute 36. This section contributes around 90% of the total journey exposure.

Figure 13 Office worker overground and Bakerloo journeys



The journeys involving the Piccadilly line from Northfields swapping onto the District line at Hammersmith and District line all the way from Ealing Broadway to Embankment were broadly similar.

This is likely because both the Piccadilly and District lines are above ground at this point with the Underground sections of both lines roughly similar in length. The District line was created mostly using the ‘cut and cover’ technique and so even in Underground sections is mostly near to the surface and has frequent small open-air sections.

The last point that appears from the graphs reinforces the theory that concentrations are higher on the Underground sections and lower on the overground sections are the differences between the evening and morning commutes. On the morning commutes, the concentrations stay low as the journey is above ground rising later in the journey as the tube goes Underground. In the evening, the reverse is true with the majority of the exposure occurring at the start.

This experiment clearly shows the Piccadilly/District line route to be the lowest exposure routes for this volunteer.



5.7. Community Coordinator

5.7.1. Introduction

Somerset House is one of the grandest and liveliest hubs in the Northbank area and home to many arts and charity organisations. This volunteer works at Somerset House coordinating events and activities across this important central London Landmark. Her journey involves commuting in from Chertsey in Surrey usually by overground train to Waterloo and then a walk over Waterloo Bridge. This volunteer, like the others, undertook a few journey variations:

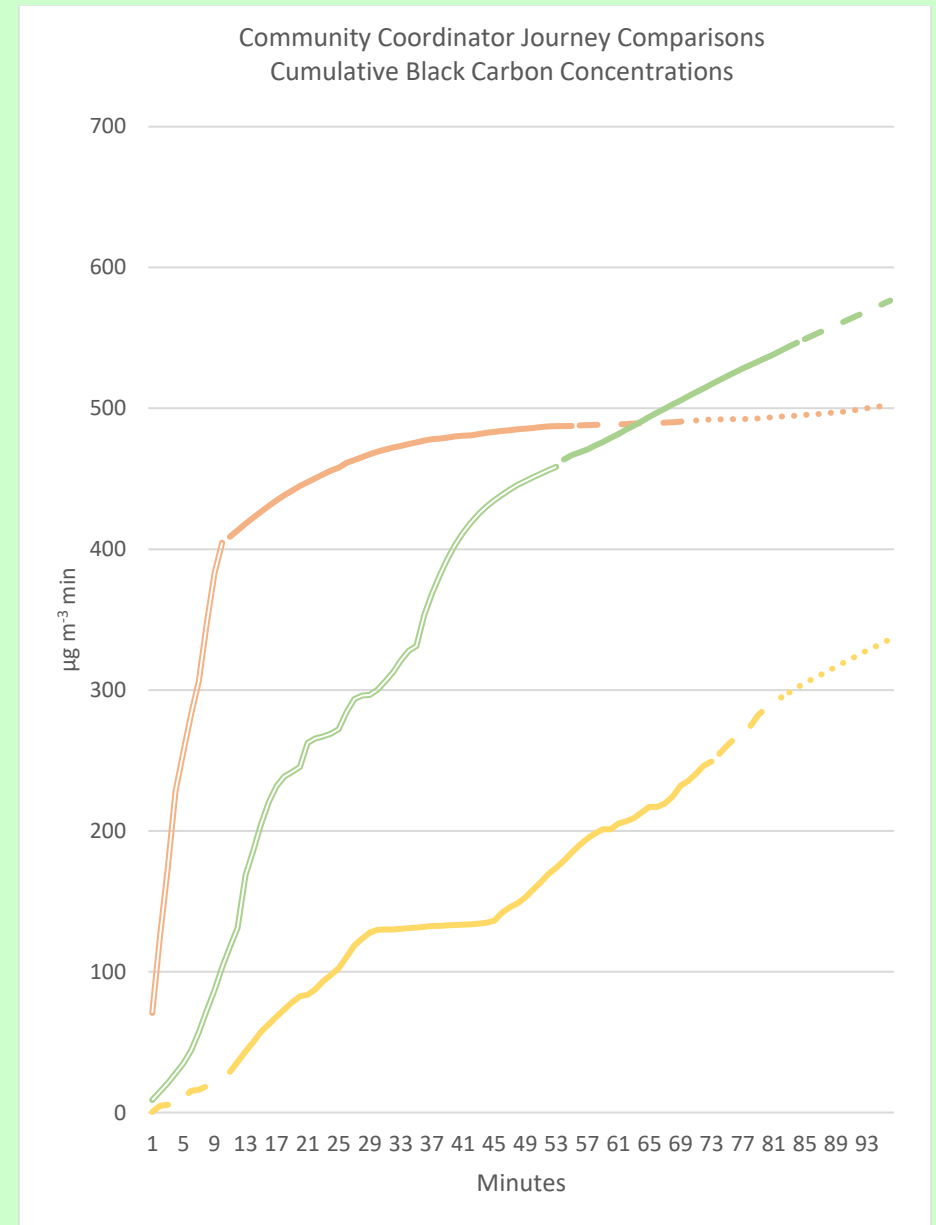
- Drive to Chertsey Station / Overground to Waterloo / Walk to Somerset House
- Walk to Chertsey Station / Overground to Waterloo / Walk to Somerset House
- Drive to Richmond Station / Overground to Waterloo / Walk to Somerset House

To ensure a fair comparison, all journeys compared were morning commutes from home to work. All journeys were equalised in length to the longest one using extra time in the office if necessary.

5.7.2. Results

The graph in Figure 14 opposite shows cumulative black carbon concentrations recorded for each of the three journeys detailed above. Walking is indicated with a dashed line, driving with double lines, train and tube with solid lines and office with dotted lines.

Figure 14 Community coordinator journey comparisons



Key:

- Drive to Chertsey / Overground to Waterloo / Walk
- Drive to Richmond / Overground to Waterloo / Walk
- Walk to Chertsey / Overground to Waterloo / Walk

Table 7 below shows the cumulative totals for each of the journeys in the graph and the percentage difference between the highest and lowest journeys.

Table 7 Community Coordinator exposure comparison

Journey	Cumulative total ($\mu\text{g m}^{-3}$ min)	Difference (rel to highest)
Drive / Chertsey / Train / Walk	502	
Drive / Richmond / District / Walk	576	
Walk / Chertsey / Train / Walk	336	-42 % (Vs Drive/Richmond)

5.7.3. Discussion

The results show that the two journeys with a car section had the greatest exposure and the journey that involved only walking and overground train was the lowest.

Previous studies by King's have shown that car drivers and passengers are exposed to more pollution than pedestrians as pollution enters the cabin from the traffic in front and builds up (King's College London, 2014). Pedestrians on the other hand, tend to walk adjacent to traffic where pollution is dispersed more rapidly than in a vehicle.

The cumulative exposure during the walking and overground journey was 33% lower than the same journey which included a car journey at the start and was 42% lower than the highest journey which involved driving to Richmond.



5.8. Vicar

5.8.1. Introduction

As one of the oldest parts of London, the Northbank is home to several places of worship.

This volunteer is a Vicar who lives in Guildford. His normal commute involves driving to Guildford station, overground train to Waterloo and a walk or cycle over Waterloo Bridge.

The journey comparison below shows a commute where the Vicar walks from the church, along the Strand and over Waterloo Bridge to Waterloo then overground train to Guildford.

In the second journey, the Vicar travels in from Guildford to Waterloo and cycles over Waterloo Bridge and along the Strand.

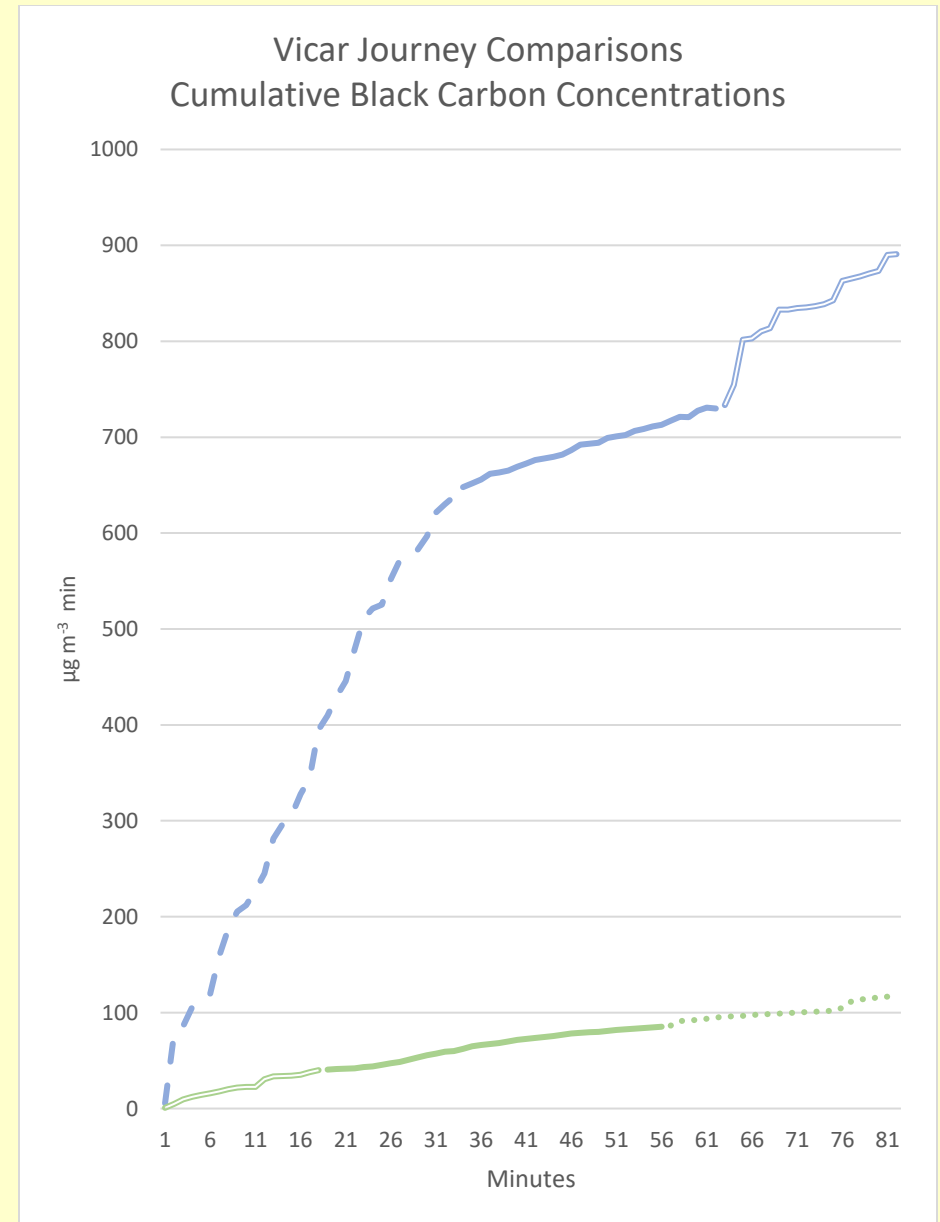
5.8.2. Results

The graph in Figure 15 shows the cumulative black carbon concentrations recorded over each of the journeys.

The blue trace shows the journey which involved walking along the Strand and over Waterloo Bridge, the green trace shows the journey where this was cycled instead.

The dashed lines indicate walking, the solid lines are train journeys, the dotted line is a cycle and the double stroke line is driving.

Figure 15 Vicar journey comparisons



Key:

- Walk to Waterloo / Train / Drive
- Drive to Guildford / Train / Walk to Strand

Table 8 below show the cumulative concentrations of each journey.

Table 8 Vicar exposure comparison

Journey	Cumulative total ($\mu\text{g m}^{-3}$ min)	Difference (rel to highest)
Walk / Train / Drive	890	
Drive / Train / Cycle	117	-87%

5.8.3. Discussion

The results indicate that walking along the Strand added a significant exposure burden to the journey compared with cycling - an increase of seven times.

In previous studies conducted by King's, cycling was often found to be the lowest exposure mode of transport as it's usually the quickest (King's College London, 2014).

The Strand is often congested with buses and taxis queuing along its length.

It's important to note for this volunteer that this is just one single journey compared with another.

A more rigorous comparison of the two journey options would be needed before a firm conclusion can be reached.

6. Conclusions

This study demonstrates large differences in air pollution exposure on a wide variety of commutes into and out of the Northbank area.

In each case, we were able to identify a change of route or mode of travel which led to a reduction in exposure, sometimes by a large margin.

Overall it shows that overground trains and sections of Tube network where trains are above ground have much lower concentrations of particulate pollution than Underground sections, particularly the deeper lines.

The study demonstrates that, aside from walking and cycling being beneficial from a cardiovascular health perspective; pedestrians and cyclists generally have more options to alter their routes to take advantage of quieter streets and parks than motorcyclists and drivers do.

The principle of utilising quieter backstreets and parks also applies to journeys within the Northbank area. The Clean Air Route Finder, utilising pollution mapping from King's and available on The Northbank's website can help visitors and commuters find low pollution routes through the BID area. <https://thenorthbank.london/making-progress/clean-air/>

7. Recommendations

This study found that participants who switched to quieter walking and cycling routes were able to reduce their exposure by 30-50%

Allied to this, studies have shown that walking and cycling in London have an overall beneficial effect on health. Pedestrians and cyclists also emit no pollution.

Transport for London (TfL) are investing in cycling infrastructure and the Mayor's Healthy Streets programme aims to encourage more people to walk around London.

This study shows that, as well as encouraging walking and cycling, consideration should be given to separating cyclist and pedestrians from traffic, as this can significantly reduce their exposure.

The biggest contrasts in this study were between overground and Underground train journeys. Volunteers travelling in overground trains had some of the lowest particulate exposures and those on the Underground some of the highest. One volunteer in this study reduced their exposure by 89% by switching from an Underground to overground train. Overground trains are low exposure environments as they are fast and separated from the road network.

As noted in the Summary, the composition of particulates above ground and in the Underground is different. A recent review of subway particles published in 2015 concluded “It is still unclear whether subway air is more or less toxic than outdoor air” (Moreno, 2015). Comparisons between above ground and Underground journeys in this study should be considered with this in mind.

In June 2017, the Mayor announced a new plan to improve air quality on the Tube network (Transport for London, 2017). This includes a new cleaning regime and a new investigation into the composition and health effects of dust in the Tube network.

This study also found that participants who travelled by motorbike/bus/car experienced some of the largest ranges of exposures. This was mostly a function of traffic, sometimes they had a quick journey, sometimes they were caught in congestion.

This demonstrates how traffic congestion can exacerbate both outside air quality for pedestrians and cyclists, and also in-vehicle exposure for those stuck in traffic.

A recent study into long-term trends of PM2.5 particulate in London by King’s found that roadside PM2.5 concentrations had fallen by around 25% between 2010 and 2015 (King's College London, 2017). This is the result of all policies aimed at reducing urban particulate concentrations.

By contrast, volunteers in this study were able to achieve reductions in excess of this in their daily commutes, mostly without incurring any extra cost.

It is important to continue to drive down ambient pollution concentrations as this improves air quality for everyone. This study demonstrates that reducing personal exposure, particularly during the daily commute, can also be an effective additional way of reducing exposure to air pollution.

This is one of the largest and most comprehensive assessments of the personal exposure characteristics of commuters undertaken in London. It offers unique insights into the exposure characteristics of workers commuting into and out of the Northbank area. We hope the findings will help provide evidence for policy development and help many more commuters reduce their exposure to pollution every day.


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