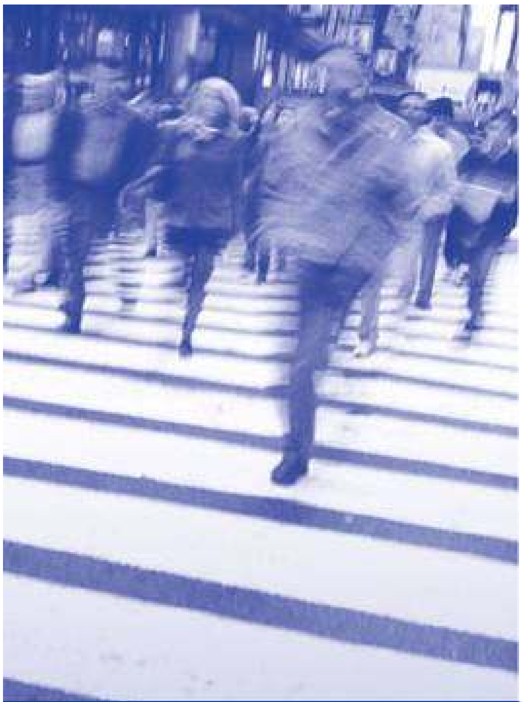

CIVITAS

Cleaner and better transport in cities

ARCHIMEDES

AALBORG • BRIGHTON & HOVE • DONOSTIA - SAN SEBASTIÁN • IAŞI • MONZA • ÚSTÍ NAD LABEM

Brighton & Hove

T3.1 – Emissions Variable Message Signage (VMS) Project

Brighton & Hove

September 2011

THE CIVITAS INITIATIVE
IS CO-FINANCED BY THE
EUROPEAN UNION

Project no.	TREN/FP7TR/218940 ARCHIMEDES
Project Name	ARCHIMEDES (Achieving Real Change with Innovative Transport Measure Demonstrating Energy Savings)
Start date of the Project	15/09/2008
Duration:	48 months
Measure:	No. 3
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Contents

1. Introduction

1.1 Background CIVITAS

CIVITAS - cleaner and better transport in cities - stands for CIty-VITAlity-Sustainability. With the CIVITAS Initiative, the EC aims to generate a decisive breakthrough by supporting and evaluating the implementation of ambitious integrated sustainable urban transport strategies that should make a real difference for the welfare of the European citizen.

CIVITAS I started in early 2002 (within the 5th Framework Research Programme);
CIVITAS II started in early 2005 (within the 6th Framework Research Programme) and
CIVITAS PLUS started in late 2008 (within the 7th Framework Research Programme).

The objective of CIVITAS-Plus is to test and increase the understanding of the frameworks, processes and packaging required to successfully introduce bold, integrated and innovative strategies for clean and sustainable urban transport that address concerns related to energy-efficiency, transport policy and road safety, alternative fuels and the environment.

Within CIVITAS I (2002-2006) there were 19 cities clustered in 4 demonstration projects, within CIVITAS II (2005-2009) 17 cities in 4 demonstration projects, whilst within CIVITAS PLUS (2008-2012) 25 cities in 5 demonstration projects are taking part. These demonstration cities all over Europe are funded by the European Commission.

Objectives:

- to promote and implement sustainable, clean and (energy) efficient urban transport measures
- to implement integrated packages of technology and policy measures in the field of energy and transport in 8 categories of measures
- to build up critical mass and markets for innovation

Horizontal projects support the CIVITAS demonstration projects & cities by :

- Cross-site evaluation and Europe wide dissemination in co-operation with the demonstration projects
- The organisation of the annual meeting of CIVITAS Forum members
- Providing the Secretariat for the Political Advisory Committee (PAC)
- Development of policy recommendations for a long-term multiplier effect of CIVITAS

Key elements of CIVITAS

- CIVITAS is co-ordinated by cities: it is a programme “of cities for cities”
- Cities are in the heart of local public private partnerships
- Political commitment is a basic requirement
- Cities are living ‘Laboratories' for learning and evaluating

1.2 Background ARCHIMEDES

ARCHIMEDES is an integrating project, bringing together 6 European cities to address problems and opportunities for creating environmentally sustainable, safe and energy efficient transport systems in medium sized urban areas.

The objective of ARCHIMEDES is to introduce innovative, integrated and ambitious strategies for clean, energy-efficient, sustainable urban transport to achieve significant impacts in the policy fields of energy, transport, and environmental sustainability. An ambitious blend of policy tools and measures will increase energy-efficiency in transport, provide safer and more convenient travel for all, using a higher share of clean engine technology and fuels, resulting in an enhanced urban environment (including reduced noise and air pollution). Visible and measurable impacts will result from significantly sized measures in specific innovation areas. Demonstrations of innovative transport technologies, policy measures and partnership working, combined with targeted research, will verify the best frameworks, processes and packaging required to successfully transfer the strategies to other cities.

1.3 Participant Cities

The ARCHIMEDES project focuses on activities in specific innovation areas of each city, known as the ARCHIMEDES corridor or zone (depending on shape and geography). These innovation areas extend to the peri-urban fringe and the administrative boundaries of regional authorities and neighbouring administrations.

The two Learning cities, to which experience and best-practice will be transferred, are Monza (Italy) and Ústí nad Labem (Czech Republic). The strategy for the project is to ensure that the tools and measures developed have the widest application throughout Europe, tested via the Learning Cities' activities and interaction with the Lead City partners.

1.3.1 Leading City Innovation Areas

The four Leading cities in the ARCHIMEDES project are:

- Aalborg (Denmark);
- Brighton & Hove (UK);
- Donostia-San Sebastián (Spain); and
- Iasi (Romania).

Together the Lead Cities in ARCHIMEDES cover different geographic parts of Europe. They have the full support of the relevant political representatives for the project, and are well able to implement the innovative range of demonstration activities.

The Lead Cities are joined in their local projects by a small number of key partners that show a high level of commitment to the project objectives of energy-efficient urban transportation. In all cases the public transport company features as a partner in the proposed project.

2. Brighton & Hove

Brighton & Hove is an historic city, in the south-east of England, known internationally for its abundant Regency and Victorian architecture. It is also a seaside tourist destination, with over 11km of seafront attracting eight million visitors a year.

In addition, it is a leading European Conference destination; home to two leading universities, a major regional shopping centre, and home to some of the area's major employers. All of this, especially when set against the background of continuing economic growth, major developments across the city and a growing population, has led the city council to adopt a vision for the city as a place with a co-ordinated transport system that balances the needs of all users and minimises damage to the environment.

The sustainable transport strategy that will help deliver this vision has been developed within the framework of a Local Transport Plan, following national UK guidelines. The ARCHIMEDES measures also support the vision, which enables the city to propose innovative tools and approaches to increase the energy-efficiency and reduce the environmental impact of urban transport.

3. Background to the Deliverable

A vision for the city of Brighton & Hove as a place with a co-ordinated transport system that balances the needs of all users and minimises damage to the environment has been expressed through a sustainable transport strategy, which seeks to reduce road traffic, pollution and congestion, improve sustainable transport modes, and increase community awareness of the impacts of travel decisions.

As with most urban areas of the UK, traffic-generated emissions (e.g. particulates, NOx) are a significant contributor to poor air quality. Thus, improving this in Brighton & Hove is a major commitment for the city council.

The city council already delivers many projects and campaigns to encourage residents and visitors to use more sustainable travel modes (e.g. JourneyOn, www.journeyon.co.uk).

The council also routinely carries out its statutory air quality[1] duties to monitor certain pollutants using fixed monitoring stations in the city.

The measures taken, however, did not – until the advent of CIVITAS funding, which enabled the installation of two VMS (variable message sign) cycle counters – include any variable message signs.

Specific resources have been invested in initiatives to encourage a reduction in car journeys to and from school through the national Travel to School[2] initiative (TTSI). In the last two years, CIVITAS funding has enabled the reach of this to be extended to independent schools and younger age groups (i.e. nurseries) primarily through encouraging the development of school travel plans.

[1] see http://www.brighton-hove.gov.uk/index.cfm?request=b1000293

[2] see http://www.brighton-hove.gov.uk/index.cfm?request=c1227814

The Emissions VMS project sits alongside this work. The primary objective of the project is to monitor vehicle emissions and ambient air quality around selected schools in order to educate pupils about their environment and how local transport activity can affect this.

It should be noted that the original project description proposed measuring the emissions of passing vehicles and 'grading' these emissions levels by displaying a highly visible score on Variable Message Signs. However, following an initial scoping exercise, the project was amended for reasons outlined fully in Section 4.4. These included the fact that the technology available to measure emissions from specific cars was deemed to be unreliable and likely to require significant expense to develop.

Nevertheless, the project delivered is closely related to the original measure and meets the same core objectives. In addition, through the inclusion of further educational and technological development elements, the revised project can also be seen as providing better value. The partners with whom the emissions VMS project is now working (Imperial College and its associated limited company, Duvas Technologies) were able to provide everything needed to meet the project aims, (i.e. raising awareness of the impacts of personal travel choices with a view to changing travel behaviour through involving schools in educational projects on emissions and air quality), while simultaneously displaying real time air quality information in the school. This measure will be evaluated through a tailored evaluation plan. The evaluation results are expected to be available in 2012; however, some findings from the initial implementation are presented in section 4.6.

3.1 Summary Description of the Task

This deliverable documents ARCHIMEDES task 8.7, which is the only task within measure 3 of the project.

Task 8.7 relates to the measurement of vehicular emissions and ambient air quality and the display of this information using real time electronic display equipment.

This project is being undertaken in partnership with three schools which has enabled the educational objectives of the measure to be enhanced. The intention is that the variable message signs relay information about vehicle emissions and their impact on local air quality. This is combined with educational programmes at the schools that raise awareness about the link between the emissions from traffic and air pollution.

4. Emissions Variable Message Signage (VMS) Project

4.1 Description of the Work Done

As noted in Section 3, initial scoping was completed on a project as detailed in the original CIVITAS ARCHIMEDES Measure Description Form (MDF). However, following this it was determined that the project would need to be revised in order to deliver a practical, beneficial project that did not greatly exceed the original budgets. This was communicated to the EC, as the funding partner, through an amendments report together with the interim and annual reporting process. A further note of the problems encountered with the original proposal is provided in Section 4.4.

Nevertheless, the revised project is in line with the spirit of the original MDF and, through an innovative technological approach, allowed the key objectives to be met. This section summarises the main actions that were undertaken in relation to the revised project.

Three schools were chosen on the basis of their location within the CIVITAS corridor (see Figure 1) as well as their close links to the city council's school travel team and their commitment to participate and contribute to the project's objectives.

Figure 1: **Map Showing Schools Participating in Emissions VMS Project** (*Source: © Crown Copyright. All rights reserved. Licence: 100020999. Brighton & Hove City Council 2011 © Cities Revealed)*

Note: Not to scale; shaded area represents CIVITAS corridor in Brighton & Hove.

Trials are due to be carried out at the three selected schools and designated junctions nearby in order to make longer-term comparisons.

The objectives of the project are as follows:

- Assessing the impact of Walk to School week at three local schools from several perspectives pertaining to personal exposure, vehicle fleet composition and local ambient air quality.
- Improved understanding of the effects of transport activity on local air quality through the development and delivery of tailored educational programmes for schools.
- Raising the consciousness of the environment in schoolchildren, their parents and school staff (especially teachers).
- Deployment of novel techniques for measuring and real time monitoring of local air quality.
- Long-term impact assessment studies with the view to developing greener local transport initiatives and evidence-based policies.

The above activities associated with this measure are linked to a national travel initiative - Walk to School (WTS)[3] week and as such provide a means of assessing and demonstrating its impact. The connection with Walk to School Week is manifest both in terms of the timing of the project (with implementation tying in with the former and its biannual implementation during the months of May/ October) and its existing place on the curriculum of schools. The Emissions VMS project sought to build on this through the provision of the specially designed educational programme noted above and the monitoring of emissions before, during and after Walk to School Week, with the intention being to assess its impact.

The key milestones to be completed within this deliverable are as follows:

- Three schools were identified to work with, and agreed to participate – Balfour Junior, Elm Grove Primary, St Bartholomew's Primary.
- Imperial College, and its in-house "partner" company Duvas Technologies, were identified and agreed as the providers of the educational programme and the technology respectively.
- The first trials and development of the technology took place at the first school from February 2010, initially in preparation for Walk to School Week in May 2010), but after further development full deployment took place during October, again connecting with the Walk to School initiative..

4.2 Summary of Activities Undertaken

Imperial College, London was appointed in October 2009 to work in partnership with the City Council, using innovative technology developed by Duvas Technologies. Imperial College demonstrated a proven ability to oversee and deliver the educational component of the project through its leadership of the OPAL[4] and outreach programme[5], while Duvas Technologies was able to research and provide the equipment required.

Between November 2009 and March 2010, Duvas Technologies developed the technology that enables both traffic emissions and ambient air quality to be monitored simultaneously using two forms of equipment sited on both sides of the adjoining road (the "Open Path (OP2)" system,

[3] See http://www.walktoschool.org.uk
[4] OPAL is a national initiative led by Imperial College London that aims to encourage people to investigate study, enjoy and protect their local environment. See: http://www.opalexplorenature.org
[5] Imperial College London's Reach Out lab links public engagement and outreach initiatives at the university. See: http://www3.imperial.ac.uk/outreach/reachoutlab

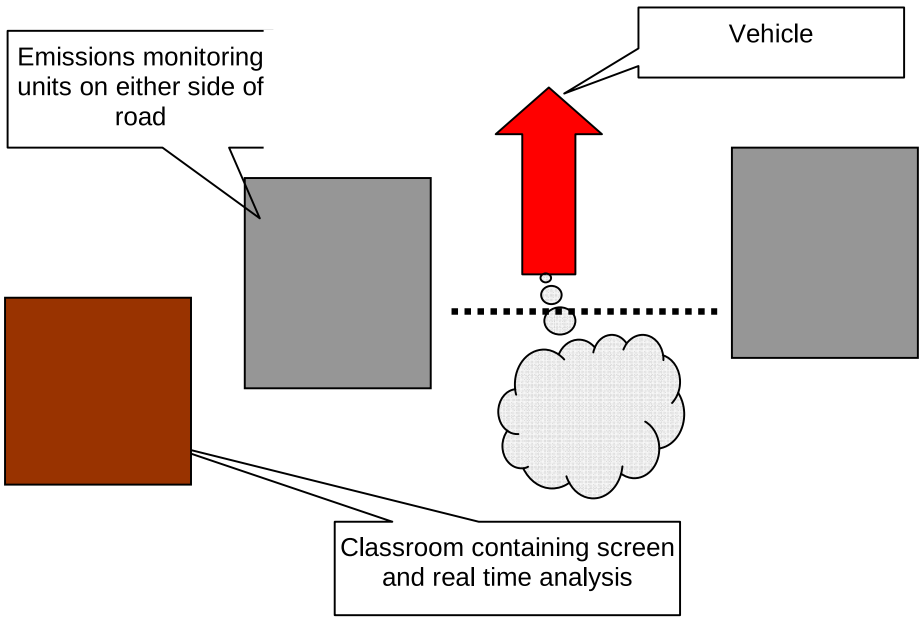
pictured in Figure 2), and on the school buildings respectively (through monitoring equipment known as "006"). A weather station, which will remain at the school after equipment decommissioning, was also installed, together with a real-time plasma screen to display the VMS data which was installed in the school's ICT suite. Finally, two portable units (shown in Figure 3) were provided so that children could take the equipment out of the school for home/school journeys and monitor air quality on those journeys.

To date, the project has been deployed at one school (Balfour Junior) with two further sites (Elm Grove and St Bartholomew's) to follow in the coming year.

The intention for all the three participating schools is to align their activities with either national Walk to School [WtS] Week (www.walktoschool.org.uk) which takes place during one week in May, or International Walk to School Month [IWtSM] (www.iwalktoschool.org), which takes place in October each year. As full deployment at Balfour Junior School was not achieved in time for national WtS Week, attention focused on IWtSM 2010. This included Imperial College's OPAL (Open Air Laboratories) staff providing interactive curriculum-linked workshops; see the lesson plan in Appendices for more information.

Using the first site (Balfour Junior) as an example, the first step of the implementation process is the monitoring of emissions from passing vehicles in close proximity to the participating school using innovative "open path – or OP2" technology (see Figure 2). The data were then displayed in the school in real time using Variable Message display equipment installed in the school in order to raise awareness of the impact that individual vehicles can have on local air quality.

***Figure 2:* Diagram Showing Basic Set up of the OP2 Technology** (*Source: Based on information supplied by Duvas Technologies Ltd)*



The initial work at Balfour Junior School took place between February and summer 2010. Significant progress was made during this time on the development, calibration and testing of the open path technology. A further, full scale, deployment then took place in October 2010. In addition to numerous site visits as part of the process of developing the innovative technology, staff from OPAL attended Balfour Junior to deliver the educational programme (see Figure 3). The overall educational objective was to allow pupils to develop an understanding of air quality, pollutants, and their causes and effects. Further details of the educational programme can be found in Appendix 2.

Year 5 and Year 6 students from Balfour Junior attended Imperial College in September 2010 for a site visit and meeting with education staff.

Additional to this, ambient air quality within the local vicinity of school grounds was monitored with accompanying educational programmes to educate young students about their environment and how local transport activity might affect it.

Figure 3: **Pictures of Emissions Monitoring Technology and Educational Programme.**

Clockwise from top left: Dr Mark Richards (Duvas), Cllr Vanessa Brown (BHCC Cabinet Member) and pupils of Balfour Junior School adjacent to OP2 unit and showing portable unit

Balfour Junior pupils attending Imperial College

4.3 Main Outcomes

Since the project began, the following outcomes have been achieved:

- Development of innovative technology followed by trials at one school, additional development and further deployment at this site.
- The project and associated publicity (some examples of which can be found in Appendix 3) is anticipated to have led to a greater awareness of air quality in the city, and has helped to support wider initiatives (Walk to School) in educating people on sustainable travel choices.

4.4 Problems Identified

As mentioned (see Section 3) the original proposal as outlined in the original MDF focused on displaying an indicator of a vehicle's emissions quality to drivers; however, this proved to be problematic to deliver. This followed detailed feasibility work which showed that the project as outlined was not deliverable for a number of reasons. The most significant problem was that technology is not suitably advanced to enable the emissions created by specific cars to be accurately measured, especially in areas where general residual levels of pollution are likely to be quite high. This was addressed through the revised project specification which developed and used innovative technology and fostered the research and development process that was required to advance this.

Associated with this, it was apparent that the project would cost significantly more than anticipated if the technology was developed further, which was not felt to represent good value for money.

In order to overcome these issues, an amended project was devised and successfully implemented, thus enabling the original objectives to be met. However, some problems were encountered, particularly as a consequence of the very innovative nature of the project (and the technology it uses).

- A number of complications arose as a result of the unique nature of each site and lack of previous experience from all parties, for example:
  - The OP2 equipment required an electrical supply, which it was known would affect the precise location. However, Site 1 (Balfour), presented particular difficulties as contractors identified that the lamppost columns in this location that would otherwise be used were historic and consequently incompatible with the requirements for the OP2 unit, although was a site-specific as opposed to OP2-specific issues. In this case, it was agreed that the supply would be drawn from a household neighbouring the school for the duration of the deployment.
  - Imperial/Duvas encountered problems in fixing equipment problems on-site. It was therefore decided the equipment would not be deployed straight from Site 1 to Site 2 (Elm Grove), but would be taken back to Imperial for testing and practical tweaking before being returned for use to the second site. Problems included the accumulation of condensation on integral elements of the measuring devices which required subsequent modifications.
- The innovative nature of the technology inevitably meant that the technology required a number of amendments, meaning the trial process was more protracted than originally foreseen. Although this is to be expected and all parties felt that the project was implemented successfully, this protracted process had the potential to impact upon the interest of children and staff. Related to this, school calendars are such that it is crucial that the technology ‘performs’ during the allocated slot.

4.5 Mitigating Activities

When identifying suitable schools for the project, there was an initial difficulty in that, after much discussion, one target school opted not to become involved in the project. The fact that the progress of the project was not impeded was owing to the preparation of a contingency list of schools and existing relationships through school travel initiatives.

Meanwhile, in relation to the problems identified in Section 4.4, it is anticipated that future sites will benefit enormously from the lessons learnt from the first deployment. This will be in the form of more reliable technology and experience of the process, but also through the amendment of project plans to include a greater period of preparation at schools prior to the Walk to School weeks that form the focus of deployments.

The latter innovation will allow greater consideration of the site and for potential problems to be overcome in advance of the main deployment periods. The benefit of doing this has been highlighted by experiences at the second school (implementation date May 2011). The road outside this site (Elm Grove), is (unlike Site 1), a major two-carriageway arterial route for the city. The BHCC contractor liaison and Duvas identified that deploying the OP2 equipment directly outside the school, next to a controlled crossing, would unfortunately be unsuitable for this location due to its lack of a suitable electricity supply. In addition, the “Open Path” system functions only with a single stream of traffic. However, an advanced follow-up site visit identified an alternative site some 10m further up Elm Grove: this location has the advantage of featuring a pedestrian refuge, which will be able to supply electricity. Duvas also confirmed that a “time allowance” could be programmed, to ensure that traffic-derived data was still accurate. The time consuming preparations for both phases of the project to date has led to a decision to undertake initial site visits at the third location far in advance of the final deployment in October 2011. Site 2 does, however, feature an existing B&HCC traffic counter, data from which has been gathered continuously since 2008. This fact has been drawn to the attention of Imperial/Duvas, as it offers the potential to cross-reference data, thus enhancing the research and evaluation aspect.

4.6 Initial Impacts

Analysis of the air quality readings taken by Duvas Technology and Imperial College have shown that there is a regular pattern of the peak levels of NO_2 with a 24 hour frequency that corresponds to the peaks in the local travel patterns. There is a 4.5 hour offset between the peak traffic level and the peak in the NO_2 level linked to the time taken for the NO emitted by the vehicles to oxidise in the ambient air to form NO_2. Variations in the regular pattern of NO_2 levels were observed at various times that were linked to fluctuations in weather patterns that brought in additional pollution from neighbouring major roads when the wind was in a particular direction, leading the peak from the local roads at the school to be partially obscured by an increased background.

A detailed examination of these factors is contained within Appendix 4 – a detailed academic paper written by Rebecca Parrish and Mark Richards of Imperial College.

4.7 Future Plans

The second deployment is scheduled for May 2011 and the final deployment is due to take place during October 2011, with both projects again timed to fit in with the academic year and planned Walk to School weeks. These implementation phases will draw on the lessons learnt from the first school and all results will be fully documented in the evaluation report for this measure in 2012.

Elm Grove is a larger school than Balfour Junior, so two, rather than one, school visits to Imperial College, London, will take place to enable both Y6 classes to participate in the project. These are currently scheduled for consecutive weeks in June 2011.

Meanwhile, a filming project is planned, centred on the second school, to tell the story of the project from different perspectives. This will also be an awareness-raising tool which will enable BHCC to communicate and promote the project between schools, giving the Emissions VMS project greater scope and influence over the longer term.

Appendix 1

Technical Background

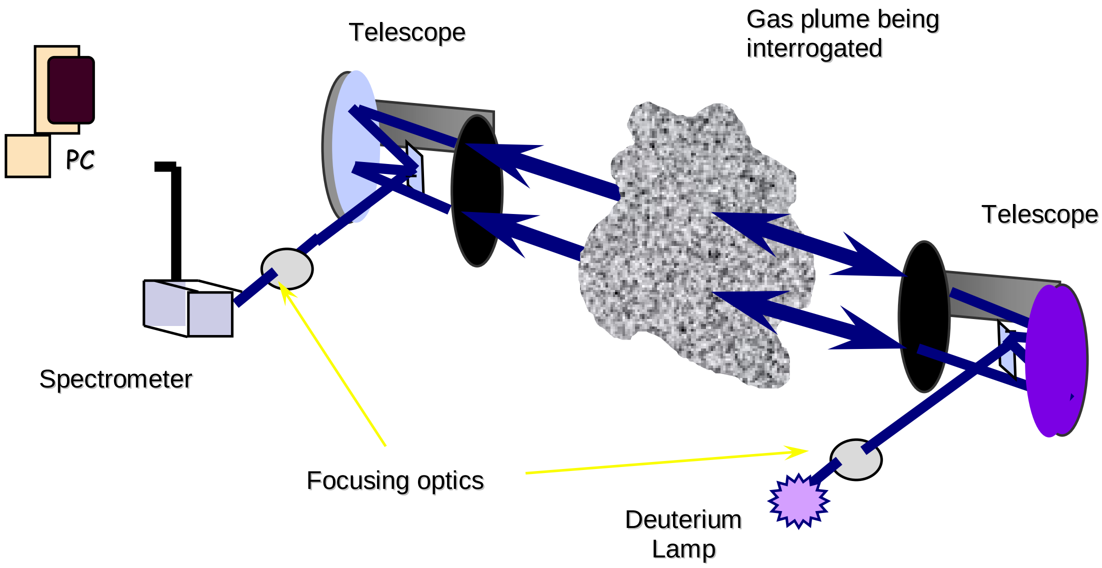
Source: Duvas Technologies Ltd.

The following is intended to provide an overview of the technology used for the Emissions VMS project. Further information about the work of Duvas Technologies can be found by visiting Duvas technologies' website[6].

Traffic emissions were measured using a variant of established Open-Path technology known as Differential Optical Absorption Spectroscopy (DOAS) that has been developed by DUVAS.

Further information on the technological principles involved can be found on the website of the Department of Atmospheric and Oceanic Sciences of the University of California[7]. This notes that DOAS is a methodology that allows the concentrations of gases to be determined through passing a light source between two points. The set up used for the Emissions VMS project and OP2 technology developed by Duvas for the purposes of this project is shown in Appendix 1.1.

Appendix 1.1: **Diagram Showing OP2 Technology** *(Source: Duvas Technologies Ltd)*



Ambient air quality at the site was measured using portable or personal units, with a focus specifically on nitrogen oxide (NO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2), though the technology does have the capacity to measure a greater range of gases.

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6 http://www.duvastechnologies.com/index.php

7 http://www.atmos.ucla.edu/~jochen/research/doas/DOAS.html

Appendix 2

Education Element: Summary of Lesson Plans

Source: Duvas Technologies Ltd

The following provides a summary of the lesson plans devised by Duvas Technologies for this project.

Activity 1

The OP2 technology continually collected emissions data from vehicles passing the school which was relayed to a plasma screen in the school's ICT suite. The interactive set up allowed analysis of the levels of pollutants emitted by passing vehicles and the ability to represent this graphically over a period of time.

Activity 2

PowerPoint presentation provided by Imperial containing topics on the following which teachers could use as a basis for lesson planning:

- The OP2 system and how it works to measure vehicle emissions
- Air composition
- Sources of pollution
- Pollution and health
- Greenhouse gases and their effects
- Acid rain

Activity 3

Hand held emissions monitoring units (looking at personal exposure) were designed to allow two students per night to measure pollution on their walk from and to school. The routes and times are then able to be plotted which the class would be able to analyse

Activity 4

This activity involves the use a wheel mounted unit which, for the purposes of this activity, is designed to be taken into neighbouring streets. The use of GPS data then allowed the data collected to be mapped through equipment installed in the school's ICT suite.

OPAL Outreach visits to Imperial College, London

The visits encompassed a hands-on overview of relevant scientific principles to the project including the carbon cycle and pollution.

Appendix 3

Examples of Publicity[8]

CIVITAS

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Posted: 02 Nov 10

Pupils study air quality around schools in Brighton & Hove (CIVITAS ARCHIMEDES)

Balfour Junior School is the first in the city to take part in a groundbreaking science project that involves monitoring vehicle emissions near schools. Brighton & Hove City Council has joined with Imperial College, London and Duvas technologies to run the project, which will use real evidence to improve understanding of the effects of transport activity on local air quality.

Community scientists have been working with the teachers to develop lessons and pupils have visited Imperial College and the Science Museum. Accompanying educational programmes will also help the children develop an understanding of the biodiversity in their local environment.

Data was collected during the last two weeks of Walk to School Month in October and is continuing into November. Pupils are able to look at the results in the school's IT suite and are carrying out experiments with a portable unit that they can move around the playground to see how emissions travel.

The project is providing many unique opportunities to develop pupils' interest in science, using new technology and practical data. Councillor Vanessa Brown, cabinet member for children and young people, said: "This is a wonderful opportunity for children to learn more about their environment from scientific experts and find out how science applies to their world."

The monitoring will also give the council a greater understanding of the impact of Walk to School initiatives from various perspectives; from driver habits to local air quality. Elm Grove and St Bartholomew's primary schools will be the next schools to take part in the two-year project. They will join with a national initiative that aims to create and inspire a new generation of nature lovers through learning about the environment and how to protect it.

Monitoring equipment is being provided by Duvas technologies and the project is funded by CIVITAS. The city council won £2.2 million to invest in small-scale transport projects and is the only city in the country to win European money from the CIVITAS Plus (ARCHIMEDES) Project for such schemes. Council officers are working with five other cities in Europe to share best practice, experience and skills.

The national initiative is called the OPAL project - more at www.opalexplorenature.org

Contact: Debbie Reed

Latest News

- Vitoria-Gasteiz holds cycling course for seniors (CIVITAS MODERN)
- Pupils study air quality around schools in Brighton & Hove (CIVITAS ARCHIMEDES)
- Pedometer and Walk to School Week Sticker Challenge in Brighton & Hove (CIVITAS ARCHIMEDES)
- Learning history workshops in Zagreb (CIVITAS ELAN)
- Sustainable Mobility Week mobilises citizens of Vitoria-Gasteiz (CIVITAS MODERN)
- CIVITAS Day in Brno focuses on vandalism (CIVITAS ELAN)
- Vitoria-Gasteiz named as winner of the European Green Capital Award for 2012 (CIVITAS MODERN)
- Update on Funchal's bus and bike pilot scheme (CIVITAS MIMOSA)

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[8] Clockwise from top left: CIVITAS website, generic press release (BHCC website), CIVITAS Move newsletter, Brighton & Hove City Council City News Magazine

Press release

Friday, 22 October 2010

Educational project brings the science of air quality to pupils

Balfour Junior School is the first in the city to take part in a groundbreaking science project that involves monitoring vehicle emissions near schools.

Brighton & Hove City Council has joined with Imperial College, London and Duvas technologies to run the project, which will improve understanding of the effects of transport activity on local air quality through tailored educational programmes for schools.

Community scientists have been … the teachers to develop lessons and pupils have visited … Science Museum.

… help the children develop an … ironment.

… School Month (11-29 … in the school's IT suite. … le unit that they can … vel.

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The …

Walk …

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Testing the air

Balfour Junior School is the first in the city to take part in a groundbreaking science project that involves monitoring vehicle emissions near schools.

The council is working with Imperial College, London, which will use real evidence to improve understanding of the effects of transport activity on local air quality.

Pupils are able to look at the results and carry out experiments with a portable unit that they ca… move around the playground to see how emissions travel.

The project is providing many unique opportunities to develop pupils' interest in science, using new technology and practical da…

The project is funded by the European Civitas programme.

Pictured are ten-year-old Ra… Thulborn and Nathan Cornish…

Pupils study air quality in Brighton & Hove

Brighton & Hove, UK, has launched a groundbreaking project that allows children to monitor vehicle emissions around their schools.

The CIVITAS-funded project will use local data to improve the students' understanding of the effects of transport activity on local air quality. Local scientists have been working with teachers to develop lessons in the first school taking part in the national project, which runs for two years.

Data collection started during the last two weeks of Walk to School Month, which took place at the end of 2010. Accompanying educational programmes will also help the children develop an understanding of the biodiversity in their local environment.

Pupils can examine the results in the school's IT suite and are carrying out experiments with a portable unit in the playground in order to see how emissions travel. The results will also give the council a greater understanding of the impact of Walk to School initiatives. Two more primary schools have been lined up to take part in the project.

For more information, contact Veronika Moore (veronika.moore@brighton-hove.gov.uk). Brighton & Hove is a member of the CIVITAS ARCHIMEDES consortium.

Appendix 4

A Statistical Analysis of the Dynamics of Air Pollution at Balfour Junior School, Brighton

Source: Rebecca Parrish and Mark Richards of Imperial College

Abstract

Due to the negative impacts on human and environmental health of air pollution and its close relation to traffic levels, ongoing research into the dynamics of air pollution is essential. Traffic as a source displays a highly diurnal trend which it is proved that ambient Nitrogen Dioxide (NO_2) concentration levels mimic. Meteorological factors also affect the concentration variation of atmospheric pollution, necessitating their consideration in an analysis of air pollution dynamics. A range of sensors were installed on a test site in Brighton, where ambient NO_2 levels, simultaneously with time of day, air temperature and relative humidity and wind velocity (speed plus compass bearing) were remotely monitored. It was confirmed that NO_2 levels are highly periodical, with a spike occurring at approximately 12.30pm every 24hours. An offset of 4.5 ± 2 hours was found between mid rush hour and occurrence of daily highest concentration reading. This has been attributed to time taken for oxidation of the primary traffic pollutant NO, into ambient NO_2, and the effect of air dispersion by wind. Particularly important is the direction of dispersing winds as human use of the local land varies from sources of high levels of pollution (i.e. main roads) to areas of negligible air pollution (such as parks). The direction from which wind blows has the effect of either blowing higher concentrations of pollutants into or out of the test area.

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1. Introduction

Air pollution is a problem in industrialised countries worldwide for its adverse health impacts on the population (M. Richards, 2006). In Britain, although efforts have been made to reduce the amount of air pollution given off by factories and automobiles; with some success, ambient pollution levels still are high enough to cause damage with long term exposure. (World Health Organisation, 2003) The causes of air pollution may be categorised into stationary - such as power plants and factories, local – which are smaller stationary sources such as dry cleaners, and mobile – including all automotives and natural sources (M. Richards, 2006). The combined effects of these sources are the increase in trace concentration levels of such pollutants as benzene, Oxides of Nitrogen (collectively NO_x), Sulphur Dioxide and Ozone. The problem of air pollution is so prevalent because of the detrimental impacts on human health and plant life. Long term exposure to air pollution can lead to decrease in lung capacity and increase in cases of chronic lung and heart diseases such as bronchitis and asthma (U.S. Environmental Protection Agency, 2009), and can cause damage to leaves of plants (E.J. Sikora, 2004).

A variety of factors are known to affect the concentration levels of pollutants in the troposphere. The severity of the source is a predominant factor locally. Meteorological factors can also have a large effect. Conditions such as air temperature, pressure, humidity, rainfall and wind speed and direction all can affect pollutant concentration levels. Traffic has a highly diurnal cycle in the form of a morning and afternoon rush hour and school run, based around human behavioural patterns. As the primary source of pollution within the Balfour School area, it is also highly probable that local pollutant concentration levels will follow this automotive trend. This report follows an investigation into hypothesised diurnal trends in ambient concentration levels of nitrogen dioxide and meteorological effects on the pollutant levels. In particular the following meteorological factors shall be investigated: air temperature, humidity and wind speed and direction. It shall be assumed that pressure remains constant at standard value of 1atm.

Balfour Junior School, in Brighton played host to several different types of air monitors. The main source of pollution in the area is a network of main roads located approximately 1km south of the school. Several different sensors were used, taking continuous readings and averaging every 5 minutes. A timeframe of two weeks, from the 19th October to the 2nd of November was selected, containing a good quantity of useable data.

The remainder of this report will explain the origins and elucidation of the aforementioned hypothesis; describe the process of data collection via spectroscopy, followed by a comprehensive discussion of all findings.

2. Theory

DUVAS Technologies (Differential Ultraviolet Absorption Spectroscopy) use spectroscopy at the ultraviolet band width to discern the number density and identity of particles within a small volume of air contained within the air monitor.

2.1 Derivative Absorption Spectroscopy (UV/VIS)

Molecular Absorption spectroscopy is a powerful analytical tool, allowing accurate diagnosis of a gas sample to determine the constituent molecules and their abundances. Using light in the UV and visible parts of the spectrum, of wavelength between 190nm and 1000nm, absorbing molecules will emit UV/VIS spectra (Laqua, 1988).

A molecule in its ground state will have an internal energy as shown in Equation 1:

$$E_{int} = E_{el} + E_{vib} + E_{rot}$$ **Equation 1**

Where E_{el} is the electronic or translational energy, E_{vib} is the vibrational Energy and E_{rot} is the rotational energy. The absorption of a photon of wavelength and energy determined by 2 results in a vibronic transition i.e. particular electronic plus vibrational transition and corresponds to an absorption band consisting of rotational lines (ANDOR technology, 2011).

$$E = \frac{hc}{\lambda}$$ **Equation 2**

Calculation of the concentration of a known analyte may be done using the Beer-Lambert-Bouguer law as shown in Equation 3.

$$A = -\log_{10}\frac{I_t}{I_0} = -\log_{10} t_i = -\varepsilon c d$$ **Equation 3**

Where A is the Absorbance, I_t is the monochromatic radiant power incident on the medium, I_0 is the power transmitted by the absorbing medium, τ_i is the transmittance (= $\frac{i_t}{i_0}$), ε is the molar (decadic) absorption coefficient, c is the amount concentration and b is the absorption path length. The Beer-Lambert-Bouguer law will only hold if the medium is uniform and the absorbing species behave independently of each other.

Derivative spectroscopy can improve the detection of sharp bands in a broad background, or a narrow shoulder on a broad main band. Gradual changes in background flux - as is inevitable within a dynamic system such as the atmosphere, may be less pronounced using derivative spectroscopy (Laqua, 1988).

Derivative spectra may be found via the digital differentiation of the radiation entering the sample. The first two orders of differentiation of absorbance in terms of spectral wavelength are:

$$\frac{dA(v)}{dv} = \left(-\lambda^2\right)\frac{dA(\lambda)}{d\lambda}$$ **Equation 4**

$$\frac{d^2A(v)}{dv^2} = \left(-\lambda^4\right)\frac{d^2A(\lambda)}{d\lambda^2} + 2\lambda^3\frac{dA(\lambda)}{d\lambda}$$ **Equation 5**

All DUVAS air monitors operate using these principles, and are capable of calculating concentration of several analytes within a complex system. For this study into the dynamics of ambient air pollution, the continuous detection of varying NO_2 concentrations is vital.

Example of a Spectrum from a Mixed Crystal, derived using Absorption Spectroscopy

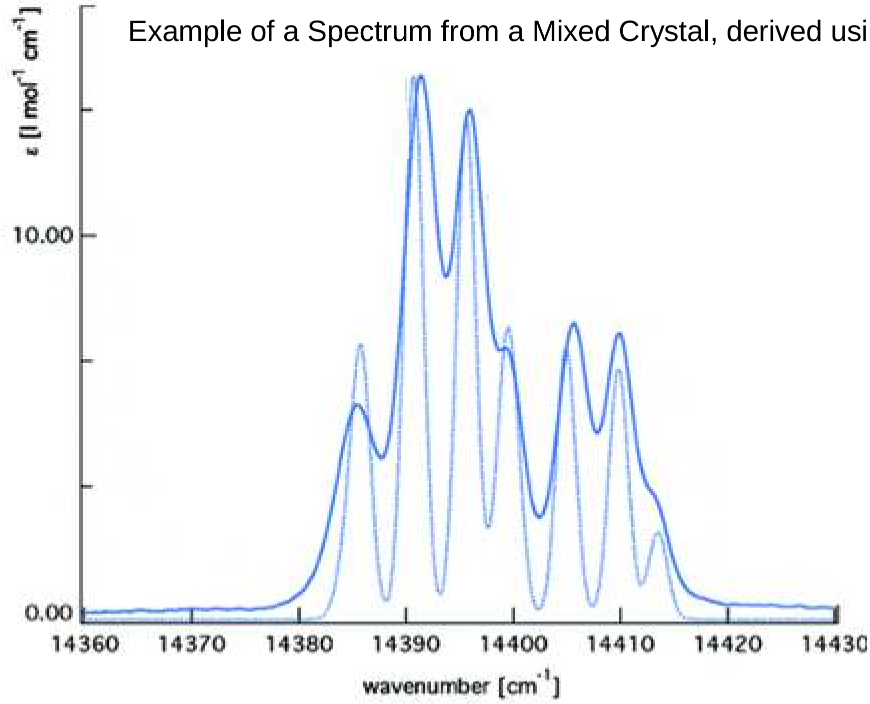

Figure 1: An example of an absorption spectrum. The 'dips' in the darker blue line shows absorption of light of the associated wavenumbers. The analyte responsible can be looked up and its concentration found using the Beer-Lambert law. This particular Spectrum demonstrates the presence of Zn, Ru and $NaCr(ox)_3$. (M. Milos, 2010)

2.2 Hypotheses

2.2.1 Diurnal Trends

It is well known that internal combustion engines within motor vehicles are emitters of, amongst others, NO, which is created by the reaction of N_2 and O in the heated air within the engine. Due to heavy dependence of people on the roads as a method of transport to and from work, there is a vast increase in road traffic between the approximate hours of 0600 and 1000 each day. It is expected therefore that roadside NO concentration levels at these times will be greatly increased as a direct effect of the 'morning rush hour' and the 'school run'. It is also suspected that this effect will cause an increase in ambient levels of NO_2, with an appropriate time lag. NO quickly oxidizes in air to form NO_2 as shown in

$$2NO + O_2 \rightarrow 2NO_2 + O_2 \qquad \text{Equation 6}$$

Therefore, by the time pollutants from car exhausts disperse and become background or ambient pollution, the majority of the NO will have converted into NO_2, which is what the DUVAS monitors set up at the school shall monitor. If a diurnal trend resembling that of traffic can be detected then it can be inferred that traffic is a big impact on permanent, ambient pollution levels. The extent of this factor will provide valuable knowledge on road traffic pollution, its effect on our environment, health and the importance of its continued monitoring and consideration in government legislation.

Furthermore, if indeed there is a strong relation between daily traffic variation and specific pollutant levels, it is reasonable to extrapolate from that hypothesis, that there may exist weekly, seasonal and annual trends. It is beyond the timeframe of this project to be able to investigate season variation in atmospheric pollution. It can be hypothesized that during the weekend, pollutant levels will continue to emulate traffic levels, but that due to different traffic behavior caused by considerably altered social routines, there will not be a morning spike (previously attributed to morning rush hour traffic) but that the all day, average concentration will be increased.

2.2.2 Meteorological Effects

Temperature

Dispersion

Meteorological factors are known to affect the concentration levels of gases in the air and indeed the density of air itself. An obvious contributor to air density and hence concentration variation is temperature. With increased temperature, particle velocity increases and hence density decreases. However, atmospheric temperature changes are only in the range of a few degrees, and so this effect will be extremely negligible in atmospheric conditions, as will the impact of cross winds that atmospheric temperature gradients can create.

Pollution Chemistry

A more prominent effect of temperature will be a change in the rate of reaction of the volatile NO_x and the ratio of NO to NO_2 in the atmosphere. NO_2 emissions in the United Kingdom are 34 parts per billion (ppb) per annum (NationMaster, 2003). Road traffic is the primary pollution source in the area under investigation. Automotive Internal Combustion Engine produce large quantities of NO (amongst other particulates) Since NO is less stable than other oxides of nitrogen such as NO_2, it quickly reacts with oxygen in the air to form this, in accordance with Equation 6.The hotter the air in which the NO is present, the faster the rate of the reaction.

The NO to NO_2 ratio constantly alters. Higher temperatures cause a larger amount of successful collisions of air particles (in this case, NO with O_2). However, the more NO that is oxidised, the lower the concentration and hence the less collisions there are. Arrhenius equation defined the temperature dependency of reaction rate coefficient (k):

$$k = Ae^{\frac{-E_a}{RT}} \qquad \textbf{Equation 7}$$

Where E_a is the activation energy, R is the universal gas constant, T is temperature and A is a constant known as the frequency factor. The Rate of Reaction (*r*) is proportional to *k*(T) [shown in Equation 10] and from Equation 7 it is expected that an increase in temperature will therefore cause an increase in reaction rate.

Due to this effect, it is possible for temperature to have significant effect on reaction rate. A typical value of E_a (assuming a homogeneous solution) is of order of magnitude, 10 kcal/mol. This corresponds to a rough reaction rate increase of a factor of 2 to 3 for each 10°C rise in temperature (Connors, 1990). This is the maximum temperature variation that we are likely to see within this experiment.

$$r = k(T)[A]^{n'}[B]^{m'}$$ Equation 8

Where $k(T)$ is the reaction coefficient, A and B chemicals reactants and n' and m' are the derivatives of the stoichiometric quantities of A and B respectively.

Table 1 demonstrates the exponential decay of NO into NO_2 in standard atmospheric conditions (273K, 100kPa). In the elevated heat and pressure of a car engine, this rate is greatly increased. The table demonstrates the high reactivity of NO and the small amount of time it takes for even low concentrations to oxidize. Increasing temperature will serve to increase the rate of this reaction.

Table 1: shows the decay of NO into NO_2 with time, at fixed temperature. (Branch Environmental Corporation)

NO concentration in air [ppb]	Time required for half NO to be oxidized to NO_2 [seconds]
200 000	0.00105
20 000	0.0105
2 000	0.105
200	1.05
20	10.5

This table shows the likelihood of a small lag time between traffic emissions of NO, and a registered increase in NO_2 concentrations. Added to this lag time will be the effect of air dispersion (see below).

Humidity

Relative humidity is a measure of how much H_2O is mixed within in the air, as a percentage of total possible water containment at a fixed temperature. 100% relative humidity means the air is completely saturated for that temperature. As temperature decreases, though total volume of water present remains constant, the amount of water particles that the less energetic air particles are able to suspend in the air decreases, and hence the relative humidity is increased. Precipitation is expected to affect concentration levels as NO_2 can be dissolved in water to form acid rain, and so each time it rains, concentration levels dip as pollutants are washed out of the air. However, the short time period of this project and inadequate amounts of rainfall means that an analysis of correlation between rainfall and concentration levels will not yield reliable results and so shall not be investigated.

Since it is known that temperature levels increase throughout the first half of the day, and then decrease through the evening and night, it is logical to expect humidity to show an inverse trend to this. The suspected effect that this change will have on NO_x levels is that the less humid the air, the more highly concentrated the suspect pollutants shall be. This is because dry air has a higher density than moist air at a constant dry bulb temperature.

A further effect of the presence of H_2O will be the dissolving of NO_2 to form Nitric acid (Acid Rain). This would have the effect of decreasing the concentration levels. However, this is a relatively slow and gradual process which would have the result of overall diminishment of concentration levels and it is not expected that a pattern shall be detected within this investigation.

2.2.2.3 Wind Velocity

The final meteorological factor that shall be investigated is a combination of wind speed and direction. A simple, negative linear relationship is expected between concentration levels and wind speed since the faster the wind blows the more pollutants shall be dispersed. It will be interesting to observe the effect of wind direction on concentration levels since depending on from where the wind blows, air containing higher concentration levels may be blown into the area, from the main road -where busier traffic levels will undoubtedly increase the levels of pollutants within the air, or the contrary may happen and wind direction will cause less polluted air to be blown into the area, perhaps from across the nearby park.

Wind is one of the main factors involved in air dispersion. Equations to predict concentration levels due to air dispersion for roadside traffic and plume pollution has been ongoing since the 1930s when a Gaussian plume dispersion equation was derived by Bosanquent and Pearson. (Beychok, 2005) Eventually, ESL (Electromagnetic Systems Laboratory) manipulated this to form an equation applicable to a infinite line source, which can be used to approximate a road and is shown in Equation 9:

$$\chi = \int_0^{\infty} \frac{q}{\pi(udcx^2)(\cos\alpha)}\left(exp\frac{y^2}{2c^2x^2}\right)dx \qquad \text{Equation 9}$$

where χ is the concentration of particulate [g/m^3], q is the source pollution emission rate (g/s), x is the distance from the observer to the roadway, y is the height of the observer, u is the mean wind speed, α is the angle of tilt of the line source relative to the reference frame, c is the standard deviation of the horizontal wind direction [radians] and d is the standard deviation of vertical wind direction [radians].

Equation 11 shows how wind velocity (u) will have an inverse relation to concentration level, as the higher the winds, the more they disperse pollutants within the air. An inverse square law relating concentration to distance from the linear source is also evident, as expected. Integration along the line of the road is necessary as part of the application of a Gaussian model for a point source, to fit a linear model to which roads are approximated.

3. Experiment

It was in partnership with Imperial College London and supported by Brighton City Council that DUVAS was able to run *The Brighton Emissions Project*. Working with Balfour Junior School as a joint research and education project, DUVAS have implemented several different monitors in and around the school for data collection. Each monitor collects and archives data online, which can be remotely accessed for analysis. Figure 2shows the layout of the sensors set-up.

3.1 The Sensors

OP2 is an open path sensor made up of a main unit, which is the transceiver, and across the road is the Retro-reflector, which is made up of two aluminium oxide (Al_2O_3) parabolic mirrors. UV rays are transmitted out of unit one, across the road and into unit 2, where they are reflected back. It is through this gap that cars travel, emitting trace gases, including NO and NO_2, the concentration of which OP2 measures.
The unit 006 is a differential UV absorption spectroscope which is fixed onto the roof of the main school building.
The weather station unit consists of a variety of instruments, including a thermometer, anemometer and humidity sensor. This allows data collection of the meteorological factors under investigation including air temperature (℃); Relative humidity (%); wind speed (km/h) and wind direction (displayed as a compass direction). Relationships can be discerned by correlating concentration levels detected by 006, with one or more weather factors using the data collected by the weather station.
004 is very similar to 006 but to aid scientific research into air pollution, was designed to be portable. This means it could be easily transported along the roadside and to other major roads in the area so that further investigation into the relationship between concentration levels and distance from the roadside can be carried out.
Each of the DUVAS air monitors is capable of measuring Nitrogen Monoxide, Nitrogen Dioxide and Sulphur Dioxide. Sulphur Dioxide levels in the atmosphere are negligible and not in the scope of this project to be investigated. Nitrogen Monoxide bears close relation to Nitrogen Dioxide. Both NO and NO_2 constantly undergo reaction within the atmosphere, maintaining an equilibrium and so it is important to consider this when carrying out analysis on affecting factors on air pollution. As NO_2 is the more stable of the two Nitrogen Oxides under discussion, it is this pollutant which demonstrated massive variation and shall be looked at in further detail in the Results section of this project.

3.2 Deployment and data collection

Each of the three air monitors; OP2, 006 and the weather station were deployed in suitable locations, as shown in Figure 2. From this point it was intended that all data necessary for analysis could be accessed remotely and minimal equipment handling would be necessary for these stations. Both 006 and OP2 unfortunately experienced several technical setbacks, as is unavoidably the case with practical experiments and collecting of real data, particularly using new technology and deployment strategies. This involved several trips to Brighton to investigate and tend to the problems.
Slight calibration errors occurred with all of the pollution monitors. However, they caused little problem and the errors could be easily overcome by assuming a slight offset.

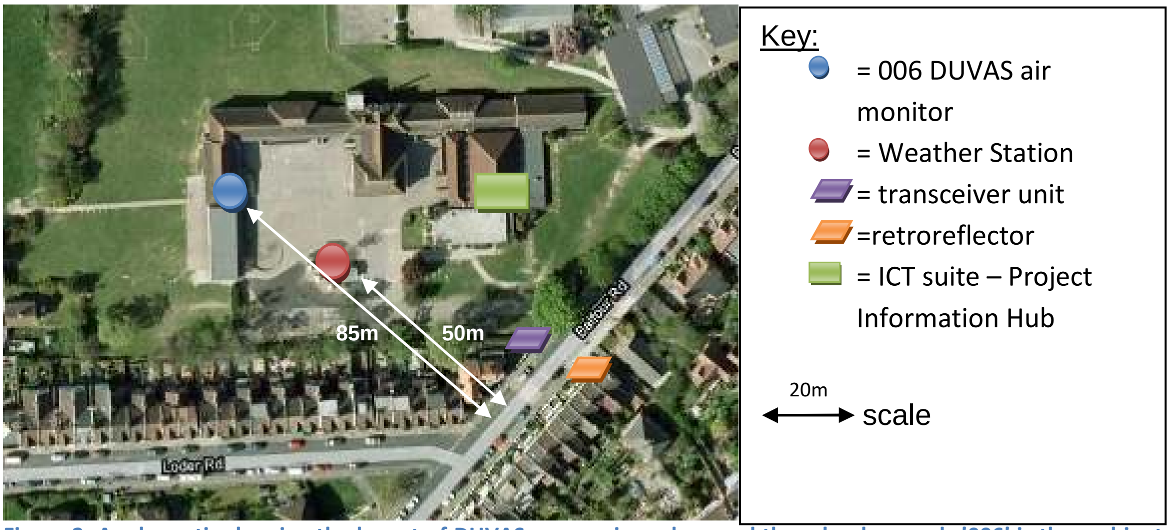

Figure 2: A schematic showing the layout of DUVAS sensors in and around the school grounds.'006' is the ambient sampling point on the roof, with accompanying weather station. 'OP2' is made up of the retroreflector and transceiver unit, monitoring vehicle emissions per car, as they drive past. Image from Google Maps: http://maps.google.co.uk/

Figure 3: shows Balfour School (marked A) and the surrounding area. To the south and south east is a network of A roads which will be a large source of local pollution, especially as a result of the morning rush hour. To the North are suburbs, villages and less busy roads. Image from Google Maps: http://maps.google.co.uk/

4. Results

4.1 Diurnal Variations in NO_2 concentration levels

The first aspect of air pollution variation was an investigation into diurnal changes. Figure 4 shows the time variation of the concentration readings of NO_2 from 006. This is a line graph joining the 5minute averages taken at the time of extracting the data from the DUVAS website (DUVAS technologies). From Figure 4 a daily trend is clear in the form of a midmorning spike –between the hours of 0930 and 1200 almost every day in the sample.

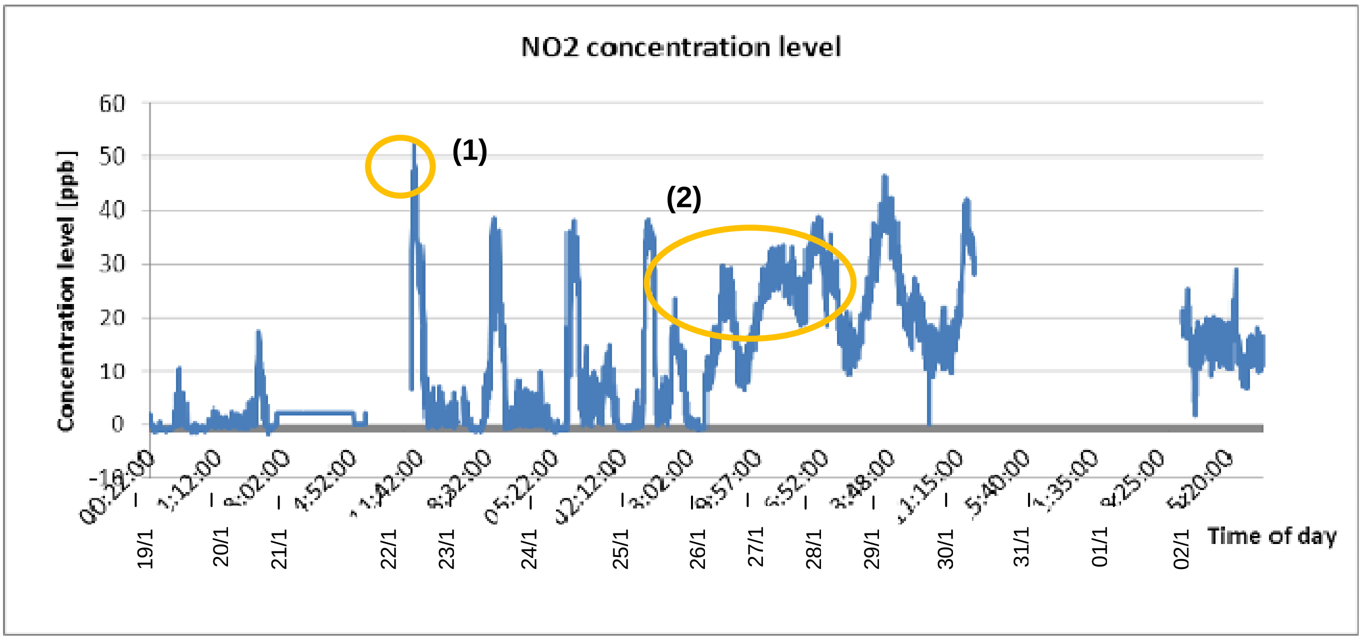

Figure 4: shows a plot of NO_2 concentration as a function of time. Gaps in the data are evident and due to the 006 air monitor being non-operational at these times. The vertical dates on the horizontal axis align closely with midnight at the start of the specified day. The irregular spacing is due to a difference in the number of readings being taken by 006 on each day, caused by small malfunctions.

The first notable fact is the apparent offset of this data. This is a systematic error most likely due to a slight miscalibration of the air monitors. It will not affect the trends observed but creates uncertainty in all absolute values. As an estimation of this systematic error, the lowest reading taken by 006 (which is below zero and clearly not accurate) may be added as an additional error onto all readings. This systematic error holds the value of,

σ_s = 1.8ppb

Highlighted are certain interesting features due to the unexpected shape of the data curve: (1) demonstrates an unusually high spike in concentration levels (of a reading of χ=52 ± 1.8 ppb) and (2) shows particularly noisy data and less pronounced spikes than expected. These points shall be investigated in more detail further on in the results (please refer to Figures 13 and 15 respectively). Between the dates of 22nd and 26th there can be seen a well formed, oscillating graph with period of approximately 24hours. Between 26th and 29th a daily peak can still be detected but the data has a smaller range than other daily spikes. To investigate this further and prove whether there is a discernable daily trend in the form of a mid-morning peak, a Fourier Transform shall be carried out on the days for which a complete data set was available, 22nd-29th.

Fourier analysis can be used to understand how a physical system such as the atmosphere will respond to a complex stimulus. By breaking down the stimulus into a superposition of its constituents and consider each constituent separately, then a better understanding of the system can be achieved.
A Discrete Time Fourier Transform as shown in Equation 4 is appropriate for this time varying data sample,

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-2\pi ft}\,dt \qquad \text{Equation 10}$$

Where X(*f*) = the transformation of the original signal, *x*(*t*), into the frequency domain.

$f = \frac{1}{T}\,[s^{-1}]$ where T is the sample interval [s]

t = specific point in time

A full calculation of the Fourier Transform was not possible without computer modeling, however an analytical calculation of the sum of each discrete data cell within the timeframe (22nd-29th) was carried out and the results summarized in Figure 5.

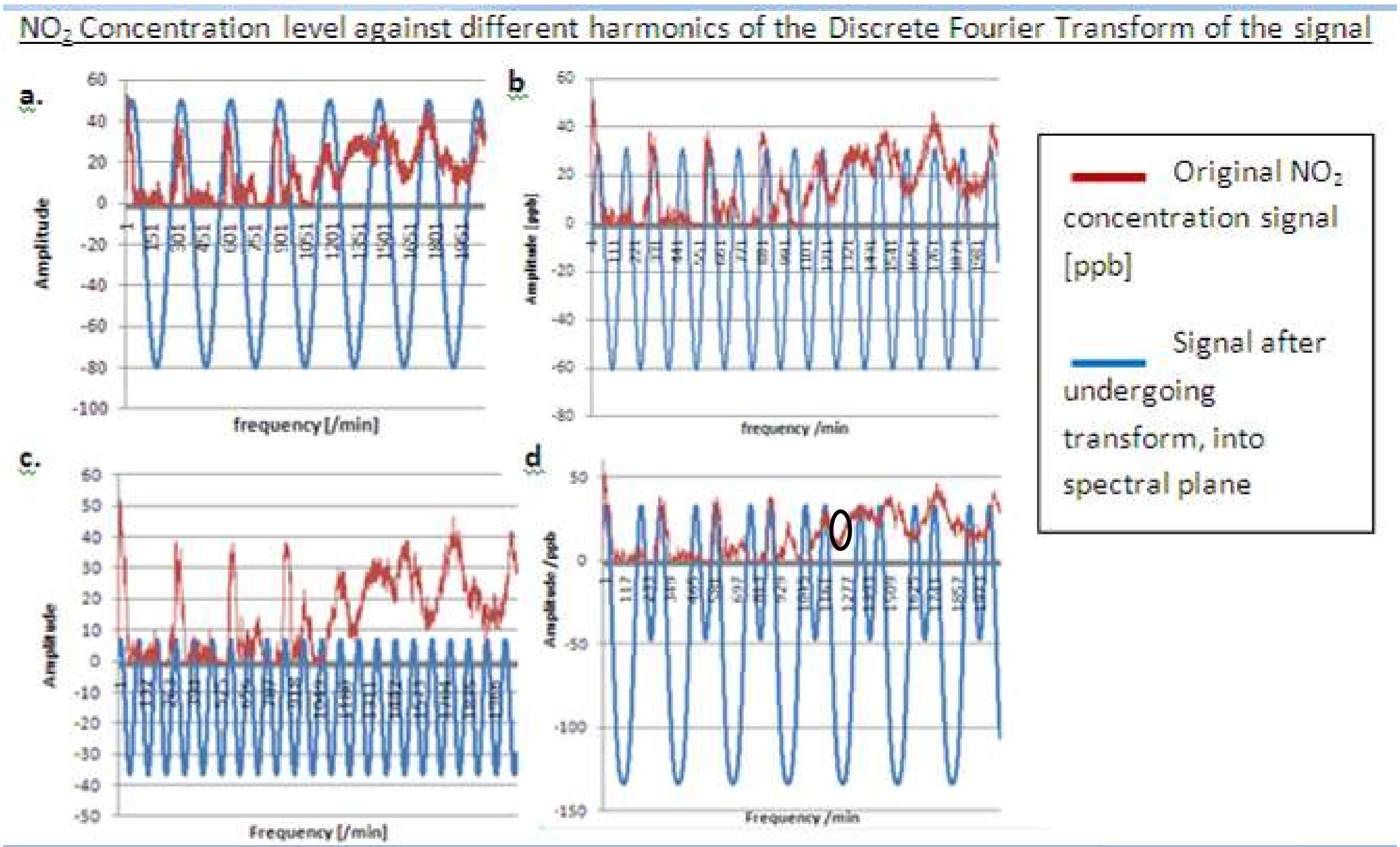

Figure 5: shows the time varying signal of NO_2 variation plotted with its Fourier Transform. Figure 5a. is the fundamental mode of the transform, where the frequency is one 24hour period. 5b. and 5c. are the first and second harmonics respectively. Figure 5d. shows the superposition of all the harmonics.

A Fourier Transform is an excellent way to determine the existence and frequency of a periodic trend, as can be proved by observing the alignment of the NO_2 signal peaks, with the peaks of the transformed trigonometric function. Figure 5.d shows the reconstructed signal from the Fourier Components and it can be seen to almost perfectly match the original signal in periodicity and amplitude. Noise from the original signal however cannot be treated using Fourier analysis. This is evident in the circled point on graph 5.d. This is point (2) of interest to be further investigated in as it has been shown not to follow the trend.

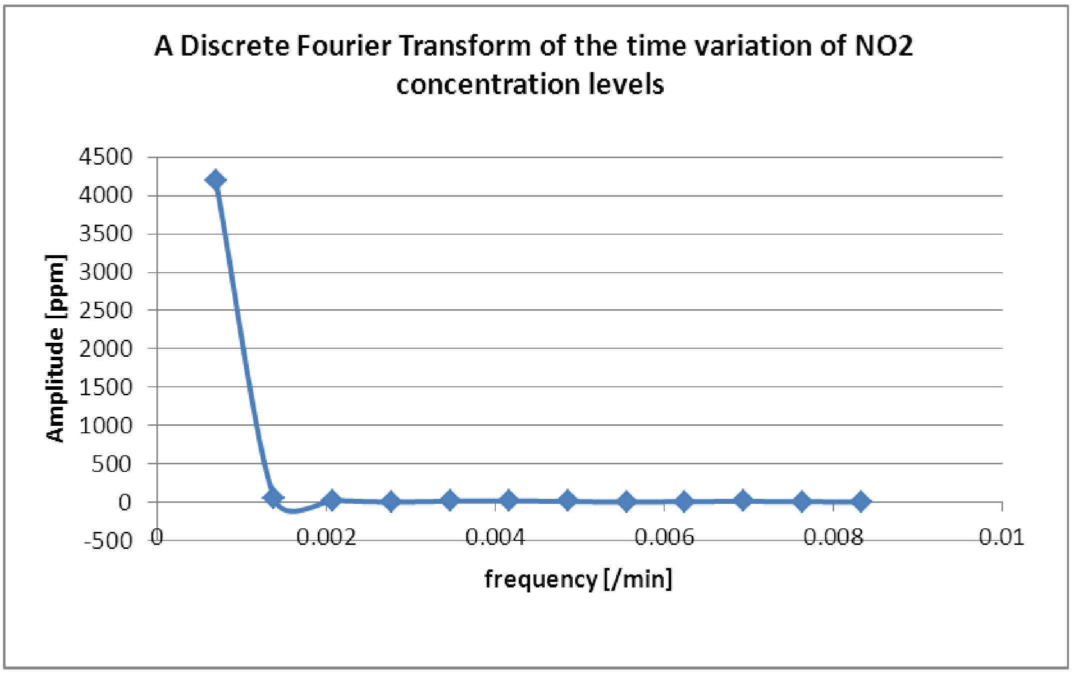

Figure 6: shows the Fourier Transform for the first 12 harmonics with a range of frequencies from once per 24hour, to once per hour.

Taking the fundamental mode of the Transform, the argument of X(*f*) was found to be

Φ= 0.80rads (see appendix 1 for calculation).

Dividing this value by 2π and multiplying by 24hours gave the time from which the sample started, at which the peak of the transform occurs. This value was 3h2m. The Fourier sample was begun at 09:32 on October 22nd, meaning that the Fourier Analysis found the average peak time to be at approximately 12:30pm each day.

It should be noted the amplitudes of the harmonics shown in Figure 6 are not of zero value, but are negligible in comparison to the amplitude of the fundamental. This shows that only a 24hour period is able to show any significant repeating trend. In other words, there is a strong daily trend in the form of a concentration spike occurring at an average time of 12:30pm, and no other daily trends have been observed. As production of the pollutant occurs as a result of increased emission levels of NO at rush hour, 0600-1000, the average observed time delay in which NO is oxidized to NO_2 and transported from the roadside to the Balfour site, is

$$t = 12.5 - \frac{6+10}{2} = (4.5 \pm 2)\text{hours}$$

Where an error of 2 hours was found by halving the range of hours during which rush hour occurs.

Referring back to Figure 4 however, the concentration spike on the morning of the 20th occurs at 0952, which is outside of the acceptable error range of the time delay. To investigate reasons for this, a graph of atmospheric conditions on that day was plotted as shown in Figure 7 below.

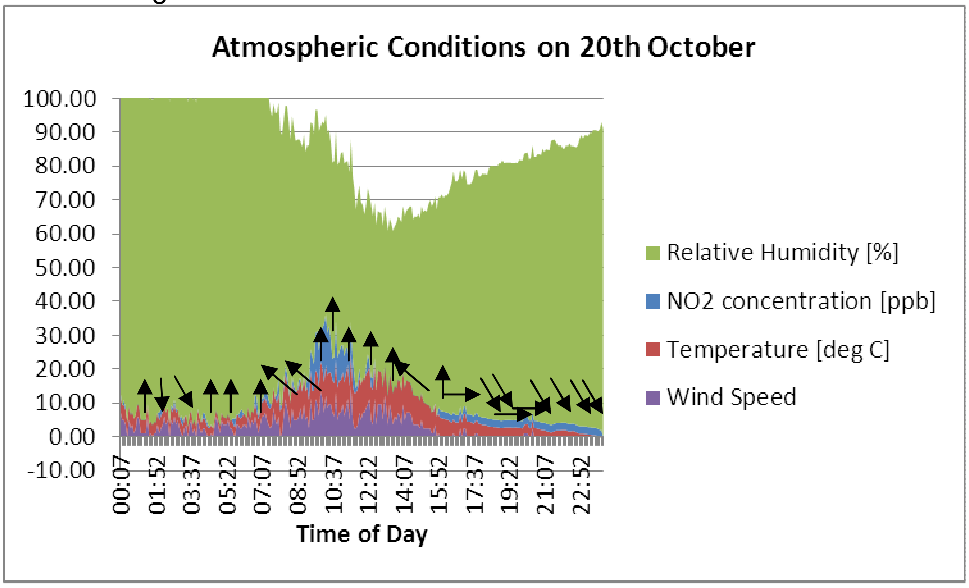

Figure 7: shows the uncharacteristically early NO_2 spike which peaks at occurring at 0957(at 13ppb). Plotted also are the monitored atmospheric conditions that day. The arrows represent the two-dimension wind direction vectors calculated by taking the modal direction per hour.

Interestingly, the meteorological factors plotted show little of interest to suggest them accountable for the premature NO_2 spike observed. Temperature appears to be consistently low, though this alone could not explain the time at which concentration levels peaked. Both humidity and wind speed are within the acceptable error bars of the average and hence suggest little to explain the observed phenomenon on this day. The only suspect factor is the consistent South and South-Easterly wind direction leading up to and at the time of the spike, which would blow pollution into the area from the A roads seen in Figure 3. The unfaltering wind direction may have a larger impact on an increase in pollutants in the area since the average wind speed before 0957 was not excessive as shown in the table below:

Table 2: shows a comparison between the atmospheric conditions on the morning of 20th October, compared to the average morning concentrations throughout the investigated time frame. Temperature appears uncharacteristically low, but all other meteorological factors are within the average error bar of the entire sample.

	Temperature [℃]	Humidity [%]	Wind Speed [km/h]
Average before 0957 on 20th	4.5 ± 2.0	91.0 ± 10.0	3.8 ± 2.6
Average before 0957 for 19th Oct – 2nd Nov	9.2 ± 3.2	84.0 ± 14.0	4.3 ± 4.7

From Figure 4 it is not possible to detect any kind of weekly trend. The data set is too short to be able to detect trends with a weekly periodicity. Unlike the hypothesised scenario, the graph shows no differentiation between weekday and weekend results. In fact, the circled point indicating the highest morning spike occurs not at weekday rush hour, but on a Saturday.

4.2 Meteorological investigation

4.2.1 Contribution of temperature variation on concentration level fluctuation

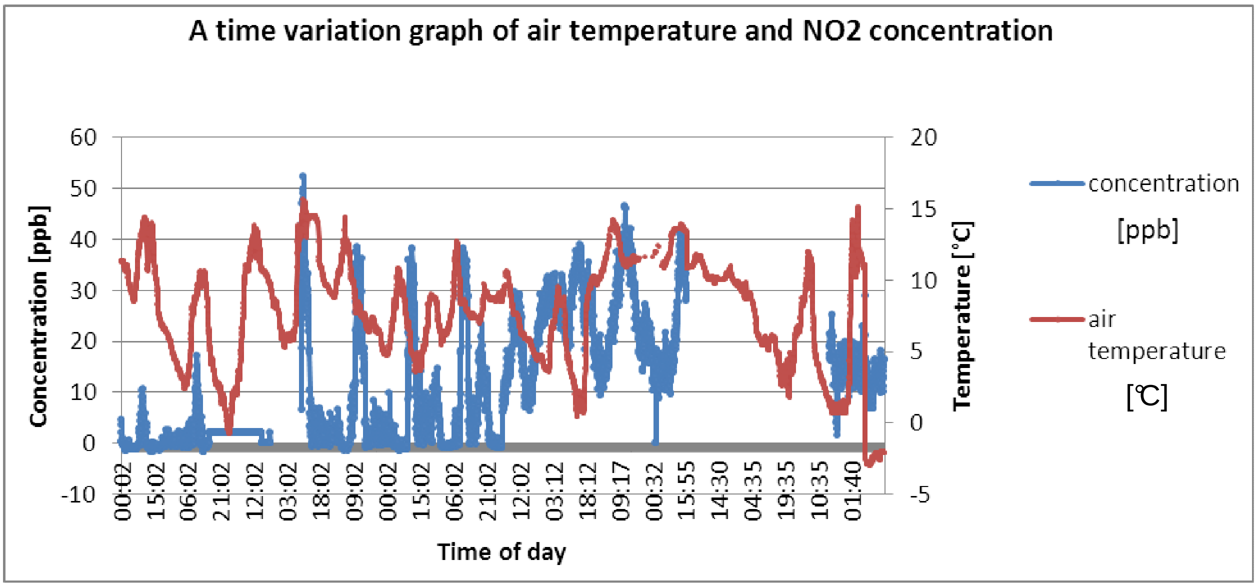

Figure 8: Time variation of NO_2 concentration and of air temperature.

Through analysis of Figure 8 it appears as though each spike in concentration is preceded by a spike in temperature. This follows from the argument that rises in temperature lead to an increase in the rate of reaction and hence an increase in the quantity of NO_2 in the air according to Equation 6. However, Figure 9 below shows very little correlation between the times at which the peak of each variable occurs. The linear regression of the graph in Figure 9 was found to be,

$R^2 = 0.0232$,

Proving little correlation to exist.

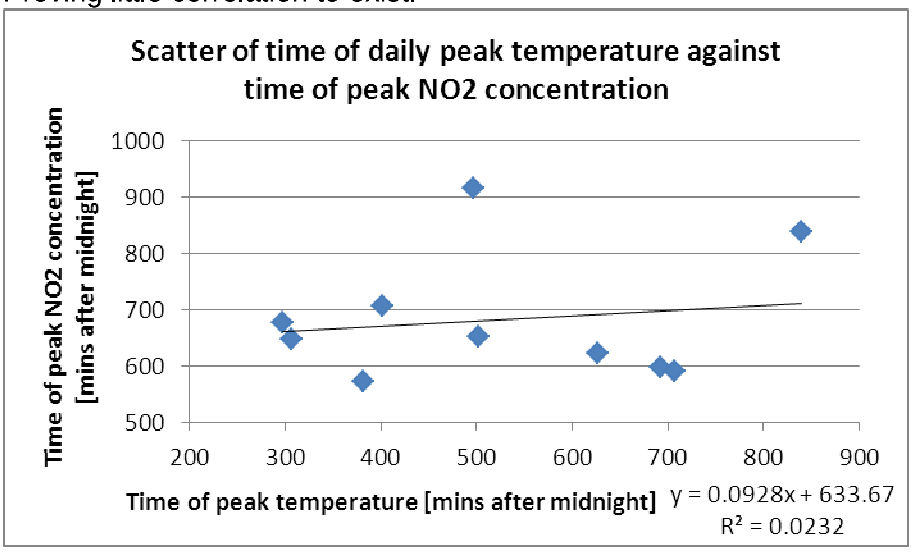

Figure 9: shows extremely low correlation between the time at which NO_2 concentrations are highest, and the time at which air temperature peaks each day.

4.2.2. Contribution of Humidity variation on concentration level fluctuation

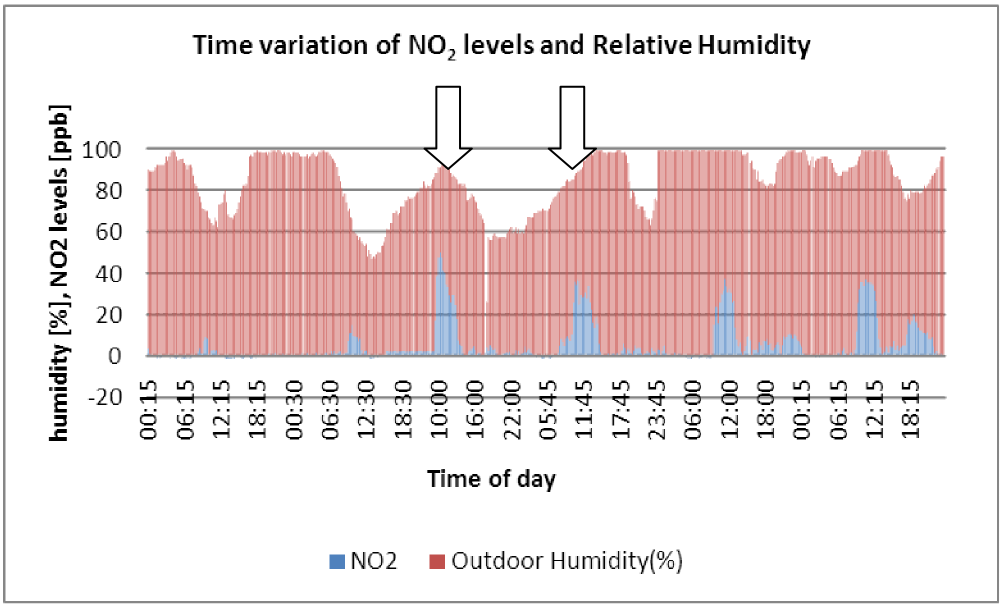

Figure 10: a graph to allow direct comparison between daily NO_2 concentration levels variation alongside daily humidity variation.

Marked with arrows in Figure 10 are a couple of examples of alignment of climaxing humidity and NO_2 concentration levels. However, this is an unconvincing argument to suggest a positive relationship since there are multiple points at which humidity alters considerably without a consequential alteration in NO_2 levels. A low correlation coefficient of $R^2 = 0.0004 \approx 0$ as shown by construction of Figure 11 backs this finding.

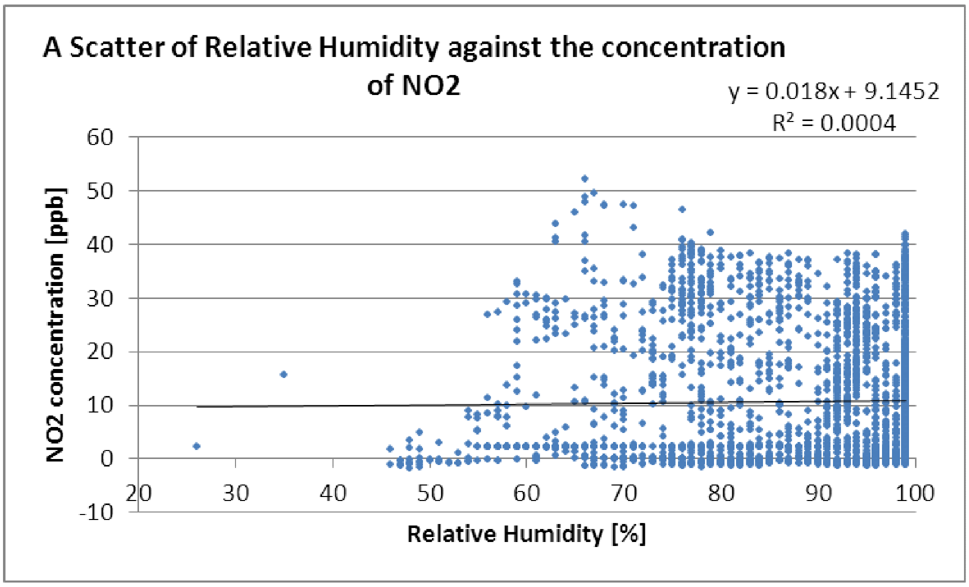

Figure 11: demonstrates very little relation between humidity and concentration levels. Vague vertical lines can be discerned because the humidity often is seen to remain at a certain percentage for a relatively long period of time, whilst the pollutant concentration may vary. This further shows low correlation between the two factors.

4.2.3 Wind velocity

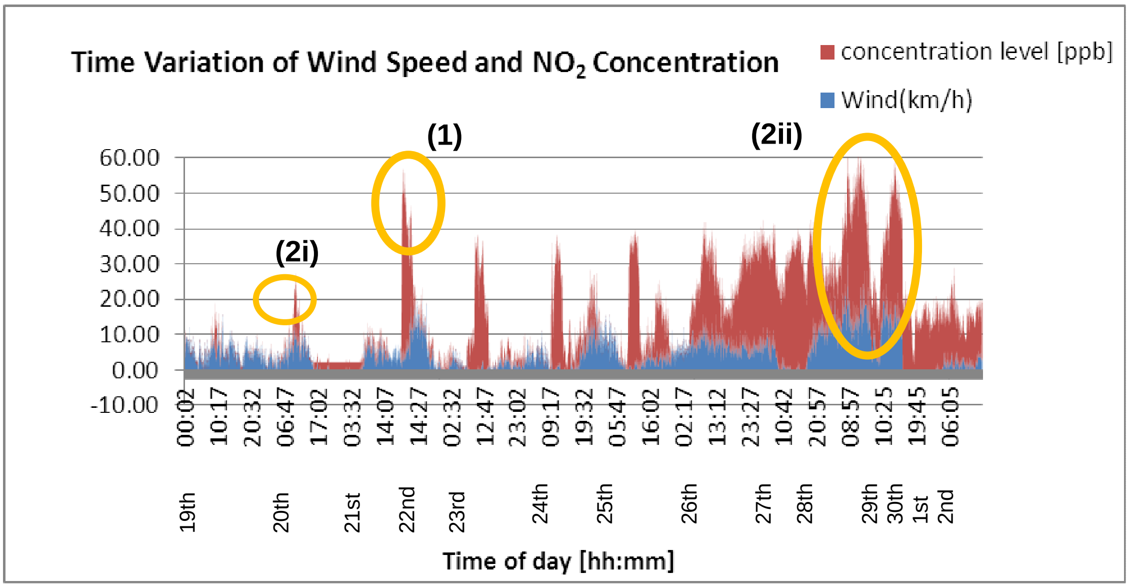

Figure 12 shows the progression of both wind speed and NO_2 concentration levels over time.

Figure 12 can be used to observe the effect that wind speed has on concentration levels. At points on the graph, a possible good relationship can be detected. By studying the points (2i) and (2ii) the crests of the wind plot align with those of the concentration plot, suggesting that increased wind speed increases concentration levels. This effect is of course also highly dependent upon the direction from which the wind blows. Even a strong breeze blowing from across green fields will have less bearing on concentration level than a medium breeze blowing directly from high congestion. The next plot therefore shows data for 22^{nd} Oct {point (1)} in more detail, displaying also the wind direction as a 2-Dimensional vector. Referring back to Figure 4, this is point (1) of interest for the large magnitude of the concentration spike. As shown in Figure 13, the wind speed is low and so dispersion shall be at a minimum, however the prevailing wind at the time the spike forms is South Easterly, transporting pollutants to the site from the main road (see Figure 3 for map). Wind speed grows later in the afternoon simultaneous to a reduction in NO_2 levels to near zero. This lends to the argument that wind velocity is pivotal in air dispersion. The average wind speed for the experiment was (3.93 ± 1.54) km/h. The network of A-roads is approximately 1km away, and so at this wind speed, it would take only 15 minutes to transport any pollutants emitted by relatively high levels of traffic to the site. Comparing with data in Table 1, in this time even small concentrations of NO traffic emissions could be oxidized.

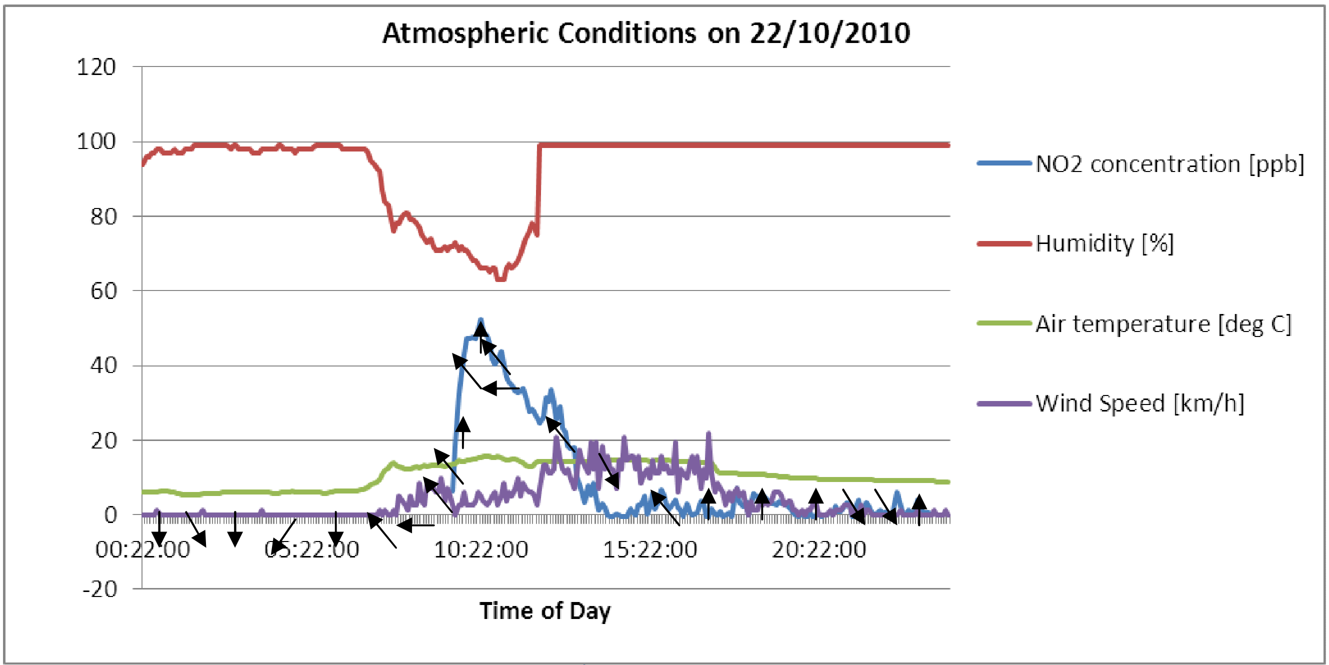

Figure 13: shows in detail the trend of the data on the 22nd October. Included are 2-Dimension vectors representing the variation in wind direction calculated using the modal wind direction per hour. See below for key.

Table 3: Key to Wind Vectors

↓ Northerly wind	↖ South Easterly wind
↘ North Westerly wind	↑ Southerly wind
↙ North Easterly wind	← Easterly wind

4.3 Combining factors

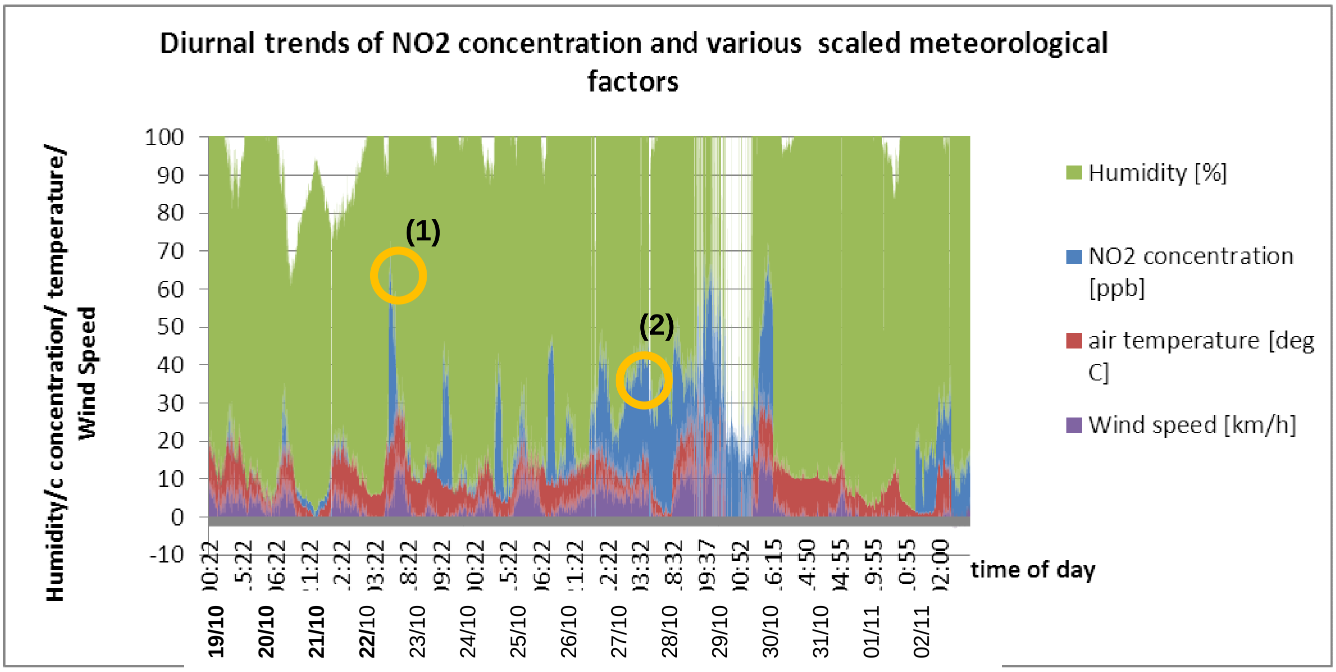

Figure 14: A culmination of all Atmospheric Conditions under investigation for the duration of the experiment.

Figure 14 shows all the monitored atmospheric conditions on one set of axes. It can be seen that the spikes in concentration level, humidity and temperature roughly align in most cases. Circled once more are the points of interest. (1) is shown in Figure 13 and (2) is plotted below.

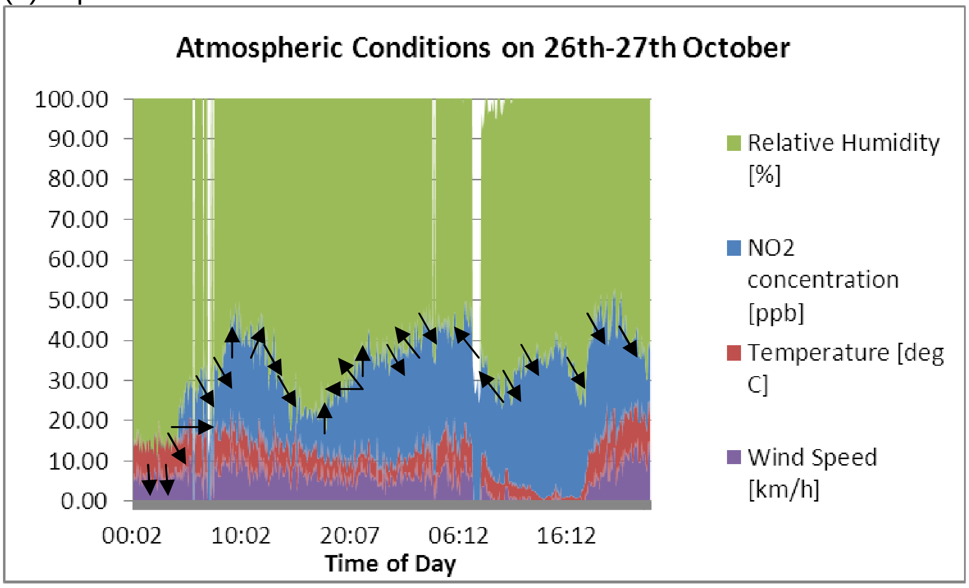

Figure 15: shows atmospheric conditions including two-dimensional, modal wind direction (plotted using the modal direction each hour) for the 48hour period of the 26th=27th October. See Table 3 for key to wind vector.

Unlike Figure 13, the prevailing wind for this extract is a North-Westerly wind which blows over suburbs and parks, with minimal busy roads. This may help to explain the less defined peaks than was observed in Figure 13. With a lower quantity of pollution being blown into the vicinity coupled with relatively steady wind speed, the pollutant levels will not be increased by gaseous transportation from other areas. The average wind during this period is (7.07 ± 2.55) km/h which is much higher than the entire sample average of (3.93 ± 1.54) km/h. Considering Equation 11, which shows concentration to be inversely proportional to wind speed, the high winds observed here will cause increased dispersion by a factor of:

$F = \frac{7.07}{3.93}$

$\sigma_f = \pm \left(\frac{1.54}{3.93}\right)^2 + \left(\frac{2.55}{7.07}\right)^2$

$\rightarrow F = 1.80 \pm 0.28$

This significant increase in dispersion may be accountable for the less pronouncement concentration spike. This appears to be likely when the other atmospheric conditions are examined and seen to vary little: humidity remains almost constant at 100% for both days, whilst temperature and humidity varies minimally.

5. Conclusions

It was firstly established that there existed a cyclic pattern in ambient NO_2 concentration levels. Analysis of a graph of concentration against time, as shown in Figure 4 shows the periodic presence of a large spike in pollutant concentration. These increased levels originated as Nitrogen Monoxide (NO) emitted in larger quantities from the exhausts of cars in the morning rush hour through reaction of abundant Nitrogen (N_2) and oxygen (O_2) within the increased heat and pressure of automotive internal combustion engines. Through air dispersion, the trace gases from the roads were transported to within the detection zone of the experimental monitors. During this lag time, through reaction with O_2 in normal atmospheric condition, the NO was oxidised to form NO_2 and became an ambient air pollutant.

A Fourier Analysis was carried out on these readings which confirmed the existence of a daily cycle with a period of twenty-four hours. A higher frequency trend was not detected (as shown by the negligible amplitudes of the harmonics of the Transform, demonstrated in Figure 6). Furthermore, the analyse revealed that the peak NO_2 concentration was detected on average, at 1230pm each day. Since rush hour typically spans between 0600 and 1000 it can be estimated that the lag time is (4.5 ± 2) hours.

Figure 9 shows only a correlation of 0.02032 between peak temperature occurrence and peak concentration level occurrence. In other words, the time at which temperature reaches its highest during the day bares very little relation to the time at which concentration readings will be at their highest. Similarly, Figure 11 demonstrates the lack of correlation between Humidity and concentration level with a correlation coefficient of only 0.0004. A drop in humidity levels does not coincide with a diminishment of NO_2 nor does a spike correspond to elevated NO_2 readings. Though this cannot confirm the hypotheses made about the suspected impact of increasing temperature on the rate of production of NO_2, it does not disprove the theory. A more in depth investigation into NO and NO_2 readings is recommended to better understand this relationship. Concerning humidity, there also appears to be little evidence to support the hypothesis that increased air moisture decreases density and hence reduces concentration.

During the timeframe, temperature readings do not vary greatly throughout each day or between consecutive days. Therefore, though temperature variations do alter the rate of reaction of conversion of NO into NO_2, this effect is likely to be small, especially when the dynamics and conflicting reagents within the atmosphere are considered. Furthermore, as traffic is indirectly the main emitter of the NO_2 being measured, assuming traffic levels vary to a similar extent each day, the quantity of pollutants in the air will still be the same. The lag time of 4.5hours at standard atmospheric conditions is ample to convert emitted NO into NO_2 despite a maximum temperature range of 12.6℃ duri ng the duration of the experiment.

It therefore remains that wind velocity must play a vital role in the detected fluctuations. As seen by Equation 11 and confirmed in part in Figure 12, it is expected that the higher the wind speed, the more it shall disperse pollutants. However, real atmospheric investigation is inevitably more complex as wind direction and human use of the surrounding land is relevant. If wind blows from an area of higher emission rate, such as the A-road network located 1km south-east of the Balfour site, then as well as dispersing pollutants, the effect of the wind shall be to blow into the area, a higher density of pollutants from the source and depending on the rate of dispersion, it is possible that this effect would counteract the effect of the speed of the wind in air dispersion. Figure 13 shows the beginnings of an investigation into this. The low wind speed of this sample demonstrates how wind direction (primarily blowing trace gases *into* the area), outweighs the effect of wind speed in air dispersion, resulting in large NO_2 spike. In contrast, Figure 15 demonstrates how when wind direction does not serve to blow more densely polluted air into the sample area, wind speed takes precedence and causes noticeable dispersion of air as shown by the poorly defined NO_2 spike which would normally be expected. The highly typical and average readings of the other meteorological factors further adds to the prevalence of wind direction in each of these graphs.

In summary, it is known that the atmosphere is an extremely complex and dynamic system where a multitude of chemical and meteorological factors affect both each other and the concentration levels of NO_x gases. Different meteorological factors take precedence depending on other atmospheric conditions. The annual average limit of Nitrogen Dioxide, allowed by government legislation is 21ppb. This study proves average concentration levels to be below this limit, though many of the noontime spikes are seen to rise above this limit showing the necessity for continued observation, control. Public awareness can help by encouraging people to take alternative modes of transport and make informed decisions about when to travel, particularly those vulnerable to chronic lung or heart conditions.

Recommendations for further work

A Statistical Analysis of the Dynamics of Air Pollution is a very open-ended investigation, with a multitude of factors suitable for investigation. Other meteorological conditions such as air pressure could be investigated as the original assumption that air pressure is constant within the atmosphere is flawed. As part of *The Brighton Emissions Project,* DUVAS technologies also provided the portable 004 unit and Open Path Sensor (OP2) which could be used for investigation of roadside emissions and simplistic modelling for an air dispersion model. Furthermore, the National Atmospheric Emissions Inventory (NAEI) have similar air monitors set up in over 133 site throughout the UK, including Preston Park located less than a kilometre from Balfour Junior School. Readings from the NAEI Preston Park monitor may be downloaded and compared to the DUVAS readings for reaffirmation of any findings and measurement of absolute values, accounting for the calculated systematic error.

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