Measure title: **New Low Emission Zone**

City: **Norwich** *Project:* **SMILE** *Measure number:* **6.2**

A Introduction

Within Norwich City Centre an air quality management area (AQMA) has been declared due to levels of Nitrogen Dioxide (NO_2) pollution. There is also a perceived problem associated with PM_{10} pollution and black smoke, which can adversely affect the image of public transport and also public health. The area of the Low Emission Zone (LEZ) is relatively small and is centred on one street adjacent to the castle, Castle Meadow. Vehicular traffic within the street is limited to buses, taxis, delivery vehicles and the emergency services. The street is however an important bus route and as such the removal/cancellation of bus services within it would be counter productive. It is not the vision of Norfolk County Council to remove buses from Castle Meadow, however reducing the amount of pollution is key to meeting government air quality targets. To date no amelioration activity has taken place; however, the local air quality management action plan identifies the development of a LEZ as a solution to the Castle AQMA issue and as such was a proposed measure in the CIVITAS II project.

By attaching a Traffic Regulation Condition (TRC) under environmental grounds, the councils will regulate bus emissions by imposing requirements that a certain percentage of a bus operator's fleet meet set emission criteria. The criteria is split into two tiers, the most frequent buses entering Castle Meadow will be required to meet stricter emissions criteria than the least frequent buses. This will be monitored by both the Traffic Commissioner for the Eastern region and Norfolk County Council. To aid bus operators meet the LEZ requirements, Norfolk County Council has offered a 65% grant towards fitting pollution reducing equipment.

Additional measures to compliment the LEZ are also being implemented. A Traffic Regulation Order stating that all vehicles waiting in Castle Meadow must switch their engines off except when passengers are boarding or exiting buses has been implemented. A further initiative is to promote eco-driver training, free places on a half day course have been offered to all affected bus operators.

A1 Objectives

The measure comprises the introduction of a Low Emission Zone (LEZ) in the city centre covering the Castle AQMA and one objective is to meet UK regulation ($40µg/m^3$ [21ppb]) for annual average NO_2 levels and future UK objective ($20µg/m^3$) for annual average particle (PM_{10}) levels.

The measure objectives are as follows:

- **Objective 1 -** Prohibit access into Castle Meadow for < Euro III buses
- **Objective 2 -** Improve public perception that exhausts are cleaner
- **Objective 3 -** Convert 5 taxis to LPG operation (at Euro IV)
- **Objective 4 -** Retrofit of vehicles to comply with the LEZ (see further under Description)
- **Objective 5 -** Retrofit 30 fire service vehicles
- **Objective 6 -** Implement supplementary measure such as 'Engine Switch Off' for vehicles and eco-driver training

A2 Description

The first task involved assessing user needs and priorities. This was undertaken initially through consultation with all the stakeholder groups involved (i.e. the local authorities, bus operators, emergency services and taxi operators etc). The second task involved the development of the castle area LEZ based on regulatory measures, restricting access to higher polluting buses. The LEZ itself required confirmation of the specification, public consultation, statutory order making, scheme design and implementation. The task included securing the necessary statutory approvals, this included retrofitting of essential public transport (including 25 buses operated by First Group) more than initially proposed in the inception report, 30 fire tender vehicles that need access to the zone and the proposed conversion of 5 hackney carriages operating in the zone to Liquefied Petroleum Gas (LPG).

The Norwich Low Emission Zone (extent of the LEZ can be seen in the **Appendix A**) became operational in July 2008 and is regulated through a Traffic Regulation Condition, which is attached to the public vehicle operator's license. The criteria of the TRC can be seen in **Appendix B** of this report. The LEZ restricts access to a percentage of buses which are below the Euro III emission standard. In order to monitor compliance with this condition, public service vehicle operators must supply details of the emissions capability as defined by the equivalent Euro exhaust emissions standards of each vehicle within their bus fleet used on local bus services operating in Castle Meadow to Norfolk County Council on a bi-annual basis.

To aid bus operators in meeting the new emission standards in Castle Meadow, Norfolk County Council made grants available for any operator wishing to retrofit vehicles in their fleet. Grants were also made available to taxi operators wishing to convert their vehicles to LPG and free eco-driver training was offered to all affected bus operators. In total:

- 25 buses operated by First were retrofitted
- 2 buses operated by Neaves were retrofitted
- The Norwich tour bus was re-powered (new Euro IV engine fitted)
- No hackney carriages were converted to operate on LPG
- 30 fire tenders were retrofitted to reduce PM_{10} emissions
- Contribution to Anglian for 4 new Euro IV buses

Further supplementary measures have also been implemented including an engine switch off Traffic Regulation Order (TRO) which came into force in May 2007. This order required the driver of any vehicle parked or waiting at the kerbside in any area of Castle Meadow to switch off the vehicles' engine, other than when actively loading or unloading passengers. Free eco-driver training was also offered to all bus operators with 90 drivers undertaking either the 2 hour or half day courses.

B Measure implementation

B1 Innovative aspects

The innovative aspects of the measure are:

- **New conceptual approach** – This is one of the first Low Emission Zones within the UK and is implemented via a Traffic Regulation Condition rather than a TRO.
- **Use of new technology -** The use of Selective Catalytic Reduction (SCR) to reduce nitrogen oxide is a relatively new technology being utilised by bus operators.
- New LPG conversion technology was researched and considered in order to convert diesel 'Hackney Carriages' to Liquefied Petroleum Gas.

- Emission results from bus fleet on-board measurements during real road, bus route cycles and from the test engine were used to predict the pollutant emission concentrations within the LEZ with comparison to the urban air measurements monitored within the Castle Meadow LEZ area.
- Utilised multiple nitrogen dioxide diffusion tube monitors within the LEZ with continuous monthly monitoring. This is innovative as this total street coverage and extended monitoring methodology is rarely used due to expense and man power requirement.
- Portable factory customised and additionally ‘in house’ custom automotive approved analysers (*Horiba and Autologic* co.) for ‘real-time’ bus exhaust gas measurement for nitrogen dioxide (NO_2), smoke, carbon monoxide (CO), carbon dioxide and hydrocarbons (HC) have been used. This allowed prediction of any changes in air quality within the LEZ. A modelling student under the supervision of a senior lecturer in Atmospheric Sciences used ADMS software to help model the pollution in Castle Meadow.
- **New economic instrument –** Through implementing an ‘Engine Switch Off’ TRO, fixed penalty notices will be given to offending drivers/operators.
- Providing financial contributions towards fitting abatement equipment and also free eco-driver training has been offered.
- **New organisational arrangements or relationships -** Cooperation between local authorities – Norwich City Council and Norfolk County Council – the University of East Anglia, and local bus companies.

B2 Situation before CIVITAS

Air quality problems have been identified in three areas of the city resulting in these being designated AQMA’s, an LEZ has been promoted as one way of reducing pollution in this area, prior to CIVITAS a LEZ was not in place. Castle Meadow did have access restrictions along its length, these restrictions were introduced in May 1998. The closure of Castle Meadow was implemented for the purpose of delivering the Norwich Area Transport Strategy (NATS), when it was recognised that there was limited road space, pollution issues and more priority was needed to be given to public transport, cycling and walking.

Retrofitting of buses is a relatively new technology and as such none had been undertaken on buses in Norfolk prior to CIVITAS. Eco-driver training has been undertaken by both the council and private companies prior to CIVITAS; however the offer of free Eco-driver training is a new initiative.

The tool used to regulate the LEZ is the use of a Traffic Regulation Condition based on environmental grounds; this has never been attempted in Norfolk before and is only the second in the U.K.

Norwich City Council monitored many streets, roads and areas within Norwich with diffusion tubes using 1 or 2 per site and because of limited resources, measurement within selected areas, roads and streets, is not constant although the overall monitoring is continuous, however sites are rotated or reselected.

There was very little public knowledge of LEZ’s prior to CIVITAS, however due to consultations and promotional material the profile of LEZ’s has been raised.

B3 Actual implementation of the measure

The measure was implemented in the following stages:
Stage 1: Assessing user needs and priorities (Aug 2005 – Mar 2006) - This was done initially through consultation with all the stakeholder groups involved (i.e. the local authorities, bus operators, emergency services, taxi operators, municipal vehicle fleet operators and local traders etc). There was also some initial direct consultation with members of the public (e.g. through focus groups) asking for their views on a Low Emission Zone.

Stage 2: Stakeholder Consultation –Extensive consultation with bus operators, taxi operators, businesses and the general public was undertaken to elicit views on the scheme. It was paramount that adequate notification was given to both bus and taxi operators of the implementation of a LEZ, in order for operators to take this into account in planning their vehicle replacement strategies.

Stage 3: Developed criteria for LEZ – First and foremost it was vital to determine existing bus fleet composition, this would allow us to determine the number of buses which would be affected by any proposals. Following extensive consultation with both taxi and bus operators it was clear that the originally proposed Traffic Regulation Order approach to regulating the LEZ would be too rigid and onerous for the majority of bus operators to comply with. It was agreed that a Traffic Regulation Condition with a phased approach would be more achievable in the required time scale. Further outcomes of these initial talks included the idea that the most frequent services into Castle Meadow should meet stricter criteria than those who enter less frequently, thus targeting the most polluting vehicles.

Stage 4 Engine switch off TRO – Under new powers local authorities can instruct motorists to switch off their engines while their vehicles are parked and can be issued Fixed Penalty Notices, given to those drivers who refuse to co-operate. Following consultation with stakeholders and approval from the Norwich Highways Agency Joint Committee the Engine switch off TRO was advertised in February 2007 and came into operation in April 2007. The driver of any vehicle parked or waiting at the kerbside in any area of Castle Meadow must switch off the vehicles' engine, other than when actively loading or unloading passengers.

Stage 5: Grant system devised– Following consultation with operators Norfolk County Council devised a grant system whereby funding was made available (65%) towards the cost of retrofitting buses. This offer was made to all affected operators and the choice of abatement equipment was decided upon by the operators themselves. As part of the LEZ, Eco-driver training (either 2 hour or half day courses) was also offered to all operators in Norfolk.

Stage 6: Retrofit programme – A programme of works for the retrofitting of fire trucks and buses was devised. Applications were invited to apply for grants towards retrofitting, with various operators showing expressions of interest. Operators supplied details of vehicles which they considered warranted retrofitting and a programme of works was devised. See ***Fig. 3*** and the table both in **Appendix C** for details of existing and predicted bus fleet compositions.

Stage 7: Detailed design of LEZ - An evolutionary approach of introducing the Norwich Low Emission Zone has been implemented, in association with other measures for a holistic approach to air quality management in the Castle area and beyond. This phased approach was considered the most appropriate in order to give operators/companies who use Castle Meadow adequate time to consider the options available and then take appropriate measures such as obtaining cascaded vehicles, buying new vehicles and/or devising a retrofit programme.

Stage 8: TRC application – Following objections being received to the first application, a revised application which amended specific criteria was resubmitted to the traffic commissioner for the eastern region. A copy of the TRC and the map (***Fig.2***) showing the extent of area where the higher percentage of vehicles meeting Euro III will apply to services operating wholly within this area
can both be seen in **Appendix B**.

Stage 9: LEZ Implementation (July 2008) – Following advertisement of the TRC the LEZ was officially launched in July 2008. A condition of the TRC is that all affected public service vehicle operators must supply details of the emissions capability as defined by the equivalent Euro exhaust emissions standards of each vehicle within their bus fleet used on local bus services operating in Castle Meadow to Norfolk County Council. Updated information is to be supplied to the Council at six monthly intervals for receipt by 31 March and 30 September each year.

Stage 10: Evaluation and Monitoring - *S*takeholder surveys, exhibitions, face to face and telephone interviews, as well as questionnaires have been undertaken. On-going monitoring and evaluation of air quality, due to the fact that 100% of buses needing to comply with the LEZ criteria will not be reached until 2010 this will continue past the end of the CIVITAS project.

B4 Deviations from the original plan

The deviations from the original plan comprised:

Change to funding source – Following the withdrawal of the Governments Energy Saving Trusts 'Clean Up' grant system, additional time and resources were needed to obtain alternative funding.

Use of a different form of 'regulatory tool' to achieve the LEZ – Following extensive consultation with bus operators it became clear that the proposed regulatory approach of using a Traffic Regulation order was to rigid (it is an all or nothing approach). It was agreed a more flexible and favourable approach would be the use of Traffic Regulation Condition (TRC). This TRC allows for a structured implementation of the conditions for vehicles to comply with the environmental conditions (see TRC information supplied in **Appendix B**).

Conversion to LPG part of taxi fleet – It became apparent at an early stage in the measure that the technology for converting diesel engines to LPG is still in its infancy and it was hoped the technology would evolve over the duration of the project. Unfortunately uncertainties still remain with regard to the technology and as such taxi operators are reluctant to commit time and financial resources to an untried technology.

Retrofitting of buses – It was envisaged that 45 buses would be retrofitted; however bus operators were reluctant to do this or didn't feel a need to undertake retrofitting. At the outset it was felt that retrofitting Anglian buses could in fact skew the results as they are participating in the bio-diesel trails (measure 5.4). However, a contribution was made towards the purchase of 4 new Euro IV buses. Norfolk County Council also made contributions to Awayadays to fit a new Euro IV engine.

B5 Inter-relationships with other measures

The measure is related to other measures as follows:

Measure 5.4 – Alternative fuelled vehicle fleet - Both Norwich City and Norfolk County Councils are actively investigating the use of alternative fuels and in particular a trial is on going looking into the use of 5%, 20%, 50% and 100% bio-diesel blends on some buses in the Anglian fleet.

Measure 8.5 - On street automated ticket vending machines – The objective of this measure is to reduce bus boarding times at city centre bus stops and other key bus stops by providing facilities for passengers to purchase a ticket at the bus stop prior to boarding. 16 roadside ticket vending machines have been installed. The systems will be capable of being upgraded to support future initiatives, for example smart cards. This measure will undoubtedly enhance the Low Emission Zone objectives as boarding times will be greatly reduced as will bus dwell time.

Measure 12.9 - Provision for real time passenger information – This measure is designed to release data from BusNet for 3rd party uses thus giving improved information about bus services, congestion, etc to increase bus patronage and increase public transport modal share. It is envisaged this measure may lead to reduced emissions from buses as other drivers endeavour to avoid congested areas.

C Evaluation – methodology and results

C1 Measurement methodology

C1.1 Impacts and Indicators

METEOR / GUARD INPUTS				
NO.	**EVALUATION CATEGORY**	**INDICATOR**	**DESCRIPTION**	**DATA /UNITS**
	ECONOMY			
2	**ENERGY**	Operating costs	Costs per PT pkm	Euros/pkm, quantitative, derived or measurement
3		Vehicle fuel efficiency	Fuel used per vkm, per vehicle type	MJ/vkm, quantitative, derived or measurement
	ENVIRONMENT			
6		NOx levels	NOx concentration	Ppm or g/m3, quantitative, measurement
7		Particulate levels	Particulate (PM_{10}) concentration	Ppm or g/m3, quantitative, measurement
11		Small particulate emissions	PM10 per vkm	G/vkm, quantitative, derived
	SOCIETY			
13		Awareness level	Degree to which the awareness of the policies/measures has changed	Index, qualitative, collected, survey

Detailed description of the indicator methodologies:

Indicator 2 (*Operating costs*) – The methodology will involve identifying any on-going operating costs attributed to retrofitting. This will be measured through maintenance records, with both before and after data being evaluated.

Indicator 3 (*Vehicle fuel efficiency*) – The methodology used was to undertake test cycles on a bus with a standard exhaust and retrofitted exhaust and compare findings. Studies undertaken previously have also been referred to. It was apparent that there was potentially a diminutive fuel cost associated with retrofitting and as a result corrective measures were introduced and analysed. Fuel savings from eco-driving training were collaborated and analysed using test cycles of before and after training data. The introduction of the 'Engine Switch Off' TRO was two-fold, improved air quality and also reduced fuel consumption. Unfortunately, time and resource constraints make predicting actual fuel savings from the engine switch off very difficult. However, predictions regarding the potential fuel savings can be made using approximations regarding number of vehicles travelling through Castle Meadow and the time vehicles are switched off.

Indicator 6/7 (*NOx levels and Particulate Levels)* – Levels of NOx were monitored by both static and mobile sampling units. Data was collected from diffusion tubes (all locations have duplicate tubes allocated to measure precision and accuracy), static air quality monitoring station and mobile units. Triplicate control tubes were placed at the Norwich city centre background air quality station (off St George's Street) and the mobile air quality station sited in Castle Meadow adjacent to Opie Street. The comparison of the diffusion tubes with the instrumental results from the background station is known as the tube bias. The diffusion tube monitoring started in September 2005. Tubes are exposed for approximately one month, the time exposed in hours noted, and then they are sealed and exchanged for new unexposed tubes for another month allowing continuous cover. A solid state NOx monitor **-** a potential 'stand alone self powered' lamp post monitor was a powerful tool for urban pollution monitoring, this is cutting edge use of existing sensor technology in a new application and the prototype unit is constructed and laboratory tested. Normally, several years of LEZ pollution data are required to determine in detail any changes, trends or seasonal variation in ambient air pollutant concentrations from our selected date of July 2007. Traffic data is being obtained via SCOOT loops which are located in Castle Meadow, these data sets are collected on a monthly basis. Images of the air monitoring equipment can be seen in **Appendix D**.

Indicator 11 (*Particulate emissions*) **-** It is difficult to measure, if not impossible to detect PM_{10} from diesel exhausts, as the particles are mostly nanoparticles or macro soot particles which are under 10 microns. However, we have the capability at looking at the blackening of instrument exhaust gas filters replaced before every new analysis and comparing it with unused blank filters as a measure of the change that is seen in black smoke particles with blends. Particulates are measured in Castle Meadow by TEOM in the air station.

Indicator 13 (*Awareness Level*) – Telephone surveys were undertaken in May/June 2007 and August 2008 to determine public awareness and acceptance of the measure.

C1.2 Establishing a baseline

All the following results for air quality up to July 2007 can be considered as background pollution assessment and baseline attainment for analysis of the effects of the measures and other influences on the LEZ. The main chronological influences and proposed measures on the LEZ area:

March 2006: Infrastructure modification works took place in LEZ.

May 2007: Engine switch off during extended stopping at bus stand legislation.

Sept. 2007: Anglian bus introduced 10 new Euro IV *Optare* buses with M.A.N. engines in operation within the city.

April 2008: Retro-fitting of 15 older engine specification First buses with SCR exhaust treatment systems began in April and has now been completed.

August 2008, Retro-fitting of 10 older engine specification First buses with SCR exhaust treatment systems began in April and has now been completed.

The selected pollutants of interest within the LEZ have the following background air quality limits (maximum annual mean):

Nitrogen dioxide (NO_2) = 40 µg m^{-3}
Particulates PM_{10} = 40 µg m^{-3}
(All mass units are at 20 °C and 1013mb).
LEZ roadside proposed future limits:
NO_2 <40 µg m^{-3}
PM_{10} <20 µg m^{-3}

Air quality baseline data for 2006 for Castle Meadow is:

NO_2 = 49µg m^{-3} (9µg m^{-3} above current Government guidelines)

PM_{10} = 25µg m^{-3} (5µg m^{-3} above future 2010 Government guidelines)

NETCEN - DEFRA city background station reports NO_2 µg m^{-3} (annual mean):

Year	Norwich Road side NO_2 µg m^{-3}	(Norwich Centre) NO_2 µg m^{-3}	PM_{10} µg m^{-3}	Centre Tubes NO_2	UEA
2000	29	25	17	N/A	N/A
2001	31	28	15	N/A	N/A
2002	30	25	16	N/A	N/A
2003	33	25	18	N/A	N/A
2004	29	21	17	N/A	N/A
2005	25	22	13	28	24
2006	34**	21	23	21	25
2007	31**$^{\alpha}$	23	22	23	24
2008	N/A$^{\beta}$	28$^{\gamma}$	23$^{\gamma}$	23	24

$^{\alpha}$ to 30 Sept 2007, $^{\beta}$ to July 08, $^{\gamma}$ Norwich centre station deactivated mid May 08 to move to new background location – scheduled commissioning early 2009, ** moved to Norwich Forum, N/A - not available.

An arbitrary 'background' comparison nitrogen dioxide diffusion sample tube was positioned near to the main bus stop at the University of East Anglia (UEA) (***Fig. 4***). Traffic through put only includes UEA bus routes, the staff car park and service vehicles. The mean of all UEA NO_2 concentrations measured since Sept. 05 to Dec. 08 = 24 µg m^{-3} (for Jan. 2008 to Dec 08 = 24 µg m^{-3}). This compares reasonably well with the above table of Norwich Centre background concentrations considering the UEA is to the west of the city centre in a more 'rural' area.

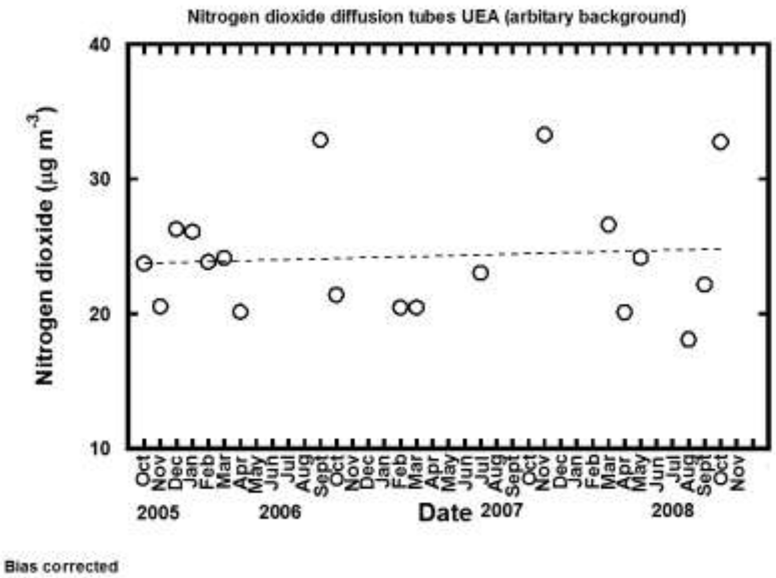


Fig. 4. UEA located nitrogen dioxide diffusion tube – used as a 'secondary' background location

Nitrogen dioxide diffusion tube available data
Diffusion tube NO_2 data are also available for sometime before CIVITAS-II
($\mu g\ m^{-3}$ annual mean uncorrected for bias)

Year	Castle Meadow	St. Stephen's Street	Data ID
1993	-	70	UEA (MSc)**
2003	46	39	City council
2004	49	41	City council
2005*	53	57	UEA - CIVITAS
2006	49	53	UEA – CIVITAS
2007	47	55	UEA – CIVITAS
2008 $^{\beta}$	52	57	UEA – CIVITAS

* From Sept 2005, $^{\beta}$ to July 08.
** MSc project ENV UEA Gareth Collins Spatial variations in nitrogen dioxide in a street canyon.
UEA-CIVITAS data included for comparison purposes. Bias can vary. **Corrected in Table** below:

Year	Castle Meadow	St. Stephen's Street	Data ID
1993	-	67	UEA (MSc)**
2003	44	37	City council
2004	47	39	City council
2005*	50	54	UEA - CIVITAS
2006	47	50	UEA – CIVITAS
2007	45	52	UEA – CIVITAS
2008 $^{\beta}$	52	57	UEA – CIVITAS

* From Sept 2005, $^{\beta}$ to July 08 – from May08 no bias correction centre air station deactivated for relocation. ** MSc project ENV UEA Gareth Collins Spatial variations in nitrogen dioxide

in a street canyon. UEA-CIVITAS data included for comparison purposes. Corrected for mean bias (Tube value/1.052026).

The 2007 nitrogen dioxide concentration for Castle Meadow showing a mean value of 47 µg m^{-3} correlates well with the last LAQM 2007 City of Norwich official report which indicated a tube mean value of 46 µg m^{-3} (this slight variance could be attributed to the fact that more tubes were used for the CIVITAS project). Currently, there is an increase so far in this years mean annual concentration measured by the diffusion tubes as listed in the table above.

Using our bias results calculated from comparing the concentrations obtained from our control tubes and automatic air station NETCEN data, a mean tube bias to date was calculated to be 1.048742 (the concentration given by our tubes compared to the central air station values), the concentrations in the above table do not reduce by many units and so most exceed the annual limit of 40µg m^{-3}.

The 1993 data is representative of a different generation of vehicle engines, fuel types (diesel is now more popular) and catalytic converter transition phase. This data is included as it was available and to compare concentration profiles along the street then and today. St. Stephen's street is discussed in relation to the Castle Meadow area further on in the text.

Additional baseline data regarding air quality in Norwich City centre can be seen in the **Appendix E** of this report.

Traffic data

Castle Meadow SCOOT traffic count data has been verified a number of times by the work package leader as being accurate and the UEA by manual survey counting, our confirmation is given below:

23 April 2007 SCOOT counted 96.1% of the vehicles passing each direction and of all vehicles 67% were buses from the manual count.

After considerable manual analysis of the major bus operators in Norwich, First bus, Anglian bus and park and ride timetables (not taking into account the few other companies with only a few buses), 189756 buses passed through the LEZ calculated for the April – July 2007 period. SCOOT counted a total number of vehicle movements of 365433 and so buses accounted for 52% of the movements.

Current baseline conclusions are that just over 50% to 67% of the vehicles passing through the Castle Meadow LEZ (buses, taxis and delivery vans only).

SCOOT currently provides us with baseline mean vehicle counts of 122 per hour, 2930 per day and 20507 per week (all derived from the mean per week, over 7 days).

In comparison, from bus timetables as above, 1506 bus movements per day (mean for the week) actually 1749 per working day, 1472 on Saturdays and 325 on Sundays in Castle Meadow.

C1.3 Building the business-as-usual scenario

On going air quality monitoring would continue to ascertain NO_2 and PM_{10} data obtained by Norwich City Council monitoring station. The graphs (***Fig.7* and *Fig. 8***.) below display the relationship between the mean of all position tube data and the city council historic data for the Castle Meadow area. Both can be considered background diffusion data for Castle Meadow LEZ using data to the selected date of July 07 from which most LEZ implementations start. From the regression trends pre-CIVITAS nitrogen dioxide concentrations were increasing (dashed line). Since the start of the CIVITAS-II project to July 07 there is a distinctive downward trend in NO_2 concentrations as measured by diffusion tubes and would be predicted to meet the 2010 Guidance on Assessment under the EU Air Quality Directives Final draft nitrogen dioxide limit of 40µg m^{-3}. However, currently data from July 07 to July 08 predicts that the downward trend will miss the 2010 mandatory nitrogen dioxide limit of 40 µg m^{-3} using data to-date.

Fig. 7 . Base line nitrogen dioxide concentrations, pre CIVITAS-II (*dashed line*) in Castle Meadow as measured by diffusion tubes – Current, (*solid trend line*) Sept. 05 to Dec. 08 trend indicates a gradual downward trend in the NO_2 concentration in the LEZ.

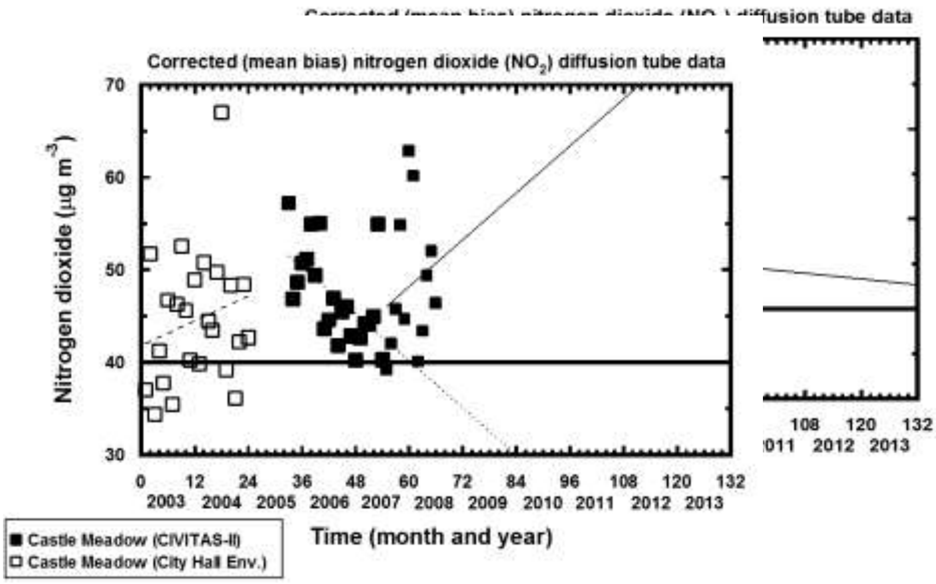


Fig.8. Base line nitrogen dioxide concentrations, pre July 07 (*dashed and dotted trend lines*) in Castle Meadow as measured by diffusion tubes – Current, (*solid trend line*) July 07 to July 08 trend indicates NO_2 concentration increase in the LEZ.

From current examination, present bus fleet turnover 'natural evolution' it is expected that 10 new Euro IV buses will replace older, more polluting buses such as the vehicles with pre-Euro rated engines, this equates to a change in bus fleet of 4.5 %. This indicates that in 2010 Castle Meadow NO_2 levels would be 43µg m^{-3}, a small improvement in predicted air quality; however NO_2 concentrations are predicted to still be over the required annual mean of 40µg m^{-3}.

A Department for Transport report stated there could be a 12% increase in bus patronage in the decade from 2002.Therefore, if this is the case NO_2 in 2010 would be 51µg m^{-3}, significantly higher than the government guidelines. It was also considered that a realistic increase in single deck buses to accommodate a 1.2% annual increase in passenger capacity for one year would lead to only a 1 µg m^{-3} increase of NO_2 in Castle Meadow (47 µg m^{-3}).

Euro IV emission engines will eventually replace all Euro rated buses prior to Euro IV over time as the older buses come to the end of their useful life. In addition, the total city bus fleet engine power will increase also as modern vehicles require more power for basic functioning of additional technology and emissions and are quoted as g kWh power. The existing mean of 175 kWh for all the fleets could reach a new mean of 210 kWh per bus when all existing buses are replaced by Euro IV vehicles. This would mean NO_2 levels in the LEZ as 25µg m^{-3}.

These predicted NO_2 air concentrations are well within the annual mean value and would comply. They are well on the way to halving the air pollution in the LEZ assuming no increase in fleet numbers or throughput frequency.

The business as usual scenario takes into account that the Engine Switch Off TRO would not be in place and also the fact that a high proportion of bus drivers would not have undertaken eco-driver training.

C2 Measure results

Ambient urban air pollution monitoring in the Castle Meadow area is established and ongoing and should be available for the duration of the Norwich CIVITAS-II project and beyond. Baseline concentrations within the LEZ have been determined for comparison when all work package implementations have taken place influencing this area.

C2.1 Economy

Indicator 2 – Operating costs

The costs of providing a Selective Catalyst Reduction (SCR) system vary depending on the type of vehicle being fitted, however the SCR equipment fitted to the FIRST bus fleet cost in the region of £10,000 per installation (as First are partners in the CIVITAS project they are eligibly for 35% match funding).

Exact costs for maintaining SCR are not yet available as the systems have only been implemented within the last 12 months and as such no definitive costs will be available until some time next year. However, it is accepted that ongoing maintenance costs associated with the implementation of SCR will involve regular replacement of the redundant, either ammonia or urea. Replacement of the ammonia gas cylinder will only be required around every 9,000 miles for a taxi, but will be much more frequent for a heavy duty vehicle. The volume of urea consumed relative to diesel will depend on the size of vehicle, but is likely to be around 13% for bus or refuse vehicle. Urea can also be bunkered on site and therefore makes refueling more flexible.

Further costs associated with the LEZ include administration costs for both bus operators and Norfolk County Council in order to keep fleet Euro standards up to date. There is also a cost associated with the enforcement of the TRC and engine switch off TRO.

C2.2 Energy

Indicator 3 Vehicle fuel efficiency

Fuel consumption was both derived from bus operators and also test data obtained by the company which supplied the abatement equipment. It was found that fuel consumption measured over the test cycles gave a 3-5% reduction. This is a good saving and combining this with eco-driver training a significant fuel saving can be obtained.

Eco-driver training (either 2 hour or half day courses) was offered to all affected operators. Eco-driving improves road safety as well as the quality of the local and global environment and saves fuel and costs. Driving efficiently can lead to reduced fuel consumption, it was calculated that one operator would save approximately £2800 per month, equating to £33,600 per year on fuel costs. Driving in congested, stop-start conditions will incur higher fuel consumption, whereas steady state operation at optimum efficiency speeds will have lower fuel consumption. Other benefits of Eco-driving include reductions in air pollution, noise and reduced maintenance costs.

Operator	Before Training (mpg)	After Training (mpg)	% fuel savings
1	38.21	44.6	19.46
2	35.3	40.7	15.29
3	38.6	46.2	19.68
4	41.6	46.1	10.81
5	36.9	42.8	15.98
6	38.6	44.4	15.02
AVERAGE	**38.2**	**44.13**	**16.04**

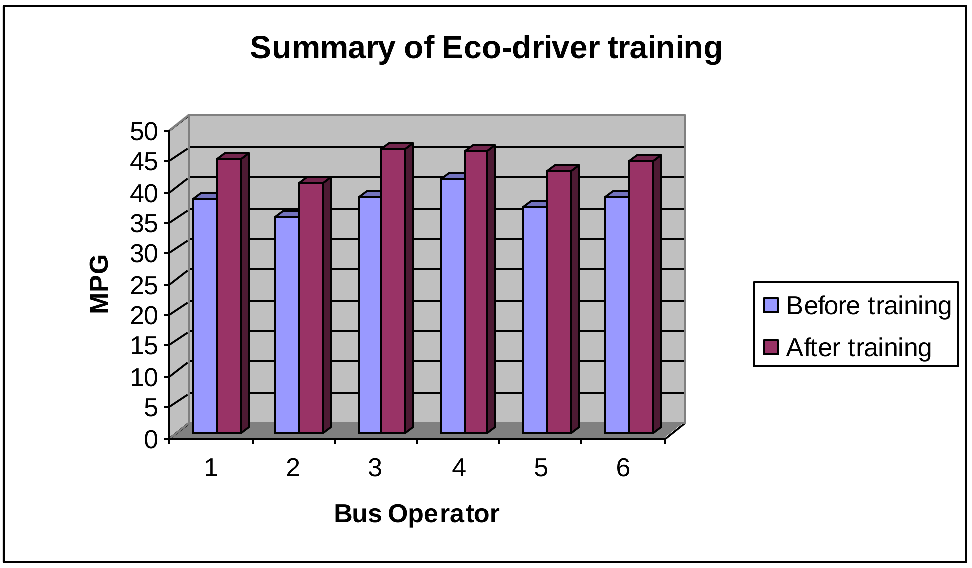


Fig. 9. Graph summarising Eco-driving results from all participating operators.

The table and graph (***Fig. 9***.) above summarises the eco-driving results, in total 92 drivers from 6 different operators were trained. As can be seen from the table and graph, the majority of drivers trained showed significant savings on fuel consumption on their second drive (following the training). The total saving from all operators was calculated to be 16.04%, which if this was transferred to their daily driving habits would see a significant reduction in fuel costs for the operator and could also could give considerable emission reductions.

C2.3 Environment

Indicator 6 - NOx levels

Date range	Castle Meadow	St. Stephens Street	Red Lion St.
Oct. 05 – June 07	**46**	**50**	**47**
July 07 – Nov. 07	48	57	53
Jan. 06 – June 06	48	49	47
July 06 – Dec. 06	44	50	48
Jan. 07 – June 07	44	49	46

July 07 – Nov. 07	**48**	**57**	**53**
Jan 08 – June 08	49	55	53
July 07 – July 08	49	54	53
July 08 – Dec. 08	**43**	**54**	**50**

Mean of all NO_2 diffusion tube data in various combinations to indicate before and after scenarios of the implementation date July 2007 when we are expected to see the result of changes – Engine *switch off regulations, Euro IV buses and biodiesel blends*.

The data listed in the table is the mean NO_2 for the dates given, which show currently an improvement in the air quality for nitrogen dioxide in Castle Meadow (*LEZ*) when compared to June 07. More difficult is the trend in Red Lion Street and St. Stephens Street (*non-LEZ declared zone*) which join Castle Meadow as they share some of the bus and taxi traffic but not all, and they have public motor car vehicles allowed unlike Castle Meadow where they are prohibited. Here the nitrogen dioxide concentrations have remained at similar concentrations since our monitoring began. Therefore, this gives some evidence that the LEZ implementations are beginning to have a beneficial effect on air quality.

Current air monitoring data in Castle Meadow Automatic Station

Daily emailed air quality data from AEA Energy and Environment (AEA Technology plc) for Norwich DEFRA sites and our ‘Calibration Club’ site from the 10 Sept. 2006 after installation and verification have been gathered. The ‘mobile’ air quality monitoring station is positioned on the pavement in Castle Meadow near Opie Street and the results to date are as follows:

Castle Meadow Automatic Air Station instrumented data

Date	Nitrogen dioxide (NO_2)	PM_{10}	$PM_{2.5}$
10 Sept. 2005 – 31 Dec. 2006	68	19	13
01 Jan. 07 – 29 Aug. 07	52	18	11
01 Jan. 07 – Nov. 07	51	22	14
01 Jan. 07 – Jun. 07	56	25	16
01 July 07 – Nov 07	45	19	13
01 Jan. 08 – July 08	50	21	15
July 07 – July 08	44	17	15
July 08 – Dec. 08	**35***	**18**	**11**

(mean values all µg m^{-3}): (NO_2 - chemiluminescent analyser) (TEOM - particulates)
* Oct-Nov 08 less than 75% data capture.

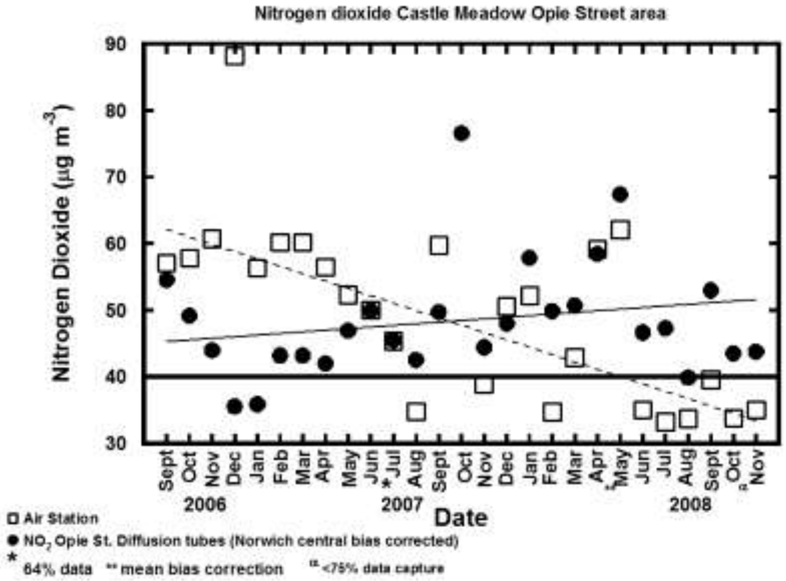


Fig. 10. Monthly NO_2 data from the automatic mobile air station in Castle Meadow to Nov. 07.

Fig. 10. above displays the tube data with linear regression trend of increasing nitrogen dioxide with time. The diffusion tube monthly mean value deviates from the monthly mean of the hourly mean automatic air station data, trend of decreasing NO_2 with time – the air station monitored nitrogen dioxide concentration is predicted at the statutory 40 µg m^{-3} (2010) concentration now. Possible explanation on the deviation of the monthly mean diffusion tube concentrations and the more instantaneous chemiluminescent instrument measurements is shown in the updated principle component analysis graphs shown later in the report which considers the effect of wind.

Diffusion tube locations in Castle Meadow

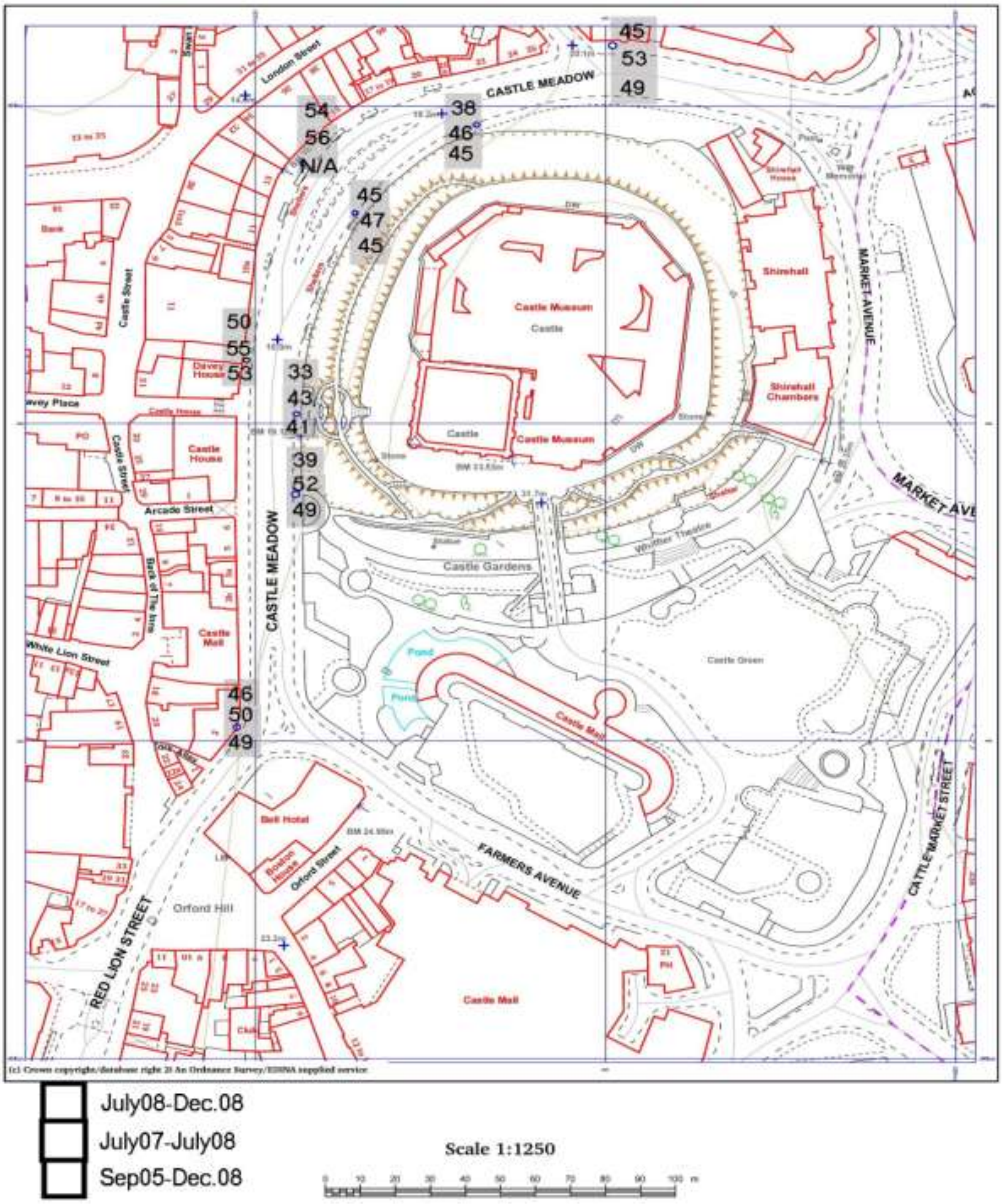


Fig. 11. Diffusion tube sample points in Castle Meadow mean values nitrogen dioxide µg m^{-3} ***(upper value)*** July 2008 – Dec. 2008 ***(middle value)*** July 07 – July 08 ***(lower value)*** Sept. 2005 to Dec. 2008 mean.

The map above (***Fig. 11***) depicts the diffusion tube sample points (blue circles) in the Castle Meadow area with the mean of the nitrogen dioxide (NO_2) concentration for the position over the time periods of July 07 to July 08 and Sept. 05 – Jul. 08.

Three of the positions monitored are now below the annual limit mean value for nitrogen dioxide. Although, the other positions are over the annual mean limit they are gradually reducing and thus reflects the LEZ measures beginning to have a positive effect on improving air quality in Castle Meadow. These results are also depicted in graphical form in **Appendix F**.

Higher concentrations of nitrogen dioxide are present where transient engine effects take place (acceleration) such as moving up gradients, pulling away from bus stops and traffic lights when stationary and in more street canyon sheltered areas. This can be seen reflected in the concentration of NO_2 measured on the bend of Castle Meadow at the relatively recent additional position *CMextra*, the only data displayed on ***Fig.11*** with a N/A (not available) notation.

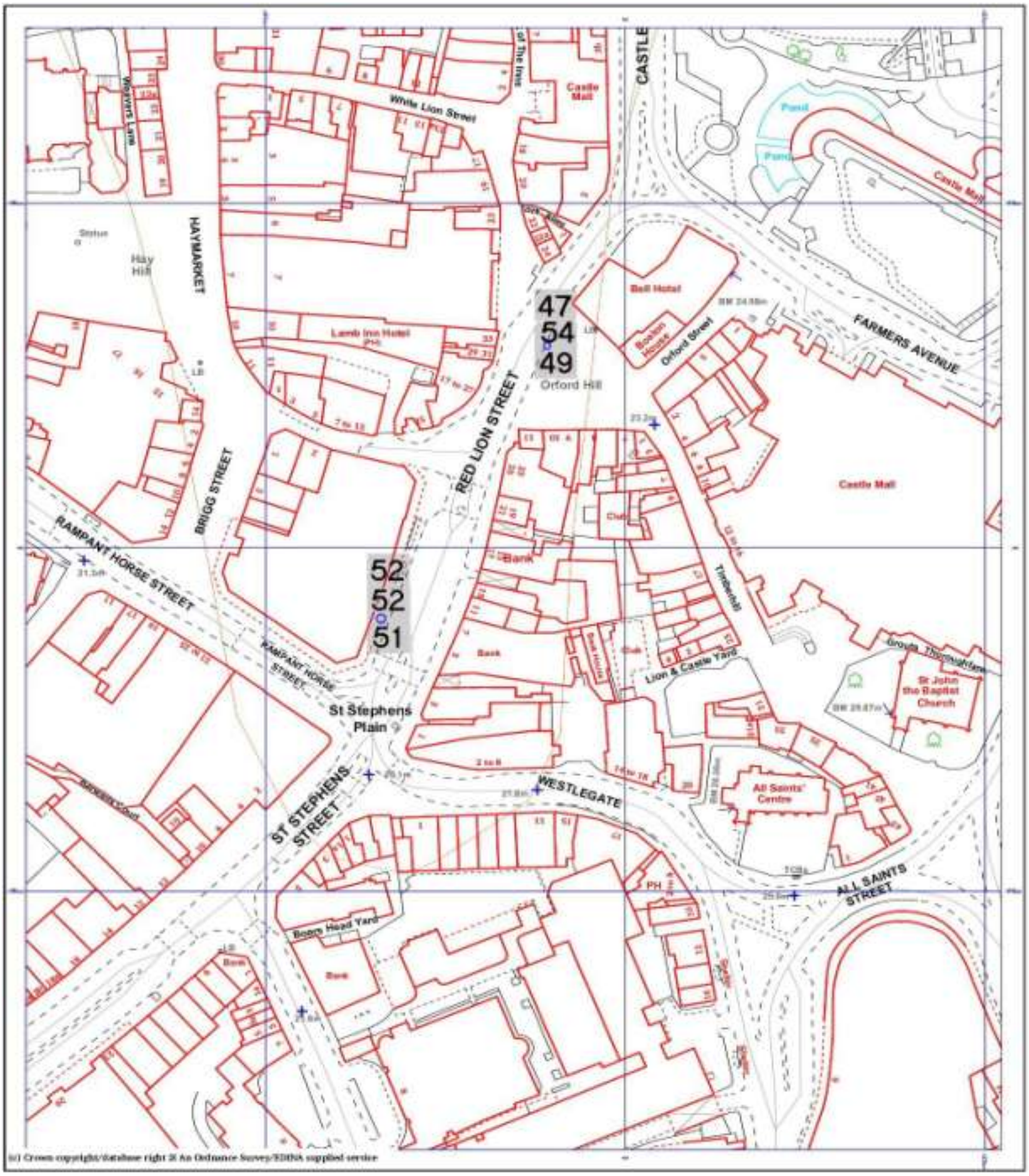
From analysis of the Castle Meadow area using gradient data from the road remodelling plans together with the traffic direction flow there is an explanation for the measured NO_2 concentrations observed as displayed in Figure 11. As the buses enter the Castle Meadow interchange area from the top right-hand side of the map they are on a slight downward gradient (0.018 as calculated from the level upper part of Castle Meadow to the sample points) and the engines will be off load as they approach the bus stops. Hence most concentrations on the right side of the road as looking at the map will generally be lower than the NO_2 concentrations measured on the left side of the Castle Meadow road. In addition, the slight downward gradient helps the buses pulling away from the bus stops by assisting the momentum by the aid of gravity. Where there is an increasing upward gradient (0.003, 0.013 to 0.023) more power is required when pulling away from the bus stops and hence more exhaust emissions as this is a transient engine effect and when approaching the bus stops the engine load is only reduced at the last moment. This is confirmed near the junction of Castle Meadow with Red Lion Street (at the bottom of the map) there is a (0.009) gradient towards Red Lion street so engines will be on load towards Red lion street due to the junction traffic lights and gradient and on less load from Red Lion Street to the bottom of Castle Meadow.

Additional traffic light controlled pedestrian crossings and raised crossing areas all added to engine transient effects (engine load increased and acceleration). Typically, the buses, taxies and delivery vans flow reasonably well through this area apart from the road restriction sometimes impairs bus flows due to the vehicle sizes as the main traffic control points (junction traffic lights) are at each end of Castle Meadow.

Towards the end of the bus exhaust emission tests the intention is to map (position using GPS and emissions) the transient emission events (concentration peaks) as the bus travels through Castle Meadow to St. Stephen’s Street in both directions together with engine load via rpm and throttle position to verify the above observations and inferences.

Figure 19 shows the mean NO_2 concentrations for the time periods shown for Red Lion Street. This road interconnects Castle Meadow with St. Stephen’s Street (potentially a future LEZ area). The elevated concentrations above that of 40ug m^{-3} once again highlight junctions, transient effects and stops and starts.

Fig. 19 Diffusion tube sample points in Red Lion Street mean values nitrogen dioxide µg m^{-3} ***(upper value)*** July 2008 – Dec. 2008 ***(middle value)*** July 07 – July 08 **(*lower value)*** Sept. 2005 to Dec. 2008 mean.



Scale 1:1250

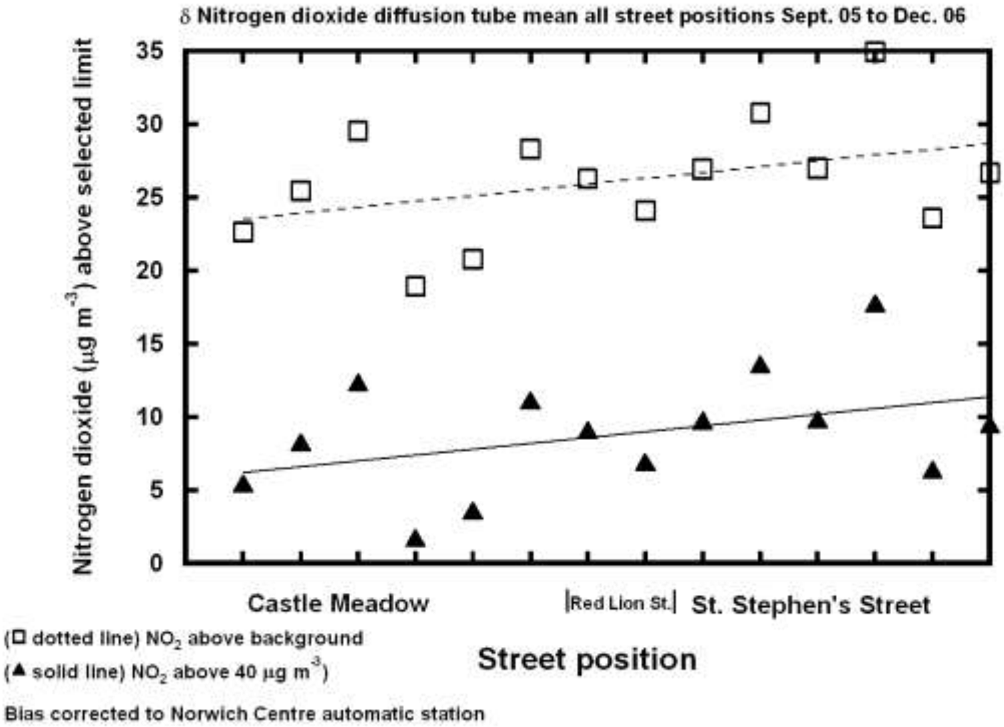


Fig. 20 Indicates the measured NO2 pollution concentration above that of the annual mean limit and also that of background

The background concentration plays a role in the reduction of pollution in the Castle Meadow area as this is influenced by traffic in other areas of the city. This has to be considered especially if background concentrations increase and gradually approach the annual mean limit as there will be less room for reduction within the LEZ.

It was decided during the initial stages of the project to deploy NO_2 diffusion tube monitors in the adjoining Red Lion Street and St. Stephen's Street as they are relatively close, share a high proportion of the bus routes, bus interchange areas and St. Stephen's is also a main shopping street (see **Appendix G** for a detailed analysis).

Indicator 7 - Particulate (PM10) concentration

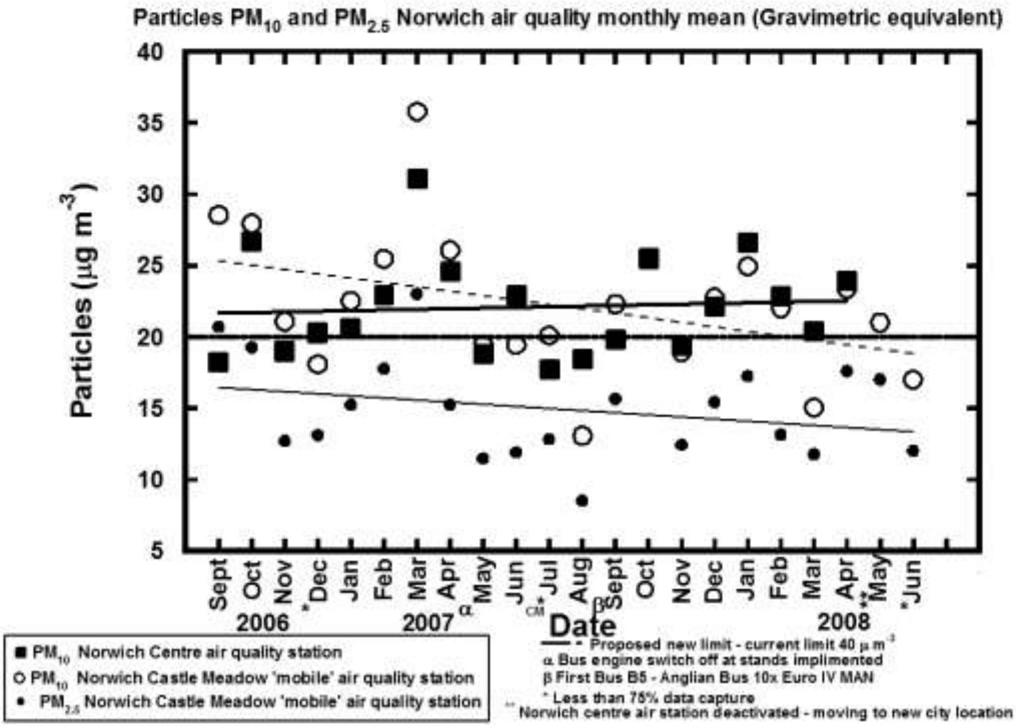


Fig. 26. Particulates measured by TEOM.

Particulates in general are also of concern due to potential health problems they can cause because of their size and the presence of poly aromatic hydrocarbons (PAHs). Currently, particulates are at background Norwich urban mean concentrations in Castle Meadow and are close to the future proposed Government limit of 20 µg m^{-3}. The introduction of bio diesel blends will reduce exhaust particulates (US EPA420-P-02-001, October 2002, A Comprehensive Analysis of bio-diesel Impacts on Exhaust Emissions, Draft Technical Report), bio-diesel is also a fuel that contains no aromatic hydrocarbon fractions. Any retrofitting will also have an effect. Once again if 20µg m^{-3} is set as the limit careful consideration must be given to background concentrations especially if they exceed this value. From ***Fig. 26*** it can clearly be seen that the particulate concentrations PM_{10} and $PM_{2.5}$ as measured in Castle Meadow follow the Norwich Centre background air quality station results very closely indicating that there is a contribution to this LEZ area from the surrounding area traffic. We have a baseline value from the flat linear regression for PM_{10} of 22 µg m^{-3} close to the mean value. However, the PM_{10} and $PM_{2.5}$ concentrations in Castle Meadow show a downward trend and are expected to be below the new proposed limit in several months if the trend continues. These values are half the actual limit at present and comply well with existing Government limits.

Vehicle throughput and pollution concentration

Examination of our previous initial limited (SCOOT) vehicle flow data and pollutant concentration using principle component analysis for the selected LEZ Castle Meadow area, indicates an association of particulates with nitrogen dioxide although vehicles seem to be slightly further away (***Fig. 27***) which could indicate background pollution influences.

The following plots of the latest more substantial Castle Meadow SCOOT data will be addressed under each of the Figures 27-34.

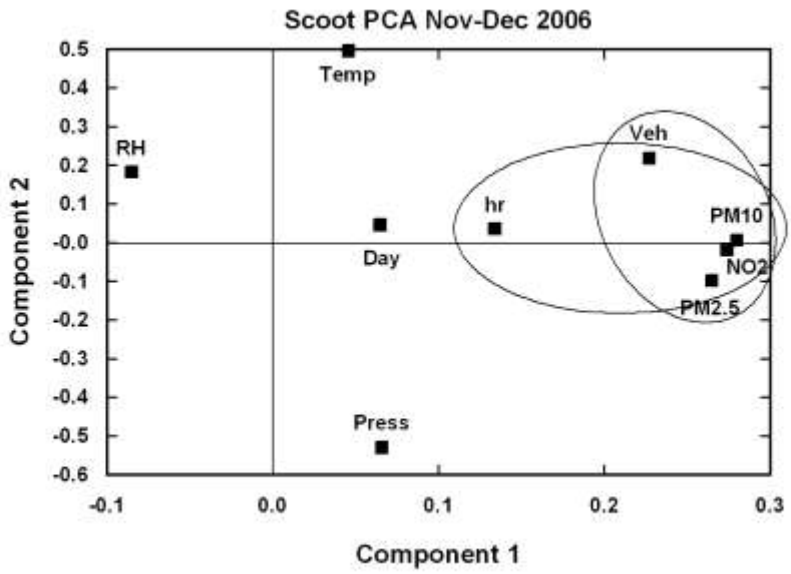


Fig. 27. displays the result of plotting the hourly data for particulates and NO_2 and a correlation trend is seen

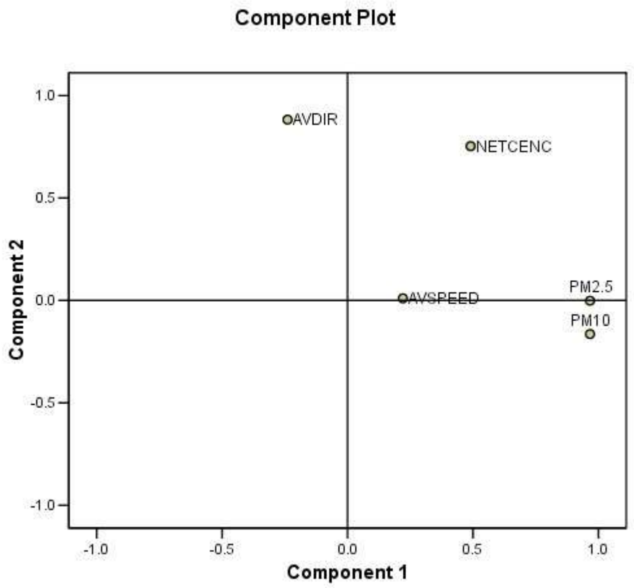


Fig. 28. Displays the results of plotting the result of PCA analysis from the monthly Castle Meadow station data NO_2, and particulates, and Marham RAF station wind direction and speed.

In Figure 28, it can be seen that the two particulate size ranges are related and are expected to be derived from the same source. Average wind direction in Marham (there is no official weather station in Norwich) being in a separate component quadrant will have little influence on NO_2 or particulates. Once again, this is expected as wind direction in street canyons is influenced by the buildings, street orientation and gaps. Wind speed is known to influence pollutant concentrations as a stronger wind will either displace the pollution or dilute it if it is cleaner air or possibly bring in polluted air from other parts of the city or from cities further a field. So AVSPEED, NETCENC (NO_2) and the particulates PM_{10} and $PM_{2.5}$ could be encircled and loosely connected.

Relationship between Vehicle Data, NO, NO_2 and PM levels

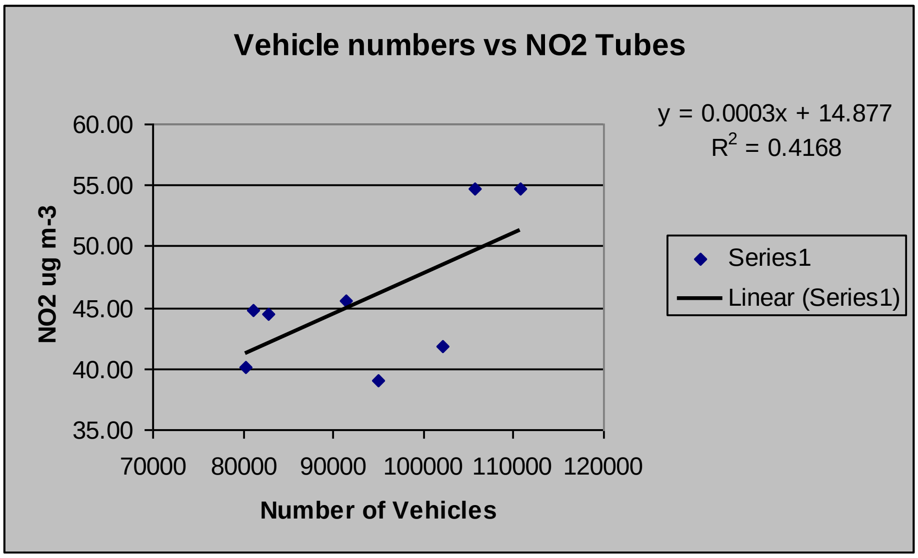


Fig.29. Indicates the relationship between vehicle numbers and NO_2

The above graph displays the results of the plots initiated by the principle component analysis (PCA) and the possible relationship with traffic volumes. It appears there is a positive relationship between the number of vehicles in Castle Meadow and an increase in Nitrogen Dioxide.

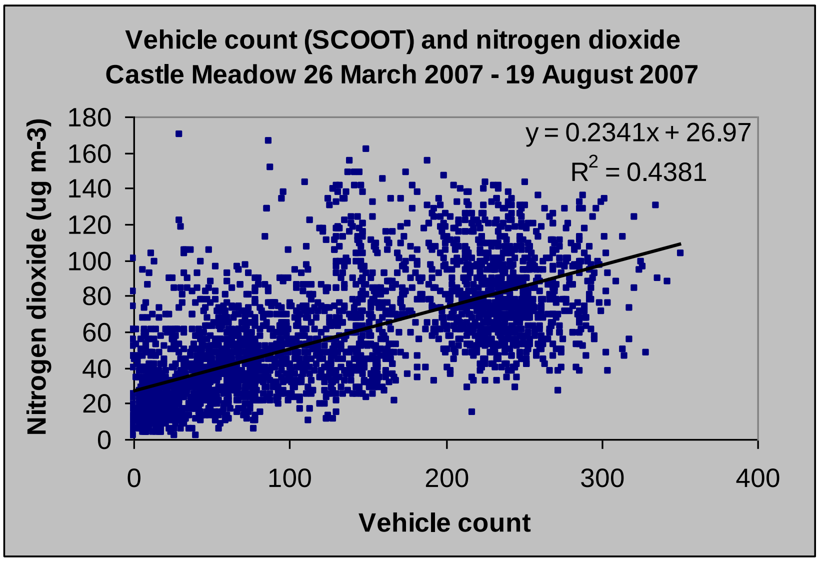


Fig 30. Depicts vehicle count and nitrogen dioxide in Castle Meadow

It can be seen from the graph above that there is an increase in NO_2 the principle result of (NO) oxidation in the atmosphere (secondary pollutant) from vehicle exhausts with traffic counts as one would expect. The intercept, NO_2 present when there are theoretically no vehicles is 27µg m^{-3} and the yearly mean background was 20ug m^{-3}.

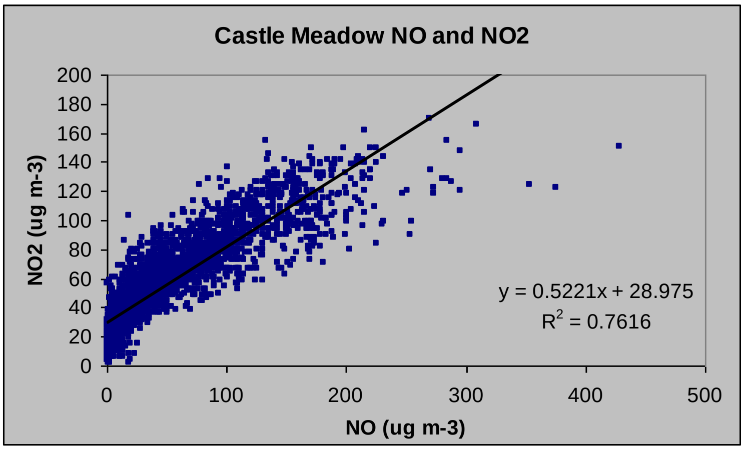


Fig. 31. Depicts the relationship between NO2 and NO in Castle Meadow

The relationship of NO_2 to the emitted NO is seen in Figure 31 above, as the correlation coefficient is reasonably high. The slight curvature in the data points could be due to background nitrogen dioxide (NO_2) drifting into the LEZ and thus increasing the concentration from that emitted in the direct locality. Very little NO_2 is emitted directly from the internal combustion engine. The presence of an 'oxycat' catalyst after treatment would speed up the conversion of NO to NO_2 so that NO_2 is emitted directly from the exhaust – an important consideration when retrofitting.

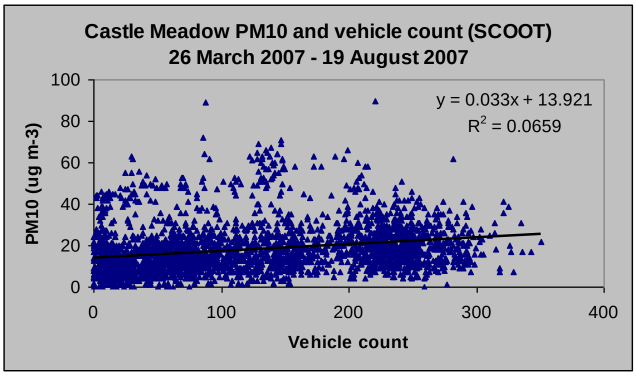


Fig. 32. Relationship of PM10 and No. of vehicles

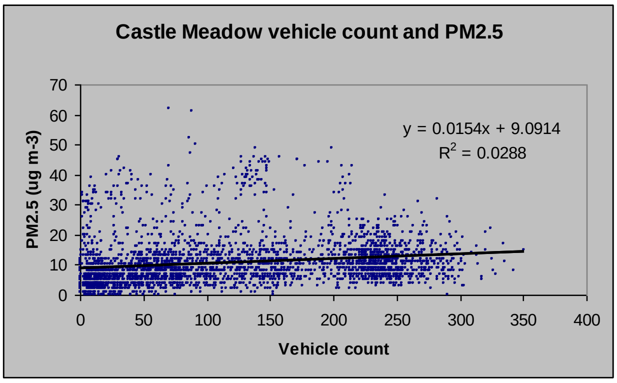


Fig. 33. Relationship of PM2.5 and No. of vehicles

As mentioned previously (see Figure 25), background concentrations of particulates seem to be influencing the concentrations found in Castle Meadow and from Figures 32 and 33 there is little correlation with vehicle numbers in this area. Mostly nano particles are emitted by exhaust gases especially modern engines and the larger 2.5 and 10 micron particles measured here form later in the atmosphere from aggregation. Other sources are dust in general, tyre and road dust.

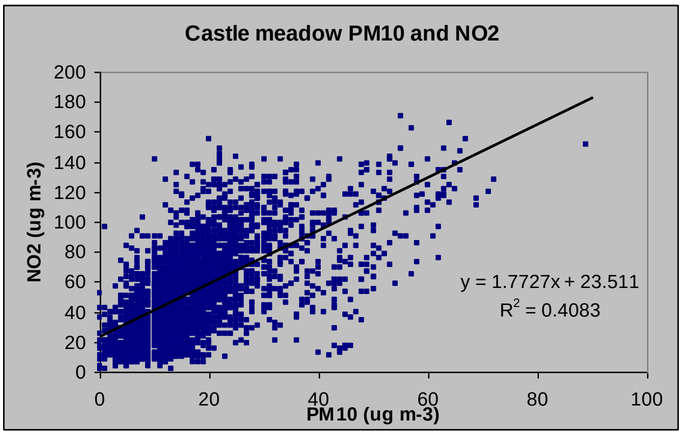


Fig. 34. Relationship between NO_2 and PM_{10}

In Figure 34 we can see that there is a correlation of an increase of particulates with NO_2 as we might expect but the regression linear fit would be expected to be much steeper from the density of the data points up to 40ug m^{-3} on the PM_{10} axis. This gives further evidence of a contribution by background particulates influencing the concentrations in the LEZ.

On analysis of SCOOT vehicle count data for the time period of March 07 to July07 and March 08 to July 08 with correction for one loop failure based on previous data there was a 3.5% increase in vehicle numbers through Castle Meadow and if compared to event code ‘G’ in the model prediction in **Appendix H,** the mean NO_2 concentration measured concurs.

Portable NO and NO2 monitor

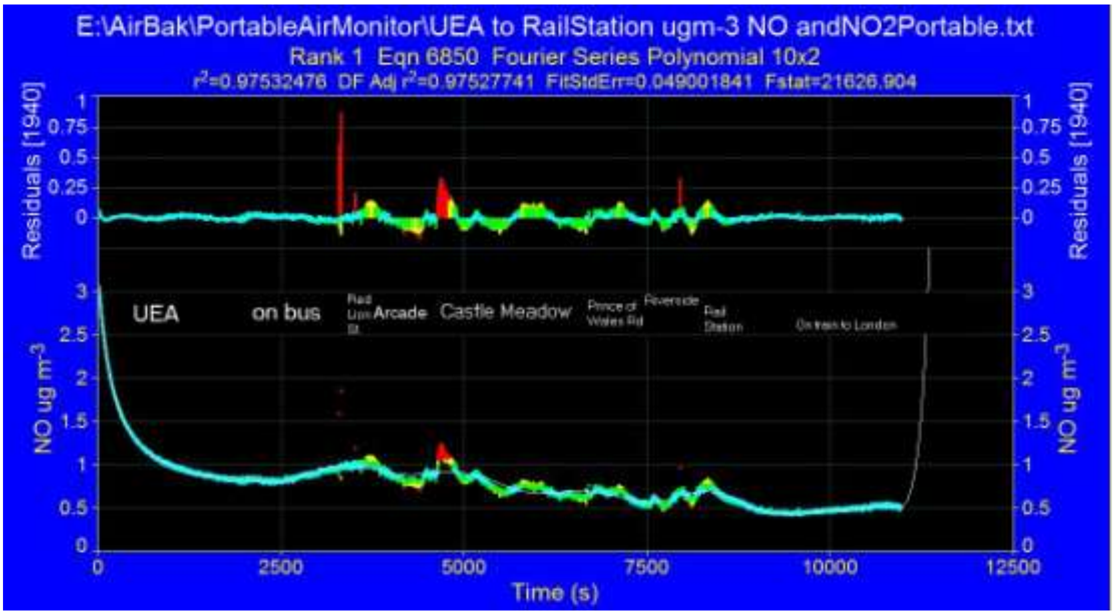


Fig. 35. Profile of NO within our area of interest in Norwich

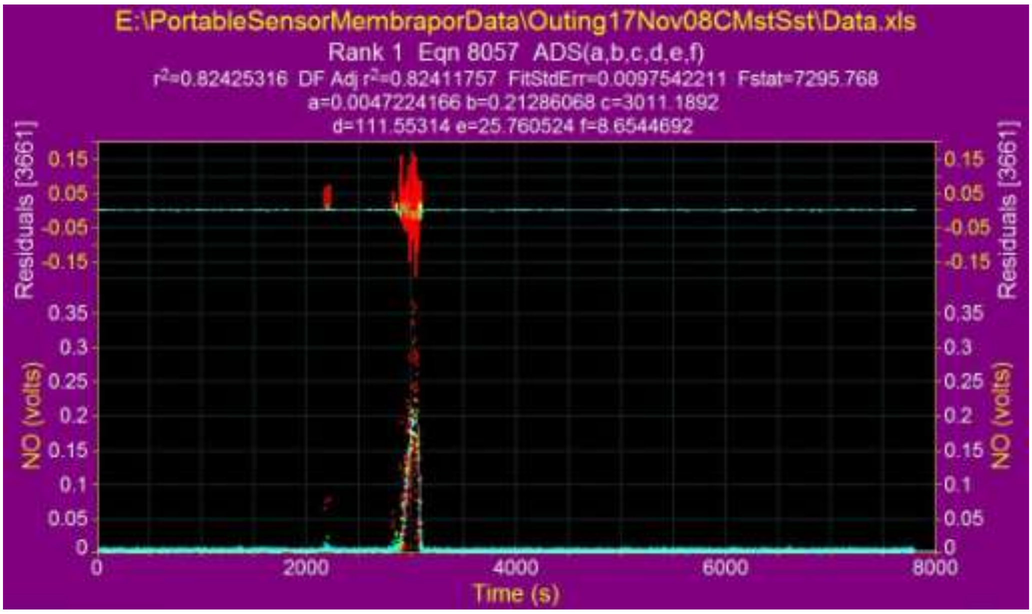


Fig. 36. Profile of NO within our area of interest in Castle Meadow Norwich after electronics modified to give a stable baseline.

Figures 35 and 36 display the street profiles and trends of NO from vehicle exhausts found in the city centre of Norwich for NO using a portable NO_x monitoring unit. Distinct events can be picked out on the traces such as from time zero in the office at the UEA 'rural area' and then on the bus to Castle Meadow. In Fig. 36 the new modified electronics give a much more stable baseline and a known area of high nitrogen dioxide, an area of concern, is identified by simply walking the unit slowly through the streets and a result within an hour is equated. This compares very favourably with diffusion tubes that would take several tubes, several months before a result is obtained. Although calibrated the concentrations seem low, but it is a useful tool for profiling the length of a street – profiling from the curb side to a building does not yield results using short time periods of sampling. It is possible the device is responsive to NO and vehicle counts.

Engine Switch Off Regulation

The emissions from buses as they switch off their engines and restart a hot engine have raised concerns that excessive emissions are produced. We have found that the mean NOx from start up is 160ppm compared to a mean of 512ppm during a 'test cycle' where the maximum peak NOx was 1192ppm. On engine start up, NOx is much lower than the mean NOx from normal use. The benefits of a cut in NOx from engine switch off can be clearly seen and as such any length of time an engine is switched off would bring air quality benefits.

C2.5 Society

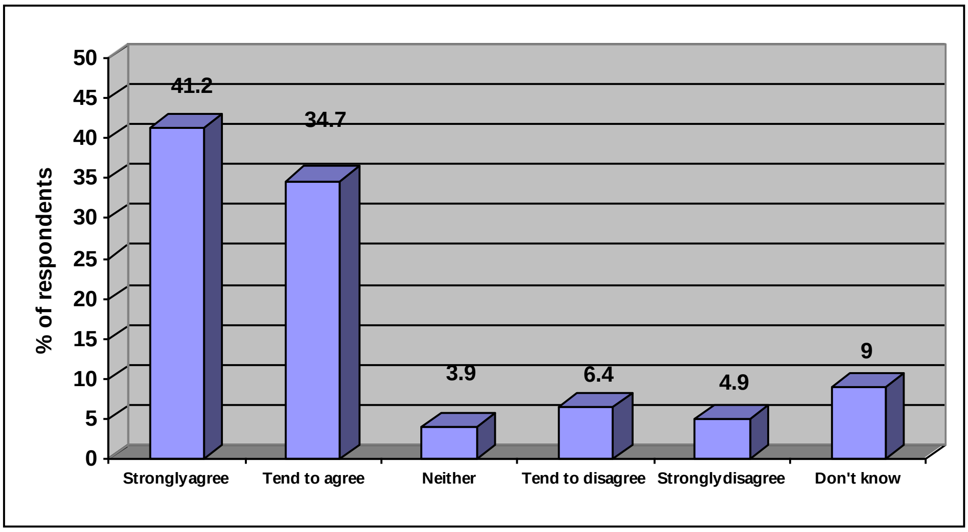
Indicator 13 - Awareness level

Building public support to improve air quality must be an integral part of the measure. In the long term, improving and sustaining air quality will require behavioural change by individuals and businesses. Individuals can help improve air quality by reducing car use and changing driving styles. Businesses can help improve air quality by implementing travel plans and reducing vehicle emissions. People's decisions about the way they travel have an impact on air quality in the city and even small changes in travel behaviour could help reduce pollution. If people are well informed about the air pollution problem and the solutions they will feel more empowered and may be more likely to do their bit to help improve air quality. It is considered that when personal travel choices are taken in isolation they may appear ineffective. However, it is starting to be recognised that the widespread adoption of 'smart choices' for alternative travel can offer genuine long-term benefits in their contribution to pollution reduction.

Telephone interviewing began on the 16 May and ran until 19 June in which time 808 valid interviews were obtained. The after data was collected in August 2008.

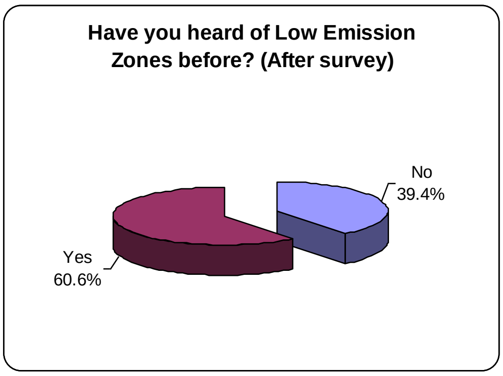
The results of the interview survey conducted before and after the implementation of the LEZ indicate that awareness levels of the LEZ have increased significantly. There was a 4% (35 people) rise in the number of people who had heard of LEZ's before. The number of respondents who were aware of a LEZ in Norwich had increased three-fold to 17%, with a 10% increase in the number of respondents who were aware of where the LEZ is located. Over three quarters (75.9%) of respondents either strongly agreed or tended to agree that the introduction of a LEZ would reduce pollution and bring health benefits for people living and working in Norwich. This statistic is very encouraging as people are very much aware of the benefits associated with LEZ's. Conversely more than one respondent in ten (11.3%) either strongly disagreed (6.4%) or tended to disagree (4.9%), see graph below:

Fig. 37. Agreement that the introduction of a Low Emission Zone in Norwich will reduce pollution and bring health benefits for people living and working in Norwich

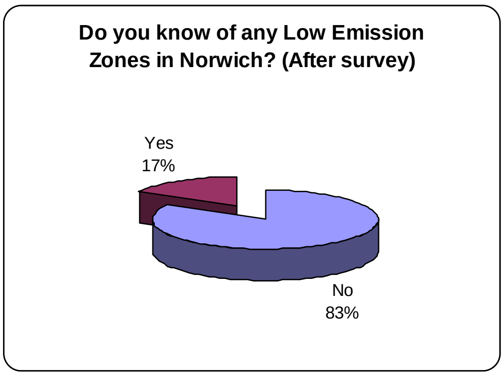


AFTER IMPLEMENTATION RESULTS

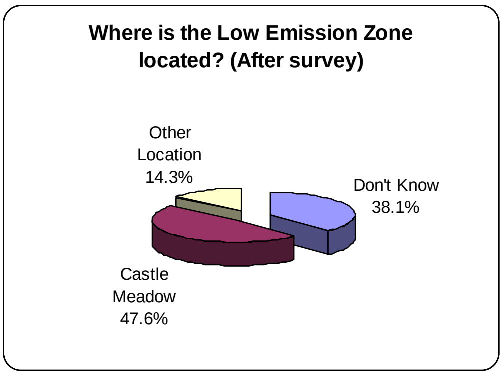
Three fifths (60.6%) of respondents had heard of low emission zones (LEZ's) before.



Approximately 3 out of 20 respondents said that they knew of a LEZ in Norwich

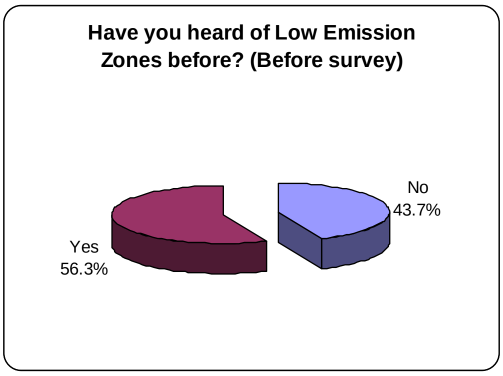


Just under one half (47.6%) of respondents who said they knew of a LEZ in Norwich thought that it was located in Castle Meadow, just under two fifths (38.1%) did not know whilst one in seven (14.3%) thought it was in another location.

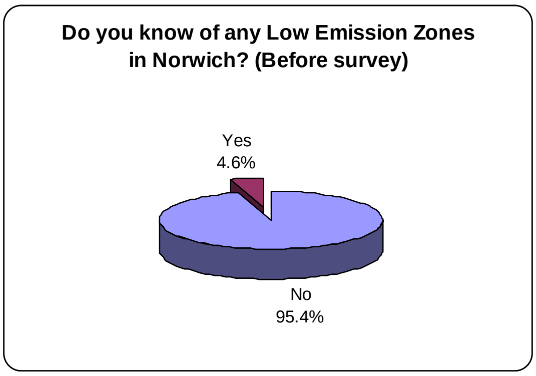


BEFORE IMPLEMENTATION RESULTS

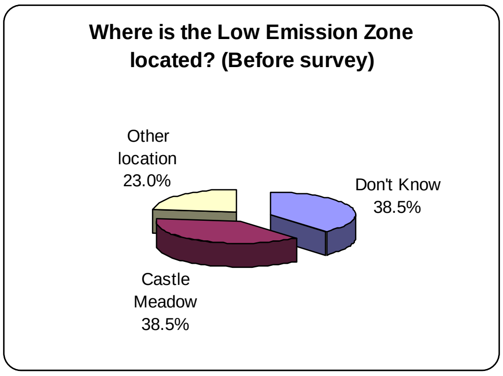
Just under three fifths (56.3%) of respondents had heard of low emission zones before.



Just one in twenty (4.6%) said they knew of a LEZ in Norwich



Just under two fifths (38.5%) of respondents who said they knew of a LEZ in Norwich thought that it was located in Castle Meadow, just under two fifths (38.5%) did not know whilst almost one quarter (23.1%) thought it was in another location.



C3 Achievement of quantifiable targets

No.	Target	Rating
1	Prohibit access into Castle Meadow for < Euro III buses	**
2	Improve public perception that exhausts are cleaner	**
3	Convert 5 taxis to LPG operation (at Euro IV)	0
4	Retrofit of vehicles to compliment the LEZ (see further under Description)	***
5	Retrofit 30 fire service vehicles	**
6	Implement supplementary measure such as 'Engine Switch Off' for vehicles and Eco-driving training	***
NA = Not Assessed 0 = Not achieved * = Substantially achieved (at least 50%) **= Achieved in full *= Exceeded**		

Evaluation

C4 Up-scaling of results

If following a long term review of the Norwich LEZ following the CIVITAS project, it appears positive outcomes have been achieved for both the perceived and actual levels of air quality in Castle Meadow, which can be attributed to introduction of the LEZ, consideration could be given to increase the area the LEZ covers. In must be borne in mind however, that at present due to Castle Meadow already having access restrictions it is far easier to monitor which vehicles are entering Castle Meadow and due to the good working relations Norfolk County Council have made with bus operators it is easier to engage them in new ideas. If extending the LEZ to other streets did occur, where access restrictions were not in place it would be increasingly difficult to identify which parties would be affected. In many instances this will be the first contact Norfolk County Council would have made with these stakeholders and may make progressing an extended LEZ more difficult.

Euro IV emission engines will eventually replace all Euro rated buses over time as the older buses come to the end of their useful life A further consideration with regard to up scaling could be to raise the Euro standard required to comply with the LEZ.

A further option could be to increase the number of retrofitted buses in service. From the prediction model it can be seen that if all buses were retrofitted to Euro Standard III, the level of NO_2 in Castle Meadow would reduce to 30ug m^{-3}.

If all the bus fleets comply at all times in this area then it could be assumed residence time is reduced by say 1 min which cuts residence time down say from 4 minutes per passenger to 3 minutes, NO_2 levels in Castle Meadow to 35ug m^{-3}. Further engine switch off TRO's could be implemented in other areas of the city, for example if engine switch off included St Stephens it is predicted that NO_2 in this street would fall to 39ug m^{-3}. Most benefit will be seen if older lower Euro Standard buses switch off for any length of time in the city. However, for all buses any length of time that the engines are not running will result in reduced emissions.

A further consideration would be to encourage bus operators to undertake further eco-driver training and also have annual refresher courses as eco-driving technique apparently diminishes with time after training as previous driving habits most often return. The pollution reduction by eco-driving and the effect on air quality will depends on the number of buses and the engine Euro rating. It would be sensible to train the drivers of all the older buses first if resources are limited as Pre-Euro to Euro II vehicle drivers will have most effect on pollution reduction.

Various future scenarios can be seen in **Appendix H**, the model uses the data inputs – specific vehicle counts, Euro engine ratings, engine NO_2 emissions per km, selected engine powers of buses, HGVs, cars, taxis and LGVs. The nitrogen dioxide concentration mean for one month in $\mu g\ m^{-3}$ can be predicted for the Castle Meadow LEZ area (CM - LEZ) and St. Stephens Street (possibly will be included in the LEZ in the future).

Assumptions made in compiling the model are that Castle Meadow and St Stephens are completely isolated in the model from the rest of the city air pollution (background concentration) which in reality is not true but any pollution from other areas has to pass over or through relatively small gaps, roads, pedestrian walkways between buildings in the street canyon. Also the same basic calculation was used to form St Stephens Street model as used for Castle Meadow. In some calculations the vehicle emission ratings for vehicles other than buses, such as cars or taxis, remained unmodified or static when future bus events were predicted for simplicity. This is because the bus fleets by the larger engine size per vehicle compared to taxis and passenger cars and due to the frequency of passing through these bus interchange areas are expected to have the dominant effect on the air quality.

C5 Appraisal of evaluation approach

On review, in general the evaluation of measure 6.2 worked well with all significant parts of the project being evaluated to good standard and giving good data sets. Utilising multiple nitrogen dioxide diffusion tube monitors within the LEZ with continuous monthly monitoring proved to be very good as this targeted total individual street coverage and extended monitoring methodology which is rarely used due to expense and man power requirement. The relocation of the air monitoring station and leaving in situ for a longer time period than normal was beneficial. However, as stated a longer prior to implementation period would have aided in drawing out exact causes and benefits.

Portable automotive approved analysers (*Horiba and Autologic* co.) factory customised and with additional modifications were used for ‘real-time’ bus exhaust gas measurement for nitrogen dioxide (NO_2), smoke, carbon monoxide (CO), carbon dioxide and hydrocarbons (HC). This allowed more flexible monitoring and the NO_x results obtained will allow modelling, prediction of any changes in air quality within the LEZ.

Traffic flow data proved hard to obtain, particularly for St Stephens Street as there are no appropriate SCOOT loops in this street. It may have proved beneficial to provide permanent automatic traffic counts; however there are significant costs involved.

It proved very difficult to draw out exact sources of pollution from background pollution levels and it was also difficult to determine the exact affect each separate component of the LEZ had on overall air quality i.e. exact affect of engine switch off and eco-driver training had on air quality. Several years of LEZ pollution data are required to determine in detail any changes, trends or seasonal variation in ambient air pollutant concentrations, unfortunately this was not possible in the life of CIVITAS.

It proved difficult to assess the exact fuel savings attributed to eco-driver training as each vehicle is potentially different and as such no specific details are available. Bus operators are also very reluctant to give fuel information to outside parties. As FIRST bus undertake eco-driver training in–house there is no data available and as FIRST have the largest share of services it would have been beneficial to obtain data.

Establishing data for the length of time buses switch off and the benefits involved is difficult to evaluate, the use of Busnet has helped, however assumptions are made and exact timings are not available.

With regard to the awareness questionnaire more specific in depth questions regarding the LEZ and in particular the other components of the LEZ would have given a more comprehensive guide to actual awareness, for example questions such as have you noticed an increase in the number of buses turning engines off or do you feel less pollution is evident in Castle Meadow. A question related to levels of noise may also have been of help.

Following retrofitting it would have been advantageous to monitor individual vehicles, both buses and fire trucks which would have given more accurate air pollution results, however this is time consuming and costly. One bus was monitored in real conditions however, every vehicle varies from another.

C6 Summary of evaluation results

The key results are as follows:

● Restricting access to Castle Meadow for buses with an emission Euro Standard of below Euro III has been implemented. The LEZ became operational in July 2008 and is regulated using a Traffic Regulation Condition. Monitoring will continue past the life of CIVITAS

● Public perception has increased following the implementation of the LEZ. 75.9% of respondents either strongly agreed or tended to agree that the introduction of low emission zones in Norwich will reduce pollution and bring health benefits for people living and working in Norwich.

● Unfortunately due to problems mentioned throughout this report at present we have not converted any taxis to LPG, however it is still hoped that as technology and public acceptance of environment issues increase some taxis will be converted in the near future.

● Retrofitted 25 First buses using SCR technology. In addition to this, two buses from Neaves under went retrofitting and a contribution was made to the Norwich tour bus in order to fit a new Euro IV engine.

● 30 Fire service vehicles have been retrofitted.

● Additional supplementary measures were implemented including engine switch off TRO and 92 free eco-driver training sessions.

● It is clear that the ‘Natural’ evolution of the bus fleets will not bring fast enough changes to lower the levels of NO2 to meet Government guidelines, due to the age of the main First bus fleet and the small number of new vehicles purchased over two year intervals. It has been found that the bus fleets have the dominant influence on air pollution and air quality in the Castle Meadow LEZ.

MEASURE RESULTS (Data analysis: September 2005 – July 2008)

All concentrations µg m^{-3}

Background concentrations in Norwich centre for 2007, 2008:
NO_2 = 23, 28 (both well within limits)
PM_{10} = 22, 23

Castle Meadow concentrations 2007, 2008
NO_2 = 56 (air station), 47, 52 diffusion tubes (over limit respectively)
PM_{10} = 23 (now over new 20 proposed limit)
$PM_{2.5}$ = 15

St. Stephen’s Street concentrations 2007, 2008
NO_2 = 55, 57 (over limit)
PM_{10} = 20* (would be on new limit)

$PM_{2.5}$ = 14*
* Historic 1999 – 2000, no current particulate measurements in St. Stephen's St.

UEA mean of all samples from our alternative background tube located on the UEA university site near the main bus stop road.
NO_2 = 24 µg g m^{-3} No change, the same value after an extra 6 months of data.

Date range	Castle Meadow	St. Stephens Street	Red Lion St.
Oct. 05 – June 07	**46**	**50**	**47**
July 07 – Nov. 07	48	57	53
Jan. 06 – June 06	48	49	47
July 06 – Dec. 06	44	50	48
Jan. 07 – June 07	44	49	46
July 07 – Nov. 07	48	57	53
Jan 08 – June 08	49	55	53
July 07 – July 08	**49**	**54**	**53**

Tube data

Castle Meadow Automatic Air Station instrumented data

Date	Nitrogen dioxide (NO_2)	PM_{10}	$PM_{2.5}$
10 Sept. – 31 Dec. 2006	68	19	13
01 Jan. – 29 Aug. 2007	52	18	11
01 Jan.2007 – Nov 2007	51	22	14
01 Jan.2007 – Jun. 2007	56	25	16
01 July 2007 – Nov 2007	45	19	13
01 Jan 2008 – July 08	50	21	15
July 2007 – July 2008	44	17	15

D Lessons learned

D1 Barriers and drivers

D1.1 Barriers

- **Barrier 1** – The need to secure political support for the measure was a potential barrier to its implementation. This was overcome by seeking political approval from the Norwich Highways Agency Joint Committee prior to any detailed design.
- **Barrier 2** – The need to regulate the proposed LEZ was a significant barrier as it was felt that a TRO would be too rigid (all or nothing approach). To overcome this issue a TRC was applied for and obtained.
- **Barrier 3 –** The application to obtain the necessary TRC was particularly onerous as revisions were required which delayed the implementation of the LEZ.
- **Barrier 4 –** The technology associated with converting diesel hackney carriages to LPG was found not to be reliable as was thought at the outset of the project and hence taxi operators were reluctant to participate.
- **Barrier 5 –** The sheer volumes of data to be processed required considerable time.
- **Barrier 6 –** As the councils have very little control over bus operators it proved difficult to encourage them to retrofit in the early stages of the project.
- **Barrier 7 –** It proved difficult to ascertain exact Euro standards of buses in order to prioritise which buses needed abatement equipment fitted, unless expensive testing was undertaken. To overcome this registration numbers were used as proxy.
- **Barrier 8 –** It proved difficult to ascertain an exact breakdown of emission sources.
- **Barrier 9 –** The solid state monitors did not function well; software was a problem on the circuit board and as such delayed the monitoring.
- **Barrier 10 –** One of the main barriers was the time involved in obtaining background state data from which we should see any improvements to air quality levels in the LEZ.
- **Barrier 11 –** A potential financial barrier was the withdrawal of the Energy Saving Trust 'Clean Up' grant which at the outset of the project was earmarked for a significant contribution (65%) towards bus operators retrofitting costs. This delayed the programme as other funding sources were sought. This risk was mitigated by obtaining additional funding through the Local Transport Plan.
- **Barrier 12 –** Following consultation with bus operators a retrofit programme was established however the manufactures and fitters had difficulty meeting the proposed timescales due to outside influences such as the London LEZ. To overcome this problem a revised programme of works was devised however this did delay the project.
- **Barrier 13 –** The need to secure acceptance by bus operators of the proposed access restrictions in Castle Meadow was assessed as a high risk to the delivery of the measure. If bus operators objected to the TRC proposals there was potentially a need for a public enquiry which would have been a time consuming process and inevitably would have significantly delayed the progression of the measure. The strategy to overcome this barrier was the involvement of all affected bus operators as key stakeholders from the outset of the project: to ensure the proposals were flexible enough and the ability to spread the costs over a number years whilst making the regulations strict enough to meet the LEZ requirements; and finally to ensure that any issues raised were addressed without delay in order to avoid any formal objections. This risk was realised, but eventually overcome

through regular communication with the bus operators to request that approval was expedited.

- **Barrier 14 –** A general economic downturn has been witnessed in the U.K during the life of the CIVITAS project and as such private companies are more reluctant to invest in new initiatives which may be seen as a risk.

- **Barrier 15 –** Whilst the use of SCR equipment, which involves the injection of urea or ammonia, achieves significant NOx reductions, the problems of topping up and storing the reactant caused concern for some bus operators.

D1.2 Drivers

- **Driver 1 -** The main driver of the measure is the fact that Castle Meadow has been designated an Air Quality Management Area and as such there is a statutory requirement to take action to improve air quality in the area to meet Government guidelines.

- **Driver 2** – Constant pressure on the bus operators by the measure leader, supported by Norfolk County Council officers with regard to the retrofitting programme and acceptance of the TRC proposals was required to move the measure forward.

- **Driver 3 –** Businesses in Castle Meadow were eager to see pollution reduced in Castle Meadow as it was perceived that air quality in Castle Meadow was of concern. Businesses were more than willing to encourage their delivery drivers to switch engines off when making deliveries to their premises. It was felt by businesses in the area that by creating a higher quality urban environment there may be an increase patronage.

- **Driver 4 –** As part of the Local Transport Plan Norfolk County Council has made a commitment to work in partnership with district councils to develop, manage and deliver transport measures to reduce emissions in Air Quality Management Areas. The targets of the LTP are to reduce nitrogen dioxide levels by 20% on 2004 levels in Norwich Castle AQMA by 2010.

D2 Participation of stakeholders

- **Bus operators -** Thorough consultation was undertaken with all bus operators at the outset of the project to gauge opinion and obtain an understanding of setup of current fleets and ways forward to meet the proposed LEZ criteria. It became apparent at an early stage that some operators were more willing to engage than others. However, following the advertisement of the proposed TRC many more operators became involved. The majority of operators were very supportive of the retrofit programme and interested in obtaining grants towards the costs of fitting abatement equipment in particular First Eastern Counties buses who were partners in the project. Anglian bus, who were also partners in the project showed a keen interest to retrofit however it was decided that due to the fact they were involved in the bio-diesel trials, this may not give a true representation of the benefits of retrofitting. With regard to the offer of free Eco-driver training, all operators with the exception of First Eastern Counties (they supply in-house training) showed a keen interest and the majority of operators sent a number of their drivers onto the 2 hour or half day courses. The feedback of the eco-driver training was very positive from all operators.

- **Fire service –** The Norfolk fire service was very receptive to the idea of retrofitting a number of fire trucks and gave very positive feedback. One issue was finding a suitable time to take each vehicle out of service.

- **Norwich Hackney Trade Association –** Consultation was undertaken with the association to gauge interest of the potential to convert Hackney carriages to LPG. This proposal was initially met with strong opposition, however following further dialogue some of the taxi operators showed increased interest. Concerns still remained with regard to the reliability of the conversion equipment and taxi operators remained apprehensive and were reluctant to commit financially to a relatively untested technology which may jeopardise their source of income.

- **Businesses in Castle Meadow –** Businesses in Castle Meadow were consulted with on both the LEZ itself and the engine switch. Responses to both proposals received very good levels of support. Many businesses in Castle Meadow embraced the engine switch off and encouraged their delivery drivers to switch engines off when making deliveries.

D3 Recommendations

Recommendation 1 - Consideration should be given to the use of a TRC instead of a TRO as a regulatory tool for a LEZ as it provides greater flexibility recognising that in the short term it may not be cost effective to retrofit buses which infrequently enter the LEZ. This approach will also allow operators more time to comply and for compliance costs to be spread over a number of years.

Recommendation 2 - As LEZs become more common throughout Europe it would be beneficial to have a consistent approach to LEZs so that similar criteria to admit or exclude vehicles be consistent throughout Europe with regard to signing, required emission levels, hopefully the CIVITAS project can help achieve this.

Recommendation 3 - It is important to encourage local availability of cleaner alternative fuels especially LPG, this was one of the factors which has delayed the conversion of diesel taxis to LPG within the CIVITAS project.

Recommendation 4 – It is beneficial to share experiences and problems with other interested bodies such as other councils. Attending or setting up Low Emission Strategies Forums are good sources of information sharing.

Recommendation 5 - Consideration should be given to promoting measures which result in benefits for both air quality and climate change. Ensure that abatement technologies do not have disbenefits for CO_2 emissions and do not impinge on local/national commitments to reduce greenhouse gases. At a basic level, a measure that results in a ‘win’ for air quality and a ’win’ for climate change would be one that reduces the emissions of all pollutants that are important to both issues. A win-win measure is broadly defined as one that is likely to result in reductions of pollutants of importance to air quality and climate change relative to a business as usual case. Furthermore, in some cases there can be other trade offs. Some measures, for example, might reduce most air quality pollutants but result in the increased emission of another air quality pollutant. There are inherent methodological difficulties in identifying the impact of measures on emissions of pollutants of concern from an air quality perspective and those that have impacts, directly or indirectly, on climate. It is vital that councils consider emissions of greenhouse gases and air quality pollutants together; it is important to develop a holistic approach to the control of NO_2 and PM. A holistic approach is key when considering the combined issue of climate change and air quality.

Recommendation 6 - It is paramount that early consultation is undertaken with bus operators and all affected stakeholders at the earliest possible stage. It is important to work in partnership with bus operators to reduce vehicle emissions, providing them with assistance, support and information to help them identify practical solutions for retrofitting of emissions reduction equipment that will not unduly burden them with additional costs.

Recommendation 7 – The implementation of the LEZ could be taken up by other cities who have similar air quality issues to those seen in Norwich. Involvement of bus operators at an early stage was vital to success of the measure.

Recommendation 8 - This project has focussed on a narrow range of pollutants (NO_2 and PM) and has considered air quality and not impacts on climate change. It is therefore difficult to assess the overall impacts of different measures to air quality and climate change issues.

Some consideration should be given to cumulative emissions over a specified time period when assessing different measures.

Recommendation 9 – Detailed consideration should be given to developing better means of expressing the influence of air quality pollutants on climate, and for inter-comparing the benefits of abatement strategies in respect of air quality and climate change.

D4 Future activities relating to the measure

As the LEZ becomes progressively more stringent up to 2010 its proposed objectives will be monitored and evaluated. Feedback from this monitoring process should allow the LEZ to be refined and further developed to ensure that the scheme is meeting its objectives, this may include extension of the existing LEZ. Consideration should be given to how the extension may impinge on other stakeholders such as private businesses/delivery vehicles/private cars etc. and how the extended LEZ is regulated.

Over the next 2 years the criteria for the LEZ will increase until 100% of the most frequent buses must comply with Euro III Standard by 2010. As part of this, on going monitoring of bus operators fleets to give information on the exact Euro Standard makeup of their fleets must be examined and verified. This monitoring will be undertaken by our Public Transport Unit team which will examine bus operator’s fleets on a six monthly basis in order to ensure compliance. In order to aid bus operators the Passenger Transport Unit will send annual reminders of the forthcoming changes in emission criteria.

Extensive on going monitoring of air quality in Castle Meadow will be undertaken by the University of East Anglia and will continue until 2010 and possibly beyond. Specialist modelling skills will be sought and negotiated at the UEA and a model licence (paid for by the UEA only not CIVITAS) for pollution modelling within the LEZ using our determined data with comparison to other city centres.

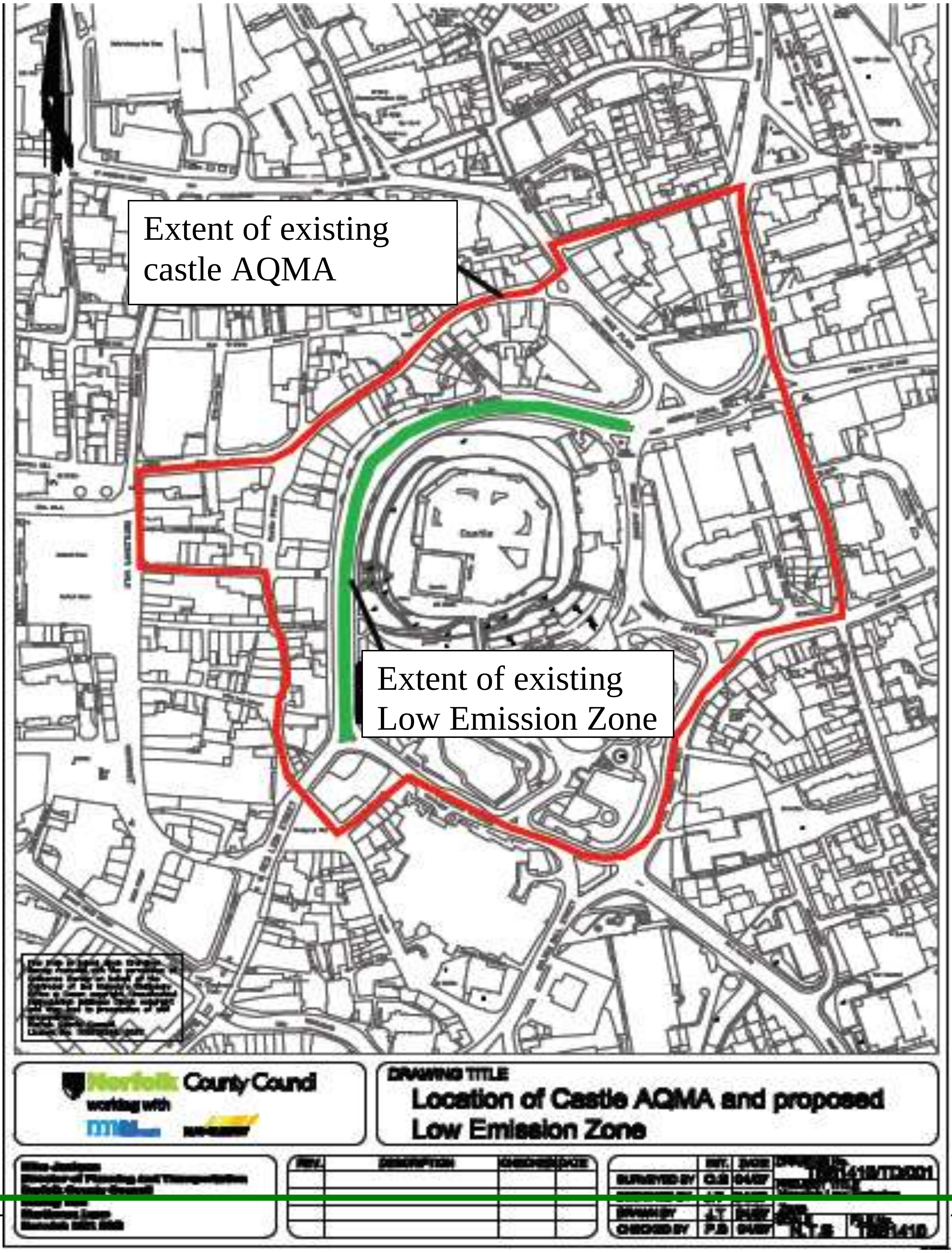
If additional funding can be secured possibly through the LTP there may be potential to offer additional retrofitting to bus operators. It is also worth considering providing additional retrofitting to municipal vehicles. The possible advantages of providing abatement equipment to municipal vehicles such as residential waste vehicles is the fact that there the councils have some control over contracts/operations.

It is proposed to undertake periodic publicity campaigns over the next few years to carry on promoting the LEZ and also highlight the fact that the emission criteria is being increased. The dissemination/sharing of experiences and lessons learnt associated with the implementation of the LEZ will continue to be undertaken both through publications and forums etc.

The enforcement of the engine switch off TRO will be continued and monitored by Norwich City Council and potentially the TRO could be provided in other streets of Norwich. As some drivers may fall back into their old driving styles following the eco-driver training it is proposed to offer refresher eco-driver training courses, which will be undertaken by Norfolk County Council’s road safety team.

Appendix A

Fig. 1 – Plan indicating extent of the Castle AQMA and newly implemented LEZ



Appendix B

Traffic Regulation Condition

Traffic Regulation Condition to be attached to the PSV operator licences of all operators currently operating or wishing to operate local bus services registered under the Transport Act 1985 where the registered route of the service includes Castle Meadow, Norwich, except for services meeting one of the following criteria.

1. Local bus services with less than five departures per week from Castle Meadow

As from 1 April 2008, 40 per cent of the vehicles used on local bus services operating in Castle Meadow, Norwich and with both registered terminal points within the area defined in Figure 1 will be required to comply with the Euro III (or equivalent) or higher exhaust emission standard.

As from 1 April 2008, 20 per cent of the vehicles used on local bus services operating in Castle Meadow, Norwich and with a registered terminal point outside the area defined in Figure 1 will be required to comply with the Euro III (or equivalent) or higher exhaust emission standard.

As from 1 April 2009, 70 per cent of the vehicles used on local bus services operating in Castle Meadow, Norwich and with both registered terminal points within the area defined in Figure 1 will be required to comply with the Euro III (or equivalent) or higher exhaust emission standard.

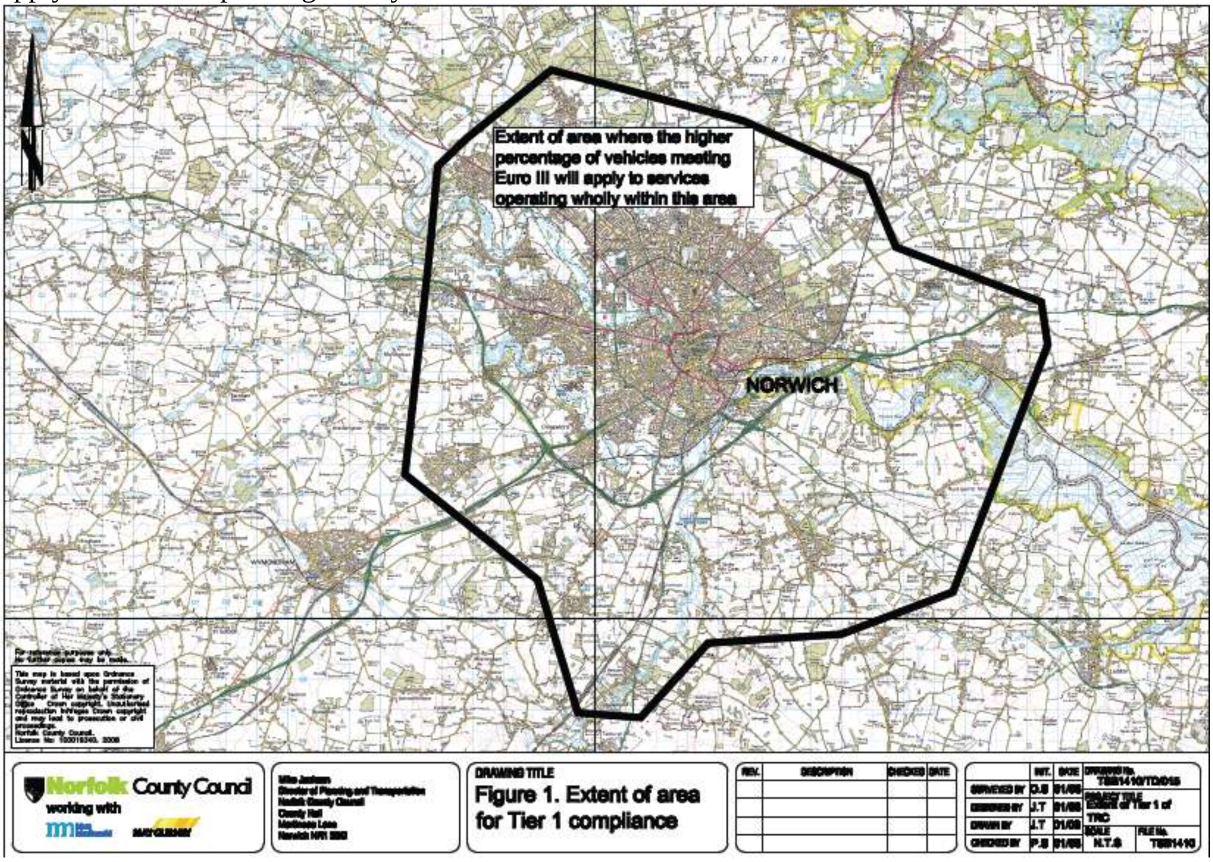
As from 1 April 2009, 35 per cent of the vehicles used on local bus services operating in Castle Meadow, Norwich and with a registered terminal point outside the area defined in Figure 1 will be required to comply with the Euro III (or equivalent) or higher exhaust emission standard.

As from 1 April 2010, all vehicles used on local bus services operating in Castle Meadow, Norwich and with both registered terminal points within the area defined in Figure 1 will be required to comply with the Euro III (or equivalent) or higher exhaust emission standard.

As from 1 April 2010, 50 per cent of the vehicles used on local bus services operating in Castle Meadow, Norwich and with a registered terminal point outside the area defined in Figure 1 will be required to comply with the Euro III (or equivalent) or higher exhaust emission standard.

In order to monitor compliance with this Condition, as from 1 April 2008 PSV operators must supply details of the emissions capability as defined by the equivalent Euro exhaust emissions standards of each vehicle within their bus fleet used on local bus services operating in Castle Meadow to the Director of Planning and Transportation, Norfolk County Council. Updated information is to be supplied to the Council at six monthly intervals for receipt by 31 March and 30 September each year.

Fig. 2 – Map showing extent of area where the higher percentage of vehicles meeting Euro III will apply to services operating wholly within this area



Appendix C

Existing and Future Fleet Compositions

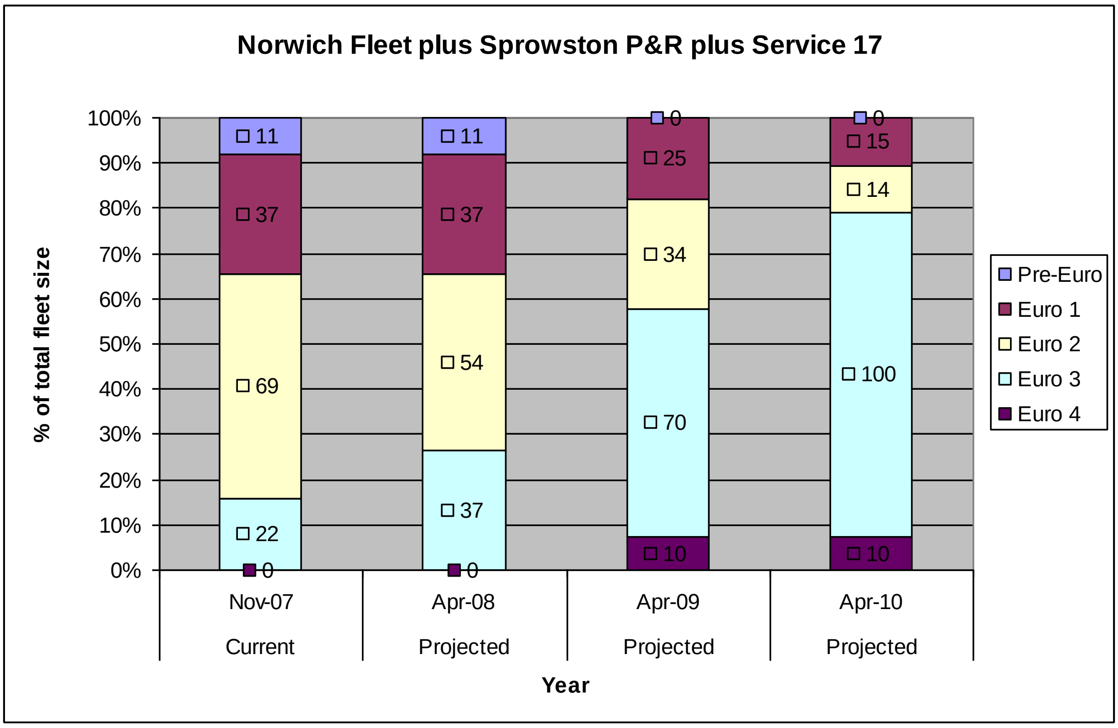


Fig. 3. Shows projected numbers of particular Euro Standards in the bus fleet of Norwich

The table below shows the number of departures of each operator from Castle Meadow in a 24 hour period. It can be seen that the operator First has significantly the most departures. It is estimated from

Operator	Code	No Departures	% Total

SCOOT loop data that 24 hour two-way vehicle flow in Castle Meadow is approx 3438. As can be seen below buses represent over half of all vehicle movements.

First	EC	1453	77.70%
Norfolk County Services	NCX	207	11.07%
Sanders	SA	79	4.22%
Anglian	AN	76	4.06%
Neaves	NE	18	0.96%
Eastons	ES	10	0.53%
Awayadays (Norwich Tour)	AWA	8	0.43%
Simonds	SIM	6	0.32%
Norfolk Green	NG	5	0.27%
Semmence	SE	4	0.21%
Travel Royall	AMZ	2	0.11%
Carters	CL	2	0.11%
Total		**1870**	**100.00%**

Appendix D

Images of Air Monitoring Equipment

Testing the portable solid state NO_x sensor unit on the mobile air quality station at the roadside in Castle Meadow.

Custom modular emission equipment

Portable air sampling NO_x instrument)

Diffusion tube in situ

Appendix E

Additional Baseline Air Quality Data

NO at concentrations of several hundred parts per million (ppm) the precursor of NO_2 (secondary pollutant produced over several hours from NO in the atmosphere) in urban atmospheres will be emitted from engine exhausts particularly diesel engines without catalytic converters fitted. The values indicated in the main report are not unexpected especially from roadside sampling compared to background statutory monitoring. As an example comparison Marylebone Road, London is frequently used as a comparison example of a very congested UK road and mean concentrations monitored for the period 1 Sept 2005 – 17 Feb. 2007 are as follows:

NO_2 115 µg m^{-3}
PM_{10} 47 µg m-3
$PM_{2.5}$ 27 µg m-3

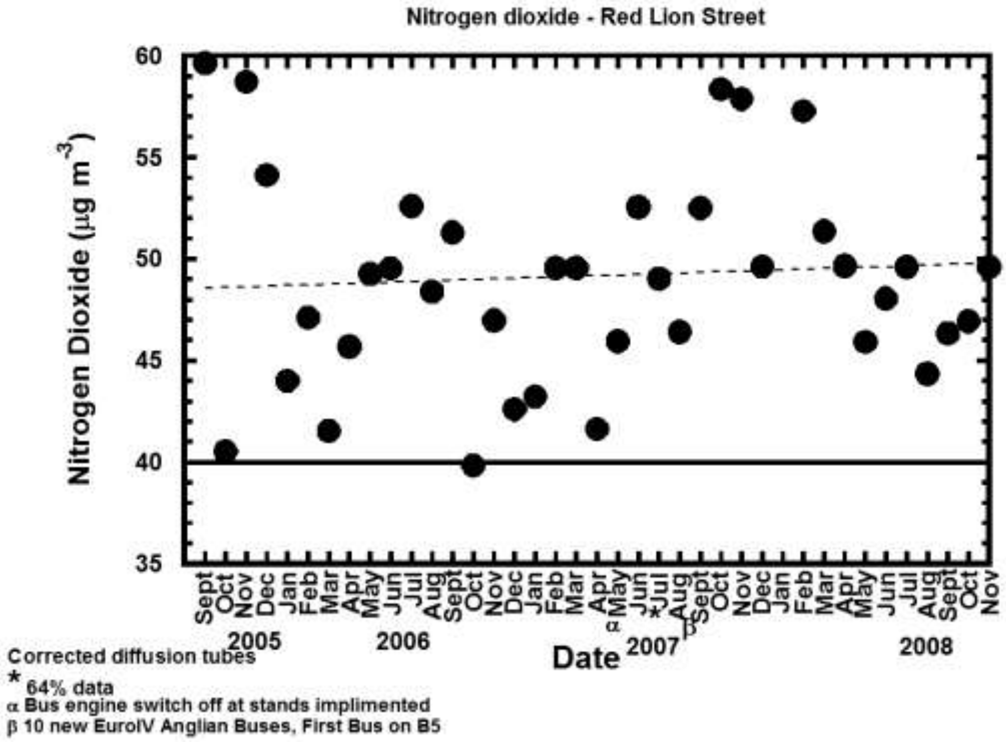


Fig. 5. Red Lion Street – for comparison as it connects Castle Meadow to St. Stephen's street.

Figure 5 above is the mean of two duplicate sample positions in Red lion Street and the trend line indicates relatively consistent NO_2 concentrations for the monthly mean values with a possible very slight upward trend now compared to a much steeper upward trend when the data are fitted to June 2008. Therefore, a slight improvement in air quality can be seen in Red Lion Street.

The figure below (***Fig 6***.) displays the diffusion tube data with a linear regression trend of increasing nitrogen dioxide with time. The diffusion tube monthly mean value deviates from the monthly mean of the hourly mean automatic air station data, trend of decreasing NO_2 with time – the air station monitored nitrogen dioxide concentration is predicted at the statutory 40ug m^{-3} (2010) concentration now. One possible explanation on this deviation of the monthly mean diffusion tube concentrations and the more instantaneous chemiluminescent instrument measurements is shown in the updated principle component analysis graphs shown later in this report showing the effect of wind.

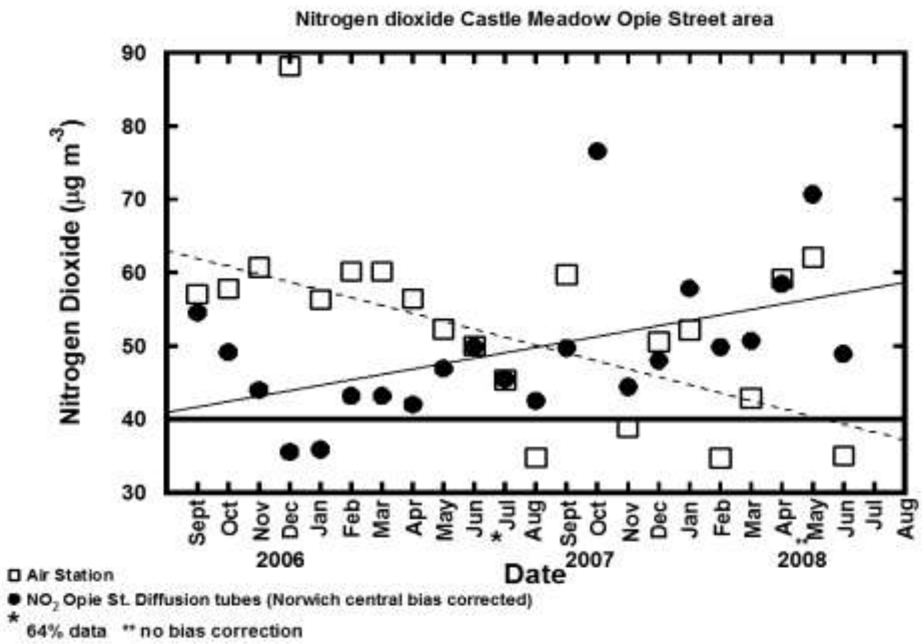


Fig. 6. Monthly NO_2 data from the automatic mobile air station in Castle Meadow to Nov. 07.

Appendix F

Additional Results

The plots below (***Fig. 12*** and ***13***.) display the individual sample point data for each Castle Meadow diffusion tube over the time period we have sampled during this project. They all tend to follow the same trend each month although on such as relatively short sampling campaign time series analysis is more difficult.

Figure 14displays the mean concentration over the monitoring campaign for all positions monitored including the adjoining Red Lion Street and St. Stephen's Street. From figures 15-18 it can be seen that the concentrations measured at all sample points are over the annual mean 40 µg m^{-3} (solid line). Although one Castle Meadow tube position is nearing the limit. The two higher results in Castle Meadow and St. Stephen's Street are situated some distance in the street canyons from the individual end junction road systems and are sheltered from cross winds and have numerous bus stands and bus movements.

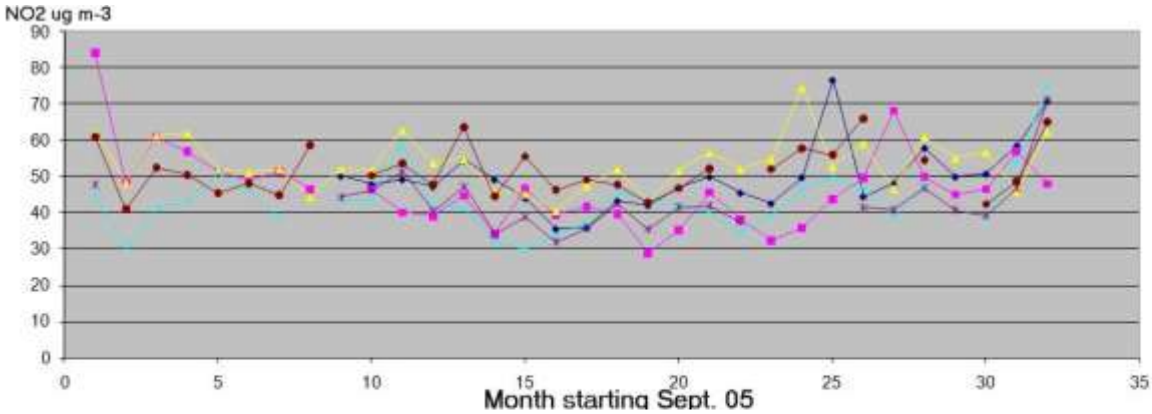


Fig. 12. Nitrogen dioxide profile of individual tube positions against time for Castle Meadow.

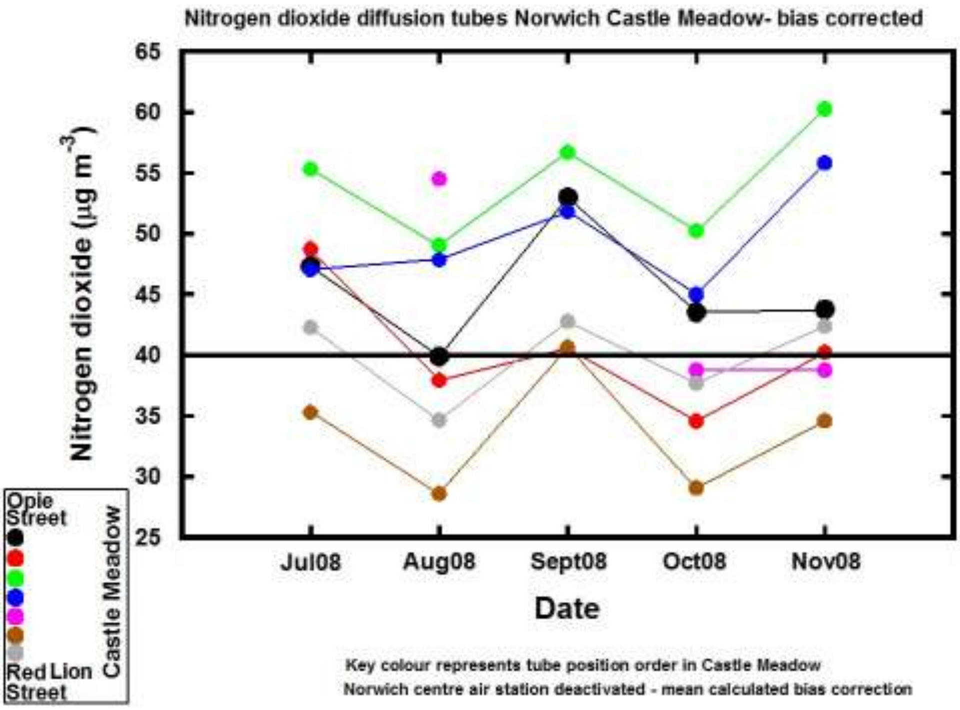


Fig. 13. Nitrogen dioxide profile of individual tube positions against time for Castle Meadow Jul08-Dec08.

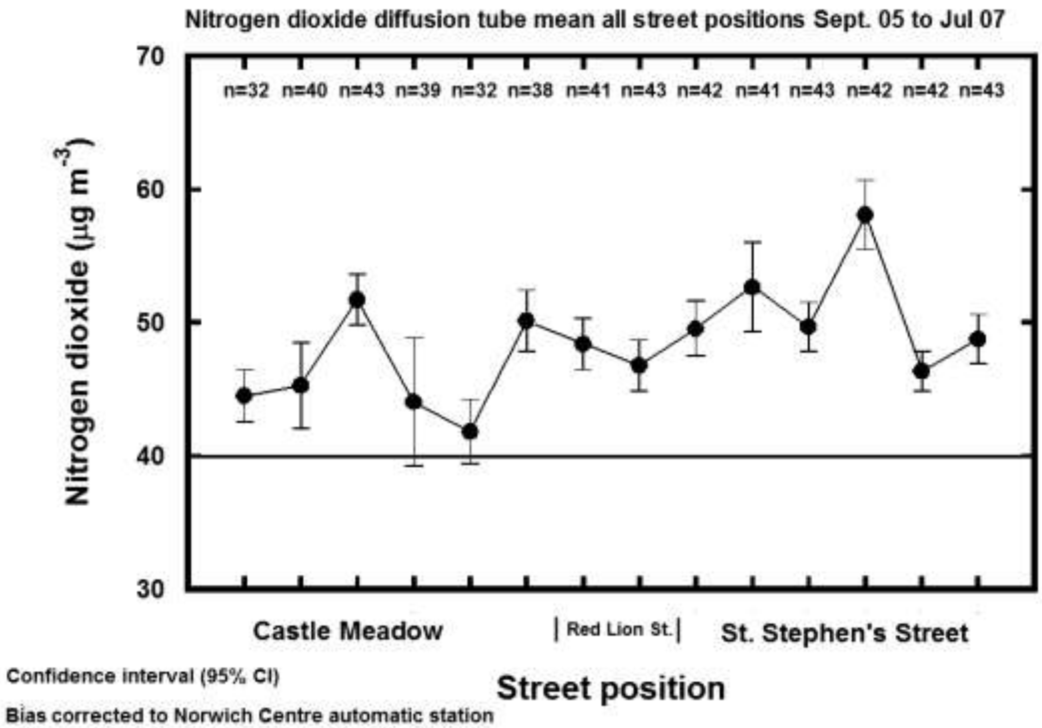


Fig. 14. Nitrogen dioxide profile for Castle Meadow through St. Stephen's Street Sept. 05 to July 07. Scale does not represent distance only that tubes have individual location positions.

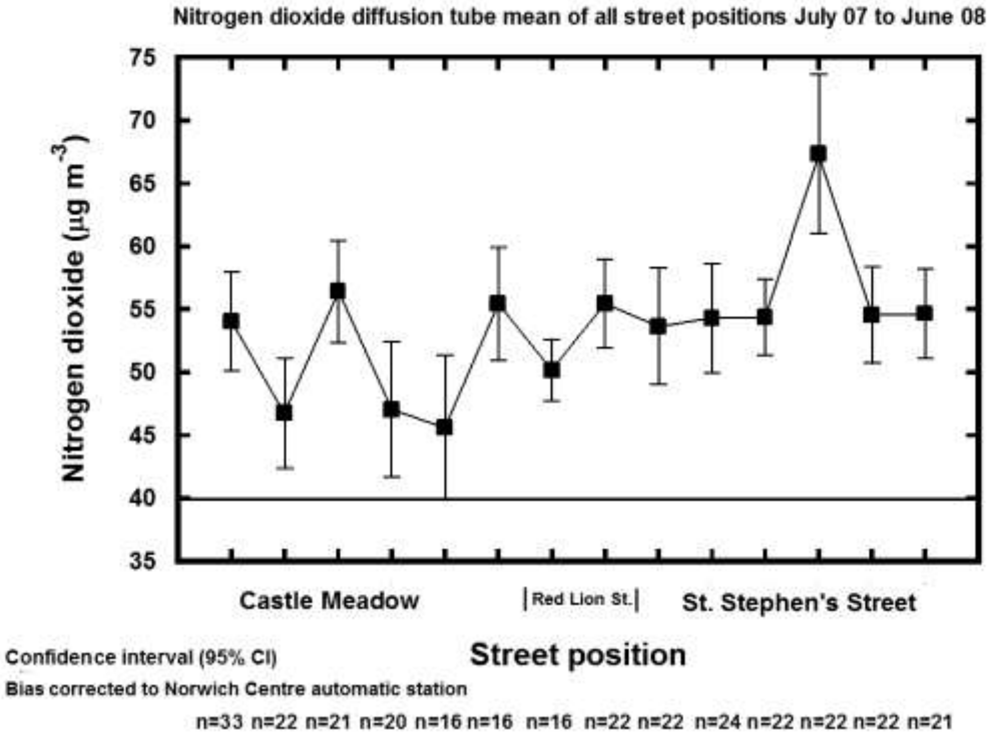


Fig. 15. Nitrogen dioxide profile for Castle Meadow through St. Stephen's Street July 2005 to July 2007. Scale does not represent distance only that tubes have individual location positions.

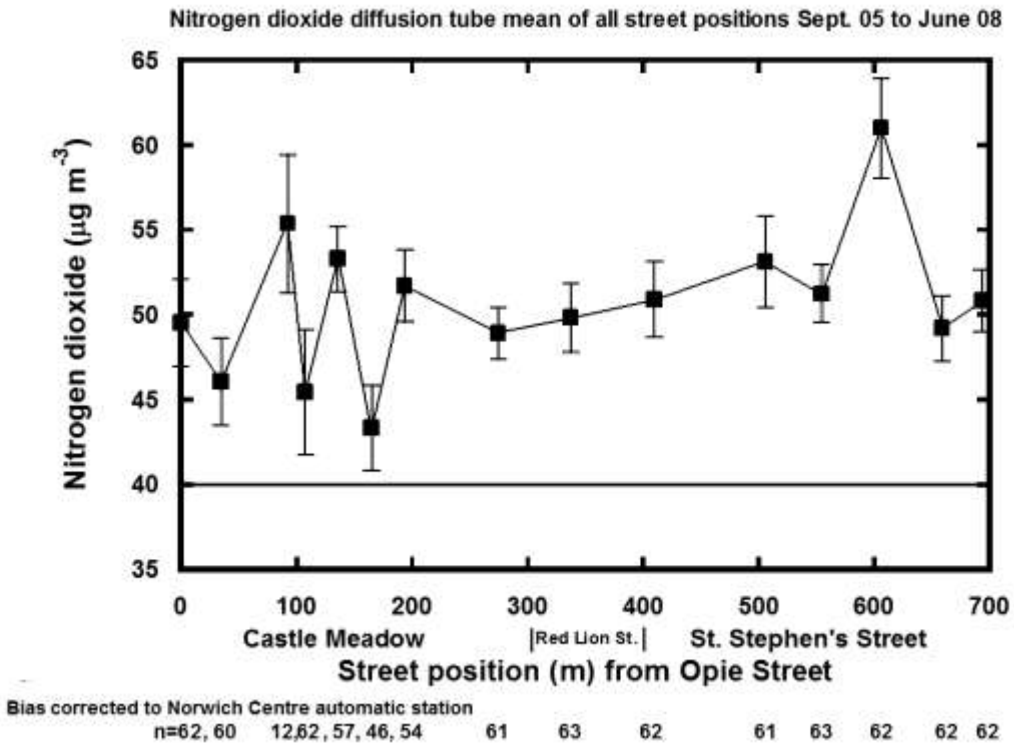


Fig. 16. Nitrogen dioxide profile along Castle Meadow and the adjoining streets – x-axis is an indication of tube position from the air station in Castle Meadow near Opie Street. Error bars 95% Confidence interval (CI) of mean.

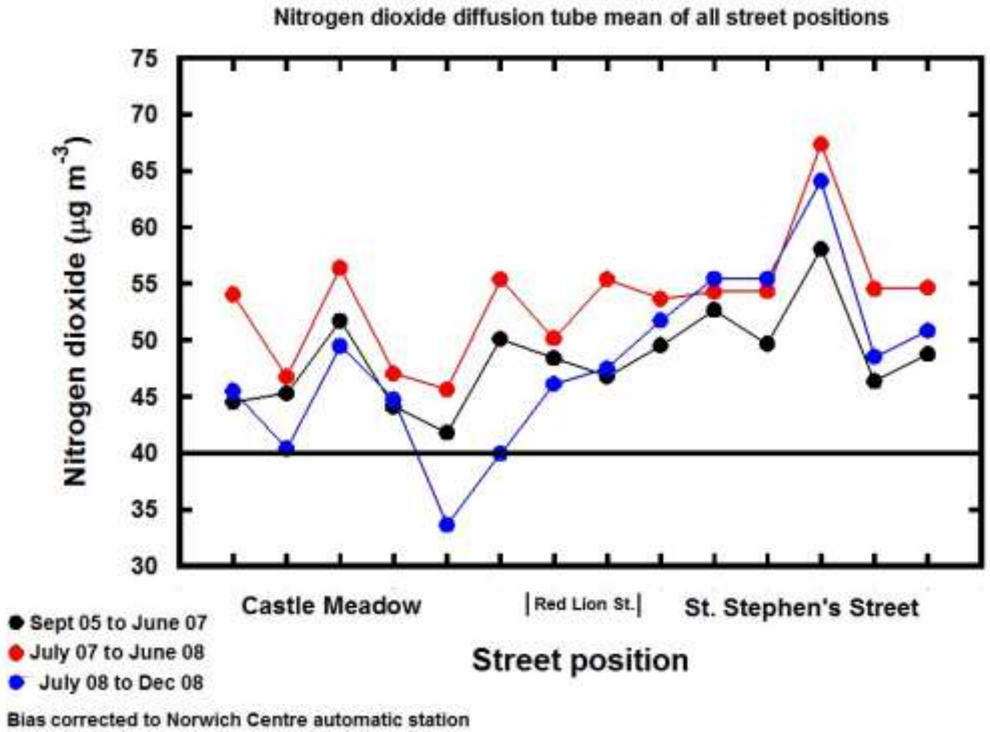


Fig. 17. Nitrogen dioxide profiles along Castle Meadow and the adjoining streets for the time periods stated before and after LEZ implementation of measures July 07 – x-axis is an indication of tube position in relation to the streets of interest and is not a distance scale.

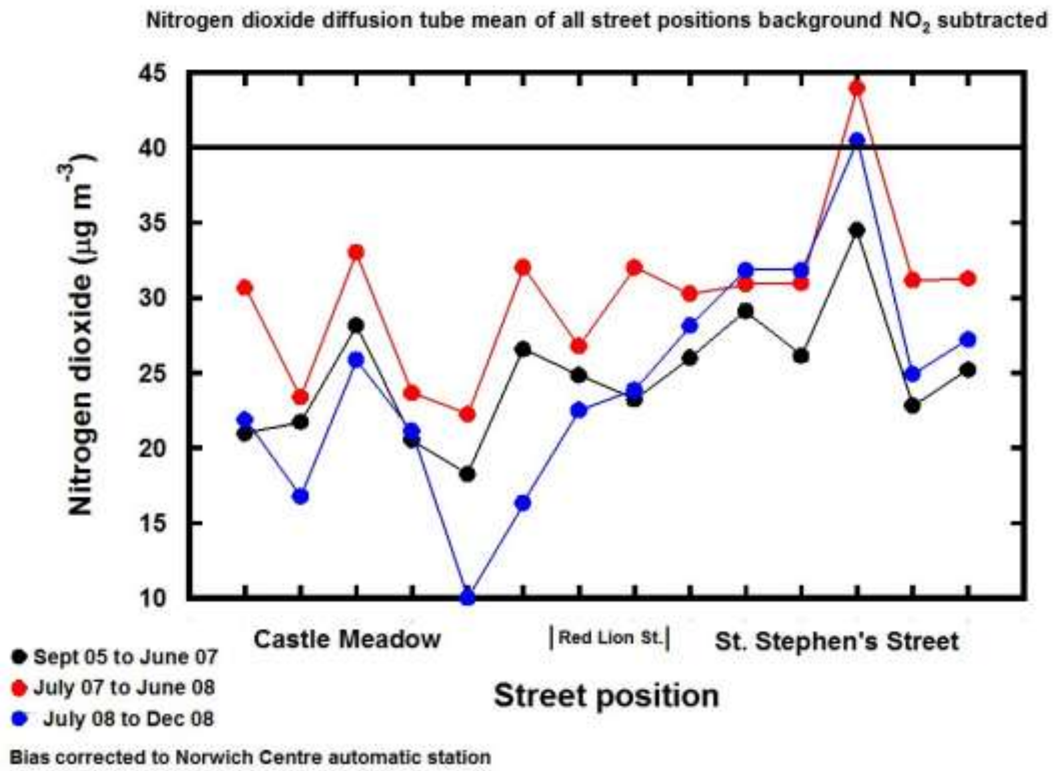


Fig.18. Nitrogen dioxide profiles along Castle Meadow and the adjoining streets for the time periods stated before and after LEZ implementation of measures July 07 with background NO_2 subtracted – x-axis is an indication of tube position in relation to the streets of interest and is not a distance scale.

Appendix G

St. Stephen's Street typically has higher concentrations of NO_2 than Castle Meadow (see ***Fig. 21*** below). One explanation could be traffic through put numbers such as cars, buses and taxis are allowed full access to St Stephens, opposed to only buses and taxis in Castle Meadow. In addition, the traffic moves very slowly in this area due to traffic control, the width of the road and there are some delays to buses entering the bus stand area due to congestion. Traffic calming which also acts as non-controlled pedestrian crossing areas also cause acceleration, transient hot spots.

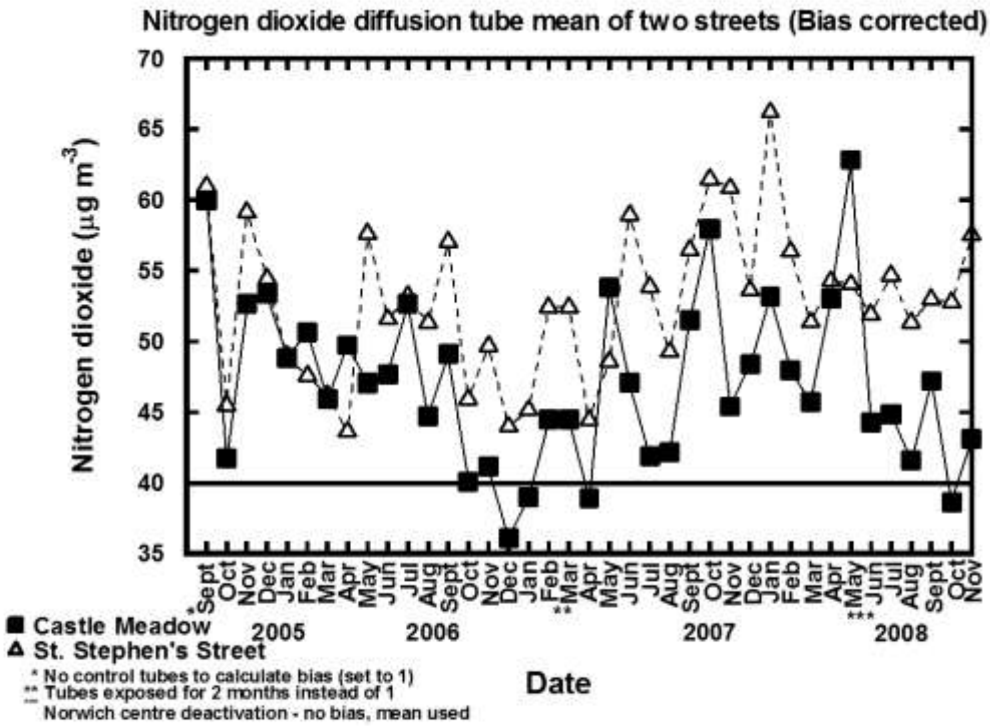


Fig. 21. The mean of all tube positions in the two streets displayed against time.

Diffusion tubes in St. Stephen's Street

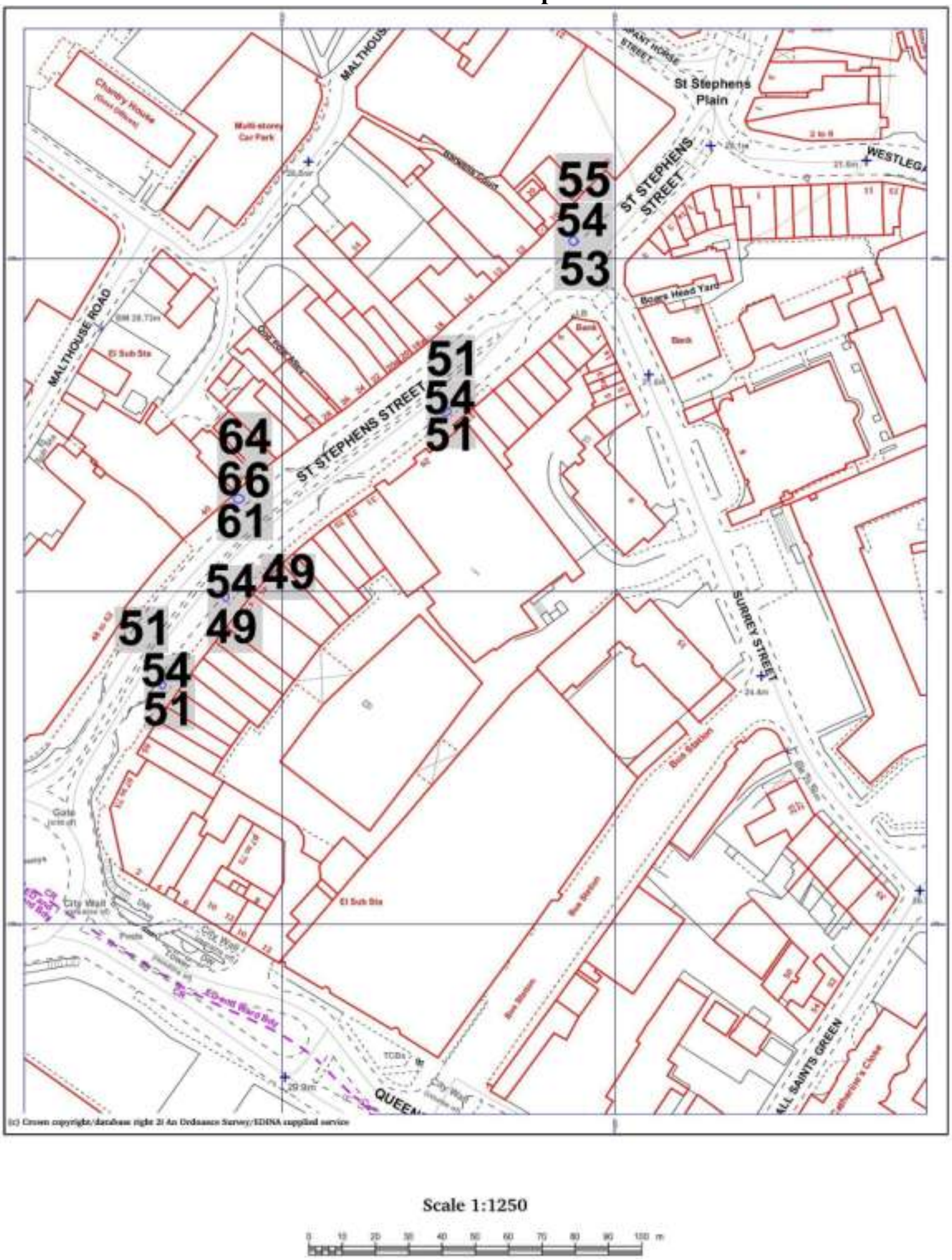


Fig. 22 Diffusion tubes positions deployed in St. Stephen's Street – ***(upper value)*** July 2008 – Dec. 2008 ***(middle value)*** July 07 – July 08 **(*lower value)*** Sept. 2005 to Dec. 2008 mean values at each position.

Nitrogen dioxide concentrations in the entire length of St.Stephen's Street remain above the yearly mean limit.

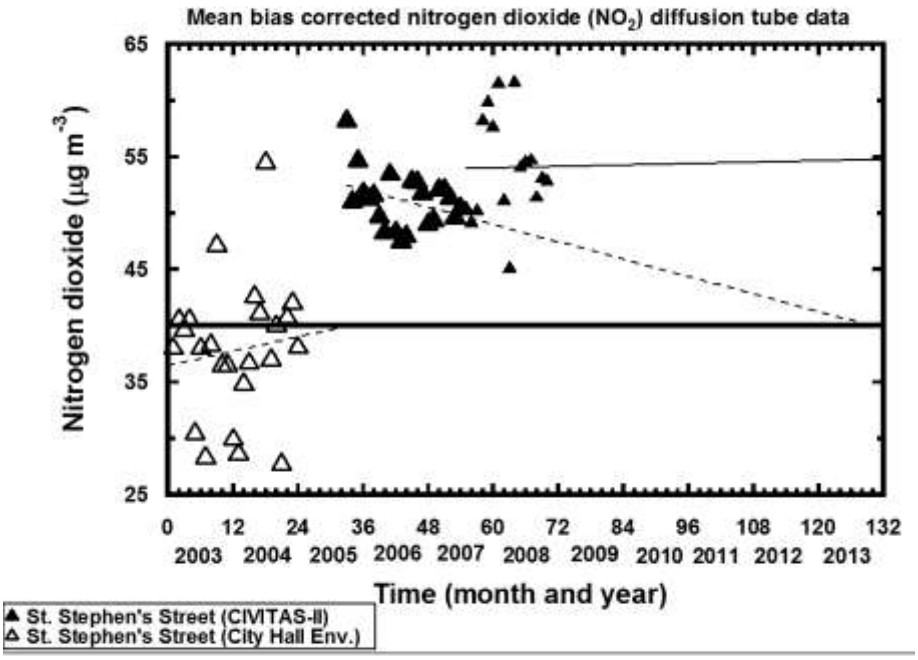


Fig. 23. Historic diffusion tube data *Open symbols* and CIVITAS tube data *Solid symbols* for St. Stephen's Street.

The St. Stephen's Street nitrogen dioxide tube data clearly indicates an increase above the yearly mean value (solid horizontal line in ***Fig. 23***) since 2003, probably due to traffic through, possibly the increase in park and ride bus frequency, but we are not aware of any traffic counts since that time period and do not have tube data for early 2005. SCOOT data does not exist for St. Stephen's Street due to lack of sensors – data from some manual surveys were available and have been used to predict various emission and traffic scenario outcomes in the accompanying model prediction report (**see Appendix H).** Linear regression of the data indicated six months ago a decrease in NO_2 and a predicted compliance with the yearly mean limit by early 2014 far beyond the required 2010. However, recently to July08 the trend was upwards, however it has levelled off but the data is quite scattered. The start of this decrease may be due to traffic saturation and engine with exhaust after treatment technological advances making there way into transport fleets and private vehicles. A further possible explanation is an increase in traffic flow as seen in Castle Meadow.

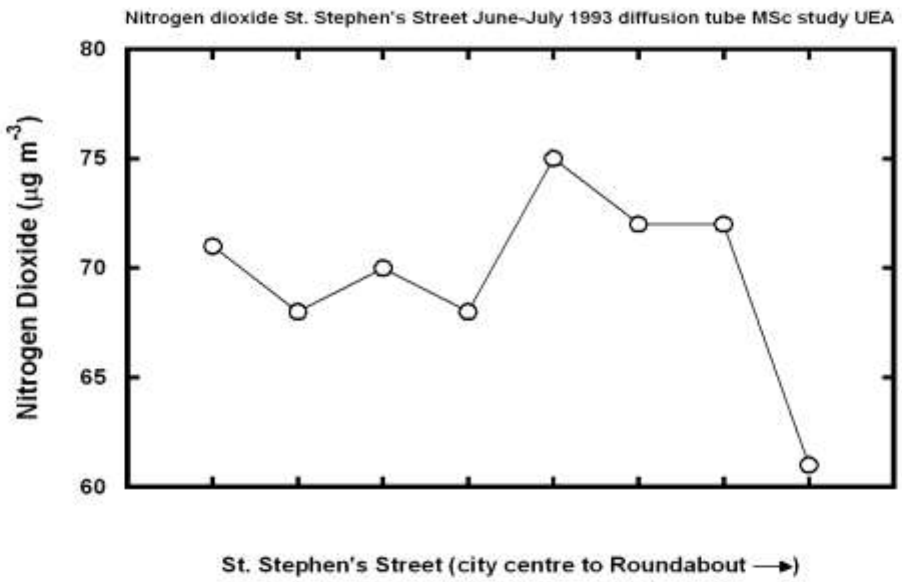


Fig. 24. Historic 1993 data NO_2 concentration profile of St. Stephen's Street (not bias corrected)

There are similarities in the trend; the street canyon in effect has not changed only some street furniture, lane separation partition and also traffic calming. This road during this time has always been a busy vehicular area and is currently very busy with buses, cars, vans and taxis with frequent traffic queues caused by a set of traffic lights. It is known that engine transient effects (frequent acceleration) produces more pollution than constantly flowing traffic even slow moving traffic.

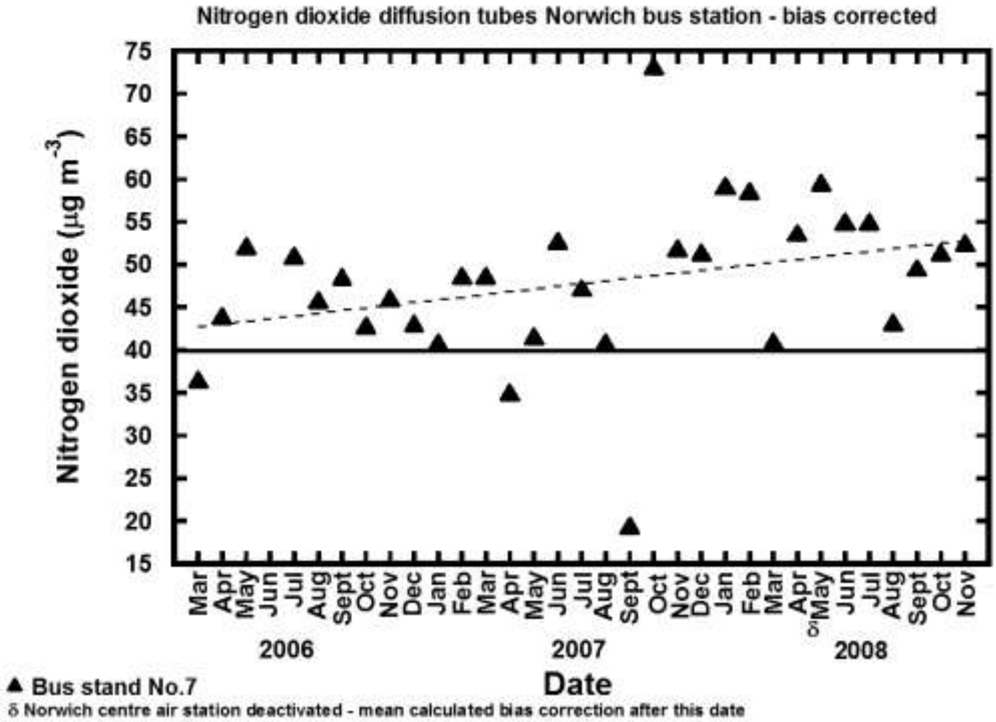


Fig.25. Norwich Bus station.

An additional study involves placement of tubes under the canopy of the Norwich bus station as many of the buses entering the Castle Meadow area also pass through the bus station. For the complete time period indicated the mean concentration of NO_2 is 48µg m^{-3}, no change in concentration from the mean of all values six months ago. Up to July 07 concentrations were 45µg m^{-3} and from July 07 to July 08 wee calculated to be 51µg m^{-3}. The mean concentration from July 08 to Dec. 08 is 49µg m^{-3}. This concentration is still lower than expected because of the vehicular throughput and the confined area. We would expect higher concentrations in this area, but Castle Meadow's mean concentration for 2008, 47µg m^{-3} of nitrogen dioxide is now lower than the bus station area. One explanation why the concentrations are lower than expected is that the location is set back from the main streets and more open to the effects of wind. Nitrogen dioxide and PM_{10} concentrations in Castle Meadow are not affected by slow wind speeds within the street canyon from our first initial results. The linear regression on these results indicates that the nitrogen dioxide concentration is likely to remain unchanged in the short term.

Appendix H

Model prediction of mean monthly nitrogen dioxide concentration and PM_{10} particulates in air within the Castle Meadow (CM-LEZ) and St. Stephen's Street

Summary of most important model prediction conclusions*

The bus fleets have the dominant influence on air pollution and air quality in the Castle Meadow LEZ and St. Stephens Street.

'Natural' evolution of the bus fleets may not bring fast enough changes due to the age of the main First bus fleet and the small number of new vehicles purchased over two year intervals.

A complete bus fleet upgrade to Euro IV vehicles driven under correct conditions is predicted to decrease LEZ nitrogen dioxide concentrations by significant amounts to make a difference to comply.

Older Bus retro-fitting will decrease the NO_2 concentration a small amount but the LEZ will still be over 40µg m^{-3} annual mean. Whole fleet retro-fitting will have the most beneficial effect but has to be considered economically against new bus purchases. In situ new vehicle manufacturer evolution is normally more efficient and effective.

LPG conversion of taxis will have little effect on the NO_2 concentrations but would help with smoke reduction.

Engine 'switch off' rigorously enforced would reduce pollution below the current limit.

Stopping cars using St. Stephen's street has no over all effect on air pollution reduction using this model. However, if they were restricted the bus residence time is expected to be reduced as the traffic queue to the traffic signals would also be reduced and, air quality could be improved.

Particles are more complex as they can be produced from dust as well as from secondary effects after emissions from exhausts.

Event Code	Predicted Event Description	NO_2 (µg m^{-3}) Monthly mean Annual mean		Model variation compared to the monthly mean NO_2 diffusion tube value (µg m^{-3})		% change compared to the monthly mean NO_2 diffusion tube value	
		CM	**St. S st**	**CM**	**St. S st**	**CM**	**St. S st**
A	**Annual 2007 mean diffusion Tube nitrogen dioxide µg m^{-3} Concentration**	**46**	**52**	-	-	-	-
B	**Prediction using current data On bus fleets and traffic Flow and vehicle classification**	46	52	0	0	0.0	0.0
C	**'Natural evolution' of the bus Fleets (could be considered as A 'do nothing situation'**	43	48	-3	-4	-6.5	-7.7
D	**12% annual increase in bus passenger numbers**	51	58	5	6	10.9	11.6
E	**A realistic 1.2% annual increase in bus passenger numbers**	47	53	1	1	2.2	1.9
F	**If all buses in fleets upgraded to new Euro IV vehicles**	25	29	-21	-23	-45.7	-44.0
G	**Annual increase in LGVs 3.3%, cars 1.5% and HGVs 2.0%**	46	52	0	0	0.0	0.0
H	**Possible variation of exhaust NOx emissions from using biodiesel in current bus fleets +5% NOx increase**	48	54	2	2	4.3	3.8

Event Code	Predicted Event Description	NO_2 (µg m^{-3}) Monthly mean Annual mean		Model variation compared to the monthly mean NO_2 diffusion tube value (µg m^{-3})		% change compared to the monthly mean NO_2 diffusion tube value (µg m^{-3})	
		CM	St. S st	CM	St. S st	CM	St. S st
I	Possible variation of exhaust NOx emissions from using biodiesel in current bus fleets -5% NOx decrease	44	49	-2	-3	-4.3	-5.8
J	All Euro IV on biodiesel with a +5% NOx increase for comparison to Euro IV engine buses on fossil diesel.	26	30	-20	-22	-43.5	-42.3
K	All Euro IV on biodiesel with a -5% NOx increase for comparison to Euro IV engine buses on fossil diesel.	24	28	-22	-15	-47.8	-28.8
L	L - *Retrofit* of 15 First bus Euro II engine buses to Euro III by April 2008	45	51	-1	-1	-2.2	-1.9
M	If an extra 10 *First* buses are Retrofitted in the future	45	50	-1	-2	-2.2	-3.8
N	Complete transformation of Main bus fleets by Euro engine Rating to a min. of Euro III	30	34	-16	-18	-34.8	-34.6
O	All Euro V with modern engine power mean value 210 kWh and NO_x emission 2.0 g kWh compliant Oct 2009. Bus fleet set to current size.	14	17	-32	-35	-69.6	-67.3

Event Code	Predicted Event Description	NO_2 (µg m^{-3}) Monthly mean Annual mean		Model variation compared to the monthly mean NO_2 diffusion tube value (µg m^{-3})		% change compared to the monthly mean NO_2 diffusion tube value (µg m^{-3})	
		CM	St. S st	CM	St. S st	CM	St. S st
P	Euro VI and 210 kWh with 0.2 g kWh NOx proposed emission mass. Other vehicles set at Euro III	1	4	-45	-48	-97.8	-92.3
Q	Taxi LPG conversion whole fleet powershift approved conversion (N/A – not available PM_{10} LPG)	46	-	0	N/A	0.0	N/A
R	Engine switch off Castle meadow at stand	35	39	-11	-13	-23.9	-25.0
S	Eco driving for bus drivers	41	47	-5	-5	-10.9	-10.6
T	Only buses in CM and St. S st	46	51	0	-1	0	-1.9
U	Park and ride in CM Increased frequency 5 min	48	-	2	-	4.3	-
V	Park and ride in CM Decreased frequency 15 min	42	-	-4	-	-8.7	-

PARTICULATES (PM_{10})

Event Code	Predicted Event Description	PM_{10} ($\mu g\ m^{-3}$) Monthly mean Annual mean (22 TEOM) (N/A)* CM	St. S st	Model variation compared to the monthly mean NO_2 Air station TEOM ($\mu g\ m^{-3}$) CM	St. S st*	% change compared to the monthly mean PM_{10} ($\mu g\ m^{-3}$) CM	St. S st* (*No PM_{10} monitor in St.Sst)
C	'Natural evolution' of the bus fleets (could be considered as a 'do nothing situation'	19	22	3	N/A	13.6	N/A
L	Retrofit of 15 First bus Euro II engine buses to Euro III by April 2008	21	23	1	N/A	4.5	N/A
M	If an extra 10 *First* buses are Retrofitted in the future	21	23	1	N/A	4.5	N/A

Calculations using the model - Event codes – and Results

A - ***Current situation***
The 2007 annual mean of the nitrogen dioxide diffusion tube values from our CIVITAS-II monitoring of Castle Meadow – 46 μg m^{-3} and St. Stephens Street 52 μg m^{-3} (maximum concentration of NO_2 found at tube position 10 in St. S. st for comparison of a maximum monthly mean is 60 μg m^{-3}).

B – ***Model prediction using current flow and vehicle fleet data***
Using SCOOT traffic flow data for Castle Meadow, bus timetable data, bus company fleet age. First bus, Anglian buses and park and ride bus fleets are considered in detail. Other smaller bus companies or occasional charter coaches are included as they will register as a vehicle on the SCOOT count but may be classified as a smaller vehicle in this model. However, the main bus fleets are expected to have the dominant effect in this LEZ area. Prediction results CM 46 μg m^{-3} and St.Sst 52 μg m^{-3}, a good fit.

C – ***Normal evolution of the major Norwich bus fleets***
From current examination current bus fleet turnover 'natural evolution' it is expected that 10 new Euro IV buses will replace older more polluting buses such as the vehicles with pre-Euro rated engines. Change in bus fleet 4.5 %. CM 43 μg m^{-3}, St.S st 48 μg m^{-3}.

A small improvement in predicted air quality but NO_2 concentrations are predicted to still be over the required annual mean of 40 μg m^{-3}.

D - ***Passenger number increase – can be considered as another 'do nothing situation'***
DfT report stated there could be a 12% increase in bus the in decade from 2002. Here we will consider an increase in single deck buses to accommodate the increase in passenger capacity. Here we use the whole 12% increase in one year to obtain a maximum pollution event for prediction purposes. CM 51 μg m^{-3}, St.S st 58 μg m^{-3}.

This is a maximum prediction for this variable and air quality subsequently decreases.

E - ***Passenger number increase – can be considered as another 'do nothing situation'***
DfT report stated there could be a 12% increase in bus the in decade from 2002. Here we will consider a realistic increase in single deck buses to accommodate a 1.2% annual increase in passenger capacity for one year. CM 47 μg m^{-3}, St.S st 53 μg m^{-3}.

An increase of only 1 μg m^{-3} for each area.

F - ***Fleet evolution powertrain increase and engine emission reduction***
Euro IV emission engines will eventually replace all Euro rated buses prior to Euro IV over time as the older buses come to the end of their useful life. In addition, the total city bus fleet engine power will increase also as modern vehicles require more power for basic functioning of additional technology and emissions are quoted as g kWh power. My mean selected 175 kWh for all the fleets could reach a new mean of 210 kWh per bus when all replaced for Euro IV. CM 25 μg m^{-3}, St.S st 29 μg m^{-3}.

These predicted NO_2 air concentrations are well within the annual mean value and would comply. They are well on the way to halving the air pollution in the LEZ assuming no increase in fleet numbers or throughput frequency.

G - ***Growth in cars and LGVs***
DfT 2002 to 2003 report *survey of privately owned vans,* van traffic in a decade has increased by 33.33%, cars 15% and heavy goods 20%. This will effect st.S.st more than CM although CM passenger increase 12% may affect taxis too. We will use 3.3% LGV, 1.5% cars and 2.0% HGV as an annual increase. For CM we have combined vehicle counts for all vehicles so we will use the mean for HGVs and LGVs, 2.7%. In St. S st the mean of the annual increase for all vehicles 2.3% will be used. CM 46 μg m^{-3}, St.S st 52 μg m^{-3}.

This calculation confirms buses have dominant influence over the air pollution in Castle Meadow and St. Stephens Street.

H, I - ***Variation of NOx emissions when using biodiesel and its blends in all current bus fleet numbers and frequency of passing through CM and St S st remaining unchanged for 1 month at current levels***
It is possible to have no increase in NO_x from exhaust emissions and we have results of this experiment our own biodiesel blends tested on a fixed bed Ford 2 L diesel engine at Cambridge. However, in the literature exhaust NO_x variation can vary from about +5% or -5%. The variations are due to biodiesel type, engine type and manufacturer of the engines and methods of analysis and drive cycles. We do not expect any NOx increase to be this high for B5 but, if at all, only possibly at higher blends used in the future.

CM	+5% BioD NOx CM	48 ug m^{-3}	-5% BioD NOx	44 ug m^{-3}
StSst	+5% BioD NOx CM	54 ug m^{-3}	-5% BioD NOx	49 ug m^{-3}

The increase is only 2 ug m^{-3} but nevertheless an increase in an LEZ area. The decrease does not aid compliance.

J, K - ***All bus fleets upgraded to Euro IV using biodiesel fuel and considering a +5% NOx increase to show effect of Euro IV regulation will decrease NOx for comparison with Euro IV engine buses on petroleum diesel.***

CM	+5% BioD NOx CM	26 ug m^{-3}	-5% BioD NOx	24 ug m^{-3}
StSst	+5% BioD NOx CM	30 ug m^{-3}	-5% BioD NOx	28 ug m^{-3}

Increases and decreases by 1 ug m^{-3} compared to a whole Euro IV fleet on fossil diesel fuel (Event F). Overall effect is the lower emission Euro IV buses.

L - ***Retrofit of 15 First bus Euro II rated engine buses to Euro III by April 2008***

CM 45 ug m^{-3}	PM_{10}	21 ug m^{-3}
StSst 51 ug m^{-3}	PM_{10}	23 ug m^{-3}

A saving of 1 ug m^{-3} on the mean monthly air pollution concentration. This particular retro-fitting will not meet the NO_2 limit of 40 ug m^{-3}, but is a small reduction.

M - ***If an extra 10 buses were retrofitted in addition to those in Event (L) with more funds in the future***
CM 45 ug m^{-3} StSst 50 ug m^{-3}

No change to Event (L) 15 retro-fits, which indicates more than 10 extra retrofits would be recommended.

N - ***Complete transformation of all selected main bus fleets by Euro engine rating***
All upgraded to Euro III
CM 30 ug m^{-3} StSst 34 ug m^{-3}

Now we have significant improvements and compliance with current air quality requirements in this model.

O - ***All Euro V, increased modern engine power to a mean value of 210 kWh and emission 2.0 g kWh compliant on Oct 2009. Bus fleet set to current size.***
CM 14 ug m^{-3} StSst 17 ug m^{-3}

Compliance even with more powerful engines but note no increase in fleet size or number of stops at bus stands.

P - ***Euro VI and 210 kWh with 0.2 g kWh NOx proposed emission mass***
All the bus fleets involved with no increase in numbers of buses other vehicles set at Euro III. CM 1 ug m^{-3} StSst 4 ug m^{-3}

Future prediction using proposed engine regulation in the year 2013, significant reductions.

Q - ***Taxi LPG conversion for example whole fleet powershift approved after market conversion 2002-2003 using 0.123 g NOx km^{-1}***
CM 46 ug m^{-3}

Here we will have to assume half of the other smaller vehicles in the CM area due to lack of specific taxi counts. Limitation of the StSst official traffic survey was that cars and taxis are accumulated and not reported separately. Note no change in mean NO_x concentration.

R – Engine ***switch off in Castle meadow at bus stand.***
If all the bus fleets comply at all times in this area then we could assume residence time is reduced by say 1 min which emissions cuts residence time down say from 4 mins per pass to 3 mins. Re: many do not currently switch off.
CM 35 ug m^{-3}, StSst if 'switch off' is extended to StSst 39 ug m^{-3}.

Most benefit will be seen if older lower Euro buses switch off for any length of time in city. However, for all buses any length time the engines are not running emissions will be reduced.

S - ***Eco driving can save 10 to 15% fuel consumption.***

We will use the lower saving rate for this calculation. Less transient engine events i.e. hard acceleration and smoother, traffic flow anticipating driving will reduce NOx and smoke. So here we will reduce g NOx kWh^{-1} by 10%. As a side note, it must be remembered that the ecodriving technique apparently diminishes with time after training as previous driving habits most often return.
CM 41 ug m^{-3}, StSst 47 ug m^{-3}

Pre-Euro to Euro II vehicle drivers will have most effect on pollution reduction. The pollution reduction by ecodriving and the effect on air quality will depends on the number of buses and the engine Euro rating. It would be sensible to train the drivers of all the older buses first if resources are limited.

T - ***No cars in Castle Meadow and St. Stephens street***
If we stop cars, from St. S st. and only allow buses and delivery vehicles and LGVs there is little effect on the air quality improvement. St S st. 51 ug m^{-3}.

For testing purposes, if we allow no other vehicles apart from buses into CM to see their contribution to the whole then there is no apparent effect over all.
CM 46 ug m^{-3}.

Buses have the dominant effect on the CM-LEZ and St. S St.

U - ***Park and ride increase in frequency***
If the park and ride bus frequency was increased to accommodate more passengers such as stops every 5 minutes. CM 48 ug m^{-3}.

V - ***Park and ride decrease in frequency***

If park and ride frequency was decreased i.e. slightly longer time between buses to save fuel and carbon emissions for CM stand buses. Say 15 minutes or every 20 minutes then calculated mean monthly air concentrations would be:
CM 42 ug m^{-3}.

Discussion
Assumptions – All vehicles passing through monitored areas are diesel: Castle Meadow traffic consists of only permitted buses, delivery vehicles and taxis. St. Stephens Street allow buses, delivery vehicles taxies and private cars to enter. Many new private vehicles are now diesel and most Light Goods Vehicles (LGVs) are diesel powered. Mean power rating is selected for all buses at an older lower rating. For cars and LGV to avoid too many variables the power rating is set equally for all to a mean selected value. However, in the future if all buses were replaced by modern more powerful buses this can be tested as above in the results. City background NO_x, NO_2 emissions remain constant at present concentrations.

Maximum emission of NO_2 as NO_x from the Euro rating of engines are used. Emission gases will depend on driving conditions and the maximum limits may not be reached but it is expected that over a period of time it would even out and thus max values are used to calculate the maximum effects and maximum pollution events.

Measured data – Castle Meadow vehicle flow, nitrogen dioxide monthly mean concentration, vehicle (bus) residence time in Castle Meadow and St. Stephens street.

Known data – First bus, Anglian bus and park and ride bus fleet size, engine Euro rating from vehicle type, make and age. Engine g NO_2 km^{-1} for cars and LGV.

Calculated – From street maps and in conjunction with actual street measurements, the volume of air space in Castle Meadow and St. Stephens Street canyons. Air flow in the CM area from measured flow rates in the street and from the nearest weather station (Marham) for flow above roof height.

Possible deviations - 28/09/06 and 28/09/05 St. Stephens street survey data is not current so St.S st predicted values are normalised to the Castle Meadow – LEZ results where the model fits the best.

***Note: The results and conclusions from this model can not be used as definitive confirmation of future air pollution concentrations within the selected areas. They are indicative of possible air quality changes under test situations.**