Air Quality
CONSULTANTS

Air Quality Neutral:
Update to Benchmarks

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Contents

1 Introduction

1.1 In April 2014, Air Quality Consultants Ltd. (AQC), in association with ENVIRON UK Ltd., published a report based on a study commissioned by the Greater London Authority (GLA) to support the implementation of the "air quality neutral" policy. The approach was subsequently adopted into the Mayor's 2014 Supplementary Planning Guidance (SPG) on Sustainable Design and Construction.

1.2 The approach was based on the establishment of benchmarks for both buildings (energy use) and transport (car trips), translated into both NOx and PM_{10} emissions, expressed as g/m^2 (or g/dwelling) for different land-use classes.

1.3 AQC has been commissioned by GLA to review the approach taking into account lessons learned over the past five years. Specifically, the study aims to:

- Revise the benchmarks to bring them into line with the draft London Plan to ensure that new developments in London minimise their impacts on air quality; and
- Provide additional guidance on applying the policy to complex development types, and offsetting of emissions where the benchmarks are exceeded.

1.4 This study has been carried out in association with the Hodkinson Consultancy (with regard to the Building Emissions Benchmarks) and Vectos (with regard to the Transport Emissions Benchmarks).

1.5 The revised Benchmarks are intended to apply to "major developments" as defined in the London Plan. Where revised benchmarks have been identified for e.g. "small houses" they are only intended to apply where individual dwellings form part of a larger scheme that would be classed as a major development.

2 Issues Identified

Building Emissions Benchmarks

2.1 The Building Emissions Benchmarks (BEBs) in the current guidance were derived from:

- Fossil fuel energy density (kWh/m^2) for different land-use classes;
- Percentage energy use for gas and oil, for residential, commercial and industrial activities;
- Local gas consumption data; and
- NOx and PM emission factors for gas and oil, for residential and commercial/industrial use.

2.2 The principal shortcomings of this approach are;

- The benchmarks were founded on the existing building stock in London, and so do not reflect current standards of building design and energy plant; and
- Complying with the benchmarks will, in most cases, be achieved if the CHP/boiler emissions limits defined in the Mayor's SPG are met.

2.3 In addition, there is no precise guidance on how the benchmarks should be applied to phased developments, or where new developments are linked to an existing (or upgraded) district heating network.

Transport Emissions Benchmarks

2.4 The Transport Emissions Benchmarks (TEBs) in the current guidance were derived from:

- Number of car trips associated with different types and sizes of development (e.g. trips/m^2/annum);
- Typical distance of each trip (km/trip); and
- The average emission per vehicle-kilometre (g/km).

2.5 In practice, the TEB is founded only on the number of trips/annum. The trip distance and emissions per veh-km are only used to quantify the NOx and PM emissions.

2.6 Shortcomings of the approach are:

- The TEB is only related to car trips (as data on other trips were not available in a robust manner from the TRAVL database);
- TEBs have only been developed for a limited number of land-use categories; and

- The development trip generation rates are usually derived from the same database (TRICS which now incorporates TRAVL) as was used to generate the TEBs, making the assessment "circular".

3 Revised Building Emission Benchmarks

Introduction

3.1 The revised Building Emission Benchmarks (BEBs) have been developed in association with the Hodkinson Consultancy. A copy of their full report is provided in Appendix A1. A summary of the approach is set out in this section.

3.2 The revised BEBs have been developed for NOx emissions alone, based on gas combustion. There is little, if any, new development within London based on oil or solid fuel combustion, and there would be no robust data upon which to establish revised BEBs following the approach described below. In the event that development is brought forward using oil or solid fuel combustion technologies, it is recommended that the current BEBs for PM_{10} be applied.

3.3 A principal aim within the revised BEBs has been to:

- **Reflect New Building Stock**. As described in Section 2, the current BEBs were derived from energy use associated with the existing building stock in London which is predominantly old. As new building stock is designed to much higher standards of energy efficiency, and with lower emission combustion technologies, there is an opportunity to set lower BEBs for new development;
- **Reflect Varying Energy Strategies**. NOx emissions from new development are strongly linked to the selected energy strategy and not just to the building use. There is, therefore, also an opportunity to develop separate BEBs for different energy strategies.

Overall Methodology

3.4 Development in London is predominantly based on the following uses:

- Dwellings (C3)
- Schools (D1)
- Hotels (C1)
- Offices (A2 and B1)
- Retail (A1)

3.5 Accordingly, a detailed analysis has been based on these land-use classes, also split by selected energy strategy. For the other land-use classes not described above, revised BEBs have been derived by applying a factor similar to the change applied to the current BEBs. By way of example, Class A3-A5 uses (restaurants/bars/cafes) have current BEBs similar to Class C1 (hotels); if the revised BEB for hotels was 40% lower than the current BEB, a similar reduction would be applied to the revised BEB for A3-A5.

Types of Energy Strategy

3.6 A detailed discussion on the role of the Energy Strategy, and the importance of "displaced NOx emissions" with specific regard to CHP operation, is given in Appendix A1 (Section 2).

3.7 The assessment has analysed NOx emissions associated with a range of energy strategies:

- Gas boilers to individual dwellings and non-residential uses;
- Electric panel heaters;
- Air source heat pumps (ASHPs) to individual dwellings and non-residential uses;
- Communal heating ("heat network") with centralised gas boilers;
- Communal heating ("heat network") with centralised gas boilers and CHP;
- Communal heating ("heat network") with ASHPs; and
- Communal heating ("heat network") with gas boilers and ASHPs.

3.8 These strategies have been assessed against a range of development sizes, as certain energy strategies would be unsuitable for certain scales of development. This is related to both technical feasibility and planning/regulatory requirements.

3.9 By definition, energy strategies with no on-site combustion sources (such as electric resistance heating or ASHPs) do not generate building-related on-site emissions of NOx. However, both energy solutions deliver quite different CO_2 performances as the sources of electricity and efficiency of the systems are different. These electric strategies are included in the analysis, although not in the context of setting BEBs.

Revised BEBs for Class C3 (Dwellings)

3.10 Table 1 sets out proposed BEBs for dwellings in which seven potential energy strategies are evaluated against eight varying sizes of development. For the reasons described above, not all strategies are appropriate to all development sizes.

3.11 The BEBs in Table 1 have been derived using the emissions standards for gas boilers (40 mg/kWh) and CHP (95 mg/Nm^3) defined in the GLA's 2014 Supplementary Planning Guidance on Sustainable Design and Construction[1]. Full details of the calculation methodology are set out in Appendix A1 (Section 3).

1 GLA (2014)

3.12 There is variability in the calculated BEB between different scales of development based on the same energy strategy. For example, a large ($200m^2$) house with an individual gas boiler would generate a lower BEB than a small ($100m^2$) house. It would be impractical to set different BEBs for different scales of development at this level of detail, and in each case the highest calculated BEB has necessarily been selected. Whilst consideration was also given to defining the BEBs based on a g/kWh metric (see Table 3 in Appendix A1), this approach was rejected due to the complications this would introduce into the assessment, and the lack of comparability with the existing approach.

3.13 As described in Table 1, this provides three revised BEBs:

- Electric-only strategies (electric panel heaters and ASHPs) do not generate any on-site NOx emissions. Exceptions may occur where backup generators are used, but the number of operational hours will normally be very small, and usually only applied for critical developments such as hospitals;
- Not all energy strategies are suitable to all development sizes. GLA has a strong preference for decentralised heat networks on medium to large scale developments, and, as such, the application of individual heat sources would be unlikely. Similarly, it would be technically and financially infeasible to install heat networks to very small developments;
- The BEB for developments using a heat network with ASHPs and gas boilers has been set at the same level as that for a heat network with gas boilers alone. In reality, the former would have a lower calculated BEB, but it would not be reasonable to apply this as a proportion of the heat is generated by a low carbon and zero emission source;
- A higher BEB has been set for heat networks which use a CHP than those based on gas boilers alone. This is because:
    - NOx as a result of electricity generation is also included; and
    - There remains a strategic case for the use of CHP in certain strategies to support the financial case for a heat network. Should a development be directed to follow such a strategy, it would be unreasonable to require the compliance with a BEB based on a gas boiler network.

Table 1: Proposed Building Emission Benchmarks – Class C3 Dwellings ($gNOx/m^2/annum$)

<table>
<tr><th>Pollutant</th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boiler Network</th><th>ASHP Network</th><th>ASHP + Gas Boiler Network</th></tr>
<tr><td>Small House ($100m^2$)</td><td rowspan="6">3.5 g/m^2</td><td rowspan="6">No Heat-related NOx Emission</td><td rowspan="6">No Heat-related NOx Emission</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td></tr>
<tr><td>Medium House ($130m^2$)</td></tr>
<tr><td>Large House ($200m^2$)</td></tr>
<tr><td>0-10 Flats</td></tr>
<tr><td>11-50 Flats</td><td rowspan="4">5.7 g/m^2</td><td rowspan="4">25.5 g/m^2</td><td rowspan="4">No Heat-related NOx Emission</td><td rowspan="4">5.7 g/m^2</td></tr>
<tr><td>51-400 Flats</td></tr>
<tr><td>401-1000 Flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td></tr>
<tr><td>>1000 Flats</td></tr>
</table>

Application of Enhanced CHP Targets

3.14 The BEB for energy strategies including CHP are based on an assumed emissions standard of 95 $mgNOx/Nm^3$. However, a review of this emissions standard has been carried out by ACC and the Hodkinson Consultancy on behalf of the City of London[2]. This study concluded that whilst the emission standard for low-NOx boilers should not be tightened, existing abatement technologies would allow more stringent standards to be set for gas-fired CHP engines:

- 25 mg/Nm^3 for CHP engines using Selective Catalytic Reduction (SCR) and
- 50 mg/Nm^3 for CHP engines using 3-way catalysts

3.15 The BEBs described in Table 1 have been adjusted to apply the more stringent (enhanced) CHP emissions standards. As size (output) of the CHP primarily determines whether SCR or 3-way catalyst technology is used, the enhanced BEBs have been assigned to different scales of development, but there is no absolute cut-off point. Thus, where a development of less than 400 flats utilises CHP with SCR, then the lower BEB should be applied, and *vice versa*.

3.16 The enhanced BEBs are described in Table 2.

2 Options to minimize emissions from non-transport sources in the City of London. Report J3201A/1/F1. Air Quality Consultants, September 2018.

Table 2: Proposed Building Emission Benchmarks With Enhanced CHP Standards– Class C3 Dwellings (gNOx/m²/annum)

<table>
<tr><th>Pollutant</th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boiler Network</th><th>ASHP Network</th><th>ASHP + Gas Boiler Network</th></tr>
<tr><td>Small House (100m²)</td><td rowspan="6">3.5 g/m²</td><td rowspan="6">No Heat-related NOx Emission</td><td rowspan="6">No Heat-related NOx Emission</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td></tr>
<tr><td>Medium House (130m²)</td></tr>
<tr><td>Large House (200m²)</td></tr>
<tr><td>0-10 Flats</td></tr>
<tr><td>11-50 Flats</td><td rowspan="4">5.7 g/m²</td><td rowspan="2">14.1 g/m²</td><td rowspan="4">No Heat-related NOx Emission</td><td rowspan="4">5.7 g/m²</td></tr>
<tr><td>51-400 Flats</td></tr>
<tr><td>401-1000 Flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">7.8 g/m²</td></tr>
<tr><td>>1000 Flats</td></tr>
</table>

3.17 It is noted that even based on enhanced CHP emissions BEBs, the use of CHP to deliver the energy strategy results in higher emissions of NOx per kWh of generated heat than gas boilers.

Consideration of CO_2 Emissions

3.18 Tables 1 and 2 present the NOx BEBs, but do not take any account of the related CO_2 emissions associated with each energy strategy. Table 3 is based on the same types of development and energy strategies, but shows the related CO_2 emissions. The reductions in each case are shown against the Part L 2013 Building Regulations baseline (Target Emissions Rate) under SAP 2012 conditions (see Appendix A1, Section 2).

Table 3: SAP 2012 CO_2 Reductions Against Selected Energy Strategy

<table>
<tr><th>Pollutant</th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boiler Network</th><th>ASHP Network</th><th>ASHP + Gas Boiler Network</th></tr>
<tr><td>Small House (100m²)</td><td rowspan="6">0%</td><td rowspan="3">-35%</td><td rowspan="3">25%</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td></tr>
<tr><td>Medium House (130m²)</td></tr>
<tr><td>Large House (200m²)</td></tr>
<tr><td>0-10 Flats</td><td rowspan="3">-30%</td><td rowspan="3">15%</td></tr>
<tr><td>11-50 Flats</td><td rowspan="4">0%</td><td>25%</td><td rowspan="4">40%</td><td rowspan="4">10%</td></tr>
<tr><td>51-400 Flats</td><td>30%</td></tr>
<tr><td>401-1000 Flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td>35%</td></tr>
<tr><td>>1000 Flats</td><td>40%</td></tr>
</table>

3.19 Table 4 replicates the data in Table 3 but utilising SAP 10 emission factors.

Table 4: SAP 10 CO_2 Reductions Against Selected Energy Strategy

<table>
<tr><th>Pollutant</th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boiler Network</th><th>ASHP Network</th><th>ASHP + Gas Boiler Network</th></tr>
<tr><td>Small House (100m^2)</td><td rowspan="6">0%</td><td rowspan="6">0%</td><td rowspan="3">50%</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td></tr>
<tr><td>Medium House (130m^2)</td></tr>
<tr><td>Large House (200m^2)</td></tr>
<tr><td>0-10 Flats</td><td rowspan="3">30%</td></tr>
<tr><td>11-50 Flats</td><td rowspan="4">-10%</td><td>-35%</td><td rowspan="4">50%</td><td rowspan="4">20%</td></tr>
<tr><td>51-400 Flats</td><td>-30%</td></tr>
<tr><td>401-1000 Flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td>-25%</td></tr>
<tr><td>>1000 Flats</td><td>-20%</td></tr>
</table>

3.20 If the data in Table 1 are compared with the data in Tables 3 and 4, the following conclusions can be drawn:

- Under SAP 2012 emission factors, CHP delivers a very good CO_2 performance, and this has been a primary driver for use in heat networks even though NOx emissions are higher in relation to other technologies. However, under SAP 10 emission factors, the CO_2 performance is poor and the argument for use of CHP is no longer justified;
- Electric panel heaters do not generate on-site emissions of NOx, but also do not deliver the CO_2 emissions reductions of other electrically-led technologies (such as ASHP);
- The efficiency of heat distribution in heat networks has a significant impact on both NOx and CO_2 emissions; and
- The introduction of the SAP 10 carbon emission factors reduces conflicts between energy strategies which promote CO_2 emissions reduction at the expense of higher NOx emissions.

Revised BEBs for Non-Residential Uses

3.21 The majority of new development in London is residential or residential-led, and the principal emphasis has been on revising BEBs for Class C3 use. However, specific consideration has also been given to other principal types of development:

- Class A1 (Retail)
- Class A2 and B1 (Offices)
- Class C1

- Class D1 (Schools)

3.22 The revised BEBs for the above land-uses have been calculated using a similar approach to that for Class C3; in place of the SAP outputs for heat demands, the outputs from the Simplified Building Energy Model (SBEM) have been used.

3.23 For the land-use classes not identified in para 3.21, BEBs have been estimated using the following approach:

- Land-use classes not explicitly considered have been "paired" with each of the four land-use classes that have. By way of example, the current BEB for A3-A5 is 75.2 g/m^2/annum. The most similar BEB for a land-use class that has been fully calculated is C1 (70.9 g/m^2/annum);

- A "difference" factor has then been calculated (e.g. 75.2/70.9, or 1.061). The revised BEB for A3-A5 has then been estimated by multiplying the revised BEBs for Class C1 by 1.061.

3.24 The revised BEBs are set out in Table 5.

Table 5: Proposed Building Emission Benchmarks Non-Residential Uses (gNOx/m^2/annum)

Pollutant	Individual Gas Boilers	Electric Resistance Heating	Individual ASHPs	Gas Boiler Network	CHP + Gas Boiler Network	ASHP Network	ASHP + Gas Boiler Network
Retail (A1)	0.53	No Heat-related NOx Emission	No Heat-related NOx Emission	0.97	4.31	No Heat-related NOx Emission	0.97
Restaurants / Bars (A3-A5)	10.94			20.06	89.54		20.06
Offices (A2 & B1)	1.43			2.62	11.68		2.62
Industrial (B2-B7)	1.07			1.95	8.73		1.95
Storage (B8)	0.55			1.01	4.50		1.01
Hotel (C1)	10.32			18.91	84.42		18.91
Care Homes / Hospitals (C2)	9.97			18.27	81.56		18.27
Schools (D1)	0.90			1.66	7.39		1.66
Entertainment / Leisure (D2)	13.14			24.09	107.52		24.09

Phased Developments and Heat Networks

Phased Developments

3.25 Large-scale developments are normally phased, with individual plots coming into use while other plots are under construction. Such phasing can take place over many years. The issues related to calculation of the BEBs include:

- Components of the scheme may come into use before the main energy centre is commissioned within a component of the scheme that has not yet been constructed. In this case a temporary solution to the provision of heat and hot water needs to be provided;
- The energy centre may be phased and scaled up to meet the heat demand of the development as it is brought forwards.

3.26 In both cases, the calculations should be done for the heat demand required for the quantums of land use under consideration at the time. Where the full quantums of land use were evaluated at the time an outline application was submitted for the whole scheme, the calculations may need to be revisited when individual elements are brought forwards, e.g. with a Revised Matters Application, or Section 73 Application.

3.27 Temporary solutions to heat demand in the early phases of a large development may include the construction of free-standing plant (comprising CHP and/or boilers) or construction of a temporary energy centre in the early phase plots which is decommissioned at a later stage. In either case, the assessment should be carried out for the quantums of land to be served by the temporary solutions.

3.28 Where the energy centre is delivered by scaling up (e.g. the plant room is designed to accommodate the full energy centre, but plant are only commissioned in line with the heat demand of each phase) the assessment should be carried out for the quantums of land to be served by the installed plant.

Heat Networks

3.29 Policy SI13 of the draft London Plan requires that developments should connect to existing heat networks wherever feasible. There are two specific cases that need to be considered with regard to the BEBs, where heat networks are used.

3.30 Where new development is brought forward using heat from an existing source that would otherwise be wasted. An example would be drawing heat from an existing energy-from-waste plant. In principle, drawing heat in this manner does not increase emissions, and the building emissions associated with the development can be considered as zero.

3.31 Where the development is intended to connect to a purpose-built heat network, then the position is less clear and requires careful consideration. To meet the heat load of the new development, the heat network may be required to operate at a higher load, or for an increased number of hours. Alternatively (or as well) the heat network may need to be upgraded with additional plant to meet the necessary demand. In either case, the additional emissions associated with supplying the additional heat to the new development should be quantified, and compared with the relevant BEBs.

Comparison with Current Benchmarks

3.32 Appendix A3 provides a direct compares the current and revised benchmarks, while Appendix A4 presents a series of case studies where actual developments have been compared against both the current and revised benchmarks.

4 Revised Transport Emissions Benchmarks

4.1 The revised Transport Emission Benchmarks (TEBs) have been developed in association with Vectos. A copy of their full report is provided in Appendix A2. A summary of the approach is set out in this section.

4.2 Consideration was given at an early stage of the project to evaluate how the benchmarks could be defined using a different approach, but alternative options were discounted on the grounds of complexity and lack of coherence to the manner in which transport assessment are undertaken (and, by definition, the availability of data).

4.3 The current TEBs are based on car trips only and exclude servicing trips. An appreciable proportion of the trip generation of many new developments is likely to comprise servicing vehicles, including taxis, deliveries, and refuse collections. However, in terms of deliveries and collections, it is highly unlikely that any trip would be solely associated with the new development; with visits instead forming stops on existing routes. While consideration was given to including TEBs for servicing trips, it was decided that this was neither practical nor ultimately desirable.

4.4 The revised TEBs have been developed for NOx and $PM_{2.5}$ emissions, based on car trips, trip lengths and updated vehicle emission factors.

4.5 For the reasons stated in the original 2014 report, non-road traffic emissions (e.g. from rail, shipping and aircraft) have not been included.

Car Trips

4.6 The TRAVL database used to derive the current TEBs has now been incorporated into TRICS. Updated trip data have been extracted from TRICS based on the most recent five-year period of data available.

4.7 Car trip rates were extracted for the Central Activities Zone (CAZ), Inner London and Outer London, for retail (A1), office (B1) and residential (C3) representing the most common development categories. These data are shown in Table 6 over the period 0700 to 1900 hours.

Table 6: TRICS Car Trip Rates for Major Land Use Categories (0700-1900)

Land Use	Zone	No. Surveys	Trip rates
C3 Residential	Outer	12	1.125
	Inner	6	0.286
	CAZ	3	0.171
B1 Office	Outer	4	4.085
	Inner	2	0.288
	CAZ	2	0.496
A1 Retail (Food Superstore	Outer	4	54.513
	Inner	1	18.424
	CAZ	3	9.920
A1 Food Convenience Store	Outer	4	69.087
	Inner	1	35.000
	CAZ	1	4.545

Note: Residential trip rates are per dwelling. Office and retail trip rates are per 100 m^2 of Gross Internal Floor Area

4.8 The trip rates in Table 6 have been factored to a 24-hour period to reflect an average daily trip for a weekday, Saturday and Sunday based on the National Travel Survey (NTS0501, 2018). To derive the total number of trips per annum, the weekly trips (5 x weekday + Saturday + Sunday) were multiplied by 52 (weeks). The results are shown in Table 7.

Table 7: Average Car Trips Per Annum

Land Use	Annual Trips Per	Car Trips		
		CAZ	Inner London	Outer London
C3 Residential	Dwelling	68	114	447
B1 Office	GIA (m^2)	2	1	16
A1 Food Superstore	GIA (m^2)	39	73	216
A1 Food Convenience Store	GIA (m^2)	18	139	274

Trip Lengths

4.9 The current TEBs were based on the 2007-2010 London Travel Demand Surveys (LTDS) deriving trip length data for trips originating and terminating in the CAZ, Inner and Outer London. The data included information on the land use categories associated with the trip destinations and trip lengths (in kilometres).

4.10 It has not proved possible to update these data from the 2018 LTDS, as the information is not available in the required format. The data extracted from the 2007-2010 LTDS have been factored based on information within Figure 6.2 of the TfL Travel in London Report 9, which represents the change in trends in road traffic (vehicle kilometres) for all motor vehicles in Central, Inner and Outer London between 2010 and 2015. These data are summarised in Table 8.

Table 8: Trends in Road Traffic (veh-km) All Motor Vehicles in Central, Inner and Outer London. Index Year 2000 = 100

Year	Central	Inner	Outer	Greater London
2010	81	89	93	92
2011	79	87	92	90
2012	77	84	92	89
2013	76	82	92	89
2014	79	83	94	90
2015	79	83	94	90

4.11 The data in Table 8 show a slight decrease in overall vehicle-kilometres in Central and Inner London, but a small increase in Outer London. The overall reduction of vehicle-kilometres in Greater London since 2010 is 2%. These slight decreases were applied to the average distances originally derived from the 2007-2010 LTDS to provide updated values for each land use class and location. The updated values are shown in Table 9.

Table 9: Average Distance Travelled by car per Trip

Land Use	Distance (km)		
	CAZ	Inner London	Outer London
C3 Residential	4.2	3.4	11.4
B1 Office	3.0	7.2	10.8
A1 Retail	9.2	5.5	5.4

4.12 The average annual trip generation (Table 7) can be combined with the average trip length (Table 9) to give the average distance travelled per annum. These derived values are shown in Table 10.

Table 10: Average Distance Driven per Annum

Land Use	Annual Trips Per	Veh-km/annum		
		CAZ	Inner London	Outer London
C3 Residential	Dwelling	288	392	5,115
B1 Office	GIA (m2)	6	8	176
A1 Food Superstore	GIA (m2)	362	402	1,174
A1 Food Convenience Store	GIA (m2)	166	764	1,488

Emissions per Vehicle

4.13 The final step is to combine the average distance driven per annum (Table 10) with the average emission rates for cars in g/veh-km for the CAZ, Inner and Outer London, for both NOx and $PM_{2.5}$. The 2016 London Atmospheric Emissions Inventory (LAEI) provides an estimate of the total emissions from all passenger cars in Central, Inner and Outer London in 2016. These emissions are based on a detailed inventory of link speeds and include a provision for cold-starts. The LAEI also provides the total vehicle-kilometres driven by cars in 2016 in each area. The approach has been to divide the total emissions by the total vehicle-kilometres; thus providing the average assumed emissions per vehicle-kilometre in each area in 2016. The emission factors used are shown in Table 11.

Table 11: Emission Factors

Pollutant	g/vehicle-km		
	CAZ	Inner	Outer
NOx	0.48	0.39	0.35
$PM_{2.5}$	0.036	0.032	0.028

4.14 Table 12 sets out the proposed TEBs

Table 12: Proposed Transport Emission Benchmarks

Land Use	g/annum per	g/annum		
		CAZ	Inner London	Outer London
NOx				
C3 Residential	**Dwelling**	139	153	1,790
B1 Office	**GIA (m^2)**	2.90	3.13	61.6
A1 Food Superstore	**GIA (m^2)**	175	157	411
A1 Food Convenience Store	**GIA (m^2)**	80.1	299	521
$PM_{2.5}$				
C3 Residential	**Dwelling**	10.2	12.6	145
B1 Office	**GIA (m^2)**	0.21	0.26	5.00
A1 Food Superstore	**GIA (m^2)**	12.9	13.0	33.3
A1 Food Convenience Store	**GIA (m^2)**	5.90	24.6	42.2

Benchmark Trip Rates for Other Land Use Classes

4.15 The current benchmarks include trip rates for additional land use classes where it was not possible to derive trip lengths. Because calculating emissions requires an estimate of trip length, these are provided as trips per annum. The approach to updating these values has been to multiply the current benchmark trip rate by the ratio of the revised *vs* current benchmark trip rates for similar use classes. Table 13 sets out these ratios (as percentages). As explained in Appendix A2, there are some land use classes where the revised trip rates are higher than the current trip rates. Appendix A2 explains the reasoning for this and why the revised trip rates are considered to be appropriate. However, when using these ratios to infer changes to other use classes, it was not considered appropriate to uplift the trip rates. Thus, scaling factors greater than 1 (i.e. 100%) were not used. In the case of land use classes D1 and D2, it was not considered appropriate to scale the existing benchmark trip rates based on just one of the three classes (A1, B1, and C3) for which revised trip rates were available and so all three use classes were combined as shown in Table 13.

4.16 The revised trip rates are set out in Table 14.

Table 13: Multipliers Used to Derive Additional Benchmark Trip Rates

Land Use		Scaling Factor		
Applied to	Derived From	CAZ	Inner London	Outer London
C1, C2	C3	53%	28%	100%[a]
B2, B8	B1	100%[a]	25%	89%
na	A1 Superstore	91%	73%	100%[a]
A3, A4, A5	A1 Convenience	42%	100%[a]	100%[a]
D1, D2	Mean [b]	73%	47%	96%

[a] For the reasons explained in 4.15, where the revised trip rates for C3, B1, or A1 are higher than the existing trip rates, no scaling has been applied.

[b] This is a basic, unweighted, arithmetic mean except that the two sets of A1 percentages have first been averaged, meaning that C3, B1, and A1 all receive equal weighting.

Table 14: Average Car Trips per Annum for Additional Land Use Classes

Land Use	Car Trips (trips/m^2/annum)		
	CAZ	Inner London	Outer London
A3	64.0	137	170
A4	0.8	8.0	-[a]
A5	-[a]	32.4	590
B2	-[a]	3.9	16.3
B8	-[a]	1.4	5.8
C1	1.0	1.4	6.9
C2	-[a]	1.1	19.5
D1	0.1	30.3	44.4
D2	3.6	10.5	47.2

[a] Benchmark trip rates not previously provided.

Comparison with Current Benchmarks

4.17 Appendix A3 provides a direct compares the current and revised benchmarks, while Appendix A4 presents a series of case studies where real-life developments have been compared against both the current and revised benchmarks.

5 Addressing Exceedances of the Benchmarks

5.1 If a scheme is projected to result in net positive emissions, i.e. higher than the air quality neutral benchmarks, redesign or re-specification to reduce those emissions is the preferred first step. However, if this is not possible, or cannot eliminate the excess emissions, some form of financial payment could be levied. There are several available options for calculating the appropriate level of payment, although they essentially fall into two approaches:

- impact compensation: a fee levied to compensate for the damage caused to human and environmental health which could result from the emissions; and
- abatement compensation: a fee levied to compensate for the cost of abating the emissions at another location.

5.2 While, in many ways, abatement compensation logically makes greater sense, there are no abatement costs available for $PM_{2.5}$ and those for NO_2 are outdated. It is understood that Defra may update the abatement cost guidance but the timescale for this is not known.

5.3 Appendix 5 discusses how the compensation approach might be used to provide a funding structure for exceedances of the air quality natural benchmarks and sets out suggested damage costs for NOx and $PM_{2.5}$ emissions. Such compensation could be secured via condition in the planning approval or via a legal Section 106 agreement.

6 Conclusions

6.1 The revised benchmarks address many of the issues with the current value identified in Section 2. In particular, the BEBs are designed to reflect current building and plant design and, as shown in Appendix A4, are less easily achieved than the current BEBs. Furthermore, guidance is provided on applying the revised benchmarks to phased developments and in situations where a development links to an off-site heat network.

6.2 In terms of the revised TEBs, it has not been possible to address all of the shortcomings identified in Section 2. This is because the main limitations cannot practically be addressed within the overall concept of air quality neutral. It remains the case that TEBs relate to car trips only, since the nature of servicing trips is not straightforward to address. Furthermore, TEBs have not been identified for additional land use categories and there remains an element of circularity if the same TRICS survey data used to calculate the benchmarks are used for scheme assessments. Despite these issues the revised benchmarks can be considered a representative update to the current values.

6.3 It is considered that the revised benchmarks for building emissions and transport emissions can usefully be used in air quality neutral assessments.

7 Appendices

A1 Report by Hodkinson Consultancy

Revised Building Emissions Benchmarks for Residential and Non-Residential Land Use Classes

Air Quality Consultants

Air Quality Neutral - BEBs

Draft V2

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ABOUT HODKINSON CONSULTANCY

Our team of technical specialists offer advanced levels of expertise and experience to our clients. We have a wide experience of the construction and development industry and tailor teams to suit each individual project.

We are able to advise at all stages of projects from planning applications to handover.

Our emphasis is to provide innovative and cost effective solutions that respond to increasing demands for quality and construction efficiency.

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CONTENTS

1. INTRODUCTION

1.1 This document has been prepared by Hodkinson Consultancy (HC), a specialist energy and environmental consultancy for planning and development.

1.2 Our brief is to assist Air Quality Consultants in the determination of a new set of Building Emissions Benchmarks (BEBs) in NOx for the Greater London Authority's (GLA) Air Quality Neutral standard. Our work will accompany their report on the wider Air Quality Neutral (AQN) standard in relation to transport and other pollutants such as PM_{10}. This document should therefore not be read in isolation from this wider work.

Methodology

Current Assessment Methodology

1.3 The current methodology for achieving a standard of Air Quality Neutral (AQN) is based on a series of Building Emissions Benchmarks (BEBs) which have been determined for each land use class, as shown in Figure 1, below. These are set out in grams/m^2 and were introduced as part of the GLA's Sustainable Design and Construction SPG (2014).

Land Use Class	NOx (g/m^2)	PM_{10} (g/m^2)
Class A1	22.6	1.29
Class A3 - A5	75.2	4.32
Class A2 and Class B1	30.8	1.77
Class B2 - B7	36.6	2.95
Class B8	23.6	1.90
Class C1	70.9	4.07
Class C2[1]	68.5	5.97
Class C3[1]	26.2	2.28
D1 (a)	43.0	2.47
D1 (b)	75.0	4.30
Class D1 (c -h)	31.0	1.78
Class D2 (a-d)	90.3	5.18
Class D2 (e)	284	16.3

Figure 1: Current Building Emissions Benchmarks

1.4 As a reminder, this assessment only considers NOx related Building Emissions Benchmarks, and not the BEBs for PM_{10}. Separate transport related benchmarks are also not considered here.

1.5 The AQN standard only applies to 'Major Development', which is classed by the GLA as a development of 10 or more dwellings, or ≥1,000m^2 of non-residential space.

1.6 It is understood that the GLA wish to revisit these BEBs in order to better reflect the following, which the current benchmarks do not differentiate by:

> **New building stock** – The current set of air quality benchmarks were developed to reflect the emissions associated with the wider building stock in London, which is predominantly old (i.e. pre 21st century). New building stock is designed to a much higher standard of energy efficiency and with cleaner on-site combustion sources. It is therefore considered reasonable to hold these developments to a higher standard of building-related air quality.

1.7 It is the view of HC that a re-evaluation of these targets also represents an opportunity to consider the following:

> **Varying energy strategies** – A development's NOx emissions will be strongly linked to its selected energy strategy, and not just the proportion of land-use classes. It would seem reasonable to put in place different targets for different strategies.

Proposed Methodology

1.8 Our work therefore intends to propose a new set of BEBs which take into consideration these factors. It is understood that the following building types are of particular focus for the GLA:

> Dwellings;

> Schools;

> Hotels;

> Offices;

> Retail.

1.9 As the majority of Major Development assessed under the AQN standard is residential-led, either in its totality or with a small proportion of non-residential provision, this analysis will be split between the following use classes:

> Class C3 (dwellings);

> Class A1 (retail), A2 & B1 (offices), C1 (hotels), D1 (schools).

1.10 Each of the above classes will also be split on the selected energy strategy. This is explained further in Section 2. This is to illustrate where there may be inherent conflicts between energy (CO_2) and air quality (NOx) objectives.

1.11 Other non-residential land-use classes not addressed in point 1.8 which are covered in Figure 1 will still be given revised BEBs. These are to be established by applying the same factor by which similar assessed BEBs have changed. For example, restaurants/bars (class A3-A5) have a current BEB which is similar to that of hotels (class C1). If it were determined that the revised BEB for hotels were to be e.g. 40% lower than the current BEB, then the same reduction in percentage terms would be applied to restaurants/bars.

2. ROLE OF ENERGY STRATEGY

2.1 The selection of an energy strategy for a development will have a marked effect on its associated NOx emissions. As the reader may be aware, the current landscape for energy assessments of new development is a dynamic one. Updates are imminent to SAP (Standard Assessment Procedure) methodology, the approved means of determining the energy performance of new dwellings. This is due to be formally incorporated into the revised version of Part L of the Building Regulations (see the recently released *Future Homes Standard* consultation). It can be reasonably expected that similar updates will be transposed into SBEM (Simplified Building Energy Model) methodology, the approved means of assessing non-residential buildings.

2.2 An adoption date for the next iteration of Part L has been indicatively set for autumn 2020, however the GLA have asked that certain key proposed changes are taken into consideration now when proposing energy strategies for new development. This is set out in their Energy Assessment Guidance (October 2018), for use from January 2019. The two central changes are:

> Application of higher (i.e. more realistic) heat losses to energy strategies which utilise communal heating;

> Revision of the CO_2 emissions factor associated with electricity generation and supply from the electricity grid.

2.3 The importance of these changes is to be stressed as part of this assessment because there remains a crucial relationship between a selected energy strategy, often sought for a targeted reduction in CO_2 emissions, and how this affects a development's contribution to localised NOx emissions. It is critical that the GLA consider both when setting and administering policy.

Effect of SAP Changes

2.4 The source of on-site NOx in the development of BEBs is linked directly to the type of heating system which is used. NOx as a result of transport through the development is accounted for in the separate transport benchmarks.

2.5 Only those energy strategies which use on-site combustion practices will need to be assigned a BEB. Other strategies have nonetheless been assessed as part of this work to inform on the CO_2 performance and where NOx may nonetheless be generated which cannot be accounted for within the BEBs (e.g. combustion sources outside the development locality).

2.6 For the purposes of this assessment it has also been assumed that on-site combustion practices utilise natural gas from the national gas grid. It has been assumed that no new developments will utilise other fuels to facilitate combustion for the delivery of heat. This is considered a strong reflection of new residential-led development in London.

2.7 Where on-site combustion practices are used (and fuel content is assumed to remain homogenous), NOx emissions are linked to:

> Quantity and capacity of heat sought;

> Efficiency of combustion process;

> Proportion of generated heat delivered to end-user.

2.8 One of the central aims of the revised SAP methodology is to 'rebalance' certain aspects of the current energy assessment process which are not considered reflective of reality. The application of higher heat losses for communal heating systems and a realignment of the electricity CO_2 emissions factor, revised to better reflect the ongoing decarbonisation of the electricity grid, are considered the two most significant elements of this.

2.9 The inclusion of these two changes will result in the following:

> Higher heat losses - larger quantities of fuel inputted into the combustion process in order to deliver the same end-user heating provision;

> Revised electricity CO_2 emissions factor – promotion of strategies which use mains electricity for part or indeed all of a development's heating requirements.

2.10 Both changes will alter the reporting of expected on-site NOx. The former will increase *expected* on-site NOx, whilst not increasing *actual* on-site NOx because it is an accommodation of a more realistic heat loss assumption in the calculation methodology. The latter will move the emissions point for building-related NOx (discussed below in more detail), but it will not necessarily reduce the overall output of NOx.

2.11 It should be noted that the analysis in this report uses SAP 10 CO_2 emissions factors, as at the time of writing this remains the preferred assessment metric for the GLA. Further revisions were made to the CO_2 emissions factors under SAP 10.1, which forms part of the recently released document outlining the consultation on the *Future Homes Standard*, however these have not been utilised in this work as it was released too late for consideration.

Displaced NOx

2.12 As this analysis only addresses the emission of building-related on-site NOx, the application of an electric heating strategy will evidently be advantageous from an on-site NOx perspective. Here it is important to make the distinction between building-related *on-site* NOx and *all* building-related NOx. This is because only the latter accounts for displaced NOx. This is NOx which is emitted as a result of energy generation which is used on-site, but for which the NOx is emitted elsewhere. For instance, the production of NOx from centralised thermal power stations for electricity generation which is then supplied to urban locations and used on a development site.

2.13 The displacement of NOx is particularly prevalent when considering the NOx emissions associated with gas Combined Heat and Power (CHP) engines. Efficiencies for CHP engines when focusing exclusively on thermal output are low (~35-50%) when compared with new gas boilers (~85-90%). This is because the primary output from CHP engines is electricity, with heat a useful by-product. The required fuel input to produce the same thermal output is therefore significantly higher for a CHP engine than a gas boiler, because the CHP engine is producing two useful outputs, only one of which is contributing to the heat demands of a development.

2.14 As this analysis intends to take into account NOx emissions within the GLA's administrative boundary, with NOx emissions predominately a concern for public health in urban areas, CHP NOx associated with both thermal and electrical outputs will need to be accounted for. NOx associated with mains electricity generation is highly likely to have occurred outside the GLA administrative boundary, and therefore will not be accounted for. For this reason the CHP-generated NOx cannot be displaced when determining a set of revised BEBs.

Types of Energy Strategy

2.15 This assessment will analyse how the following energy strategies affect a development's building-related on-site NOx emissions:

> Gas boilers to individual dwellings & non-residential areas;

> Electric resistance heating;

> Air source heat pumps (ASHPs) to individual dwellings & non-residential areas;

> Communal heating ('heat network') with centralised gas boilers;

> Communal heating ('heat network') with centralised gas boilers and CHP;

> Communal heating ('heat network') with ASHPs;

> Communal heating ('heat network') with gas boilers and ASHPs;

2.16 These strategies have been assessed against a range of development sizes, with certain strategies being unsuitable for certain development sizes. This could be on the grounds of technical feasibility and/or planning/regulatory requirements.

2.17 As outlined earlier in this section, strategies which do not propose on-site combustion practices – such as electric resistance heating or ASHPs – will not have building-related on-site NOx emissions. However, both will deliver quite different CO_2 performances as the source of the electricity and efficiency of the systems vary considerably. One aim of this work is to present a more rounded view of energy strategies, where CO_2 and NOx emissions are not assessed in isolation, and so electric strategies will still be included in this assessment even though their building-related NOx is effectively zero.

2.18 Although seven separate energy strategies have been assessed as part of this work, it is unlikely that this will result in seven different BEBs per land-use class due to the presence of on-site combustion practices in only some of these strategies.

2.19 It is the intention of this report to provide as much information and explanation as possible to assist the GLA in determining how to go about revising the current BEBs.

3. REVISED BUILDING EMISSIONS BENCHMARKS - CLASS C3 (DWELLINGS)

3.1 Table 1, below, sets out the proposed BEBs for dwellings, as determined from this analysis. The seven potential energy strategies as outlined in Section 2 are assessed against eight varying development sizes, ranging from single dwellings up to large apartment complexes.

<table>
<tr><th></th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boilers Network</th><th>Heat Pump Network</th><th>Heat Pump + Gas Boilers Network</th></tr>
<tr><td>Small House (100m^2)</td><td rowspan="6">3.5 g/m^2</td><td rowspan="6">No Heat-related NOx</td><td rowspan="6">No Heat-related NOx</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td></tr>
<tr><td>Medium House (130m^2)</td></tr>
<tr><td>Large House (200m^2)</td></tr>
<tr><td>0-10 flats</td></tr>
<tr><td>10-50 flats</td><td rowspan="4">5.7 g/m^2</td><td rowspan="4">25.5 g/m^2</td><td rowspan="4">No Heat-related NOx</td><td rowspan="4">5.7 g/m^2</td></tr>
<tr><td>50-400 flats</td></tr>
<tr><td>400-1000 flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td></tr>
<tr><td>1000+ flats</td></tr>
</table>

Table 1: Proposed Residential BEBs – NOx grams/m^2

3.2 As explained in Section 2, this has not led to the conclusion that 56 different BEBs for Class C3 should be set. Rather, only three have been set. This is for the following reasons:

> Electric only heating strategies (includes heat pumps) do not generate any on-site combustion-related NOx emissions. An exception to this would be the use of backup generators, which are usually diesel-led. These have not been considered in this work due to the small run hours across a year, and that they are often present only for emergency power purposes in vulnerable settings such as hospitals;

> Not every energy strategy is equally suitable to each development size. For instance, given the GLA's strong preference for decentralised heat networks to be installed on medium to large scale developments, it is highly unlikely that a strategy utilising individual heat sources would be adopted at this scale. Similarly, it would likely be considered technically and economically inappropriate to install a heat network on a very small development of only a few dwellings;

- There is a degree of variability in the calculated BEB between different development sizes on the same energy strategy. For instance, a large house (200m^2) using an individual gas boiler would result in a calculated BEB lower than that of a medium (130m^2) or small (100m^2) house. This is due to the difference in floor area which affects the current BEB metric (grams/m^2). It is considered burdensome and confusing to set different BEBs on the basis of floor area alone. It would also result in an infinite number of variations if taken to its limit. For simplicity and ease of assessment, the BEBs set have been done so to allow those development sizes most disadvantaged by floor area to still meet the set BEB using current widely used NOx abatement technology (see Section 5 for more details);

- The proposed BEB for developments utilising a heat network with both heat pumps and gas boilers as heat sources is the same as that used for a heat network with gas boilers only. It is considered unreasonable to effectively penalise the former approach by setting a lower BEB because a portion of the generated heat is coming from a low carbon and clean heat source;

- Similarly, a higher BEB has been set for heat networks which use CHP than those which only use gas boilers. This is because:

  a) NOx as a result of electrical generation is also included;

  b) There remains a strategic case for CHP in certain instances where it may be an essential element of the financial case for proceeding with a heat network. A development may therefore be directed down this route to meet planning objectives, in which case it may be considered unreasonable to expect the same air quality standards to be met as a boiler only network.

3.3 The GLA may decide to apply only one BEB for the whole C3 land use class, therefore not accounting for any variance in selected energy strategy. This report aims to provide as much explanation as possible to inform on what disadvantages this may result in.

Calculation Methodology

3.4 The NOx BEBs in Table 1 have been calculated using the existing GLA emissions standard for gas boilers and gas CHP plant. These are set out in Appendix 7 of the Sustainable Design and Construction SPG (2014). As a reminder, these are:

> Gas CHP – 95mg/Nm^{-3} (at 5% reference O_2);

> Gas Boilers – 40mg/kWh (based on fuel input).

Inputs

3.5 The calculation of the BEBs has been undertaken using the following process. As described in point 2.6, only gas-based systems have been assessed:

> Annual heat demands for each development type taken from SAP outputs. The energy performance of the dwellings has been set at the minimum Part L 2013 baseline, so the heat demands represent a nationally representative build specification;

> Efficiency of heat distribution is then added (only necessary for communal systems);

> Efficiency of heat generation is then added (again, only necessary for communal systems as individual boilers already account for this in the SAP heat demand outputs);

3.6 This first step results in an annual gas demand for a particular development size and development strategy combination. The following two calculations are then undertaken to determine a NOx standard in g/kWh:

1. (Annual Gas Demand x NOx Emission Benchmark) / 1000;

2. Answer to Calculation 1 / Total Development Heat Demand (at dwellings).

3.7 To convert this into the more recognisable g/m^2 metric:

3. (Answer to Calculation 2 / 100) / Average Floor Area (for particular development type).

3.8 The inputs as listed in point 3.4 are complicated by the presence of a CHP engine, which will require an additional line to split the heat output coming from the CHP engine and the supplementary gas boilers. Under point 3.5, two sets of Calculation 1's will then need to be undertaken as the gas boilers and the CHP engine have different NOx benchmarks in the SPG.

3.9 It is also necessary to convert the CHP benchmark to 0% O_2 reference. This is done through the following calculation:

- NOx Emission Benchmark x (20.9 / (20.9 – X)) *Where X is the excess reference O_2 (usually 5%)*

3.10 It is also then necessary to convert the CHP metric from mg/Nm^{-3} to mg/kWh. This is done by multiplying this 0% reference figure by 0.857 (see Pol 01 calculation methodology for BREEAM 2011).

3.11 Assumed efficiencies in point 3.4 were used to calculate the revised BEBs. These are:

- Losses associated with heat distribution – 40% (between dwellings and Energy Centre/Plant Room);
- Gas boiler efficiency – 84% (as used by Heat Trust in their Heat Cost Comparator);
- (If present) CHP thermal efficiency – 40%.

Assumption Deficiencies

3.12 Should any of the backstop efficiencies differ in the calculation of NOx on specific developments then it could make it very difficult to achieve any revised set of BEBs.

3.13 The backstop efficiency which is most likely to vary is that of network losses on communal heating networks. As such, an efficiency margin has been added to the proposed BEBs based on communal heating systems to allow for an appropriate degree of variance. This increases these calculated BEBs by 10% (this has been included in the proposed BEBs in Table 1).

3.14 It is unlikely that new gas boilers would be unable to achieve a declared efficiency of 84%, or that a CHP engine would have a thermal efficiency much below 40%. No variance has been added on these factors.

Enhanced CHP Targets

3.15 Hodkinson Consultancy undertook an assessment of the current GLA Emission Benchmarks as part of a wider report by Air Quality Consultants for the City of London in 2018. The intention of the review was to determine whether the existing benchmarks could be enhanced for adoption in a new set of planning documents for the borough.

3.16 Our conclusion was that the NOx abatement technology at the time did not present a viable path for the existing gas boiler benchmark of 40mg/kWh to be enhanced further.

3.17 However, it was concluded that existing abatement technology would allow an enhanced benchmark to be set for gas CHP engines. The analysis further concluded that it may be appropriate to set two separate CHP benchmarks, to take account of the two different abatement technologies (Selective Catalytic Reduction and 3-Way Catalysts). These were:

- $25mg/Nm^{-3}$ for CHP engines using SCR;

> 50mg/Nm^{-3} for CHP engines using 3-Way Catalysts.

3.18 It was considered justifiable to set an enhanced target for CHP engines with SCR as there is no decipherable cost increase or additional technical complexity as a result of setting an SCR system to deliver 25mg/Nm^{-3} as opposed to 50mg/Nm^{-3}.

3.19 Table 2, below, shows the adjustment to the CHP-related BEBs when the two enhanced CHP NOx benchmarks are used. As size (output) of CHP is the primary determinant for whether a SCR or 3-Way Catalyst is likely to be fitted, the enhanced BEBs have been split based on development size. It should nonetheless be noted that it would be possible for a development of less than 400 dwellings to have a CHP engine with an SCR fitted, and vice versa, as the point at which one is appropriate and the other is not is due to the presence of a turbocharger on the CHP engine. This output point varies based on the specific model and manufacturer of the selected engine.

<table>
<tr><th></th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boilers Network</th><th>Heat Pump Network</th><th>Heat Pump + Gas Boilers Network</th></tr>
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<tr><td>50-400 flats</td></tr>
<tr><td>400-1000 flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">7.8 g/m^2</td></tr>
<tr><td>1000+ flats</td></tr>
</table>

Table 2: Enhanced CHP BEBs – NOx grams/m^2

3.20 One interesting conclusion that can be drawn from Table 2 is that even using the enhanced CHP benchmarks, CHP still produces more NOx per kWh of generated heat than a gas boiler does.

3.21 Further analysis on the technological solutions available for NOx abatement is provided in Section 5.

g/kWh Metric

3.22 One of the considerations under point 3.2 is the variance caused by setting the BEBs against the existing grams/m^2 metric. It would be overly complex to set multiple different BEBs on the basis of floor area differences alone. However, not doing so means that it is easier for e.g. a large house to meet the same BEB as set for a small house, in spite of all other considerations being the same.

3.23 If the BEBs were to employ a metric which did not have to address this variance at all, and instead set targets on the basis of grams/kWh of NOx, then it would be considered a more accurate reflection of what affects a development building-related NOx. Namely heating demand rather than floor area.

3.24 Table 3, below, updates the BEBs if they were reported against the g/kWh metric.

<table>
<tr><th></th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boilers Network</th><th>Heat Pump Network</th><th>Heat Pump + Gas Boilers Network</th></tr>
<tr><td>Small House ($100m^2$)</td><td rowspan="6">0.05 g/kWh</td><td rowspan="6">No Heat-related NOx</td><td rowspan="6">No Heat-related NOx</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td><td rowspan="4">Strategy Not Appropriate</td></tr>
<tr><td>Medium House ($130m^2$)</td></tr>
<tr><td>Large House ($200m^2$)</td></tr>
<tr><td>0-10 flats</td></tr>
<tr><td>10-50 flats</td><td rowspan="4">0.09 g/kWh</td><td rowspan="2">0.39 g/kWh (0.22 g/kWh enhanced CHP)</td><td rowspan="4">No Heat-related NOx</td><td rowspan="4">0.09 g/kWh</td></tr>
<tr><td>50-400 flats</td></tr>
<tr><td>400-1000 flats</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">Strategy Not Appropriate</td><td rowspan="2">0.39 g/kWh (0.12 g/kWh enhanced CHP)</td></tr>
<tr><td>1000+ flats</td></tr>
</table>

Table 3: Proposed BEBs – NOx grams/kWh

3.25 As with Table 1, a 10% efficiency margin has been added to the BEBs derived on communal heating systems.

Consideration of CO_2

3.26 Section 3 has thus far not presented the impact on CO_2 emissions that a development's energy strategy causes. As described in Section 2, it is beneficial not to consider air quality (NOx) and energy performance (CO_2) in isolation. One of the central aims of this report is to present both aspects to enable a more comprehensive analysis.

3.27 Table 4, below, takes the same development types and energy strategies and shows the related CO_2 emissions. The reductions for each entry have been shown against the Part L 2013 Building Regulations baseline (Target Emissions Rate), under SAP 2012 conditions.

	Individual Gas Boilers	Electric Panel Heaters	Individual ASHPs	Gas Boiler Network	CHP + Gas Boilers Network	Heat Pump Network	Heat Pump + Gas Boilers Network
Small House (100m²)	0%	-35%	25%	*Strategy Not Appropriate*	*Strategy Not Appropriate*	*Strategy Not Appropriate*	*Strategy Not Appropriate*
Medium House (130m²)		-35%	25%				
Large House (200m²)		-35%	25%				
0-10 flats		-30%	15%				
10-50 flats		-30%	15%	0%	25%	40%	10%
50-400 flats		-30%	15%	0%	30%	40%	10%
400-1000 flats	*Strategy Not Appropriate*	*Strategy Not Appropriate*	*Strategy Not Appropriate*	0%	35%	40%	10%
1000+ flats				0%	40%	40%	10%

Table 4: SAP 2012 CO_2 Reductions Against Selected Energy Strategy

3.28 Table 5, below, shows the conditions of Table 4 when utilising SAP 10 emission factors. Section 2 outlines what changes have been made between the two SAP metrics.

	Individual Gas Boilers	Electric Panel Heaters	Individual ASHPs	Gas Boiler Network	CHP + Gas Boilers Network	Heat Pump Network	Heat Pump + Gas Boilers Network
Small House (100m²)	0%	0%	50%	*Strategy Not Appropriate*	*Strategy Not Appropriate*	*Strategy Not Appropriate*	*Strategy Not Appropriate*
Medium House (130m²)		0%	50%				
Large House (200m²)		0%	50%				
0-10 flats		0%	30%				
10-50 flats		0%	30%	-10%	-35%	50%	20%
50-400 flats		0%	30%	-10%	-30%	50%	20%
400-1000 flats	*Strategy Not Appropriate*	*Strategy Not Appropriate*	*Strategy Not Appropriate*	-10%	-25%	50%	20%
1000+ flats				-10%	-20%	50%	20%

Table 5: SAP 10 CO_2 Reductions Against Selected Energy Strategy

Comparison of NOx and CO_2

3.29 Comparing the contents of Tables 1, and Tables 4 and 5, the following conclusions can be drawn:

- Under SAP 2012 emission factors, CHP results in a very good CO_2 performance. This, alongside its role in the promotion of heat networks, has often been pursued in spite of the poor air quality associated with CHP engines. Under SAP 10 emission factors, it can be seen that the argument that the CO_2 performance of CHP can override its poor NOx performance no longer stacks up;
- Direct electric heating, although not a source of any on-site building-related NOx, does not deliver the equivalent CO_2 savings that other electrically-led strategies such as heat pumps do;
- The efficiency of heat distribution in heat networks has a significant impact on both development CO_2 and NOx emissions;
- The revision of the SAP emission factors to better reflect the decreasing carbon intensity of mains electricity is reducing any conflict between energy strategies which prioritise CO_2 savings over air quality considerations.

4. REVISED BUILDING EMISSIONS BENCHMARKS – NON-RESIDENTIAL

4.1 It is understood that the vast majority of planning applications submitted to the GLA where an air quality assessment is required are residential-led. To this end it is right that the analysis presented in this report is focused predominantly on this area.

4.2 Nonetheless, it would not be appropriate to revise the BEBs for Class C3 (dwellings) and retain the existing ones for all other land use classes. Section 4 of this report therefore outlines revised BEBs for all non-residential land use classes.

4.3 Returning to Figure 1 (current BEBs), this analysis has picked out four of the remaining non-residential building types. These are:

- Class A1 (retail);
- A2 & B1 (offices);
- C1 (hotels);
- D1 (schools).

4.4 These have been selected based on a judgement that they reflect the most sensitive building uses to air quality considerations.

4.5 Other non-residential land-use classes not addressed in point 4.3 which are covered in Figure 1 will still be given revised BEBs. These are to be established by applying the same factor by which similar assessed BEBs have changed. For example, restaurants/bars (class A3-A5) have a current BEB which is similar to that of hotels (class C1). If it were determined that the revised BEB for hotels were to be e.g. 40% lower than the current BEB, then the same reduction in percentage terms would be applied to restaurants/bars.

4.6 As with the residential BEBs, these have been calculated using the existing GLA emissions standard for gas boilers and gas CHP plant as set out in Appendix 7 of the Sustainable Design and Construction SPG (2014).

4.7 Table 6, below, shows the proposed BEBs for all remaining land-use classes (other than dwellings).

4.8 It is understood that the proportion of development (by floorspace) that is evaluated against the Air Quality Neutral benchmarks is heavily weighted towards residential uses. Non-residential new development often supplements residential-led development within London, for instance as a ground floor shop or two floors of basement office space in a 15+ storey apartment block. In instances where non-residential development is a standalone submission, it is likely that communal heating strategies may not be appropriate, and that only the individual gas boiler BEBs would apply.

<table>
<tr><th></th><th>Individual Gas Boilers</th><th>Electric Panel Heaters</th><th>Individual ASHPs</th><th>Gas Boiler Network</th><th>CHP + Gas Boilers Network</th><th>Heat Pump Network</th><th>Heat Pump + Gas Boilers Network</th></tr>
<tr><td>Retail (A1)</td><td>0.53</td><td rowspan="9">No Heat-related NOx</td><td rowspan="9">No Heat-related NOx</td><td>0.97</td><td>4.31</td><td rowspan="9">No Heat-related NOx</td><td>0.97</td></tr>
<tr><td>Restaurants/Bars (A3-A5)</td><td>10.94</td><td>20.06</td><td>89.54</td><td>20.06</td></tr>
<tr><td>Office (A2 & B1)</td><td>1.43</td><td>2.62</td><td>11.68</td><td>2.62</td></tr>
<tr><td>Industrial (B2-B7)</td><td>1.07</td><td>1.95</td><td>8.73</td><td>1.95</td></tr>
<tr><td>Storage (B8)</td><td>0.55</td><td>1.01</td><td>4.50</td><td>1.01</td></tr>
<tr><td>Hotel (C1)</td><td>10.32</td><td>18.91</td><td>84.42</td><td>18.91</td></tr>
<tr><td>Care Homes/Hospitals (C2)</td><td>9.97</td><td>18.27</td><td>81.56</td><td>18.27</td></tr>
<tr><td>School (D1)</td><td>0.90</td><td>1.66</td><td>7.39</td><td>1.66</td></tr>
<tr><td>Entertainment/Leisure (D2)</td><td>13.14</td><td>24.09</td><td>107.52</td><td>24.09</td></tr>
</table>

Table 6: Proposed BEBs for Non-Residential Uses (g/m² of NOx)

HODKINSON

4.9 The calculation methodology followed to determine the non-residential BEBs has used the same approach and calculation route as that described in Section 3. In place of SAP outputs for heat demands, the non-residential assessment has used outputs from SBEM calculations.

4.10 A 10% efficiency margin has similarly been added to all proposed BEBs on communal heating systems.

4.11 As outlined in point 4.5, these calculations have been undertaken on the four most sensitive non-residential building types. These results are highlighted in bold in Table 5.

4.12 An example of how the remaining BEBs in Table 5 have been calculated is as follows:

> Those land use classes that have not been fully recalculated are ‘paired’ with those that have. The pairing is based on the most similar existing BEB, as shown in Table 1. For instance, the existing BEB for restaurants/bars (A3-A5) is 75.2. The most similar existing BEB of the land use classes selected for full recalculation is that of hotels (C1) which is 70.9;

> A difference factor is calculated from this (simply the former divided by the latter). This factor (in the case of this specific example being 1.061) is then multiplied by the recalculated BEB in bold in Table 5. This specific example would result in:

10.32 x 1.061 = **10.94** *(For individual gas boilers in this example)*

> This is then repeated for each energy strategy.

SBEM and SAP Deficiencies

4.13 Analysis by CIBSE and AECOM (TM54:2013 – *Evaluating operational energy performance of buildings at the design stage*) has shown how estimated energy use through SBEM methodology can significantly underestimate actual energy use. The vast majority of this additional load is non-heating related and could be considered as unregulated energy, however it should be stated that SBEM should not be considered an explicit design guide.

4.14 SAP methodology has been shown to be broadly representative of regulated heat energy use, although does not account for unregulated energy usage.

4.15 The key summary is that both SBEM and SAP provide a useful barometer for comparison between different energy strategies and building designs, and provide a simple and recognisable set of outputs which can be understood both by modelling teams and planning authorities alike.

5. NO_X REDUCTION TECHNOLOGIES

5.1 As outlined in Sections 3 and 4, the revised BEBs have been calculated on the basis of the existing SPG (2014) NOx emission targets for new gas boiler and CHP plant.

5.2 Section 3 has also shown in Tables 2 and 3 how an enhanced BEB could be set for developments with CHP engines if enhanced NOx emission targets beyond that of the SPG were used.

5.3 Section 5 aims to demonstrate how, in practice, these NOx standards can be achieved.

Types of Reduction Technologies

5.4 It is not possible for certain combustion plant to achieve the emission targets in the SPG (2014) without modification. In these instances, to further reduce NO_X emissions from combustion plant additional technologies are utilised which either manipulate the conditions within the combustion chamber which result in NO_X formation, or address NO_X emissions post-combustion through treatment of the exhaust gases.

5.5 Four NO_X reduction technologies have been identified as part of the analysis. These are as follows:

- Pre-mix burners (for shell and tube boilers);
- External Flue Gas Recirculation (for shell and tube boilers);
- Three-Way Catalysts (for naturally aspirated CHP engines);
- Selective Catalytic Reduction (for turbo-charged CHP engines).

5.6 The 40mg/kWh target for gas boilers in the SPG (2014) does not allow for any differentiation between boiler type. For instance, whereas all new domestic scale gas boilers and commercial scale condensing boilers are able to meet this target without modification or the addition of further equipment, this is not possible for larger shell and tube boilers. The latter is likely to require the installation of either a pre-mix burner or the addition a burner and pipe combination which can recycle a portion of flue gases back into the combustion mix (External Flue Gas Recirculation).

5.7 Gas CHP engines are also unable to achieve the SPG (2014) target of $95mg/Nm^{-3}$ (at 5% O_2) without additional equipment. As outlined in Section 3, two methods are used to do this. For smaller CHP engines (naturally aspirated) it is quite common to fit a three-way catalyst to the exhaust. These are very similar to those fitted to most vehicles. For larger (turbo-charged) CHP engines, the excess fuel/air mix which is forced through the engine renders a three-way catalyst obsolete. The exhaust output of these larger engines requires a much more substantial system to manage NOx emissions, know as Selective Catalytic Reduction (SCR).

5.8 Factsheets have been prepared to summarise in greater detail these four technology types. Please see Appendix A.

6. SUMMARY

6.1 This report has been developed to assist Air Quality Consultants in the determination of a new set of Building Emissions Benchmarks (BEBs) in NOx for the Greater London Authority's (GLA) Air Quality Neutral standard. Our work is to accompany their report on the wider Air Quality Neutral standard in relation to transport and other pollutants such as PM_{10}.

6.2 It is understood that the GLA wish to revisit these BEBs in order to better reflect the following, which the current benchmarks do not differentiate by:

> **New building stock** – The current set of air quality benchmarks were developed to reflect the emissions associated with the wider building stock in London, which is predominantly old (i.e. pre 21^{st} century). New building stock is designed to a much higher standard of energy efficiency and with cleaner on-site combustion sources. It is therefore considered reasonable to hold these developments to a higher standard of building-related air quality.

6.3 It is the view of HC that a re-evaluation of these targets also represents an opportunity to consider the following:

> **Varying energy strategies** – A development's NOx emissions will be strongly linked to its selected energy strategy, and not just the proportion of land-use classes. It would seem reasonable to put in place different targets for different strategies.

6.4 Our report has developed a revised set of BEBs for NOx emissions taking into account the role of a development's energy strategy, as well as ensuring they are focused on heating profiles more in line with new buildings.

6.5 The revised BEBs have been presented in two different metrics (g/m^2 and g/kWh), and intend to demonstrate that policy setting should consider the roles of CO_2 and NOx more closely, so as to appreciate that in some instances contradictions may remain if one is thought of in absence of the other.

APPENDICES

Appendix A
NOx Technology Factsheets

Appendix A - Technology Factsheets

Factsheet - Premix Burners

Premix burners aim to produce the optimal air-fuel mix upstream of the combustion point, resulting in a very clean and compact flame while reducing the size of the combustion chamber. They are a well-established technology in condensing boilers, with their application as larger burners for the shell and tube market a relatively recent development only. Premix burners are more complex than standard forced draught burners due to the control systems operating to ensure a precise air-fuel mix.

Applies To	All Shell and Tube Boilers up to the 1.5MW range.

Impact analysis

NO_X	Can reduce NO_X emissions to 30 mg/kWh with appropriate boiler/burner selection.
CAPEX	Higher than forced draught burners, with a slightly shorter lifespan due to increased complexity. Cost difference exacerbated above circa 1MW range.
OPEX	Should not require any additional maintenance beyond standard. boiler/burner works.
Capacity (kW) Scalability	Maximum of 1.5MW.
Spatial Requirements	Negligible, does not require additional spatial allowance.
Production scalability	Understood that premix burners are not widely used yet and are therefore a fledgling technology. Scalability likely to be limited.
Technology robustness	More complex than forced draught burners due to precise mixing of air-fuel. This may require additional commissioning and servicing.

Additional notes

Flame Flashback – Good pre-mix design should ensure that the velocity of the air-fuel mix is always sufficient enough to prevent the flame to flashback into the pre-mix burner itself.

The optimum operation for pre-mix burners requires 8-10% CO_2.

Factsheet – External Flue Gas Recirculation

Flue gas recirculation (FGR) aims to affect the chemical composition during combustion, therefore impacting the formation of thermal NO_X. A proportion of the flue gases are recirculated over the combustion air flow, in turn reducing the oxygen content and absorbing heat energy from the flame. The principle can be designed to occur within the combustion chamber of the boiler itself, however is much more effective when the flue gases are removed via an external pipe and injected into the air-fuel supply prior to the flame (external FGR).

Applies To	Shell and Tube Boilers that are Three Pass designs only.

Impact analysis

NO_X	Can reduce NO_X emissions to 30 mg/kWh, provided appropriate boiler/burner selection.
CAPEX	There is standard cost that is not significantly impacted by boiler size. It is in the range between £5,000 - £10,000 per application.
OPEX	It is expected that standard maintenance will be acceptable.
Capacity (kW) Scalability	Understood not to be affected by boiler size.
Spatial Requirements	Requires additional spatial planning and allowance on the side and above the boiler, as the images describes.
Production scalability	Several manufacturers already offering this technology.
Technology robustness	Requires electrical sensors to detect and set appropriate operating conditions. More complicated than ordinary boiler/burner setup but not considered too complex.

Additional notes

Proportion of flue gas recirculated – Usually set to be around 10-15% of total flue gas output. If this is too low, then flame temperature and oxygen will not be reduced sufficiently to enable lower NO_X emissions. If set too high, then combustion can effectively be ‘choked’ and impede on boiler output.

Control Settings – To ensure optimal conditions for both boiler output and NO_X reductions are consistently achieved, sensors which detect e.g. temperature and oxygen content must be regularly tested.

Factsheet – Three-Way Catalysts

Also known as non-selective catalytic reduction (NSCR), three-way catalysts (TWCs) also address Carbon Monoxide (CO) and unburnt hydrocarbons. The exhaust gases are passed over a reduction catalyst and then an oxidation catalyst. The former splits NO_X emissions into nitrogen and Oxygen, and the latter oxidises CO and unburnt hydrocarbons to form CO_2 and H_2O. TWCs cannot operate in an environment with excess oxygen, so are limited to CHP applications which operate under stoichiometric conditions. The technology has been employed on automobiles since the early 1980s.

Applies To	Spark Ignition CHP (stoichiometric burn) less than circa $500kW_e$.
Impact analysis	
NO_X	Usually set to achieve $50mg/Nm^3$, they are limited by available space within the engine shell and therefore generally do not achieve NO_X reductions much below this point.
CAPEX	An additional £1,500 - £5,000 on top of the main CHP CAPEX.
OPEX	Regular cleaning required. Main expense is from catalysts which are likely to need replacing every 1-3 years.
Capacity (kW) Scalability	Cannot be applied on engines operating in 'lean burn' mode which use a turbocharger and engines circa $500kW_e$.
Spatial Requirements	Usually design to fit within the CHP engine shell therefore has requires a taller or wider enclosure.
Production scalability	Widely available with most CHP manufacturers.
Technology robustness	Well understood and widely applied.

Additional notes

Operational Conditions – The catalysts facilitate the reaction at a lower temperature than otherwise would be possible. However, exhaust gas temperatures still need to be in excess 200°C (for TWCs) to enable NO_X reductions. Under engine start conditions, it is therefore likely that for a short period (5-10 minutes) unabated NO_X will be passing through the catalysts.

Effectiveness of Catalysts - The impact of high temperatures and toxins within the exhaust gases reduce the effectiveness of the catalysts over time. Regular cleaning to relieve blockages is a critical part of the maintenance regime.

Factsheet – Selective Catalytic Reduction

Selective Catalytic Reduction (SCR) only addresses NO_X emissions. A chemical reagent, usually ammonia or urea, is injected into the exhaust gases which are then passed through a series of catalyst slides. This then converts the NO_x to nitrogen and water. SCR is the predominant means by which NO_x is addressed in larger turbocharged engines.

Applies To	Turbocharged CHP engines in the range of 250-500kWe and above.

Impact analysis

NO_X	NO_X is addressed outside of the CHP engine shell, thereby removing the spatial constraints of TWCs. It is possible to reduce NO_X emissions to a very low amount, circa 15mg/Nm^3. This is however based on theoretical output and has been shown in a single case. Market ready solutions currently reduce NO_X to 25mg/Nm^3.
CAPEX	High. Likely to be an additional 15 – 25% on top of main CHP CAPEX.
OPEX	Similar maintenance requirements to the 3-way catalyst. However, size of catalysts means replacement costs are likely to be £3,000-£5,000 per catalyst, additionally stocks of chemical reagent need to be maintained and stored safely.
Capacity (kW) Scalability	Not limited by output of CHP engine
Spatial Requirements	Substantial. Dimensions subject to individual design and requirements of CHP; however, an SCR unit could be as long as the CHP engine itself. Size is linked directly to CHP engine output.
Production scalability	CHP manufacturers tend to employ specialists to design and install an SCR solution. Research has indicated a very small number of companies are able to offer this. Scalability is considered to be limited at this current time.
Technology robustness	Systems are usually monitored and maintained by specialists. Technology is considered robust.

Additional notes

Operational Conditions – Catalysts facilitate the reaction at a lower temperature than otherwise would be possible. However, exhaust gas temperatures still need to be more than 300°C to enable NO_X reductions. Under engine start conditions, for a short period (5-10 minutes) unabated NO_X will be passing through the catalysts.

Effectiveness of Catalysts - The impact of high temperatures and toxins within the exhaust gases reduce the effectiveness of the catalysts over time. Regular cleaning to relieve blockages is a critical part of the maintenance regime. With SCR it is also recommended that the front catalyst is replaced every 1-2 years.

Dosing of Reagent - Should the amount of injected reagent be too low, a larger proportion of NO_X will remain unaddressed. Should the amount be too high then some of the reagent will not react, resulting in the venting of dangerous chemicals through the exit stack.

A2 Report by VECTOS

Greater London Authority – Transport Emission Benchmark

Air Quality Neutral Policy Update

September 2019

194833/N01

Introduction

1. Vectos has been commissioned by Air Quality Consultants to provide advice on the proposed update to the development of the Mayor's policy related to "air quality neutral" developments.

2. An initial report setting out the Transport Emission Benchmark (TEB) calculations was published in April 2014 and subsequently used to advise the Sustainable Design and Construction Supplementary Planning Guidance. It is understood that Greater London Authority intends to revise the policy in response to changes in travel behaviour and emissions.

3. This Technical Note outlines the proposed methodology and subsequent results of the updated calculations of the TEBs. This note also sets out the current methodology limitations and key discussion points.

Car Trips

Number of Trips

4. As part of the 2014 TEB methodology trip data was extracted from the TRAVL (Trip Rate Assessment Valid for London) database for retail, office and residential developments for the period 2000 – 2012. Since the derivation of the TEBs in 2014, the TRAVL database, which was previously designed specifically for the use in London, has been incorporated into the TRICS database. Given that the data used in setting the TEBs is at least 7 years old, updated trip data has been extracted from the TRICS database to ensure that the new assessment reflects changing travel habits. Only surveys for the most recent five-year period (available within TRICS database) were included as part of the assessment.

5. Trip rates were derived for Inner and Outer London and Central Activities Zone (CAZ) to reflect the methodology of the original assessment. Land use classes selected for this assessment replicated those considered in 2014 therefore: retail (A1), office (B1) and residential (C3), which was considered to cover the major land use classes.

6. **Table 1** overleaf presents a summary of the updated trip rates extracted from TRICS which form the basis for further assessment. Each individual TRICS survey provides trip data for a range of different time periods therefore, for consistency, all daily trip rates in the table only consider the hours from 07:00 to 19:00.

Table 1: TRICS Trip rates for the major land uses.

Main Land Use	Sub Land Use	Zone	Number of surveys available	Trip Rates		
				Cars (07:00 to 19:00)	Service Vehicles (07:00 to 19:00)	Total (cars + service vehicles) 07:00 to 19:00
03 - Residential	C - Flats Privately Owned	Outer London	12	1.125	0.285	1.410
		Inner London	6	0.286	0.546	0.832
		Central Activity Zone	3	0.171	0.365	0.536
02 - Employment	A - Office	Outer London	4	4.085	0.534	4.619
		Inner London	2	0.288	0.684	0.972
		Central Activity Zone	2	0.496	0.634	1.130
01 - Retail	A - Food Superstore	Outer London	4	54.513	2.864	57.377
		Inner London	1	18.424	1.870	20.294
		Central Activity Zone	3	9.920	3.708	13.628
	O - Convenience Store	Outer London	4	69.087	5.880	74.967
		Inner London	1	35.000	3.808	38.808
		Central Activity Zone	1	4.545	1.192	5.737

Note:

Residential trip rates are calculated per dwelling while employment and retail trip rates are calculated per 100 sq. m of gross floor area.

7. The trip rates set out in the above table were subsequently factored to 24hrs to represent an average daily trip for a weekday, Saturday and Sunday based upon the National Travel Survey (NTS0501, 2018). To derive the total number of trips per annum the weekly trips (5x weekday + Saturday + Sunday) were multiplied by 52 (number of weeks in a year). For comparability with the 2014 report, retail and employment trips were converted to represent trips per one square meter. The results are presented in **Table 2** below, whilst the original 2014 values are included in **Table 3** overleaf for comparison.

Table 2: Average number of Trips per Annum for Different Development categories – Cars Only.

Land Use	Annual Trips per	Car Trips		
		CAZ	Inner London	Outer London
Retail (A1) Food Superstore	1 sq.m	39	73	216
Retail (A1) Convenience	1 sq.m	18	139	274
Office (B1)	1 sq.m	2	1	16
Residential	Dwelling	68	114	447

Table 3: Average number of Trips per Annum for Different Development categories – Cars Only (2014).

Land Use	Annual Trips per	Car Trips		
		CAZ	Inner London	Outer London
Retail (A1)	1 sq.m	43	100	131
Office (B1)	1 sq.m	1	4	18
Residential	Dwelling	129	407	386

8. The above tables indicate that the trend in London since the last assessment is a reduction of car trip number in the Inner London and CAZ with a slight increase of car trip associated with sites in located in Outer London. This is particularly significant for residential uses where 47% and 72% is observed for CAZ and Inner London respectively. This may be associated with the policy changes aiming to reduce the use of private car in Central London and effectiveness of sustainable travel planning.

9. The above tables present the average annual number of car trips per year only and as such it does not include other motor traffic associated with the potential development, such as servicing vehicles.

Trip Length Data

10. The 2014 assessment made use of the 2007 - 2010 London Travel Demand Surveys (LTDS) as a source for trip length data for those trips originating and ending in CAZ, Inner and Outer London. The assessment identified that the data included information on the land use class of the trip destinations and the length of these trips in kilometres.

11. At this stage it has not been possible to extract like for like trip length data from the 2018 LTDS. Therefore, the data extracted from 2007 – 2010 has been factored based upon data extracted from Figure 6.2 of the TfL Travel in London Report 9 which represents the change in trends in road traffic (vehicles kilometres) for all motor vehicles in central, inner and outer London between 2010 and 2015. This data is illustrated in **Table 4** below.

Table 4: Figure 6.2 of TfL Travel in London Report 9 (Extract)

Year	Central London	Inner London	Outer London	Greater London
2010	81	89	93	92
2011	79	87	92	90
2012	77	84	92	89
2013	76	82	92	89
2014	79	83	94	90
2015	79	83	94	90

12. The trends in road traffic identified a slight decrease in overall vehicle kilometres in Inner and Central London, however a small increase in vehicle kilometres travelled in Outer

London. The overall reduction of vehicle kilometres travelled in London between 2015 and 2010 is 2%.

13. These slight decreases in overall vehicle kilometres were applied to the average distances travelled by car as set out in Table 8 of the 2014 report to provide an updated average distance for each land use class and location. The results are presented in **Table 5** below.

Table 5: Average Distance Travelled by Car per Trip

Land Use	Distance (km)		
	CAZ	Inner	Outer
Retail (A1)	9.2	5.5	5.4
Office (B1)	3.0	7.2	10.8
Residential (C3)	4.2	3.4	11.4
2010 to 2015 reduction factor	*99%*	*93%*	*100%*

14. By combining the average annual trip generation presented in **Table 2** with the average trip distance presented in **Table 5** above, the average distance travelled per annum can be derived. These results are presented in **Table 6** which is an update to Table 9 of 2014 Report.

Table 6: Average Distance (km) Driven per Annum for Major Land Use Categories

Land Use	Unit	Distance (km/ annum)		
		CAZ	Inner London	Outer London
Retail (A1) Food Superstore	1 sq. m	362	402	1174
Retail (A1) Convenience	1 sq. m	166	764	1488
Office (B1)	1 sq. m	6	8	176
Residential	dwelling	288	392	5115

Emissions per Vehicle Kilometre

15. To calculate the final TEB, the average distance driven by car (**Table 6**) is combined with the average emission for cars. These rates have been extracted from Air Quality Consultants 2014 report for CAZ, Inner and Outer London. These factors take into account typical driving conditions (such as driving speed) in each area and allow to estimate TEB for the major land-use categories. **Table 7** provides emission factors applied.

16. It is noted that these factors should be updated to reflect technology and policy changes (i.e. lower emissions and introduction of Ultra Low Emission Zone).

Table 7: Emission Factors

Land Use	g/ vehicle-km		
	CAZ	Inner	Outer
NO_x	0.4224	0.3700	0.3530
PM_{10}	0.0733	0.0665	0.0606

17. The resulting TEBs for the major land uses included in this assessment are presented in **Table 8** below.

Table 8: Transport Emission Benchmarks

Land Use	Area		
	CAZ	Inner London	Outer London
NOx (g/ sq. m/ annum)			
Retail (A1) Food Superstore	153	149	414
Retail (A1) Convenience	70	283	525
Office (B1)	2	3	62
NOx (g/ dwelling/ annum)			
Residential	122	145	1805
PM10 (g/ sq. m/ annum)			
Retail (A1) Food Superstore	27	27	71
Retail (A1) Convenience	12	51	90
Office (B1)	0	1	11
PM10 (g/ dwelling/ annum)			
Residential	21	26	310

18. The above table represents an update of Table 11 in the 2014 report.

Servicing Trips

19. The 2014 report set TEBs for car trips only due to the limitation of the TRAVL database at the time with regard to information on the quantum of taxi, LGV, OGV trips associated with each land use class. Within London a large proportion of any sites trip generation is likely to comprise servicing vehicles which include taxis, deliveries and refuse collection vehicles.

20. An exercise has therefore been completed to capture this from TRICS. Data has been extracted for taxis, LGVs and OGVs based upon the same parameters as car trips. Trip rates for these vehicles are presented in **Table 1** alongside car trips.

21. The methodology used in deriving TEBs for cars has then been followed for servicing trips and **Table 9** below provides results of the average annual servicing traffic associated with the major land uses in London.

Table 9: Average number of Trips per Annum for Different Development categories – Servicing Vehicles.

Land Use	Annual Trips per	Servicing Vehicle Trips		
		CAZ	Inner London	Outer London
Retail (A1) Food Superstore	1 sq.m	15	7	11
Retail (A1) Convenience	1 sq.m	5	15	23
Office (B1)	1 sq.m	3	3	2
Residential	Dwelling	145	217	113

22. Using data provided in **Table 5** (average distance travelled) and **Table 7** (emission factors) the annual average distance travelled and TEBs for service vehicles has been calculated and is presented in **Table 10** and **Table 11** respectively.

Table 10: Average Distance (km) Driven per Annum for Major Land Use Categories) – Service Vehicles

Land Use	Unit	Distance (km/ annum)		
		CAZ	Inner London	Outer London
Retail (A1) Food Superstore	1 sq. m	135	41	62
Retail (A1) Convenience	1 sq. m	43	83	127
Office (B1)	1 sq. m	7	19	23
Residential	dwelling	615	748	1296

Table 11: Transport Emission Benchmarks – Service Vehicles

Land Use	Area		
	CAZ	Inner London	Outer London
NOx (g/ sq. m/ annum)			
Retail (A1) Food Superstore	57	15	22
Retail (A1) Convenience	18	31	45
Office (B1)	3	7	8
NOx (g/ dwelling/ annum)			
Residential	260	277	457
PM10 (g/ sq. m/ annum)			
Retail (A1) Food Superstore	10	3	4
Retail (A1) Convenience	3	6	8
Office (B1)	1	1	1
PM10 (g/ dwelling/ annum)			
Residential	45	50	79

Limitations and Discussion

23. The process of updating the 2014 TEBs through the calculations presented in this note has identified a number of limitations with the data sources which should be considered in a

greater detail. A summary of these limitations along with key discussion points are presented below:

- The TRICS database contains a limited number of survey sites for some of the land use classes (e.g. retail located in CAZ and Inner London). Using a small sample of sites increases the risk of the results being skewed by a single site with unique characteristics. Should the review be extended to include other land use classes, it is likely that the same issue of limited survey sites will be experienced.
- No up to date, comparable data on the average car journey length by land use for three study zones was available, therefore the data from 2014 report was used as a baseline. To account for trends in a road traffic, a percentage reduction in vehicle kilometres between 2010 and 2015 was applied. This method could be considered overly simplistic and also is not reflective of the 2018/19 London traffic behaviour.
- The emission factors used in this assessment are extracted from 2014 report and should be updated with more recent figures. This is to take an account of technology changes and restrictions results from recent introduction of Ultra Low Emission Zone in Central London.
- Whilst it may be appropriate to include service vehicle trips (OGVs, LGVs and taxis) the application of the conversion factors as used for private cars should be treated with caution. The majority of service trips (e.g. refuse collection, deliveries) would likely take place during a weekday daytime and therefore the application of weekend (Saturday and Sunday) factors to determine average annual traffic could lead to major overestimation.
- In addition to the above issues with estimating the average annual traffic, it is not considered appropriate to apply the average journey length (**Table 5**) to service vehicles. It is highly unlikely that any service trip generated by a single site would be associated solely with this site, i.e. most of these would be linked trips. As such the average distance travelled per trip is more likely to be a small fraction total daily distance travelled by these service vehicles.
- Given different types of vehicles, the emission factors for larger service vehicles is likely to be different from those applied for private cars.

Next Steps

24. Vectos seeks to meet with Air Quality Consultants to discuss the findings presented in this report and agree on methodology used in a final assessment.

A3 Comparison with Current Benchmarks

Building Emissions Benchmarks

A3.1 Table A3.1 compares the existing and revised NOx building emissions benchmarks for residential developments and shows that the revised benchmarks are appreciably more stringent.

Table A3.1: Comparison of Current and Revised Residential Building Emissions Benchmarks (gNOx/m^2 /annum)

Benchmark	Energy Strategy	gNOx/m^2/annum
Current Benchmarks	All energy strategies	26.2
Revised Benchmarks	Individual Gas Boilers	3.5
	Gas Boiler Network	5.7
	CHP + Gas Boiler Network	25.5
	ASHP + Gas Boiler Network	5.7
Revised Benchmarks with Enhanced CHP Targets	CHP + Gas Boiler Network 10-400 Flats	14.1
	CHP + Gas Boiler Network >400 Flats	7.8

A3.2 As explained in Paragraph 3.23, the revised benchmarks for non-residential use classes have been scaled from the existing benchmarks using “difference” factors. It is nevertheless useful to show how the revised benchmarks, as they will be applied in practice, compare with the current benchmarks. Table A3.2 thus sets out the full range of current benchmarks alongside the full range of revised benchmarks.

Table A3.2: Comparison of Current and Revised Building Emissions Benchmarks for Non-Residential Uses (gNOx/m² /annum)

Land Use Class	Current Benchmarks	Revised Benchmarks			
		Individual Gas Boilers	Gas Boiler Network	CHP + Gas Boiler Network	ASHP + Gas Boiler Network
Class A1	22.6	0.53	0.97	4.31	0.97
Class A3 - A5	75.2	10.94	20.06	89.54	20.06
Class A2 and Class B1	30.8	1.43	2.62	11.68	2.62
Class B2 - B7	36.6	1.07	1.95	8.73	1.95
Class B8	23.6	0.55	1.01	4.50	1.01
Class C1	70.9	10.32	18.91	84.42	18.91
Class C2	68.5	9.97	18.27	81.56	18.27
D1 (a)	43.0	0.9	1.66	7.39	1.66
D1 (b)	75.0				
Class D1 (c -h)	31.0				
Class D2 (a-d)	90.3	13.14	24.09	107.52	24.09
Class D2 (e)	284				

Transport Emissions Benchmarks

A3.3 Table A3.3 compares the current and revised TEBs[3]. Clearly the TEBs for PM_{10} and $PM_{2.5}$ cannot be compared directly. Furthermore, while it is convenient to compare the NOx TEBs, such a direct comparison may be misleading. This is because they represent the combined effect of changes to the trip rates, trip lengths, and emissions factors, but both the trip lengths and emissions factors are also specified for use in the assessment methodology. Thus, while changes to the emissions factors and trip lengths will affect the *magnitude* of an exceedance of the emissions benchmark (which would in turn affect the result of any associated cost calculation) they do not have any effect on whether or not the benchmark will be exceeded. Whether the benchmark becomes more, or less likely, to be exceeded is determined solely by changes to the trip rates. These are set out for comparison in Table A3.4. The current and revised trip lengths, and emissions factors, are set out for comparison in Table A3.5 Table A3.6.

[3] Percentage changes calculated from rounded numbers as presented in reports, since these are the values used in assessments.

Table A3.3: Comparison of Current and Revised TEBs

	Land Use	g/annum per	g/annum		
			CAZ	Inner London	Outer London
Current	NOx				
	C3 Residential	Dwelling	234	558	1553
	B1 Office	GIA (m2)	1.27	11.4	68.5
	A1 Retail	GIA (m2)	169	219	249
	PM_{10}				
	C3 Residential	Dwelling	40.7	100	267
	B1 Office	GIA (m2)	0.22	2.05	11.8
	A1 Retail	GIA (m2)	29.3	39.3	42.9
Revised	NOx				
	C3 Residential	Dwelling	139	153	1,790
	B1 Office	GIA (m2)	2.9	3.13	61.6
	A1 Food Superstore	GIA (m2)	175	157	411
	A1 Food Convenience Store	GIA (m2)	80.1	299	521
	$PM_{2.5}$				
	C3 Residential	Dwelling	10.2	12.6	145
	B1 Office	GIA (m2)	0.21	0.26	5
	A1 Food Superstore	GIA (m2)	12.9	13	33.3
	A1 Food Convenience Store	GIA (m2)	5.9	24.6	42.2
% Change	NOx				
	C3 Residential	Na	-41%	-73%	+15%
	B1 Office	Na	+128%	-73%	-10%
	A1 Food Superstore	Na	+4%	-28%	+65%
	A1 Food Convenience Store	Na	-53%	+37%	+109%

Table A3.4: Comparison of Current and Revised Trip Rates

	Land Use	CAZ	Inner London	Outer London
Current	C3 Residential (trips/dwelling/yr)	129	407	386
	B1 Office (trips/m^2/yr)	1	4	18
	A1 Retail (trips/m^2/yr)	43	100	131
Revised	C3 Residential (trips/dwelling/yr)	68	114	447
	B1 Office (trips/m^2/yr)	2	1	16
	A1 Food Superstore (trips/m^2/yr)	39	73	216
	A1 Food Convenience Store (trips/m^2/yr)	18	139	274
% Change	C3 Residential	-47%	-72%	16%
	B1 Office	+100%	-75%	-11%
	A1 Food Superstore	-9%	-27%	+65%
	A1 Food Convenience Store	-58%	39%	+109%

Table A3.5: Comparison of Current and Revised Trip Lengths

	Land Use	CAZ	Inner London	Outer London
Current (km/trip)	C3 Residential	4.3	3.7	11.4
	B1 Office	3.0	7.7	10.8
	A1 Retail	9.3	5.9	5.4
Revised (km/trip)	C3 Residential	4.2	3.4	11.4
	B1 Office	3.0	7.2	10.8
	A1 Retail	9.2	5.5	5.4
% Change	C3 Residential	-2%	-8%	0%
	B1 Office	0%	-6%	0%
	A1 Retail	-1%	-7%	0%

Table A3.6: Comparison of Current and Revised Emissions Factors

Pollutant	Pollutant	g/vehicle-km		
		CAZ	Inner	Outer
Current (g/vehicle-km)	NOx	0.4224	0.370	0.353
	PM_{10}	0.0733	0.0665	0.0606
Revised (g/vehicle-km)	NOx	0.48	0.39	0.35
	$PM_{2.5}$	0.036	0.032	0.028
% Change	NOx	14%	5%	-1%

A4 Case Studies

A4.1 In order to test the revised benchmarks, they have been applied to a number of developments which have recently sought planning permission. They have been selected to represent a range of different development types.

1) A Mixed Residential Development

A4.2 A mixed-use development in inner London for up to 29,022 m^2 of development, comprising:

- Class A1 (Shops) up to 120 m^2;
- Class B1 (Business) up to 110 m^2;
- Class C3 (Dwelling Houses) up to 28,000 m^2;
- Class D1 (Non-residential institutions) up to 660 m^2;
- Class D2 (Assembly and Leisure) up to 130 m^2; and
- an Energy Centre comprising 3 gas-fired boilers with a maximum NO_x emission rate of 40 mg/kWh.

Building Emissions

A4.3 Total NO_x emissions from the development were calculated to be **80 kg/annum**, based on an estimated annual gas consumption of 2,100,000 kWh.

A4.4 The total benchmarked building NO_x emission is calculated from the land use categories and the BEBs and is shown in Table A4.1. This shows that the total benchmarked emissions using the current BEBs is **779.8 kg/annum**, which reduces to **164.2 kg/annum** using the revised BEBs. This development is thus air quality neutral in terms of building emissions using both sets of BEBs.

Table A4.1: Calculation of Current and Revised Benchmarked Building Emissions for Example Development 1

Land Use	GIA (m^2)	Current Benchmarked NOx Emissions (kg/annum)	Revised Benchmarked NOx Emissions (kg/annum)
A1	118.6	2.7	0.1
B1	107.8	3.4	0.3
C3	28,006	733.6	159.6
D1	662.5	28.4	1.1
D2	126.9	11.7	3.1
Total Benchmarked NOx Emissions (kg/annum)		**779.8**	**164.2**

Road Transport Emissions

A4.5 The transport assessment for the development predicted that the development will generate a total of **157,244 car trips per annum.** TEBs are not predicted for all of the land uses in the development and so the assessment has been made against the benchmark trip rates. Table A4.2 shows the calculation of both the current and revised benchmarked trip rates. This shows that the total benchmarked trip rate using the current benchmarks is **190,143 car trips per annum**, which reduces to **74,936 car trips per annum** using the revised benchmarks. The development is thus air quality neutral in terms of transport emissions using the current benchmarks, but it is not air quality neutral when using the revised benchmarks.

Table A4.2: Calculation of Current and Revised Transport Benchmarked Trip Rates for Example Development 1

Land Use	GIA (m^2) / Number of Dwellings	Current Benchmark Trip Rates (trips/annum)	Revised Benchmark Trip Rates (trips/annum)
A1	118.6	11,860	16,485
B1	107.8	431	108
C3	324	131,868	36,936
D1	662.5	43,129	20,074
D2	126.9	2,855	1,333
Total Benchmark Trip Rate (trips/annum)		**190,143**	**74,936**

2) A Residential-led Mixed-use development

A4.6 A mixed-use development in outer London for up to 9,271 m^2 of development, comprising:

- Class B1 (Business) up to 1,583 m^2; and
- Class C3 (Dwelling Houses) up to 7,688 m^2.

- Heat and hot water to be provided by individual boilers with a maximum NO_x emission rate of 40 mg/kWh and air source heat pumps.

Building Emissions

A4.7 Total NOx emissions from the development were calculated to be **20 kg/annum**, based on a predicted gas usage for heat and hot water demand of 500,000 kWh per annum.

A4.8 The total benchmarked building NOx Emission is calculated from the land use categories and the BEBs and is shown in Table A4.2. This shows that the total benchmarked emission using the current BEBs is **250.2 kg/annum**, which reduced to **29.2 kg/annum** using the revised BEBs. This development is thus air quality neutral in terms of building emissions using both sets of BEBs; albeit that the margin by which it the BEB is achieved is significantly reduced using the revised data.

Table A4.2: Calculation of Current and Revised Benchmarked Building Emissions for Example Development 2

Land Use	GIA (m^2)	Current Benchmarked NO_x Emissions (kg/annum)	Revised Benchmarked NO_x Emissions (kg/annum)
B1	1,583	48.8	2.3
C3	7,688	201.4	26.9
Total Benchmarked Building Emissions (kg/annum)		**250.2**	**29.2**

Road Transport Emissions

A4.9 The transport emissions for comparison against the benchmarked emissions have to be calculated using the methodology provided. They are based on the number of car trips generated by different land-use classes, together with the associated trip lengths and vehicle emission rates.

A4.10 The transport assessment for the development predicted that it will generate a total of 94,900 car trips per annum for the residential apartments (C3), and a further 18,200 car trips per annum from the B1 commercial space.

A4.11 Table A4.3 shows how the transport emissions for the development are calculated for comparison against both the current and revised benchmarks.

Table A4.3: Calculation of Road Transport Emissions for Example Development 2 - for Comparison with against the Benchmarked Emissions Calculated using both the Current and Revised TEBs

Land Use	Distance (km)		Emission Factors (g/veh-km)				Transport Emission (kg/annum)[a]			
	Current	Revised	Current		Revised		Current		Revised	
			NOx	PM_{10}	NOx	PM_{10}	NOx	PM_{10}	NOx	PM_{10}
B1	10.8		0.353	0.0606	0.35	0.028	69.4	11.9	68.8	5.5
C3	11.4						381.9	65.6	378.7	30.3
SUM							**451.3**	**77.5**	**447.5**	**35.8**

[a] Calculated as: Car trips per annum x Distance (km) x Emission Factor

A4.12 Table A4.4 shows the calculation of both the current and revised benchmarked emissions for the development. The benchmarked emissions using the current TEBs are **282.4 kg/annum** for NOx and **48.6 kg/annum** for PM_{10}. Using the revised TEBs, these increase to **298.0 kg/annu**m for NOx, and reduce to **24.1 kg/annum** for PM_{10}. This development is not air quality neutral using either set of TEBs.

Table A4.4: Calculation of Current and Revised Benchmarked Transport Emissions for Example Development 2[a]

Land Use	GIA (m^2) / Number of Dwellings	Current Benchmark Emissions ($g/m^2/annum$)		Revised Benchmark Emissions ($g/m^2/annum$)	
		NO_x	PM_{10}	NO_x	PM_{10}
B1	1,583	108.4	18.7	97.5	7.9
C3	112	173.9	29.9	200.5	16.2
Total Benchmarked Transport Emission (kg/annum)		**282.4**	**48.6**	**298.0**	**24.1**

[a] The benchmarked emissions are calculated as: GIA (m^2) (or number of dwellings) x TEB (g/annum).

3) Apartment Hotel

A4.13 An aparthotel in outer London, comprising:

- Class C1 up to 7,322 m^2; and
- an Energy Centre comprising a CHP unit, with an 56.8% estimated gross thermal efficiency, in combination with back-up gas-fired boilers with a maximum NO_x emission rate of 40 mg/kWh.

Building Emissions

A4.14 Total NOx emissions were calculated to be **499.3 kg/annum**, based on an estimated CHP heat output of 1,076,160 kWh (76% of total heat output), with the remaining 342,370 kWh provided by the gas-fired boilers.

A4.15 The total benchmarked building NO_x emission is calculated as shown in Table A4.5. This shows that the total benchmarked emission using the current BEBs is **519.1 kg/annum**, which increases to **618.1 kg/annum** using the revised BEBs. This development is thus air quality neutral in terms of building emissions using both sets of BEBs.

Table A4.5: Calculation of Current and Revised Benchmarked Building Emissions for Example Development 3

Land Use	GIA (m^2)	Current Benchmarked NO_x Emissions (kg/annum)	Revised Benchmarked NO_x Emissions (kg/annum)
C1	7,322	519.1	618.1
Total Benchmarked Building Emissions (kg/annum)		**519.1**	**618.1**

Road Transport Emissions

A4.16 The transport assessment for the development predicted that the development will generate a total of **38,382 car trips per annum**. TEBs are not provided for the land use of this development, and so the assessment has been made against the benchmark trip rate. Both the current and revised benchmark trip rates are the same, i.e. 6.9 trips/m^2/annum. Thus, the total benchmarked trip rate is **50,522 car trips per annum**. The development is thus air quality neutral in terms of transport emissions.

4) A Large Mixed-Use Development

A4.17 A mixed-use development for up to 67,112 m^2 of development in the CAZ, comprising:

- Class A1 (Shops) up to 17,780 m^2;
- Class B1 (Business) up to 46,694 m^2;
- Class D2 (Assembly and Leisure) up to 2,638 m^2; and
- an Energy Centre comprising 3 gas-fired boilers with a maximum NO_x emission rate of 40 mg/kWh, in combination with two emergency diesel generators.

Building Emissions

A4.18 Total NO_x emissions were calculated to be **280 kg/annum**, taking account of estimated gas consumption and routine testing of the generators.

A4.19 The total benchmarked building NO_x emission is calculated from the land use categories and the benchmarks and is shown in Table A4.6. This shows that the total benchmarked emission using the current BEBs is **2,589.2 kg/annum**, which reduces to **203.1 kg/annum** using the revised BEBs. This development is thus air quality neutral in terms of building emissions using the current BEBs, but it is not air quality neutral using the revised BEBs.

Table A4.6: Calculation of Current and Revised Benchmarked Building Emissions for Example Development 4

Land Use	GIA (m^2)	Current Benchmarked NO_x Emissions (kg/annum)	Revised Benchmarked NO_x Emissions (kg/annum)
A1	17,780	401.8	17.2
B1	46,694	1,438.2	122.3
D2	2,638	749.2	63.6
Total Benchmarked Building Emissions (kg/annum)		**2,589.2**	**203.1**

Road Transport Emissions

A4.20 This transport assessment for the development states that the development will not lead to any car trips; with all traffic generation restricted to taxis and servicing/deliveries. The development is thus, by definition, air quality neutral in terms of transport emissions.

A5 Charging Scheme for Excess Emissions

A5.1 If a scheme is projected to result in net positive emissions, i.e. higher than the air quality neutral benchmarks, redesign or re-specification to reduce those emission is the preferred first step. However, if this is not possible, or cannot eliminate the excess emissions, some form of financial payment could be levied. There are several available options for calculating the appropriate level of payment, although they essentially fall into two approaches:

- Impact compensation: a fee levied to compensate for the damage caused to human and environmental health which could result from the emissions.
- Abatement compensation: a fee levied to compensate for the cost of abating the emissions at another location.

A5.2 While, in many ways, abatement compensation logically makes greater sense, there are no abatement costs available for $PM_{2.5}$ and those for NO_2 are outdated. It is understood that Defra may update its abatement cost guidance but the timescale over which this will be done is not known.

Valuing Air Quality Impacts

A5.3 There is a mature and expanding evidence base demonstrating that air pollution has impacts on human health, ranging from increased mortality though morbidity and including productivity losses through staff sickness. Air pollution also impacts on ecosystems, through acidification and eutrophication, and on cultural heritage. Assigning emissions of particular pollutants from specific sources and at specific points in time to those impact is both complex and, at an individual level, highly uncertain. However, population scale impacts can be quantified and, in order to take them into account in policy and scheme appraisal, methodologies have been developed to assign values to impacts.

A5.4 Values for the human and environmental health impacts of air pollution are now routinely used as part of cost-benefit calculations in the UK, EU, USA and elsewhere. The UK approach falls within HMT's Green Book project appraisal methodology[4]. Before considering the potential for these approaches to be used as a basis for impact compensation, some of their key features should be noted:

- The values ascribed are intended to represent the "social" cost of air pollution. Monetisation of impacts allows them to be compared on a like for like basis with the physical cost of the scheme or policy, such as the capital and running cost of abatement equipment. However, these social costs are developed through revealed or expressed preference studies and do not represent real

[4] https://www.gov.uk/guidance/air-quality-economic-analysis

world financial costs, e.g. they do not represent the costs to the health service of treating conditions caused or exacerbated by air pollution; and

- The values do not represent all impacts. In the UK, the values used only reflect mortality effects from a limited range of pollutants (mainly $PM_{2.5}$), not morbidity or productivity impacts. Nor are ecosystem effects included, although work on this is progressing through the ecosystem services approach.

Damage Cost Approach

A5.5 The HMT Green Book approach offers two main methodologies for estimating the social costs of air pollution: **impact pathway** and **damage costs**. Impact Pathway is the more comprehensive of the two, whereby the pathway of pollutants from emission to receptor is modelled and the impact of the received dosage on health (or whichever other impact is assessed) is calculated. However, this methodology is too complex to be used routinely as part of the Air Quality Neutral assessment process.

A5.6 The damage cost approach is derived from impact pathway analyses but rather than attempting to link emissions directly with effects, it ascribes a monetary value to the emissions themselves. It is described in supplementary guidance for the HMT Green Book, with the latest version being published in January 2019[5].

A5.7 The guidance provides a seven-step process for assessing the air quality impacts of a policy or project:

1. Quantify the additional emissions caused or emissions saved in each year of the assessment period
2. Identify the appropriate damage cost value
3. Convert damage costs to the relevant base year prices using a GDP deflator (to ensure that costs and benefits are based on the same year)
4. Uplift damage costs be 2% per year over the appraisal period
5. Calculate the benefits for each year
6. Discount the benefits across the appraisal period to give a net present value
7. Undertake a sensitivity analysis, using the low and high sensitivity damage costs and repeating steps 3-6.

A5.8 This process is complex and seeks to ensure that the costs and benefits of a policy or project are compared on a like for like basis.

[5] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf

Applying the Damage Cost Approach to Air Quality Neutral

A5.9 Adapting this process for an Air Quality Neutral charging scheme means that some of these elements can be excluded. Firstly, there is no need to balance costs against benefits, and so uplifting to base year prices using a GDP deflator (step 3) is unnecessary.

A5.10 Secondly, benefits discounting (step 6) is used to increase the relative value of benefits in the short term over those in the long term. Using this for excess emission charging would, effectively, reward scheme that emit more in the future and so it should be taken out of the calculation. Lastly, there is no need to undertake a sensitivity assessment (step 7) as the outputs will not be used in a cost benefit analysis and so there is no need to produce a high and low range estimate.

A5.11 Two questions now remain: what is the "assessment period" and which are the appropriate damage costs?

A5.12 The assessment period should effectively be the design life of the building or scheme in question. However, the design life of the building is not the same as the real-world operational life and so is not a good benchmark for the length of time over which the excess emissions will occur. For simplicity, it is suggested that a fixed period is used, taken from the point of first use of the building or scheme. To an extent, the time period used is arbitrary; costs for real-world examples shown below have used both 10- and 20-year periods.

A5.13 The Government's damage cost guidance provides national, or default, damage costs for five pollutants: NO_X, $PM_{2.5}$, SO_2, VOC and NH_3. It also provides costs for specific types of location and emission source, including for central, inner and outer London, for NO_2 and $PM_{2.5}$. The categories relevant for London are shown in Table A5.1. The National damage costs for NO_X and $PM_{2.5}$ are shown for comparison. The sectors in grey text are included for completeness although for the vast majority of cases, the damage costs for industrial, commercial or domestic will be used.

Table A5.7 Specific Damage Costs for London (2019 guidance, 2017 prices)

Source and Location Type		NOx (£/t)	$PM_{2.5}$ (£/t)
Generic	National	6,199	105,836
Buildings	Industrial	5,671	95,847
	Commercial	13,307	63,797
	Domestic	13,950	85,753
	Part A process[6]	1,599-4,829	3,355-81,059
	Aircraft	11,672	194,269
	Offroad	8,656	153,487
	Rail	9,009	163,413
	Shipping	2,506	33,739
	Waste	6,766	162,082
	Agriculture	-	46,442
Road transport	Central	57,517	1,111,831
	Inner	58,967	1,132,776
	Outer	31,326	602,201

Applying Damage Costs to Real Air Quality Neutral Assessments

A5.14 Five scheme proposals from the last few years were used to test the proposed excess emissions charging scheme. The first two of the examples (A and B) used the excess emissions as calculated in the original Air Quality Neutral Assessment. The other three use emissions as assessed using the revised Air Quality Neutral benchmarks set out in this report, including more up to date (2016) emission factors.

A5.15 For each example, the annual NO_X and $PM_{2.5}$ emissions above the Air Quality Neutral benchmarks were calculated for the first year of operation for the scheme – these were all between 2022 and 2025. The emissions were split between road transport (NO_X and $PM_{2.5}$) and buildings (NO_X only). Where emissions had been calculated for PM_{10}, the PM_{10} to $PM_{2.5}$ conversion factor of 0.977 was used, taken from the damage cost guidance. A simple uplift tool was used to calculate the damage costs for each year up to 2050, using a 2% increase per year from the 2017 baseline. Using the damage cost appropriate for the scheme – industrial, commercial or domestic for the building

[6] Damage cost depends on the category of Part A process, 1-9

emissions and central, inner and outer for the traffic emissions – the charge for each year was calculated, from the first year of operation and each of 20 years subsequent to that. The charge using the default national damage costs was also calculated, for comparison. The results of that process are shown in Table A5.2.

A5.16 One weakness of this approach is that it does not take into account predicted changes in the road fleet, as the proportion of cleaner vehicles, including electric vehicles increases. To do this, future fleet emission factors would be required in order the calculate the road transport contribution of the scheme for each year after its first use. A simple calculator tool could be used to scale the first-year emissions, much in the same was at the damage costs have been uplifted by 2% each year to account for inflation. However, while future emission factors are available for the national fleet, Air Quality Neutral is based on LAEI emission factors. These are not currently available for future years although it is understood that they are being developed.

A5.17 An alternative approach would be to assume that all road vehicles are zero emission (exhaust) at point of use in 2050 and that a linear reduction in tailpipe emissions could be used up to that date. However, while this would be relatively simple for NOX, zero emission (electric) vehicles will still emit PM2.5 from brake, tyre and road wear. It is not currently possible to split out the exhaust and non-exhaust emission components for current LAEI fleet emission factors for $PM_{2.5}$.

A5.18 On this basis, the examples in Table A5.2 assume that the road traffic emissions remain constant for future years from the year of first use. This can be reassessed once LAEI future fleet emission factors become available.

Table A5.8: Potential excess emission charges for five example schemes

Description	1st year	Location		Annual Emissions above benchmarks (t)			Charge in 1st year		10 Year Charge		20 Year Charge	
		Type	Zone	Road NOx	Road $PM_{2.5}$	Building NOx	Nat. damage costs	Specific damage costs	Nat. damage costs	Specific damage costs	Nat. damage costs	Specific damage costs
A: mixed commercial and residential	2025	Commercial	Outer	0.701	0.117	0	£19,609	£108,334	£214,721	£1,186,235	£429,443	£2,372,471
B: conversion of hospital into research institute	2024	Commercial	Central	0	0	0.236	£1,679	£3,605	£18,393	£39,483	£36,786	£78,966
C: Residential development	2022	Domestic	Outer	0.104	0.0171	0	£2,819	£15,571	£29,673	£163,879	£59,347	£327,758
D: Mixed use retail Park	2024	Commercial	Inner	0.417	0.0895	0	£13,845	£144,656	£151,601	£1,583,944	£303,203	£3,167,888
E: Mixed use commercial	2024	Commercial	Central	0	0	0.0767	£546	£1,172	£5,980	£12,837	£11,960	£25,674