West Hampstead Limited

Liddell Road

Noise and vibration survey and analysis

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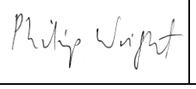
		Signature			
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Contents

1 Introduction

West Hampstead Limited have appointed Arup to assess the current exposure of the Liddell Road site to environmental noise and vibration. This includes measurement of the current levels of noise and vibration at the site and assessment of the implications on the design of three new buildings on the site.

2 The Liddell Road site

Three new buildings will be built at the Liddell Road site, located in West Hampstead. The three buildings will be located in areas which are currently brownfield site, enclosed by site hoarding. The site includes Kingsgate Primary Lower School, which was recently built during an early phase of the Liddell Road development.

The site is bordered on the north side by the Midland Main Line railway, a busy rail line carrying a number of high speed intercity trains, commuter trains and freight. Noise from train pass-bys are a significant source of perceptible environmental noise on site.

Other audible sources of noise on site include:

- Local traffic noise, particularly on Maygrove Road which borders the south side of the site.
- Activity noise from Kingsgate Primary Lower School and its playground.
- Activity in Maygrove Peace Park which borders part of the west side of the site. This includes noise from the basketball court, including portable music loudspeaker systems.
- Activity from residential buildings which border part of the west of the site, including home music systems.
- Distant rail noise from other railways in West Hampstead, to the south of site.
- Aircraft overhead, including large commercial/passenger aircraft and regular helicopters.

The 2021 measurements we made during a period in which national restrictions due to Covid were eased, however day-to-day life remained changed from pre-pandemic activity. It is therefore feasible that noise and vibration measured on site does may not be representative of pre-pandemic levels.

Figure 1 illustrates the planned developments in context of the wider environment.

3 Historic data and information sources

This report is based on Arup's noise and vibration measurements undertaken on site in June and July 2021, which supplements and updates data measured by Gillieron Scott Acoustic Design in October 2014. This data was previously assessed in the following reports:

- *Draft Environmental Noise and Vibration Report* by Gillieron Scott Acoustic Design, issued 5 December 2014
- *Environmental Noise and Vibration Report* by Gillieron Scott Acoustic Design, issued 5 December 2014.
- *Noise and Vibration Review* by Arup, issued 8 December 2014 – a peer review of the Gillieron Scott reports.

We have used rail data which is publicly available from https://www.realtimetrains.co.uk/ in order to match unmanned vibration data to train types.

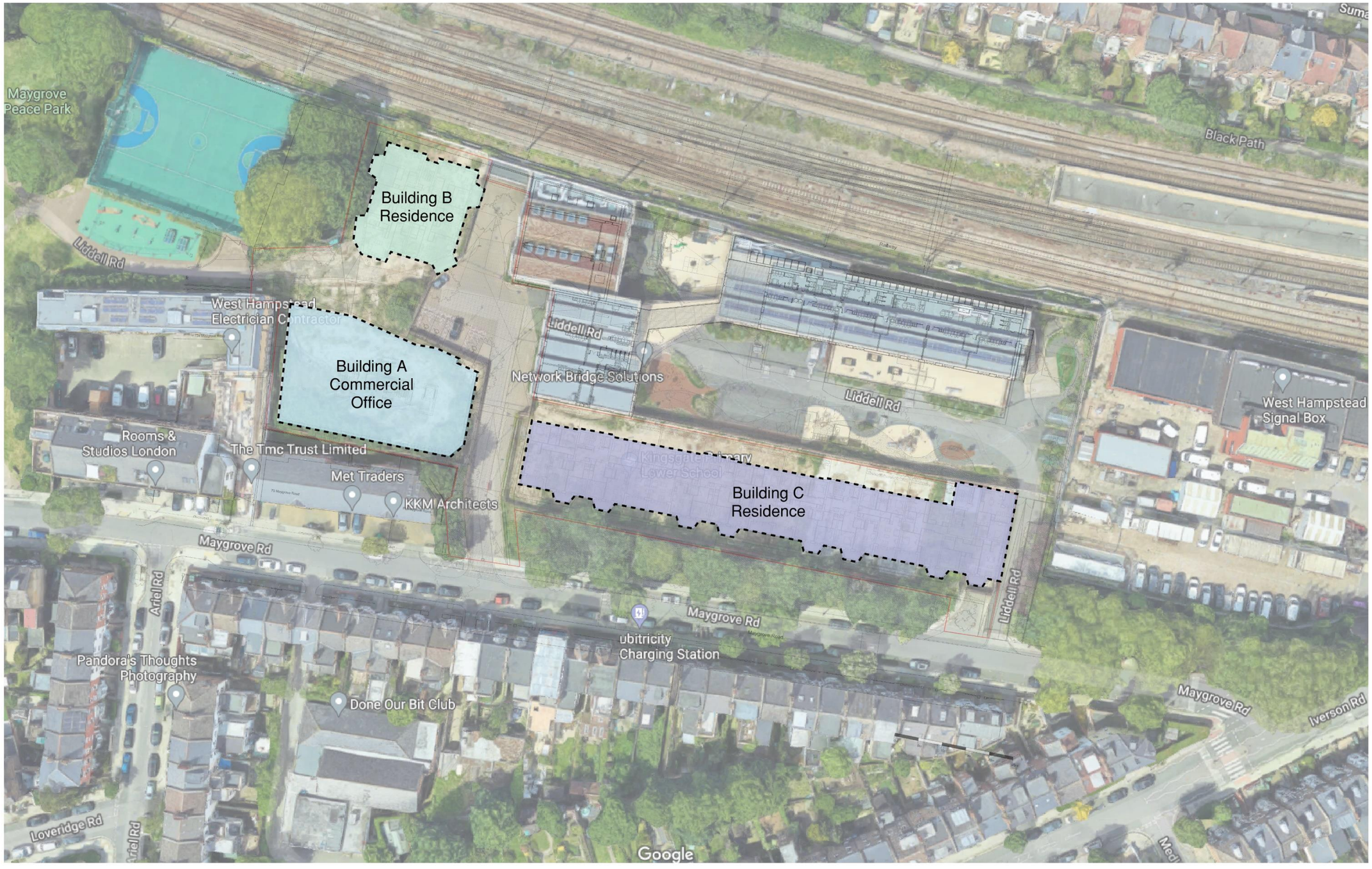

Figure 1: The Liddell Road site

4 Criteria

4.1 Metrics

We have assessed the environmental noise and vibration on site using seven noise and vibration metrics.

Peak particle velocity vibration magnitude (PPV)

PPV relates to how high instantaneous vibration levels within a building get during an event: for example during a train passage.

Vibration dose values (VDV)

VDV is an averaged measure of vibration amplitudes within a building, over a reasonably long time frame such as a typical day or night. The measure accounts for magnitude and number of events. It is the measure referred to in BS 6472-1:2008[1], the current British Standard relating to human response to vibration in buildings.

Groundborne noise (GBN) L_{ASmax}

The GBN L_{ASmax} is the maximum noise level within a building caused by train vibration transmitted into the building via the ground, and radiated as sound. Each train passage will produce a GBN L_{ASmax} value, and so there will be a statistical distribution of L_{ASmax} values over any extended time period such as a day or night.

Groundborne noise (GBN) L_{Aeq}

The GBN LAeq is an average GBN noise level over a day or night period. It is affected by individual L_{ASmax} values and how many train passages occur.

Airborne noise L_{AFmax}

The airborne L_{AFmax} is the maximum level of sound transmitted through the air (not through the ground) from individual events such as a train passage, and often drives the performance requirements of windows and ventilation strategy. Again there will be a statistical distribution of individual event levels.

Airborne noise L_{Aeq}

The airborne L_{Aeq} is an average noise level over a day or night period. It is affected by individual L_{AFmax} values and how many individual noise events occur.

Airborne noise background level L_{A90}

The airborne L_{A90} is the noise level exceeded for 90% of the measurement duration. It is commonly used to represent the *background level* which is used for assessment of impact of new noise emissions from new developments, such as from items of building services plant.

[1] BS 6472-1:2008 Guide to evaluation of human exposure to vibration in buildings. Vibration sources other than blasting. British Standards Institute.

4.2 Relevant regulations, codes and guidance documents

4.2.1 National policies

With regard to suitability of sites for new development, the National Planning Policy Framework 2021 (NPPF) states that:

[Section 15, paragraph 185]

Planning policies and decisions should also ensure that new development is appropriate for its location taking into account the likely effects (including cumulative effects) of pollution on health, living conditions and the natural environment, as well as the potential sensitivity of the site or the wider area to impacts that could arise from the development. In doing so they should:

a. *Mitigate and reduce to a minimum potential adverse impacts resulting from noise from new development – and avoid noise giving rise to significant adverse impacts on health and the quality of life.*

b. *Identify and protect tranquil areas which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason.*

For the definition of adverse impacts, the NPPF references the Noise Policy Statement for England 2010 (NPSE). The NPSE describes the following concepts:

Lowest observed adverse effect level (LOAEL)

The LOAEL is the level above which adverse effects on health and quality of life can be detected.

Significant observed adverse effect level (SOAEL)

The SOAEL is the level above which significant adverse effects on health and quality of life can occur.

Therefore the NPPF states that noise levels above the SOAEL should be avoided and that noise levels above the LOAEL should be mitigated and reduced.

4.2.2 ProPG: Planning and noise – New residential development

The Professional Practice Guidance (ProPG) on planning and noise for new residential development was issued in 2017 by the Institute of Acoustics (IOA), the Chartered Institute of Environmental Health (CIEH) and the Association of Noise Consultants (ANC). The guide was produced to provide practitioners with guidance on a recommended approach to the management of noise within the planning system in England. It aims to enable situations where noise is not an issue to be clearly determined, and to help identify the extent of risk at noisier sites.

The ProPG advocates a systematic, proportionate, risk based, two stage approach. The two sequential stages of the overall approach are:

- Stage 1 – an initial noise risk assessment of the proposed development site.
- Stage 2 – a systematic consideration of four key elements:
  - Element 1 – demonstrating a “good acoustic design process.”
  - Element 2 – observing internal “noise level guidelines.”
  - Element 3 – undertaking an “external amenity area noise assessment.”
  - Element 4 – consideration of “other relevant issues.”

The ProPG summarises the Stage 1 initial site noise risk assessment in a figure. The numerical values from the figure are summarised in Table 1.

Noise risk assessment	**Negligible risk**	**Low / medium / high risk**
	No adverse effect	**Increasing risk of adverse effect**
Indicative daytime noise levels* $L_{Aeq,16hr}$	< 50dB	> 50dB
Indicative night time noise levels* L_{Aeq},8hr	< 40dB	> 40dB
Noise events at night	An indication that there may be more than 10 noise events at night with LAFmax > 60dB means the site should not be regarded as negligible risk.	
** Indicative noise levels are the combined free-field noise level from all sources of transport noise and may also include industrial / commercial noise where this is present by is “not dominant”*		

Table 1: Numerical values associated with Stage 1 - initial site noise risk assessment in ProPG.

ProPG notes that national planning and noise policy does not require that these internal noise levels are always achieved, in particular, if to do so would disproportionately increase the cost of the development or lead to an outcome that does not meet the test of good acoustic design. It further notes that BS 8233 (see below) provides advice on the possible relaxation of the internal noise target levels by up to 5dB.

4.2.3 International guidance

The World Health Organisation (WHO) Guidelines for Community Noise set out specific noise limits for a number of health effects, using the lowest noise level that produces an adverse health effect. These can therefore be deemed as the LOAEL in UK NPPF terms.

The guidelines suggest that the LOAEL for dwellings (indoors) is 35dB$L_{Aeq,16hr}$ during the daytime and evening, and 30dB$L_{Aeq,8hr}$ inside bedrooms at night.

In addition, the number of events exceeding 45dB L_{AFmax} should be minimised.

4.2.4 Building regulations

There are currently no building regulations requirements for noise and vibration transfer into residential buildings – this being effectively controlled by the planning process. However it is relevant to note that a draft Approved Document [X] concerned with overheating in residential premises was issued by the Government for consultation in January 2021. That document includes a section on internal noise levels which might be acceptable when façade elements are opened to alleviate overheating (see also a related reference to the AVO guide document below).

4.2.5 BS 8233

For dwellings, BS 8233:2014[2] recommends average (L_{Aeq}) noise levels which are consistent with WHO recommendations. The table below lists these levels.

Activity	Location	07:00 to 23:00	23:00 to 07:00
Resting	Living room	35dB $L_{Aeq,16hr}$	–
Dining	Dining room / area	40dB $L_{Aeq,16hr}$	–
Sleeping (daytime resting)	Bedroom	35dB $L_{Aeq,16hr}$	30dB $L_{Aeq,8hr}$

Table 2: Indoor ambient noise levels for dwellings, reproduced from BS 8233:2014

In this standard groundborne noise is specifically excluded from the target levels, because it is considered a special case.

In the case of individual noise events the standard states that regular individual events can cause sleep disturbance, and that a *guideline value* may be set in terms of SEL or L_{AFmax} depending on the character and number of events per night.

The previous version of BS 8233:2009 recommended a night-time limit of 45dB L_{AFmax} to prevent sleep disturbance.

4.2.6 BS 6472-1

BS 6472-1:2008 describes the human response to vibration in buildings and recommends limits in terms of VDV values as set out below.

[2] BS 8233:2014 Guidance on sound insulation and noise reduction for buildings. British Standards Institute.

Place and time	Low probability of adverse comment $ms^{-1.75}$ *	Adverse comment possible $ms^{-1.75}$	Adverse comment probably $ms^{-1.75}$ **
Residential buildings 16h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8h night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

** Below these ranges adverse comment is not expected*
*** Above these ranges adverse comment is very likely*

Table 3: Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings, reproduced from BS 6472-1: 2008

The standard recommends that for offices a multiplying factor of 2 should be applied to these VDVs ranges for a 16 hour day. Therefore VDV ranges for offices are as follows:

Place and time	Low probability of adverse comment $ms^{-1.75}$ *	Adverse comment possible $ms^{-1.75}$	Adverse comment probably $ms^{-1.75}$ **
Offices 16h day	0.4 to 0.8	0.8 to 1.6	1.6 to 3.2

** Below these ranges adverse comment is not expected*
*** Above these ranges adverse comment is very likely*

Table 4: Vibration dose value ranges which might result in probabilities of adverse comment within offices, according to guidance set out in BS 6472-1:2008

4.2.7 British Council for Offices (BCO) Guide to Specification

For offices, the BCO Guide to Specification 2019 references the guidance on vibration in BS 6472-1:2008 described above.

In addition, it suggests that train induced vibration should not result in re-radiated noise levels of more than the following:

Type	Noise level
Cellular offices	40dB L_{ASmax}
Meeting rooms	40dB L_{ASmax}
Open plan offices	45dB L_{ASmax}

Table 5: Groundborne noise levels from train induced by train vibration, described in BCO Guide to Specification 2019

In addition, it advises that these levels may be perceptible, and that each case must be examined carefully accounting for the occupants' uses and expectations, background masking noise levels, extent and magnitude of levels, together with the number and duration of individual vibration events and – in the case of over-ground trains – any airborne noise intrusion from the same source.

The guide further advises that building vibration isolation can be costly and should have a cost/benefit/risk analysis. Audio simulations of the predicted ground-borne noise levels, together with those of background masking noise, can be extremely worthwhile during the decision-making process, especially where they are near the threshold of acceptability.

The BCO Guide also recommends that external noise intrusion levels should not be more than the noise rating (NR) levels in the table below (referencing BS 8233:2014) when the office floor space is fitted out to a CAT A level of finish. Where 'T' is the period between 09:00 and 17:00.

Office type	Guideline NR levels, where 'T' is the period between 09:00 and 17:00
Open plan offices	NR40 ($L_{eq,T}$)
Speculative offices*	NR38 ($L_{eq,T}$)
Cellular offices / meeting rooms	NR35 ($L_{eq,T}$)
** The speculative office criterion is a compromise between that for open plan and cellular rooms*	

Table 6: Recommended NR levels that external noise intrusion should not exceed, according to the BCO Guide to Specification.

The BCO Guide also recommends in addition, to avoid speech interference, regular noise events – e.g. scheduled aircraft or passing trains – should not normally be more than 55dB $L_{A01,1hr}$ in open plan / speculative offices or 50dB $L_{A01,1hr}$ in cellular offices / meeting rooms.

4.2.8 Acoustics ventilation and overheating residential design guide (AVO Guide)

The Acoustics Ventilation and Overheating Design Guide[3] ('the AVO Guide') recommends an approach to acoustic assessments for new residential development that takes due regard of the interdependence of provisions for acoustics, ventilation and overheating.

The AVO Guide aims to assist designers to adopt an integrated approach to consider sound insulation, ventilation and overheating, where these are interdependent. Application of the AVO Guide is intended to demonstrate good acoustic design as described in ProPG when considering internal noise level guidelines.

These guidance documents recognise that sustainable design aspirations can mean that natural ventilation design solutions are preferable to mechanical systems for overheating and purge ventilation scenarios. The AVO Guide provides a method for assessing the impact of noise exposure levels which are in excess of the BS 8233 'desirable' levels for these scenarios, based on a consideration of the duration of these scenarios and the environmental noise exposure on the residence.

4.2.9 Camden Local Plan

The Camden Local Plan sets out Camden Council's planning policies and replaces the Core Strategy and Development Polices, covering the period from 2016 to 2031.

Appendix 3 of the Camden Local Plan 2017 provides noise thresholds for noise and vibration for evaluation of noise impact in terms of the LOAEL and SOAEL effect levels described in the NPPF. Three basic design criteria have been set for proposed developments:

- Green – where noise is considered to be at an acceptable level.
- Amber – where noise is observed to have an adverse effect level, but which may be considered acceptable when assessed in the context of other merits of the development.
- Red – where noise is observed to have a significant adverse effect.

For the purposes of this report Table A, Table B and Table C of Appendix 3 of the Camden Local Plan are relevant, and reproduced below.

[3] Acoustics, Ventilation and Overheating Residential Design Guide. *Version 1.1*. Published by the Association of Noise Consultants, January 2020.

Vibration description and location of measurement	Period	Time	Vibration levels (vibration dose values)
Vibration inside dwellings	Day and evening	07:00 – 23:00	0.2 to 0.4 VDV $ms^{-1.75}$
Vibration inside dwellings	Night	23:00 – 07:00	0.13 VDV $ms^{-1.75}$
Vibration inside offices	Day, evening and night	00:00 – 24:00	0.4 VDV $ms^{-1.75}$

Table 7: Vibration levels from uses such as railways, roads, leisure and entertainment premises and/or plant or machinery at which planning permission will not normally be granted, described in Camden Local Plan Appendix 3 Table A.

Dominant noise source	Assessment location	Design period	LOAEL (green)	LOAEL to SOAEL (amber)	SOAEL (red)
Anonymous noise such as general environmental noise, road traffic and rail traffic	Noise at 1m from noise sensitive façade/free field	Day	< 50dB $L_{Aeq,16h}$*	50dB to 72dB $L_{Aeq,6h}$*	> 72 dB $L_{Aeq,16h}$*
		Night	< 45dB $L_{Aeq,8h3}$	45dB to 62dB$L_{Aeq,8h}$*	> 62dB $L_{Aeq,8h}$*
			< 40dB $L_{Aeq,8h}$**	> 40dB L_{night}**	
	Inside a bedroom	Day	< 35dB $L_{Aeq,16h}$	35dB to 45dB $L_{Aeq,16h}$	> 45dB $L_{Aeq,16h}$
		Night	< 30dB $L_{Aeq,8h}$	30dB to 40dB $L_{Aeq,16h}$	> 40dB $L_{Aeq,8h}$
			42dB L_{AFmax}	40dB to 73dB L_{AFmax}	> 73dB L_{AFmax}
	Outdoor living space (free field)	Day	< 50dB $L_{Aeq,16h}$	50dB to 55dB $L_{Aeq,6hr}$	> 55dB $L_{Aeq,16h}$
Non-anonymous noise	See guidance note on non-anonymous noise				

** $L_{Aeq,T}$ values specified for outside a bedroom window are façade levels.*
*** L_{night} values specified for outside a bedroom window are free field levels.*

Table 8: Noise levels applicable to noise sensitive residential development in areas of existing noise, described in Camden Local Plan Appendix 3 Table B.

Existing noise sensitive receptor	Assessment location	Design period	LOAEL (green)	LOAEL to SOEAL (amber)	SOAEL (red)
Dwellings**	Garden used for main amenity (free field)	Day	*Rating level* 10dB* below background	*Rating level* between 9dB below and 5dB above background	*Rating level* greater than 5dB above background
	Outside living or dining or bedroom window (façade)				
	Outside bedroom window (façade)	Night	*Rating level* 10dB* below background	*Rating level* between 9dB below and 5dB above background	*Rating level* greater than 5dB above background

** 10dB should be increased to 15dB if the noise contains audible tonal elements.*
*** Levels are given for dwellings, however, levels are use specific and different levels will apply dependent on the use of the premises*
.

Table 9: Noise levels applicable to proposed industrial and commerical developments (including plant and machinery, described in Camden Local Plan Appendix 3 Table C.

The figures in Table 9 are used to determine the limits for cumulative environmental noise emissions from the development (including from all items of building services plant).

4.2.10 BREEAM and the Code for Sustainable Homes

The Liddell Road developments have historically targeted BREEAM (for offices) and Code for Sustainable Homes (CfSH – for residences) credits. CfSH was historically mandated by some local authorities: it is now operational, but voluntary.

For offices, BREEAM has credits available for achieving the indoor ambient noise levels set out in BS8233:2014. Further points are available for sound insulation, acoustic environment and noise pollution.

For residences, CfSH has a scale of credits available for sound insulation standards in excess of the building regulations. CfSH does not have credits associated with internal ambient noise levels.

4.3 Criteria for the Liddell Road development

Based on the regulations, code and guidance documents described above, we proposed the following criteria to inform the design for Liddell Road:

	Threshold of VDV at which isolation is considered, $ms^{-1.75}$	**Notes**
Residences – daytime	0.2	Aligned with onset of low probability of adverse comment set out in BS 6472-1. Aligned with BCO (for offices)
Residences – night time	0.1	
Offices	0.4	

Table 10: Criteria for vibration.

	Groundborne noise level at which vibration isolation mitigation is recommended, dB L_{ASmax}	**Notes**
Residences	35dB L_{ASmax}	Aligned with historic Camden policy, although it is not the more recent Camden Plan (2017). It is also consistent with other local authorities and infrastructure projects such as Crossrail
Offices	40dB L_{ASmax}	Aligned with BCO

Table 11: Criteria for groundborne noise.

	External ambient noise levels at which noise presents a risk to development on the site.	**Notes**
Indicative daytime noise levels* $L_{Aeq,16hr}$	50dB	Aligned with ProPG
Indicative night time noise levels* $L_{Aeq,}$8hr	40dB	
Noise events at night	More than 10 noise events at night with L_{AFmax} > 60dB	

Table 12: Criteria for external environmental noise levels.

Activity	**Location**	**07:00 to 23:00**	**23:00 to 07:00**	
Resting	Residences - Living room	35dB $L_{Aeq,16hr}$	–	Aligned with BS 8233:2014*
Dining	Residences - Dining room / area	40dB $L_{Aeq,16hr}$	–	
Sleeping (daytime resting)	Residences - Bedroom	35dB $L_{Aeq,16hr}$	30dB $L_{Aeq,8hr}$ 45dB L_{AFmax}	
Offices		NR38 ($L_{eq,9am-5pm}$) 55dB $L_{A01,1hr}$	–	Aligned with BCO

** Figures presented here not include any allowance for relaxation up to 5dB as described in BS 8233:2014, as might be appropriate where such a relaxation is in the interest of more sustainable ventilation and overheating strategies. See Section 7.2.1 of this report for further discussion.*

Table 13: Criteria for internal ambient noise levels.

5 Noise and vibration survey

Arup undertook measurements at the Liddell Road site in June and July 2021:

- Attended noise measurements on 24 June 2021.
- Attended noise measurements on 19 July 2021.
- Unattended (‘logged’) noise measurements between 7 July and 19 July 2021.
- Unattended (‘logged’) vibration measurements between 7 July and 19 July 2021.

Figure 2 shows the positions on site at which measurements were undertaken.

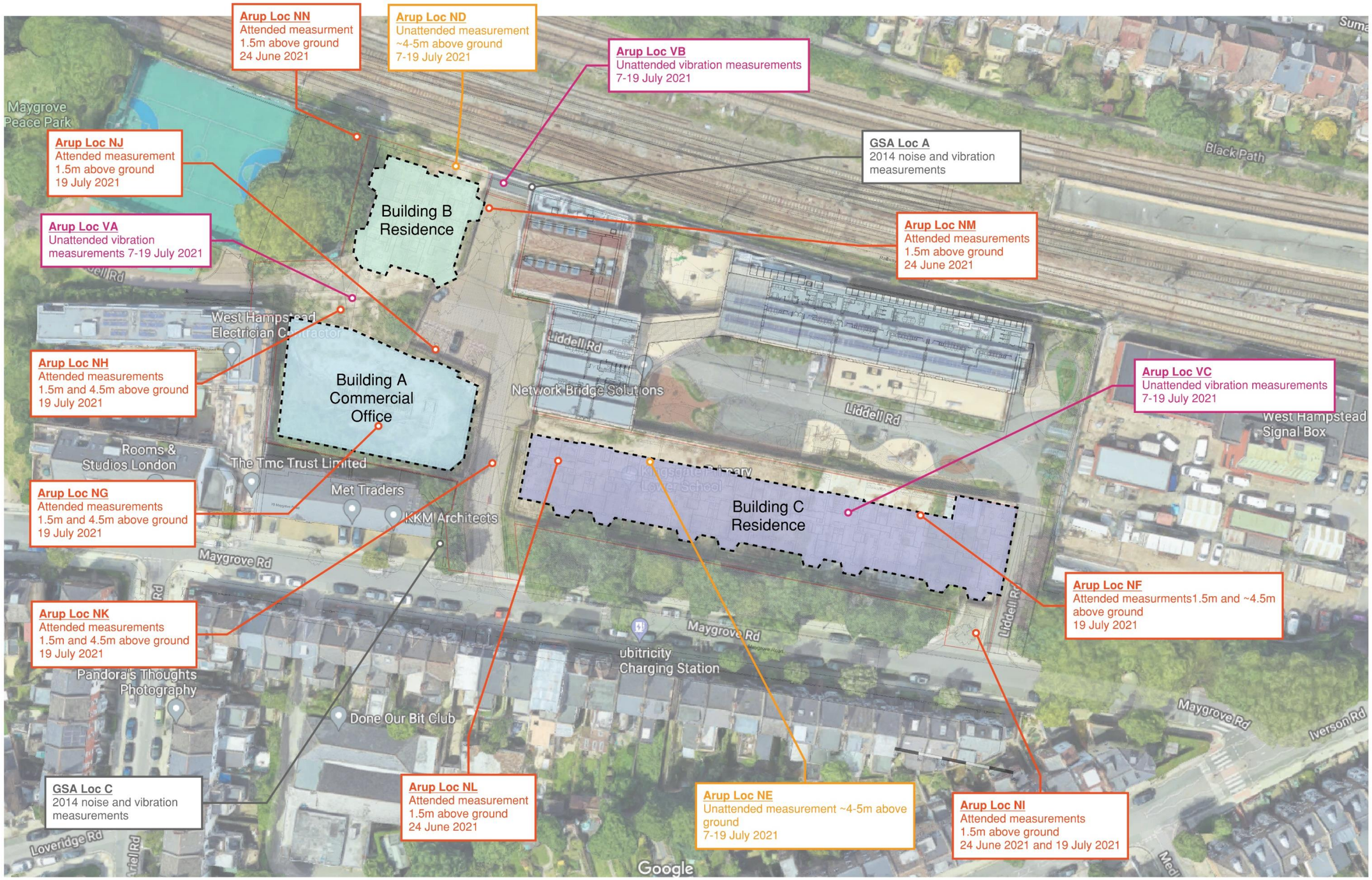

Figure 2: Noise and vibration measurement locations

6 Analysis of vibration on site

6.1 Overview of results

The unattended data loggers recorded vibration velocity waveforms. Freight and commuter train pass-by events have been identified from publicly available daily train schedules/recordings. These datasets provide both expected and actual train movements along the Network Rail lines. Near the development site, the following maximum numbers of train pass-bys were observed (and have been assumed in the following analysis) during the survey days for the day-time and night-time periods.

	East Midlands trains	Thameslink trains	Freight trains
Day period [07:00-23:00]	310	190	10
Night period [23:00-07:00]	50	30	5

Table 14: Number of identified train pass-bys. Note that up to 45 (daytime) and 20 (night time) freight train slots are typically scheduled. However most of these slots are generally not used by the freight operators.

From the measured time history, the VDV and vibration velocity spectra were derived for each pass-by using the Prosig DATS7 software. This requires the application of appropriately weighted filter networks on each geocentric axis. The values thus obtained are used to calculate either the resultant VDV, or to obtain the spectral components of the vibration signals, to carry out the required analysis for the prediction of structure-borne noise (SBN) for each pass-bys for the three train services.

Figure 3 illustrates vibration velocity spectra of typical pass-bys for Thameslink, East Midlands and freight trains. A wide range of amplitude can be observed. The spectra have a significant energy content at low frequency, in the one third octave bands below 50Hz. These frequencies are at the lower range of human hearing where humans are less sensitive to sound, but extend into the range of perceptible vibration.

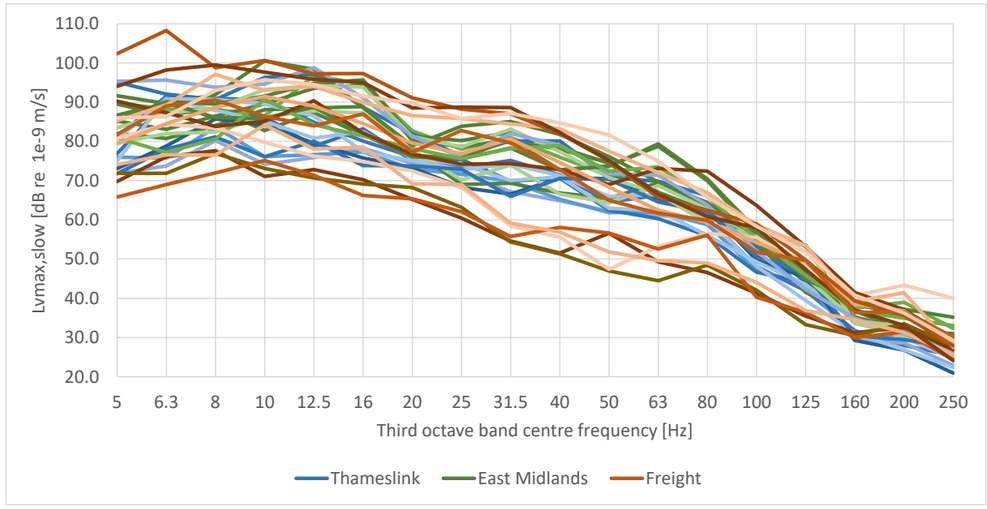

Figure 3 Typical vibration velocity spectra of freight (red), East Midlands (green) and Thameslink (blue) pass-bys at the closest measurement location.

6.2 Predicted levels in buildings

Vibration measurements have been undertaken either on remaining ground structure of the previous buildings or on the existing ground slab of the existing school bin store. Appropriate correction factors need therefore to be applied to the measured vibration to assess the effect of the proposed building structures.

6.2.1 Vibration

A collaborative study[4] between British Rail and LUL indicated that vertical VDVs measured near the centre of first floor of brick-build residential properties were found to be around four times the level measured in outside the properties. In the HS2 Environmental Statement[5], this correction factor is considered to provide a worst-case estimate for first floor and above for concrete high-rise buildings. This factor has been applied in this analysis to assess the impact of the proposed development structure.

Our calculations assume all floors are concrete. We understand that timber constructions such as timber suspended floors are not currently considered for the developments at Liddell Road.

[4] Greer R. J., 1993, Methodology for the prediction of re-radiated noise in residential buildings from trains travelling in tunnels, Proceedings of Internoise 1993

[5] HS2 Ltd, 2013, London-West Midlands Environmental Statement – Volume 5 | Technical Appendices, Methodology, assumptions and assessment (route-wide) (SV-001-000) Sound, noise and vibration

	Predicted VDV $ms^{-1.75}$	
	Day	**Night**
Building B - Residential Tower	0.22	0.16
Building C - Town Houses	0.12	0.07
Building A - Office building	0.20	0.13

Table 15: Predicted VDV.

In Building A and Building C, the VDVs are below the proposed criteria. In Building B, VDVs are in the low range of the day-time criteria range and slightly above the night-time planning requirement, suggesting a potential, albeit at a relatively low probability, of adverse comments.

The VDVs in the residential tower are driven by freight and commuter trains, passing on the nearside track. The vibration of some of these trains is likely to exceed the PPV thresholds of perception[6], depending of the speed, track and rolling stock conditions. This means levels of vibration above the threshold of perception, i.e. residents in the lower floors of the tower might perceive occasionally vibration from trains, in the absence of any mitigation.

6.2.2 Groundborne noise

The measured vibration spectra have been used to estimate the groundborne noise levels within the buildings of the proposed development. The possible response of the future buildings needs to be considered and spectral correction factors applied to the measured vibration spectra. These frequency-dependent corrections relate to:

- attenuation from floor to floor,
- mid-span amplification on suspended floor slabs,
- noise radiation from the floor/ceiling slabs and walls.

Since the measurements have been undertaken either on remaining ground structure of the previous buildings or on the existing ground slab, no additional corrections have been applied for coupling losses between the ground and the building foundations.

The groundborne noise ($L_{Amax,S}$) predictions have been based on the methodology and correction factors defined by the Association of Noise Consultants publication[7]. It should be noted that there are many complex factors that affect actual levels of noise, and these predictions should necessarily be considered approximate. The predictions have been made for the worst-case location in the proposed building (i.e. first suspended floor).

[6] British Standards Institution, 2009, BS 5228-2:2009+A1:2014, Code of practice for noise and vibration control on construction and open sites. Vibration.

	Predicted groundborne noise $L_{Amax,S}$
	Per train passby
Building B - Residential Tower	Generally below 35dB $L_{Amax,S}$ Occasionally between 35dB – 40dB $L_{Amax,S}$ due to freight trains One recorded freight train exceeded 40dB $L_{Amax,S}$
Building C - Town Houses	Below 30dB L_{ASmax}
Building A - Office building	Below 35dB L_{ASmax}

Table 16: Predicted groundborne noise.

6.2.3 Variation in time

It is important to note that vibration levels from railways, and the associated groundborne noise levels, are known to vary significantly over time. This variation is often associated with the maintenance cycle of railways – for example it is highly dependent on the wheel / rail interface and rail roughness or corrugation effects. It is also affected by changes to rolling stock and other operational factors.

The Gillieron Scott data from 2014 generally show higher vibration magnitudes than we measured. This may in part be due to a reduction in level over that period, although there are other variable associated with measurement method and location. But equally vibration levels may increase over time, and so it is necessary to be mindful of this when considering the implications for the design.

6.3 Implications for building design

For Building A and Building C, no additional groundborne noise and vibration mitigation are required.

For Building B, the large majority of freight and commuter trains movements appear likely to radiate groundborne noise levels in the lower floor apartments below (within) the design criteria, but some occasional trains (generally freight trains passing in the nearest track) are likely to generate groundborne noise between 35 and 40dB$L_{Amax,S}$, or slightly higher.

The design presently includes spring isolation below Ground Floor level of Building B to mitigate vibration and structureborne noise. Based purely on the site data we obtained, the situation appears marginal. An argument could be made that isolation is not necessary. However, perceptible vibration and some exceedances of design criteria appear likely in the context of an unmitigated design, and there is good reason to consider that vibration levels will be subject to variation over time, either for the worse or the better. On balance, we consider it appropriate to retain the proposed mitigation for Building B.

Because of the relatively low frequency content of the measured vibration (peaking around 8Hz in our data, and 6Hz in the Gillieron Scot data), the isolation system would require a

[7] Acoustics & Noise Consultants, 2020, Measurement & Assessment of Groundborne Noise & Vibration – 3rd Edition

resonance frequency of no greater than 3.5Hz to minimise the effect on the perceptible vibration. With such a system, based on measured levels both groundborne noise and vibration VDV levels would be expected to be within the planning and design criteria. Associated care will be needed with the detailed building structure design to ensure structural resonances are not unfavourably aligned in relation to the isolation system natural frequency or excitation frequencies.

7 Analysis of noise on site

7.1 Overview of results

Figure 4 and Figure 5 show the unattended LAeq, LAFMax and LA90 measurements at the two measurement locations at which loggers were deployed. Figure 6 shows the average Leq spectra and Figure 7 shows typical 99th percentile Lmax spectra at these locations.

Based on our attended and unattended noise measurements, we have estimated typical environmental noise levels incident on facades. Our predictions take in to account the screening of noise by new buildings modelled by Gillieron Scott Acoustic Design in their 2014 report. These predictions are indicated in Figure 8 below.

The noise levels indicated in Figure 8 represent the upper bound of our estimations for each facade. Noise levels will naturally vary across a single façade and it may be feasible to account for variation in the design of the building envelopes.

	Lowest measured $L_{A90,5min}$ over entire measurement period	
	Location ND	**Location NE**
Day	34dB	34dB
Evening	38dB	37dB
Night	32dB	32dB

Table 17: Lowest measured $L_{A90,5min}$ background noise levels

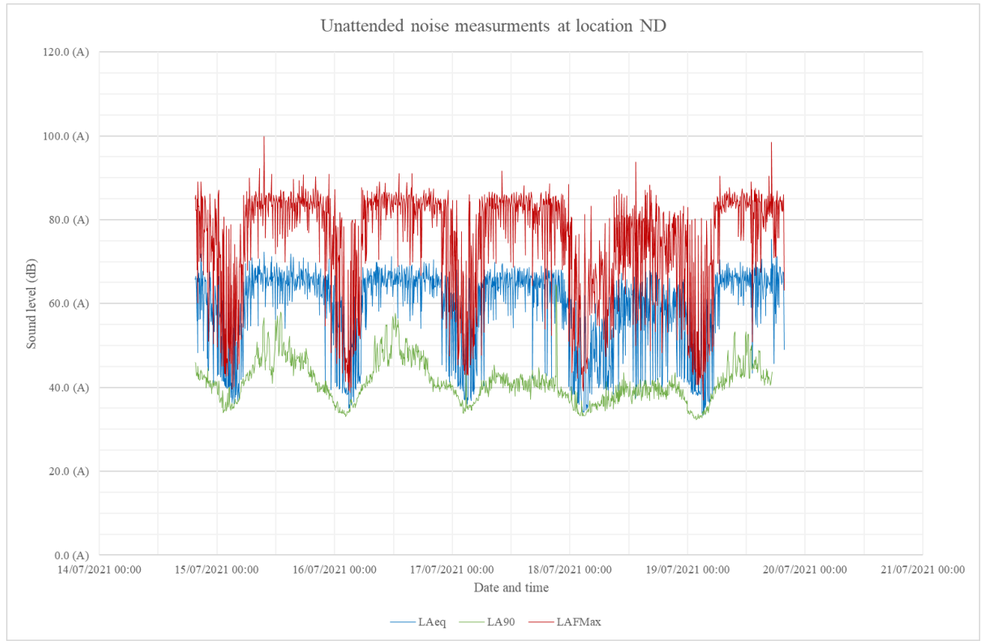

Figure 4: Unattended noise measurements at location ND.

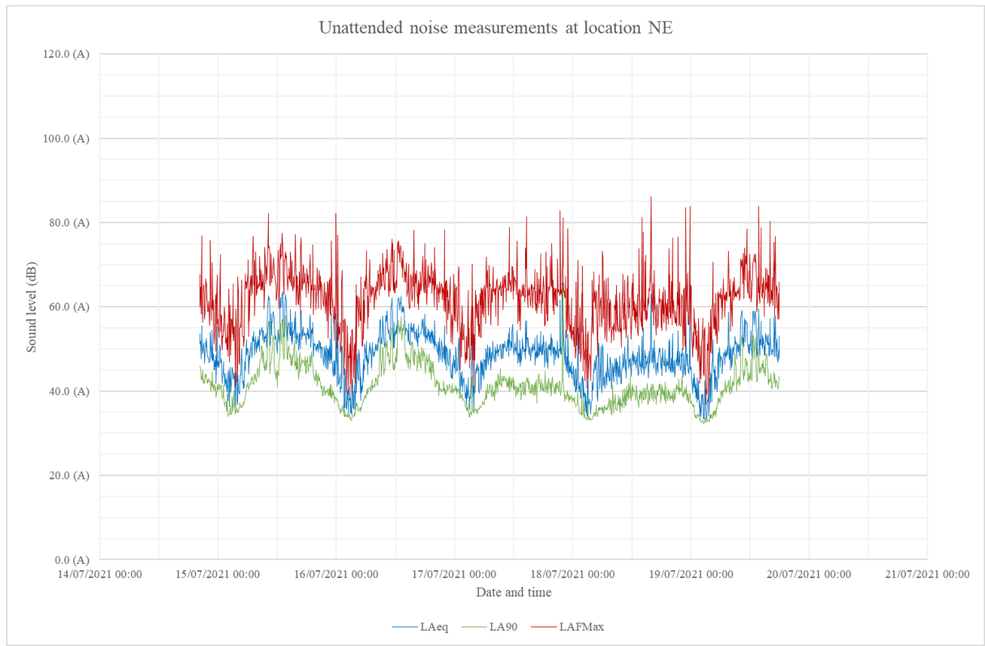

Figure 5: Unattended noise measurements at location NE.

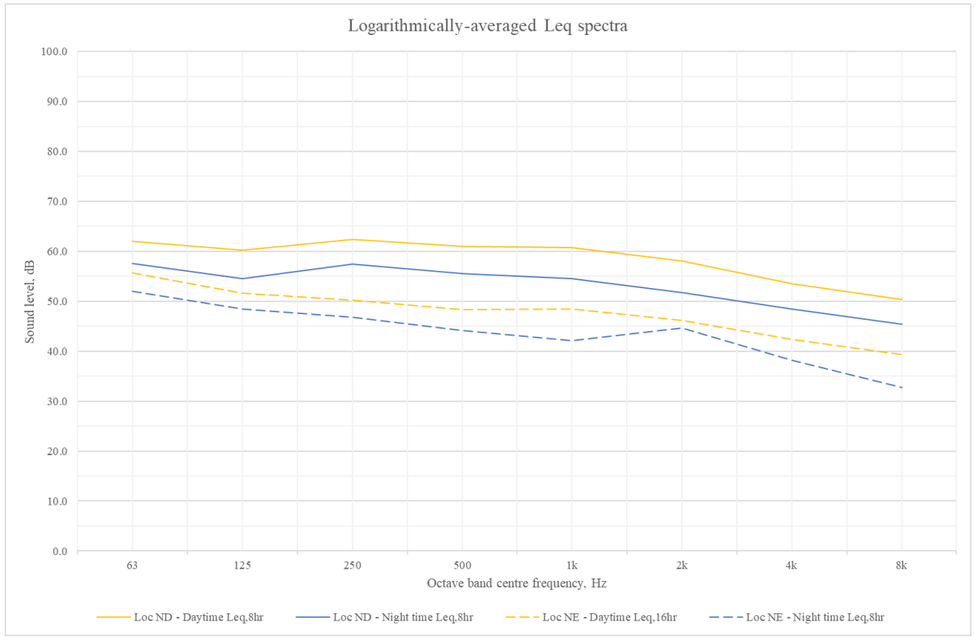

Figure 6: Average L_{eq} spectra.

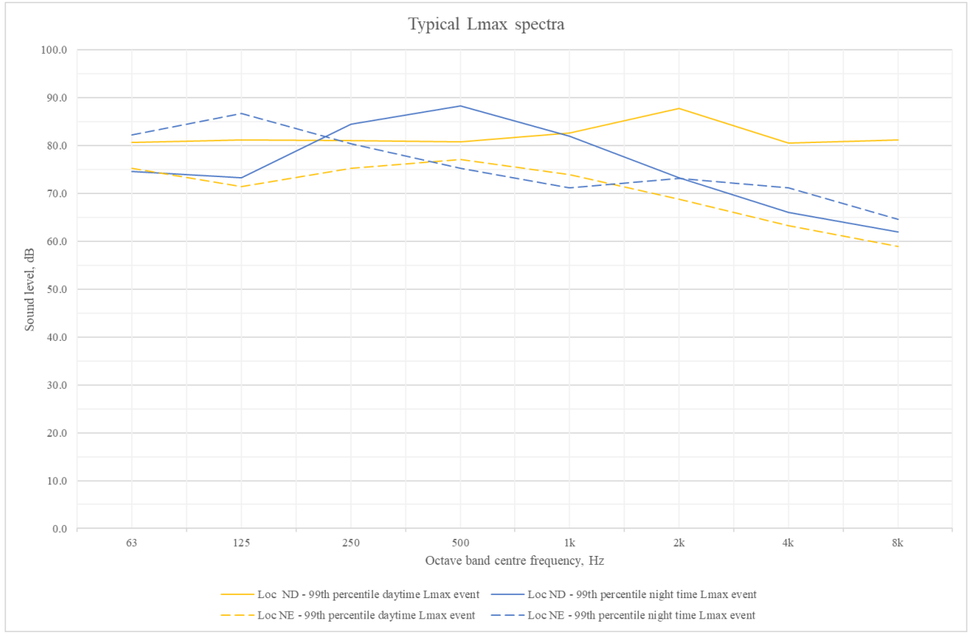

Figure 7: Average L_{Fmax} spectra.

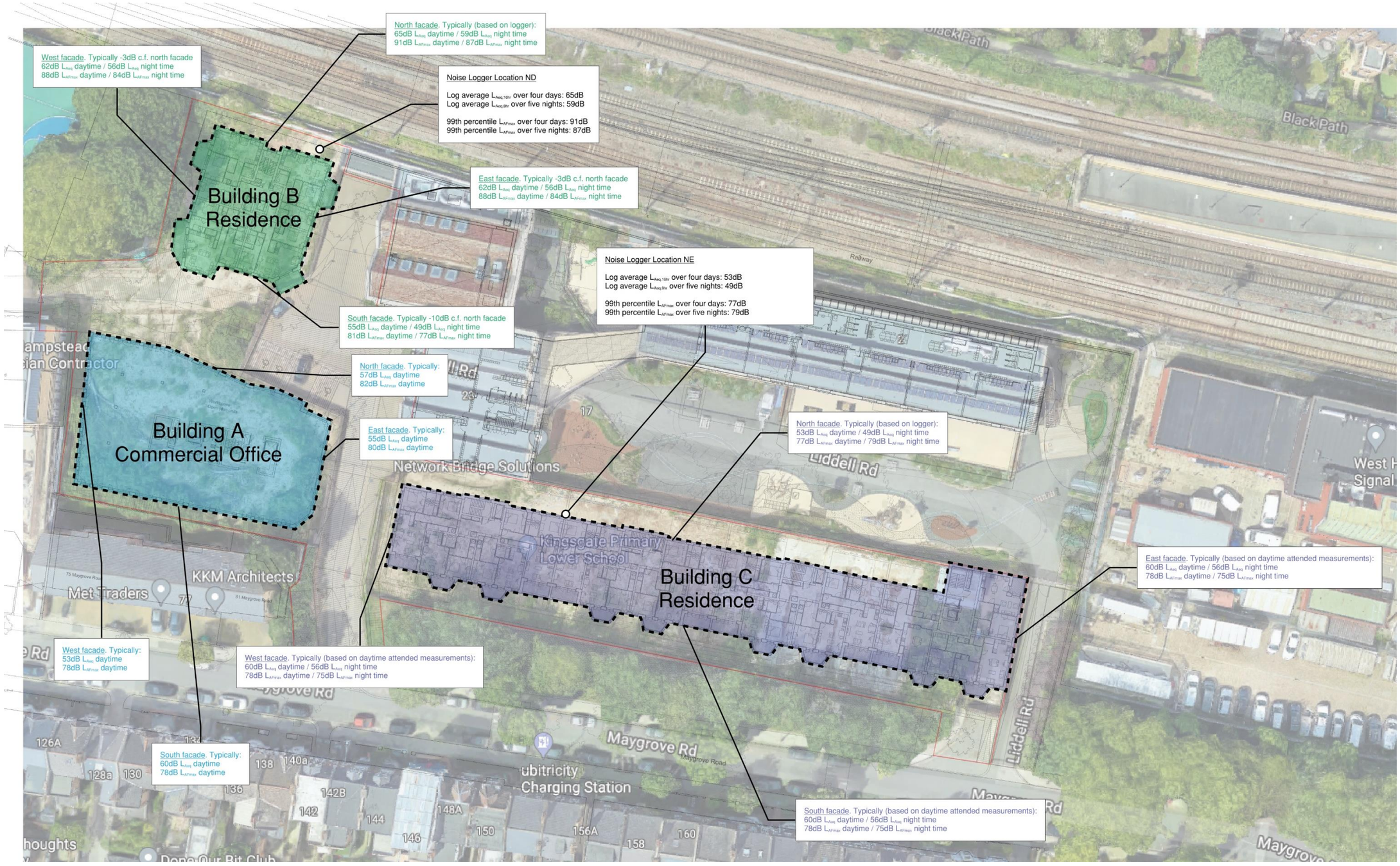

Figure 8: Predicted environmental noise levels incident at facades (free-field levels).

7.2 Implications for building design

The external ambient noise levels at all locations across site significantly exceed the criteria listed in Table 12 above. Therefore at all locations on site the external ambient noise presents a significant risk to development. The development will rely on good acoustic design, co-ordinated with the strategies and the design of façade, ventilation and cooling systems, to reduce adverse effects to a minimum and to ensure that the indoor ambient noise level criteria set out in Table 13 are achieved.

7.2.1 Ventilation and cooling (overheating) strategies

Following discussion with the MEP engineers, we understand that the design for the residential buildings is based on individual residences serviced by individual MVHR systems, with individual attenuated local intake and exhaust ducts. This strategy does not require opening windows or natural ventilation systems to be used for ventilation or cooling (including overheating), and this strategy is compatible with mitigating the risk from noise ingress to residences. Attenuation will be required to the inlet and discharge connections for the MVHR systems, as is normal, and the MEP engineers have advised that this has already been planned for.

When windows are opened it is clear that the internal noise criteria will in many cases be exceeded during that time. but this will be at occupants' discretion, and occupants will not be compelled to do this to alleviate thermal discomfort.

We understand that the current design for the office building is based on mechanical ventilation so that opening windows or natural ventilation systems are not required for ventilation or cooling. This strategy is preferred in terms of mitigating the risk from noise ingress to offices.

7.2.2 Façade design

The levels of external ambient noise require high levels of sound reduction from the façade elements in some locations – in particular for Building B on the North, East and West elevations.

We will compare alternative triple and secondary glazed systems alongside the other designers to establish the most appropriate solution in each location. Because the railway noise in particular will have specific angles of incidence to the windows, angle of incidence effects that are not normally accounted for in published test performance data will need to be considered.

Our initial predictions suggest that it might be possible to achieve the required sound reductions using the highest-performing packaged double / triple glazing units (typically up to 60mm thickness). An example of the order of magnitude for the façade with the highest noise exposure is indicated in Table 18.

Facade	Octave band centre frequency, Hz					
	125	250	500	1k	2k	4k
Building B North facade	-32	-39	-48	-54	-57	-63

Table 18: Typical minimum facade sound reduction index, dB, to achieve indoor ambient noise criteria.

7.2.3 Noise emissions from building services

The background noise levels in Table 17 serve as a basis for establishing cumulative limits for building services associated with the development. On this basis, the rating level for plant is provided in Table 19.

Where Arup has previously designed buildings in such low background environments, local authorities have agreed to set absolute levels as recommended in BS 4142 rather than work to a level relative to background. Typically, 35dB$L_{Aeq,10min}$ is an acceptable limit, to allow for an indoor level of less than 30dB(A) in bedrooms with windows open.

Background levels are low, which means that plant attenuation requirements will be relatively significant. Requirements for nominated plant selections should therefore be established as soon as possible in order to anticipate any associated dimensional or cost implications.

At 1m from windows of nearby sensitive receivers		Cumulative building services noise emission limits, dB$L_{Ar,Tr}$
Day	7am – 7pm	24dB
Evening	7pm – 11pm	28dB
Night	11pm – 7am	22dB

Table 19: Limits of noise from plant at sensitive receivers near to the Liddell Road development, based on 10dB below background

8 Conclusions

Our conclusions from site measurements and analysis of external ambient noise and vibration at the Liddell Road site are as follows:

- Our site measurements and analysis of vibration, based on the assumptions set out in this report, do not suggest that vibration isolation is required for Building A or Building C.
- Our site measurements and analysis of vibration, based on the assumptions set out in this report, suggest the likelihood of occasional exceedance of vibration and of ground borne noise criteria in Building B.
    - The design presently includes spring isolation below Ground Floor level of Building B to mitigate vibration and structureborne noise.
    - An argument could be made that isolation is not necessary. However, perceptible vibration and some exceedances of design criteria appear likely in the context of an unmitigated design, and there is good reason to consider that vibration levels will be subject to variation over time, either for the worse or the better.
    - On balance, we consider it appropriate to retain the proposed mitigation for Building B.
- Our site measurements and analysis of vibration, based on the assumptions set out in this report, suggest that the external ambient noise levels at all locations across site present a significant risk to development in health and wellbeing terms, as would be expected given the location. This will require good acoustic design, coordinated with the strategies and the design of façade, ventilation and cooling systems, to reduce adverse effects to a minimum. However the design currently does not rely on opening windows or natural ventilation routes for ventilation or cooling in any of the buildings, and this enables appropriate mitigation of external noise to achieve suitable internal conditions.