EMPIRICAL RELATIONSHIP BETWEEN L_{NIGHT} AND L_{AMAX}

Nick Conlan Apex Acoustics
Weigang Wei Apex Acoustics
Jack Harvie-Clark Apex Acoustics

1 ABSTRACT

Following the publication of the ProPG: Planning and Noise, and the AVO Guide, there has been renewed interest in the measurement and assessment of noise from events, typically described with the $L_{AF,max}$ indicator. The analysis presented here includes 478 night-time measurements from 239 separate measurement locations, each covering the full 8-hour night-time period, recorded at 1 second intervals. The statistical relationship between the $L_{Aeq,\ 8\ hr}$ (ie L_{night}) and the different design cases is characterised. These data will inform the debate around the importance of using $L_{AF,max}$ as a design parameter for residential developments.

The analysis finds the use of L_{AFmax} values are often the significant parameter when considering the façade design, but the measurements have a greater uncertainty than time averaged noise levels.

Based on meeting guideline values for L_{night} of 30 dB, and the 10^{th} highest $L_{AF,max}$ of 45 dB, in the majority of cases the 10th highest $L_{AF,max}$ is likely to be the most significant design constraint, as on average it is 18.5 dB higher than the L_{night}. Similarly, if undertaking an assessment of noise and overheating according to the AVO Guide, the single highest $L_{AF,max}$ is most likely to be the most significant constraint with the average difference of 27.8 dB between the L_{night} and the highest $L_{AF,max}$.

2 INTRODUCTION

There has been renewed interest is measuring and assessing noise from events typically using the $L_{AF,max}$ parameter, particularly for noise assessments of transportation noise impacts on new residential developments. However, the typical relationship between general ambient noise levels (L_{night} or $L_{Aeq,\ 8\ hr}$) and the noise from events, $L_{AF,max}$ is not widely reported or known. Understanding the potential uncertainty from $L_{AF,max}$ measurements is also becoming more important as validation measurements of residential buildings is becoming more common prior to occupation, and the risks of measurements during a potential 'noisier' night should be understood and accounted for within the façade design.

3 IMPORTANCE OF $L_{AF,MAX}$ FOR UK NOISE ASSESSMENTS

There is a general consensus that assessing the effects of noise on sleep should include a consideration of individual noise events ($L_{AF,max,T}$, $L_{AS,max,T}$) as well as the average noise levels over the night-time period ($L_{Aeq,8hr}$, also referred to as L_{night}) and many studies have shown clear exposure response relationships between the maximum level of individual noise events and impacts during sleep.

ProPG: Planning & Noise [1] provides guidance on dealing with noise events and states:

"In most circumstances in noise-sensitive rooms at night (e.g. bedrooms) good acoustic design can be used so that individual noise events do not normally exceed 45 decibels $L_{A,max,F}$ more than 10 times a night. However, where it is not reasonably practicable to achieve this guideline then the judgement of acceptability will depend not only on the maximum noise levels but also on factors such as the source, number, distribution, predictability, and regularity of noise events.

In such a case it is recommended that a more detailed assessment should be undertaken using available dose-response relationships appropriate for the types of noise sources being considered, *in line with the WHO NNG publication and any other relevant research. This assessment should advise decision makers to what extent adverse effects from individual noise events on sleep will be mitigated and minimised and report the likely residual effects on sleep of affected persons".*

The Acoustics, Ventilation, Overheating: Residential Design Guide (AVO Guide) [2] contains separate guideline values for noise from events, $L_{AF,max}$. It indicates that these should be achieved while providing whole dwelling ventilation, and that should be achieved when using provisions for mitigation overheating (e.g. opening windows). The reasoning behind the approach and guideline values is described by Paxton et al [9].

The 1999 WHO Guidelines for Community Noise [3] state that:

"if the noise is not continuous, sleep disturbance correlates best with L_{Amax} and effects have been observed at 45 dB or less. This is particularly true if the background level is low. Noise events exceeding 45 dBA should therefore be limited if possible. For sensitive people an even lower limit would be preferred. It should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB). To prevent sleep disturbances, one should thus consider the equivalent sound pressure level and the number and level of sound events. Mitigation targeted to the first part of the night is believed to be effective for the ability to fall asleep."

Reference to a specific value of L_{Amax} was removed in BS 8233: 2014 [4] when it was revised from the 1999 edition. Note 4 to Table 4 – Indoor ambient noise levels for dwellings states:

"Regular individual noise events (for example, scheduled aircraft or passing trains) can cause sleep disturbance. A guideline value may be set in terms of SEL or $L_{Amax,F}$, depending on the character and number of events per night. Sporadic noise events could require separate values."

The 2009 WHO Night Noise Guidelines [5] propose 42 dB L_{Amax} as the NOEL for conscious awakening by transport noise and propose lower guidelines (32-35 dB L_{Amax}) for biological effects such as motility, EEG awakening and changes in sleep structure and fragmentation of sleep.

4 LITERTAURE SEARCH

4.1 A good practice guide on the sources and magnitude of uncertainty arising in the practical measurement of environmental noise

The good practice guide [6] provides detail of potential areas of uncertainty. For this assessment, the measurement location is constant for each position, and the likely areas of uncertainty between consecutive nights will be the noise source (variation in traffic flows and types of vehicles) and the transmission path (weather conditions, particularly wind direction, wind speed and variation of wet or dry road surfaces).

The guide also includes a case study which refers to a lecture entitled 'Designing outdoor sound measurements' by Ian Findell. The lecture compares sampling strategies for the estimation of annual indicators of road traffic noise ($L_{Aeq,24hr}$) with the probability of being within 1 dB of the annual average as shown in Table 1.

Table 1: Uncertainty of measured noise levels with annual average based on sampling strategy

Sampling Strategy	**Probability sample is within 1 dB of annual average**
1 day	35 %
7 days continuous	50 %
14 days continuous	54 %
28 days continuous	60 %
7 days random	68 %
14 days random	84 %
28 days random	94 %

4.2 ANC Green Book

The ANC Green Book: Environmental Noise Measurement Guide [7] contains guidance on the selection of a representative design value. It states:

"Only in the most extreme situations would it be appropriate to adopt the highest measured L_{Amax} value… as a descriptor of an appropriate design case. In most situations, an average, typical or modal value, specific to the time period in question, needs to be selected or derived from the survey data. The frequency of occurrence of specific L_{Amax} events is critical in determining their typicality (hence the importance of sample period selection during scoping). No single fixed method is appropriate for all situations, and the reasoning behind the approach adopted should be thoroughly documented".

This guide continues to outline some common approaches to selecting the design case L_{Amax}. However, those notes may be considered in the context of the AVO Guide.

4.3 The 2018 WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep

The WHO Environmental Noise Guidelines are based on a series of systematic reviews. The Systematic Review on Environmental Noise and Effects on Sleep [8] includes review of studies on noise induced awakenings published since the year 2000. Although the evidence for cortical awakenings was not considered strong enough for inclusion in the eventual WHO Guidelines, exposure-response curves are presented for road, rail and aircraft, derived from the raw data from two large polysomnographic field studies conducted by the German Aerospace Center (DLR) referred to as STRAIN 9 and DEUFRAKO 11. These studies were respectively conducted to investigate the effects of aircraft and rail noise on sleep, with results from both studies combined to derive the relationship for road traffic.

Although most European research, particularly on the effects of aircraft noise, is based around a slow weighted maximum, $L_{AS,max}$, in the UK, the majority of past guidance on maximum noise events is stated in terms of $L_{AF,max}$, making this a more familiar and widely used parameter. In the DEUFRAKO study (rail and road), both $L_{AS,max}$ and $L_{AF,max}$ were measured; the differences found between the two metrics are shown in Table 2.

Table 2: Difference between $L_{AS,max}$ and $L_{AF,max}$ from the DEUFRAKO study

Source of noise event	**Mean absolute difference, dB**	**2.5% - 97.5 % confidence range, dB**
Road	0.86	0 – 3.5
Rail	0.72	0 – 4.0

5 SURVEY DATA FOR PARAMETER COMPARISON

The surveys selected for the data analysis included measurements from two consecutive night-time periods. All surveys were undertaken by Apex Acoustics using calibrated sound level meters. Data from 289 separate measurement locations, from 139 separate projects between 2015 and 2021, were included. This provided data for 578 separate measurements of noise over a full eight hour night time period. Where the L_{night} between separate days varied by more than 3 dB the data was omitted if the variation was due to weather conditions, measurements over a weekend or where measurements were dominated by plant or entertainment noise. The final dataset used for the analysis consisted of 478 night-time measurements from 239 separate measurement locations.

All measurements were recorded at one second intervals, which were analysed using a computer script to calculate the parameters listed in Table 3 for each whole night survey period.

Table 3: Parameters calculated for each whole night period

Parameter	**Reference time period, T, and parameters calculated**
$L_{Aeq,8hr}$ (L_{night})	8 hours
Highest $L_{AF,max,T}$	Highest $L_{AF,max,1\ min}$
	Highest $L_{AF,max\ 5\ min}$
	Highest $L_{AF,max\ 15\ min}$
10th Highest $L_{AF,max\ T}$	10th Highest $L_{AF,max\ 1\ min}$
	10th Highest $L_{AF,max\ 5\ min}$
	10th Highest $L_{AF,max\ 15\ min}$

The initial concept was to look at variations for different land uses, such as urban, suburban and rural, in a similar way to the Defra National Noise Incidence Study [10]. However, when the survey locations were reviewed it was clear that there were very few rural locations, and it was difficult to differentiate between urban or suburban locations. Therefore it was decided to not separate the surveys into the land use categories. Rather, all the measurement locations are representative of locations where residential properties were proposed to be built, and the dominant sources were transportation noise.

The data is presented graphically as box and whisker plots, without outliers; the mean and standard deviations are provided in the accompanying tables.

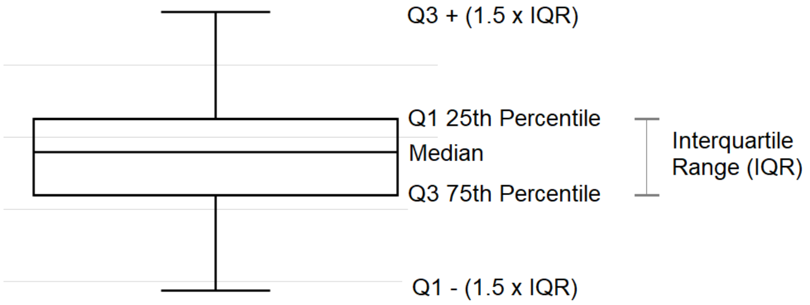

Figure 1: The anatomy of a box and whisker plot

6 COMPARISON OF CONSECUTIVE DAYS

The comparison over two days is based on 239 sets of measurements and has been established for the L_{night} value, the single highest maximum for each night and the 10th highest maximum for each night, based on 1 minute sampling periods. This comparison is to enable an estimate to be made of how each parameter may change if it were to be repeated on a different day. The results are presented in Table 4 and shown graphically in Figure 2.

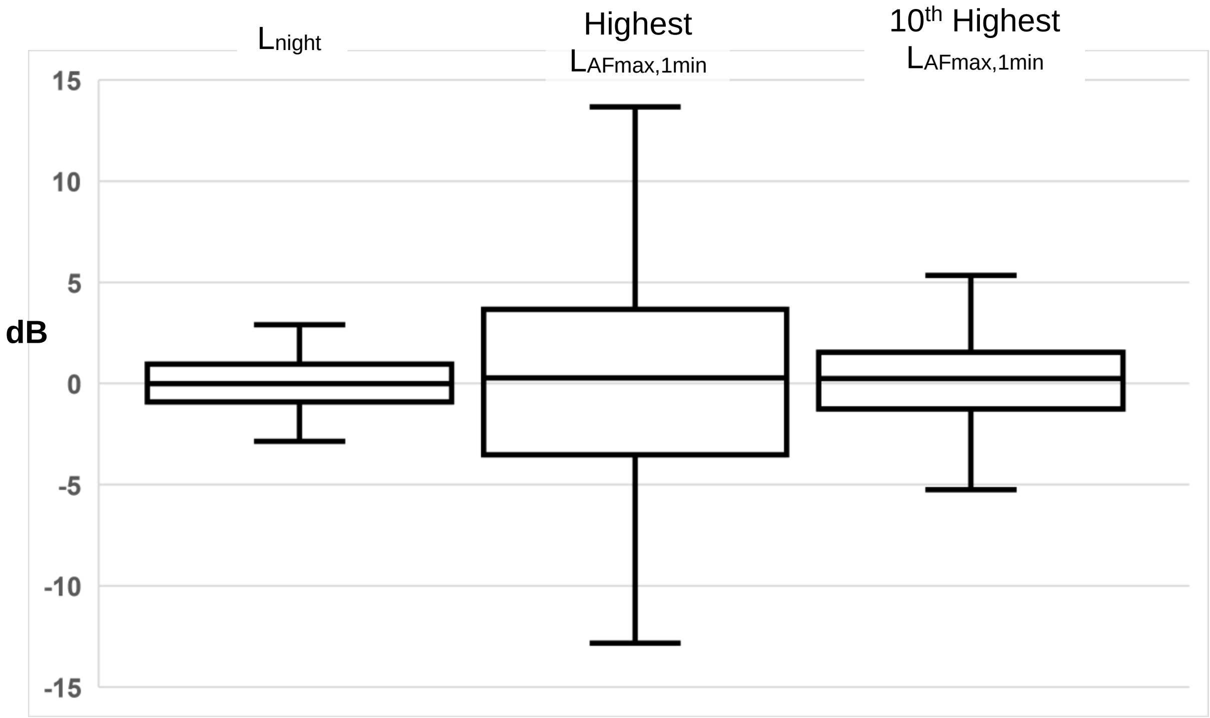

Figure 2: Variation in noise levels between consecutive nights

Table 4: Variation in noise levels between two consecutive nights

Parameter	Mean (dB)	Standard Deviation	Median (dB)	25th percentile	75th percentile
(Day one L_{night}) – (Day two L_{night})	0.05	1.30	-0.01	-0.92	0.94
Day one Highest $L_{A,F,max,1min}$ – Day two Highest $L_{A,F,max,1min}$	-0.27	6.80	0.27	-3.43	3.57
Day one 10th Highest $L_{A,F,max\ 1min}$ – Day two 10th Highest $L_{A,F,max\ 1min}$	-0.24	2.88	0.24	-1.26	1.54

The results indicate the range of change to the L_{night}, the highest and 10th highest $L_{AF,max,1\,min}$ over two consecutive nights. On this basis, the uncertainty from a single night's measurement may be acceptable for the assessment if a tolerance of 2 dB is added to the 10th highest $L_{AF,max}$. There is greater uncertainty in the consequential measurement of the single highest $L_{AF,max}$.

7 COMPARISON BETWEEN L_{NIGHT}, THE HIGHEST L_{MAX} AND 10TH HIGHEST L_{MAX}

Most UK noise assessments which consider night-time noise use the criteria of 30 dB L_{night} and a maximum noise level of 45 dB L_{AFmax}. Although most local authorities will accept the 10th highest L_{AFmax} value, some do request that the single highest value is used. Therefore if the difference in values is less than 15 dB, the L_{night} value will be the most important parameter for the night-time assessment, and if it is greater than 15 dB then the maximum level will be the most important.

Based on 478 night-time measurements, the comparison between these parameters is presented in Table 5 and shown graphically in Figure 3.

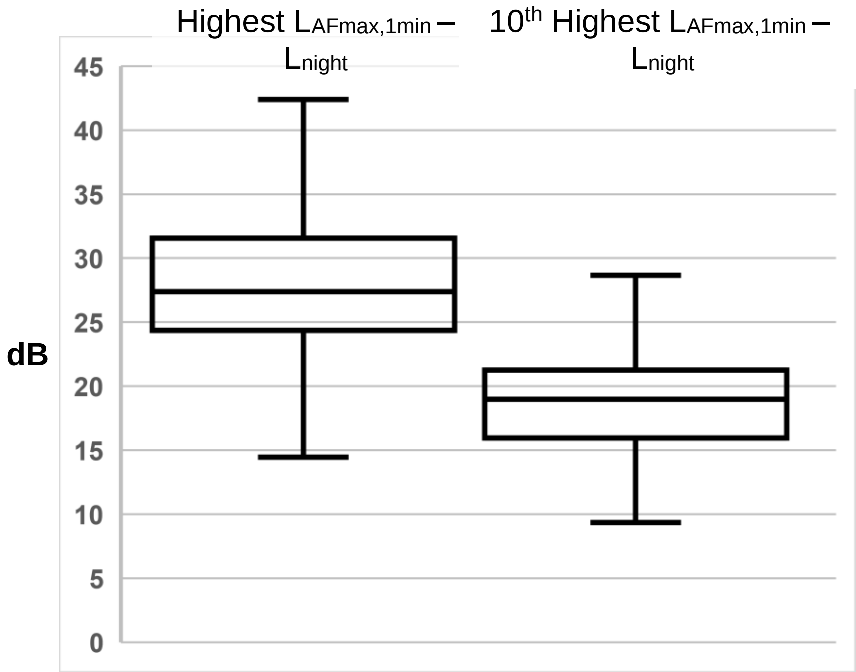

Figure 3: Comparison of the difference between L_{night} value and the L_{AFmax} values for the single highest and 10th highest values

Table 5: Comparison of the highest maximum and 10th highest maximum with the L_{night} value

Parameter	Mean (dB)	Standard Deviation	Median (dB)	25th percentile	75th percentile
Highest $L_{A,F,max,1min}$ - L_{night}	27.8	5.7	27.4	24.4	31.6
10th Highest $L_{A,F,max\,1min}$ - L_{night}	18.5	4.2	19.0	15.9	21.2

These data indicate that in more than 75 % of cases, the 10th highest $L_{AF,max}$ would be the most significant design constraint if internal targets are 30 dB L_{night}, and 45 dB $L_{AF,max}$ (10th highest). Similarly, if undertaking an assessment for the overheating condition according to the AVO Guide, in about 75 % of cases, the highest $L_{AF,max}$ would be a more significant design constraint than the L_{night}.

8 COMPARISON OF DIFFERENT TIME LOGGING PERIODS

A typical approach to identifying individual noise events in a measurement is to split the night-time period is into short intervals of length T and identify the L_{Amax} level in each. Using a probability-based approach for noise-induced awakenings, clearly the choice of the time interval length T will significantly affect the expected number of noise event induced awakenings, due simply to the number of "events" considered. Previous studies [8, 9] have concluded a time period of between 1 and 3 minutes to be appropriate for assessing maximum levels and sleep disturbance, therefore it is useful to understand the uncertainty should the only available data be for a longer time period.

478 full night measurements are used for the comparison between the 10th highest value based on a 1 minute logging period and the 10th highest values for both 5 minute and 15 minute time periods. The results are presented in Table 6 and shown graphically in Figure 4.

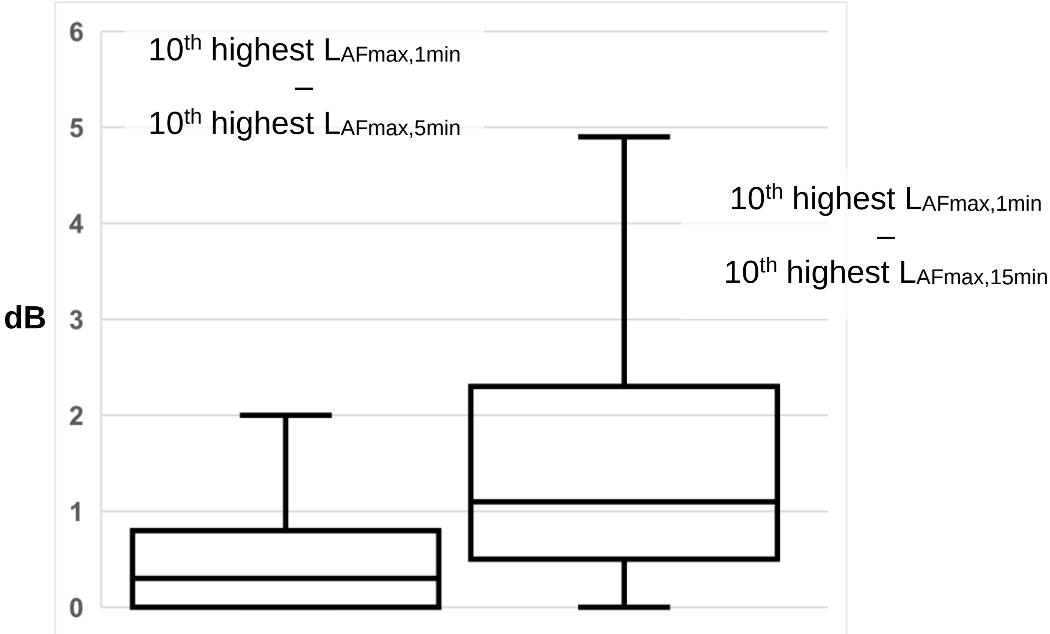

Figure 4: Comparison of the difference between one minute and five or 15 minute sample periods

Table 6: Comparison of the one minute sample period with five and 15-minute sample periods

Parameter	Mean (dB)	Standard Deviation	Median (dB)	25th percentile	75th percentile
10th Highest $L_{A,F,max\ 1\ min\ (23:00\text{-}07:00)}$ - 10th Highest $L_{A,F,max\ 5\ min\ (23:00\text{-}07:00)}$	0.69	1.38	0.3	0	0.8
10th Highest $L_{A,F,max\ 1\ min\ (23:00\text{-}07:00)}$ - 10th Highest $L_{A,F,max\ 15\ min\ (23:00\text{-}07:00)}$	1.89	2.39	1.1	0.5	2.3

These data indicate that the difference between one and five minute periods is relatively small when considering the 10th highest $L_{AF,max}$. For a quarter of measurements there is no difference at all. However, a 15 minute measurement period introduces significant addition uncertainty.

9 CONCLUSIONS

A large sample of full night time measurements in locations for potential residential development has been analysed. This indicates that a one minute sample time for the $L_{AF,max}$ is preferable to reduce uncertainty, compared with a five or 15 minute sample time. Between consecutive nights, the variation between the 10th highest $L_{AF,max}$ and the L_{night} is relatively small, and a 2 dB tolerance added to one night's measurement may provide a suitable safety margin for design purposes. Variations in the single highest $L_{AF,max}$ is much greater between different nights.

Based on meeting guideline values for L_{night} of 30 dB, and the 10th highest $L_{AF,max}$ of 45 dB, in the majority of cases the 10th highest $L_{AF,max}$ is likely to be the most significant design constraint, as on average it is 18.5 dB higher than the L_{night}. Similarly, if undertaking an assessment of noise and overheating according to the AVO Guide, the single highest $L_{AF,max}$ is most likely to be the most significant constraint.

10 REFERENCES

1. The Association of Noise Consultants, Institute of Acoustics, Chartered Institute of Environmental Health, ProPG: Planning & Noise Professional Practice Guidance on Planning & Noise New Residential Development, (May 2017).
2. The Association of Noise Consultants, Institute of Acoustics. Acoustics, Ventilation, Overheating: Residential Design Guide, 2020
3. World Health Organization, Guidelines for Community Noise, Stockholm: Stockholm University and Karolinska Institute, (1999).
4. British Standards Institute, BS 8233:2014 Guidance on sound insulation and noise reduction for buildings, London: BSI, (2014).
5. World Health Organization Regional Office for Europe, Night Noise Guidelines for Europe, Copenhagen: WHO Regional Office for Europe, (2009).
6. The University of Salford, A good Practice Guide on the Sources and Magnitude of Uncertainty Arising in the Practical Measurement of Environmental Noise, NJ Craven, G Kerry, 2007
7. The Association of Noise Consultants, Environmental Sound Measurement Guide 2nd Edition, 2021.
8. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep. Mathias Basner and Sarah McGuire. Int. J. Environ. Res. Public Health 2018, 15, 519
9. B Paxton, N Conlan, J Harvie-Clark, A Chilton, D Trew, Assessing L_{max} for residential development, the AVO Guide approach, Proceedings of the Institute of Acoustics, Vol. 41. Pt. 1. 2019
10. The National Noise Incidence Study 2000 / 2001, BRE, for DEFRA. February 2002.