Relevance of the equal energy principle to individual sources of neighbourhood noise

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ABSTRACT

The characterization of noise is relevant to acoustic disciplines concerned with effects and impact on humans. The $L_{Aeq,T}$ is often applied to assessments of environmental and occupational noise. $L_{Aeq,T}$ is used as an environmental noise descriptor for characterizing the total ambient sound environment and specific elements of the soundscape. Environmental noise standards generally concentrate on dose response relationships based primarily on research of transportation sources. However, such relationships do not appear to exist for specific sources in the sound environment, for example neighbourhood noise arising from a specific site, due to non-acoustic factors. This paper considers three sources of neighbourhood noise that are discriminable at residential dwellings. Reliance on the equal energy hypothesis, applied to neighbourhood sources, appears to understate the impact of noise on receptors following repeat exposure when applied to specific elements of the soundscape. Application of the equal energy principle as a means to characterize noise impact and its effects appears less relevant to the specific sources considered. Standards for characterizing sources of neighbourhood noise are required to provide a complete assessment considering not only the total ambient noise dose but specific components of the sound environment and annoyance response.

Keywords: Neighbourhood noise, Annoyance, Psychoacoustics
I-INCE Classification of Subjects Numbers: 63.2, 66.2

1. INTRODUCTION

Environmental noise standards are widely applied to assess noise impact on humans within a home environment. The World Health Organization (WHO) define community noise as "…noise emitted from all sources except noise at the industrial workplace"(1). Regarding noise management, the Department for Environment, Food and Rural Affairs (DEFRA, UK) within the Noise Policy Statement for England (NPSE) recognise 'noise' as falling into three categories:

"environmental noise" which includes noise from transportation sources
"neighbour noise" which includes noise from inside and outside people's homes; and
"neighbourhood noise" which includes noise arising from within the community such as industrial and entertainment premises, trade and business premises, construction sites and noise in the street" (2)

This paper considers three sources of neighbourhood noise including an industrial size electricity sub station, low frequency noise and resonance from a sewerage pipeline and motor sport with related activity. All three sources, when occurring, dominate the soundscape and are clearly perceptible at existing residential dwellings both internally and externally. The sources are not 'anonymous' or steady state. The individual sources the subject of this paper are essentially single exposure situations during periods when the source dominates. Such sources are less commonly studied in comparison with sources of air, road and rail traffic. The individual sources exhibit different characteristics that attract the listener's attention and are associated with a specific operator exercising control. Any reference to 'noise' means unwanted sound i.e. a judgment has been applied to the sound to determine it as being unwanted and without value.

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2. Equal energy principle and its limitations

2.1 Background

The WHO define the equal energy principle as a "hypothesis that states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time"(1).

The equal energy hypothesis forms the basis of the $L_{Aeq,T}$ guideline values provided by the WHO 1999 & 2009 (1,3) for community noise in specific environments. The A-weighted 'equivalent continuous sound level' ($L_{Aeq,T}$) is a convenient descriptor summing the total energy over a reference time period. It is considered useful for the harmonization of noise characterization of road, rail and aircraft noise within member states. This simple approach assumes the equal energy principle is valid when applied to most types of noise with the caveat the $L_{Amax,f}$ descriptor (level and number) may be more appropriate where discreet noise events occur at night affecting sleep.

Regarding the Environmental Noise Directive (END), the European Environment Agency (EEA) recognise the Lden and Lnight noise indicators are applicable to environmental noise created by humans including road traffic, rail traffic, air traffic and from sites of industrial activity (4,5). However, the EEA identify the noise indicators as applied to industrial noise are based on a study by Miedema and Vos in 2004 and the END exposure-response relationship was derived from road traffic noise (6). The EEA also identify a lack of studies into industrial noise and sleep disturbance. Whilst industrial noise affects a lower percentage of the population it is the second most dominant source affecting our environment behind road traffic noise with further research required (5). In England, as stated in the NPSE, industrial noise is considered a source of neighbourhood noise.

2.2 Application of the equal energy principle in the UK

In the UK, many noise impact assessments prepared by developers' consultants rely on the equal energy principle. Assessments are based on a comparison with the WHO 1999 & 2009 guideline values for dwellings ($L_{Aeq,T}$ and $L_{Amax,f}$) (1,3) as the benchmark for noise acceptability for individual sources of neighbourhood noise. Examples include noise from a new school with sports pitches, metal fabrication, a new beer garden at a public house, night club, fixed plant including fans, blanking press, dog barking from kennels, shale gas extraction, supermarket deliveries and from a theme park. WHO guideline values are applied regardless of the noise source characteristics, character of the neighbourhood, distribution of sound energy over time or the influence of non acoustic factors (e.g. frequency of impact, availability of guaranteed respite, activity affected, human expectation etc.).

Regarding the application of the $L_{Aeq,T}$ the WHO document "Community Noise" states "LAeq is now widely used in standards and legislation throughout the world as the basis on which to develop a dose-response relationship for noise annoyance. It is particularly useful where the noise is steady and broadband. However, care must be taken when assessing most community noises to ensure that significant characteristics associated with the noise are considered" (7).

The UK Environment Agency (EA) regulate industrial sources of neighbourhood noise in England and Wales. Historically, the EA recognise "..one difficulty with the guidelines is that they discuss general outdoor noise and do not focus on the specific issues of industrial noise. Hence it is possible that for specific industrial sources levels lower than those identified by the WHO 1999 may give rise to annoyance if ambient levels from other sources are lower still.. For industrial noise, undoubtedly the excess of noise over the background noise is a key issue and an indicator of likely noise impact" (8).

2.3 Noise and annoyance

The term 'noise' introduces a subjective element to an individual's decision of whether sound has value. Response to noise is subjective and the likelihood a noise will cause annoyance is multifactoral (9). This individual perception, cognitive processing and reaction includes modifiers including attitude/perception of the source and source operator, attitude to message imparted, perception of control over the specific source, individual sensitivity and sensitivity to the specific characteristics of the noise.

Historical research by Zwicker and Hellman recognizes the inability of the $L_{Aeq,T}$ to adequately represent annoyance when physically measuring decibel levels in noise complaints. Their research highlights that measured dB(A) values may not satisfy annoyed people because the output of the sound level meter does not match with their hearing and quite often the annoyed people are right and dB(A) value is wrong (10).

Recent studies demonstrate there is not a clear exposure-response relationship between road, rail and aircraft noise. Berry recommended that separate dose-response curves are used as the basis for any methodology for assessing separately the effects of road traffic noise and aircraft noise (11). Based on knowledge at the time this implies greater adverse health effects (hypertension) for aircraft noise exposure than an equivalent exposure to road traffic noise. A recent study by Michaud et al in Canada, looking at wind turbine noise annoyance concluded substantial variations in comparable response to transportation noise sources that it necessitates re-analysis of the use of L_{AeqT} and L_{den} for environmental noise. This study demonstrated on average communities are about 11dB less tolerant of wind turbine noise (WTN) than of aircraft noise, 16dB less tolerant of WTN than of road traffic noise and 26dB less tolerant of rail noise without vibrations (12). The inference being that the relative annoyance due to different sources of transportation noise varied.

In addition, the UK courts have long recognized in a number of cases that noise can be effectively immeasurable and still cause a nuisance where it is “incongruous” and “out of character” in the area where it occurs. (see Godfrey v Conwy CBC 2001). (13) The importance of noise characterization has been recognized historically in former standards such as the Community Reaction Criteria for External Noises by Kosten and Van Os to rate noise character (14).

3. Measurements of neighbourhood noise

3.1 Methodology

The noise sources chosen were subject to ongoing regulatory (statutory nuisance) or civil litigation (private nuisance) investigation in the UK. All three sources of neighbourhood noise were the subject of ongoing noise complaints to regulators. This study presents noise levels from real-life situations where humans were exposed to neighbourhood noise sources causing ongoing annoyance.

When occurring, all three noise sources were perceptible, discernible, dominant for significant periods and recognizable as emanating from a specific site where the operator was known i.e. a person or body had direct responsibility for the emissions. Physiologically the human receptors could identify, perceive and attribute noise emissions as arising from the site, specifically related to the activity undertaken. The character of the area in all three scenarios was rural or suburban with primarily only localized road traffic in addition to the assessed sources. The residual sound environment in each comprised of natural sounds including a river, stream, wildlife, birdsong and psithurism i.e. sounds with a positive psychological connotation reminding the listener of their location. None of the locations were close to continuous or dominant transportation noise sources during the periods of greatest impact. The measurements were undertaken with a positive wind vector from source to receiver and wind speeds below 5m/s. Sample graphs are provided but extensive periods of similar impact were observed.

3.2 Results

The results are presented below in a series of noise graphs. The graphs contain the key noise data analyzed for each source with a summary description of the inherent acoustic features. The graphs show extracts from longer term noise monitoring and A-weighted decibel levels. The longer reference periods of 8 hour night or 16 hour daytime equivalent continuous (noise) level are described within the text. Graphs were selected to represent typical and commonly occurring worst case noise impact. A comparison with the WHO 1999 & 2009 guideline values for dwellings, as regularly applied by some acousticians in the UK, to specific sources of neighbourhood noise, is provided. For daytime, this assessment applies the WHO 1999 guideline values for the onset of moderate (50dB LAeq,16hr) and serious (55dB LAeq,16hr) annoyance i.e. the lowest recognized value that produces an adverse effect. For night time, the internal guideline value for sleep disturbance (30dB LAeq,8hr)(1) and the European WHO 2009 night noise guideline (NNG) (Lnight,outside of 40dB)(3) is compared. [The author does not advocate the use of these criteria but applies them here to assess what is commonly used by some in the UK].

3.3 How to read the graphs

The X axis represents absolute time and Y axis the A-weighted decibel level. Levels are of average noise over time denoted by the $L_{Aeq,125ms}$ or $L_{Aeq,1s}$ index. The varying profile shows how the noise changes over time. In some cases the spectral content of the noise has been plotted on the graph or provided as an inset chart within the main graph. Spectral content is given in single or third octave bands and each graph clarifies whether these levels are linear or A weighted.

3.3.1 **Electricity substation (>40,000m^2)**

Figure 1 shows noise levels external to the dwelling dominated by buzzing and humming from the substation, increasing the $L_{Aeq,T}$ by 12dB compared to the $L_{A90,1hr}$ value as used in the UK as a background sound level indicator. The 'mini' spectrum graph within figure 1 shows the influence of noise in the 400Hz and 500Hz 1/3 (one third) octave bands (A-weighted). The external $L_{Aeq,8hr}$ was 48dB with the specific contribution from the electricity substation calculated as 41dB $L_{Aeq,8hr}$. Figure 1 shows a 5 minute period from 0255hrs.

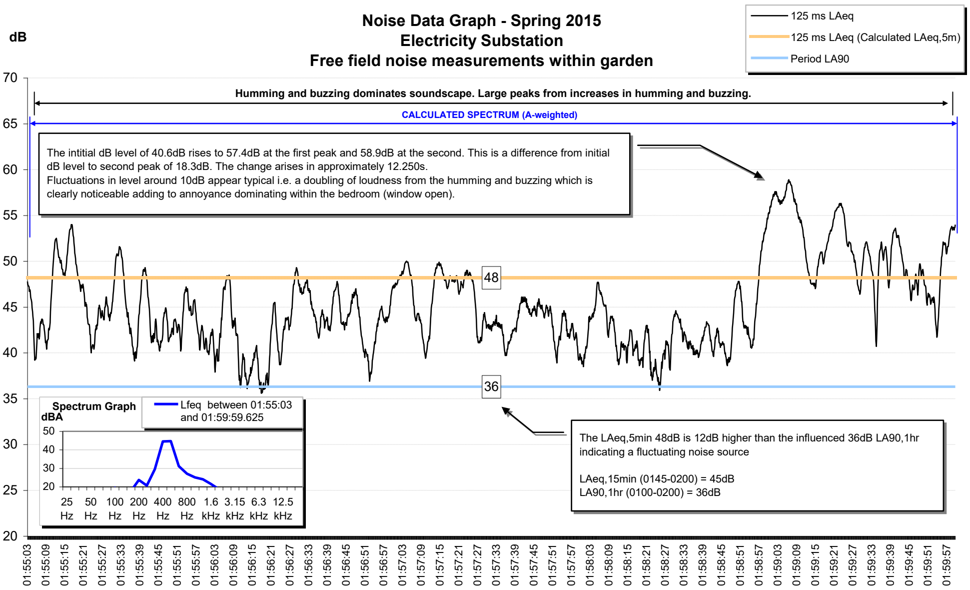

Figure 1 Representative graph of typical worst case noise levels from the electricity substation

Fig 2 provides a comparison of external (free field) and internal noise levels. Peaks of buzzing and humming arise in this case. Figure 2 shows a difference in free field noise levels from 48dB $L_{Aeq,5min}$ externally to 31dB $L_{Aeq,5min}$ internally giving a level difference of 17dB. The specific sound level for the period from 0245hrs was 45dB $L_{Aeq,15min}$. Between 0200-0300hrs the $L_{Aeq,5min}$ varied between 36-48dB externally and 21-32dB internally. The graphs show comparative levels of fluctuating noise emissions during the night. The specific contribution from the electricity substation internally was calculated as 27dB $L_{Aeq,8hr}$.

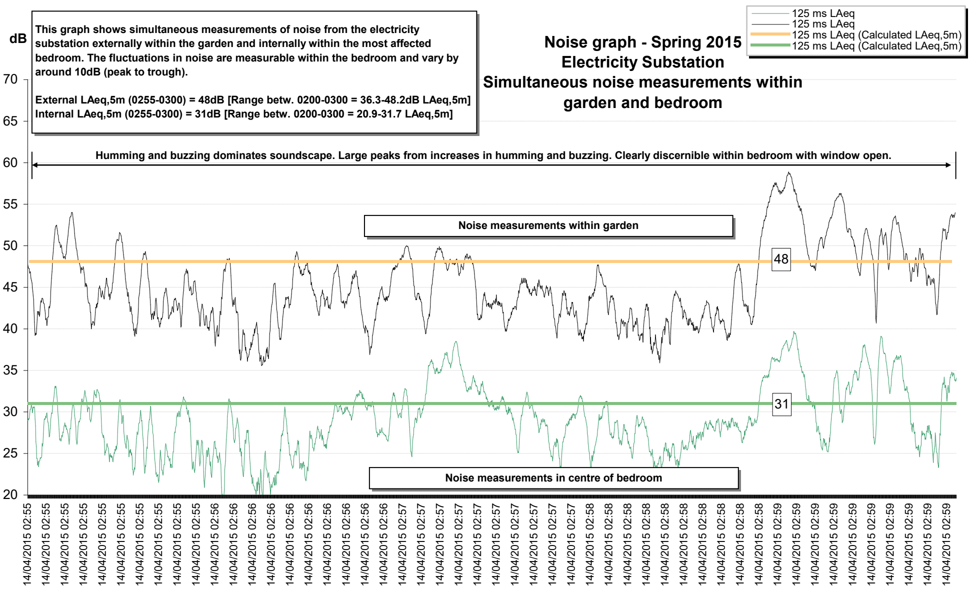

Figure 2 Representative graph of simultaneous internal and external noise monitoring

As noted above, a night time $L_{Aeq,8hr}$ of 41dB (external) was calculated at the dwelling arising from the electricity substation. Assuming the state of affairs of impact were regular this would be 1dB above the long term WHO 2009 NNG and what can be considered the lowest observed adverse effect level (LOAEL) for sleep disturbance. In reality, noise levels will likely be lower under a range of meteorological conditions especially when averaged over a year. Internally, the $L_{Aeq,8hr}$ arising from the electricity substation was calculated as 27dB, 3dB below the WHO 1999 internal guideline for sleep disturbance of 30dB $L_{Aeq,8hr}$. This noise resulted in substantial and widespread community complaints and judged grossly unacceptable by enforcers of noise standards.

3.3.2 Resonating sewerage pipeline

Figure 3 shows a distinct pattern of noise from a resonating underground pipeline within the dwelling entrance lobby. The noise is clearly audible and constant at this location during monitoring and throughout the night consisting of a deep pulsating resonant noise rising and falling in loudness. The noise fluctuates but dominates over all other noise. Figure 3 demonstrates the $L_{Aeq,1s}$ and contribution of noise within the 50Hz 1/3 octave frequency band (linear). The lobby was representative of internal impact in various parts of the dwelling. The noise level trace at 50Hz (red line) reflects the pattern of the overall A weighted noise level for the period (black line). This establishes that the 50Hz 1/3 octave band dominates and is the key frequency responsible for the overall noise levels.

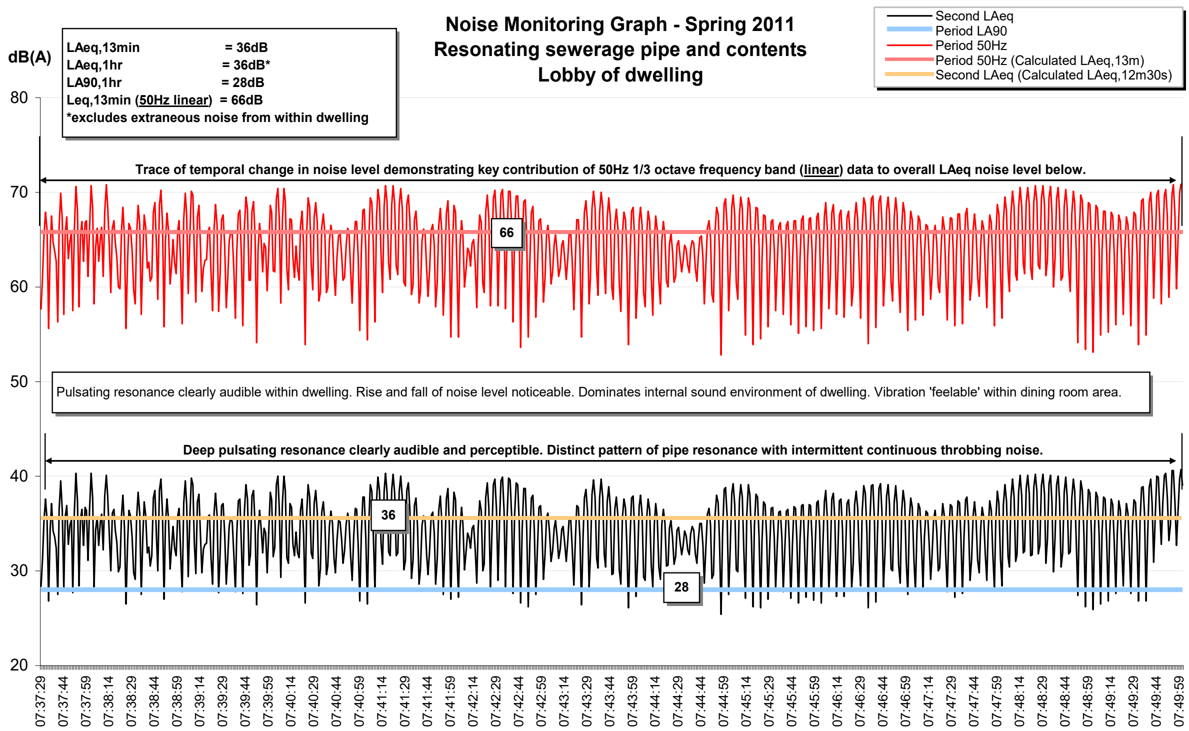

Figure 3 Noise monitoring of resonating sewerage pipeline within dwelling lobby

Figure 4 shows a 15 minute period of noise at the end of the hour. This demonstrates a change in the pattern of the noise emissions. The red line indicates the contribution to the overall noise level from the 50Hz 1/3 octave band (linear) spectrum, which this time is within the front bedroom. The 50Hz 1/3 octave band energy dominates and is the key frequency responsible for the overall noise levels. The noise level trace at 50Hz also shows a distinct change in pattern of the resonance pattern experienced within the front bedroom, different to the lobby. Subjectively the fluctuation and characteristics of the noise change over time although they remain ever present and audible.

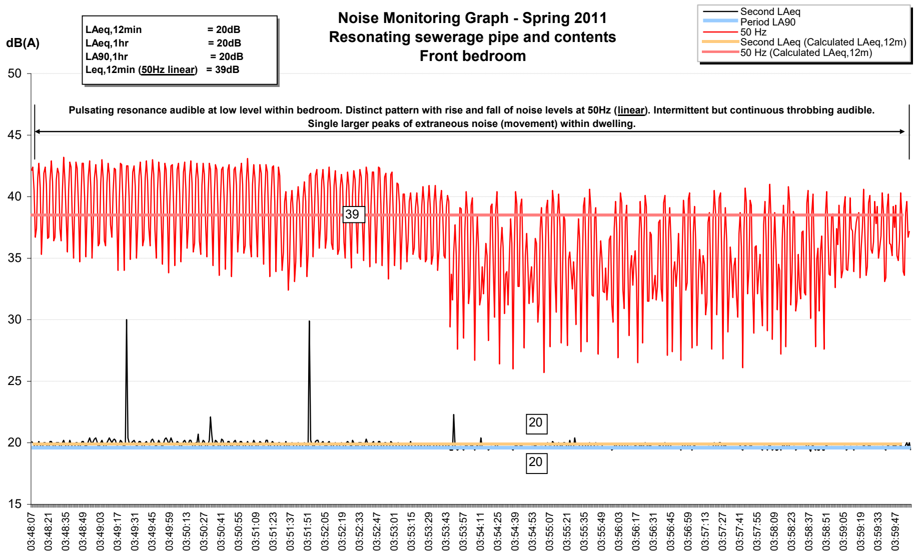

Figure 4 Noise monitoring of resonating sewerage pipeline within front bedroom of same dwelling as reflected in Fig 3. [Note linear dB levels are much lower in sound energy compared to Fig 3]

Table 1 below shows the measured noise levels within different rooms of the dwelling at different times during the night. In the lobby the $L_{Aeq,1hr}$ is 33dB, dining room 23-24dB $L_{Aeq,1hr}$ and within the front bedroom 20-21dB $L_{Aeq,1hr.}$. The latter is close to the noise floor of the sound level meter. The differences between the L_{Aeq} and L_{Ceq} vary between 18dB and 29dB indicating variance of low frequency noise content.

Table 1: Resonating sewerage pipeline noise monitoring results

Location within dwelling	Start time	Period $L_{Aeq,1hr}$ (dB)	Period $L_{A90,1hr}$ (dB)	Period $L_{Ceq,1hr}$ (dB)	Difference between L_{Aeq} and L_{Ceq} (dB)
Lobby	23:00	33	27	62	29
Lobby	00:00	33	27	62	29
Dining Room	01:00	24	23	42	19
Dining Room	02:00	23	22	44	21
Front Bedroom	03:03	20	20	39	19
Front Bedroom	04:00	20	19	38	18
Front Bedroom	05:00	20	19	41	21
Front Bedroom	06:00	21	19	39	18
Total	$L_{eq, 8hr}$	28		56	
Bedroom only	8hr (equiv. 4hr)	20		39	19

The $L_{Aeq,8hr}$ was calculated to be 20dB in the front bedroom, 33dB in the lobby and 24dB in the dining room. The noise emissions were continuous in nature. The differences between the L_{Aeq} and L_{CEq} were typically around 20dB ranging between 18-29dB indicating the presence of significant and dominant low frequency noise. This was also evident from the third octave data. The $L_{Aeq,8hr}$ value of 20dB internally within the bedroom was 9-10dB below the WHO 1999 guideline value for the onset of sleep disturbance. The WHO 1999 recognizes lower limits may be necessary where there is dominant low frequency noise. The unacceptability of the noise was accepted following the start of litigation.

3.4 Motor sport

Figure 5 shows large peaks of noise from motorbikes circuiting a racetrack and from use of tannoy (public announcement). The free field average noise level of 71dB $L_{Aeq,15min}$ and influenced background noise level of 48dB $L_{A90,15min}$ are shown. The graph demonstrates a period of loud intrusive motor sport noise during a race far in excess of levels normally considered acceptable for regular intrusion. In the absence of motor sport noise, the background sound level falls to around 37-38dB $L_{A90,15min}$. Considering figure 5 this is a difference of 33dB (71-38=33dB). The noise is substantially louder than the background sound environment. There were prolonged periods of tannoy before and after the racing which was highly intrusive due to the speech content.

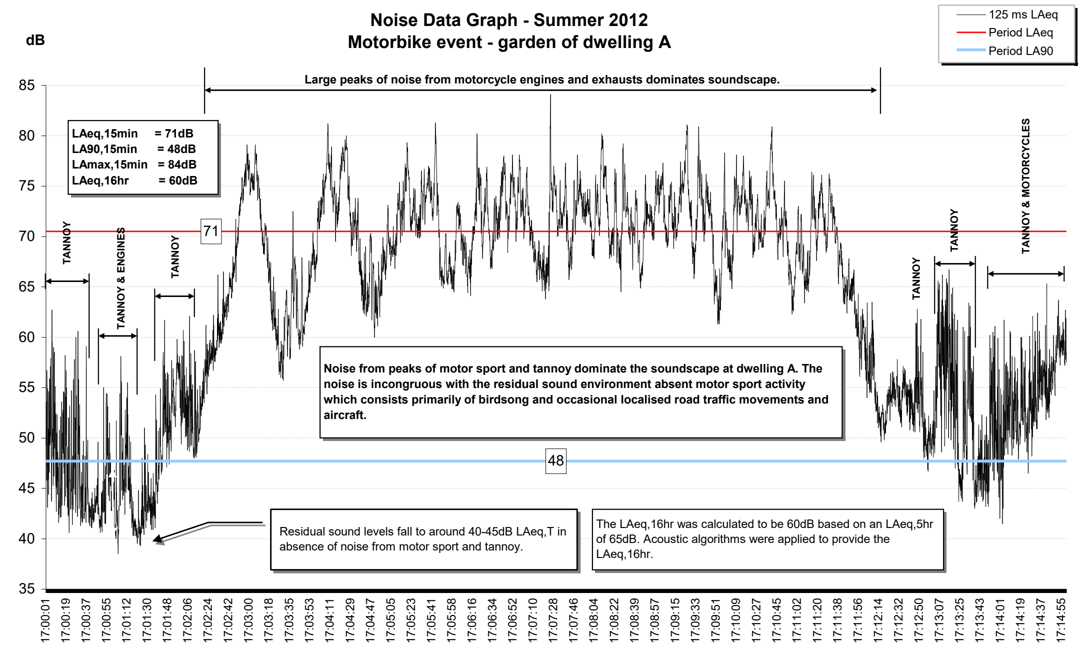

Figure 5 Noise monitoring of motor sport and associated activity

The results are presented in table 2 below. All time periods are 15 minutes. When motorbikes are present on the track the $L_{Aeq,15min}$ varies between 62-71dB, with the tannoy only producing levels ranging between 52-55dB $L_{Aeq,15min}$. Absent vehicles the $L_{Aeq,15min}$ falls to around 45dB. The typical worst case $L_{Amax,f}$ values vary between 74-81dB, with motorbikes present, producing impulsive (rapid onset) characteristics. The $L_{Aeq,16hr}$ value was calculated to be 60dB for the activity on this occasion.

Table 2: Motor sport noise monitoring results

Location (Dwelling)	Activity at racetrack	Start time	Period L_{Aeq} (dB)	Period L_{A90} (dB)	Motor sport L_{Amax} (dB)
A	Racing	12:00:01	68	47	78
A	Racing	12:15:02	62	40	76
A	Activity, no racing	12:30:02	49	40	N/A
A	Activity, no racing	12:45:02	47	40	N/A
A	Activity, no racing	13:00:02	50	39	N/A
A	Racing	13:15:01	62	39	74
A	Racing	13:30:01	69	50	81
A	Tannoy only	13:45:01	55	43	65 (tannoy)
Monitoring at a different residential location during this period with data affected by motorbikes accessing the racetrack					
A	Racing	16:15:01	69	52	80
A	Racing	16:30:02	67	50	78
A	Racing	16:45:01	62	46	73
A	Racing	17:00:01	71	48	84
A	Racing	17:15:02	67	51	79
A	Racing	17:30:02	62	49	77

A	Tannoy only	17:45:02	52	41	N/A
A	No motor sport	18:00:02	45	38	N/A
A	No motor sport	18:15:02	45	37	N/A
A	No motor sport	18:30:02	45	37	N/A

Thus at the dwelling, the daytime $L_{Aeq,16hr}$ within the garden was calculated as approximately 60dB $L_{Aeq,16hr}$ when the event noise was averaged over the full 16 hour period. This level is 5-10dB above the WHO 1999 guideline value for the onset of moderate and serious community annoyance. Arguments continue over the acceptability of this intrusion.

4. Discussion

4.1 Summary assessment of noise acceptability

4.1.1 Electricity substation

Noise from the substation was identifiable within and outside the dwelling consisting of a combination of humming, buzzing and noticeable fluctuations that appear cyclic and following a sinusoidal waveform. The source is readily identifiable and sufficiently loud not to be masked by sound within the environment. The noise intrudes due to its persistence and inherent character but also due to its decibel level. It is an alien noise which is incongruous and in stark contrast to the background sound environment in the area, especially during the night and early hours of the morning when other masking sounds reduce. The character of the locality upon which the noise impacts is one that experiences low background noise levels in the absence of the noise from the substation. This compares to the high levels of fluctuating and unpredictable noise generated by the substation. It raises average internal decibel levels by a substantial amount and introduces characteristics which exacerbate intrusion and increase sensitivity. Noise emissions from the site varied but were continuous with noise levels increasing and decreasing dependant upon the apparent electrical demand placed on the substation at any point in time and also possibly changing propagation effects.

4.1.2 Sewerage pipeline

The fluctuating nature of the noise adds to its annoyance, especially as at times the noise fluctuates more than twice its level of loudness every few seconds. It occurred at any time of any day with predominant and greatest impact arising during the evening, night and early hours of the morning. There was a lack of respite from the noise. Impact at the site was continuous with noise levels increasing and decreasing dependent upon the sewage load placed on the pipeline. The noise observed was considered sufficient to prevent and/or disturb sleep and sleep disturbance was reported by the resident. The presence of low frequency tonality within the noise adds to the intrusiveness. The resonance was pervasive and clearly audible throughout the dwelling. This is due to the significant low frequency content of the noise and low background noise levels in the locality. The low frequency noise content leads to an inability to ‘shut out’ the noise and it was inescapable within the dwelling. Shutting windows reduced noise levels but also masked broadband elements of the noise and filtering out other noise leaving a noise source with increased bias in the low frequencies. Impact occured within garden areas as well as internally thereby affecting the use and enjoyment of the whole property. There was identifiable vibration within the garden and dining room, due to the pipeline. This exacerbated what was perceived as adverse and unreasonable impact within a location where freedom from such vibration should be expected.

4.1.3 Motor sport

The observations, human responses and measurements confirmed the existence of a substantial level of noise intrusion, due to a motor sport event. It was of such levels that it wholly dominated the noise environment. The high energy levels meant sound penetrated throughout dwellings leading to reported disruption and material interference with normal activity. Impact was exacerbated by loud and dominating tannoy, also considered intrusive. It was judged only a few days of noise at this level of intrusion were required to lead to a conclusion that excessive and unreasonable impact was occurring. The impact in this case occurs regularly and is judged by investigators and the community as unreasonable. A variety of coping strategies were adopted by residents including upgrading glazing, closing doors and windows, avoiding external conversation, inability to watch TV in comfort, leaving the dwelling during events and moving to a new house. The character of the noise including acceleration, revving, tyre squeal and use of the tannoy speakers as well as the regularity of impact at differing decibel levels and character along with the lack of adequate periods of respite from noise intrusion were key factors in determining acceptability in this case. Important factors included the character of the noise, its loudness, duration, the low background noise levels absent the motor sport against which it emerged and the incongruent presence / alien nature of motor sport within a rural locality. However, most significant was the effect on the use of dwellings both internally and externally including the inability to escape the noise inside even with doors and windows closed.

In both cases of night noise, indirect effects on sleep were observed including hearing the noise when trying to sleep prolonging the process, waking prematurely, perception of lower quality sleep and hearing the noise. This lead to secondary annoyance during daytime due to lack of sleep and recollective memory.

4.2 Comparison of sources with WHO 1999 & 2009 guideline values

Table 3: Comparison of measured specific noise levels against WHO guideline levels

<table>
<tr><th>Noise source</th><th>Specific noise level(s) ($L_{Aeq,T}$)</th><th>8 hour / 16 hour average noise level (L_{Aeq8hr} / $L_{Aeq\ 16hr}$)</th><th>WHO guideline value (L_{Aeq8hr} / $L_{Aeq\ 16hr}$)</th><th>Noise character</th></tr>
<tr><td rowspan="5">Electricity substation (night)</td><td>48dB $L_{Aeq,5min}$ external</td><td rowspan="3">48dB L_{Aeq8hr} external (total ambient)
41dB L_{Aeq8hr} external (substation only)</td><td rowspan="3">40dB L_{Aeq8hr} (external)</td><td rowspan="5">Buzzing & humming at 400Hz / 500Hz 1/3 octave bands</td></tr>
<tr><td>36-48dB $L_{Aeq,5min}$ external</td></tr>
<tr><td>48dB $L_{Aeq,15min}$ external</td></tr>
<tr><td>31dB $L_{Aeq,5min}$ internal</td><td rowspan="2">27dB L_{Aeq8hr} internal (substation only)</td><td rowspan="2">30dB L_{Aeq8hr} (internal)</td></tr>
<tr><td>21-32dB $L_{Aeq,5min}$ internal</td></tr>
<tr><td rowspan="3">Sewerage pipeline (night)</td><td>33dB $L_{Aeq,1hr}$ internal - lobby</td><td>33dB $L_{Aeq,8hr}$ internal - lobby</td><td rowspan="3">30dB L_{Aeq8hr} (internal)</td><td rowspan="3">Pulsating resonant noise, fluctuating in loudness. 50Hz 1/3 octave band noise dominant. Significant low frequency noise [dB(C) - dB(A) ≈18-29dB]</td></tr>
<tr><td>23-24dB $L_{Aeq,1hr}$ internal - dining room</td><td>24dB $L_{Aeq,8hr}$ internal - dining room</td></tr>
<tr><td>20-21dB $L_{Aeq,1hr}$ internal - bedroom</td><td>20dB $L_{Aeq,8hr}$ internal - bedroom</td></tr>
<tr><td rowspan="4">Motor sport (day)</td><td>71dB $L_{Aeq,5min}$ external</td><td rowspan="4">60dB $L_{Aeq,16hr}$ - garden</td><td rowspan="4">50-55dB $L_{Aeq,16hr}$ (external)</td><td rowspan="4">Significantly above background sound level by ≈33dB, tannoy noise, impulsive racing noise</td></tr>
<tr><td>62-71dB $L_{Aeq,15min}$ external motorbikes</td></tr>
<tr><td>52-55dB $L_{Aeq,15min}$ external tannoy</td></tr>
<tr><td>74-81 dB $L_{Amax,f}$ external</td></tr>
</table>

The data shows that in each case the noise dose is 3-10dB (substation and sewerage pipe bedroom) below the WHO 1999 guideline values for the onset of sleep disturbance internally either when considered separate or applying the total ambient sound level. When applying the WHO 2009 NNG, noise from the substation alone exceeds the guideline by 1dB. Each source contains special characteristics which are recognized to increase intrusiveness but are not taken into consideration when simply applying the equal energy principle.

In the case of the electricity sub-station the WHO 2009 NNG is 40dB compared to a source level of 41dB. However, this was clearly unreasonable noise with a combination of relatively narrow band noise that is at the lower speech end. The critical factors are the incongruity of such a relatively narrow range of sounds and its erratic rise and fall. The dominance of this noise was considered a primary factor along with its occurrence in an otherwise quiet locale. Acceptability is dependent on the level of masking noise within the narrow range of frequencies.

In the case of the sewerage pumping, noise levels in the bedroom were 10dB below the WHO 1999 internal guideline for bedrooms of 30dB. Whilst the WHO 1999 recognize lower limits are necessary where there is significant low frequency content, it does not seek to address the other character effects and no guidance on limits of acceptability for low frequency noise are provided. The primary factors include vibration in some locations, increases and decreases in decibel level every few seconds by as much as 10dBA, all of which increased impact but are not empirically recognized by the WHO guideline values. The detectable presence of this noise was sufficient to lead to severe adverse reaction.

In the case of the motor sport noise, this source is significantly louder than the ambient sound environment and produces a WHO guideline value comparison of 60dB when averaged over a 16 hour day. This is 10dB above the onset of moderate and 5dB above the onset of serious community annoyance. However, acceptability is relative to the number of occurrences when such noise occurs, especially as it is restricted to the daytime only, albeit primarily at weekends. The identifiable elements of acceleration and deceleration, multiple varying tones, impulse content and altered human voice (tannoy) all accentuate intrusiveness. A suitable dB $L_{Aeq,16hr}$ level is not therefore applicable in this case and it becomes a function of how many days of such intrusion are tolerable by the community.

Decibel evidence has been acquired in terms of A-weighted and spectral content for each noise source. It is possible to compare their noise energy dose either daily or annually. Arguably it may also be possible to look at some form of penalty to reflect the different responses due to different elements in each noise and how it impacts communities. However, the primary analysis at this stage is whether there is a simple energy relationship or alternatively if the compounding factors are simply too complex and indeterminable as to their appropriate weighting or intrusiveness.

4.3 Application of the NPSE

In England, the NPSE does not apply decibel levels to determine acceptability but instead seeks to analyse the effect or response to noise. The NPSE places less importance on decibel levels but more on outcomes with no set criteria in any particular set of circumstances (context). Applying the principles of the NPSE it was generally considered that all three sources would cause “adverse” and “significant adverse” impact, as defined by the NPSE. The policy advice would be to avoid this level of impact through noise management. Impact in all three cases was considered above what is termed the Lowest Observed Adverse Effect Level (LOAEL) and above a point considered to be the Significant Observed Adverse Effect Level (SOAEL) would occur. The NPSE requires other factors, including potential economic and social benefit from noise generators, to be balanced with assessment of noise impact. These other factors are not considered to outweigh noise impact in these cases.

5. CONCLUSIONS

For individual sources of neighbourhood noise, the equal energy principle applied as a daily or long term noise dose, when assessing an individual source or the total noise dose (intrusive source plus environmental noise) appears to understate the impact i.e. is less relevant. This is demonstrated particularly where the airborne noise content arises in combination with vibration and / or significant low frequency noise content.

For all three noise sources, the data shows significant temporal fluctuation which is an added feature of intrusion that is understated by any long term average analysis. There is no recognized way of empirically comparing these three sources of noise and even if this could be done, it is incapable of weighting or penalizing the noise dose to reflect the multiple and complex characteristics nor the way they affect residential use.

Large scale population studies into health effects related to environmental (transportation) noise sources demonstrate a dose response relationship between increasing noise exposure and negative health outcomes. Similar guideline values for the onset of critical health effects are applied to assess impact related to the absolute decibel level to road, rail and air traffic. To the contrary, there is a lack of research into the effects of neighbourhood noise on humans within dwellings. However, recent research shows differences in community reaction and tolerance to road, rail and air traffic which varies depending on the neighbourhood noise being compared.

There is no simple metric for weighting the intrusiveness of neighbourhood noise and human response. Standards seeking to apply just tonal and impulsive content fail to address a range of other factors of varying significance. This cannot be simplified and it is unsafe to rely on L_{Aeq} other than when comparing sources of known equal or degree of different impact levels as now implied for WFN.

5.1 Further research needs

Clear policy that considers environmental noise (road/rail/air) but makes a clear distinction between these and site specific sources that appear to cause annoyance at lower decibel levels is required. Clear advice from the WHO on how their guideline values relate to individual sources of neighbourhood noise affecting dwellings should be published.

Qualitative rather than quantitative epidemiological studies into specific sources of neighbourhood noise where complaints arise are needed to acquire similarities in annoyance response. Research into the long term effects of neighbourhood noise, potentially in combination with high levels of transportation noise, vibration, poor air quality etc. is urgently needed.

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