ProPG and AVOG

The ProPG: Planning & Noise, May 2017 ('ProPG') is jointly published guidance issued by the CIEH, IOA and the ANC. The Acoustics Ventilation and Overheating Residential Design Guide, Version 1.1, 2020 ('AVOG') was published jointly by the ANC and the IOA.

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This article analyses common ground and difference between ProPG and AVOG. It identifies important areas of divergence between the guidance documents and aims to provide insights into how the two guidance documents can be used alongside each other to achieve consistent outcomes. The aim of this article is to provoke discussion and debate on some of the issues identified; such debate is intended to improve the two documents so that use of them together is more coherent than currently.

Key points

The key findings of this paper are summarised below:

1. Both documents aim to achieve integrated design[1] and good acoustic design and recognise that the overheating conditions must be accounted for.
2. The AVOG only applies to situations where good acoustic design cannot be achieved with windows open through consideration of site layout and other design options that might control internal noise levels. The starting position for AVOG is to consider mitigation of noise impact on new residential development after good acoustic design has been applied, site-wide, as described in the ProPG.
3. The noise standards are not directly comparable because the documents use different terminology. Neither is there any consistency between the documents on how the frequency and duration of internal noise levels should be considered. In other words, there is no alignment how frequency and duration of internal noise levels should be interpreted.
4. The AVOG levels are significantly greater than the levels recommended by the ProPG. A level of noise exposure that is "*increasingly dangerous*" for public health represents a level that is greater than a SOAEL and is a situation that could be unacceptable, as defined by Planning Practice Guidance. According to the ProPG, the upper levels specified in Table 3-3 of the AVOG could give rise to unacceptable levels of noise if they occurred more than occasionally[2].
5. From a public health perspective, all possible adverse effects on sleep should be considered. The advice given in the AVOG on the assessment of $L_{AF,max}$ levels, which is based on recalled awakenings, should be used with extreme caution as significant adverse effects on health and quality of life can occur at levels lower than this threshold.
6. In noisy locations, before reverting to closed windows and non-natural means of ventilation and control of overheating, practical solutions including non-standard construction types should be considered alternative to the approach of diverging from the noise thresholds in the ProPG as recommended in the AVOG.
7. It is appropriate, where possible, that noise should be assessed with windows open to avoid risk of overheating and the overheating design strategy relies on windows being open to control indoor temperatures. Overheating is not, however, the only factor that should be considered. The occupants of dwellings and other buildings may choose to open windows for a variety of reasons as well as controlling thermal comfort. Residents in noisy locations will therefore be exposed to higher noise levels when windows are open. This is a choice that residents should be allowed to make. However, the potential impacts on health and quality of life need to be allowed for when deciding if housing in such circumstances is appropriate, and design and construction optimised to permit natural ventilation and control of overheating before relying on an approach based on closed windows and non-natural ventilation and control of overheating.
8. In the absence of robust data on the frequency and durations that windows are kept open for different designs of dwelling, it is recommended that the information reported in the WHO Night Noise Guidelines or other general occupancy data is used to consider the duration of windows open/ closed over P54

1 Integrated design is a comprehensive holistic approach to design which brings together specialisms usually considered separately. It attempts to take into consideration all the factors and adjustments necessary to a decision making process.

2 For example, 5 or 6 times per year.

a typical annual period. Even though thermal dynamic models are complex it is not possible to predict exactly how people will behave in reality. Assuming that windows are only opened when overheating occurs is inappropriate.

9. There is little if no evidence to support the assertion that the adaptive comfort model can be used to assess the impact of noise. This is especially true at night does because there is little awareness in the general population of the harmful effects of exposure to noise at night. It would be wrong therefore to assume that the occupants of dwellings can make properly informed choices about the trade-off between acoustic and thermal conditions.

10. CIBSE TM59 does not consider the adverse effects of noise. It considers overheating in isolation and provides pass/ fail criteria for thermal comfort. There is no mechanism to relax the criteria for overheating to allow a balance between overheating and noise. Practitioners should be aware of the limitations of TM59 when applied in areas of medium and high exposures to noise and be cautious about relaxing the noise standards in order to achieve strict pass/fail criteria for overheating. Such an approach is not supported by the available evidence.

Scope

There are many similarities between the guidance documents. Both consider acoustic issues associated with providing new housing in noisy locations; however, there are also material differences.

Both documents aim to achieve integrated design[3] and good acoustic design[4], while recognising that windows may need to be opened to control overheating and that this can lead to adverse noise impacts. Unlike the current version of BS8233:2014, neither document advocates that it is appropriate to assume closed windows when a mechanical ventilation system[5] is used to provide background ventilation, in accordance with Part F of the Building Regulations and without any consideration of overheating. Assuming windows closed may only be appropriate when integrated and good acoustic design cannot achieve suitable acoustic conditions with windows open. Both documents recognise that the overheating conditions must be accounted for.

People may open windows for a variety of reasons. Controlling thermal comfort only represents one of several reasons why occupants may choose to have window open. For example, connection with the outside, sense of fresh air, and sense of control over one's environment. The AVOG explicitly states that consideration of these factors is beyond the scope of the guidance.

ProPG addresses internal noise in the context of other design aspects affecting the health and quality of life of the inhabitants and other sustainable design objectives. In other words, it is based on a holistic design approach. The design aspects referred to includes ventilation and overheating. The ProPG also addresses external noise amenity. By contrast, the AVOG deals with internal noise and specifically acoustics, ventilation and overheating and is intended to supplement the ProPG.

Importantly, the AVOG only applies to situations where good acoustic design cannot be achieved with windows open through consideration of site layout and other design options that might control internal noise levels. The starting position for AVOG is to consider mitigation of noise impact on new residential development after good acoustic design has been applied, site-wide, as described in the ProPG. The AVOG therefore only considers design options that relate to the building envelope.

The AVOG aims to fill the gap left between other guidance in achieving comfortable, climate resilient, sustainable dwellings. The basis for this claim is not clear however, not least because the ProPG also considers sustainable design objectives as part of other relevant factors.

The table below summarises the key aspects of scope and application of the two documents.

Right: Table 1: Scope of ProPG and AVOG

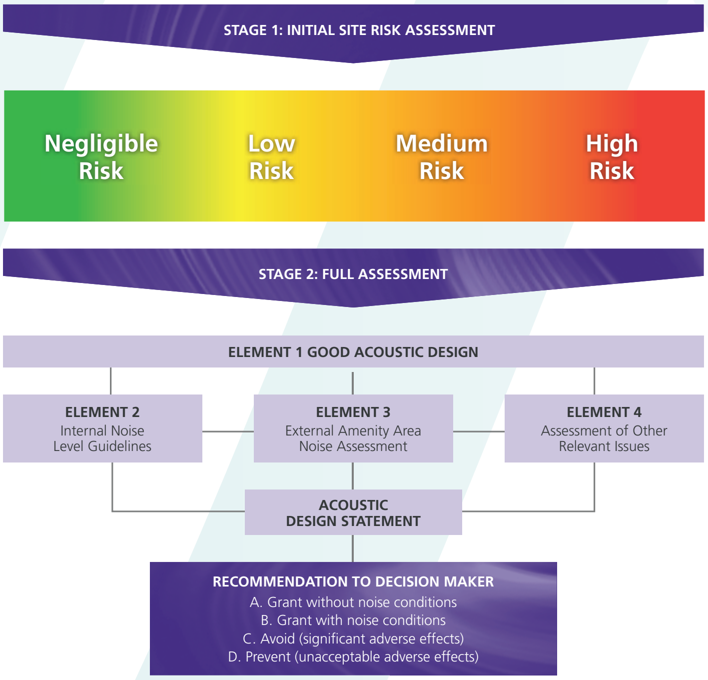
Aspect	ProPG	AVOG
Sources	Predominantly transportation noise and some commercial or industrial noise when it is not dominant	Transportation noise
Application	All residential development	Only parts of residential development not meeting good acoustic design in accordance with ProPG
Situations	Internal and external noise	Internal only
Factors	All aspects of the built environment affecting living conditions	Acoustics, ventilation and overheating
Sustainability objectives including climate change	Yes, covered under other relevant issues	Yes, indirectly
Noise from mechanical systems	No	Yes

3 Integrated design is a comprehensive holistic approach to design which brings together specialisms usually considered separately. It attempts to take into consideration all the factors and adjustments necessary to a decision making process.

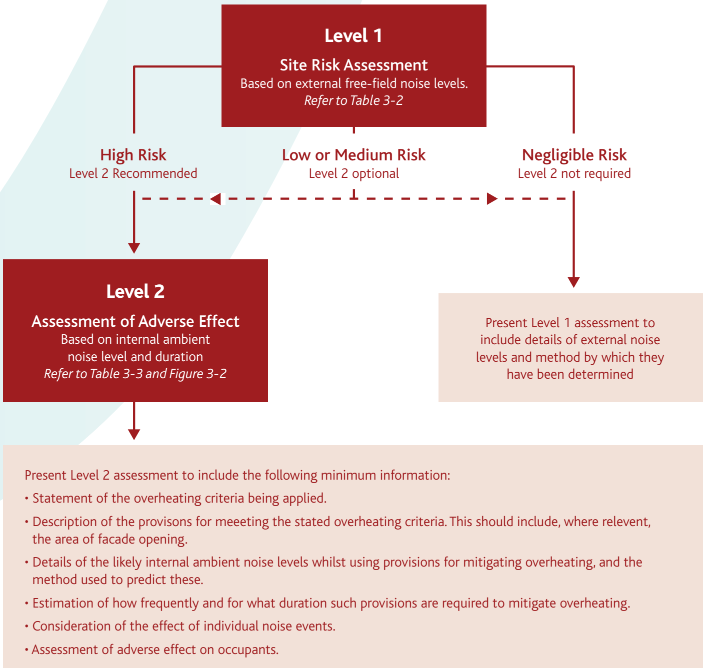
4 ProPG – "A good acoustic design will be one that continues to minimise noise impacts and to avoid significant noise effects for the lifetime of the development or as long as is practicable taking into account other economic, environmental and social impacts."

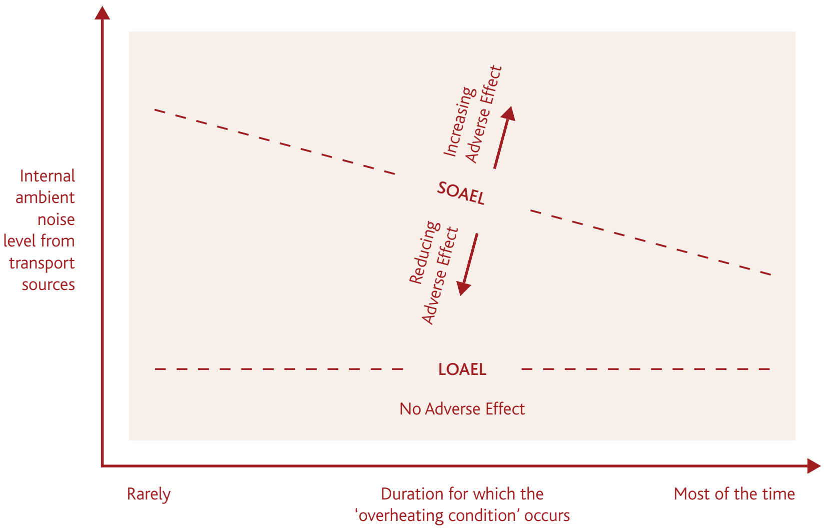
5 There is a distinction between ventilation and overheating. Background ventilation as per AD-F - is separate to the overheating, which would require much higher levels of ventilation to achieve comfortable temperatures during summer (and is not considered in AD-F). Background ventilation is the rate that is needed all year round for good air quality, prevent humidity, mould and mildew etc - additional boost ventilation and open windows for overheating is just during the summer when it's hot. Background ventilation is provided all year round to ensure that homes are sufficiently ventilated.

Below: A summary of the overall ProPG approach is provided in Figure 4.



Below: Figure 3-1 Two-level noise assessment procedure - overheating condition





Left: Figure 3-2 Qualitative guidance on combined effect of internal ambient noise level and duration for the overheating situation

Process

The ProPG advocates a systematic, proportionate, risk based, two-stage, approach. Stage 1 is an initial noise risk assessment of the proposed development site; and Stage 2 sets out a systematic consideration of four key elements for higher noise exposure sites. Where Stage 2 is applicable it leads to recommendations for the decision maker. In simple terms the choice of recommendation is as follows: grant without conditions, grant with conditions, 'avoid' or 'prevent'.

In the case of environmental noise ingress, the AVOG also describes a two-level assessment procedure for the overheating condition. The first level is a site risk assessment based on external noise levels and the assumption that opening windows are the primary means of mitigating overheating. The second level assessment considers the potential for adverse effect on occupants based on internal ambient noise level. The Level 2 assessment is recommended for 'High' risk sites. For 'Low' and 'Medium' risk sites, a Level 2 assessment can optionally be undertaken to give more confidence regarding the suitability of internal noise conditions. This may be particularly appropriate for sites in the 'Medium' risk category.

The Level 2 assessment suggests that assessment of the adverse effect from noise exposure should include an estimate of how frequently and for what duration the overheating condition occurs. No guidance is provided however on what durations and levels of frequency will be considered to be appropriate.

Rather, the Level 2 assessment provides qualitative guidance to apply a sliding scale for acceptable levels of internal noise based upon the frequency and duration over which the overheating condition occurs (see figure 3-2 reproduced from AVOG). The practitioner then has to use this information to inform an assessment of adverse effects on the occupants: however, no further guidance is given about the way in which this information should be used as part of the decision making and design process. In particular, the document provides no guidance on how to assess the risks to health and quality of life of following the AVOG guidance.

Comparison of the noise standards

Both guidance documents use the internal noise criteria derived from WHO Community Noise Guidelines 1999 and BS8233 as a starting point for desirable internal noise standards.

The ProPG allows for a relaxation of the desirable standards when it is not possible to meet internal target levels with windows open. It states: *Where development is considered necessary or desirable, despite external noise levels above WHO guidelines, the internal L_{Aeq} target levels may be relaxed by up to 5 dB and reasonable internal conditions still achieved. The more often internal L_{Aeq} levels start to exceed the internal L_{Aeq} target levels by more than 5 dB, the more that most people are likely to regard them as "unreasonable". Where such exceedances are predicted, applicants should be required to show how the relevant number of rooms affected has been kept to a minimum.'*

It can be seen that it is a question of degree in terms of the noise level, the extent of exceedances as a proportion of the development, and the frequency of occurrence if the situation is to be considered unreasonable or not. The reference to frequency and duration can be used to link the noise assessment to the overheating assessment. P56

If the internal L_{Aeq} levels exceed the target levels by more than 10 dB, ProPG advises that: *'they are highly likely to be regarded as "unacceptable" by most people, particularly if such levels occur more than occasionally. Every effort should be made to avoid relevant rooms experiencing "unacceptable" noise levels at all and where such levels are likely to occur frequently, the development should be prevented in its proposed form.'*

Again, the frequency and duration must be considered as part of a judgment on the acceptability of the situation and the need to refuse the development.

The AVOG recommends that the desirable noise standards can be relaxed during the overheating condition on the basis that: *'the overheating condition occurs for only part of the time. During this period, occupants may accept a trade-off between acoustic and thermal conditions, given that they have some control over their environment. In other words, occupants may, at their own discretion, be more willing to accept higher short-term noise levels in order to achieve better thermal comfort. The importance of control is relevant to daytime exposure, but not to night time exposure where the consideration is sleep disturbance.'*

There is little if any robust scientific evidence to support this assertion at this time.

For the daytime period, the upper category of >50 dB is defined on the basis that $L_{Aeq,T}$ 50 dB represents the upper end of the range for reliable speech communication. For the night-time period, the upper category of >42 dB is defined with reference to the WHO Night Noise Guidelines for Europe. The individual noise event Lmax value of 65 dB refers to the level that has been shown in Basner et al (2006) to result in longer duration awakenings that are more likely to be remembered the next day.

The criterion is further qualified in the notes and explains that: *'The $L_{AF,max}$ indicator associated with the upper category is intended for road traffic; it may be more appropriate to use the "one additional noise-induced awakening" method for noise from rail traffic or aircraft.'*

The noise standards are not directly comparable because the documents use different terminology. Neither is there any

Right: Table 3-3 Guidance for Level 2 assessment of noise from transport noise sources [Note 1] relating to overheating condition

Internal ambient noise level [Note 2]			Examples of Outcomes [Note 5]	
$L_{Aeq,T}$ [Note 3] during 07:00 – 23:00 [Note 6]	$L_{Aeq,8h}$ during 23:00 – 07:00	Individual noise events during 23:00 – 07:00 [Note 4]		
> 50 dB	> 42 dB	Normally exceeds 65 dB $L_{AF,max}$	Noise causes a material change in behaviour e.g. having to keep windows closed most of the time	Avoiding certain activities during periods of intrusion. Having to keep windows closed most of the time because of the noise. Potential for sleep disturbance resulting in difficulty in getting to sleep, premature awakening and difficulty in getting back to sleep. Quality of life diminished due to change in acoustic character of the area.
Increasing noise level			Increasing likelihood of impact on reliable speech communication during the day or sleep disturbance at night	At higher noise levels, more significant behavioural change is expected and may only be considered suitable if occurring for limited periods. As noise levels increase, small behaviour changes are expected e.g. turning up the volume on the television; speaking a little more loudly; having to close windows for certain activities, for example ones which require a high level of concentration. Potential for some reported sleep disturbance. Affects the acoustic environment inside the dwelling such that there is a perceived change in quality of life. At lower noise levels, limited behavioural change is expected unless conditions are prevalent for most of the time. [Note 8]
≤ 35 dB	≤ 30 dB	Do not normally exceed $L_{AF,max}$ 45 dB more than 10 times a night	Noise can be heard, but does not cause any change in behaviour	Noise can be heard, but does not cause any change in behaviour, attitude, or other physiological response [Note 9]. Can slightly affect the acoustic character of the area but not such that there is a perceived change in the quality of life.

Note 1 The noise levels suggested in Tables 3-2 and 3-3 assume a steady road traffic noise source but may be adapted for other types of transport.

consistency between the documents on how the frequency and duration of internal noise levels should be considered. In other words, there is no alignment how frequency and duration of internal noise levels should be interpreted.

The ProPG suggests that internal $L_{Aeq,T}$ greater than 40 dB during the day (living rooms) and 35 dB at night could be unreasonable and should be avoided if the levels were expected to occur frequently. The use of the word avoid is deliberate and links to the noise objectives set out in the NPSE and policy in the NPPF and the PPG (which references the ProPG). The AVOG suggests that the upper internal ambient levels greater than 50 dB during the day and 42 dB at night could be considered to represent SOAEL values, depending on the frequency and duration. In policy terms the NPSE recommends that SOAEL values should be avoided and are therefore comparable to the ProPG levels set at 5 dB above the WHO CNG levels. Thus, it can be seen that the AVOG could potentially give rise to a significantly lower level of protection to health and QoL than the ProPG depending on the duration and frequency these ambient levels might occur. In fact, the AVOG levels are significantly greater than the levels that ProPG would recommend could be unacceptable, as defined by Planning Practice Guidance, if they occurred more than occasionally. It can be reasonably be concluded therefore that, according to the ProPG, the upper levels specified in Table 3-3 of the AVOG could give rise to unacceptable levels of noise if they occurred more than occasionally.

It is not that surprising that the upper levels defined in Table 3-3 could be considered to be unacceptable if they persisted for any period of time. Allowing an internal/ external noise correction for an open window, internal ambient levels greater than 50 dB during the day and 42 dB at night would represent external noise levels of 63 dB day and 55 dB night. An external daytime level of 65 dB is considered by many to represent a level that is considered harmful to health. An external night-time level of 55 dB, which the WHO NNG states: *'The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.'*

From a policy perspective, a level of noise exposure that is "**increasingly dangerous**" for public health represents a level that is greater than a SOAEL and is a situation that should be prevented (our emphasis). It is recommended therefore that such levels should be considered to be unacceptable if it is likely that such levels are likely to occur more than occasionally.

Consideration of L_{max} criteria

A detailed consideration of the adverse effects of sleep disturbance is given in Appendix A of ProPG and the article on zero sleep disturbance from aircraft noise (Cobbing, 2021)

There is clear evidence that chronically disturbed or curtailed sleep is associated with a number of negative health outcomes.

Studies have shown that noise can affect sleep in terms of immediate effects (e.g. arousal responses, sleep state changes, awakenings, body movements, total wake time, autonomic responses), after-effects (e.g. sleepiness, daytime performance, cognitive function) and long-term effects (e.g. self-reported chronic sleep disturbance; cardiovascular effects such as increased blood pressure, heart attacks). This is summarised in the schematic by Basner (2018). It is important to realise that two different types of sleep outcomes have been examined. Self-reported sleep disturbance which is linked to external average metrics such as L_{night}; and objective sleep disturbance which uses polysomnography (PSG) to record biophysiological changes that occur during sleep and changes in sleep stages which has been linked to individual noise events such as L_{Asmax}. Reports between self-reported sleep disturbance and objective sleep disturbance can differ as individuals are not always aware of or recall biological awakenings. Average metrics such as $L_{Aeq,T}$ may not be best for assessing noise impacts on sleep disturbance, as noise events in the night are intermittent not continuous, which means that the same Lnight value can result from differing numbers of events. The two types of sleep disturbance should both be considered in assessment and may have separate implications for guidance.

Disturbance of the sleep cycle that causes biological awakenings can be a significant adverse effect as defined in the NPPG Noise Exposure Categories when such arousals cause sleep disturbance on a regular basis, as this leads to poor sleep quality due to fragmentation of the sleep cycle. Researchers ([1]Eus J.W. Van Someren, 2015) note that *'Although superficially more subtle than total sleep deprivation (TSD), chronic sleep disruption has far-reaching consequences starting from the effects on brain cells and ending with recent insights in the mechanisms involved in the chronically disrupted sleep experienced by people suffering from insomnia, one of the most common disorders. In some cases, negative consequences result from the fragmentation of the normal sleep pattern into short sleep bouts frequently interrupted by brief awakenings, even if the total daily amount of sleep is not decreased.'*

The same researchers go on to say: "The relevance of findings from experimental studies is supported by observational studies on the consequences of naturally occurring sleep disruption, whether due to environmental and societal demands or pathological conditions such as sleep-disordered breathing or insomnia. The resulting insights lay ground for a mechanistic understanding of the epidemiological finding that disrupted sleep contributes to the major health challenges facing our aging society, including type 2 diabetes, cardiovascular disease, neurodegeneration, and depression."

Consequently, as well as assessing the "unacceptable" adverse effect of self-reported sleep disturbance, it is also important to consider impacts of noise on sleep at noise levels that induce biological awakenings i.e. objective sleep disturbance but can have significant adverse effects in terms of sleep disturbance which in the long-term could cause fragmenting sleep due to interference with the sleep cycle on a regular basis.

Basner et al [2006] proposed a health protection scheme for the Leipzig/Halle airport in Germany to manage the risk of sleep disturbances associated with aircraft noise. Basner et al recommended that:

- on average there should be less than one additional EEG awakening induced by aircraft per night[6] , and
- awakenings recalled the following morning should be prevented as much as possible, and
- there should be no relevant impairment to the process of falling asleep again. P58

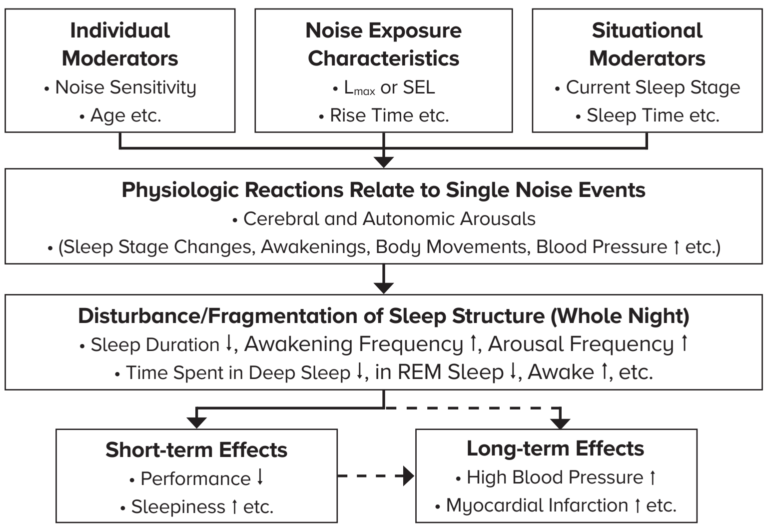


Figure 1. Effects of noise on sleep. It is hypothesised that health consequences will develop if sleep is relevantly disturbed by noise over long time periods (dashed lines: figure reproduced from Basner et al. [25])

6 On average 365 days per year

In order to prevent recalled awakenings Basner et al proposed that the maximum noise level inside the bedroom should not exceed 65 dB. The impairment to the process of falling asleep again is suggested to be dependent upon the number of events and the time interval between events.

Recent research has examined this noise protection concept in relation to railway noise exposure (Mohler, Liepert, Skowronek, Mueller, & Schreckenberg, 2018; Mueller, Schreckenberg, Mohler, & Liepert, 2018; Schreckenberg et al., 2018). Undertaken on behalf of the Hessian Ministry of the Environment in Germany and re-analysing the NORAH and DEUFRAKO studies it was found that the L_{Aeq} on its own was not enough to explain the percentage with high sleep disturbance (self-reported) and it was suggested that L_{Amax} should additionally be taken into account (Mohler et al., 2018; Schreckenberg et al., 2018). L_{Amax} on its own or in combination with the number of trains may better characterise high sleep disturbance (Schreckenberg et al., 2018). To protect sleep, an L_{Amax} criterion was proposed to supplement the German L_{Aeq} external night-time limit for noise of 49 dBA was proposed, based on the difference between the L_{Amax} and L_{Aeq} being limited to 15 dB(A), and the maximum number of awakenings not exceeding three (Mohler et al., 2018).

This study is generally supportive of the ProPG and AVOG because both documents recommend that Lamax be considered as well as the L_{Aeq}. The finding that the difference between the L_{Amax} and L_{Aeq} should to be limited to 15 dB(A), is supportive of the ProPG which recommends a difference of 15 dB(A) and is not supportive of the AVOG which recommends a difference of 23 dB(A).

The analysis also suggests that the number of additional awakenings induced by noise per night should not be treated as a fixed standard and can be modified according to the particular circumstances under consideration. The analysis showed that number of biological awakenings was higher for high volume railways (100 trains/night) compared to a low volume railway (20 trains/night). This is consistent with the findings of the 2019 paper on assessing Lmax for residential development to support the AVO Guide Approach (Paxton et al., 2019), which calculated 21 noise-induced awakenings during a single night with windows open for a busy A-road.

The upper $L_{AF,max}$ criterion set out in Table 3-3 of AVOG of 65 dB is only based upon one of the three elements of Basner's health protection concept i.e. to prevent awakenings recalled the following morning as much as possible. Simply basing the assessment criteria on recalled awakenings will effectively neglect the adverse effects of noise resulting from:

- fragmentation and interference with sleep quality caused by noise induced EEG awakenings at event noise levels below which recalled awakenings will occur; and
- impairment to the process of falling asleep again.

From a public health perspective, such effects should not be ignored. The advice given in the AVOG on the assessment of $L_{AF,max}$ levels should therefore be used with extreme caution.

The AVOG does not provide any guidance regarding the frequency of occurrence at which the objective awakening impacts of the suggested upper L_{Amax} levels in the AVOG are likely to constitute a significant adverse effect as defined in the Planning Practice Guidance. It is recommended that further information is provided as to how the guidance contained in AVOG relates to the Planning Practice Guidance for Noise.

When a detailed assessment of sleep disturbance is necessary, the ProPG recommends that this should be undertaken using available exposure-response relationships appropriate for the types of noise sources being considered, in line with the WHO Night Noise Guidelines publication and any other relevant research[7]. It is worth noting that Basner's recent paper (Basner et al, 2018) provides exposure response relationships for self-reported and objective sleep disturbance for each source of transportation noise which can be used to perform a detailed assessment of sleep disturbance. This assessment will detail the adverse effects from individual noise events on sleep. It will also advise on risk mitigation measures and how these can be implemented and report the likely residual effects on sleep of affected persons.

A detailed risk assessment may not always be proportionate. Under such circumstances, it is recommended that a simple assessment is carried out assuming that the difference between the L_{Amax} and L_{Aeq} should be limited to no more than 15 dB(A). This would suggest that L_{Amax} values greater than 50 dB and 55 dB would be considered to unreasonable and unacceptable respectively if they were normally exceeded more than 10 times per night .

It should be recognised that there are limitations associated with the Basner exposure response relationships for road traffic noise as the evidence obtained for road traffic noise has been derived indirectly from studies conducted for aircraft and railway noise.

In the polysomnography studies reviewed by Basner to derive ERFs; road, rail, and aircraft events were identified by listening to indoor sound recordings and the start and end of each noise event was scored. For each noise event, the first sleep stage affected by a noise event (first noise epoch) was defined as the first epoch that contained more than 15 s of the event. If the subject was asleep in the epoch prior to the first noise epoch) then the next three epochs (90 s) were screened for a transition to wake or Stage S1.

During a road, rail, or aircraft event, additional outdoor or indoor noises can occur. In this analysis a noise event was considered 'undisturbed' if the following criteria were met: (1) only events from the same noise source could occur one minute before (e.g. the end of a prior noise event) and 1.5 min after the start of the event, and (2) sounds made by the subject such as turning over in bed were allowed before and during the noise event of interest as they could be reactions to the noise. Events defined as 'disturbed' consisted of those in which any other noise event occurred 60 s prior or up to 1.5 min after the start of the first (30 second) noise epoch[8] .

7 The other requirements relating to frequency and duration would also apply

8 Scoring of sleep stages is usually done on an epoch-by-epoch basis, with a 30-second length used as a standard. More information on objective sleep measurements can be found in the WHO Night Noise Guidelines Chapter 2.

It can be seen from this that the analysis only works well for discrete events that are reasonably well separated in time. Most practitioners will appreciate that such conditions do not always occur with exposure to road traffic noise, especially when the exposure results from high traffic flows. Road traffic noise can often be experienced as a series of multiple events or a steady stream of events over a period of time. There is no evidence to suggest that multiple road traffic noise events occurring within the same epoch will result in more awakenings. Equally, it is plausible that multiple road traffic noise events could be more disturbing to sleep compared to discrete events. It must also be recognised that exposure to more than one source of noise could be more disturbing than exposure to a single source of noise.

Despite these limitations, there is no reason to suppose that all adverse effects from road traffic noise can be discounted and effectively ignored and that only recalled awakenings should be considered. In fact, in the absence of evidence it must be a matter of concern that exposure to road traffic noise involving multiple events could be more disturbing than discrete events. As such, practical solutions should be considered as an alternative to the approach recommended in the AVOG. For example, it may be appropriate to determine the $L_{AF,max}$ levels within 1 or 2 minute time intervals and then use this data to calculate the number of additional awakenings for a given $L_{AF,max}$ distribution over an eight hour night period. In addition, the number of additional noise-induced EEG awakenings could be calculated using assumptions for windows open and closed over the period of a year. In this way the risk assessment on sleep could assess short-term effects as well as long-term, chronic effects. Such an assessment could be linked to the overheating assessment as well as other occupancy data for how often people open and close windows.

Until a consensus is reached on how best to assess impacts on sleep from road traffic noise it is recommended that the upper noise criterion set out in Table 3-3 of AVOG is used with extreme caution.

Adaptive models for acoustics and overheating

It must be recognised that overheating can also have significant adverse effects on health and quality of life. In extreme circumstances, excessive heat can be a direct cause of death, therefore it is clearly a serous public health issue. Three heatwaves in summer 2020 resulted in 2,556 excess deaths (**https://www.gov.uk/government/publications/phe-heatwave-mortality-monitoring/heatwave-mortality-monitoring-report-2020**). A more detailed review of the adverse health effects of overheating was reported as part of the MHCLG consultation on Approved Document [x]. (2021)

The AVOG refers to TM59 and suggests the methodology set out in the CIBSE guidance can be used to assess the risk of overheating.

TM59 does not consider the adverse effects of noise. It considers overheating in isolation and provides pass/ fail criteria for thermal comfort. There is no mechanism to relax the criteria for overheating to allow a balance between overheating and noise.

AVOG suggests that it is appropriate to relax the noise standards during an overheating condition but does not consider whether it might also be appropriate to relax the criteria for overheating. As such, there is an implied presumption that acoustic conditions can be compromised so as avoid adverse effects from overheating conditions. This is an issue that was raised during the recent consultation by the MCHLG on the proposed new Approved Document [x] for overheating. In its response to the consultation the CIEH **https://www.cieh.org/media/5168/the-future-building-standard.pdf**) argued that: *'We agree that dynamic thermal analysis provides a valuable means of reducing the risk of overheating. We also agree that the TM59 analysis approach is an appropriate method and encourages a consistent approach. We do not however agree that the TM59 pass/ fail criteria represents an appropriate method. TM59 aims to prevent overheating rather than minimising the risk of overheating, on balance. In addition, TM59 and the maximum recommended temperatures are not strongly supported by evidence, as demonstrated by the evidence review contained in the Phase 1 report: Research into overheating in new homes, published as part of this consultation.*

'Minimising the risk of overheating should be a question of balance, having proper regard to all factors affecting health and quality of life. This is especially the case in medium and high noise exposure areas where there needs to be a balance between overheating and noise. The Professional Practice Guidance: Planning and Noise for New Residential Development provides a framework for achieving an appropriate balance between acoustics, overheating and other factors. The Building Regulations should be aligned with this guidance.

'The Chief Medical Officer's report on all types of pollution has determined that "Noise stands second to poor air quality in terms of the burden of ill health caused by a single pollutant".1 The effects of noise on health and quality of life must therefore be taken into consideration when designing and building new dwellings.

'It is very likely that the strength of evidence for the adverse effects of noise at levels of exposure frequently encountered in and around homes in the UK is greater than that for overheating. The World Health Organization has found strong evidence that noise causes annoyance, sleep disturbance, impact on mental wellbeing and longer-term health effects. Weight should be given to acoustics, overheating and other factors affecting health and quality of life.Judgement is required because the evidence on health effects from overheating do not currently allow its effects to be quantified. This situation should change and the MHCLG should encourage or require post-occupancy monitoring to determine the health and quality of life implications of different design solutions. The instruments are already available to undertake such monitoring and so there is no excuse for not encouraging evidence-based designs and decision making.'

It remains to be seen how much of the proposals to manage overheating are taken forward by the MCHLG. There is a possibility that the proposals may be modified to allow for more balance between acoustics and overheating. When the outcome of the consultation is known it may be necessary to revise ProPG and AVOG. Until then, it is suggested that practitioners should be aware P60

of the limitations of TM59 when applied in areas of medium and high exposures to noise and be cautious about relaxing the noise standards in order to achieve strict pass/fail criteria for overheating. Such an approach is not supported by the available evidence.

AVOG suggests that the relationship between acoustics and temperature is linear (see figure 3-2, reproduced from the AVOG). It also suggests that there is a single exposure response to noise relating to a range of overheating conditions. These are assumptions which are not currently supported by evidence. There is a significant research gap in the way in which the occupants of dwellings respond to noise in buildings with different levels of risk of overheating e.g. low probability of overheating ranging to a high probability of overheating for sustained periods during the summer. These research gaps need to be acknowledged. It is also recommended that figure 3-2 of AVOG is revised to explain that:

- there may be a range of possible responses to noise depending on the severity of the overheating condition as well as the duration and frequency an overheating condition occurs; and
- the relationship between noise and temperature may not be linear.

So far, we have only considered the interrelationship between noise and overheating. It is of course appropriate that noise should be assessed with windows open if there is a risk of overheating and the overheating design strategy relies on windows being open to control indoor temperatures. That said, overheating is not the only factor that should be considered. As explained earlier, the occupants of dwellings and other buildings may choose to open windows for a variety of reasons as well as controlling thermal comfort. The AVOG however explicitly states that consideration of these factors is also beyond the scope of the guidance.

The windows open/closed question was considered by the WHO in the NNG. They refer to studies conducted by Passchier-Vermeer et al. in 2002 which carried out detailed noise measurements inside and outside the bedroom and at the same time measured window position with sensors. The results showed that windows are fully closed only during 25% of the nights.

It was this survey that led to the recommendation to use an annual average inside/outside differences of around 21 dB.

It was stressed that this figure should only apply to façades that have not been fitted with special appliances to reduce noise impact. For example, rooms equipped with air conditioning so that windows can stay closed or could even be sealed. It was also recognised that little is known, however, about the inhabitants' experiences (long-term use, appreciation) of these and other solutions. For example, sound-attenuated ventilation openings are sometimes blocked, in order to cut out draughts.

It is unfortunate that we have little robust information how the occupants of new dwellings open and close windows throughout the year. In the absence of better data, it is recommended that the information reported in the NNG is used to consider the duration of windows open/ closed over a typical annual period. The noise assessment should not assume that windows are only opened when overheating occurs.

AVOG suggests that it is appropriate to extrapolate the adaptive thermal comfort model to an assessment of adverse noise impacts. It states: *'It is considered reasonable to allow higher levels of internal ambient noise from transport sources when higher rates of ventilation are required in relation to the overheating condition.*

'The basis for this is that the overheating condition occurs for only part of the time. During this period, occupants may accept a trade-off between acoustic and thermal conditions, given that they have some control over their environment. In other words, occupants may, at their own discretion, be more willing to accept higher short-term noise levels in order to achieve better thermal comfort. The importance of control is relevant to daytime exposure, but not to night time exposure where the consideration is sleep disturbance.

'It is important to note that there is no specific research available to support this view regarding human response to combined exposure to heat and noise. However, the notion that control over one's environment moderates the response to exposure is well established in the field of thermal comfort, and underpins the adaptive thermal comfort model.'

Although it is suggested that the adaptive comfort model does not apply at night this advice is not carried through to the rest of the document and, in particular, the guidance contained in Table 3-3. There is no reason to assume, however, that an adaptive comfort model should apply at night. The fact is that there is little awareness in the general population, or indeed amongst health practitioners, that biological awakening impacts of noise at night can be harmful to health. Given that there is little awareness of the harmful effects of exposure to noise at night it would be wrong to assume that the occupants of dwellings can make properly informed choices about the trade-off between acoustic and thermal conditions.

High temperatures also impact on sleep and so it should not be a trade-off between noise and overheating; designs should be optimised to avoid and minimise adverse effects from noise and overheating together.

Cooling strategies and emerging policy

The starting point for ProPG is to achieve internal acoustic standards with windows open. It allows for windows to be closed but only where it is demonstrated that despite good acoustic design internal acoustic standards cannot be achieved with windows open and where such a situation can be justified. This allows for mechanical cooling systems to be used[9].

Until recently, it is fair to say that mechanical cooling systems have been used commonly in medium and high noise exposure areas to avoid the need to open windows in order to mitigate the adverse effects of noise. This is even true of development in London where the London Plan only allows for active cooling as a method of last resort[10].

9 Active cooling is a design feature to control thermal comfort, separate to providing ventilation to the home, and is the last resort of the cooling hierarchy.

10 The London Plan requires overheating to be able to be mitigated through passive means as far as possible, however it does not prohibit the installation of active cooling systems. As long as the developer can demonstrate that active cooling systems would not need to be relied upon by residents for good thermal comfort.

The MHCLG consultation on the new Approved Document [x] contained strong proposals to incorporate passive design solutions to be used to minimise the risk of overheating. The proposals included measures to avoid solar gain and to remove excess heat. Measures to minimise solar gains in summer included any of the following:

a. fixed shading devices;
b. glazing design, including limiting the amount of glazing; and
c. building design, for example the placement of balconies for shading.
d. Shade of adjacent permanent buildings, structures or landscape.

The draft Approved Document [x] then went on to propose: *'Excess heat from the residential building should be removed through any of the following:*

a. opening windows, made more effective by cross-ventilation;
b. ventilation louvres in external walls; and
c. a mechanical ventilation system.

The building should be constructed to meet [the requirement for overheating (1)] without the need for mechanical cooling (air-conditioning). However, mechanical cooling is not prohibited by the requirement.'

In its response to the consultation the CIEH sought clarification on this proposal and suggested that it be considered within a wider strategy to reduce carbon emissions. The CIEH's response raised an important point that the prohibition of mechanical colling systems could potentially sterilise brown field land and that this had not been fully considered or explored by the MHCLG as part of the proposals.

The current version of ProPG refers to sustainable development policies and suggests that the design should be considered within the context of local policies and plans. For example, the London Plan and the cooling hierarchy, which suggests that mechanical cooling should be a method of last resort.

The ProPG approach works perfectly well for now but it may be necessary to update the guidance if the UK government announces any stronger policies or standards to either prohibit or otherwise discourage the use of mechanical colling systems.

In relation to passive design the AVOG provides helpful guidance on the importance of early design considerations to minimise overheating. It advises that: *'In accordance with sustainable design and construction principles, development proposals should, amongst other things, maximise opportunities to orientate buildings and streets to minimise summer and maximise winter solar gains; use trees and other shading; increase green areas in the envelope of a building, including its roof and environs; and maximise natural ventilation. These sustainable design principles mirror good acoustic design as described in the ProPG.'*

This advice is useful and emphasises the need to consider the application at the earliest possible stage. This guidance could be improved if it provided more information on passive design solutions and how passive acoustic design could be integrated with passive design measures to minimise overheating. For example, how balconies could be used to minimise noise as well as overheating.

Recommendations

This article highlights areas of significant commonality, but it also identifies areas of divergence. It is hoped that this article will encourage discussion and debate to allow the IOA, ANC and CIEH to work together and produce guidance that is aligned as far as possible. This would be helpful to all practitioners and anybody who has an interest in planning and design.

Acoustic and environmental health practitioners should involve noise and health experts in the process to ensure that guidance accurately reflects the best available evidence on the effects of different factors affecting health and quality of life.

A series of workshops to discuss these issues may help practitioners to come together and explore these issues further.

This article identifies some limitations with the AVOG that practitioners should be aware of in the application of the guidance. It also identifies some areas where the ProPG may benefit from future revisions.

It is recommended that the IOA, ANC and CIEH work collaboratively with CIBSE to explore issues relating to integrated design for acoustics and overheating. The possibility of providing joint guidance should be explored. ◎

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