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Adaptive acoustic comfort: assessing noise with provisions for ventilation and overheating in dwellings

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ABSTRACT

In the design of residential developments, it has been common practice for façade sound insulation (to protect against outdoor noise) to be considered separately from the provisions for ventilation and for mitigating overheating. This fragmented approach has led to different designers making different, incompatible assumptions about the internal environmental quality conditions: the acoustic designer assumes that windows are closed to control external noise ingress, while the mechanical designer assumes that windows are open for ventilation or mitigating overheating. Occupants are likely to accept reasonable increases of external noise ingress when using windows to mitigate overheating: adaptive acoustic comfort – but what is reasonable?

The problem is exacerbated by increased overheating risk in modern energy efficient buildings and future climate scenarios. The Association of Noise Consultants has produced the draft Acoustics Ventilation and Overheating (AVO) Residential Design Guide. The AVO Guide recommends an approach to acoustic assessment that takes regard of the interdependence of provisions for external noise ingress, ventilation and overheating. This paper describes the context, background and content of the AVO Guide. There are references to passive attenuated options for ventilative cooling to help designers avoid simply specifying mechanical cooling.

Keywords: Acoustics, noise, ventilation, overheating, dwellings, residential, facade sound insulation, passive attenuated ventilative cooling.

1. INTRODUCTION

In the design of residential developments, it has been common practice for façade sound insulation (to protect against outdoor noise) to be considered separately from the provisions for ventilation and for mitigating overheating. This fragmented approach has led to different designers making different, incompatible assumptions about the internal environmental quality (IEQ) conditions: while the acoustic designer assumes that windows are closed to control external noise ingress, the mechanical designer, considering ventilation and mitigation of overheating, assumes that windows are open. Conlan et al (1) reviewed 122 planning applications for major developments in London between 2014 and 2017, which had both noise and over- heating assessments; 85% of these assumed closed windows for reasonable noise conditions, with open windows assumed for reasonable thermal conditions. No assessment of acoustic conditions when using opening windows to provide thermal comfort was made. The result is residential accommodation in which the occupants may choose either acoustic comfort or indoor air quality and thermal comfort, but the extent of achieving a reasonable balance between thermal and acoustic comfort is rarely considered.

The risk of overheating is exacerbated by global heating and the move towards better insulated,

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more airtight, often lightweight buildings with large amounts of fenestration. Heightened risk means that many modern residential buildings require windows to be open for longer periods in the year to mitigate overheating, compared with older buildings. The need to consider residential development on noisier sites, particularly in urban areas, means that new dwellings may also be subject to high environmental noise levels. The Chartered Institute for Building Services Engineers (CIBSE) TM60 – Good practice in the design of homes (2) describes the need to consider integrated design and notes that early consideration is often required to achieve passive design solutions. The need to open windows to achieve reasonable IEQ has hitherto rarely been properly considered in the design of the façade sound insulation: indeed, there has been no guidance on how to do so.

1.1 Planning and noise

A requirement to assess and provide mitigation against outdoor sound for a residential development in the UK in urban areas is likely to be invoked through the local planning authority as regulators in the planning system; thus, the local planning authority maybe responsible for assessing and enforcing the proposed mitigation. The local authority may have standards for the control of noise as well as overarching sustainability standards requiring an assessment of the need to mitigate overheating risk. The need for and provision of adequate ventilation is outlined in the Building Regulations and therefore managed through the building control system. Although there is currently no statutory requirement to assess the potential for overheating in dwellings as part of the English Building Regulations (beyond a tick box exercise in SAP), an assessment may be undertaken to meet planning and/or the developer's requirements. Hence, as well as being undertaken by different designers, the adequacy of the provisions for each aspect may be assessed by different bodies and potentially based on different assumptions about the use of the windows.

The ProPG: Planning & Noise (ProPG) (3) was jointly issued by the Institute of Acoustics, the Association of Noise Consultants and the Chartered Institute of Environmental Health in June 2017. The ProPG provides a framework to consider noise impacts for residential development. It describes the need to undertake an assessment of the acoustic impacts of the ventilation strategy and provisions or overheating where closed windows are necessary to achieve reasonable internal noise levels.

The Association of Noise Consultants (ANC) established a working group at the end of 2015 to provide guidance on acoustic conditions and design when considering both the provision of ventilation and prevention of overheating – the Acoustics, Ventilation and Overheating (AVO) Guide (4). The information being developed by the AVO group was fed back to the ProPG group; the AVO Guide offers a means of undertaking an integrated assessment of noise with proposed provisions for ventilation and overheating. This paper describes the progress of the AVO Guide that has progressed since the earlier presentation of this work by Harvie-Clark et al. (5) This work developed out of the problems in residential design for ventilation and noise as previously described by Harvie-Clark and Siddall (6).

Appropriate application of the AVO Guide is intended to align with the principles of good acoustic design as described in the ProPG when considering internal noise level guidelines. The ProPG contains no quantitative guidance on when the designer should implement noise mitigation for the occupants, but merely states a set of principles. The AVO Guide intends to inform this lack of guidance so that all stakeholders may adopt a consistent approach, and suitable measures are taken to protect occupants' residential environments from excessive noise in a holistic manner.

1.2 Unintended adverse consequences

The evolution of energy performance requirements under building regulations has led to increased air tightness and enhanced thermal insulation. However, these changes can have unintended consequences. Internal air quality can be poor unless ventilation systems are effective, whereas the efficacy of ventilation systems in leakier buildings was of less consequence. When there is an increased capacity to retain heat, dissipation of excessive heat gains can become more problematic, with the consequential increase in overheating risk. Other factors currently contributing to overheating risk include climate breakdown and the urban heat island effect.

A fragmented design approach results in accommodation that may be uncomfortable to occupy and hence may be considered unsustainable. Residual risks for stakeholders include health and wellbeing risks for occupants, design risks for consultants and legal risks for developers. The increasingly urgent need for an integrated approach to consider noise, ventilation and overheating has been the motivation to produce the AVO Guide.

1.3 Scope

The AVO Guide is intended for the consideration of new residential development that will be exposed predominantly to airborne sound from transport sources and to sound from mechanical services that are serving the dwellings in question. Other sources of noise, such as noise from industrial, commercial or entertainment premises, and of ground-borne noise and vibration, are outside the scope. New apartments, flats and houses are the most common type of new residential development; however, the approach may also be used for other types of residential development such as residential institutions, care homes, etc.

There are other benefits for occupants from opening windows, such as the connection with the outside, sense of fresh air and perception of draughts when overheating, and sense of control over one's environment. Consideration of these factors is beyond the scope of the AVO Guide.

The ProPG emphasises the importance and principles of good acoustic design; the AVO Guide is intended to contribute to the practice of good acoustic design. It is noted that the overarching aspiration of good acoustic design is that residents may open windows without any adverse acoustic impact (ProPG: paragraph 2.33); where a site layout achieves these conditions, the portion of the AVO Guide relating to environmental noise becomes effectually redundant. In particular, the paragraphs 2.34–2.36 of the ProPG indicate that an integrated design approach must be taken to acoustic, ventilation and thermal comfort conditions.

The AVO Guide includes an explanation of ventilation requirements under the Building Regulations and as described in Approved Document F (ADF), (7) along with typical ventilation strategies and associated noise considerations. While these Statutory Requirements have been around for many years their correct implementation into building design from both regulators (local authority) and building designers has been inconsistent. It describes the overheating assessment methodology described in CIBSE TM59 (8) and identifies potential acoustic criteria and guidance relating to different ventilation and overheating conditions for both environmental noise ingress and building services noise. There is a worked example of the application of the AVO Guide including potential design solutions.

2. Current planning policy, regulations and guidance for noise

2.1 Planning policy

Noise management is a devolved issue in the UK. This means that, although there are many similarities, different policies and regulations apply in England, Wales, Scotland and Northern Ireland. In England, the overarching policy on noise management is set out in the Noise Policy Statement for England (NPSE) (9). It contains the vision of promoting good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development. The NPSE contains three aims, namely:

Through the effective management and control of environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development:

- Avoid significant adverse impacts on health and quality of life;
- Mitigate and minimise adverse impacts on health and quality of life and
- Where possible, contribute to the improvement of health and quality of life.

With regard to land-use planning in England, the relevant policy is primarily set out in the National Planning Policy Framework (NPPF) (10). For noise, the requirements are consistent with the NPSE and set out at paragraph 180: "Planning policies and decisions should . . .: (a) mitigate and reduce to a minimum potential adverse impacts resulting from noise from new development – and avoid noise giving rise to significant adverse impacts on health and the quality of life"**.**

The implementation of the policies in the NPPF is supported by a suite of web-based guidance, including the Planning Practice Guidance on Noise (PPG(N), www.gov.uk/guidance/noise--2). It contains much advice and includes a table which summarises the noise exposure hierarchy based on the likely average response. The PPG(N) makes it clear that noise can override other planning concerns. It points out, though, that neither the NPSE nor the NPPF expects noise to be considered in isolation, separately from the economic, social and other environmental dimensions of proposed development. In the 2018 revision to the NPPF, there is also a reference at paragraph 149 to mitigating the risk of overheating.

In their local development plans, Local Planning Authorities can include noise exposure values as standards for various situations. The PPG(N), however, states that care should be taken to avoid these standards from being implemented as fixed thresholds as specific circumstances may justify some variation being allowed.

2.2 BS 8233

British Standard 8233 (11) provides a wide range of guidance regarding sound insulation and noise reduction in buildings. For noise from steady external sources, it recommends that it is desirable for the internal ambient noise levels set out in Table 1 not to be exceeded. These levels are accompanied by various notes to indicate that the levels are annual average data based on existing guidelines issued by the World Health Organisation (12,13). Where a development is considered necessary or desirable, the levels in Table 1 may be relaxed by up to 5 dB and reasonable internal conditions still achieved.

Table 1 – Indoor ambient noise levels for dwelling from BS 8233.

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

The British Standard includes only qualitative, not quantitative guidance regarding the assessment of noise maxima at night. The lack of quantitative guidance in the British Standard has been addressed by information on guideline values proposed by Paxton et al (17).

2.3 WHO Environmental Noise Guidelines for the European Region 2018

Published in October 2018, the WHO Environmental Guidelines for the European Region (14) followed a new approach to developing guidance. Throughout the process, the approach used was the Grading of Recommendations Assessment, Development and Evaluation (GRADE). Based on the defined scope and key questions, these guidelines reviewed the pertinent literature in order to incorporate significant research undertaken in the area of environmental noise and health since the Community Noise Guidelines (12) and Night Noise Guidelines for Europe (13) were issued.

Eight systematic reviews of evidence were conducted to assess the relationship between environmental noise and various health outcomes. A separate systematic review of evidence was conducted to assess the effectiveness of environmental noise interventions in reducing exposure and associated impacts on health. We look forward to incorporating the findings from these reviews and new Guidelines.

2.4 CIBSE, Guide A, Approved Document F

Recommended comfort criteria for indoor noise levels from mechanical services are given in Table 1.5 of Industry guidance document CIBSE Guide A, (15) although no limits are given for bathrooms, toilets or circulation areas. Building Regulations Approved Document F (Section 4.3.6) also gives guidance on noise levels that should not be exceeded by a continuously running mechanical ventilation system on its minimum low rate, although currently the noise caused by ventilation systems is not controlled by the Building Regulations

2.5 Proposed guideline values

The contribution to internal noise levels from transport sources and from mechanical services is considered separately and independently. For both sources of noise, the AVO guidance makes a clear distinction between the situation where ventilation is being provided as defined by ADF whole dwelling ventilation ('ADF ventilation condition') and the situation where measures are in place to reduce overheating risk ('overheating condition'). In terms of noise effect, the important distinction between these two situations is that the ADF ventilation condition applies continuously all year whereas the overheating condition applies only for a portion of the year. Existing guidance is referenced for noise from mechanical services. In the case of noise from transportation sources, there is no distinct or appropriate existing guidance for the overheating condition. The guidance presented in the AVO Guide considers the potential acceptability of higher internal ambient noise levels in terms of the effect on occupants.

3. Internal noise levels guidelines: *adaptive acoustic comfort*

3.1 Transportation noise sources

The desirable internal noise guidelines within Table 4 of BS 8233 (as reproduced in Table 1) should be achieved when providing adequate ventilation as defined by ADF whole dwelling ventilation. However, it is considered reasonable to allow higher levels of internal ambient noise from transport sources when higher rates of ventilation are required to mitigate overheating ('ventilative cooling').

The basis for this is that the overheating condition occurs for only part of the year, and occupants may accept a trade-off between acoustic and thermal conditions given that they have some control over their environment. Occupants may be more willing to accept higher short-term noise levels in order to achieve better thermal comfort. The working group are not aware of 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 accepted in the field of thermal comfort and underpins the adaptive thermal comfort model. We describe this as "adaptive acoustic comfort". The acceptability of higher internal ambient noise levels has been considered in terms of various effects such as daytime annoyance and interference with activities (e.g. conversation) and sleep disturbance at night time.

The effect of increased internal ambient noise from transport noise sources will depend both on the absolute noise level and the amount of time that an increased ventilation rate is required to control overheating. A good design process should therefore, as a priority, seek to minimise heat gains, thereby reducing the amount and duration of ventilation required to control overheating and the consequential effect from increased noise ingress. A two-level risk assessment procedure is proposed to estimate the potential impact on occupants in the case of the overheating condition, as illustrated in Figure 1.

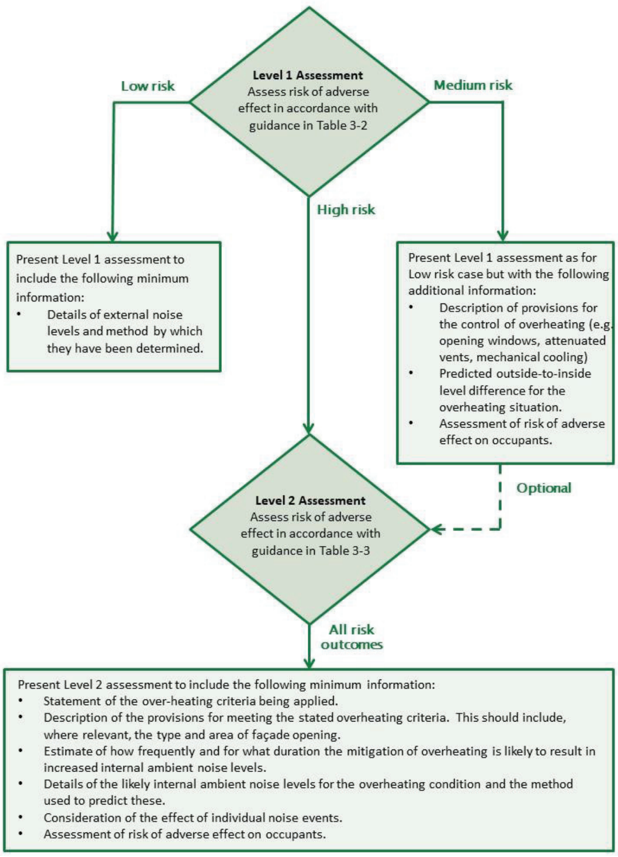

Figure 1. Two-level noise assessment procedure – overheating condition

The Level 1 assessment may be sufficient for developments on 'Low' and possibly 'Medium' risk sites. The Level 2 assessment may be appropriate for 'Medium' risk sites, depending on the potential overheating risk and is always suggested for 'High' risk sites. The Level 1 assessment is based on the assumption of using a partially open window to mitigate overheating. The AVO Guide presents values that are 13 dB higher than those in Table 2, to suggest a set of external free-field noise levels. The assumed outside-to-inside level difference of 13 dB is taken into account for partially open windows from the facade level externally, according to Locher et al (16). This level difference is considered representative of typical domestic rooms with simple facade openings of around 2% of the floor area. It should be noted that this area of opening is not necessarily adequate to mitigate overheating and, should the design under consideration deviate significantly from this situation, then the levels should be adjusted accordingly. The noise levels suggested in Table 2 assume a steady road traffic noise source but may be adapted for other types of transport.

Table 2 – Guidance for Level 2 assessment of internal noise (external sources) for overheating condition

$L_{Aeq,T}$ 07:00–23:00	$L_{Aeq,T}$ 23:00–07:00	Individual noise events during 23:00-07:00	Example of outcomes	Risk category
≤ 35 dB	≤ 30 dB	Do not normally exceed 45 dB $L_{AF,max}$ by > 10 dB or 10 times a night	Noise can be heard, but does not cause any change in behaviour or attitude.	Negligible
> 35 dB and ≤ 40 dB	> 30 dB and ≤ 35 dB	-	Noise can be heard and causes small changes in behaviour and/or attitude.	Low
> 40 dB and ≤ 50 dB	> 35 dB and ≤ 42 dB	Do not normally exceed 65 dB $L_{AF,max}$	Increasing risk of adverse effect. Noise levels at the lower end of this category may be suitable even where occurring for a significant proportion of the year. Noise levels at the upper end of this category may still be suitable provided they only occur for limited periods.	Medium
> 50 dB	> 42 dB	Normally exceeds 65 dB $L_{AF,max}$	The noise causes a material change in behaviour and/or attitude.	High

The values presented in these tables should not be regarded as fixed thresholds, and reference can also be made to relevant dose response relationships, such as those described in ProPG. Regular individual noise events should also be considered – refer to Appendix A of ProPG for further guidance, and Paxton et al (17). The risk of an adverse effect occurring will also depend upon the timing, duration and frequency that mitigation of overheating is likely to result in increased internal noise levels. The daytime levels presented in this table may not be appropriate for residential care homes or other situations where conditions for daytime resting are known, at the design stage, to be of particular importance.

3.2 Internal noise level guidelines -mechanical services

Human hearing response and annoyance of noise are of primary concern when considering building services noise in dwellings. A range of research (18–20) demonstrates that occupants adjust mechanical ventilation systems to a level of noise that is tolerable or disable them entirely if the noise is not tolerable. Either of these actions can result in insufficient ventilation if infiltration is well controlled in an airtight dwelling; the adverse effects of this include poor indoor air quality and consequential risk of adverse health effects.

While these studies are examples of how occupants respond to the noise from the equipment, the actual noise levels or the character of the noise that people may tolerate are not well documented in the literature according to Harvie-Clark et al (18). The guidance values in this chapter assume steady noise levels without distracting characteristics. There is also very little information relating to the use of mechanical systems which use ambient air to mitigate overheating ('mechanical ventilative cooling'), and very few examples of it being used in the UK. Mechanical systems which provide cooled air are more commonly used and their operation can be complex, with a combination of cooling options with associated airflow rates and noise levels. ADF suggests that to ensure good acoustic conditions, the noise levels within living rooms and bedrooms should not exceed 30 dB $L_{Aeq,T}$. A summary of the proposed noise levels from various guidance is shown in Table 3. Recommendations for desirable internal ambient noise levels for ADF ventilation conditions are set out in Table 3.

Table 3 – Indoor ambient noise levels from mechanical services – guidance level summary

Ventilation condition	Possible system or design solution	Desirable internal ambient noise levels from mechanical services, L_{Aeq}
ADF Whole dwelling	MEV or MVHR Minimum low ventilation rate	Bedrooms ≤ 26 or 30 dB Living rooms ≤ 30 dB
ADF Extract	Intermittent extract fans Continuous MEV or MVHR Minimum high ventilation rate	Bedrooms ≤ 26 or 30 dB Living rooms ≤ 35 dB Bathroom / WC / kitchen ≤ 45 dB
ADF Purge	Manually controlled fan, min. 4 ach^{-1}	No noise limits

Lower noise levels may be appropriate for some residential development, and mechanical services noise levels not exceeding 24–26 dB $L_{Aeq,T}$ within bedrooms may be required to prevent adverse reaction from some occupants when falling asleep according to Harvie-Clark et al.(18); hence the range of potential criteria in Table 3 for guideline levels in bedrooms.

Recommendations for desirable internal ambient noise levels for overheating conditions are set out in Table 1.5 of CIBSE Guide A. Section 1.10.10 of CIBSE Guide A states that the comfort criteria are a guide only, and higher or lower values may be appropriate. It suggests that a range of ±5 dB may be acceptable depending on the particular situation. The duration, regularity, degree of occupant control and magnitude of the noise levels associated with the overheating condition should be taken into consideration when establishing suitable noise levels.

BS EN 15251(23) is currently under revision as Pr-EN 16798-1 (24). The currently proposed noise levels in Pr-EN 16798-1 would be considered excessive, based on the literature described by Harvie-Clark et al (18) and would lead to significant problems if adopted. The same values with a very similar classification are also published in BS ISO 17772-1 (25).

4. Conclusions and further research

The integrated assessment of acoustic conditions along with provisions for ventilation and overheating is urgently needed to prevent residential accommodation being developed that offers occupants only one of these aspects of IEQ. The AVO Guide offers a comprehensive means to undertake this assessment within the existing planning policy framework for noise in England. The AVO Guide offers an example of its application as an Appendix to assist the user. Case studies and guidance on potential design solutions to enable passive ventilative cooling in higher noise environments are also provided as Supporting information.

No existing research has been identified that investigates the inter-dependence of acoustic and thermal comfort in dwellings or the indoor level from external sources that may be acceptable to occupants on a short-term basis when the mitigation of overheating is required. Perceived occupant control over the environment is key to higher tolerance of less than ideal conditions. It is recommended that appropriate research should be undertaken on the basis of both lab studies on relatively small groups under closely controlled conditions and also field studies on larger groups to assess behaviour in real-life conditions.

Occupants' tolerance to noise from mechanical services also requires further research if adverse intervention to the operation of ventilation systems is to be avoided. The authors are collaborating for funding to pursue this research in conjunction with Salford, Oxford Brookes and Glasgow universities.

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