NOISE, VENTILATION AND OVERHEATING IN RESIDENTIAL DEVELOPMENTS

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1 INTRODUCTION

A working group has been formed by the Association of Noise Consultants (ANC) in response to an identified urgent need to provide guidance on acoustic conditions and design when considering both the provision of ventilation and prevention of overheating. The guidance produced by the group will take the form of a design guide for acousticians. In the first instance, the design guide will consider only residential development exposed to, non-actionable, noise sources without specific character.

The need for adequate ventilation is outlined in Approved Document F and designs to achieve this have been well developed. Current Building Regulations for residential development encourage the improvement of energy efficiency through increasing air tightness and thermal insulation. However, there are no specific requirements relating to overheating in residential dwellings as part of the UK Building Regulations and the emerging consequence of increasing air tightness and thermal insulation of dwellings is leading to the potential for excessive temperatures.

The current standard method of cooling a dwelling is either:

- via the opening of a window or other façade element to allow an increase in air flow and equalisation of temperatures between inside and outside, or
- via incorporation of mechanical cooling which generally requires space allowance for an external condensing system, ongoing maintenance (and therefore cost) and is not the preferred option in terms of energy efficiency.

Where a non-acoustically-attenuated opening in the façade (e.g. a window) remains the only provision for prevention of overheating and the dwelling is located in a noisy area, the occupant is presented with a choice between uncomfortably high noise levels or uncomfortably high temperatures.

There are currently risks involved which the proposed design guide hopes to reduce, namely:

- health risks for occupants
- design risks for consultants; and
- legal risks for developers.

This design guide being developed intends to provide:

- an explanation of current definitions of ventilation and overheating;
- an indication of potential forms of acoustic criteria that could be used for design;
- examples of design solutions and case studies.

There is presently limited data on criteria and solutions and thus it is envisaged that the design guide will be an ever-evolving document, to be updated and improved as further information becomes available. This paper presents an overview of the ventilation, overheating and noise issues for residential development that will form the basis of the forthcoming design guide.

2 VENTILATION AND OPENING WINDOWS

2.1 Approved Document F

Ventilation requirements for dwellings (and other buildings) are covered under the Building Regulations 'Approved Document F – Means of Ventilation, 2010 Edition' (ADF).[1]

ADF requires that '*there shall be adequate means of ventilation provided for people in the building'.*

The document then goes on to describe the purpose of ventilation as follows:

'*Ventilation is simply the removal of 'stale' indoor air from a building and it replacement with 'fresh' outside air.'*

'*Ventilation is required for one or more of the following purposes:*
a) Provision of outside air for breathing;
b) Dilution and removal of airborne pollutants, including odours;
c) Control of excess humidity (arising from water vapour in the indoor air);
d) Provision of air for fuel-burning appliances (which is covered under Part J of the Building Regulations).'

Ventilation also provides a means to control thermal comfort and this, along with other methods, is considered in Part L of the Building Regulations and its supporting Approved Documents.

ADF then identifies the ventilation strategy that it adopts, as summarised in Table 1 below:

Type of Ventilation	Location / Reason for Ventilation	When is this required?
Whole Building (Whole Dwelling) Ventilation (see Note 1)	To provide fresh air to the building and to dilute and disperse residual water vapour not dealt with by extract ventilation as well as removing water vapour and other pollutants which are released throughout the building.	Continuously
Extract Ventilation	From rooms where most water vapour and/or pollutants are released, e.g. due to activities such as cooking, bathing or photocopying. This is to minimise their spread to the rest of the building.	Continuous or intermittent
Purge Ventilation	Throughout the building to aid removal of high concentrations of pollutants and water vapour released from occasional activities such as painting and decorating or accidental releases such as smoke form burnt food or spillage of water.	Occasionally
Note 1: 'Whole Building Ventilation' is often referred to as 'background ventilation' (a term used in the 1995 version of ADF). Note 2: ADF also states that ''Purge ventilation provisions may also be used to improve thermal comfort, although this is not controlled under the Building Regulations.'		

Table 1: ADF - Adopted Ventilation Strategy

ADF provides details of four systems that can be used to provide the ventilation strategy set out in Table 1.

The document also states, with specific reference to dwellings, that '*it is common to use intermittent extraction fans for extract ventilation, trickle ventilators for whole building ventilation and windows for purge ventilation*'.

In the general guidance section of ADF there are the following specific references to noise:

- '*In noisy areas it may be appropriate to use either sound-attenuating background ventilators or mechanical ventilation solutions, depending on the noise level and any planning conditions.*'
- '*Noise generated by ventilation fans (which may propagate through ducts and duct work) can disturb the occupants of the building and so discourage their use. Therefore, the designer should consider minimising noise by careful design and the specification of quieter products. Noise from the ventilation system may also disturb people outside of the building, so externally emitted noise levels should also be considered.*'

ADF also provides the following note with regards to the provision of purge ventilation within habitable rooms, although there is no quantitative guidance as to what constitutes an "excessive" level of noise:

- 'There may be practical difficulties in achieving this (e.g. if unable to open a window due to excessive noise from outside.'

2.2 The Role of Opening Windows

It has been identified in the previous section that windows can be used as a means to provide purge ventilation and as a means to control thermal comfort. In addition, there are a number of qualitative benefits to opening windows that are summarised below. These benefits would also apply to other types of user operated, openable façade element such as a louvre.

For these reasons, designs without openable windows (or other openable façade element) should be avoided except in exceptional circumstances.

2.2.1 Occupant control of the environment

The benefits for the occupants in being able to control their indoor environmental conditions should not be underestimated. The experience of control also changes the physical conditions that occupants report as acceptable. The adaptive thermal comfort model[2] demonstrates that people report comfort levels while tolerating significantly higher temperatures where they have control of the environmental conditions through opening windows, compared with fixed windows, mechanical ventilation and air conditioning.

2.2.2 Feeling connected with the outside world

Opening windows offer a feeling of connection with the outside environment that is valuable. There is a notion of biophilia, that humans have a natural affinity for other natural living systems, and having a sense of connection to the outside environment can be important. We know that rooms with no natural light create a sense of unease after some time; the ability to have a direct physical connection to the outside may be considered on this spectrum.

2.2.3 Perception of fresh air

There is a perception that outside air is fresh, and overcomes a stagnant internal environment. While our human sense of air quality has not yet evolved to effectively assess many modern air pollutants, the perception of air quality is a complicated field. The feeling of air movement also assists in cooling[2,3], however, and the perception of this may again be more important than the physics.

3 OVERHEATING

3.1 Models of Overheating

There is no universally accepted definition of overheating, but two competing methods of assessment. These are the Fanger model[2], described in ISO 7730, and the adaptive thermal comfort model[3], described in CIBSE TM52.

The Fanger model is based on the physics of human heat generation during different levels of activity (metabolic rate), insulation provided by clothing and seating, the effect of air movement (draughts) and the sensation of temperature in a room (operative temperature). There are fixed "universal" limits for comfort, based on average responses from climate chamber surveys.

The adaptive thermal comfort model is based on the experience of occupants in naturally ventilated buildings and correlates overheating with the difference between the internal operative temperature and the running mean external temperature. It is therefore a description of the effect of the building on the difference between internal and external temperatures, on the basis that people are able to adapt their clothing accordingly. A key element of this approach is the control of the internal environment by the occupants.

The Zero Carbon Hub[4] has recently produced a range of reports on overheating.

3.2 Building Regulations

There are no specific requirements relating to overheating in residential dwellings as part of the UK Building Regulations. Both Part F and Part L1A of the Building Regulations briefly mention overheating but do not provide much detail. However, in the section on 'buildings other than dwellings' Approved Document F refers to Part L2A of the Building Regulations for guidance.

Approved Document L1A provides guidance on limiting the effects of heat gains in summer[5]. No objective performance standards are set. However, reference is provided to the SAP 2012 Appendix P assessment methodology[6]. SAP 2012 Appendix P provides a test for overheating risk. One variable used within this test is the effective air change ventilation rate based on various ventilation strategies including opening windows. This methodology acknowledges that ground floor windows may not be left open all night due to security issues. No reference is made with regards to a constraint on opening windows due to excessive noise.

In Part L2A of the Building Regulations (conservation of fuel and power in new buildings other than dwellings) further information on overheating is provided in the section on limiting thermal gains[7]:

- '*…the developer should work with the design team to specify what constitutes an acceptable indoor environment in the particular case, and carry out the necessary design assessments to develop solutions that meet the agreed brief. Some ways of assessing overheating risk are given in CIBSE TM37 and, for education buildings, in BB101.*'

It should be noted that the above applies to buildings 'other than dwellings'.

3.3 CIBSE Guide A

The two methods of identifying if overheating is likely to occur that are generally used by mechanical services engineers are included in the 'Chartered Institution of Building Service Engineers (CIBSE) Guide A : Environmental Design' document[8,9]. These are summarized in Table 2.

Reference	Type	Description
CIBSE Guide A - 2006	Absolute ('Fixed')	Provides absolute criteria (temperatures and durations) for where overheating is likely to occur in residential buildings (living rooms and bedrooms)
CIBSE Guide A - 2015	Adaptive	Provides criteria to assess the risk of overheating based on adaptive comfort (this takes into account that people acclimatise to extended periods of hot weather)
Note: The CIBSE Guide A 2015 criteria are based on research for commercial buildings and therefore may not be applicable in residential environments. Therefore the 2006 methodology is more regularly used for dwellings.		

Table 2: CIBSE A Guide methods for assessing overheating

3.4 London Plan

Policy 5.9 of the London Plan[10], 'Overheating and Cooling', advocates that '*major development proposals should reduce potential overheating and reliance on air conditioning systems and demonstrate this in accordance with the following cooling hierarchy:*

1. *minimize internal heat generation through energy efficient design*
2. *reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls*
3. *manage the heat within the building through exposed internal thermal mass and high ceilings*
4. *passive ventilation*
5. *mechanical ventilation*
6. *active cooling systems (ensuring that they are the lowest carbon options).*'

This clearly prioritises the use of opening windows (or other means of passive ventilation) to control overheating over more energy-intensive, mechanical solutions.

4 EXISTING NOISE GUIDANCE

4.1 Noise from mechanical services

Upper limits for indoor noise levels from mechanical services are given in Table 1.5 of CIBSE Guide A[9], although no limits are given for bathrooms, toilets or circulation areas.

The noise limits described in CIBSE Guide A are applicable for the ADF whole building ventilation condition. It is not explicit what noise limits should apply to mechanical services for the ADF purge ventilation condition or when plant is operating to control overheating.

4.2 Noise from external sources

Upper limits for indoor ambient noise levels resulting from external noise sources are defined in Table 4 of BS8233[11].

The limits described in BS8233 are generally taken as being applicable for the ADF whole building ventilation condition. This typically implies noise levels with trickle ventilators in the open position but windows closed. It is not explicit what indoor ambient noise limits should apply for the ADF purge ventilation condition or when ventilation is provided for the purposes of overheating control.

A conservative approach would be to assume that it should be possible to prevent overheating whilst meeting the noise limits described in BS8233. However, this would encourage the use of more energy-intensive mechanical ventilation and cooling solutions without regard for the possibility that occupants may accept higher noise levels for limited periods, particularly where they have control over their conditions.

5 NOISE AND OVERHEATING

5.1 Noise from mechanical services

5.1.1 Purge Ventilation

Given that purge ventilation is only required occasional (refer to Table 1) and would be under manual control, it is suggested that no indoor noise limit need apply in the room being purged. However, the noise limits described in Table 1.5 of CIBSE Guide A would apply for adjacent rooms in the same dwelling.

5.1.2 Overheating Control

Where mechanical systems (ventilation and/or cooling) are used to control overheating, it is suggested that the noise limits described in Table 1.5 of CIBSE Guide A should apply under normal operation of the system. Higher noise levels should not be permitted where a boost mode is part of the normal operation of the system.

If the system has a manually controlled boost mode to achieve lower temperatures or to reach the design temperature more quickly, higher noise level may be acceptable when operating in boost mode. In this situation, the proposed classification system[12] from Table 5.4 of Cost Action TU0901 can be used as a guide for upper limits. The relevant part of this table is reproduced below as Table 3.

The TU0901 classification scheme specifies criteria for six classes A, B, C, D, E and F for dwellings, where Class A is the highest class and F the lowest class.

Type of space and sources	Class A	Class B	Class C	Class D	Class E	Class F
In dwellings due to ventilation / heating / cooling installation	≤ 20	≤ 24	≤ 28	≤ 32	≤ 36	≤ 40
Note: All values are given as LA,eq,nT as defined in ISO 16032 and ISO 10052						

Table 3: Extract from COST action TU0901 Table 5.4.

5.2 Noise from external sources

5.2.1 Purge Ventilation

Given that purge ventilation is only required occasional (refer to Table 1) and would be under manual control, it is suggested that no indoor noise limit need apply in the room being purged. However, the noise limits described in Table 4 of BS8233 would apply for adjacent rooms in the same dwelling.

5.2.2 Overheating Control

The authors of this paper are not aware of any existing research studies on 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 alleviation of overheating is required.

Ideally, research would be undertaken to provide firm evidence to use as a basis for guidance. However, given that field studies would be necessary, this will take a significant amount of time. As an interim measure, reference is made to existing research studies whose applicability might be reasonably extended to the situation of overheating.

In practice, the most common source of anonymous external noise is transport. Extensive meta-analysis shows that, for a given equivalent noise level, aircraft noise causes more night-time annoyance than either road or rail noise[13]. On this basis, it is reasonable to make use of the extensive studies on the effect of aircraft noise and assume that the conclusions can be safely applied in the case of noise from other forms of transport.

In dwellings, the noise effects with which we are most concerned are the impairment of rest and sleep, of communication, psychological well-being and performance[14]. As part of an extensive study prior to the planned construction of a new runway at Frankfurt Airport, evaluation criteria were defined[15] for various protection goals based on existing research. The following three evaluation criteria were defined:

- 'Threshold values' – exceedance of these levels can cause measurable physiological and psychological reactions but with no long-term adverse health effects.
- 'Protection guides' – the exceedance of these noise levels gives justification for mitigation measures. Remaining within these levels is expected to exclude health hazards for the average person although impairments might occur in sensitive groups.
- 'Critical loads' – the exceedance of these levels forces the establishment of noise abatement measures as health hazards are no longer excluded. These levels shall be tolerated only exceptionally during a limited time.

The evaluation criteria are defined in terms of indoor L_{Aeq} and, in the case of sleep disturbance, L_{ASmax}. The values are reproduced in Table 4 for reference.

Noise Level	Threshold Value	Protection Guide	Critical Load
Communication			
$L_{Aeq,16hr}$ indoor	35dB	40dB	45dB
Sleep			
$L_{ASmax,22:00-06:00}$ indoor	23 x 40dB	13 x 53dB	6 x 60dB
$L_{Aeq,22:00-06:00}$ indoor	30dB	35dB	40dB

Table 4: Aircraft Noise Evaluation Criteria[15]

Comparison of the values in Table 4 above with those in Table 4 of BS8233 reveals that, discounting the 1-hour shift in the definition of the night period, the 'Protection guide' and 'Critical Load' equivalent levels represent a 5dB and 10dB uplift on the BS8233 limits.

Other studies[16,17] show that residents tend to close their bedroom windows as environmental noise reaches higher levels with more than half of windows being closed when the outside road traffic noise levels exceed 55dB L_{Aeq}. Interestingly, residents with closed windows reported a reduction of sleep disturbances due to noise but also reported an increase in sleep disturbances due to poor ventilation[17].

The WHO Night Noise Guidance[18] defines Interim Target-II as 55dB $L_{Aeq,8hr}$ outdoors, a level that can be used for health impact assessments for new transport projects.

The Passchier-Vermeer study[19] found that the most common situation is for windows to be partially opened during the night period. Applying an inside-to-outside level difference of 15dB corresponding to a partly opened window[18] gives a correlation between an outdoor level of 55dB $L_{Aeq,8hr}$ and the 'Critical Load' internal level for sleep in Table 4.

Given that the control of overheating is only required for a limited portion of the year, it may be appropriate to consider the application of the 'Protection Guide' or 'Critical Load' values from Table 4. However, the acceptability of higher levels will clearly be related to how often the situation arises. A higher level would likely be viewed as acceptable on the few hottest nights of the year than that which can be expected for a large period of the summer months. It is therefore suggested that any assessment of external noise levels relating to overheating should include information about the frequency and duration of noise levels in excess of the BS8233 limits.

6 CONCLUSIONS AND FUTURE WORK

There is currently insufficient guidance regarding indoor ambient noise levels that should be achieved in residential developments in the situation where measures are required to control overheating. This lack of guidance is resulting in residential developments with poor indoor environmental conditions where residents are not able to achieve thermal and acoustic comfort at the same time.

The problem is exacerbated by the move towards better insulated, more airtight buildings and the need, particularly in urban areas, to consider development on noisier sites. It seems very likely that this is giving rise to unnecessary sleep disturbance and adverse health effects in an increasing population of people.

An ANC working group has been formed with the aim of producing a design guide to address this issue. As a start point, the design guide will clarify the relevant definitions of ventilation and overheating for residential development to act as a reference for acoustic designers. The design guide will also give quantitative guidance as to how to assess internal noise levels in the situation where windows are open or other means of controlling overheating is provided. Examples of acoustic design solutions and case studies will be provided for reference.

The work undertaken by the ANC working group to date suggests that there are no existing research studies on 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 alleviation of overheating is required. 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 behavior in real-life conditions.

The intention is that the first release of the design guide should not wait for such research to be undertaken but instead the guide be an ever-evolving document that will be updated and improved as further information becomes available.

7 REFERENCES

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