ASSESSING NOISE AND OVERHEATING IN DWELLINGS: ALIGNING ACOUSTIC AND THERMAL MODELS FOR PARTIALLY OPEN WINDOWS

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ABSTRACT

A Building Regulation to limit overheating in dwellings came into force in England in June 2022. This requires that the provisions to mitigate overheating are usable by the occupants. The internal noise limits while using opening windows for ventilative cooling at night are 40 dBA L_{night} and 55 dB L_{AMAX} (10^{th} highest). A clarification to the guidance indicates that windows may be modelled as partially open; this enables justification of reliance on natural ventilation at night in noisier locations than if windows must be modelled as fully open.
A simple acoustic model for a partially open window is examined for its accuracy. The thermal model relies on the CIBSE TM59 method, with the adaptive thermal comfort model when using opening windows. However, the ventilation performance of window openings is described in the thermal model with an "Equivalent area" (EA), and typically modellers assume an ideal aperture. Achieving a consistent understanding of the respective performance for a partially open window between the acoustic and thermal models is not simple.
The basis of the models for the acoustic and ventilation performance of a partially open window are discussed. A description for a new characteristic, the "acoustic open area", is proposed.

Keywords: Noise, Overheating, Opening windows, Residential, Thermal comfort, Acoustic comfort

1. INTRODUCTION

The English government has introduced a new Building Regulation [1] to mitigate overheating in new residential buildings. This is part of the government's response to adapting to climate change [2]. Approved Document O (ADO) [3] describes the Regulation, as reproduced in Figure 1.
When the Regulation came into force in June 2022, the government published a series of FAQs on its website [4] (ADO-FAQ). These ADO-FAQs modify the guidance given in ADO in materially significant ways, as is described in this paper. There is also guidance on the application of ADO produced by the Future Homes Hub [5], along with calculation tools.
ADO describes how windows cannot be assumed to be open during the night time period if internal noise levels exceed guideline values. This means that an acoustic assessment and an overheating assessment are both required to assess the indoor environmental quality (IEQ) conditions simultaneously. It is (surprisingly!) challenging to align assumptions regarding acoustic models and thermal models of a partially open window.

2. BACKGROUND

2.1 Noise level guidelines

The WHO's Guidelines for Community Noise (WHO GCN) [6] indicate internal noise level guidelines. BS 8233 [7] reiterates the 30 dBA L_{Aeq} guideline, but omits the 45 dB $L_{AF,max}$ guideline. ProPG: Planning and Noise

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(2017) [8] reintroduces the 45 dB $L_{AF,max}$ guideline in its notes, and approaches the concept of opening windows for thermal comfort and internal noise levels. The gap in guidance resulted in 85 % of new developments having overheating assessments assuming that the windows were open, and noise assessments assuming that the windows were closed [9].

2.2 The AVO Guide

The Acoustics, Ventilation, Overheating – Residential Design Guide [10] (AVO Guide) was published in January 2020. This was the first industry publication to propose alternative (relaxed) indoor ambient noise guidelines in residential buildings when using opening windows to mitigate overheating, based on a concept of "adaptive acoustic comfort" [11]. A joint statement has been published [12], that provides endorsement for the ProPG and AVO Guide by the CIEH.

2.3 Noise Policy Statement for England

The English Government's policy on noise is described in the Noise Policy Statement for England (NPSE) [13]. This describes how noise should be taken into account. The second aim of the Noise Policy Statement for England is:
Mitigate and minimise adverse impacts on health and quality of life from environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development.
A note in the NPSE clarifies the meaning of this statement. In developing the guidance in the AVO Guide, the authors recognised this policy aim. In the light of our sustainability crisis, the authors sought to avoid the need for construction and operation of mechanical systems to mitigate overheating as far as possible; it was considered that some adverse impacts from noise could be acceptable.

2.4 Open area terminology

Jones *et al* [14] provide a set of descriptions that can be used unambiguously to describe façade openings. For example, six different methods of attributing a value of "free area" to an open window are presented by Sharpe et al [15]. "Free area" remains an ambiguous term without consistent definition, despite its widespread use. The Equivalent Area is a description of flow performance. Appendix D of ADO refers to a tool to calculate EA [36]

3. APPROVED DOCUMENT O (ENGLAND) 2021

There are two methods described to demonstrate compliance. The first is referred to as the "Simplified Method", although according [16], it is "far from simple". The alternative method is dynamic thermal modelling. The Future Homes Hub has produced a guide to designing to comply with Approved Document O [17]. That guide refers to the (currently Draft) "Guide to Demonstrating Compliance with the Noise Requirements of Approved Document O" (GDC-ADO) [18].

3.1 The Simplified Method

The Simplified Method describes in tables the constraints to glazed areas to limit solar gain. These areas are a function of the room size, geographical location, largest glazed façade orientation, and whether there is cross-ventilation or not. Similarly, it describes requirements for what it describes as a "minimum free area". However, there is considerable confusion over the use of the term "minimum free area" within ADO, such as para. 1.12:
Openings should be designed to achieve the free areas in paragraphs 1.10 and 1.11 [of ADO]. The equivalent area of the opening should meet or exceed the free area of the opening.
The intended meaning is only confirmed in the ADO-FAQs # 8 [4], which clarify that everywhere ADO says "minimum free area", the reader can understand this to mean "minimum equivalent area".

3.2 Dynamic thermal modelling

If the Simplified Method cannot be used, then compliance must be demonstrated using dynamic thermal modelling. ADO refers to the CIBSE TM59 [19] method, but adds additional constraints to how that methodology is applied. The relevant aspects here are the indication in ADO that:
All of the following limits on CIBSE's TM59, section 3.3, apply:

- *At night (11pm to 8am), openings should be modelled as fully open if ... the following apply.*
- *...The internal temperature exceeds 23°C at 11pm*

However, the guidance of ADO FAQ #14 supersedes the guidance in ADO, by indicating that
..opening windows a smaller amount at night.
This note may facilitate designers demonstrating compliance with ADO by using natural ventilation with opening windows in many more situations that would otherwise have been possible.

3.3 Acoustic constraints

One of the requirements indicated in ADO for the "reasonable enjoyment of the residence" concerns noise levels. ADO indicates that:

… the overheating mitigation strategy should take account of the likelihood that windows will be closed during sleeping hours (11pm to 7am).

Windows are likely to be closed during sleeping hours if noise within bedrooms exceeds the following limits.

a. 40 dB $L_{Aeq,T}$, averaged over 8 hours (between 11pm and 7am).

b. 55 dB L_{AFmax}, more than 10 times a night (between 11pm and 7am).

4. SOUND INSULATION OF FAÇADE OPENINGS

In order to determine the internal noise levels from external sources it is necessary to determine the façade sound insulation provided by a partially open window. For many years, this has been the subject of much debate amongst the acoustics community. For many practitioners, the "10 – 15 dB" quoted by the WHO GCN is the answer to this question. This rule of thumb takes no account of the extent of window opening, or any of the other factors that may affect the façade level difference.

There are three methods for assessing the sound insulation of a partially open window:

- Field measurements of an equivalent installation
- Laboratory measurements applied in-situ
- Theoretical assessment

4.1 Field measurements of opening windows

In practice, representative field measurements [20] are rarely available at the design stage; moreover, the assessment is typically required before particular window types are specified. Therefore the use of appropriate field measurements is seldom a suitable strategy for determining compliance.

There are a range of studies of the in-situ performance of opening windows, notably Locher *et al* [21]. This study takes account of windows being closed, open in the tilted position, or open in the turned position – the area of opening is not explicitly identified. Comparison is also made with previous studies, including one by Ryan et al.

Ryan *et al* [22] also present window open areas and room volumes, along with external and internal level differences and standardized level differences (i.e. the internal level corrected to a reference reverberation time, in this case 0.35 secs). This enables re-calculation of the results as presented further below.

4.2 Laboratory measurements of open windows

Standardised laboratory measurements are conducted to ISO 10140-2 [23]. However, the largest laboratory study of partially open windows is reported in NANR116 [24]. The measurements in this study were not made according to ISO 10140-2, but rather from an anechoic chamber with a directional sound source, into a reverberation room. As noted in that study, the insulation rating specified from a test methodology needs to be appropriate to the intended application, but this also makes comparisons with other data more difficult. The values reported for the level difference or normalised element level difference, $D_{n,e}$ would be different compared with values measured according to BS EN ISO 10140.

Nunes et al have investigated [25] the acoustic performance of open windows, comparing the free field and diffuse field sound reduction for the same proprietary window that was tested in a laboratory. The proprietary window presented different results between freefield and diffuse field conditions; the authors suggested that openable windows should not be tested in diffuse conditions. The application of various types of laboratory data in any specific situation should be considered carefully.

4.3 Theoretical assessment of façade sound insulation

The appropriate Standard for calculating the sound insulation of a building façade against outdoor sound is BS EN ISO 12354-3 [26]. The informative Annex D of that standard suggests that for unsilenced air inlets, like openings or louvres, a global indication is given by treating the element as an opening with negligible sound reduction. This results in an element normalized level difference as shown in Eqn 1.

$$D_{n,e} = -10.lg\left(\frac{S_{open}}{A_0}\right) \qquad \text{Eqn 1}$$

Where: S_{open} is the area of the opening, in square metres

A_0 is the reference equivalent sound absorption area, 10 m^2.

The proposal in GDC-ADO is to use the "area of the opening" of a partially open window to determine the appropriate sound insulation. However, the "area of the opening" of a partially open window is not well defined. As we have seen, the term "free area" is used widely but without definition.

4.4 Acoustic open area

The GDC-ADO proposes that an "acoustic open area" (AcOA) is considered for a partially open window. This is derived by considering a partially open window light as a flat rectangular plane, within a two-dimensional plane façade. This disregards the depth of the window opening light frame and its overlap with the surrounding window frame.

The AcOA is conceived as the lesser of two areas:

- The sum of the rectangular area at the base and the two triangular areas formed on each side of the opening light;
- The width * height (w * h) of the opening in which the opening light sits

The potential AcOA is shown shaded in Figure 1.

The dimension "z" is given by simple geometry as shown in Eqn 2.

$$z = 2.w.sin\left(\frac{\alpha}{2}\right) \qquad \text{Eqn 2}$$

Where α is the opening angle.

The area of top shaded triangle is given by (1/2 * base * height), which is 0.5 * w * w.sin(α). Therefore the area of both triangles, top and bottom, is simply w^2.sin(α).

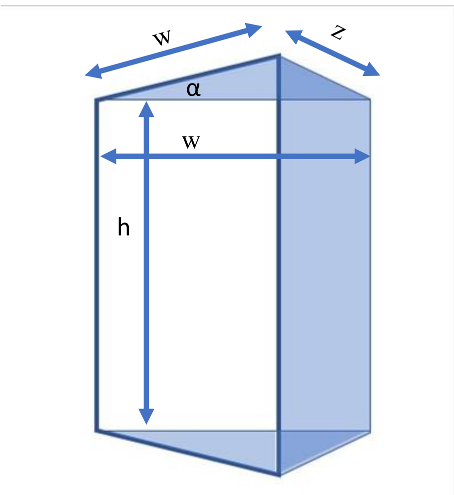

Figure 1: Concept of "acoustic open area" shown shaded, with the window opening light opening out of the page.

The total AcOA is given by the lower of areas from Eqn 3 or Eqn 4.

$$AcOA \leq w^2.sin\,(\alpha) + z.h \qquad \text{Eqn 3}$$

$$AcOA \leq w.h \qquad \text{Eqn 4}$$

For a given room volume, the partial internal level due to a partially open window can be calculated using Eqn 1, using the methods described by J Harvie-Clark [27], which is consistent with the details described above.

4.5 Potential accuracy of Acoustic Open Area (AcOA)

Where there is data available for window openings and associated sound insulation, the measured values may be compared with the predicted values using the AcOA. Three existing published data sets are used in this way:

- Proprietary window with laboratory tests
- NANR 116 laboratory tests
- Field measurements by Ryan *et al*

Additionally, we are conducting field trials to validate the use of AcOA - see Section 5.

4.5.1 Proprietary window laboratory tests

The tests [28] present a window with an opening light 1.1 * 0.3 m (w * h) open to different dimensions. The simple assumptions of the AcOA model are used to determine the AcOA and calculated element-normalised level difference. Comparison with the reported values is shown in Figure 2. This shows very good agreement between measurements and calculated values – to the limit of precision of the reported $D_{n,e,w} + C_{tr}$ values.

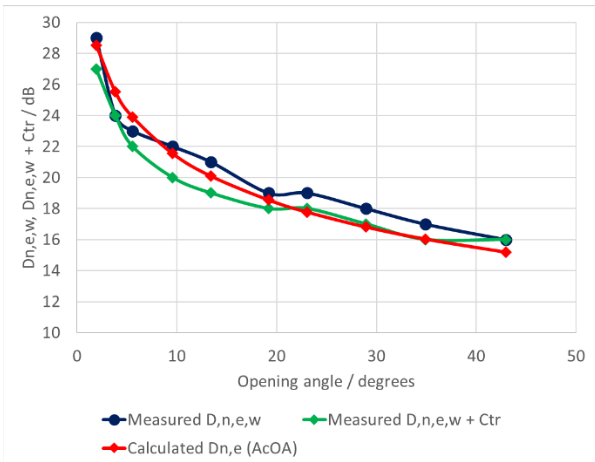

Figure 2: Proprietary window level differences

4.5.2 NANR 116 laboratory tests

As noted, the tests detailed in NANR116 deviate from standard ISO 10140-2 test methods, in order to attempt to provide data that is more representative of field conditions. The summary of the report is that opening sizes can be broadly represented by the sound insulation levels shown in Table 1. The corresponding insulation values calculated using the AcOA approach would be 23, 20, 17 dB for 0.05, 0.1, 0.2 m^2 respectively. At larger open areas, the discrepancy between calculated and inferred values is reduced, and the open areas required to mitigate overheating are typically larger than these values.

Table 1: NANR116 summary of insulation

Opening size / m^2	$D_{n,e,w} + C_{tr}$
0.05	18
0.1	17
0.2	15

To review in greater depth, the AcOA calculated and measured level differences are reviewed for the representative range of window types, as shown in Figure 3. The measured values for 0.1 m^2 AcOA (solid blue bars) may be compared with 20 dB (dashed blue line), and the values for 0.2 m^2 AcOA (solid green bars) may be compared with the value of 17 dB (dashed green line). Also included, shown hatched, are the values calculated on the EA for each window arrangement. Calculating the insulation based on the EA rather than the geometrically measured AcOA has many advantages.

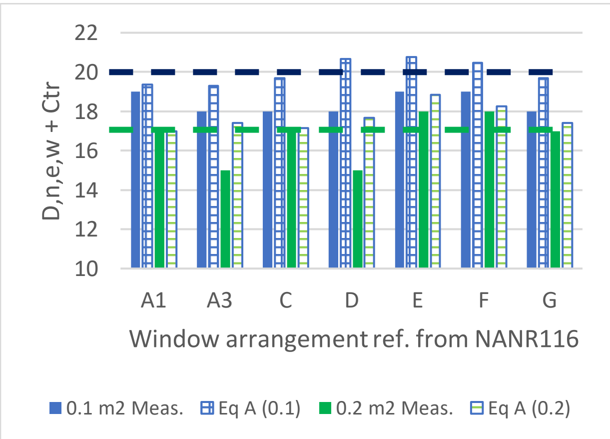

Figure 3: NANR116 measured and calculated level differences. The dashed lines represent the AcOA calculated performance for 0.2 m2 (blue) and 0.1 m2 (green) ventilation areas.

4.5.3 Field measurements by Ryan et al

Ryan notes there were no Standards for making these sound measurements; he reports that the external measurements were made in front of the façade at ground level, and a 3 dB correction was applied to account for this, without any more detail. The method used is the same as the AcOA method (following EN 12354-3: 2000), to a different reference reverberation time than is typically used in the UK (0.35s, c.f. 0.5s). These calculated results are not presented by Ryan et al, although based on the data presented it can be calculated as shown in Figure 4, with a reference reverberation time of 0.5 s; this figure also includes the Australian method in AS 3671 (1989). Figure 4 indicates that the AcOA method generally over-predicts the insulation achieved, whereas in the commentary, Ryan indicates that "*in general the calculated level internally was above the levels that the field measurement achieved*". If this were so, the AcOA calculation method would be prudent, although other evidence presented here suggests the opposite.
Ryan also indicates that "*the results of this investigation do illustrate that it is unadvisable to use this simple method to determine the noise reduction achieved by a facade with an open window subject to road traffic noise*". However, no alternative method is proposed.

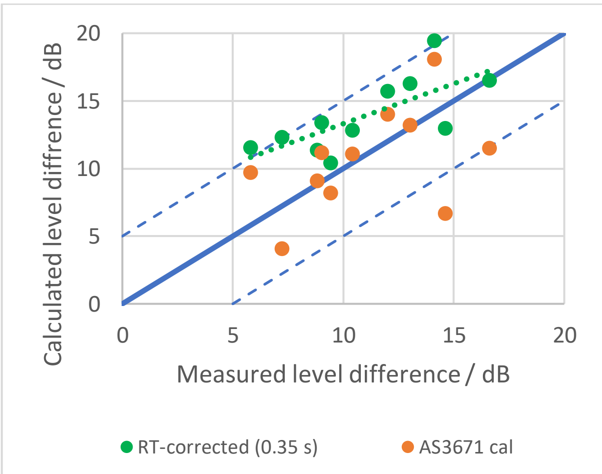

Figure 4: Measurements by Ryan et al, with the AcOA insulation calculated.

5. PRELIMINARY VALIDATION FIELD MEASUREMENTS

5.1 Methodology

The site selection comprises dwellings that are exposed to steady continuous road traffic noise travelling perpendicular to the facade. The measurements have sought to determine the standardized level difference, $D_{1m,nT}$. Measurements were taken in a first floor bedroom comprising a single window with one openable pane. An external $L_{eq,30s}$ measurement over the one-third octave bands 50 Hz to 5 kHz was taken (> 50 vehicles passing within 30s) using a fixed microphone 1 m from the facade to represent $L_{1,1m}$, based on the element road traffic method set out in [20]. Immediately after the external measurement, the window was opened by stepped amounts as measured by the gap between the frame and the window casement and in each case internal measurements of $L_{eq,30s}$ were taken using a manual scanning technique, in accordance with [20]. While consecutive measurements contribute to uncertainty, the uncertainty has not been evaluated here; further measurements will use simultaneous recordings. RT measurements with the window closed were made in accordance with BS EN ISO 3382-2. Background noise readings were also taken over the same duration using the same internal noise level sampling technique.


Photo 1: Site 1 Window Photo 2: Site 2 Window Open

Table 2: Summary of Room Parameters

Site	Room Dimensions W*D*H / m	Facade Area	Openable Pane H*W / m	Hanging & Opening
1	1.7 x 3.0 x 2.4	5.1m2	0.35 x 0.76	Top Hung, Outwards
2	5.3 x 2.8 x 2.4	14.8m2	0.798 x 1.124	Side Hung, Inwards

5.2 Results

The measurement data is evaluated by calculating the standardized level difference in accordance with [20], normalized to a room reverberation time of 0.5s. The calculated $D_{1m,nT,w} + C_{tr}$ is based on Eqn 1, using the methods described by Harvie-Clark [27]. The calculated level difference based on AcOA is based on Eqns 3 & 4; when based on EA, the EA is calculated according to [36].

Table 3: Results for Site 1

Opening Distance (mm)	Opening Angle (degrees)	AcOA (m^2)	EA (m^2)	$D_{1m,nT,w} + C_{tr}$ (dB) based on		
				Meas'd	Calc AcOA	Calc. EA
300	59	0.27	0.21	9	9	10
100	17	0.11	0.11	11	12	12
50	8	0.06	0.06	10	15	15

Table 4: Results for Site 2

Opening Distance (mm)	Opening Angle (degrees)	AcOA (m^2)	EA (m^2)	$D_{1m,nT,w} + C_{tr}$ (dB) based on		
				Meas'd	Calc AcOA	Calc EA
400	30	0.78	0.57	7	9	10
350	26	0.68	0.53	9	9	10
300	22	0.58	0.48	8	10	11
250	18	0.48	0.43	8	11	11
200	15	0.39	0.36	8	12	12
150	11	0.29	0.29	11	13	13
100	7	0.19	0.21	12	15	15

5.3 Discussion

The field measurements show some correlation (within 4 dB) with the calculated $D_{1m,nT,w}$ using the AcOA. However, the calculated level difference is consistently higher than the measurements. The over estimation of actual sound insulation performance is seen with measured and calculated values in Figure 5.

It can be seen that the calculated values tend towards the measured values for higher values of AcOA. A better relationship than EA and AcOA is required before the approach can be considered accurate.

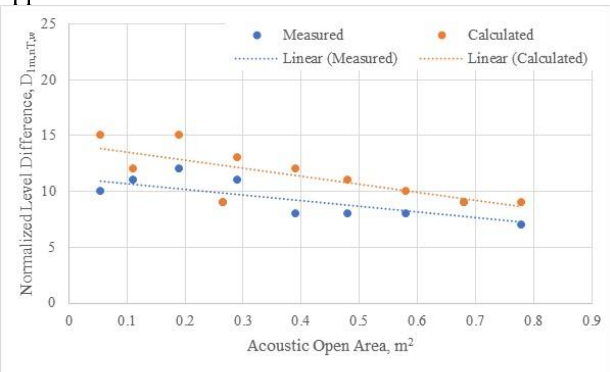

Figure 5: Measured and calculated values compared

6. MODELLING OVERHEATING RISK

According to Petrou et al [29], Tian et al [30] explains that building performance simulation uncertainty can be classified into two broad categories: Model form; and Parameter uncertainties. Empirical validation work has demonstrated how the combination of both types could lead to significant discrepancies between the model and actual indoor environment, according to Strachan *et al* [31]. Petrou *et al* focus on the magnitude of possible parameter uncertainties associated with the modellers' algorithm choice.

In the thermal model, a façade opening permits air exchange between inside and outside. The complexity of this in practice is described by Sharpe *et al* [15], who describe 15–25 % prediction errors of free area models commonly used in practice. The options available to modellers are complex; default practices are adopted that are generally considered to be "good practice" [32].

Petrou *et al* demonstrated [33] that the choice of building simulation tool, with default algorithm options, significantly affected the prediction of overheating risk. Wind-driven ventilation and surface convection algorithms were the main sources of the observed discrepancies. The choice of algorithm within each building simulation tool was investigated by Petrou *et al* [29]. The selection of non-default algorithms within each model also had a very significant impact on the results. Roberts *et al* [34] compared predictions and measurements of overheating risk in synthetically occupied test houses. It is understood that TM59 is currently under revision.

7. DISCUSSION: "ALL MODELS ARE WRONG…

.. some are useful", according to George Box [35]. While it is important that the assumptions between the acoustic and thermal models are consistent, excessive precision is unnecessary and counter-productive if it is inaccessible to most practitioners. The façade sound insulation performance that may be achieved depends on the type of incoming sound field (degree of diffusivity), angle of incident sound, arrangement of opening light, reveal depth, opening type, and internal room conditions. Most of these factors are not known or even knowable with current technology. Ryan *et al* indicates that there are additional unknowns when considering L_{max} sounds. Based on wide experimental data by Scrosati *et al* [37,38], façade sound insulation is not recommended to correlate external and internal sound level descriptors.

7.1 AcOA equated with EA

The use of the AcOA is based on an engineering concept of the façade opening and ISO 12354-3. If this same assessment is based on the EA, rather than the AcOA, there may be some additional uncertainty introduced in some assessments. The proprietary window laboratory tests have a calculated EA that matches almost exactly the AcOA, therefore there is no loss of accuracy. The NANR116 data indicates that using EA in this way makes a variable small difference to the predictions.

There is a very significant advantage in calculating façade sound insulation based on EA. It greatly facilitates the exchange of model attributes with the overheating modeller. Indeed, thermal modelers may often default to treating an open area as an EA in any case.

8. CONCLUSION AND FURTHER WORK

There is a great deal of uncertainty in the prediction of the façade sound insulation of a partially open window. Many advances in acoustic measurements, modeling, laboratory tests, and standardization of these new methods will be required to significantly reduce this uncertainty. The industry will need to judge if this is a priority, or if simple methods are sufficient. To this end, it is suggested that the accuracy of the simple methods proposed here are evaluated in more depth, to determine their sufficiency or otherwise.

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