THE AVO GUIDE – WORKED EXAMPLES

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1 INTRODUCTION

The Acoustics, Ventilation, Overheating: Residential Design Guide[1,2] ("The AVO Guide") was launched by the Association of Noise Consultants and Institute of Acoustics in January 2020. It is anticipated that it will quickly become a standard reference for practitioners in the UK when considering noise affecting new residential development. It represents a significant step forwards in guidance, by integrating considerations for noise with the ventilation strategy and provisions for mitigating overheating.

The AVO Guide was developed by a group of industry experts (see Acknowledgements for full list of members), with additional input from associated professionals working in other disciplines.

Appendix B of the AVO Guide provides examples of how the guidance contained in the main part of the guide might be applied. This paper provides two worked examples of the application of the AVO Guide, one relating to noise and ventilation and one relating to noise and overheating. The worked examples relate to real projects but have been anonymised for the purpose of this paper.

2 EXAMPLE 1 – NOISE AND VENTILATION

2.1 Description of Building and Noise Environment

A block of small one and two-bedroom flats is proposed, located close to a city centre road with steady traffic throughout the day and night-time. The building layout and free-field noise levels at the location of the proposed façades are shown in Figure 1.

The dwellings to be assessed (shaded in Figure 1) are single-sided flats, one located on the quieter façade and one on the noisier façade. The dimensions of the rooms in each flat that require assessment are given in Figure 2.

The ventilation provision is being designed in accordance with Approved Document Part F (ADF)[3] and will adopt one of the template systems it describes.

Due to the single aspect design, the ventilation designers have advised that an ADF System 1 approach for a one-bedroom flat would require a minimum of 30,000mm² equivalent area vents in each bedroom and 60,000mm² equivalent area in the living/dining room.

ADF System 3 is also being considered as an alternative to System 1.

With reference to the "Step 2 – Noise & Ventilation" column of AVO Guide Figure B-1, the above information can be taken to satisfy the initial activity of "Gathering Information".

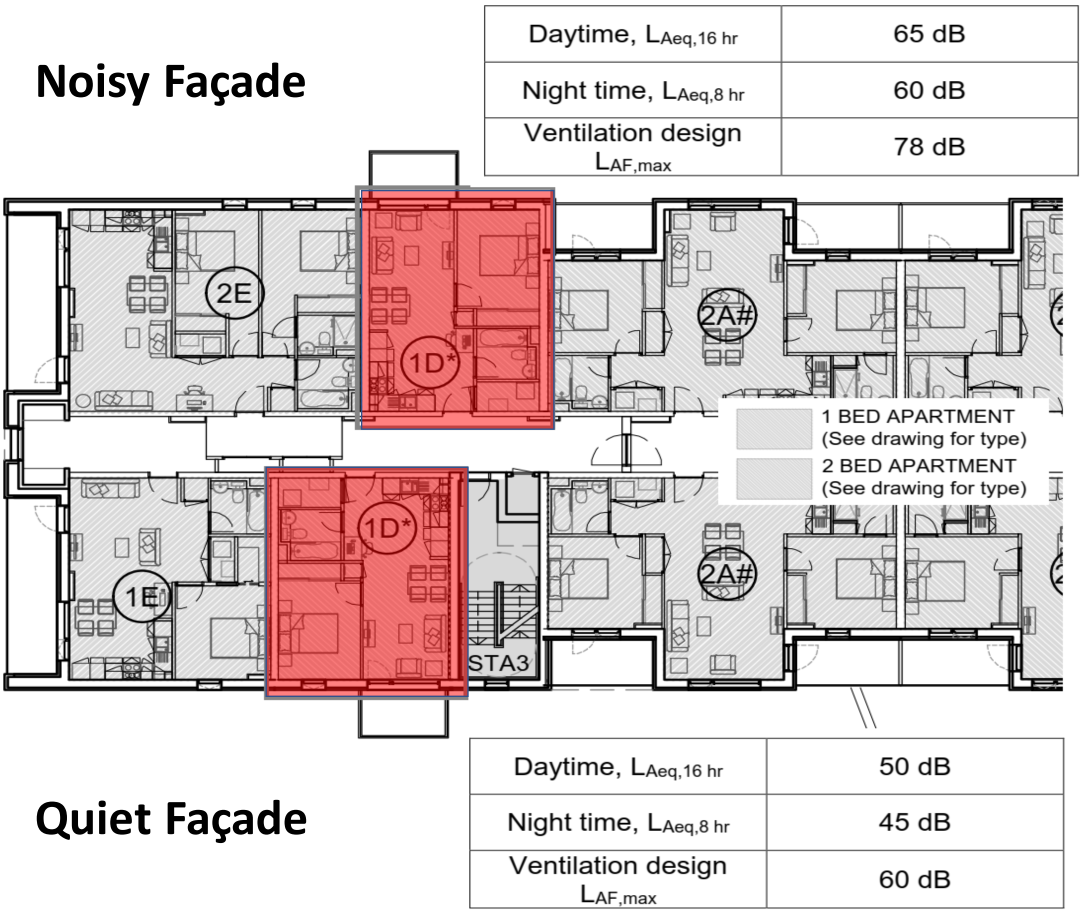

Figure 1: Building Plan (not to scale) indicating the two dwellings to be assessed and the relevant façade noise levels

Room	Floor area [m²]	Height [m]	Glazed area [m²]
Bedroom	11	2.4	1.4
Living Room	24	2.4	2.8

Figure 2: Dimensions of rooms to be assessed.

2.2 Potential Constraints on Ventilation Strategy

Following Figure B-1 of the AVO Guide, the next activity is to "Assess" which ADF template systems is likely to be feasible given the noise environment. Initially, the guidance provided in Table B-3 of the AVO Guide can be used as a basis for this assessment.

Based on Table B-3, it could be concluded that any ADF System could be used for the dwelling on the quiet façade of the building. For the dwelling on the noisier façade, all ADF Systems would be feasible but Systems 1, 2 and 3 would require the use of acoustically attenuated background ventilators (i.e. acoustic trickle vents).

However, it is important to keep in mind the underlying assumptions that are used in producing the guideline free-field external noise limits set out in Table B-3. As noted in paragraph B.20 of the AVO Guide, the guidelines for Systems 1 and 2 describes the use of 'trickle vents' giving an equivalent area of 5,000mm². This assumption is most valid for houses and flats with more than one-aspect (enabling cross-ventilation). It can be seen from the information in Section 2.1 that this assumption is not valid for the single-sided flats under consideration and the feasibility of using ADF System 1 should be reviewed in light of this additional information.

A simple way to account for the higher equivalent areas requested by the ventilation designer for this building is to adjust the Systems 1 and 2 guideline limits of Table B-3 by a factor of $10.\log_{10}(A_{equiv}/5000)$. This effectively uses the simplifying assumption that all noise break-in is due to the trickle vents. In the case of bedrooms, this revises the values down by $10.\log_{10}(30000/5000) \approx 8$dB. In the case of living rooms, this revises the values down by $10.\log_{10}(60000/5000) \approx 11$dB. Figure 3 shows the effect of making these corrections to the guideline values of Table B-3.

Having taken account of the increased equivalent area of trickle vents proposed for this building, it can be concluded the use of System 1 is not appropriate for flats on the noisy façade. It may therefore be appropriate to consider the alternative System 3 solution in this location.

ADF System	Approximate guideline free-field external noise limits		
	Original values based on assumptions stated in AVO Guide paragraphs B.14 through B.27. i.e. trickle vent equivalent area of 5,000mm²	Revised values for bedrooms using trickle vents with equivalent area 30,000mm²	Revised values for living rooms using trickle vents with equivalent area 60,000mm²
1 or 2	With high performing acoustic glazing and 'acoustic' trickle vents: • $L_{Aeq,16hr}$ 66dB day • $L_{Aeq,8hr}$ 61dB night • L_{AFmax} not normally exceeding 80dB more than 10x per night.	With high performing acoustic glazing and 'acoustic' trickle vents: • $L_{Aeq,16hr}$ 58dB day • $L_{Aeq,8hr}$ 53dB night L_{AFmax} not normally exceeding 72dB more than 10x per night.	With high performing acoustic glazing and 'acoustic' trickle vents: • $L_{Aeq,16hr}$ 55dB day

Figure 3: Approximate corrections to AVO Table B-3 guideline limits to account for the increased equivalent area of trickle vents used on this building.

2.3 Advising Acoustic Requirements

Following Figure B-1 of the AVO Guide, the next activity is to "Advise" acoustic performance for relevant elements of the building.

Given that System 1 was not considered appropriate on the noisier façade, it was decided to use a System 3 ventilation solution across the whole building using trickle vents of equivalent area 2,500mm². With reference to Table B-3 of the AVO Guide, it would be appropriate for this system to advise performance requirements for the following elements:

- Noise from mechanical systems i.e. the Mechanical Extract Ventilation
- Sound insulation of façade glazing
- Sound insulation of trickle vents

For the mechanical ventilation noise, reference can be made to the desirable internal ambient noise level values given in Table 3-4 of the AVO Guide.

In the first instance, it may be sufficient to advise that rooms on the quiet façade can use standard domestic double-glazed windows but those on the noisy façade will need high acoustic performance windows (AVO paragraph B.24 assumes a performance of R_w+C_{tr}=37dB). The actual minimum performance specification for glazing should be determined by a more detailed calculation as discussed in Section 2.4.

In the first instance, it may be sufficient to advise that rooms on the quiet façade can use standard trickle vents but those on the noisy façade will need acoustic trickle vents (AVO paragraph B.24 assumes a performance of $D_{n,e,w}+C_{tr}$=41dB). The actual minimum performance specification for trickle vents should be determined by a more detailed calculation as discussed in Section 2.4.

2.4 Calculation of Indoor Ambient Noise Levels resulting from Transport Sources

A calculation based on equation G.1 of BS 8233[4] can be used as a method to calculate indoor ambient noise levels due to break-in of external transport sources., Equation G.1 is reproduced as Equation 1 here.

$$L_{eq,2} = L_{eq,ff} + 10log_{10}\left(\frac{A_0}{S}10^{\frac{-D_{n,e}}{10}} + \frac{S_{wi}}{S}10^{\frac{-R_{wi}}{10}} + \frac{S_{ew}}{S}10^{\frac{-R_{ew}}{10}} + \frac{S_{rr}}{S}10^{\frac{-R_{rr}}{10}}\right) + 10log_{10}\left(\frac{S}{A}\right) + 3$$

Equation 1: Equation G.1 from BS 8233. $L_{eq,2}$ and $L_{eq,ff}$ are the internal level and external free field level respectively; S is the total area of elements through which sound enters the room; $D_{n,e}$ is the sound insulation of the trickle vent; subscripts $_{wi}$, $_{ew}$, $_{rr}$ refer to the window, external wall and roof respectively; A is the equivalent absorption area in the room.

To simplify the calculation, with an acceptable loss in accuracy, it can be assumed that there is no noise ingress other than that through the window and the trickle vent (i.e. $S_{ew}=S_{rr}=0$). Figure 4 shows a calculation for a bedroom on the noisy façade. For brevity, the calculation is not shown in the explicit format used in BS 8233 Tables G.1 and G.2, but the method is the same.

The calculation is based on the L_{AFmax} requirement at night as this defines the most onerous requirement for the façade performance. The 'ventilation design case L_{AFmax}'[9,11] (see paragraph B.30 of the AVO Guide) is based on Section 3.4 of the 1999 WHO guidelines[5], which states "For a good sleep, it is believed that indoor sound pressure levels should not exceed approximately 45dB L_{Amax} more than 10-15 times per night". Note that this guidance for internal L_{max} has not been updated by the 2018 Guidelines[6].

Room Volume	26.4	m3						
Window Area	1.4	m2						
Number of vents	1							
Room RT	0.5	s						
	125	**250**	**500**	**1k**	**2k**	**A**	**Rw/Dw**	**Ctr**
$L_{Fmax,ff}$	80	76	74	74	71	78		
Window R_{wi}	24	26	40	48	46		41	-7
Vent $D_{n,e}$	40	37	34	43	50		42	-3
Indoor noise level								
L_{Fmax} from Window	51	45	29	21	20	39		
L_{Fmax} from Vent	44	43	44	35	24	43		
Total, L_{Fmax}	52	47	44	35	26	44		

Figure 4: Calculation of night-time indoor ambient L_{AFmax} noise level in the bedroom on the noisy façade. Calculation applies to the Part F ventilation condition (i.e. windows closed).

The sound insulation performance of the window is based on 6mm/16mm/8.8lam glazed units (including the effect of the frame). The sound insulation performance of the trickle vent is based on Titon SFXV75 giving an equivalent area of 2500mm². Given that the indoor level is just within the target value of 45dB L_{AFmax}, it may be appropriate to use these values as a basis for specifying the minimum performance requirement for these elements.

3 EXAMPLE 2 – NOISE AND OVERHEATING

3.1 Description of Building and Noise Environment

A residential development comprised of two tall towers is proposed to be built next to a major thoroughfare in SE London. Site map can be seen in Figure 5. The dwellings are mostly flats, some having a single-sided aspect and some dual aspect.

Measured noise levels informed an acoustic model of the proposed development. Expected free-field facade levels during the daytime and night-time periods can be seen in Figures 6 through 9.

The two flats to be assessed are indicated in Figure 10. One flat is located on the SE facade of the SW tower and the other on the NE facade of the NE tower. Information regarding room geometry and local facade levels are given in Figure 11. Note that the living rooms in both flats have balconies.

The initial design proposal from the mechanical engineers (thermal modellers) is that cooling is provided by standard opening windows. The mechanical engineers have advised the ventilation free area that must be provided for each room in order to meet the TM59[7] overheating criterion. The ventilation free areas are given in Figure 11. The free areas are given as the physical size of the opening in the facade as this is the most directly relevant value for the sound insulation calculation. Please be aware of the distinction between Free Area, Effective Area and Equivalent Area as noted in the Glossary (Section 4) of the AVO guide.

The mechanical engineers (thermal modellers) have also given an indication of the overheating risk, as assessed at an early stage using the Good Homes Alliance Tool[8], also shown in Figure 11.

With reference to the "Step 3 – Noise & Overheating" column of AVO Guide Figure B-1, the above information can be taken to satisfy the initial activity of "Gathering Information". Note that for the purposes of this worked example, individual noise events (L_{AFmax}) are not considered but they would need to be for a real building[9].

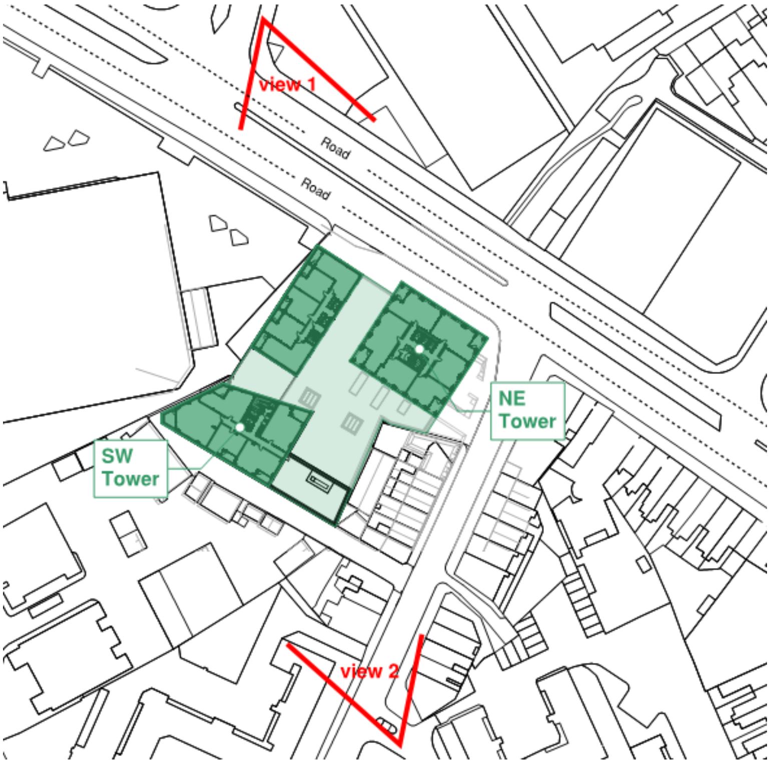

Figure 5: Site map indicating location of north-east and south-west towers of the development. The views corresponding to Figures 6, 7, 8 and 9 are also indicated.

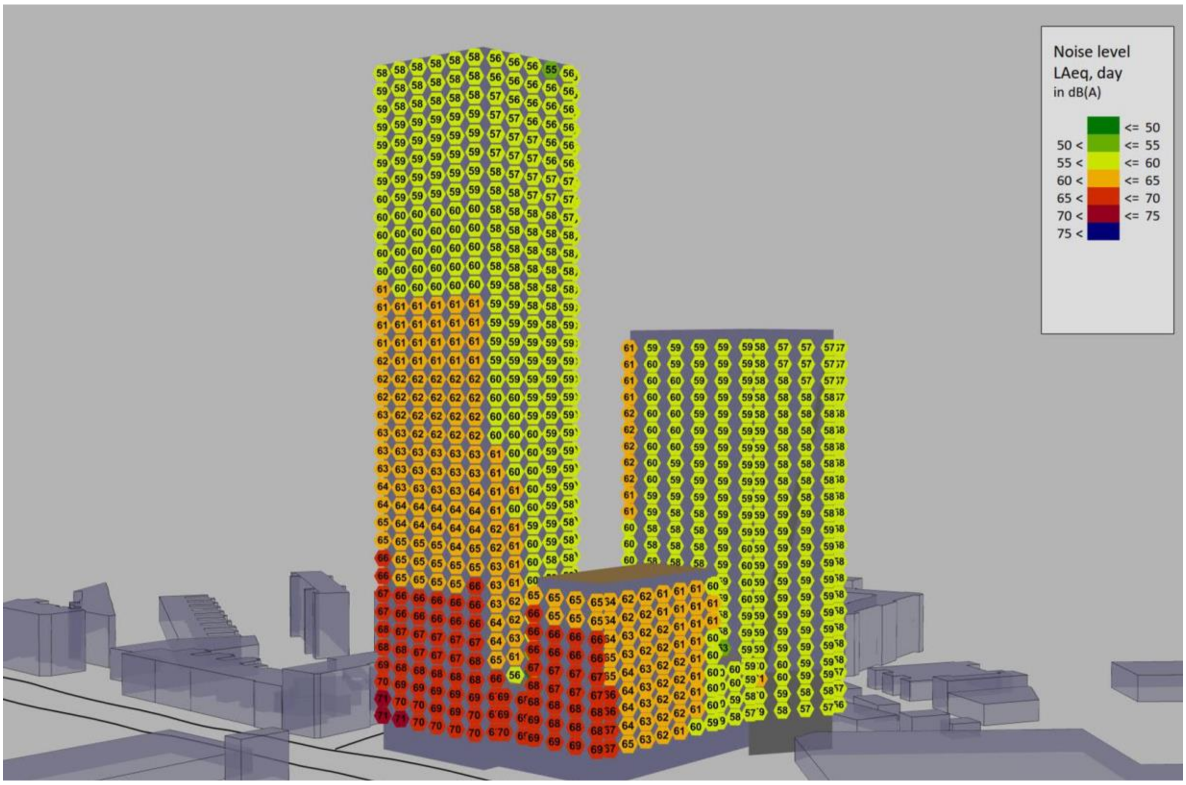

Figure 6: Daytime free-field external noise levels (View 1 as shown in Figure 5).

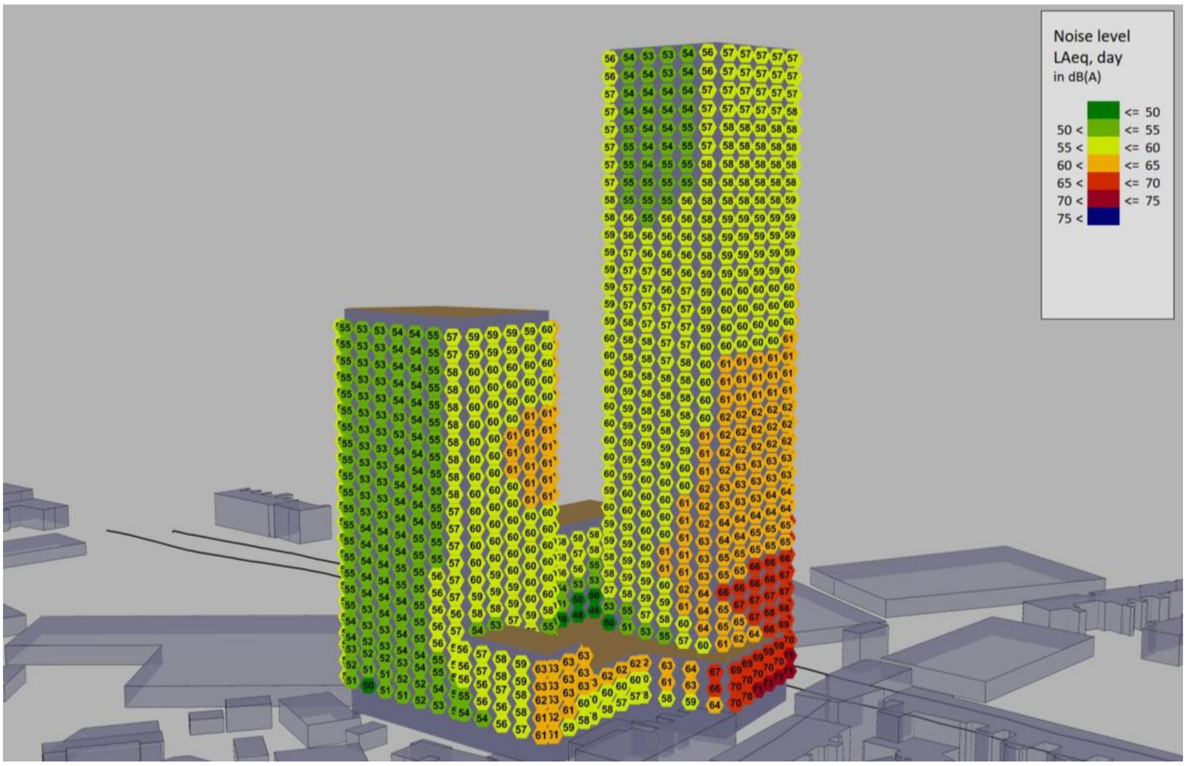

Figure 7: Daytime free-field external noise levels (View 2 as shown in Figure 5).

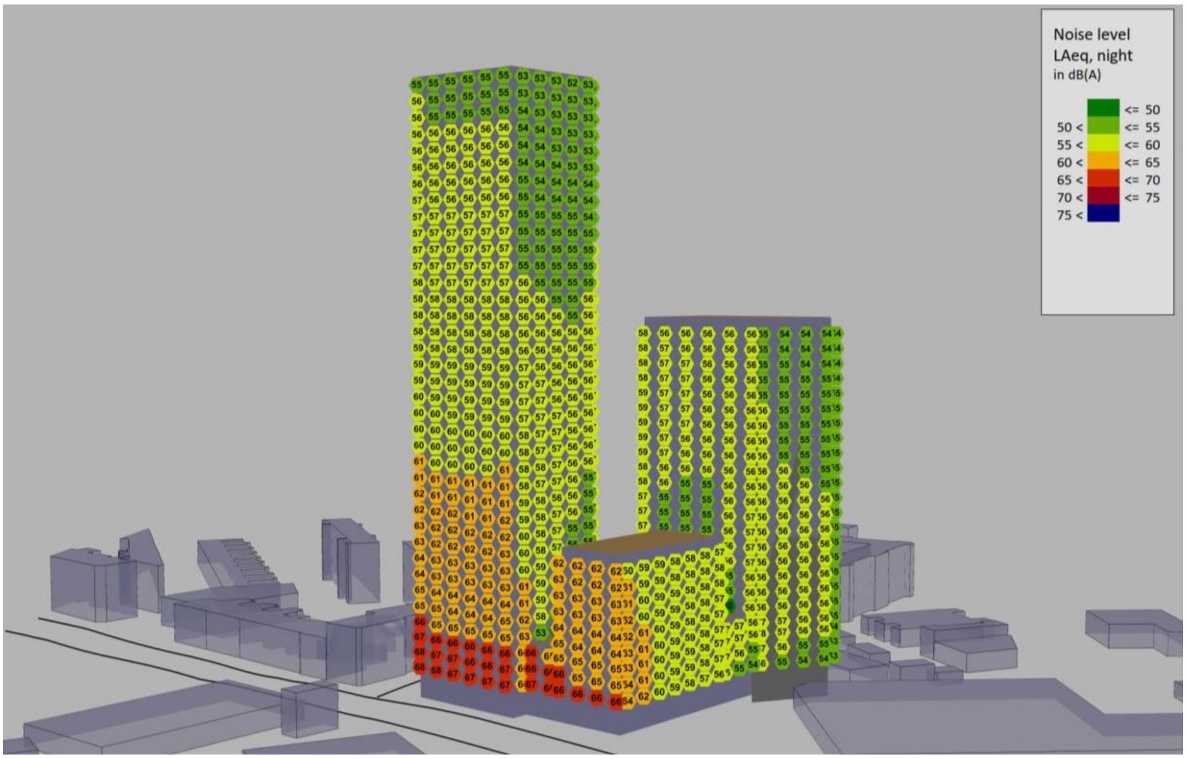

Figure 8: Night-time free-field external noise levels (View 1 as shown in Figure 5).

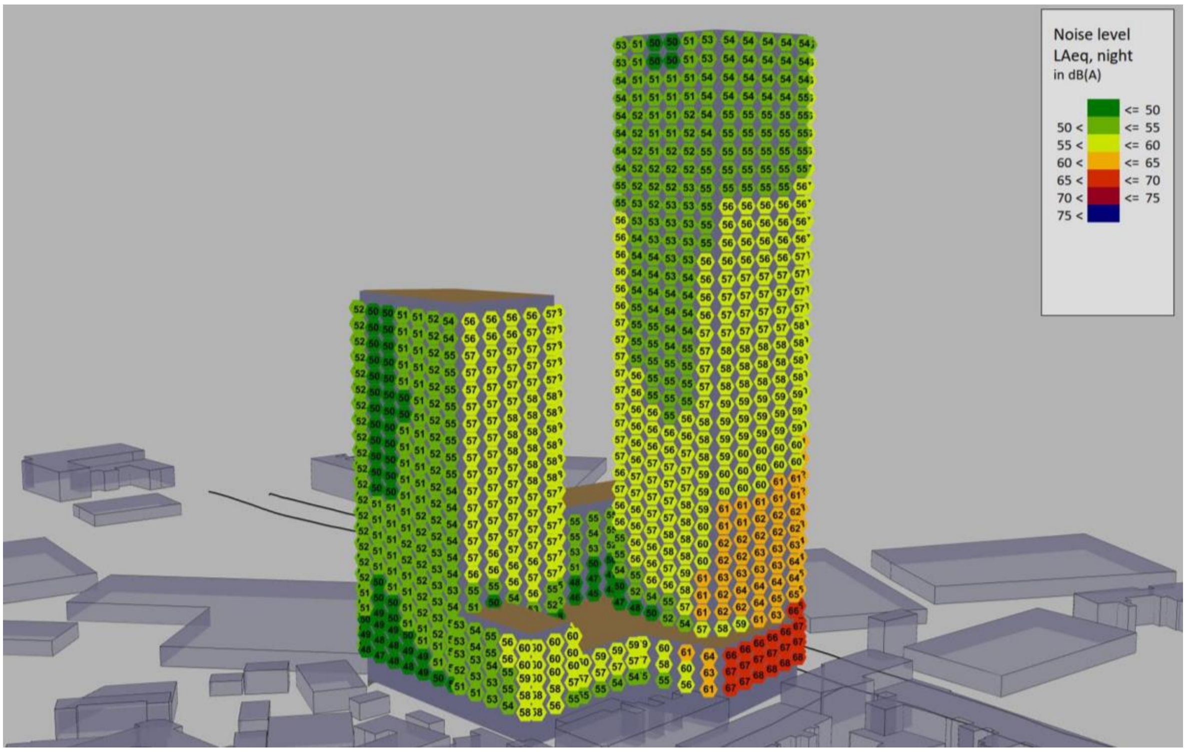

Figure 9: Night-time free-field external noise levels (View 2 as shown in Figure 5).

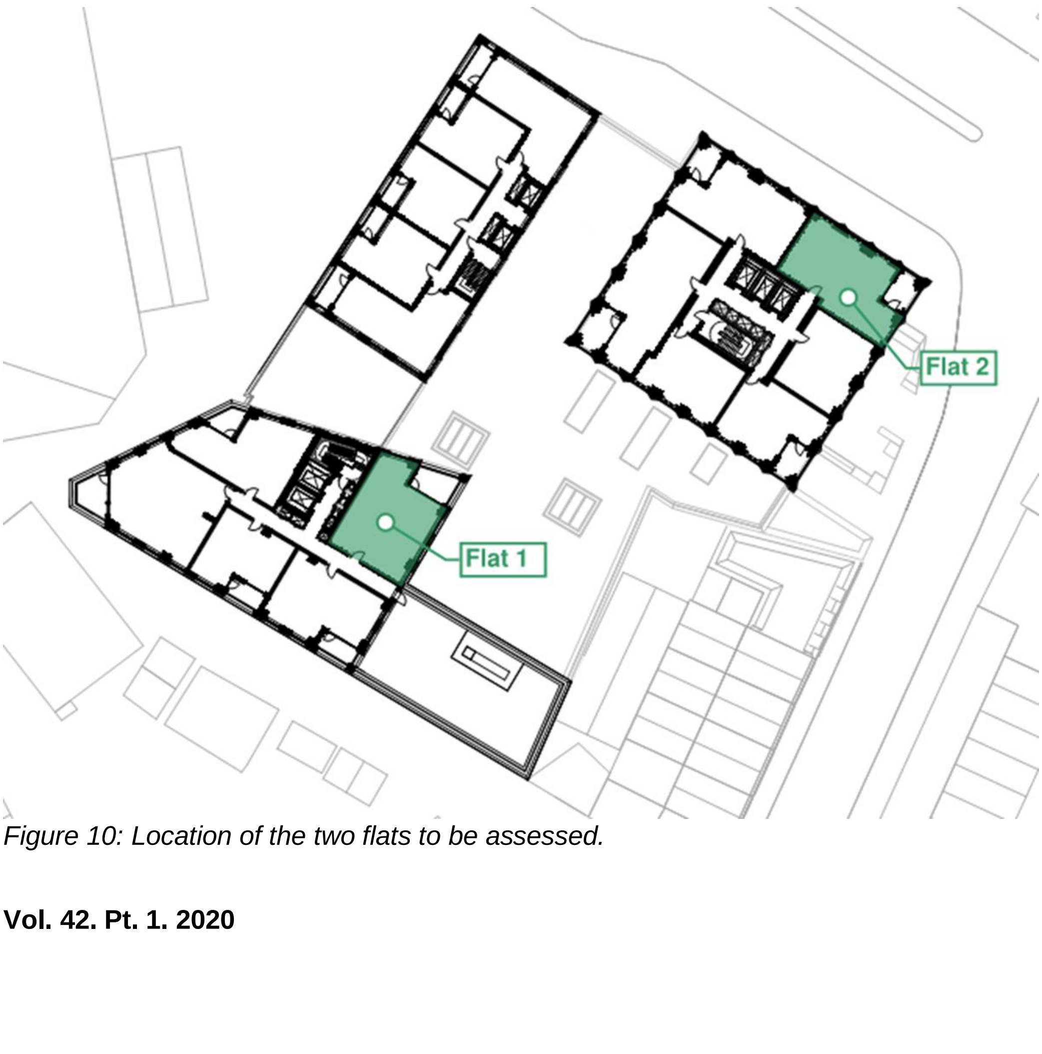

Figure 10: Location of the two flats to be assessed.

Flat	Room	External Level [dB]	Floor Area [m²]	Floor to ceiling height [m]	Facade area inc. glazing [m²]	Glazed area [m²]	Ventilation free area [m²]	Overheating risk [GHA tool]
1	Living Room	59 dB L_{Aeq} Daytime	25	2.8	12	8	1	High (SE orientation)
1	Bedroom	56 dB $L_{Aeq,8hr}$ Night	12	2.8	7	3	0.35	High (SE orientation)
2	Living Room	67 dB L_{Aeq} Daytime	25	2.8	12	8	1	Med (NE orientation)
2	Bedroom	64 dB $L_{Aeq,8hr}$ Night	12	2.8	7	3	0.35	Med (NE orientation)

Figure 11: Relevant details for rooms in flats being assessed.

3.2 Level 1 Assessment

Following Figure B-1 of the AVO Guide, the next activity is to "Assess" the effect of the overheating control strategy on noise levels. The first step is to undertake a Level 1 site risk assessment as indicated in AVO Figure 3-1 following the guidance given in AVO Table 3-2. As noted in paragraph 3.24 of the AVO Guide, the Level 1 assessment is based on external free-field levels and assumes partially open windows that result in an outside-to-inside level difference of 13dB.

With reference to Figure 11, Flat 2 would be in the 'High' risk category according to the Level 1 assessment and Flat 1 would be in the 'Medium' risk category. It is suggested that a Level 2 assessment should be undertake for both Flats. For a real building, tt would be appropriate to mark-up all areas of the façade to indicate the risk category according to the Level 1 assessment.

3.3 Level 2 Assessment

The Level 1 assessment concluded that it is appropriate to undertake a Level 2 assessment for both flats, following the guidance given in AVO Table 3-3. The Level 2 assessment is based on calculated internal ambient noise levels. In this case, the calculation should use the actual method of mitigating overheating, in this case opening windows with the ventilation free areas given in Table 11.

For the purposes of this calculation the Element Normalized Level Difference for a simple un-attenuated ventilation opening such as a window can be approximated by Equation 2 (where A_f is the free area of the opening). This relation appears as Equation D.1 in Annex D of BS EN 12354-3[10]:

$$D_{n,e} = -10log_{10}\left(\frac{A_f}{10}\right)$$

Equation 2: Element normalized level difference of an opening with negligible sound reduction, where A_f is the free area of the opening.

As in the first worked example, the internal ambient noise level can be calculated using the method set out in Appendix G of BS 8233 i.e. using Equation 1, with both S_{ew} and S_{rr} assumed to be zero. Figure 12 shows a daytime calculation for the Flat 2 living room. For brevity, the calculation is not shown in the explicit format used in BS 8233 Tables G.1 and G.2, but the method is the same.

Room Volume	70	m3						
Window Area	8	m2						
Vent free area	1	m2	(Window opening)					
Room RT	0.5	s						
	125	**250**	**500**	**1k**	**2k**	**A**	**Rw/Dw**	**Ctr**
$L_{Aeq,ff}$	69	65	63	63	60	67		
Window R_{wi}	21	17	25	35	37		29	-4
Vent $D_{n,e}$ (Open window)	10	10	10	10	10		11	-1
Indoor ambient noise level								
L_{Aeq} from Window	47	47	37	27	21	40		
L_{Aeq} from Window opening	59	55	53	53	49	56		
Total, L_{Aeq}	59	55	53	53	49	56		

Figure 12: Calculation of daytime indoor ambient L_{Aeq} noise level from external traffic sources in Flat 2 living room. Calculation applies to overheating condition (i.e. windows open to give $1m^2$ ventilation free area)

As noted in paragraph 3.26 of the AVO Guide, a Level 2 assessment "should include an estimate of how frequently and for what duration the overheating condition occurs". However, paragraph 3.19 states that "no quantitative guidance regarding the combined effect of level and duration for the overheating condition is included". One approach, which is adopted for this example, is to use Figure 3-2 of the AVO Guide ('AVO Diagram') and assume that the duration of the overheating condition can be estimated based on the Good Homes Alliance overheating risk assessment. As a first estimate, a 'Low' overheating risk can be taken to correspond to the overheating condition occurring 'rarely' and a 'High' overheating risk can be taken to correspond to the overheating condition occurring 'most of the time', with 'Medium' overheating risk falling between the two.

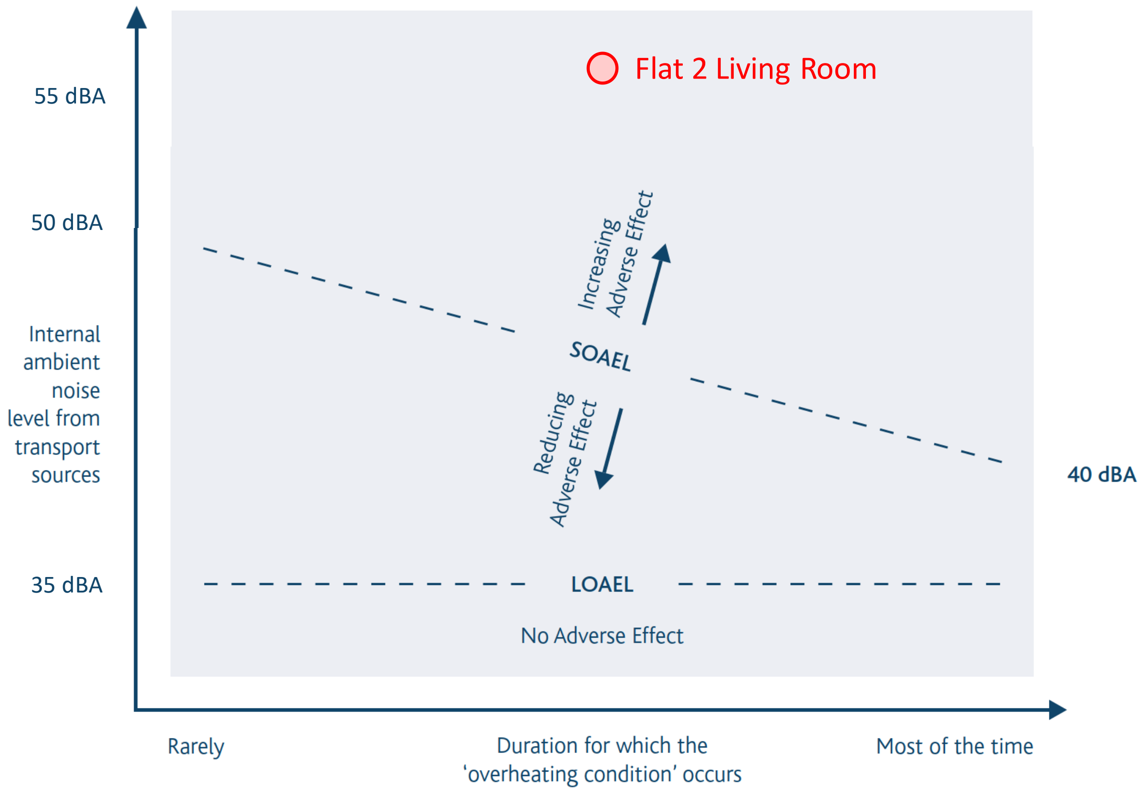

Figure 13: AVO Diagram showing the daytime situation for the Flat 2 living room.

When using the 'AVO Diagram', the same noise levels associated with adverse affects have been adopted as shown in Figure B-2 of the AVO Guide. This allows the situation for the Flat 2 living room to be plotted on an 'AVO Diagram' as shown in Figure 13, assuming that the 'Medium' overheating risk places the point around the half-way point on the 'duration'-axis (y-axis).

Based on Figure 13, the Level 2 assessment suggests that conditions in the Flat 2 living room would be likely to result in significant adverse effect.

3.4 Advising where alternative means of cooling should be developed

Following Figure B-1 of the AVO Guide, the next activity is to "Advise" that the Level 2 assessment for the Flat 2 living room suggests that an alternative means of controlling overheating should be developed in order to reduce adverse effect. Assuming the acoustic consultant is involved in the design stage of the building, it would be appropriate to communicate this to the design team so that the design might be amended. It is not the role of the acoustic consultant to advise on the design of the cooling strategy. However, it may be helpful for the acoustic consultant to advise which types of solution may be feasible in terms of achieving the required improvement in acoustic performance.

With reference to Figures B-4 and B-5 of the AVO Guide, it would be appropriate to consider one or more of the following measures for the Flat 2 living room:

- Amend the design of the living room balcony so that it provides some sound attenuation e.g. by having solid balustrades, absorbent soffits and partial glazed enclosure.
- Using attenuated windows or attenuated vents/louvres
- Providing comfort cooling
- Reducing heat gains as much as practical to reduce the duration for which overheating occurs. For example, by providing external shading to windows.

Following design development, it was decided to adopt the following design strategy for the Flat 2 living room to meet the TM59 overheating criterion:

- Living room balcony is provided with solid balustrades, absorbent soffits and partially enclosed with glazing. Improvement of 6dB expected in the outside-to-inside level difference.
- External shades are provided for living room windows, reducing solar gains and therefore the duration for which the overheating condition occurs.
- An acoustic louvre is provided in addition to opening windows. The acoustic louvre gives ventilation equivalent to a free area of 0.25m² and achieves $D_{n,e,w}+C_{tr}$=20dB. By prioritising the use of the acoustic louvre over the window opening, the duration for which the window is required to be open can be significantly reduced. (Note that the window and acoustic louvre need to be simulated as one combined ventilation area in the TM59 compliance model. A separate simulation is used to investigate the effect of prioritising the use of the acoustic louvre over the window opening on the duration for which each is required to be used).

The Level 2 assessment is repeated for the revised design. Figure 14 shows the calculation of internal ambient noise level for the situation where only the acoustic louvre is open, but the window is closed. Figure 15 shows the calculation of the internal ambient noise level with both acoustic louvre and window open.

The calculated internal ambient noise levels are then plotted on an AVO Diagram in Figure 16. The basis of the strategy is that the acoustic louvre may need to be open for 'most of the time' but the window will only need to be opened 'rarely'. It may be argued on the basis of Figure 16 that the revised strategy for meeting the TM59 criterion avoids significant adverse effect.

It may be appropriate to use the sound insulation values indicated in Figure 15 as a basis for specifying the minimum performance requirement for the window and acoustic louvre. The same procedure could be adopted in the assessment of the other rooms described in Figure 11.

Room Volume	70	m3						
Window Area	8	m2						
Number of vents	1	(Acoustic louvre)						
Room RT	0.5	s						
	125	250	500	1k	2k	A	Rw/Dw	Ctr
$L_{Aeq,ff}$	69	65	63	63	60	67		
Correction for balcony	6	6	6	6	6			
$L_{Aeq,ff}$ (with balcony)	63	59	57	57	54	61		
Window R_{wi}	21	17	25	35	37		29	-4
Vent $D_{n,e}$ (Acoustic louvre)	14	16	19	22	27		23	-3
Indoor ambient noise level								
L_{Aeq} from Window	41	41	31	21	15	34		
L_{Aeq} from Acoustic louvre	49	43	38	35	26	40		
Total, L_{Aeq}	49	45	38	35	26	41		

Figure 14: Calculation of daytime indoor ambient L_{Aeq} noise level from external traffic sources in Flat 2 living room. Acoustic louvre open but window shut.

Room Volume	70	m3						
Window Area	8	m2						
Number of vents	1	(Acoustic louvre)						
Vent free area	0.75	(Window opening)						
Room RT	0.5	s						
	125	250	500	1k	2k	A	Rw/Dw	Ctr
$L_{Aeq,ff}$	69	65	63	63	60	67		
Correction for balcony	6	6	6	6	6			
$L_{Aeq,ff}$ (with balcony)	63	59	57	57	54	61		
Window R_{wi}	21	17	25	35	37		29	-4
Vent $D_{n,e}$ (Acoustic louvre)	14	16	19	22	27		23	-3
Vent $D_{n,e}$ (Open window)	11	11	11	11	11		12	-1
Indoor ambient noise level								
L_{Aeq} from Window	41	41	31	21	15	34		
L_{Aeq} from Acoustic Louvre	49	43	38	35	26	40		
L_{Aeq} from Window opening	51	47	45	45	42	49		
Total, L_{Aeq}	53	49	46	46	42	50		

Figure 15: Calculation of daytime indoor ambient L_{Aeq} noise level from external traffic sources in Flat 2 living room. Both acoustic louvre and window open to give a combined ventilation area of 1m².

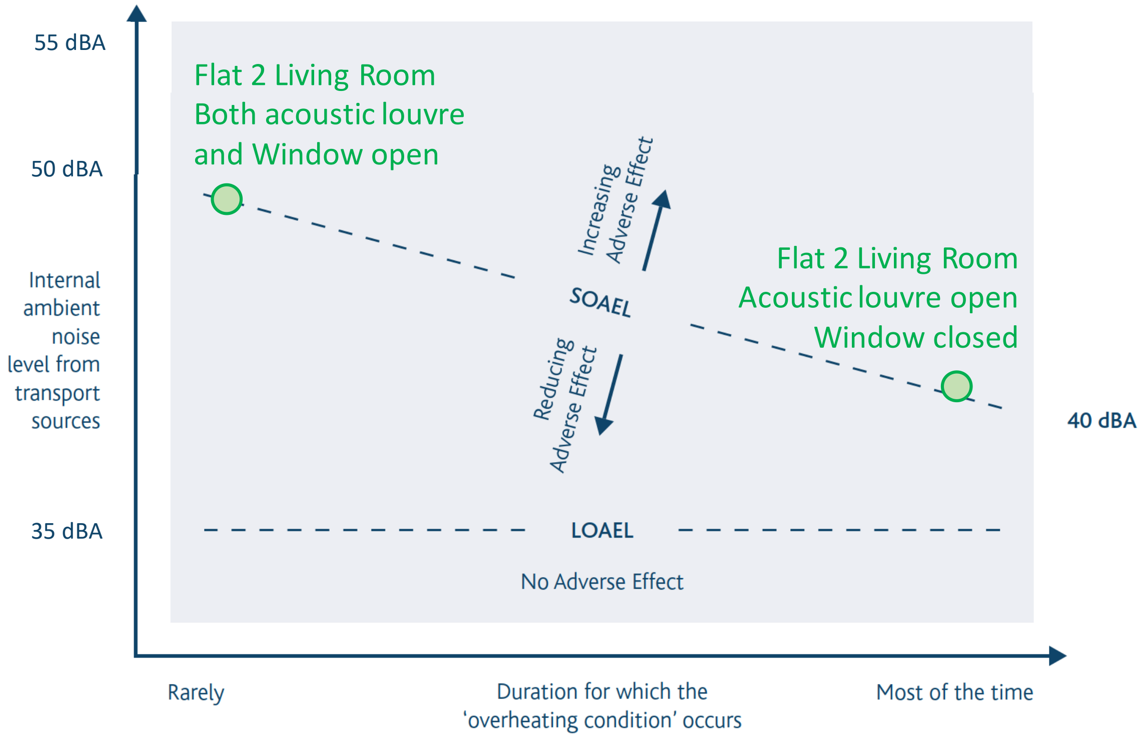

Figure 16: AVO Diagram showing the daytime situation for the Flat 2 living room with revised strategy for meeting TM59 overheating criterion.

4 CONCLUSIONS

Two worked examples of the use of the AVO Guide are presented. The worked examples are based on real projects but do not exactly represent the designs of those buildings. For the purposes of the second worked example it was assumed that the duration of the overheating condition can be estimated based on the Good Homes Alliance overheating risk assessment. This approach could be developed further and made more explicit. It is also anticipated that more quantitative methods of evaluating the duration of the overheating condition will be developed as practitioners begin to apply the AVO methodology on real projects. It is also anticipated that novel approaches for attenuated passive ventilative cooling will emerge in response to the AVO assessment method.

5 ACKNOWLEDGEMENTS

The ANC AVO Guide has been produced by the working group, all of whom have contributed their time and effort without financial recompense. The working group comprised: A Chilton (Max Fordham), Chair of Working Group; J Harvie-Clark (Apex Acoustics); N Conlan (Apex Acoustics); D Trew (Bickerdike Allen); A Long (Sandy Brown); M Hyden (Cundall); J Healey (WSP); A Passmore (Arup); B Jobling (Hoare Lea); M Scaife (MLM); M Swainson (BRE); I MacArthur (Clarke Saunders Associates); J Paris-Newton (RMP), S Turner (ST Acoustics), J McCullough, (Mid-Kent).

Assistance with developing the second worked example was provided by L Crabtree (Max Fordham) and N Kravanja (Max Fordham).

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