Response to letter by Clarke and Fiumicelli 'Reductive Proposals for BS 8233 Update' – Acoustics Bulletin November/December 2024

By Benjamin Fenech and Jack Harvie-Clark

We thank Clarke and Fiumicelli for their letter published in Acoustics Bulletin 50(6) November/December 2024. We welcome their agreement that:

a) the case for updating BS 8233 is"good";
b) recent studies show higher levels of annoyance and sleep disturbance due to transportation noise than those established historically; and
c) internal acoustic conditions need to be considered holistically with indoor air quality and overheating risk.

We also welcome our shared objective to 'improve the protection provided to citizens and thereby reduce the burden of noise related disease'.

Clarke and Fiumicelli expressed some concern with our proposals. Their concern can be summarised by the following extract from their letter:

To align with public health research the proposal is to assess and control noise exposure via the external sound levels, under the mistaken assumption that this alignment with the evidence base justifies a departure from controlling internal levels.

I don't think anyone has ever actually suggested that the community health impacts from environmental sound on residents in buildings is predicated more on the noise levels outside the buildings in which they are exposed than those they experience internally. It is just much more difficult to do large scale studies on actual internal levels in comparison with the convenience of large-scale noise mapping. Hence all the recent studies refer to external levels as a proxy.

By definition, a proxy is not the parameter we are trying to control to the benefit of residents to deliver suitable internal living conditions. It's like trying to drive a car looking only at the sat-nav screen!

This lack of precision – the failure to target the parameter itself rather than the more convenient proxy is uniquely problematic in relation to exposure of individuals to environmental sound.

Clarke and Fiumicelli go on to suggest that because of this, one can disregard the body of high-quality epidemiological evidence published over the past 25 years, summarised in the WHO Environmental Noise Guidelines (2018), showing an increased risk of chronic adverse health outcomes with increased exposure to averaged external noise levels. Instead, they argue that for transport noise we should continue to be guided by the following evidence used to inform the WHO Guidelines for Community Noise (1999):

- an assumption and empirical observation that for speaker-to-listener distance of about 1m, speech in relaxed conversation is 100% intelligible in background noise levels of approximately 35 dBA;
- two studies on self-reported sleep disturbance from road traffic noise published in 1993 and 1997; and
- evidence on noise-induced EEG awakenings.

We disagree with Clarke and Fiumicelli on these points. We are concerned over their use of a single line in WHO 2018 about WHO 1999 internal values 'remaining valid' whilst ignoring the wealth of recent epidemiological evidence demonstrating how environmental noise affects health. In our proposals for the BS 8233 revision [Harvie Clark and Fenech 2024], we recommend a two-step approach. The first consideration should be minimising external sound levels – this is where the most robust evidence exists for health impacts. The second step is to address internal sound levels through façade sound insulation requirements. This is not a departure from controlling internal levels, but rather a more holistic method of achieving healthier living conditions through better alignment with the evidence base. In the following sections we explain why, in our view, the arguments by Clarke and Fiumicelli are not supported by the scientific evidence.

Relevance of external vs internal sound for health effects

Noise is a psychosocial stressor [Lercher 1996, Babisch 2002], i.e. '*an environmental factor interacting with social and cultural factors to influence the mind and behaviour*' [Clark et al 2024]. Within this framework, noise exposure at 'home' is not limited to the sound levels inside the physical space enclosed within a building envelope. It also covers any outdoor spaces that residents consider part of their home. The international standard for measuring noise annoyance (ISO/TS 15666:2021) clearly states that the terminology 'at home' does not mean strictly indoors, but covers inside the home or outdoors at home, including balconies, gardens, etc. The standard seeks to obtain general, consistent reactions that allow respondents to integrate their experiences over different times and locations in and around their home (Clark et al 2021).

The mechanistic evidence on the relationship between chronic noise exposure and chronic health outcomes supports a direct pathway and an indirect pathway [WHO 2018, Münzel et al 2024]. Noise can elicit both biological and psychological stress responses. The indirect (psychological) pathway is mediated by cognitive and emotional responses to the personal experience of the noise, which is not limited to the sound levels experienced when inside a dwelling with windows closed [Lercher 1996, Guski et al 2017].

A dwelling is not just a physical structure – it represents a place where people call home [Weidemann and Anderson 1985]. The places where people live have a significant impact on their mental and physical health [NHS England 2018]. Furthermore, people's perceptions of the neighbourhood in which they live can have significant implications for wellbeing, life satisfaction and resilience [MHCLG, 2021]. When residents feel a deep connection to their place of residence, they are more likely to be satisfied with their living conditions. This relationship is influenced by various factors, including the quality of the physical environment, social interactions and the availability of amenities. Noise has been shown to interact with some of these factors [Appleyard and Lintell 1972, Peris and Fenech 2020]. Socio-acoustic studies from Norway found that the noise levels in the immediate neighbourhood of a home can affect residential noise annoyance, with a similar effect on both outdoor and indoor noise annoyance [Klæboe et al 2005].

Based on these evidence-based frameworks, it should be evident that the health effects of noise are not solely influenced by the 'dose' that people are exposed to when inside their homes. To supplement these frameworks, we draw on the findings from two studies that investigated the influence of the external sound environment on disturbances inside the dwelling.

Öhrström (2004) presents the findings from a before-after longitudinal study carried out in Göteborg, Sweden in 1997 and in 1999 (before and after an intervention that led to a substantial reduction in road traffic volume on a main road). The investigation area was divided into an exposed and a control area, in which the houses were situated 25-67m and 125-405m, respectively, from the main road. About 40% of the houses in the exposed area had double-glazed windows in the living room, kitchen and bedrooms while the others had some form of triple-glazed windows. For the exposed group, outdoor levels ranged from 56-69 $L_{Aeq,24hr}$ on the noisy side. Noise from transport inside bedrooms and living rooms ranged from <20 to 36 $L_{Aeq,24hr}$. For the control group, noise levels were 40-52 $L_{Aeq,24hr}$ outside and <20 $L_{Aeq,24hr}$ inside. Following the intervention, the noise levels for the exposed group reduced to 38-57 $L_{Aeq,24hr}$ outside and <20-24 $L_{Aeq,24hr}$ inside bedrooms and living rooms. Applying the arguments by Clarke and Fiumicelli, both the exposed and control group would be expected to experience minimum disturbance, because both dwellings achieve internal levels of approximately 35dB $LA_{eq,16hr}$ or less (in accordance with requirements in the current BS 8233). Similarly we would not expect the intervention to have delivered any meaningful benefits to health.

Figure 1 shows the percentage of people reporting activity disturbances indoors and outdoors, for the exposed and control groups, before (1997) and after (1999) the intervention. For the exposed group before the intervention, 15% reported disturbances to conversation, 24% had difficulties falling asleep and 38% had their rest/relaxation disturbed. Following the intervention, these disturbances dropped to 0%, 9% and 11%, respectively. For the control group (external levels < 52dB $_{LAeq,24hr}$), less than 5% of respondents had these activities disturbed by road traffic. Before the intervention nearly 60% of the exposed group expressed annoyance because road traffic noise prevented them from having windows open as often as desired; this dropped to just 4% after the intervention. The differences between the exposed and control group were even larger for outdoor activities (conversation and relaxation) when at home.

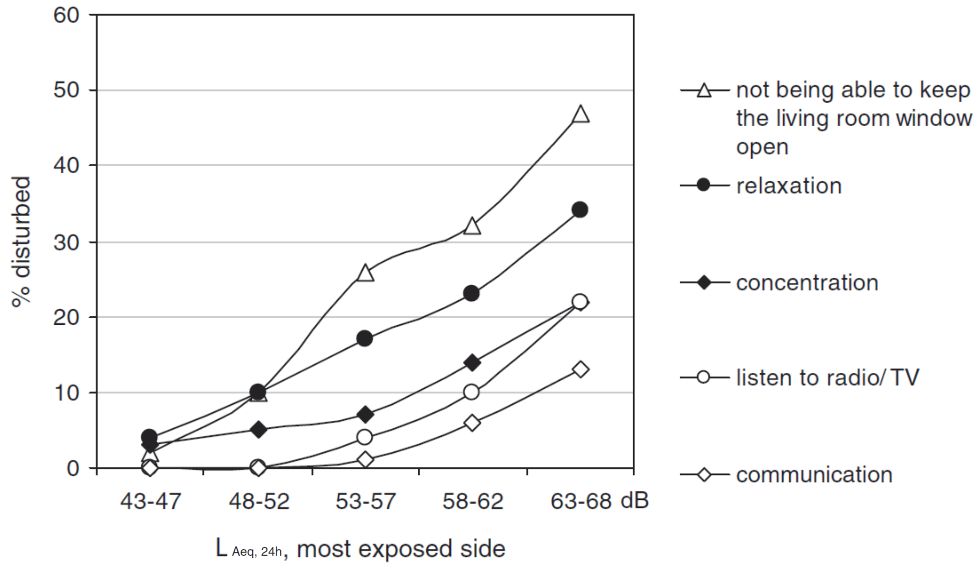
A second study looked at noise disturbance across four sites in the centre and outskirts of Gothenburg and Stockholm, Sweden (Öhrström et al. 2006). All dwellings were flats in 3-5 storey buildings. The windows were either double- or triple-glazed. The dwellings chosen were exposed to sound levels from road traffic ranging from about $L_{Aeq,24h}$ 45-68 dB at the most-exposed side. The speed of the road traffic did not exceed 50 km/h in any of the study sites. The study included responses from 956 individuals aged 18-75 years.

Below:
Figure 1:
Disturbances to indoor and outdoor activities from road traffic noise for an exposed and control group, before (1997) and after (1999) a major traffic intervention. Reproduced from Öhrström (2004)

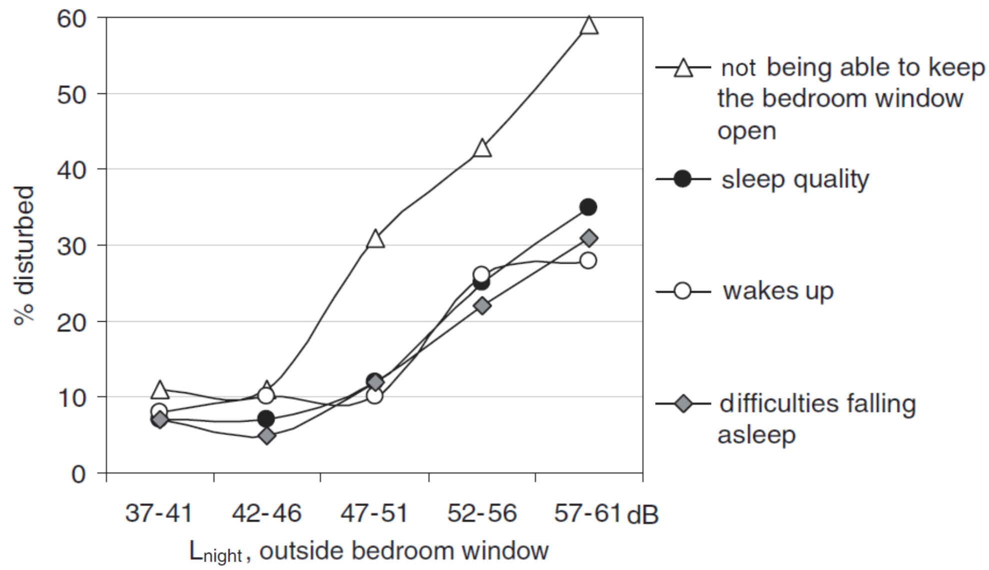
Percentage rather or very annoyed by road traffic noise during the following activities:	Exposed area		Control area	
	1997 n=50	1999 n=45	1997 n=92	1999 n=75
Indoor activities				
Conversation/telephone conversation	15	0	0	0
Radio/TV	12	2.2	1.1	0
Concentration	12	2.2	2.2	0
Rest/relaxation	38	11.1	5.4	0
Difficulties in falling asleep	24	8.9	2.2	0
Awakenings	28	8.8	3.3	0
Does not keep windows open as often as desired	58	4.4	3.3	0
Outdoor activities				
Able to be on the terrace or patio	38	4.4	1.1	0
Conversation	48	8.8	0	0
Relaxation	50	11.1	2.2	0

Figure 2 shows the activity disturbances indoors **with windows closed** in relation to sound levels at the most exposed façade. Communication was the least reported disturbance. Nearly three times as many participants reported disturbance to relaxation at any given external exposure level.

Figure 3 shows the percentage of respondents reporting daytime activity disturbances with windows closed, and the increase with windows open. If activity disturbance correlated better with the internal levels than with the external levels (as argued by Clarke and Fiumicelli), we would expect similar levels of disturbances for the 48-52 dB (windows open) and 63-68 dB (windows closed) exposure bands[1]. These bands have the closest alignment to the current BS 8233 target range for internal levels during daytime. The results do not support this hypothesis: disturbances were consistently higher with windows closed than windows open, for approximately equal internal conditions: (communication: 13% vs 5%, listen to radio/TV 22% vs 0%, concentration 22% vs 5%, relaxation 34% vs 10%.



Above:
Figure 2: Activity disturbances indoors with windows closed, as a function of noise exposure outdoors at the most exposed façade. Dwellings were flats in urban environments, all of which had double or triple glazing. Reproduced from Öhrström et al. (2006)



Above:
Figure 4: Noise-related sleep disturbances indoors with windows closed in relation to sound levels in Lnight outside the bedroom windows. Reproduced from Öhrström et al. (2006)

L_{Aeq24h} dB most-exposed side	Communication		Listen to radio or TV		Concentration		Relaxation	
	Closed	Open	Closed	Open	Closed	Open	Closed	Open
45-46	0	+1	0	+2	3	+1	4	+2
48-52	0	+5	0	±0	5	±0	10	±0
53-57	1	+13	4	+13	7	+6	17	+8
58-62	6	+15	10	+19	14	+13	23	+12
63-68	13	+28	22	+24	22	+19	34	+15

Above: Figure 3: Percentage respondents reporting daytime activity disturbance effects with windows closed and the increase in disturbance with windows open. Reproduced from Öhrström et al. (2006)

Footnote

1 Assuming an approximate external to internal sound level difference of 30dB for double and triple glazed windows, and 12dB for open windows.

Noise-induced sleep disturbances (percentage >3) with windows closed and the increase in disturbance when windows are open at different sound levels

L_{night} outside bedroom windows	Difficulties falling asleep		Wakes up		Decreased sleep quality	
	Closed	Open	Closed	Open	Closed	Open
37-41	7	+7	8	+5	7	+5
42-46	5	+6	10	±0	7	+4
47-51	12	+7	10	+5	12	+5
52-56	22	+14	26	+11	25	+11
57-61	31	+10	28	+15	35	+10

Above: Figure 5: Percentage respondents reporting noise-induced sleep disturbances with windows closed and the increase in disturbance when windows are open. Reproduced from Öhrström et al. (2006)

Similar observations were made for sleep disturbance. Referring to Figure 5, the two exposure categories aligning to current BS 8233 internal criteria (30dB $L_{Aeq,8hr}$) are 42-46 dB (windows open) and 57-61 dB (windows closed). The percentage of people reporting sleep problems is higher with windows closed than window open, for similar internal levels.

Some other studies on noise annoyance investigated differences between outdoor and indoor annoyance (see for example Danish Road Directorate 2016) and indoor annoyance with windows open and closed (see for example Preisendörfer et al 2022). These studies show that both outdoor annoyance, and indoor annoyance with windows open are important contributors to the overall annoyance reactions and therefore support the contribution of both the external and internal sound exposure at home.

Is disturbance to speech communication the key health outcome for daytime noise?

In the WHO Guidelines for Community Noise (1999), the daytime criteria were set based on interference with speech and annoyance from transport noise. The studies from Sweden suggest that interference with communication may not be the most appropriate health outcome to set indoor criteria (see Figure 2). The WHO 2018 guidelines chose annoyance as a better health endpoint that includes a broader range of disturbances [Guski et al 2017].

WHO Guidelines 2018 vs 1999

A notable omission in the letter by Clarke and Fiumicelli is any reference to the WHO Environmental Noise Guidelines for the European Region (2018), other than to state (out of context) that '*there seems to be no evidence to contradict the WHO 2018 confirmation that the internal values from WHO 1999 are still valid*'. It is our view that this statement is incorrect. Fenech and Stansfeld (2024) explain the relationship between the 1999 and 2018 WHO Guidelines, and both guidelines emphasise the importance of considering both external and internal noise levels when setting health-based criteria for residential development.

The WHO 2018 Guidelines represent a significant methodological shift from earlier noise guidelines, moving from an 'expert-based judgement' approach to one that 'formulates recommendations more strictly based on the available evidence' [WHO 2018]. This evolution resulted in a more rigorous methodology that prioritised epidemiological evidence based on external noise levels. While the 2018 Guidelines note that internal guideline values from 1999 'remain valid', these values need to be interpreted in conjunction with the external guidelines in the WHO 2018, and taking into account source-specific characteristics of the sound [Fenech and Stansfeld 2024].

Is external noise ingress with windows closed a suitable mitigation for disturbance from neighbour noise?

In their letter, Clarke and Fiumicelli also appear to suggest that up to a certain level, transport noise ingress in buildings with windows closed can have beneficial health effects:

'*If, for example, rather than achieving internal conditions at night of 30dB $L_{Aeq,8hr}$ with Lmax levels in the low 40s in two apartment buildings, we get one building with 20 $L_{Aeq,8hr}$ (L_{max} in the low 30s) and one building at 40 $L_{Aeq,8hr}$ (L_{max} in the low 50s) then BOTH sets of residents have dramatically compromised living conditions, due to annoyance and sleep disturbance in the under-attenuated case and high levels of neighbour noise disturbance in the over-attenuated building.*'

We argue that this is a dangerous and unfounded assertion. To our knowledge, there is no robust scientific evidence demonstrating that lower internal sound levels due to higher façade sound insulation leads to 'dramatically compromised living conditions' or increased neighbour noise disturbance. While anecdotal reports of increased sensitivity to neighbour noise in quieter environments exist, these have not been substantiated by systematic studies. It is not clear how noise from discrete car/train pass-bys or aircraft flyovers that averages to an internal level of 30dB $L_{Aeq,8hr}$ can be effective at reducing disturbance from neighbour noise. External anthropogenic noise ingress with windows closed should not be relied on as a sound source contributing to a positive internal soundscape in homes, because it is completely out of the control of the building occupant. Research by Torresin et al (2022) demonstrates the importance of control over one's environment to achieve an ideal indoor soundscape for work and relaxation.

We argue that neighbour noise disturbance should be managed by appropriate levels of sound insulation between dwellings and, if acoustic masking is necessary, this should be achieved by sources of sound that are under full control of the building occupants.

Towards a more holistic design of healthy homes

Our proposals for the BS 8233 revision recognise that different noise sources (road, rail, air) have different health impacts at the same averaged decibel level [WHO 2018]. The current practice of treating all sources equally once they reach internal spaces does not reflect this evidence. Specifying different façade sound insulation requirements for different noise sources can be a way of inherently considering the characteristics of these sources and their varying health impacts, while maintaining control of the internal acoustic environment.

Evidence from Western Europe has consistently shown a desire by citizens to open their windows when inside their homes [WHO 2009]. From a soundscapes perspective this offers an opportunity to connect to the place where people call home [Torresin et al 2022, Torresin et al 2024]; from a broader health perspective it is an important means of controlling indoor sources of air pollution, temperature and humidity [van Rooyen and Sharpe 2024]. This may become increasingly important with a changing climate [Dimitroulopoulou et al 2023]. The evidence discussed in this paper shows that the external sound level can act as barrier to occupants' willingness to open windows. We believe this is yet another argument why both external and internal noise conditions should form part of standards for residential acoustic design.

Concluding remarks

The external sound environment at the place where people call 'home' is not merely a 'convenient proxy' as argued by Clarke and Fiumicelli, but an important factor contributing to people's health and wellbeing. This is backed up by more than two decades of epidemiological evidence.

The revision of BS 8233 offers a once in a decade opportunity to revisit current approaches, and identify potential improvements guided by the best available evidence. The paradigm shift in our proposals is not about contradicting past guidelines, but about embracing a more evidence-based approach that reflects our current best understanding of how environmental noise affects health and wellbeing. It provides a framework that combines valuable insights from previous guidelines with the robust epidemiological evidence gathered under real world living conditions.

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