HEALTHY HOMES
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TECHNICAL PAPER

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Introduction

Much research has been carried out into the effects of noise on health. At high levels of noise exposure there is of course a risk to hearing. But at medium or even low levels of exposure, other serious effects can occur. Annoyance, activity disturbance and sleep disturbance are common, while there is a body of evidence connecting chronic long-term noise exposure to such ill-effects as heart disease and hypertension. A useful overview of known health effects was published in The Lancet in 2014.[1]

Because there is a complexity of factors which give rise to individual responses to noise, it is difficult for guidelines to be universally successful or appropriate, and planners and developers must be aware of this. Nevertheless, a good design process will take account of the available guidance in these critical respects:

- The environment into which the development is introduced, and how the development responds to it.
- The layout within the development, specifically the internal and external adjacencies created.
- Inherent tensions between acoustic considerations and other requirements.
- The constructions and detailing employed.

1 Auditory and non auditory effects of noise on health; Basner et al; The Lancet, vol 383, April 12 2014.

Key Priorities for action

Planning guidance

In the UK, consideration of the external noise environment, as well as requirements for internal noise levels in the completed development, are considered during the planning process. Local Planning Authorities (LPAs) will be aware of the official Planning Practice Guidance (PPG-Noise)[2] which states that noise needs to be considered "when new developments would be sensitive to the prevailing acoustic environment". The PPG sits within the overall policy context of the Government's Noise Policy Statement for England (NPSE)[3] and the National Planning Policy Framework (NPPF)[4]. These policy documents articulate the expectation that noise will be considered alongside other "economic, social and other environmental dimensions".

A working group from the Association of Noise Consultants (ANC), the Institute of Acoustics (IoA) and the Chartered Institute of Environmental Health (CIEH) has prepared Professional Practice Guidance (ProPG) which is currently undergoing a consultation process. The document seeks to promote "good acoustic design" where this implies a "multi-faceted and integrated approach to achieve good acoustic conditions, both internally … and externally"; and a good acoustic outcome is an "integrated solution …without design compromises that will affect living conditions and the quality of life of the inhabitants or other sustainable design objectives and requirements".[5]

2 PPG Noise, https://www.gov.uk/guidance/noise--2
3 Noise Policy Statement for England, https://www.gov.uk/government/publications/noise-policy-statement-for-england
4 National Planning Policy Framework, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf
5 ProPG: Planning and Noise, consultation draft v1.1, January 2016.

Ventilation, overheating and noise

A particular focus of attention from a health and wellbeing (and energy consumption) point of view is the resolution of acoustics with ventilation and internal temperature control. This is because external openings for natural ventilation also provide an open path for noise ingress.

In the UK the ventilation rates stipulated in Part F of the Building Regulations are a statutory minimum requirement, and in many locations background rates of ventilation can be achieved by employing acoustic trickle vents. However, significantly higher ventilation rates are often considered more appropriate by designers, and this has direct acoustic consequences: for every doubling of effective open area provided, internal noise levels will increase by 3dB.

Furthermore, to obtain rapid ventilation, or to alleviate over-heating, many building occupants would traditionally wish to open windows. Part F of the Building Regulations requires a facility for purge ventilation, and this is often utilized by designers as a means of overcoming overheating. However, it is critical that the acoustic ramifications are appreciated. Consideration should be given to internal temperature gains, the number of days in a year when windows may need to be open for comfort reasons, and the magnitude of any resulting acoustic compromise. New guidance on overheating analysis is being developed through the Chartered Institution of Building Services Engineers (CIBSE) with input from Arup and others.

This opposition can to some extent be mitigated by intelligent planning of developments, for example by creating relatively shielded locations for ventilation openings, and where circumstances allow, installing passive cooling systems to provide more desirable and sustainable solutions. Increasingly, Mechanical Ventilation with Heat Recovery (MVHR) whole house ventilation is employed in modern residential developments due to the benefits to a Building Regulations Part L score. With appropriate filtrations, MVHR systems can be employed to achieve enhanced air quality as well as background ventilation rates in noisy environments, and energy consumption can be offset by heat exchange from exhaust air.

Impact sound rating of timber floors

The apparent sustainability benefits of timber materials have led to an increased focus on timber constructions in residential development. Acoustically, timber constructions present challenges which can be overcome, but require understanding and careful detailing.

A particular feature of timber floor constructions is their tendency to produce a "thudding" sound when walked on, which can be disturbing particularly to occupants of the space below. Developing a means of testing and rating of impact sound which corresponds well with subjective experience is a complex area.[6] The testing and rating system normally used in the UK is limited in terms of how well it represents the subjective performance of timber floors.

6 Sound Insulation, Hopkins, Elsevier 2007, ISBN: 9780-0-7506-6526-1

The external environment

Reducing incident noise levels

The first priority should be to seek to reduce incident noise levels wherever possible.

Sources	• Can noise sources be removed or reduced? • Can future conditions be influenced?
Landscaping	• Is there the potential to install noise barriers, mounds, bunds, or fences? Such features could enhance external amenity as well.
Building layout and external features	• Buildings themselves are effective noise shields. Can the building be oriented intelligently with access or bathrooms facing noise sources rather than living or sleeping areas? • Can the massing be arranged to provide protected courtyards? • Can balconies be employed to screen windows?

Typical targets for internal noise levels are shown below. These are the standards proposed within the ProPG, and are in line with those set out in the WHO Community Noise Guidelines 2000[7], and BS8233:2014.[8]

Activity	Location	07:00–23:00 hrs	23:00–07:00 hrs
Resting	Living room	35 $dBL_{Aeq,16hr}$	–
Dining	Dining room/area	40 $dBL_{Aeq,16hr}$	–
Sleeping (daytime resting)	Bedroom	35 $dBL_{Aeq,16hr}$	30 $dBL_{Aeq,8hr}$ 45 dBL_{AFmax}

7 World Health Organisation, Community Noise Guidelines, 2000
8 BS8233:2014, Guidance on sound insulation and noise reduction for buildings

Some local authorities have started to request a night noise limit of 42dBL_{Amax}, based on WHO Night Noise Guidelines for Europe 2009.[9]

For external amenity, BS8233:2014 recommends 50$dBL_{Aeq,T}$ with an upper guideline value of 55$dBL_{Aeq,T}$.

How should internal noise levels be calculated during design?

For any particular space within a dwelling, the internal noise levels from external noise sources will depend on the following factors.

- The sound pressure levels incident on the exterior. It is necessary to understand these levels as a function of frequency (ie a spectrum in octave frequency bands).
- The sound insulating characteristics of the elements of the building envelope (for example solid façade elements, windows, ventilators, roofs).
- The dimensions and likely extent of soft furnishings in the internal space.

The reliability of the calculation therefore depends critically on a good understanding of the external noise incident on the building envelope, and the sound insulating properties of the envelope, and neither is straightforward to determine. External noise levels vary over time, measurements made in advance of the development being in place naturally do not take account of the screening effect of the development itself, and reliable sound insulation test data for elements of the building envelope may not be available. Nevertheless, a detailed noise survey is normally the starting point, while for large developments it is often necessary to conduct a computer modelling exercise which takes account of screening effects, to help to resolve likely façade exposure.

9 World Health Organisation, Night Noise Guidelines for Europe, 2009

Layout and vertical stacking in apartment buildings

As with the external environment, the first priority should be to avoid unsympathetic adjacencies in the first place, by intelligent layout.

Vertical stacking	Vertical stacking of common use is highly desirable and simplifies acoustic detailing, e.g. bedrooms above bedrooms; kitchens above kitchens etc.
Lobbies	Lobbied entrances in apartments reduce disturbance from corridors.
Corridors	Carpet in corridors helps to prevent disturbance.
Bedrooms	Bedrooms should be in protected locations, on quieter elevations.
Stairs	Stairs can easily cause lateral impact sound transfer; steel stairs in particular.
Lifts, cores	Lifts, waste chutes, plantrooms etc. should be located away from sensitive living spaces, with non-sensitive ancillary space used as buffers.

Sound insulation between adjacent residential units

Two forms of sound transmission are addressed in relevant legislation and guidelines.

- Airborne sound transmission. Sound sources – such as a human voice or a television – generating in the air which cause surrounding walls and floors to radiate sound into adjacent spaces.
- Impact sound transmission. Footsteps by their direct mechanical contact cause vibration of floors and ceilings and sound radiation into adjacent spaces.

Separating and Flanking Constructions

Sound transmission from one space to another occurs not just via the separating element (wall or floor), but also via "flanking" elements. This means that all such elements must be addressed in a successful acoustic design, and explains why official requirements are normally set in terms of final "room-to-room" levels of sound insulation, and not just in terms of the performance of separating elements.

Minimum standards for sound insulation between dwellings are a requirement of the Building Regulations Approved Document E (AD-E).[10]

Pre-Completion Testing and Robust Standard Details

"Pre-completion testing" (PCT) is generally required to demonstrate compliance with Building Regulations requirements (see AD-E, section 1), however testing is not required if "Robust Details"[11] for separating and flanking constructions are adopted (see AD-E Annex E). These details have the benefit of having satisfied an empirical on-site qualification process. Therefore, even if they are not incorporated in all respects (which they must be to avoid PCT) they are, along with those constructions

10 Building Regulations 2010 – Approved Document E: Resistance to the Passage of Sound, HM Government, ISBN 978 1 85946 616 2
11 Robust Details Ltd, www.robustdetails.com

shown in AD-E, a valuable resource as a basis for design. They cover masonry, timber stud and steel stud separating walls; and concrete, timber and steel & concrete composite separating floors. Corresponding details for control of flanking transmission are indicated, together with guidance on ceiling and floating floor elements. Each construction is given together with an indication of the margin of compliance with Building Regulations standards: just compliant, 3dB better, 5dB better or 8dB better; steps which also align with Home Quality Mark[12] and BREEAM[13] multi-residential sustainability credits.

Privacy and background noise

Limited levels (see below) of background noise provide useful masking of otherwise intrusive sounds. Therefore, when setting standards for sound insulation it is important to note whether continuous background noise is present, for example from mechanical ventilation, although care needs to be taken not to assume masking from systems which will not run permanently. It may be possible artificially to sustain moderate continuous background noise masking as part of the external amenity design, for example through incorporation of water features. This can be a useful approach particularly in situations where opened windows increase the risk of transfer between residential units.

Timber Floors and Impact Sound

Because of the difficulty in rating impact sound from timber floors, great care must be taken to ensure acoustic transmission characteristics will be satisfactory for occupants. If possible, mock-up constructions should be employed to establish the acceptability of construction proposals.

Sockets and switches

Wall mounted sockets and switches always have the potential to cause significant weaknesses in sound insulation, or to transmit structure-borne sound. It is good practice to avoid back-to-back sockets and switches, and to ensure that sockets in drywalls are boxed-out. Mechanical switches should only be mounted on independent wall linings.

Key flanking elements

Facades	The potential for flanking via facades both horizontally or vertically is a very significant issue to address early on. Traditional solid facades with "punched windows" are the best starting point.
Floors and ceilings	Continuous structural floors will provide a continuous flanking path between horizontally adjacent units. This path is often controlled by a floating floor construction above, and a ceiling construction below, both of which should be discontinuous at the party wall line.
Risers	Riser enclosures must be robust to prevent flanking transmission and control pipe flow noise.

12 Home Quality Mark, Technical Manual, 2015, http://www.homequalitymark.com/
13 BREEAM Multi-Residential Scheme Document, www.breeam.com

Internal sources of noise

All mechanical or electrical system components must be selected with great care to ensure not only that the internal noise criteria are met, but also to avoid any tonal or other attention-catching features. The industry commonly adopts the "NR" rating system for noise levels, but noise levels must be compatible with the standards above. It is beneficial for occupants to have a manual override control of mechanical systems so that they can use a set-back mode for reduced noise in bedrooms at night.

Detailed acoustic design calculations will be required to ensure that systems are compatible with appropriate internal noise criteria. Some important "Watch-its" are set out below.

Equipment location	Noise producing equipment must be located sensibly, away from the most sensitive rooms wherever possible, in robust enclosures.
Equipment isolation	All active equipment will need to be isolated – i.e. resiliently mounted.
Ventilation and cooling units	It is essential that low noise units at suitable operating points are selected.
Appliances	Where possible appliances such as washing machines and dryers should be located in utility rooms. Select low noise appliances for living spaces (e.g. in studio apartments).

Key elements

Ceilings	Ceilings are often an important part of the sound insulation strategy because the presence of the ceiling cavity provides some natural isolation from the floor. They help to control impact sound from footsteps noise above, but also are an important contributor to vertical and horizontal flanking airborne sound insulation.
Ceiling weight	Ceiling mass is very beneficial (it is common for ceilings to be a double plasterboard layer for acoustic reasons).
Cavities and hangers	A good cavity depth, resilient hangers and an insulation layer all help significantly.
Lights and other fittings	Care must be taken to maintain the integrity of ceilings, for example by using low power light fittings with continuous casings
Floors	The walking surface is where most impact sound is introduced, so it is critical that floors either have a soft covering such as carpet, or are "floating" with an effective resilient layer beneath the walking surface. Floating floors can also help to provide vertical airborne sound insulation and horizontal flanking sound insulation. Take care to ensure that at the perimeter of floating floors a soft joint is provided, and skirting boards are clear of the walking surface, to avoid acoustic bridging. Proprietary impact sound-reducing layers or floating floor systems are tested on a standard concrete structural floor, so these results will not be valid for timber floors. Ensure that resilient layers run across footprint of each room, extending beneath appliances and joinery. Rigid fixings of through resilient layers must be avoided at all costs, including services such as floor boxes or pipes.

Internal partitions	The Building Regulations stipulate minimum standards for internal partitions and floors. It is often advisable to provide an enhancement. Staggered or independent stud constructions can be used to protect bedrooms from structure borne sounds from bathrooms or kitchens.
Doors	Seals are critical to door performance. Durable seals which are under modest compression when doors are closed work best. Bathroom and toilets are often under negative air pressure owing to extract systems, with make-up air delivered via door undercuts or grilles. These features seriously reduce acoustic separation and independent make-up air should be provided where necessary.
Windows	Required acoustic performance of windows and ventilators must be established by calculations based on external noise levels. Bear in mind open windows will only provide around 10dB of attenuation, and ventilators with high acoustic ratings are large and deep.
Finishes	Building Regulations requires control of reverberation in common parts. Carpeted rooms are rarely considered acoustically harsh. If hard floors are likely, acoustic control will only come from soft furnishings. In hallways or other clear areas with primarily hard finishes, consideration should be given to the use of sound absorbent finishes to reduce noise build-up, and also to help reduce transmission of sounds to other parts of the dwelling. Hard floors in hallways or corridors adjacent to bedrooms can be particularly disturbing, owing to footsteps noise. Sound fields in domestic rooms are likely to be non-uniform (modal) at lower frequencies. This can cause amplification of low frequency external sources of sound, such as low revving engines, leading to underestimates of resulting internal noise levels

Case Study:
Victoria Hall King's Cross, UK

Victoria Hall is a recently constructed student accommodation building at King's Cross, London, designed by Stanton Williams Architects. Arup advised on the acoustic design. The building is exposed to significant noise from surface rail traffic, including Eurostar trains.

Protection against external noise

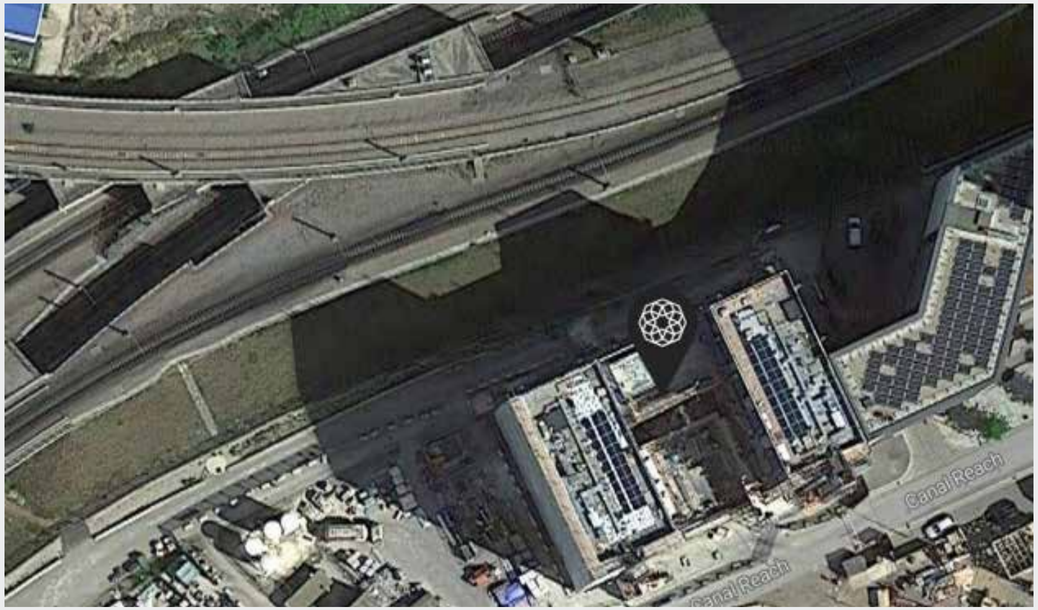
Noise from train movements is an intermittent source; periods of relative quiet are interrupted by distinctive high levels of noise. During daytime, if train passbys are infrequent this may be audible but cause little disturbance of everyday activities. However at night time, intermittent high noise levels cause (conscious or unconscious) disruption of sleep, which has consequential effects on long term health.

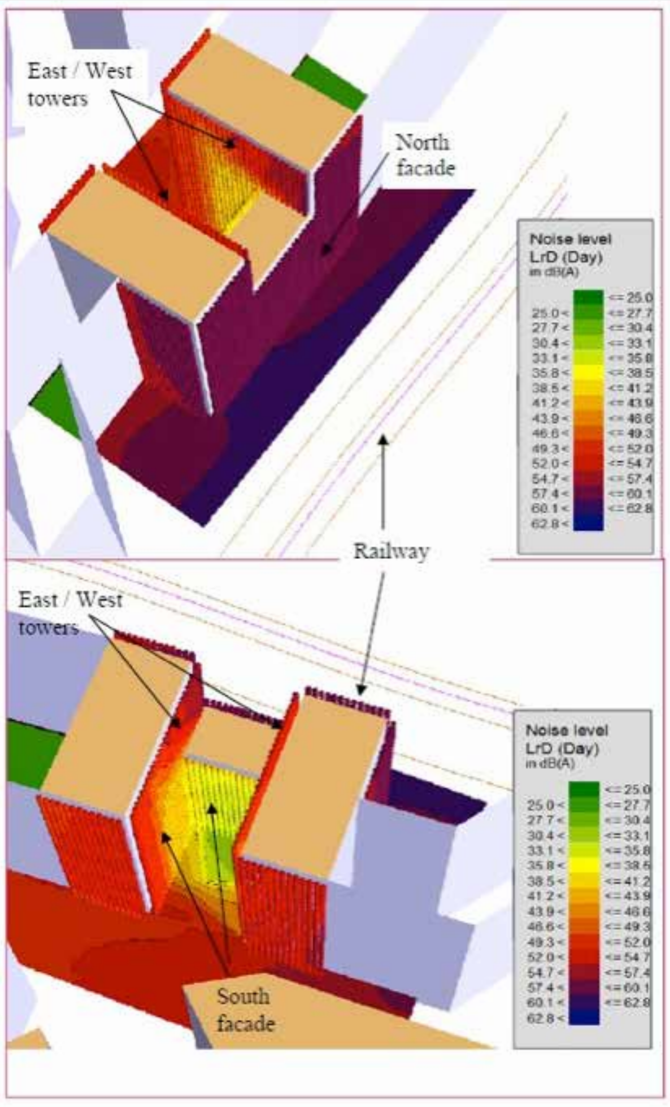
Noise from the trains produce maximum levels of 82dBL_{AFmax} at windows along the northern boundary of the site. Internal noise level design targets were:

- 35dBL_{Aeq} for study bedrooms during day and night
- 45dBL_{AFmax} maximum noise levels in bedrooms, to minimise the risk of sleep disturbance.

To meet normal requirements for the control of noise, this requires substantial sound insulating glazing and precludes the use of natural ventilation via simple openable windows.

The development is massed to provide a natural screening of southerly elevations around a courtyard. This provides outdoor amenity protected from noise. A second garden on the 9th floor is screened from the rail noise by the edge of the building and parapet. This screening effect was quantified using specialist software to establish the noise level exposure of each of the facades.





Early in the design, investigations were made to consider whether study bedrooms should be located predominately on the north façade of the building, providing long views across London but significantly exposed to the train noise, or whether bedrooms should be predominantly on the south, overlooking the courtyard.

An auralisation in Arup's SoundLab was set up to demonstrate the different noise climates on the two sides of the building. At this time, natural ventilation was considered via proprietary lined trickle vents and through open windows only. The conclusions were broadly that traffic noise levels on the south side of the building were acceptable, but train noise levels (specifically from the Eurostar, not other train types) on the noise side were not. Bedrooms were therefore planned for the south facades of the building as much as possible.

Some rooms remained on the north façade, exposed to noise from the Eurostar. Rooms in the east and west towers also had some view of the railway line. A bespoke acoustically lined trickle vent was proposed for the north studio rooms in order to control noise. This vent uses the height of the window to gain more attenuation length and better performance than that available with a proprietary vent, such that noise through ventilation routes was acceptable.

On this north facade, cooling could not be provided by opening the window. Noise levels would have risen to more than $60dBL_{Amax}$ and were considered not acceptable, even under the control of the room occupant.

The design considered carefully the balance between internal temperature control and noise ingress control.

For study activities the design range for internal temperature was:

- 25°C for less than 5% of the time
- 28°C for less than 1% of the time

For sleeping, the design temperature was:

- 26°C for less than 1% of the time

The design was developed to achieve satisfactory background ventilation using an acoustically attenuated trickle vent, and with the self-cooling of the building sufficient to ensure that for all student rooms the windows do not need to be open during the night-time, and sufficient cooling is provided by the trickle ventilation.

On the south façade, when windows are fully opened for cooling, noise levels in the worst case were calculated to be $44dBL_{Aeq}$. This is only necessary on the hottest days of the year, and for partially open windows noise levels are a few decibels lower. This was considered to be an acceptable outcome in comparison with most urban areas.

Privacy between bedrooms

It was important to be satisfied that the degree of acoustic privacy obtained between study bedrooms with open windows was subjectively acceptable, where two rooms are closely adjacent across the corners of the courtyard. This was therefore modelled and auralised within the Arup SoundLab. With the masking effect of external background noise sources included, this showed that privacy was sufficient.

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